

Moreton Bay Regional Council Acid Sulfate Soils - Beachmere Area



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Published by Department of Natural Resources and Water, Indooroopilly, Queensland, Australia.

May 2007

Material from this publication may be used providing both the author and the publishers are acknowledged.

Citation of this publication should take the form:

Pointon SM, Malcolm DT, Manders JA and Hall IR (2007). *Moreton Bay Regional Council Acid Sulfate Soils – Beachmere Area*. Department of Natural Resources and Water, Indooroopilly, Queensland, Australia.

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Acknowledgements

The authors wish to thank:

- **Graham Clements** for project assistance with access to Council areas
- **Dr Angus McElnea** for assistance in interpreting laboratory data
- **Natural Resource Sciences Chemistry Centre** for soil laboratory analysis
- **Sheryl Crofts** for cartographic expertise
- **Carl Cross** for assistance in the field and with the report compilation

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Summary

In 2000, approximately 4000 ha of acid sulfate soils (ASS) was identified on relatively undisturbed land in Moreton Bay Regional Council, southeast Queensland (Smith *et al.* 2000) based on broad scale 1:100 000 maps. Increased development pressure in Moreton Bay Regional Council has resulted in the need for more precise data to guide the Council's processes consistent with the *State Planning Policy 2/02: Planning and Managing Development Involving Acid Sulfate Soils*, and *Integrated Planning Act 1997*.

In 2006, Council focussed on the identification of acid sulfate soils in three priority areas along Moreton Bay Regional Council's coastal zone. The project aim was to develop maps based on medium resolution (ie. 1:50 000) ASS mapping undertaken by the Department of Natural Resources and Water (NRW). This report focuses on 1:25 000 scale acid sulfate soil investigations of 367 hectares of land in the Beachmere area of Moreton Bay Regional Council.

The investigation in the Beachmere area included 70 boreholes undertaken to a maximum depth of 7.6 metres. The 70 soil profiles were then described and sampled (as per the *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland* (Ahern *et al.* 1998)). The presence or absence of acid sulfate soils was determined using both field and laboratory testing. Laboratory methods used included the Chromium Reducible Sulfur method (S_{CR}) and/or SPOCAS method (Ahern *et al.* 2004).

The accompanying 1:25 000 scale acid sulfate soils map displays the depth to the first occurrence ASS. Of the 367 hectares investigated, 15 hectares were found to contain actual acid sulfate soils (AASS) with existing acidity up to 0.17 %S at shallow depth in the top 1.0 m. Of the remaining 352 hectares, potential acid sulfate soils (PASS) with up to 2.7 %S were found to occur at various depths ranging from less than 0.5 m to 4 m below the surface.

These results indicate the need for caution in planning and managing developments in the Beachmere area so as to avoid costly damage to the environment and local infrastructure. Additional investigation will be required prior to construction or excavation to satisfy the recommendations of the *Sampling Guidelines* (Ahern *et al.* 1998).

1. Introduction and brief overview of acid sulfate soils

Acid sulfate soil (ASS) is the name given to naturally occurring sediments (sands, silts, or clays) that contain sulfides, primarily iron sulfides (FeS_2). The sulfides remain chemically stable while buried in oxygen-free, waterlogged environments. However, when exposed to oxygen, they undergo a series of chemical reactions resulting in the production of sulfuric acid. As an example: one tonne of iron sulfides can produce about 1.5 tonnes of sulfuric acid when oxidised. This can have major environmental, health, and engineering impacts.

In an undisturbed, waterlogged state ASS may range from dark grey silty clays to grey sands and peat with pH values close to neutral (6.5–7.5). In this state they are termed potential acid sulfate soils (PASS) because they have the potential to oxidise and produce sulfuric acid. When ASS are exposed to air, the sulfides oxidise and sulfuric acid is produced. In this state they are known as actual acid sulfate soils (AASS). AASS are very acidic ($\text{pH} < 4$), and often contain a straw yellow mineral called jarosite. The term ASS includes both AASS and PASS. AASS and PASS are often found in the same soil profile, with AASS generally overlying PASS as surface layers are more likely to be exposed to oxidation.

In recent years, increasing development pressures particularly in coastal areas of southeast Queensland have resulted in the need for more detailed information about acid sulfate soils. In 2006 a jointly funded project between the Moreton Bay Regional Council and the Department of Natural Resources and Water led to the commencement of acid sulfate soil mapping within low lying (< 5 m AHD) areas of Moreton Bay Regional Council. Three key areas were identified by Council representatives (Beachmere, Bribie Island and Toorbul–Donnybrook).

