
Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998

(October 1998, Revision 4.0)

C.R. Ahern^{}, M.R. Ahern[#] and B. Powell^{*}*

^{*}Queensland Acid Sulfate Soils Investigation Team (QASSIT)
Department of Natural Resources, RSC, Indooroopilly

[#]Formerly Department of Environment and Heritage, Brisbane

Funding assistance from
Natural Heritage Trust (NHT) National Landcare Program
and
Bureau of Sugar Experimental Stations (BSES)

DNRQ980124

Publisher Information

**Published by Queensland Department of Natural Resources, Resource Sciences Centre,
Indooroopilly, Queensland, Australia.**

National Library of Australia Cataloguing in Publication Data

Title:

**Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland
1998**

ISBN 0 7242 7442 1

DNRO980124

October 1998

This publication is protected by copyright. Material from the publication may be used or reproduced providing the meaning is unchanged and both the authors and publisher are acknowledged.

Citation in this publication should take the form:

Ahern, C.R., Ahern, M.R. and Powell, B. (1998) *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998*. QASSIT, Department of Natural Resources, Resource Sciences Centre, Indooroopilly.

Enquiries and request for copies should be directed to:

The Queensland Acid Sulfate Soils Information Officer
QASSIT
Department of Natural Resources
80 Meiers Road
Indooroopilly Qld 4068
Phone: 3896 9819 Fax: 3896 9782
email: heyk@dnr.qld.gov.au

Purpose of the Guidelines

These guidelines replace the various earlier drafts of *Sampling and Analysis Procedure for Lowland Acid Sulfate Soils in Queensland*. The last version was Revision 3.47 dated 15th October 1997. The first draft of these procedures date back to early 1996 and have been amended progressively to take account of additional technical and practical input from industry, environmental groups and government.

Recently, New South Wales completed a review and update of the NSW EPA (1995), *Assessing and Managing Acid Sulfate Soils: Guidelines for Land Management in NSW Coastal Areas*. The revised document, the '**Acid Sulfate Soil Manual**' (ASS Manual) was refereed by the ASSMAC Technical Committee and had significant input from Queensland sources. The ASS Manual includes some changes in action criteria and incorporates the latest *Laboratory Methods Guidelines* agreed to by a National Committee. The NSW Acid Sulfate Soils Manual also contains *Assessment Guidelines* and *Management Guidelines*.

These three NSW guidelines are applicable to most Queensland situations, but there are major differences in local government planning, regulations and State legislation between the two States.

This new Queensland document, *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland, 1998* has been updated to accommodate recent changes in the NSW ASS Manual. In addition, the legislation sections in the Queensland document, particularly with regard to the Integrated Planning Act 1997, require significant amendments. Such amendments will be undertaken as part of a total review and appraisal of the Queensland Guidelines, and ultimately, including production of a complete manual along the lines of the NSW ASS Manual. The technical sub-committee of the Queensland Acid Sulfate Soils Management Advisory Committee (QASSMAC) intend to produce the Queensland ASS Manual early in 1999.

Disclaimer

While the Queensland Acid Sulfate Soils Investigation Team (QASSIT) and the authors have prepared this document in good faith, consulting widely, exercising all due care and attention, no representation or warranty, expressed or implied, is made as to the accuracy, completeness or fitness of the document in respect of any user's circumstances. Users of the report should undertake their own quality controls, standards, safety procedures and seek appropriate expert advice where necessary in relation to their particular situation or equipment. Any representation, statement, opinion or advice, expressed or implied in this publication is made in good faith and on the basis that the State of Queensland, its agents and employees are not liable (whether by reason of negligence, lack of care or otherwise) to any person for any damage or loss whatsoever which has occurred or may occur in relation to that person taking or not taking (as the case may be) action in respect of any representation, statement or advice referred to above.

Acknowledgments

The **National Landcare Program of the Natural Heritage Trust (NHT)**, and the **Bureau of Sugar Experimental Stations (BSES)** have provided funding support towards a broad scale mapping program of acid sulfate soils (ASS) in South-east Queensland. This has contributed greatly in providing the impetus for the formation of QASSIT, and together with the NHT-funded Qld ASS Information Officer, has led to significant community and industry education and training, and co-operation on improving the difficult issues associated with ASS.

The authors, Col Ahern and Bernie Powell of DNR and Michael Ahern formerly of DEH, thank Doug Smith, Angus McElnea, Kylie Hey, Julie Anorov and Sue-ellen Dear of DNR; Maria Neuhold, Ian Yarrol, Nikki Moore and Brad Greenharm of DEH; John Beumer of DPI (Fisheries); and Steve Dobos of Dobos and Associates for their valuable contributions during formulation of earlier drafts. We acknowledge some tables and text have been updated from the recently released NSW *Acid Sulfate Soil Manual* (Stone *et al.* 1998) which also included material from our earlier Queensland Guidelines. The NSW Acid Sulfate Soil Management Advisory Committee Technical Committee (ASSMACTC), and various officers of CSIRO, University of NSW, Southern Cross University, University of East Anglia and commercial laboratories have provided ideas or comment which may be reflected in this publication. We are also indebted to community groups, individual consultants, developers, engineers and those associated with drilling and field testing who willingly discussed and contributed ideas for practical outcomes.

Cover:

Designed by Kylie Hey

Left photo shows the QASSIT trailer mounted, vibro suction corer

Top right shows peroxide field test on a highly reactive soil sample

Lower right shows a 4 WD mounted hydraulic, push tube sampler

Table of Contents

Publisher Information.....	ii
Purpose of the Guidelines	iii
Disclaimer	iii
Acknowledgments.....	iv
Cover:.....	iv
1. OBJECTIVES	1
2. INTRODUCTION.....	1
2.1 Queensland Specific Legislation.....	1
3. APPLICATIONS (QUEENSLAND)	2
3.1 Integrated Planning Act 1997 (IPA)	2
3.2 Environmentally Relevant Activities (ERAs).....	3
3.3 Environmental Harm	3
4. MAPPING AND SAMPLING	4
4.1 Mapping	4
4.2 Sampling Intensity.....	4
4.3 Sampling Equipment	6
5. ADVICE AND INSPECTION	8
5.1 Tendering	8
6. SOIL SAMPLE CARE/PREPARATION	9
6.1 Storing/Retaining Samples for Audit Purposes	10
7. LABORATORY ANALYSES AND ACTION CRITERIA	10
7.1 Samples Containing ‘Monosulfides’	11
7.2 Safety	11
7.3 Approved Laboratory Methods	11
7.4 Action Levels of Oxidisable Sulfur.....	12
7.5 Interpretation of the Results - Action Criteria Triggering the Need for a Management Plan.....	13
7.6 Notes on Assessment of Risks Based on the Level of Oxidisable Sulfur	15

7.7	Notes on Assessment of Risks Based on the Type of Material to be Disturbed.....	15
7.8	Assessment of Risks Based on the Maximum Level of Acid that could be Produced	16
7.9	Notes on the Assessment of Risks Based on the Quantity of Material to be Disturbed.....	17
7.10	Impacts Associated with the Physical Characteristics of Acid Sulfate Soils	17
7.11	Consider the Precautionary Principle	18
8.	REPORTING.....	18
9.	MANAGEMENT	18
9.1	Independence of Assessment and Monitoring.....	21
10.	APPENDIX: TESTS FOR ASS	22
10.1	Approved Laboratory Methods	22
i)	POCAS - Peroxide Oxidation Combined Acidity & Sulfate (Method 21).	22
ii)	TOS - Total Oxidisable Sulfur (Method 20).	24
iii)	Acid Neutralising Capacity.....	27
iv)	Other Laboratory Tests.....	27
10.2	Calculations.....	28
10.3	Field pH Tests	28
i)	Field pH in Water (pH _F).....	28
ii)	Field Peroxide pH Test (pH _{FOX})	29
11.	REFERENCES	30
12.	CONTACTS	32
13.	GLOSSARY	33

1. OBJECTIVES

The objectives of these procedures are to provide a State-wide standard, sampling and analysis regime, to enable accurate assessment of environmental impact prior to disturbance of acid sulfate soils (ASS) - the term includes potential acid sulfate soils (PASS), sands or other materials such as dredge spoil. This assessment will increase the ability of authorities to make objective decisions regarding ASS, and competently manage ASS areas, in a manner consistent with the principles of Ecologically Sustainable Development (ESD) and Best Practice Environmental Management (BPEM). While the legislative context is outlined in this document, its primary intention is to assist the applicant and streamline the process for all involved, by providing guidelines for what is often a complex environmental issue to both assess and manage. **Users should refer to the relevant legislation to confirm particular legal requirements. This procedure has not been fully updated for changes brought in under the Integrated Planning Act (1997).** The Queensland Acid Sulfate Soils Management Advisory Committee (QASSMAC) sub-committee will deal this with in 1999.

2. INTRODUCTION

Acid sulfate soils occur predominantly on coastal lowlands with elevations generally below 5m Australian Height Datum (AHD). When these lowlands are disturbed or drained, toxic quantities of acid, aluminium, iron and heavy metals may contaminate land and adjacent waterways. Following significant rainfall, such contamination may cause red spot disease in fish and destroy aquatic flora and fauna (including highly visible fish kills). 'An introduction to acid sulfate soils' (Sammut and Lines-Kelly, 1996) gives a broad overview of ASS, while for a more technical summary readers are referred to White *et al.* (1996) and Smith and Ahern (1996).

Vegetation can also be affected or killed by disturbance or drainage of acid sulfate soils. Infrastructure such as pipes, foundations, house slabs, bridges and road surfaces are also susceptible to costly acidic corrosion or sulfate effects, leading to accelerated structural failure.

As development (eg. tourism, residential, industrial and agricultural) continues to encroach on coastal lowlands, the identification, quantification and management of acid sulfate soils must be addressed as part of a commitment to the principles of Ecologically Sustainable Development (ESD). To achieve ESD, authorities employ Environmental Protection Policies and encourage Best Practice Environmental Management (BPEM) together with community consultation.

2.1 Queensland Specific Legislation

As more information is collated on the adverse impact of ASS on both the natural and developed environments, ASS investigation and management are becoming integral parts of gaining approvals under sections of the *Local Government (Planning and Environment) Act of 1990*, and licences under the *Environmental Protection Act (EPA) of 1994*. ASS contamination of aquatic ecosystems may result in contravention of the environmental harm provisions of the EPA. Acting in a capacity as either a referral agency and/or an administering authority, Local Government, the Department of Natural Resources (DNR), Department of Environment and Heritage (DEH), and Department of Primary Industries (DPI), can request acid sulfate soil investigations be conducted in a variety of circumstances.

For example:

- as part of the Terms of Reference for an Environmental Impact Statement under Section 8.2 of *Local Government (Planning and Environment) Act (1990)*. Now replaced by the *Integrated Planning Act (1997) IPA* with details to be provided in future guidelines;
- to fulfil the State Guideline 11.4 in the Draft Guidelines for Completing an Application for Environmental Authority to conduct an Environmentally Relevant Activity (ERA);
- to investigate and manage incidents of Unlawful Environmental Harm, in the form of an Environmental Evaluation or Environmental Management Program under Parts 5 and 6 respectively, of the *Environmental Protection Act (1994)*;
- to satisfy the assessment process for statutory approvals (Permits for the disturbance of Marine Plants or for Works within a Fish Habitat Area) under the *Fisheries Act 1994* where impacts are on or adjacent to tidal lands;
- to satisfy requirements of section 24 of the *Environmental Protection (Water) Act (1997)* when an activity involves disturbing or exposing acid sulfate soils or lowering the watertable associated with acid sulfate soils;
- under the *Beach Protection Act 1968*;
- to satisfy the *Coastal Protection and Management Act 1995*; and
- to satisfy the *Harbours and Marine Act 1955*.