This report details the acid sulfate soil mapping undertaken in the Beachmere area (Figure 1). Previous mapping undertaken by the Department of Natural Resources and Water (1:100 000 scale Redcliffe to Teewah Map 2 Ref. NR&M – SEA I AO 3261, 2003) has identified the likelihood of acid sulfate soils in the Beachmere area however the broadscale nature of this work makes it unsuitable for local council planning purposes. The aim of the more detailed work was to identify the presence, depth and net acidity of acid sulfate soils within the study area and present these results as a map along with an accompanying report.

2. Survey area

The Beachmere high priority ASS study area is a small peninsula comprising 367 ha, extending north from the mouth of the Caboolture River approximately 4.5 kilometres following the coastline, and 1.8 kms to the west at its widest point (**Figure 1**). It is characterised by coastal plain and estuarine deposits (Cranfield *et al.* 1986). The coastal plain deposits which consist of Holocene age beach ridge sands and shelly sands (Qhcb2) dominate the eastern and central parts of the study area, whilst the estuarine deposits consisting of Holocene age tidal flat sands and muds (Qhct) dominate the southern and western parts.

Flood (1980) described a prograded sequence of Holocene tidal flat environments preserved on the coastal plain surrounding Beachmere, with several periods of accretion evident. He also identified that the mud present in the study area originated from Caboolture River, Burpengary Creek and possibly the Brisbane River, whereas the sand originated from the northern entrance of Moreton Bay between Bribie and Moreton Islands.

McClure (1995) identified four stages of coastal plain development from Beachmere to Sandstone Point:

- Stage 1 (6500–3300 yrs before present) was the period of maximum Holocene sea levels when the most landward beach ridges to the west of Beachmere/Godwin Beach were formed.
- Stage 2 (3300–1000 yrs before present) involved the development of the coastal lowland swamp on the seaward side of the beach ridges formed during Stage 1.
- Stage 3 (~1000 yrs before present) involved the formation of a new beach ridge system to the east of the coastal lowland swamp. This beach ridge system consists of a large landward ridge and several smaller seaward ridges (Lang *et al.* 1998).
- Stage 4 (present day development) consists of the progression of smaller beach ridges with associated supratidal and upper intertidal swamps that exist to the present day.

Vegetation in the study area consists of common mangrove and *Casuarina* vegetation on the tidal flats and swamps of the southern and western parts with *Corymbia*, *Eucalyptus*, *Melaleuca*, *Casuarina* and *Acacia* species dominating the beach ridges in the central and eastern parts.