In coastal lowland areas below 5m Australian Height Datum (AHD), Local Authorities should be consulted before commencement of any drainage or excavation or disturbance below the water table, or alteration to local hydrology of lands or waterways. Local authorities should also implement a protocol for identifying and managing their own drainage, sewerage, road construction, flood mitigation and infrastructure works in ASS areas.

3. APPLICATIONS (QUEENSLAND)

3.1 Integrated Planning Act 1997 (IPA)

The Act seeks to achieve ecological sustainability by:

- coordinating and integrating planning at a local, regional and state level;
- managing the process by which development occurs; and by
- managing the effects of development on the environment.

Integrated Development Assessment System (IDAS) for State and local government approval processes, that replaces processes, not considerations. State Government legislation containing development assessment processes are to be repealed or amended to be consistent with IDAS framework.

IDAS integrates approval processes for the:

- Environmental Protection Act
- Fisheries Act
- Transport Infrastructure Act
- Land Act
- Water Resources Act
- Building Act

Impact Assessment (IA) Process - Referral co-ordination for information requests for Impact Assessment is available for some developments with a state interest. The provisions of the local government (Planning and Environmental) Act 1990 relating to 'Designated Developments' have been carried over a 12 month period. The results of impact assessment processes are available for public scrutiny.

3.2 Environmentally Relevant Activities (ERAs)

As part of the Application for Authority to conduct an ERA (as defined under Schedule 1 of the Environmental Protection Regulation, 1998, State Guideline 11.4 requires an ASS Management Plan, if ASS is expected to impact on the site. As part of this management plan, an ASS investigation would be necessary to identify and describe the extent of the problem. An adverse environmental impact due to an ASS event, occurring as a result of the activity, may not be unlawful, *if* it occurs under an Environmental Authority which includes an approved ASS Management Plan as a condition. This may be very important to an operator/developer, due to the unpredictable nature of fish kills and other environmental impacts associated with ASS disturbance.

3.3 Environmental Harm

In the case where *any* activity, directly or indirectly causes an adverse impact on the environment, whether it be a fish kill, death of vegetation, or some other environmental damage which could be interpreted as environmental harm, the person or company responsible for the activity may be liable to some form of penalty, as it is an offence under the EPA to cause unlawful environmental harm. It should be noted that a court may record a criminal conviction for some breaches of the EPA. An ASS investigation may be voluntarily conducted or officially requested, if an ASS event or related contamination is suspected to have caused direct or indirect environmental harm. This could be in the form of an Environmental Evaluation, addressed in (Part 5) of the EPA and may involve either an Environmental Investigation or an Environmental Audit. An ASS investigation could be a component of these.

An ASS investigation may be used in the formulation of an Environmental Management Program (EMP). The administering authority can also request an EMP, which if not submitted may lead to an Environmental Protection Order (EPO) or even prosecution.

Note that if any activities cause destruction or damage to fisheries resources, eg. fisheries habitat, marine fauna (including invertebrates) or flora (including mangroves and seagrasses), offences may have been committed under the Fisheries Act (1994), administered by DPI.

4. MAPPING AND SAMPLING

4.1 Mapping

A detailed map of acid sulfate soil occurrence/absence and an assessment of sulfide/pyrite content by depth is an essential prerequisite for deciding whether a proposed development/disturbance is feasible from an environmental, engineering and economic perspective. The proposal may have to be abandoned, modified, or planned excavations re-routed, if acid sulfate soils with substantial sulfide content are encountered.

Initial assessment of the likelihood of ASS occurring can be made using aerial photography, maps and information on geomorphology, soils, geology, height above sea level, land use, hydrology and any soil or water tests previously done in or around the area, (Smith and Ahern, 1996; Naylor *et al.*, 1995). Generally, projects that disturb soils located above 10m AHD, and 5m AHD for shallow disturbance, should be relatively safe and require only some confirmatory exploration and sampling. Common exceptions to this generalisation include activities that involve deep disturbance such as quarrying activities, mining and construction of deep on farm dams above 10 m AHD (Anderson *et al.*, 1996).

Soil sample intensity is somewhat dependent on the nature, depth and size of the disturbance proposed and the sensitivity of the surrounding environment. Most ASS investigations will require sufficient sampling to create three-dimensional maps and cross sectional diagrams of oxidisable S % content by depth for presentation in the ASS report.

4.2 Sampling Intensity

The number of profiles or boreholes required for the (ASS) component of most Qld Environmental Impact Statements is:

Table 1 Minimum number of sampling holes

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

More detailed transect sampling (50m intervals) will usually be required along proposed excavations e.g. canals, lakes, drainage channels and borrow pits.

Additional samples may need to be taken in areas of more intensive disturbance or in potential 'hot spots'. In these areas, sampling may be required on a 50-75 metre grid. This sampling intensity is not expected on areas of the site where the likelihood of acid sulfate soils occurring is low e.g. located above 5 m AHD or soils on hard rock. However, justification for reduced sampling intensity and some confirmatory sampling and laboratory analysis will still be required for these areas.

Sampling of material to be **dredged** from coastal rivers, lakes, dams and wetlands should be undertaken according to the transect spacing described above. Samples should be collected to

at least one metre below the maximum depth of expected material extraction, ensuring that samples from all sedimentary layers are included. Careful attention must be paid when collecting underwater sediment samples to ensure that all sediment particle sizes are collected (a vibro-suction corer is usually suitable). The fine silt and clay fraction of the dredged material may contain high concentrations of sulfide however this material can easily drain from the sample during collection. In some wet dredging operations, acid sulfate material (usually silt and clay) can separate from the bulk material (sand) during stockpiling. Assessment of such dredged material may require that the constituent fractions of the resource be separated and tested accordingly, as interpretation of soil analysis on the dredge material may be complicated due to the neutralising influences of shell or seawater in the sample. Conventional laboratory analysis must include the measurement of calcium, (optionally magnesium and sodium) in the POCAS test (Method code 21X) and/or the HCl extract of the TOS method (Method 20Bh). Acid Neutralising Capacity (ANC e.g. Method 19B1) may assist. Where considerable difference exists between the results of the acid trail and the sulfur trail, kinetic type tests involving leaching columns and incubation may be required.

Each borehole should be sampled and details recorded as follows:

- (i) **The location of each borehole** using Australian Metric Grid or Latitude and Longitude (to 0.1 of a second) **and its existing surface height (AHD) must be accurately surveyed and recorded in the report.** This assists in identifying sulfide-bearing layers which comprises essential data in development of proposed earthworks and management plans. The expected accuracy (\pm x metres) of the GPS or survey equipment used must be also specified. Investigations involving only minor disturbance may derive sufficient location information and contour data from detailed orthophoto maps which are available for some areas.
- (ii) Field descriptions of horizons using the nomenclature of the Australian Soil and Land Survey Field Handbook (McDonald *et al.*, 1990) for each site/borehole should be submitted in the report. Field texture, colour, mottles (particularly presence of straw yellow jarosite, hue of 2.5Y or yellower and chroma of 6 or more) and field pH are essential measurements. See Appendix for field pH tests that must be recorded by horizon or every 0.5m depth interval. **Field pH and peroxide pH must be recorded every 0.25 m depth.** Any presence of shell or carbonate material in the soil must be recorded, along with a measure or estimate of their abundance and size distribution. Suspected carbonate material can be tested in the field by a positive reaction/effervescence with 1M HCl.
- (iii) Starting from the present soil surface, collection of soil samples should not exceed 0.5 m intervals down the profile, **to at least one metre (1 m) below the depth of the proposed disturbance or to at least two metres (2 m) below the land surface, whichever is greater** (i.e. at least four samples would be required when sampling a profile to a depth of 2 m). Where distinct horizons occur, then sampling should be confined to within that horizon but sampling intervals should not be greater than 0.5 m apart. Where alteration of the watertable height by drainage, pumping, etc. is envisaged then sampling to at least one (1) m below the depth of the final estimated water table height is required. (These sampling requirements are essentially the same as those required in the '*NSW ASS Manual 1998*'). **Ensure all depths/horizons are collected (even when field assessments indicate the absence of ASS) as re-drilling is expensive.** Ideally, soil samples should constitute at least 0.5kg each to allow sufficient sample for physical and chemical analysis. Their analysis may be requested as part of the EIS

assessment, such as an audit process, or other unforeseen uses. Quantitative laboratory tests will need to be conducted on every 0.5m depth interval, unless strong justification is provided. Laboratory analysis confirming the absence of sulfides is often just as important as determining the actual sulfide content on a positive sample.

- (iv) The depth below the surface of any watertable must be recorded and where encountered, a water sample collected for analyses. Depending on flow rates and tidal influences, this may require returning to the site some hours later. The water sample should be analysed for at least pH, Electrical Conductivity (EC), chloride, sulfate, aluminium, calcium and iron. Ideally, the container should be filled to the top to exclude air and chilled immediately. For those users with field equipment, EC and pH should be measured immediately. A separate sample, acidified with acid is required for iron analysis. The addition of acid prevents iron precipitation, which can occur due to oxidation of a disturbed sample. This sample cannot be used for further analysis due to contamination with acid..

Quantitative laboratory tests should be conducted on all soil samples. The texture action category, (coarse, medium, fine; see Table 1) needs to be clearly indicated to laboratories for all soil samples as this affects method selection, the detection limit required and general interpretation of the result. As sampling and laboratory analyses can be an expensive process, **a staged approach to sampling is suggested.** When selecting samples for comprehensive laboratory analysis in stage 1, a number of profiles should be analysed for each 0.5 m interval or horizon rather than selecting random samples from many profiles. The emphasis should be on those sites most likely to contain sulfides based on elevation, soil type and results of field tests. It must be stressed that proving an apparent non ASS profile is clear by laboratory analysis is extremely important as that soil will not require special management.

Subject to assessment of Stage 1 sampling and analytical results, the sampling intensity may be adjusted or reduced by mutual agreement with the relevant government authorities. However, the onus will be on the applicant, developer or consultant to provide information demonstrating that less sampling and laboratory analysis is justified and that if sampling is reduced the potential for environmental harm will not be increased.

In addition to preliminary mapping, some operations such as **dredging or sluicing** may require sampling at the output pipe every 500 m³ of material for analytical determination to calculate lime requirements. Where performance of an operation is shown to be consistent then the sampling intensity may be reduced by mutual agreement.

4.3 Sampling Equipment

Various manual and mechanical sampling equipment may need to be employed. Choice of equipment will depend on soil texture, wetness and layers in the profile. Commonly used equipment are listed and commented on below:

Manual

- Jarret auger - usually restricted to the upper profile of dry and moist soil only and generally not be suitable for sands.
- Tapered gouge auger - suitable for soft muds, but not sands.
- Push tube with tapered tip - limited sample retention as suction is created on extraction and sample loss can be a problem (adding a sealable cap before extraction improves retention). It is generally not suitable for saturated sands.

- Dormer sand auger - acceptable for many soils but saturated sands may fall out and the walls of the borehole may collapse.
- Piston sampler - good for saturated sands but limited to the length of the piston as walls collapse as it is withdrawn. Using a suitable size poly pipe for casing can increase the depth of excavation on saturated sands but care is needed to limit contamination or sample mixing.