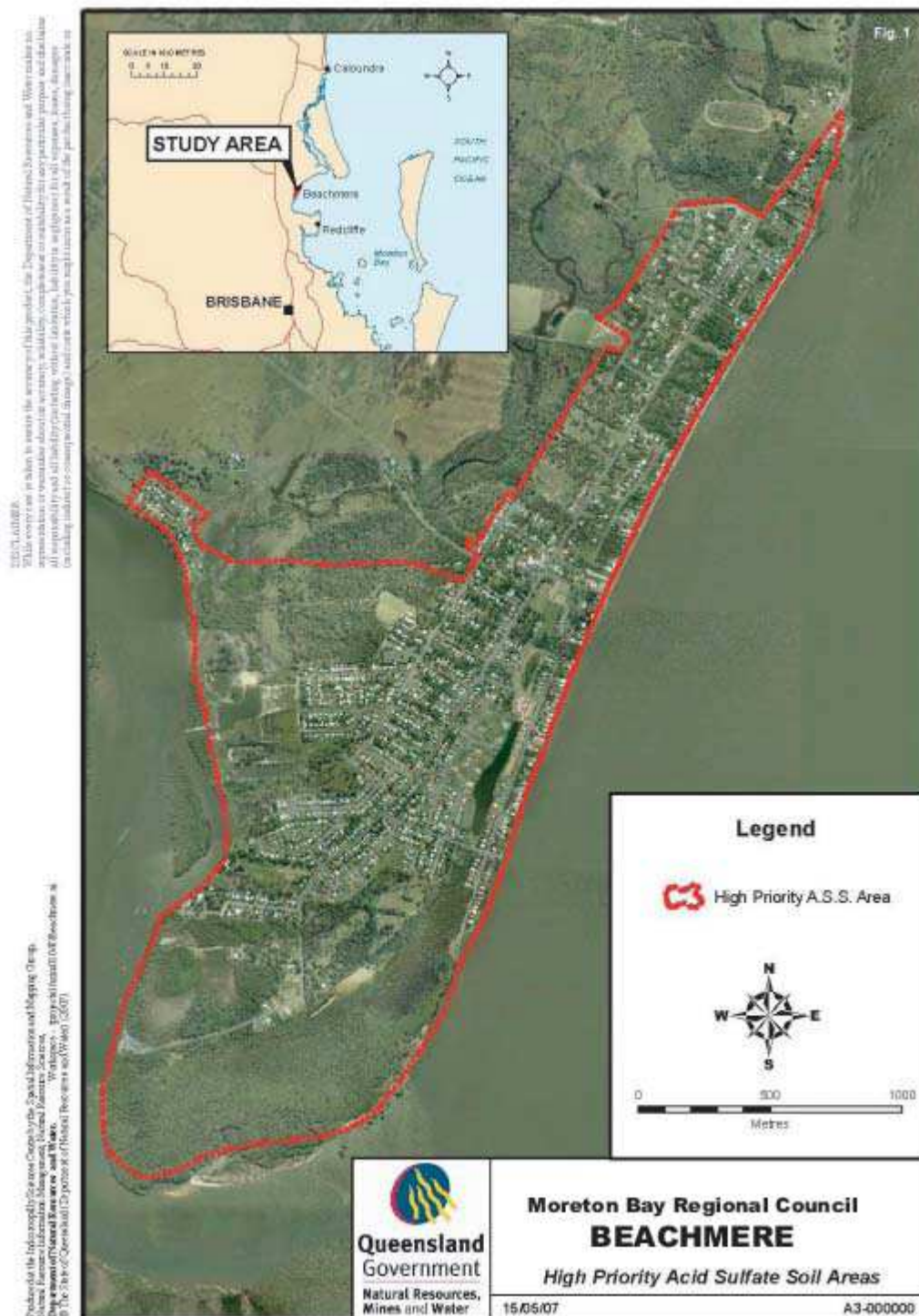


Figure 1. Location of the Beachmere high priority ASS mapping area

3. Methodology

3.1. Sampling equipment

Sampling was undertaken with a Geoprobe model 6610DT coring machine. The Geoprobe (**Plate 1**) is a track-mounted machine that obtains a 38 mm soil core in 1.5 m long removable clear PVC liners. These are photographed for the record before being sampled and assessed.



Plate 1. Geoprobe model 6610DT track-mounted coring machine

3.2. Location of sites, profile description and sampling

Sample sites were selected using the free survey technique (Reid 1988) with the aid of aerial photography and ortho photo maps supplied by Moreton Bay Regional Council. Due to the landform complexity of the Beachmere area, soil sampling was completed at a higher intensity i.e. 1:25 000 scale (approx. 5.2 ha/site).

The survey area contains a wide variety of soil types, including difficult-to-sample waterlogged muds, monosulfide sediments, non-aggregated sands and silty soils with a massive structure. The sites also included areas which had been significantly disturbed, to sites in a virtually virgin state.

The soil profiles were described using the nomenclature of the *Australian Soil and Land Survey Field Handbook* (McDonald *et al.* 1990). Decoded borehole descriptions can be seen in **Appendix 1**. Soil properties recorded included horizon depth, colour, field pH, field pH after oxidation with 30% peroxide, mottles, texture and coarse fragments (eg. shell, partly decomposed plant material). Soil pH was recorded at 0.25 m intervals down the profile, firstly in a soil and water paste (pH_F), and secondly after oxidation with 30% hydrogen peroxide (pH_{FOX}). The level of effervescence produced during the pH_{FOX} test was also recorded (**Appendix 1**). A large difference (eg. 3–4 pH units) between pH_F and pH_{FOX} , together with significant effervescence is an indicator of PASS.

The profile was sampled according to the *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland* (Ahern *et al.* 1998) at the following intervals (except where these crossed horizon boundaries): 0–0.1 m, 0.2–0.3 m, 0.5–0.6 m, 0.8–1.0 m and then at intervals of 0.5 m. Soil samples were collected from each of the boreholes. Samples were placed in sealed plastic bags and refrigerated immediately. Upon returning to the laboratory, samples were dried for 48 hours and fine ground (<1 mm).

3.3. Database recording

All field and laboratory data was entered into the Soil and Land Information (SALI) database, designed specifically for land resource surveys conducted by the Department of Natural Resources and Water. Terminology and codes in SALI are consistent with the *Australian Soil and Land Survey Field Handbook* (McDonald *et al.* 1990).

3.4. Laboratory analysis

Laboratory analyses are performed to quantify net acidity (ie. actual acidity plus potential acidity less any naturally occurring acid buffering capacity) with the choice of the methodology being determined by whether the soil layer in question, is deemed AASS or PASS according to field morphology. Two laboratory methods have been used to determine the net acidity with all laboratory analysis carried out in accordance with the *Acid Sulfate Soils Laboratory Methods Guidelines* (Ahern *et al.* 2004). Please see the Glossary (Section 8) for detailed explanation of laboratory terms and acronyms.