Mechanical

- Hydraulic push tube - hard to remove sample from tube on sticky soils, wet sands fall out (adding a sealable cap before extraction improves retention).
- Spiral auger- mixes sample, **generally unsatisfactory.**
- Hollow flight screw auger incorporating an internal 'split tube' sampler - uses a hollow screw auger with an internal sampler that can be withdrawn regularly. The internal sampler is fitted with a 'split tube' and takes suitable good cores but can have trouble with compression on muds and loss of sample on sands below the watertable. A "catcher" often improves retention on sands. Some well equipped drilling rigs can also use within the hollow auger a Standard Penetration Test (SPT) sampler or thin walled 50 mm diameter tube designated U50 (undisturbed, 50mm diameter) for sampling. 'Gemco' is one of the brands available commercially.
- Backhoe, excavator - excellent until the watertable is reached, sampling taken at measured intervals down the face. Once below the watertable, wall collapse is a substantial problem for effective sampling and personal safety. Good for sites with lots of shell as it allows a larger sample to be collected without shattering the shell, a common problem with most other sampling techniques. **Work place safety issues** need to be addressed when digging pits. If entering a pit for sampling one needs to consider the possibility of poisonous hydrogen sulfide gas overcoming the person. A rope and harness should be used and one member must always remain outside the pit to pull the other person up should such an occasion arise. Do not enter a pit to assist a gas affected person without proper breathing apparatus.
- Wash bore drilling combined with a driven Standard Penetration Test (SPT) split tube sampling - a bentonite and polymer solution which is continually pumped under pressure usually holds the borehole walls intact for deep drilling on saturated sands. Contamination of sample can be a problem even when the upper part of the core is rejected.
- Core sampling employing a suction and vibrating technique – is recommended and ideal on wet sands, muds and soft soils, giving accurate depths and intact cores. Compressed air is used to remove the sample from the tube. If the upper profile is hard and dry, a hydraulic push tube or auguring device may be required until soft moist material lower in the profile is encountered. (Contact QASSIT for further information. Their machine samples intact cores to 5m. The length of the tube limits sampling depth and the height of the mast needed to pull the tube out).

Sands below the watertable are difficult to sample, while those sites encountering gravel layers are the most challenging. At present sampling using an excavator is recommended for gravels. The further the sampling is below the watertable the more difficult it is likely to be. Gravel and sand fractions immersed in a 'pyritic soup' have been found to contain pyrite framboids in their fine pores and fractures or as mud coatings (Saffigna *et al.*, 1996). Such materials are difficult to sample representatively.

Washing down and cleaning of sampling equipment is an absolute must to avoid sample contamination. A high pressure washing system is essential for mechanical drilling equipment.

Trace amounts of sulfidic material from previous sampling may contaminate a sample with no sulfide present, resulting in a positive test. This can lead to unnecessary and costly earthworks and liming procedures being required on soils with no acid producing potential. Therefore an ASS consultant or a trained ASS technician must be present and supervise all drilling and sampling.

Details of the drilling/sampling equipment used, together with the drilling operator's name and contact phone numbers must be provided in the report.

5. ADVICE AND INSPECTION

An acceptable stage one sampling plan should be negotiated with the **local** referral agencies' officers from DNR, DEH, DPI (Fisheries), DLGP and Local Government relevant to the application. A site inspection, together with observations and field tests on some borehole samples, will usually be a necessary part of developing a staged sampling plan. It is advisable to consult all relevant authorities before drilling and sampling commences.

On proposals where ASS may be a complex or significant issue, Local and State Government referral agencies often seek/require the technical input/assessment of the Queensland Acid Sulfate Soils Investigation Team (QASSIT) at DNR's Resources Sciences Centre, Indooroopilly. Such involvement will usually require site inspections during the drilling/sampling phase. The developer/consultant should plan on a charge based on cost recovery of QASSIT's time, equipment, travel, etc. Forward planning and bookings are essential for pre-sampling discussions, site inspections, and follow up discussions/advice.

Early consultation, agreement on numbers of sample sites, depths and laboratory analyses, and follow up discussions on formulating an acceptable Environmental Management Program (EMP) based on laboratory results, should ensure smooth transition to a technically sound EMP and Environment Impact Statement (EIS). The staged approach allows a lower cost, preliminary assessment of potential ASS difficulties and an estimate of further sampling and development costs. This assists the developer to decide whether it is economically and environmentally responsible to continue with the proposal, amend it, or abandon it before costs 'blow-out'.

5.1 Tendering

When calling tenders for ASS investigations, developers/contractors should request quotes based on **the number of sites/cores drilled, a sample every 0.5 m interval and detailed laboratory analyses**. Without a sample based approach, the cheapest quote often involves insufficient number of sites, samples and analysis, resulting in costly delays or rejection by government authorities. Only experienced and appropriately qualified ASS consultants such as a Certified Professional Soil Scientist (CPSS) should be employed.

It can also be cost efficient to **stage** the approach on large projects. When the results of the initial sampling are known and presented at an informal meeting, all parties can decide on the most efficient and cost effective sampling measures (if any) that are required to complete the ASS investigation and or ASS management plan. Authorities may ultimately insist on full sampling and analyses as per these guidelines. The onus is on the proponent to justify that sufficient sampling has been undertaken to understand and manage the site without causing environmental harm. Many proposals contain site specific issues that are cannot possibly be

covered within the general guidelines. Consultation will help eliminate rejection on the grounds of a technically inadequate EIS and EMP.

Specialised sampling equipment capable of taking uncontaminated core samples from the specified depths is a vital component of any ASS investigation. *Inappropriate equipment/sampling procedure will render the laboratory results unrepresentative and hence invalidate the ASS component of the report.*

6. SOIL SAMPLE CARE/PREPARATION

In the field, all **visible shell** should be removed from soil samples. It is essential that shell material be removed in the field at the time of sampling otherwise it must be sieved out (2 mm sieve) prior to sample grinding. This is usually difficult on clayey samples as they often set hard on drying making removal of shell without breakage/shattering extremely difficult. Broken or ground shell creates fresh exposure, increases the actual reactive surface area, overestimates the true neutralising capacity and hence falsely reduces the TPA result. Most drilling techniques shatter some shell and this should be considered when selecting appropriate sampling methods for a site. Additionally, shells found in ASS commonly have a coating of relatively insoluble gypsum, silica or iron compounds, rendering much of their carbonate content ineffective for neutralisation. If large quantities of coarse shell occur at a site and it is intended to use shell materials to reduce potential liming rates, then extra tests may be useful. Extra tests may include incubation of a portion of undried sample including any shells for a number of months to provide some measure of oxidation and neutralisation rates, or determining (with separate large bulk samples) the percentage of shell present in the soil and the neutralising capacity of the uncrushed shell.

Waterproof labels, capable of withstanding oven drying at 85 °C, are essential due to the high moisture content of most samples. These can be pre-printed with appropriate name and job description on waterproof paper using a laser printer, then labelled in the field with site and depth using a **waterproof marking pen**. Samples and the correct label should be placed without delay into **sealable polyethylene bags** (with air excluded). Sample bags must also be externally labelled and all depths from the one hole/profile placed in a larger bag to improve efficiency and limit possible mistakes on receipt at the laboratory.

Immediately place the entire profile into a **portable freezer** (or **esky containing dry ice**) to quickly cool the samples and minimise sulfide oxidation (when dry ice or a freezer is not available ordinary ice or freezer blocks are the next best but are less efficient, and some minor oxidation may occur). Samples must be kept cold and transported in an insulated container to a laboratory for immediate oven drying within 24 hours of sampling. If this is not possible then they must be frozen until ready for insulated transport to the laboratory for pre-analysis drying. The laboratory should be notified prior to receipt of soil samples. This will reduce the risk of samples sitting in loading bays for extended periods of time (potentially oxidising).

Separate field samples may be required to determine bulk density to convert gravimetric results to a volumetric basis for field management plans (eg. rates of lime per m³). A sample of known volume can be sampled using equipment such as a cut off syringe. Volumetric samples are sometimes used for 'field laboratory' measurements of TPA using a time shortened version of Dent and Bowman (1996a, 1996b). Such an approach may be useful for quick site management decisions once earth moving operations are under way, but results should be calibrated by regular dispatch of a subsample to a laboratory for complete analysis. Oven dried

samples and full laboratory analyses will be required for preparing the ASS report and site mapping.

At the time of sampling, **soil colour, soil texture, field pH** (pH_F ; method 21Af, see Appendix) and **field pH after oxidation with 30 % peroxide** (pH_{FOX} ; method 21Bf) should be determined within regular 0.5 m depth intervals or soil horizons in the profile and at least on all depths sampled for further laboratory analyses. Field pH and peroxide pH should be done at every 0.25m. These field tests together with the strength of the peroxide reaction, can indicate those depths where sulfides occur. This may assist in allocating like samples to particular batches in the laboratory, optimising procedures and improving the accuracy and detection limits. The field pH can be measured on saturated soil using a combination **spear point pH probe and field pH meter**. If pH_{KCl} is substantially lower than pH_F then some oxidation of the sample during transport or drying may have occurred. Typically, pH reductions of 0.2 to 1 unit have been recorded on oven drying, without any measurable oxidation of sulfides. Oxidation of black iron monosulfides (FeS) and other unstable sulfide and iron compounds commence on disturbance and specialised sampling equipment is required to prevent oxidation. Fortunately, such compounds rarely occur in significant amounts. The use of volumetric sampling and analytical methods may be more suitable when highly unstable compounds are abundant. A method for Acid Volatile Sulfur (AVS) is contained in *Laboratory Methods Guidelines* (Ahern *et al.*, 1998a).

6.1 Storing/Retaining Samples for Audit Purposes

All soil samples collected in the field for ASS investigations should be well marked and retained for possible future call or audit purposes. Storage in an oven dried state as described in the next section is the safest and preferred approach, although most laboratories will charge a fee for drying and storage. Where not all samples are sent to the laboratory, particularly when conducting a stage one approach, a less desirable method of storage is freezing. All samples or a subsample of approximately 50 g must be retained until the end of the project unless they become an unreasonable impost then approval to discard should be negotiated with the regulatory authority. Stored samples could be important in defence of legal action. Special arrangement may need to be made with the laboratory to retain at least 50 g of sample, as most commercial laboratories would discard samples about a month after results are reported.

7. LABORATORY ANALYSES AND ACTION CRITERIA

On arrival at the laboratory, soil samples must be either immediately oven dried or kept frozen until ready to oven dry. Refrigeration will not prevent oxidation as jarosite can be seen forming in refrigerated samples stored for some weeks.

Wet muddy/clayey cores should be placed on **waterproof non-metallic dishes** (high density microwave cookware is usually suitable) and cut into smaller pieces as soon as partial thawing allows. Quick oven drying in a **forced air draft, high capacity oven at 80-85 °C** (to prevent oxidation of pyrite) for at least 48 hours is required (Ahern *et al.*, 1996a). Bulkier clay samples may require several days longer to ensure complete drying. If an estimate of field moisture is required, retain a representative portion of the soil, place in a suitable non-metallic moisture container, and weigh and determine moisture content as per method 2B1 (Rayment and Higginson, 1992).

Many large frozen samples may overload the rapid drying capacity of the oven and some minor oxidation of sulfide and substantial reduction in pH may occur (Hicks and Bowman, 1996).

Laboratories should examine the **drying capacity** of their ovens and either apply appropriate sample loadings or purchase a quick drying fan forced oven.

After drying, any coarse material not previously removed (especially **shell and gravel**) should be extracted or removed by preliminary sieving (2 mm). When required, the weight of the residual coarse material (>2 mm) may be measured and calculated as a percentage of the total sample weight. Samples which do not easily break up after oven drying (such as some heavy clays), should be rolled/crushed/ground to pass through a 2 mm sieve. It is recognised that grinding equipment is laboratory specific but it is recommended that samples for ASS analyses be fine-ground (<0.5 mm or finer), to ensure greater homogeneity. This means a smaller sample weight and less volume of reagents can be used during analysis, reducing costs. The sample should be stored in a cool dry place in an air-tight plastic or inert container for subsequent laboratory use.

7.1 Samples Containing ‘Monosulfides’

Some common locations of material containing significant monosulfides are bottom sediments of quiet coastal lakes and streams and weed infested drains where a fresh source of organic material causes the active formation of sulfides, particularly characterised by a ‘smelly black ooze’.

Samples suspected of containing **metastable sulfides** (‘monosulfides’) should be frozen immediately after they are sampled in the field with the use of dry ice then **freeze-dried** in the laboratory. Bush and Sullivan (1997) showed that greigite ($\text{FeS}_{1.34}$ or Fe_3S_4) readily oxidises within hours at room temperature and oxidises in minutes on drying at 88°C. Special precautions to prevent oxidation at sampling and drying are costly and laborious and generally used on research samples rather than routine samples. Provided monosulfide content is low then any oxidation on drying should be detectable by a significant lowering (>1 unit) of laboratory pH compared to field pH. The change would not be easily detectable using the sulfur trail but the acid trail should show a high Total Actual Acidity (TAA) result. Dioxane replacement of moisture (Crockford and Willett, 1995) may be useful where no freeze drying facilities are available. Greigite is relatively stable once dried (Bush and Sullivan, 1997). See also Bush and Sullivan (1998) Acid Volatile Sulfur Method in *NSW ASS Manual* (Stone *et al.*, 1998).

7.2 Safety

As dried ASS may contain dusty, strongly acidic substances such as jarosite, workers involved in grinding such soils should use eye protection and carry out the operation in a dust extraction cabinet or wear a suitable dust mask.

7.3 Approved Laboratory Methods

A set of standard methods have been under development for routine laboratory use on soil samples (ASSMAC, 1996; Ahern *et al.* 1996b). These earlier versions were updated at a national methods workshop in October 1996. After some minor amendments and trials by Government, University and private laboratories two methods were approved at a combined meeting in Sydney on 29 August 1997, for standard use in all future ASS environment impact assessments to be submitted to NSW and Qld Government authorities. They have now been published in Ahern *et al.* (1998a) in the *NSW ASS Manual*. An outline of the approved laboratory methods is provided in the Appendix of this document.

Site samples must be analysed by one of the two approved methods (see outline in the Appendix) for quantifying the acid producing effects of sulfidic material in soils:

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

It should be noted that the TOS method is a useful screening method for pyrite content of soils and gives **no measure** of acidity present in partially oxidised and actual acid sulfate soils. Field pH, conducted at the time of sampling, can assist identification of soil acidity but not quantification of actual soil acidity which can be a significant environmental issue if the acid, iron or aluminium leachate drain into streams. Thus, in many situations, TOS will not provide sufficient data to fully understand the complexity of ASS.

Volumetric sampling and analysis procedures using a proposed POCASV (Peroxide Oxidation Combined Acidity & Sulfate Volumetric) may be appropriate for some situations. However, it has not been fully tested or documented and hence **not yet approved**. If used in special negotiated circumstances, conversion to oven dry values using bulk density will be required for comparative purposes when reporting POCASV results in EIS documents.

Where clear relationships between the 'acid trail' and the 'sulfur trail' have been established in the EIS, authorities may consider an individual project basis, requests to use the 'acid trail' only of POCAS or POCASV methods during the earth works/construction stage. This would assist in reducing costs, facilitating a quicker turn around of results, allowing earlier liming calculations and management of exposed PASS material. When permission for using such an approach is granted, an agreed percentage of samples must be submitted for full laboratory assessment to monitor the calibration.

All analytical data presented in the report must have its analytical method clearly stated using the approved codes (see Appendix). The full list may be found in Ahern and Rayment (1998). If variations to the approved methods are used, the detail must be clearly documented in the report along with the reason or benefit of the variation. Providing **additional** data, using other methods or techniques, is acceptable and necessary in some situations.

In 1998, most laboratories providing ASS analyses for environmental investigations in Queensland, New South Wales and Victoria took part in an exchange sample program, supervised by DNR (Qld), ASSMACTC and a representative of the Australian Soil and Plant Analysis Council (ASPAC), to ensure Quality Assurance. Consultants should ensure that the laboratory providing their soil analysis is taking part in this quality assurance program and using the approved methods, otherwise the credibility of the report may be jeopardised and not accepted.

7.4 Action Levels of Oxidisable Sulfur

Queensland authorities will use indicator or action levels recently agreed to at the national workshop (and modified recently by ASSMAC Technical Committee) as a guide to call for an ASS management plan; or the appropriate treatment for small disturbances. As clay content tends to influence a soil's natural pH buffering capacity, the action levels are grouped by three broad texture categories coarse, medium and fine, as defined in Table 2.

Table 2. Action criteria based on ASS analysis for three broad texture categories

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

7.5 Interpretation of the Results - Action Criteria Triggering the Need for a Management Plan

The *Action Criteria* in Table 2 triggers the need to prepare a management plan based on the percentage of oxidisable sulfur (or equivalent TPA, TAA) for broad categories of soil types. Works in soils that exceed these action criteria require preparation of a management plan and development consent. For projects that disturb ≥1000 tonnes of ASS soils with ≥ 0.03 % oxidisable sulfur or equivalent existing or potential acidity, a detailed management plan and development consent will be required.

Table 3 provides an indication of the treatment or risk category that disturbed acid sulfate soils would entail, based on soil analysis. This allows a quantity of lime to be estimated provided the total volume/mass of acid sulfate soils to be disturbed is known and soil analysis has been performed. The table is based on the quantity of lime required to neutralise the acid that could potentially be produced and includes the minimum industry safety factor of 1.5.

TABLE 3 Treatment categories and lime required to treat a weight of disturbed acid sulfate soil – based on soil analysis

The tonnes (t) of pure fine lime required to fully treat the total weight/volume of ASS can be read from the table at the intersection of the weight of disturbed soil (row) with the soil sulfur analysis (column). Where the exact weight or soil analysis figure does not appear in the heading of the row or column, use the next highest value (or calculate values exactly using factors from Table 4).

Disturbed soil (tonnes)	Soil Analysis - Oxidisable Sulfur (S %) or equivalent TPA/TAA													
	0.03	0.06	0.1	0.2	0.4	0.6	0.8	1	1.5	2	2.5	3	4	5
1	0	0	0	0	0	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.2	0.2
5	0	0	0	0.05	0.1	0.1	0.2	0.2	0.4	0.5	0.6	0.7	0.9	1.2
10	0	0.05	0.05	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.2	1.4	1.9	2.3
15	0	0.05	0.1	0.1	0.3	0.4	0.6	0.7	1.1	1.4	1.8	2.1	2.8	3.5
20	0.05	0.1	0.1	0.2	0.4	0.6	0.7	0.9	1.4	1.9	2.3	2.8	3.7	4.7
25	0.05	0.1	0.1	0.2	0.5	0.7	0.9	1.2	1.8	2.3	2.9	3.5	4.7	5.9
35	0.05	0.1	0.2	0.3	0.7	1.0	1.3	1.6	2.5	3.3	4.1	4.9	6.6	8.2
50	0.1	0.1	0.2	0.5	0.9	1.4	1.9	2.3	3.5	4.7	5.9	7.0	9.4	12
75	0.1	0.2	0.4	0.7	1.4	2.1	2.8	3.5	5.3	7.0	8.8	11	14	18
100	0.1	0.3	0.5	0.9	1.9	2.8	3.7	4.7	7.0	9.4	12	14	19	24
200	0.3	0.6	0.9	1.9	3.7	5.6	7.5	9.4	14	19	24	28	38	47
500	0.7	1.4	2.3	4.7	9.4	14	19	24	35	47	59	70	94	117
750	1.1	2.1	3.5	7.0	14	21	28	35	53	70	88	105	141	176
1,000	1.4	2.8	4.7	9.4	19	28	38	47	70	94	117	141	187	234
2,000	2.8	5.6	9.4	19	38	56	75	94	141	187	234	281	375	468
5,000	7.0	14	23	47	94	141	187	234	351	468	585	702	936	1171
10,000	14	28	47	94	187	281	375	468	702	936	1171	1405	1873	2341

L	Low treatment: (<0.1 t lime). <i>Submit disturbance dimensions & Lab Analysis proof to Local Government (L.G.).</i> Apply 0.05 t (1 bag) or 0.1 t (2 bags) of lime as per Table 3.
M	Medium treatment: (≤0.1 to 1 t lime). <i>Submit disturbance dimensions & Lab Analysis proof to L.G.</i> Thoroughly mix lime (0.1-1 t) as per Table 3 & bund the site.
H	High treatment: (>1 to 5 t lime). <i>Submit Earthworks Application, Management Plan & Lab Analysis proof to L.G.</i> Management, bunding & monitoring required.
VH	Very High treatment: (>5 tonne lime). <i>Earthworks Application or Impact Assessment required for L.G. (& State agencies).</i> Detailed management, monitoring & bunding required.

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

Lime rates are for pure fine CaCO₃ using a safety factor of 1.5. A factor that accounts for Effective Neutralising Value is needed for commercial grade lime (see Ahern *et al.* 1998c).

An approximate weight can be obtained from volume by multiplying volume (cubic m) by bulk density (t/m³). (use 1.7 if B.D. is not known)

For example, if 100 tonnes of clay material with 0.4 % oxidisable sulfur is to be disturbed, the landowner/contractor should observe best practice, bund any extracted material and fully mix at least 1.9 tonnes of lime with the excavated material. This example would fall into the 'High Treatment category' on Table 3 and would require Local Government approval, a management plan and depending on sensitivity of the site possibly some monitoring.

If 1,000 tonnes of the same material is to be disturbed, a more detailed management plan will be required, along with development consent before the works can be undertaken. In these circumstances approximately 19 tonnes of lime will be required to treat the material. This latter example would be in the 'Very High treatment category' of Table 3. A Development Application would be needed with the Local Government (and depending on site sensitivity possibly an EIS). Check with the Local Government if State agency approvals are also required.

7.6 Notes on Assessment of Risks Based on the Level of Oxidisable Sulfur

Levels of oxidisable sulfur within a soil or sediment can indicate the level of risk to the environment if the soil is disturbed. For all soils with oxidisable sulfur values greater than the "*Action Criteria*" in Table 2, a management plan must be developed to manage the potential harm to the environment. As a general rule, the highest result (by either the "sulfur" or the "acid" trail) should be used as the action criteria. Existing acidity (TAA) needs to be included in the assessment. If it is proposed to use the lower result of the 'acid' or 'sulfur' trail, this will require justification in advance, e.g. the acid trail may be higher than the sulfur trail for organic rich surface material.

7.7 Notes on Assessment of Risks Based on the Type of Material to be Disturbed

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

As a result, this buffering process can moderate the potential impacts from the disturbance of soil with a particular level of oxidisable sulfur. Therefore, the levels of oxidisable sulfur that warrants management action will vary with the clay content. For assessment purposes, the criteria (based on oxidisable sulfur) which should trigger management action are grouped into three broad texture categories in Table 2. Lower criteria may be necessary if large quantities are to be disturbed as in Table 3. Soil samples that meet or exceed these criteria present a risk if disturbed and require management action if earthworks are to be undertaken.

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

The interpretation of results of samples from peaty soils, high organic material, coffee rock and indurated sands can also be difficult. Sulfides commonly occur inside old root channels and sulfide formation is usually closely associated with organic matter, which if abundant, may form sulfidic peats. However, it may be possible to get a positive laboratory result on peats, by both the sulfur and acid trail testing methods where there is no identifiable mineral sulfide

under the electron microscope. The positive oxidisable sulfur result in these cases *may be* attributed to a high organic sulfur content in the organic matter. Such organic sulfur compounds are less of an environmental risk.

Coffee rock is expected to be fully oxidised due to its pedological and geomorphological history and in many circumstances do not pose environmental risks. However, this is not the case for all coffee rock. The chromium reducible sulfur method (Method 22 B) Chapter 9 of the *ASS Laboratory Methods Guidelines* (Ahern *et al.*, 1998) may be useful in assisting to improve information on the contribution of organic sulfur to these complex situations.