A summarised version of the laboratory data displaying actual acidity, potential acidity, net acidity and liming rate (including a 1.5 safety factor) is provided in **Appendix 2**. Full details of laboratory analysis are available upon request from NRW. Due to budget constraints only selected samples were analysed by the full SPOCAS method to determine actual acidity and self neutralising capacity. The samples selected for analysis were based on the morphological data collected at the site. The method column in **Appendix 2** shows the method used to calculate net acidity

3.4.1 Chromium Reducible Sulfur (S_{CR})

The Chromium Reducible Sulfur (S_{CR}) method (Method 22B) as described by Sullivan *et al.* (2004) measures reduced inorganic sulfur compounds including pyrite (and other iron disulfides), acid volatile sulfides (AVS) and elemental sulfur. The method can be made specific to the iron disulfide fraction with appropriate pre-treatments to remove AVS and elemental sulfur fractions. The Chromium Reducible Sulfur method is the preferred method for low analysis sands and for highly organic or peaty soil because of its specificity to reduced inorganic S, while not determining organic sulfur. The method however does not measure existing acidity.

3.4.2 Suspension Peroxide Oxidation Combined Acidity and Sulfur method (SPOCAS)

The Suspension Peroxide Oxidation Combined Acidity and Sulfur (SPOCAS) method (Method 23) as described by Ahern *et al.* (2004) measures both the 'acid trail' and the 'sulfur trail' providing data on pH, retained acidity (S_{RAS}), actual acidity (TAA) and potential acidity (S_{POS} , TPA). The method also provides a measure of neutralising capacity (ANC_E , Ca_A , Mg_A).

3.5. Determination of PASS or AASS

The determination of which soil horizons constitute an acid sulfate soil (ASS) was based on an assessment of field morphological properties (eg. texture, soil colour, mottles and coarse fragments such as shell), field pH test results and laboratory results that met or exceeded the texture based action criteria displayed in **Table 1**.

Table 1. Texture-based action criteria (after Ahern *et al.* 1998)

Soil Texture (clay content %)	Equivalent sulfur (%S)	Equivalent acidity (moles H^+ /tonne soil)
Sands to loamy sands (≤ 5)	0.03	18
Loams to light clays (5–40)	0.06	36
Medium to heavy clays (≥ 40)	0.1	62

- **Potential acid sulfate soils (PASS)** were assessed using S_{CR} and S_{POS} analytical results.
- **Actual acid sulfate soils (AASS)** were determined by the presence of jarosite, TAA results as well as field pH (pHF) and/or laboratory (pH KCl) values of 4 or less.
- **Neutralising capacity** was assessed using a combination of $ANCE$, Ca_A , Mg_A , TPA, $ANCBT$ and pH.

4. Description of soil map units

The mapping process is a way of presenting extremely complex 3-Dimensional data in a 2-Dimensional format, so that it can be input to management decisions. At the 1:25 000 scale, it is possible to identify areas of high hazard; any disturbance of soils in these areas needs to be carefully considered because when the acid and heavy metals are released, then there are both *in situ* and off-site effects.

The map units identify areas delineated by:

- ▶ the depth of soil at which acidity is first encountered; “A” refers to an actual acid sulfate soil layer ($\text{pH} \leq 4$), while “S” refers to a potential acid sulfate soil layer. The numeric component of the map code refers to the depth at which these layers occur [0 = (0 to 0.5 m), 1 = (>0.5 to 1.0 m), 2 = (>1 to 2 m), 3 = (>2 to 3 m), 4 = (>3 to 4 m), 5 = (>4 to 5 m)];
- ▶ the codes can be used separately (eg. A0, S0, S1); but where a map unit contains both AASS and PASS layers then the codes are combined (eg. A0S0, A0S1);
- ▶ additional information is provided by code for areas of strongly acidic ($\text{pH} > 4$ and ≤ 5) soil layers.

5. Map units of the study area

The attached acid sulfate soils map displays the map units identified in the study area.

Table 2 shows the total area of each mapping unit along with the percentage of the 367 hectare total area that is occupied by each unit. It is noted that the AASS found in the survey area (15 ha) has PASS layers below it (meaning that further disturbance has the capacity to release yet more acid and heavy metals). More importantly, 100% of the area surveyed contains layers of acid sulfate soils—over half of which is within 2 metres of the surface.

Table 2. Area of individual map units

Map unit	Map unit area (ha)	Percentage of mapping area (%)
A0S1	10	2.7
A0S2	5	1.4
S0	93	25.3
S1	47	12.8
S2	39	10.6
S3	128	34.9
S4	45	12.3
Total area	367	100

5.1. Characteristics of the map units

A0S1 – This unit is located in the west of the study area adjacent to the Caboolture River. Two boreholes were undertaken in this unit to depths of 6.0 m. The predominantly sandy textured surface soils identified in the profiles appear to have originated from the large excavation (**Plate 2**) which extends from the Caboolture River to the centre of this unit. The indicative yellow jarosite mottles were evident in the exposed embankment leading into the excavation (**Plate 3**). Jarosite mottles were also evident in the surface layers of borehole CAB 96 (**Plate 4**) where 0.15 %S at 0.4–0.6 m was measured. Grey sandy PASS layers with up to 0.32% S were encountered down the profile from 0.6 m to 5.5 m with clay PASS layers extending to 6 m (**Plate 4**). In borehole CAB 97, a maximum of 1.17 %S was measured at 1.2–1.4m in a sandy clay loam layer.



Plate 2. Large excavation in the centre of the A0S1 unit; the spoil will now contain activated ASS

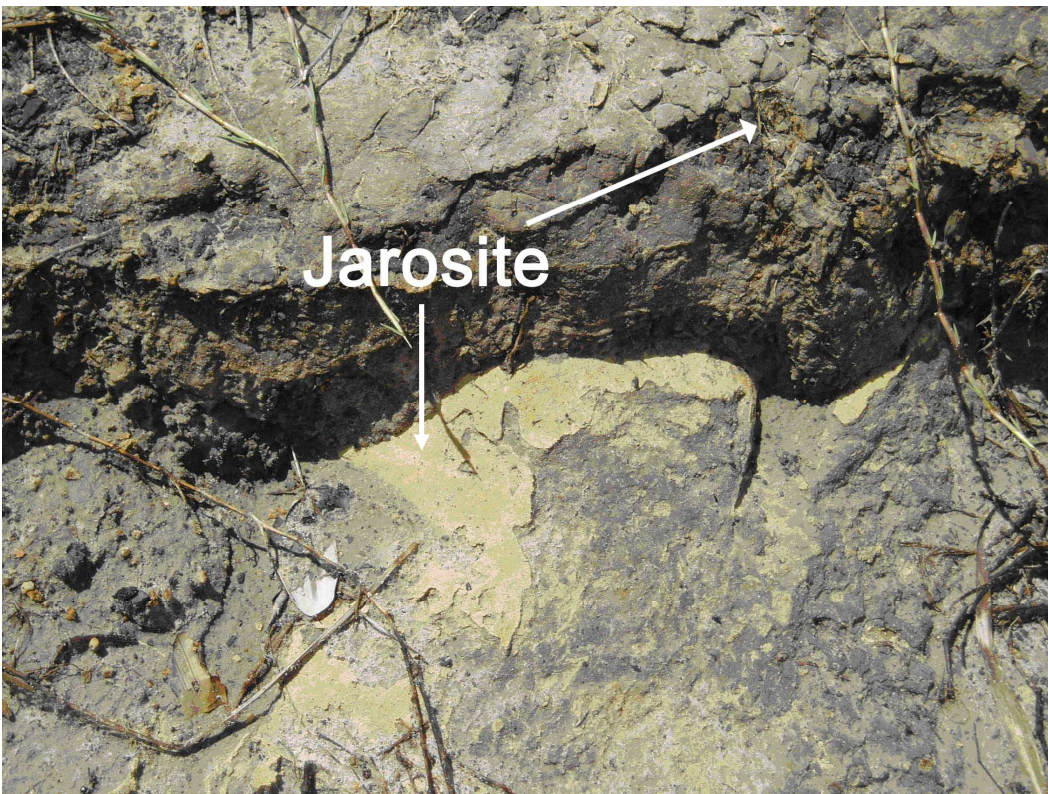


Plate 3. Jarosite indicating activated ASS in soil associated with previous excavation



Plate 4. Yellow jarosite mottling in surface layers of CAB 96

A0S2 – Situated immediately to the south of the A0S0 unit, this unit covers approximately 5 ha (**Plate 5**). Disturbance history seems to be similar to the previous unit with soil material excavated to form a channel which extends from the Caboolture River into the centre of the unit. Borehole CAB 42 (**Plate 6**) situated immediately north of the excavation displayed AASS to 0.8 m consisting of sandy light clays with jarosite mottles and very acidic field pH values of pH 3.6. It is likely that these materials were part of the original excavation and have been used as fill. SPOCAS analysis at 0.2 to 0.3 m revealed up to 0.1 %S with the actual acidity component accounting for the majority of this. Grey sandy PASS with oxidisable sulfur levels up to 0.6 %S dominated the profile however a sandy light clay layer at 5.3-5.5m contained 2.2% S.