7.8 Assessment of Risks Based on the Maximum Level of Acid that could be Produced

The analysis of the oxidisable sulfur in the soil samples can be used to calculate the theoretical maximum amount acid that can be generated as result of the complete oxidation of sulfides. The assumption is that the entire oxidisable sulfur in the sample is pyrite (FeS₂) and it produces 2 mol of sulfuric acid per mol of pyrite and no soil buffering is available. A number of methods of determining oxidisable sulfur are available (eg. S_{TOS} and S_{POS}) and their results are normally expressed as % S (or kg H₂SO₄ / t), (Table 4). Methods for titrating acidity (TAA, TPA) are usually expressed in mole of acidity / t and approximate conversions between the various units are shown in Table 4. This analysis can provide an indication of the quantity of lime that could be required to neutralise all the acid. The data in Table 4 includes a 1.5 safety factor.

Table 4. Acid sulfate soil conversions

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

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

Note 1: Assumes a bulk density of 1.0 g /cm³ or 1 tonne/m³ (range can be 0.7-2.0 and as low as 0.2 for peats). Where bulk density is > 1 g /cm³ or 1 tonne/m³ then the safety factor will increase for lime rates/m³ soil (eg. if BD=1.6, then 1 m³ of soil with 1.0 % S_{POS} will require 75 kg lime/m³ instead of 47 kg).

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

Table 4 provides an indication of the quantities of lime required and the likely financial implications and practicability of managing the disturbance of the soil. Even when an “oxidation” mitigation strategy is not proposed, the quantity of lime required provides a signal as to the likely environmental hazards from undertaking the proposed works. Using a cost of \$50 per tonne for lime, (the actual cost of lime could vary from \$40 to \$150 per tonne depending on the location and quality), a rough understanding of the likely economic costs from disturbance of the soils (earthworks not included) can be gained.

7.9 Notes on the Assessment of Risks Based on the Quantity of Material to be Disturbed

The amount of lime required to neutralise a certain quantity of acid sulfate soil can be used as an approximation to determine the degree of risk associated with disturbing acid sulfate soil. Where the volume of acid sulfate soil is small and the concentration of oxidisable sulfur is low, the risks are considered to be relatively minor. Conversely, where large volumes of acid sulfate soils are to be disturbed, the potential cumulative risks are high. A treatment rating has been developed in Table 3 based on the calculated quantities of lime required per tonne of soil. This table provides a rough guide only. It is a useful tool for those proposing the project and as an aid to the regulators in deciding the acceptability of the project.

Considerable care should be taken when using Table 3 to justify activities that disturb acid sulfate soil. Table 3 may be used as a rough risk indicator between projects with contrasting levels of soil disturbance and different concentrations of oxidisable sulfur. Individual works have their own environmental characteristics and should always be assessed on all the information available for that site and proposed works.

7.10 Impacts Associated with the Physical Characteristics of Acid Sulfate Soils

The physical characteristics of the subsoils and the potential for compaction and subsidence of unripe acid sulfate clays should be considered for projects that involve extensive landfilling, and heavy structures such as roads, bridges, dams or major buildings. Some potential acid sulfate soil clays have the consistency of a gel with up to 80% water content and hence low bearing capacity. When these soils are loaded, considerable lateral movement or subsidence can be expected under load.

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

Extreme care must be taken with sampling and laboratory methodology for the ‘coarse category’, particularly low sulfur sands as lower detection limits are required. For confident interpretation of results, usually more than one analytical method is needed on sands and hence the ‘POCAS’ method is the recommended approach (using at least double the minimum sample weight). Each case needs careful consideration. Sands have a lower action level because they can oxidise rapidly, may have little or no pH buffering capacity and often occur in sensitive environments.

Management plans will need to demonstrate that all soils with oxidisable sulfur values greater than the action levels can be managed without harm to the environment. Further details on

management are contained in Chapter 6 of *ASS Assessment Guidelines* (Ahern *et al.*, 1998b) and *ASS Management Guidelines* (Ahern *et al.* 1998c) of the *NSW ASS Manual* (Stone *et al.*, 1998).

7.11 Consider the Precautionary Principle

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

8. REPORTING

A colour photocopy of a recent aerial photograph (where available) is an essential tool in evaluating an ASS report and should be provided. Where colour is not available then at least a high quality black and white aerial photo should be provided. The location of each borehole or sampling site must be clearly marked on a map or clear overlay, preferably at the same scale as the aerial photograph. Grid references for each sample site and height (AHD) must be documented.

A detailed description of the sampling equipment and methodology is mandatory. Additionally, the name/organisation and contact details of the drilling contractor/consultant must be supplied. Sampling equipment and methods are a major issue in assessing the validity of an ASS investigation. *These issues are best resolved by planning to have a local DEH and DNR representative or a council environment officer present for at least the initial sampling/drilling. In larger developments or complex sites, technical input from QASSIT may be required (see Section 5).* The sampling intensity (boreholes/hectare) must be clearly stated along with sample depth intervals and method of sampling. Treatment of samples (storage, freezing, drying, etc.) must be stated and the new laboratory codes (see Appendix) used on column headings of data. A description of laboratory methods must be clearly described in the ASS section of the report for data analysed prior to 1997. At least some additional data using the POCAS or TOS methods will be required to fully assess a proposal that uses older analytical methods.

9. MANAGEMENT

Many ASS situations are potentially manageable, but most require detailed investigation, professional design and comprehensive management programs to ensure that adverse environmental and engineering impacts do not occur on either the natural or built environments. Some ASS are best left undisturbed, both on economic and environmental grounds.

The most important information required before drafting an ASS management plan is a detailed soil survey with analytical data on sulfide content down the profile. The acid-producing potential of the soil needs to be quantified and evaluated in the context of the local environment, including an understanding of the sensitivity of the local waterways, ground water hydrology and the chemical, physical and biological characteristics of the soils and water.

The policy applied to an ASS disturbance is that all pollutants (for ASS this usually involves acid, and water soluble iron, aluminium and sometimes heavy metals) must be contained and managed within the site boundary or at least treated to acceptable levels prior to discharge to a natural/ external water body. As pH affects the solubility of the main ASS pollutants, pH control of all 'site water bodies' is usually the cheapest and primary control expected. When water discharge is licensed or approved in the management plan then discharge must only occur when pH is in the approved range (usually 6.5-8.5). Usually an automatic recording system will be required to control and monitor the discharge point. Although natural waters (eg. ti tree swamps) may have lower pH values than pH 6.5, once ASS have been disturbed at a site, then potential exists for soluble forms of aluminium (which can be most toxic to fish around pH 5.2; Sammut *et al.*, 1996) to exist. As aluminium species in solution are pH dependent and the chemistry is complex in natural waters, raising the pH well above the 5.2 region (eg. pH>6.5) ensures a substantial reduction in the total soluble aluminium concentration and a change in the ionic species present.

The 1998 requirements for on-site water and off-site water discharge will usually be **pH 6.5 - 8.5**, unless other environmental considerations conflict. Use of stream, river or estuarine water as a primary agent to neutralise acidity is **not acceptable** at this stage, as this removes bicarbonate from the water which may adversely affect shell formation on crustaceans and the health of benthic communities. Further research is required before approval for salt water neutralising would be contemplated. On all except minor disturbances, site management plans should incorporate complete bunding of the site to control runoff water using non ASS material in the walls of the bund.

For sites with significant ASS disturbance or potential for substantial acid generation, **an automated recording device** (4- 6 hourly depending on the site) which records pH, electrical conductivity (EC), time and date will normally be required to be installed at the point of potential water discharge from the site. The recording device should be vandal-proof and located above any potential flood level. It should be re-calibrated weekly, preferably on the last day before weekend or holiday breaks. A mechanism to record corresponding discharge volumes will also be needed on larger projects or sensitive environments. Should a significant acid runoff event occur, the equipment should have recorded date, time, water volume, pH and EC. These measurements are vital in planning future corrective action. Some recording devices, now on the market, record turbidity and dissolved oxygen as well. Remote recording and an alarm system can also be incorporated should the pH drop below a set value. Such systems should be installed in major projects. Records are to be maintained and supplied to either council or DEH as applicable, and DNR or DPI if requested. If ASS management has been successful, the data logging information will also be invaluable in requesting an early hand-over to Local Authorities and release of any relevant outstanding bonds or ASS management obligations.

Sites involving substantial disturbance such as dredging, canal or lake construction, sand extraction, etc. may require more than one automated recording device, with pH monitoring/control of treatment ponds being a high priority. As a precaution against major accidents, pH control should be initiated in small treatment ponds before being discharged back to the main pond(s).

White *et al.* (1995) provides a review of ASS management techniques. The recently released NSW *ASS Manual* contains *ASS Management Guidelines* (Ahern *et al.*, 1998c). These guidelines discuss neutralising material in some detail as well. General management strategies for dealing with ASS readily accepted in Queensland include:

- avoidance, by not disturbing/developing in locations containing ASS or, if not possible, avoiding the higher sulfide content soils;
- surface water drainage - use only shallow, wide drains which do not lower the water table significantly - not deep drains;
- unavoidable disturbance of sulfidic material - neutralise this material by thorough mixing with lime at 1.5 -2 times the theoretical acid production potential; and
- re-flooding of impacted area to create reducing conditions - actual ASS require liming first and follow up water treatment may be required.

Other **potentially higher risk strategies** requiring some site specific experimental data, pilot projects, close site supervision of earthworks, retaining a bund for an extended period, and a longer term monitoring program include:

- partial removal or concentration of pyritic material by mechanical methods - followed by burying the concentrate below the permanent water level and liming the remaining lowered pyrite content material;
- oxidation and leaching, followed by neutralising the leachate. This approach can take considerable time and is not encouraged. There may be potential for leakage into ground water as well. It is costly to prove when all sulfides have oxidised and their products are now benign; and
- limiting the oxidation by non porous capping or maintaining the watertable - this technique usually needs detailed site-specific experimental evidence of its effectiveness. (Canadian acid mine drainage research shows that unless oxygen is virtually totally denied, such as potential material placed under a permanent water cover, then acid production continues).

Recently, some successful trials of specialised dredging, combined with tight control over the sluicing process, has been used on very sandy soils to remove sufficient pyrite and fines (which are returned below the water) to achieve <0.02 % oxidisable sulfur in the treated sand. The process is limited to sandy soils and requires daily multiple sampling and analysis as part of quality control. A pilot project will normally be required to prove the efficiency of the process for each site. This method normally requires a placement of some lime below the sluiced material as an added insurance. This is because any oxidation products are easily and rapidly transported through sands.

While all these management strategies (and others) are theoretically possible, several are largely unproven and often have practical difficulties in their large scale implementation. Even the complete liming technique does not guarantee the elimination of acid-free run-off as effective mixing of lime with marine clay and mud, even after drying, is difficult. In addition, the pyrite distribution in the soil can be highly variable and a complicating factor. Trials in

high rainfall areas, such as Cairns, indicate that it is not always possible to air dry, thinly-spread, marine clays sufficiently to allow efficient lime mixing.

9.1 Independence of Assessment and Monitoring

Testing, monitoring, and evaluation undertaken independently of the developer or earthworks contractor tends to be viewed with more credibility by the community, regulatory authorities and law.

Employment of a qualified ASS (such as a Certified Professional Soil Scientist, CPSS) consultant experienced in ASS projects similar to that proposed will often save time and money in the long term and reduce exposure to future litigation. The consultant or site manager should be given full authority on the site to stop dredging, earthworks, etc. if management of ASS material or other monitoring parameters fall below the standards in the ASS EMP. Tight controls of earthworks and prompt corrective action can save extensive reprocessing if regulatory authorities random/audit sampling reveals a problem.

Ultimately, managing the risk associated with any selected ASS management technique rests with the owner/developer/consultant along with the financial and or legal responsibility for any environmental harm.

10. APPENDIX: TESTS FOR ASS

10.1 Approved Laboratory Methods

Two methods have been approved for routine laboratory analysis of environmental samples for sulfides or pyrite:

- i) **POCAS - Peroxide Oxidation Combined Acidity & Sulfate** (Method 21); and
- ii) **TOS - Total Oxidisable Sulfur** (Method 20).

The method numbering (21,20) and codes for the analytical components (Tables 2-4) are compatible with Rayment and Higginson (1992) and are fully documented in Ahern and Rayment (1998).

i) **POCAS - Peroxide Oxidation Combined Acidity & Sulfate (Method 21).**

The method is aimed at standardising procedures and combining two commonly used peroxide oxidation methods - POSA (Lin and Melville 1993) which follows the 'sulfate trail'; and the modified 'double oxidation' method of Dent and Bowman (1996) which follows the 'acidity trail'. An earlier version of POCAS was published by Ahern *et al.* (1996b) however, a few minor alterations were approved at a National Methods Workshop in October 1996. **The POCAS method supersedes the POSA and 'double oxidation' methods.**

Interim copies of the POCAS and TOS methods are available in Ahern *et al.* (1998a) from NSW ASS Manual (Stone *et al.*, 1998).

A number of results are output from the POCAS method the most important being **Peroxide Oxidisable Sulfur** ($S_{\text{POS}} \%$) which follows the sulfur trail and **Total Potential Acidity** (TPA) which follows the acidity trail. Individual codes, compatible with Rayment *et al.* (1992), are given in Tables 5 and 6 for these analyses and the other outputs from the POCAS method. Brief explanations appear below:

- **Peroxide oxidisable sulfur** ($S_{\text{POS}} \%$) is determined by subtracting 1M KCl extractable soil sulfur ($S_{\text{KCl}} \%$) from the peroxide sulfur ($S_{\text{P}} \%$) after oxidation with 30 % Hydrogen Peroxide (H_2O_2). Results should be expressed as $S_{\text{POS}} \%$; [or kg H_2SO_4 /tonne of soil]. The result is similar to the POSA method (Lin and Melville, 1993) .
- **Total potential acidity** (TPA) is determined by peroxide double oxidation. This is estimated by titration (to pH 5.5) of total acidity after oxidation of the soil with 30 % peroxide (moles of acid/tonne of soil. In the report it should also be converted to equivalent oxidisable (pyrite) S % for easy comparison with ($S_{\text{POS}} \%$). On soils with low pH (pH<5.5) TPA allows the calculation of the lime required to counteract acidity due to past oxidation as well as acidity likely to be generated from the oxidation of sulfidic material. The result is similar to TPA obtained by the method of Dent and Bowman (1996). TPA may substantially underestimate environmental risk when shell is present.
- **Total actual acidity** (TAA) is determined by titration of a 1M KCl salt solution extract to pH 5.5. This is a measure of the soil's existing acidity prior to oxidation of sulfidic material. Peat/swamp soils, coffee rock and Podosols (podzols), characterised by having high organic matter, may have a significant TAA due to organic acids. Therefore when determining lime requirements on these soils, subtracting TAA from TPA to get Total Sulfidic Acidity (TSA) is acceptable. In contrast for most other soils, much of the acidity in

actual acid sulfate soils is due to aluminium and therefore when calculating lime requirement, the TPA alone should be used rather than subtracting the TAA from TPA.

- **Total sulfidic acidity (TSA) = TPA - TAA.** This is a measure of the acidity after oxidation of sulfidic material minus the soil's actual acidity. TSA should only be used to calculate lime requirements on organic rich soils as discussed above. Any negative TSA result should be treated as zero. Such results are possible on soil materials like coffee rock with high organic matter and no sulfidic material. The peroxide digestion generally removes acidity due to organic matter from the TPA result, while organic acidity is determined in the TAA determination.

Many cases have arisen where neither the sulfur trail nor the acid trail method supply enough information and therefore results by both acid and sulfur trails (POCAS) are required. The sulfur trail takes no account of carbonate content or the buffering capacity of the soil. The acid trail has been known to record 'false positives' in routine laboratories and on some soils it may underestimate the potential risk of acid leakage to the environment as not all the shell in ASS is available for immediate neutralisation of acid because of low surface area and insoluble coatings formed on the shells. The approved combination method (POCAS) includes pH in 1M KCl measurements before (pH_{KCl}) and after oxidation (pH_{POS}) representing both the acid and sulfur trails.

Table 5: Analytical method codes for method 21; Peroxide Oxidation Combined Acidity & Sulfate (POCAS), compatible (Rayment and Higginson, 1992).

Analysis Code	Symbol & units	Analysis and description
pH measurements		
21A	pH _{KCl}	pH of filtered 1:20, 1M KCl extract, overnight shake (TAA)
21Af	pH _F	pH done in the field on saturated soil sample using pH probe
21B	pH _{OX}	pH of filtered 1:20 1M KCl after peroxide digestion
21Bf	pH _{FOX}	pH done in the field of 30% peroxide reaction, pH probe
Sulfur methods		
21C	S _{KCl} %	KCl extractable S -additional codes added for S determination
21D	S _P %	Peroxide sulfur after peroxide digestion
21E	S _{POS} %	Peroxide oxidisable S [21D minus 21C]
Acidity methods		
21F	TAA (mol H ⁺ /tonne)	Total Actual Acidity in 1M KCl titrated to pH 5.5
21G	TPA (mol H ⁺ /tonne)	Total Potential Acidity in 1M KCl peroxide digestion titrated to pH 5.5
21H	TSA (mol H ⁺ /tonne)	Total Sulfidic Acidity [21G-21F]
21J	S _{TAA} %	TAA calculated as equivalent pyrite S % for comparison with 21L
21K	S _{TPA} %	TPA calculated as equivalent pyrite S % for comparison with 21E
21L	S _{TSA} %	TSA calculated as equivalent pyrite S % for comparison with 21E
Calcium values from POCAS to estimate additional calcium from acid-shell/carbonate reaction		
21V	Ca _{KCl} (Ca %)	Ca extracted in 1M KCl (TAA)
21W	Ca _P (Ca %)	Ca in peroxide digest (TPA)
21X	Ca _A (Ca %)	Ca reacted with acid generated by peroxide digestion (21W-21V)
Magnesium values from POCAS to estimate additional magnesium from acid-shell /dolomite/carbonate reaction		
21S	Mg _{KCl} (Mg %)	Mg extracted in 1M KCl (TAA)
21T	Mg _P (Mg %)	Mg in peroxide digest (TPA)
21U	Mg _A (Mg %)	Mg reacted with acid generated by peroxide digestion (21T-21S)
Sodium values from POCAS		
21M	Na _{KCl} (Na %)	Na extracted in 1M KCl (TAA)
21N	Na _P (Na %)	Na in peroxide digest (TPA)
21P	Na _A (Mg %)	Na difference (21N-21M)
Neutralising methods		
21Q	NQ (CaCO ₃ %)	Quick residual neutralising capacity
21R	NQ _S (S _R %)	Quick residual neutralising capacity 21Q, calculated as equivalent S %

Supplementary finishing step codes for S, Ca, Mg, Na as per Table 6

eg. 21Ce is KCl extractable sulfur with ICPAES finishing step

Table 6: Supplementary finishing step codes for Table 5 methods - sulfur (21C, 21D, 21E), calcium (21V, 21W, 21X) magnesium (21S, 21T, 21U) or sodium (21M, 21N, 21P).

Supplement code	Analyte and finishing step	Similar to Rayment & Higginson (1992) method
Sulfur		
a	sulfate, turbidimetric	J1a
b	sulfate, gravimetric	J1b
c	sulfate, automated colour	J1c
d	sulfate, ion chromatography	J1d
e	sulfur, ICPAES	J2a
f	sulfate, automated turbidimetric	J1a
g	sulfate, indirect, barium remaining by AAS	
Calcium		
h	calcium, ICPAES	L1c
j	calcium, atomic absorption (AAS)	L1b
k	calcium, titration EDTA	L1a
Magnesium		
m	magnesium, ICPAES	L2c
n	magnesium, atomic absorption (AAS)	L2b
p	magnesium, titration EDTA	L2a
Sodium		
s	sodium, ICPAES	L4c
t	sodium, atomic absorption	L4b
u	sodium, flame emission	L4a

eg. **21Ce** is KCl extractable sulfur using an ICPAES finish to determine S

ii) TOS - Total Oxidisable Sulfur (Method 20).

Total oxidisable sulfur is calculated as total sulfur minus 4M HCl extractable sulfur. This method is suitable for an **initial, low-cost screening** for the presence and amount of pyrite or iron disulfide (FeS_2) in reduced sediments where no oxidation has occurred, provided the levels are above the detection limits for the instruments used to determine total S. Low analysis sands will normally require the POCAS method.

Method 20 requires high capital cost equipment such as Inductively Coupled Plasma Atomic Emission Spectrometer (**ICPAES**) and a **LECO** high frequency induction furnace or **X-ray** fluorescence such as found in major analytical laboratories. However, some laboratories still use traditional chemical methods, usually accompanied by an increase in costs. The codes to identify the actual method used are given in Table 7.

- **Total sulfur** (S_T) may be determined by X-ray fluorescence (XRF), Method 10A1, Rayment and Higginson (1992); or by LECO resistance furnace coupled to a high sensitivity S analyser. Some LECO instruments include the capacity to measure carbon or nitrogen or both in addition to sulfur.

Older LECO instruments may have low sensitivity/detection limits to sulfur and where the species detected is SO_2 , conditions must be optimised such that as much of the sulfur must be converted to the detected species prior to actual quantitative detection. Instruments designed

for metal analysis (high frequency induction furnaces) have lower sample capacity, resulting in much higher detection limits and hence are less suitable for soils. Some recent data (Lancaster pers. comm. and McElnea pers. comm.) suggest some recent LECO instruments may underestimate sulfates/gypsum in samples if not specially tested.

- **Hydrochloric Acid Extractable Sulfur** (S_{HCl}) is determined on a 4M HCl extraction using overnight shake (16 hr). It is intended to remove water soluble sulfates and predominantly oxidised, non-water soluble complex sulfates such as jarosite $KFe_3(OH)_6(SO_4)_2$ or natrosite $NaFe_3(OH)_6(SO_4)_2$. When ICPAES is employed to determine S then any organic material extracted in 4M HCl is also determined.
- **Total Oxidisable Sulfur** (S_{TOS}) is calculated by subtracting hydrochloric extractable sulfur from the total sulfur value.

The calculated total oxidisable sulfur (S_{TOS}) result gives a more realistic estimate of total oxidisable sulfur from pyrite. However, the result does not include any acidity likely to be derived from jarosite or iron compounds.

The TOS method supplies less data for interpretation than the POCAS method and depending on actual instruments used, the total sulfur detection limits are usually too high for accurate assessment of low sulfur sands (action level = 0.03 % S_{TOS}). Sandy soils are best analysed by the POCAS method using double sample weight. The contribution from organic matter may also be significant in the total sulfur (S_T %) result, potentially resulting in an inflated prediction of sulfide content.

Table 7 Codes for Method 20A; Total Sulfur

20A	Total Sulfur (S_T %)
1	X-ray fluorescence (similar to method 10A1 Rayment and Higginson, 1992)
2	Leco
3	Combustion, titration end-point
4	Combustion, dry ashing sodium bicarbonate, silver oxide (Steinbergs <i>et al.</i> , 1962)
5	Alkaline sodium hypobromite oxidation + reduction hydriodic acid reduction (Tabatabai and Bremner 1970)
6	Acid oxidation using nitric, perchloric, phosphoric, hydrochloric acids (Arkley, 1961)
7	Bromine - nitric acid oxidation (Vogel 1978)
9	Summation from procedure 20D, ($S_{TOS} + S_{HCl}$)

e.g. **20A1** Total sulfur by X-ray fluorescence

Table 8 Codes for Method 20B; supplementary finishing step codes**20B Hydrochloric acid (4M) extractable sulfur (S_{HCl} %), Ca, Mg, Na, and K**

Supplementary finishing step codes.