Plate 5. Borehole CAB 42 location in A0S0 unit

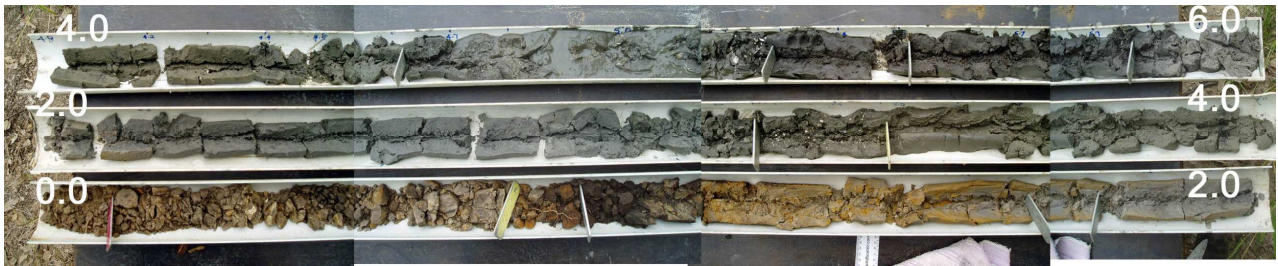


Plate 6. Soil profile CAB 42, indicative Jarosite found 0.0 to 1.8 m

S0 – Six S0 units covering approximately 93 ha have been identified predominantly in low lying intertidal areas in the southern and western portion of the study area, principally adjacent to the Caboolture River and Deception Bay. These areas are generally <0.5 m AHD with vegetation predominantly comprised of mangrove species (**Plate 7**). Unlike the previously discussed areas, minimal disturbance was observed at the time of sampling.



Plate 7. Low lying S0 unit showing mangrove vegetation.

Soil textures throughout the boreholes undertaken in these units often displayed varying layers of sulfidic grey sands, sandy loams and sulfidic silty light clays. PASS often extended from the surface to depths greater than 6 m at some sites. Laboratory analysis of samples collected within this mapping unit revealed in excess of 2 %S (site CAB 86 at 1.2–2.2 m) (**Plate 8**). Some neutralising capacity (ie. shell fragments) was observed in several of the profiles, however levels are generally insufficient to neutralise the potential acidity present. Medium to medium heavy clays likely to represent an older land surface were intercepted at some sites, generally at depths greater than 4.5 m.

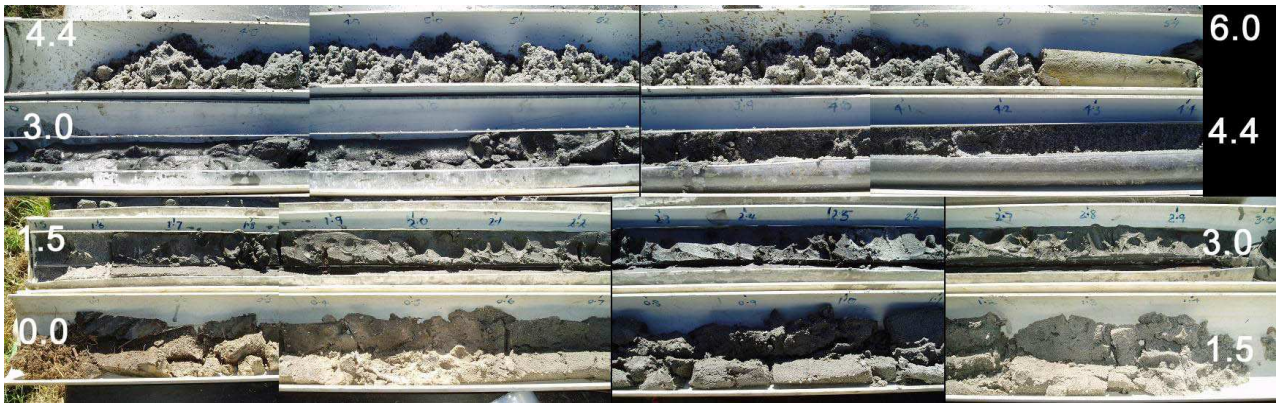


Plate 8. Soil profile CAB 86

One large S0 unit at the southern end of the of the study area contained significant numbers of dead or dying mangroves (**Plate 9**) particularly in the north eastern section of the unit. Closer inspection revealed the presence of monosulfides in surface sediments (**Plate 10**) along with extended periods of inundation by water. Surface samples taken at several sites showed significant levels of sulfides present (0.8 %S at 0.2 m–0.3 m in CAB 15; 0.3 %S at 0.0–0.1 m in CAB 17 and 0.7 %S at 0.0–0.1 m in CAB 63). Monosulfides are a highly volatile form of sulfides capable of forming and oxidising very quickly. Further work is required in these areas to determine the exact effects that monosulfides and long periods of inundation are having.