Supplement code	Analyte and finishing step	Similar to Rayment & Higginson (1992) method
Sulfur		
a	sulfate, turbidimetric	J1a
b	sulfate, gravimetric	J1b
c	sulfate, automated colour	J1c
d	sulfate, ion chromatography	J1d
e	sulfur, ICPAES	J2a
f	sulfate, automated turbidimetric	J1a
g	sulfate, indirect, barium remaining by AAS	
Calcium		
h	calcium, ICPAES	L1c
j	calcium, atomic absorption (AAS)	L1b
k	calcium, titration EDTA	L1a
Magnesium		
m	magnesium, ICPAES	L2c
n	magnesium, atomic absorption (AAS)	L2b
p	magnesium, titration EDTA	L2a
Sodium		
s	sodium, ICPAES	L4c
t	sodium, atomic absorption	L4b
u	sodium, flame emission	L4a
Potassium		
v	potassium, ICPAES	L3c
w	potassium, atomic absorption (AAS)	L3b
x	potassium, flame emission	L3a

eg. **20Be** is 4M HCl extractable sulfur using an ICPAES finish to determine S.**Table 9** Codes for Method 20C; Total oxidisable sulfur (S_{TOS} %) ie. [20A - 20B]Use the numeral indicator of the total S method followed by the lower case alphabetic character to define the method used to determine S_{HCl} %. E.g.

20C1e	Total oxidisable sulfur	by X-ray (1) and ICP (e)
20C2e	Total oxidisable sulfur	by LECO (2) and ICP (e)
20C2a	Total oxidisable sulfur	by LECO (2) and Turbidimetric (a)

Table 10 Codes for Method 20D; Total oxidisable sulfur (S_{TOS} %) pre-washed 4M HCl & water

1	X-ray fluorescence (similar to method 10A1 Rayment and Higginson, 1992)
2	Leco (the older model Leco furnace is unsuitable)
3	Combustion, titration end-point
4	Combustion, dry ashing sodium bicarbonate, silver oxide (Steinbergs <i>et al.</i> , 1962)
5	Alkaline sodium hypobromite oxidation + reduction hydriodic acid reduction (Tabatabai and Bremner (1970)
6	Acid oxidation using nitric, perchloric, phosphoric, hydrochloric acids (Arkley, 1961)
7	Bromine - nitric acid oxidation (Vogel 1978)

e.g. **20D2** Total oxidisable sulfur after HCl pre-wash determined by Leco (2)

iii) Acid Neutralising Capacity

If carbonate is present in the soil then the **Acid Neutralising Capacity (ANC)** may be determined by an appropriate method such as 19A1, 19B1, P 206 in 'The Australian Laboratory Handbook of Soil and Water Chemical Methods' (Rayment and Higginson, 1992). Other ANC methods (eg. 19C1) are available and no one preferred method has been agreed upon yet for ASS. Some codes are given below. As shell is often ground up with the soil sample, it is debatable whether any of the ANC can be taken into account when considering liming rates for soils. ANC should never be subtracted from TPA or TSA results as the acidity generated from the peroxide digestion has the opportunity to react with any carbonate or basic cations present. Where carbonate or shell is shown to be very finely divided, some reduction of the safety factor may be negotiable. Such cases will usually require a site visit or additional information, and is likely to be site specific.

Acid Neutralising methods (non-POCAS) from Rayment and Higginson (1992)

19A1	NT (CaCO ₃ %)	Neutralising -Titration Carbonates - back titration expressed as CaCO ₃ %
19B1	NV (CaCO ₃ %)	Neutralising -Volumetric Carbonates - manometric expressed as CaCO ₃ %

Methods to be added to Rayment and Higginson (1992)

19A2	NTL (CaCO ₃ %)	Neutralising – Titration carbonates (Lewis & McConchie) CaCO ₃ %
19C1	NG (CaCO ₃ %)	Neutralising - Gravimetric loss of CO ₂ expressed as CaCO ₃ %
19D1	NC (CaCO ₃ %)	Neutralising - Curve (titration) expressed as CaCO ₃ %

Determination of calcium and magnesium on the TAA extract and TPA digest of the POCAS method may assist calculations on the amount of shell or lime that has reacted with the acid produced by peroxide oxidation of pyrite in the sample. This is an easy low cost add on when analysing for sulfur on the same extract by some ICPAES instruments.

No single method gives the full information necessary to develop an ASS Management Plan for all soils. A combination of analytical methods is usually required on the soil samples containing carbonate and particularly those with shell content.

iv) Other Laboratory Tests

Additional laboratory analyses are useful for understanding the soil's potential acid generation and identifying potential environmental effects. Measurement of electrical conductivity, chloride, organic carbon, aluminium, iron and exchangeable cations all help to define and create a clearer picture. Acid volatile sulfur (Bush and Sullivan, 1998) and Chromium reducible sulfur (Sullivan *et al.*, 1998) may also be useful methods for some situations.

ASS 'Miscellaneous ASS Methods'- Code 22

Method 22A: Acid Volatile Sulfur (S_{AV} %)

Method 22B: Chromium Reducible Sulfur (S_{CR} %)

Method 22C: Scanning Electron Microscopic methods

Mass based measurements can be converted to volumetric measures for contractors (e.g. m³) by dividing by bulk density (see NSW Acid Sulfate Soil Manual for further details).

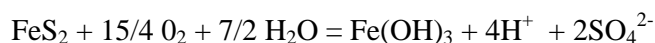
Additionally, a measure of moisture content is often required for calculations by an appropriate method such as 2B1 or 2B2 (Rayment and Higginson, 1992).

Moisture codes

Analysis Code	Symbol & units	Analysis and description
<i>Moisture Content methods from Rayment and Higginson (1992)</i>		
2B1	W_{105} (%)	As received moisture 105°C
<i>Methods to be added to Rayment and Higginson (1992)</i>		
2B2	W_{85} (%)	As received water moisture content 85°C

10.2 Calculations

Sulfide/pyrite assays are used to calculate the maximum acid that can be theoretically generated by the complete oxidation of a sample. For the initial assessment (unless more expensive fractionating analyses are undertaken), it is assumed that all S_{POS} or S_{TOS} sulfur occurs as iron-disulfide (or pyrite) and that the oxidation of this iron-disulfide proceeds according to the complete reaction:



Based on the stoichiometry of this reaction, the maximum amount of acid that could be produced by a sample containing 1 %S as pyrite would be 30.59 kg H_2SO_4 /tonne or 623.7 moles H^+ /tonne of soil. Such a soil, if fully oxidised and unbuffered, would require 31.2 kg of pure fine lime/tonne of soil to neutralise the acidity generated if completely mixed and fully reacted. As even the best grade agricultural fine lime is not pure, a factor to compensate upwards for the neutralising value of the lime needs to be included in calculations. Further details are contained in Chapters 5 and 6 of *ASS Management Guidelines* (Ahern *et al.*, 1998c).

In management plans which involve liming, an engineering safety factor of at least 1.5 -2 times the theoretical lime requirements needs to be used, to allow for the slow reactivity of lime and non homogenous mixing in the field. (Some countries eg. Canada, insist on a safety factor as high as 3). Table 4 gives some liming rates for soils with increasing sulfide content, and approximate costs of lime for a range of S_{POS} , S_{TOS} , TPA or TSA values.

10.3 Field pH Tests

Field pH tests cannot be used as a substitute for laboratory ASS analysis in an EIS. Attempts to use them in an EIS to predict oxidisable sulfur levels and therefore reduce the numbers of laboratory analysis submitted is not acceptable. However, they are a useful additional tool.

i) Field pH in Water (pH_F)

Field pH tests should be conducted on the soil profile at regular intervals (0.25 m) using a field pH meter with a robust, spear point, double reference pH electrode. If the measured pH of the suspension or soil paste is $\text{pH} < 4$, oxidation of sulfides has probably occurred in the past, indicating that an actual acid sulfate soil (AASS) is present. Low range pH indicator papers or a field pH kit based on the specifications of Ruapach and Tucker (1959) are useful if a pH meter is not available. They are based on pH dependent indicator solutions displaying a characteristic colour and **may** be subject to interference on some ASS resulting in substantial errors.

ii) Field Peroxide pH Test (pH_{FOX})

Field pH tests do not account for any sulfide present that has not yet been oxidised. To test for sulfides or potential acid sulfate soils (PASS), oxidation of the soil with 30 % or 100 volume hydrogen peroxide (H₂O₂)(**pH adjusted 4.5 - 5.5**) with a few drops of 0.1M NaOH) can be performed. Note the peroxide pH should be checked on every new container and also regularly before taking to the field. Analytical grade peroxide is the best to use but the pH may still be as low as 3. Manufacturers stabilise technical grade peroxide with acid and this can lead to pH < 2 and giving false results on the field tests. (*Caution: 30 % 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*).

The field test can be done with a few mL of peroxide and a small sample of soil in either short clear test tubes (eg. Falcon 2070 50ml conical tubes) or clear tissue culture clusters. Heating (placing test tube in hot water) or placing in the sun (UV light) may be necessary to start the reaction on cool days, particularly if the peroxide is cold. When effervescence (sometimes violent) has ceased, continue to add a few mL of peroxide at a time until the reaction appears complete. If the reaction becomes violent diluting with deionised water via a wash bottle is recommended. The test may have to be repeated with a small amount of water added to the soil prior to peroxide addition. Measure the pH_{FOX} of the resultant mixture. Care is needed with interpretation of the result on high organic or reactive soils, particularly if manganese is present. In general, positive tests on 'apparently well drained' surface soils should always be treated with caution and followed up with laboratory confirmation.

The above field 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, left to react for at least an hour or preferably overnight, then the sample moistened with deionised water before reading pH_w and pH_{FOX}. However, such procedures take time in the field and are more suited to a 'field shed' situation.

The peroxide test is done on two sub-samples from the same depth interval at which the field pH was measured on. **A combination of three factors is considered in arriving at a 'positive field sulfide identification'** (a) a reaction with hydrogen peroxide, (b) a much lower pH_{FOX} than field pH_F (Δ pH) and (c) the actual value of pH_{FOX}.

(a) The **strength of the reaction with peroxide** is a useful indicator but cannot be used alone. Organic matter 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 peat and some mangrove/estuarine muds and marine clays. This reaction should be rated.

(b) A **pH_{FOX} value at least one unit below field pH_F** may indicate a PASS. 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} value is, the better the indication of a positive result.

(c) If the **pH_{FOX} < 3**, and the other two conditions apply, then it strongly indicates a PASS. The more the pH_{FOX} drops below 3, the more positive the presence of sulfides.

- A **pH_{FOX} 3-4** is less positive and laboratory analyses are needed to confirm if sulfides are present. (If only low pH peroxide is available, the field test is less discriminatory,

particularly for sands because of their low pH buffer capacity. Low analysis sands may give confusing field test results and must be confirmed by laboratory analysis.)

- For **pH_{FOX} 4-5** the test is neither positive nor negative. Sulfides **may** be present either in small quantities and be poorly reactive under quick test field conditions 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 sulfur trail would be best to check for the presence of oxidisable sulfides.
- For **pH_{FOX} >5** and little or no drop in pH from the field value, little net 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). Again the sulfur trail of the POCAS method should be used to check for any oxidisable sulfides.

All pH_F and pH_{FOX} results by depth should be tabulated and reported in the ASS report/EIS.