Plate 9. Dying mangroves



Plate 10. Monosulfides found in surface layers of dying mangrove areas

S1 – Seven S1 mapping units were identified. In their natural state, these units are often associated with supratidal and extratidal flats that are slightly elevated above the more frequently tidally-inundated S0 units (**Plate 11**). Periodic surface inundation generally occurs during higher tidal occurrences. *Casuarina* and *Sporobolus* species (salt couch) are the most common vegetation. On disturbed and slightly more elevated sites other vegetation such as *Melaleuca*, *Eucalyptus*, and *Corymbia* species occur.

Soil profiles commonly display grey sulfidic sands and sandy loams, with shell fragments observed in many of the profiles (**Plate 12**). Laboratory analysis revealed sulfide concentrations up to 1.9 %S (site CAB 60 at 5.6–5.8 m). Excess neutralising capacity was measured in CAB 22 at 0.8–1.0 m.

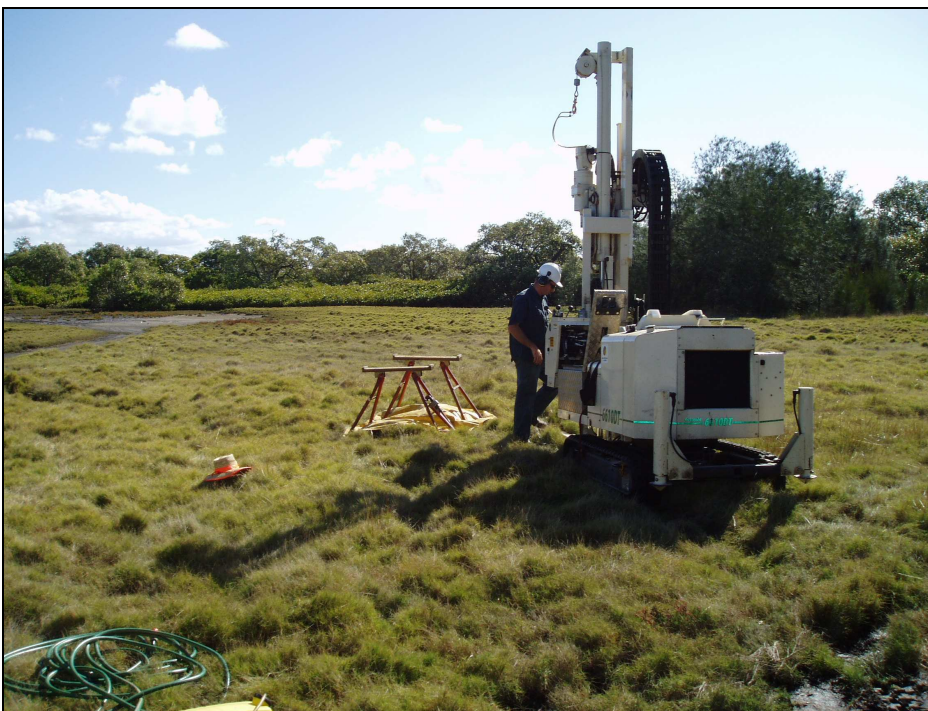


Plate 11. CAB 91 site location in S1 map unit



Plate 12. Soil profile CAB 60 showing PASS in lower layers

S2 – Seven S2 units were mapped with the majority occurring between 2 and 3 m elevation. Native vegetation where it still remained consisted of *Melaleuca* and *Eucalyptus* species. Soil profiles were dominated by sands with layers of clay fill occurring in surface layers of some profiles. PASS layers generally commenced at 1–2 m below ground surface and extended to 6.0 m. Sulfide concentrations up to 2.2 %S were measured in site CAB 47 at 1.3–1.5 m (**Plate 13**). Some neutralisation capacity in the form of small shell fragments was observed.