Other semi-field tests such as examination under a microscope for pyrite and its reaction with peroxide on the slide may be useful tools to identify pyrite presence, but they require experience and training.

Note: field techniques are useful exploratory tools, but are indicative only and definitely not quantitative. They are not a replacement for quantitative laboratory analyses. The field peroxide test has been found to be least useful on low analyses sands, particularly dredged sands approaching the action limit (0.03 % S). It is also difficult to interpret field tests on high organic or peat soils and coffee rock.

11. REFERENCES

- Acid Sulfate Soil Management Advisory Committee (1996) 'Interim acid sulfate soils analytical methods, June 1996'. Wollongbar Agricultural Institute, Wollongbar, NSW, 2477.
- Ahern, C.R. and Rayment G.E. 'Codes for Acid Sulfate Soils Analytical Methods'. In *Laboratory Methods Acid Sulfate Soils 1998*. Ahern C.R., Blunden B., and Stone Y. (Eds), Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.
- Ahern, C.R., Blunden B. and Stone Y. (Eds) (1998a). 'Acid Sulfate Soils Laboratory Methods 1998'. In *Acid Sulfate Soil Manual*. Ahern, C.R., Blunden B., and Stone Y. (Eds), Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.
- Ahern, C.R., Stone Y., and Blunden B. (1998b). 'Acid Sulfate Soils Assessment Guidelines'. In *Acid Sulfate Soil Manual*. Ahern C.R., Blunden B., and Stone Y. (Eds), Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.
- Ahern C.R., Stone Y. and Blunden B. (1998c). 'Acid Sulfate Soils Management Guidelines 1998'. In *Acid Sulfate Soil Manual*. Ahern, C.R., Blunden B., and Stone Y. (Eds), Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.

- Ahern, C.R., McElnea, A. and Baker, D.E. (1996a) 'To dry or not to dry? That is the question for sulfidic soils'. In *'Proceedings of the Australian and New Zealand National Soils Conference, 1-4 July 1996'*. Australian Soil Science Society, Melbourne.
- Ahern, C.R., McElnea, A. Hicks, W., and Baker, D.E. (1996b) 'A combined routine peroxide method for analysing acid sulfate soils'. In *'Proceedings of the 2nd National conference of Acid Sulfate Soils'*. Robert J. Smith and Associates and ASSMAC, Australia.
- Anderson, H., Ahern, C.R. and Weinand-Craske, M.M.G. (1996) 'Oops, I've gone too deep!' In *'Proceedings of the 2nd National conference of Acid Sulfate Soils'*. Robert J. Smith and Associates and ASSMAC, Australia.
- Bush, R.T. and Sullivan, L.A. (1997) 'Morphology and behaviour of greigite from a Holocene sediment in Eastern Australia'. *Australian Journal of Soil Research* ; **35**, 853-61.
- Crockford, R.H. and Willett, I.R. (1995) 'Drying and oxidation effects on the magnetic properties of sulfidic material during oxidation'. *Australian Journal of Soil Research*, **33**, 19-29.
- Dent, D.L. and Bowman, G.M. (1996a) Quick quantitative assessment of the acid sulfate hazard. 'Proceedings of the 2nd National conference of Acid Sulfate Soils'. Robert J. Smith and Associates and ASSMAC, Australia.
- Dent, D.L. and Bowman, G.M. (1996b) 'Quick quantitative assessment of the acid sulfate hazard'. CSIRO Division of Soils, Divisional Report 128.
- Hicks, W.S. and Bowman, G.M. (1996) 'Practical aspects of the quantitative assessment of acid sulfate soils'. In *Proceedings 2nd National Conference of Acid Sulfate Soils*. Robert J Smith and Associates and ASSMAC, Australia.
- Lin, C. and Melville, M.D. (1993) Control of soil acidification by fluvial sedimentation in an estuarine floodplain, eastern Australia. *Sedimentary Geology*, **85**, 1-13.
- Naylor, S.D., Chapman, G.A., Atkinson, G., Murphy, C.L., Tulau, M.J., Flewin, T.C., Milford, H. B. and Morand, D.T. (1995) *Guidelines for the use of acid sulfate soils risk maps*. NSW Soil Conservation Service, Department of Land and Water conservation, Sydney.
- McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1990) *Australian Soil and Land Survey Field Handbook*, 2nd edn, Inkata Press, Melbourne.
- NSW EPA. (1995) *'Assessing and managing acid sulfate soils: Guidelines for land management in NSW coastal areas'*. EPA 95/41. Environmental Protection Authority, Chatsworth, NSW.
- Raupach, M. and Tucker, B.M. (1959) 'The field determination of soil reaction'. *Journal Australian Institute of Agricultural Science*, **25**: 129-33.
- Rayment, G.E. and Higginson, F.R. (1992) *Australian Laboratory Handbook of Soil and Water Chemical Methods*. Inkata Press, Sydney.

Saffigna, P.G., Holland, G.L., Joyce, A.S., Cordwell, G.B., Cordwell, B.A. and Covey, N.R. (1996) 'Distribution of pyrite in silt, sand, gravel and wood in a soil profile near Yandina, Queensland. In *Proceedings of the 2nd National conference of Acid Sulfate Soils*'. Robert J. Smith and Associates and ASSMAC, Australia.

Sammut, J., Callinan, R.B. and Fraser, G.C. (1996) 'An overview of the ecological impacts of acid sulfate soils in Australia'. In *Proceedings of the 2nd National conference of Acid Sulfate Soils*. Robert J. Smith and Associates and ASSMAC, Australia.

Sammut, J. and Lines-Kelly, R (1996) *An introduction to acid sulfate soils*. (Available from NSW ASS info officer, phone 02 6626 1319 or view a copy at your local Council office).

Smith, R.J. and Ahern, C.R. (1996) 'Acid sulfate soils a constraint to Queensland coastal developments?' In *Land Management for Urban Development*. (Ed. S.A. Waring), pp 55-69. Australian Society of Soil Science Incorporated, Queensland Branch.

Stone Y., Ahern C.R., and Blunden B. (1998) *Acid Sulfate Soils Manual 1998*. Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.

Vogel (1978) "Vogel's Textbook of Quantitative Inorganic Analysis". 4th edition, Longman, London.

White, I., Melville, M.D., Lin, C., Sammut, J., van Oploo P. and Wilson, B.P. (1995) 'Fixing problems caused by acid sulfate estuarine soils'. In *Ecosystem Management: the Legacy of Science*. (Ed. C. Copeland). Halstead Press, Sydney.

White, I., Melville, M.D., Sammut, J., van Oploo, P., Wilson, B.P. and Yang, X. (1996) *Acid sulfate soils: facing the challenges*. Earth Foundation Australia Monograph 1.

12. CONTACTS

Advice on development applications, licensing and legislative matters **should be directed initially** to your Local Government or the local office of DEH, DPI (Fisheries) or DNR. Planning and Environment Officers of your local DNR office may be able to assist with indicating possible locations of ASS in your area. Various acid sulfate soils maps of south east Queensland (NSW border to Coolool) will be available by mid 1999 by contacting the Queensland Acid Sulfate Soils Information Officer - Ms Kylie Hey.

The latest version of these 'ASS sampling guidelines' may be obtained from the ASS Information Officer Kylie Hey at QASSIT, DNR, Resource Sciences Centre, Indooroopilly Ph (07) 3896 9819 or fax (07) 38969872, email heyk@dnr.qld.gov.au These guidelines will soon be available. www.dnr.qld.gov.au/land/lris/acidss/ass-home.html

The **more complex technical inquiries** on acid sulfate soils may be directed to the Queensland Acid Sulfate Soils Investigation Team (QASSIT). Members listed below:

Col Ahern or Bernie Powell (QASSIT)
Department of Natural Resources
Resource Sciences Centre, Block C
Meiers Rd., INDOOROOPILLY, Q 4068
Ph (07) 3896 9510, or (07) 3896 9398
Fax (07) 3896 9898 or (07) 3896 9782

13. GLOSSARY

Acid Sulfate Soil (ASS) - a soil or soil horizon which contains sulfides or an acid soil horizon affected by oxidation of sulfides'. This is the definition used in Queensland's Environmental Protection Policy.

Action Level of oxidisable sulfur is the level for that textures class (Table 1 Section 7) above which active management or treatment of the material will be required if disturbed.

Best Practice Environmental Management (BPEM) - Section 18 EPA: the management of the activity to achieve an ongoing minimisation of the activity's environmental harm through cost-effective measures assessed against the measures currently used nationally and internationally for the activity.

Ecologically Sustainable Development (ESD) - Section 3 EPA: allowing development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends.

Environmental Evaluation - Section 71 EPA: an *environmental audit* or *investigation* of an activity to decide the source, cause or extent of environmental harm caused by the activity, and the need for an environmental management program.

Environmental Harm - Section 14 EPA: any adverse effect, or potential adverse effect (whether temporary or permanent and of whatever magnitude, duration or frequency) on an environmental value. May be caused by direct or indirect result of an activity.

Environmental Management Program - an environmental management program approved under Chapter 3, Part 6 of the EPA, to achieve compliance with the Act by reducing environmental harm, or detailing the transition to an environmental standard.

Environmental Protection Policies (EPPs) - environmental protection policy approved under Chapter 2 of the EPA.

Environmental Value - Section 9 EPA: a quality or physical characteristic of the environment that is conducive to ecological health or public amenity; or another quality of the environment identified and declared to be an environmental value under an environmental protection policy or regulation.

Environmentally Relevant Activities (ERAs) - an activity in Schedule 1 of the Environmental Protection Regulation, 1998.

Fish Habitat Area - Sections 120 and 121, Fisheries Act 1994 giving statutory protection to key habitats to ensure long term fisheries production.

Marine Plant - Section 8 Fisheries Act 1994: includes a plant that usually grows on, or adjacent to, tidal land, whether it is living, dead, standing or fallen.

Table 11. Some theoretical ASS conversions between common units for determining pyrite acidity, liming rates and indicative lime costs

Oxidisable S %	moles H ⁺ / kg (S % x 0.624)	moles H ⁺ / t or moles H ⁺ / m ³ * (S % x 624)	kg H ₂ SO ₄ /tonne or kg H ₂ SO ₄ /m ³ * (S % x 30.59)	kg lime/tonne soil or kg lime/ m ³ * Safety factor =1.5**	Approx. lime cost/tonne soil or Cost/ m ³ of soil * \$	Cost/ha/m depth of soil @ \$50/t of lime \$
0.01	0.006	6	0.306	0.45	0.02	234
0.02	0.013	12.5	0.612	0.9	0.05	468
0.03	0.019	18.7	0.918	1.38	0.07	702
0.05	0.031	31	1.53	2.33	0.12	1,170
0.06	0.037	37.4	1.84	2.75	0.14	1,404
0.1	0.062	62	3.06	4.7	0.23	2,340
0.2	0.125	125	6.12	9.4	0.47	4,680
0.3	0.187	187	9.18	14	0.70	7,020
1.0	0.62	624	30.5	46.8	2.34	23,410
5.0	3.12	3119	153.0	234	11.70	117,000

* Assumes a bulk density of 1.0 g /cm³ or 1 tonne/m³ (range can be 0.2-2.0 including 0.2 for peats). Where bulk density is > 1 g/cm³ then factor will increase for lime rates/m³ soil (eg. if BD=1.6, then 1 m³ of soil with 1.0 % oxidisable S will require 75 kg lime/m³ instead of 47 kg).

** Minimum safety factor of 1.5 to allow for non-homogeneous mixing and poor reactivity of lime. The factor only applies for addition of good quality fine agricultural lime with neutralising value of 100. Where neutralising value less than 100 then the factor must be increased, while if neutralising value is greater than 100 (eg. dolomite) then factor may be reduced accordingly. Coarser grade limestone will require higher safety factors as may environmentally sensitive sites.