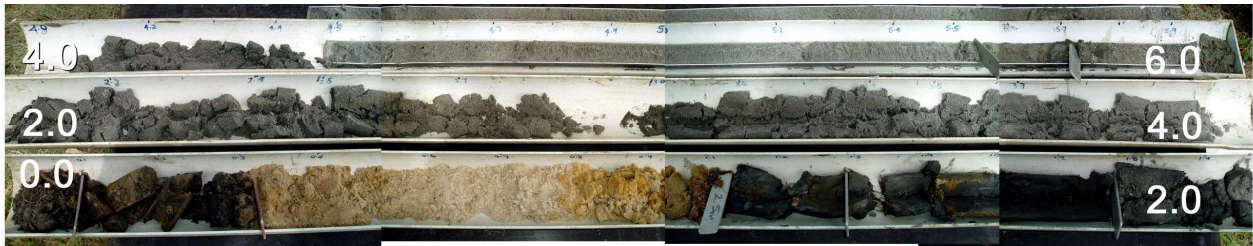


Plate 13. Soil profile composite CAB 47, PASS in subsoil

S3 – This unit is comprised of relict beach ridges that are predominantly occupied by urban residential development that dominates the eastern side of the survey area, with elevation commonly between 2 and 3 m. Soil profiles were dominated by sands with layers of sulfidic loams and clay often occurring at depths of approximately 5 m (**Plate 14**). Laboratory analysis of samples collected within this mapping unit revealed sulfide concentrations up to 2.0 %S in sulfidic clay layers (site CAB 45 at 5.8–6.0 m). Some neutralisation capacity was observed (ie. shell fragments) at depths below 2.0m.



Plate 14. Soil profile composite CAB 45, PASS in lower profile

S4 – This unit contains the higher (3–4 m) sections of the relict beach ridges that stretch from the north-east toward the south-west of the study area. Land use is again predominantly urban residential with minor areas of native vegetation, mainly *Eucalyptus* species. Soil profiles (**Plate 15**) generally displayed pale sands overlying sulfidic grey sands with up to 0.5 %S. Laboratory analysis of soil samples revealed a maximum sulfide concentration of 2.5 %S in a small loamy fine sand layer in borehole CAB 79 (3.2–3.4 m).

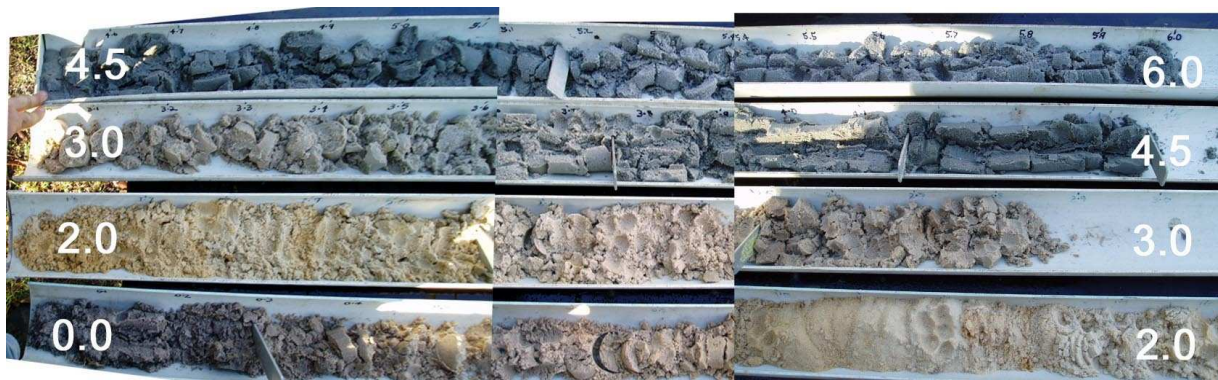


Plate 15. Soil profile composite for CAB 103 showing PASS at depth

6. Conclusions

It is evident that coastal formation processes in the Beachmere area have been conducive to the formation of acid sulfate soils. This assessment has identified both AASS and PASS in profiles of sands, loams and clays throughout the Beachmere study area.

The 15 ha of AASS identified were confined predominantly to surface layers in areas of past disturbance. Maximum net acidity values of 0.15 %S (SPOCAS method) and field pH values as low as 3.6 were measured in the AASS layers. PASS layers occurred at various depths across the entire study area with the depth to PASS generally increasing with increasing elevation. The highest net acidity values were measured in clay sediments with a maximum of 2.67 %S (CAB 82). Maximum for loams and sands were 1.9 %S (CAB 80) and 0.8 %S (CAB 47) respectively.

Average %S values for all samples across the study area were 0.20 %S for sands; 0.59 %S for loams and 0.83 %S for clays all of which are substantially higher than action criteria threshold values of 0.03%, 0.06% and 0.1% respectively.

It is suggested that major activities involving soil disturbance and drainage within the Beachmere area should follow the requirements of the *State Planning Policy 2/02; the Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland* (Ahern *et al.* 1998) and the *Soil Management Guidelines* (Dear *et al.* 2002). It should also be recognised that the scale of the mapping undertaken in this report is intended for general planning purposes only and that additional boreholes will be required if QASSIT sampling guidelines are to be met for future development in the study area.

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8. Glossary

Acid sulfate soils (ASS): Soil or sediment containing highly acidic soil horizons or layers affected by the oxidation of iron sulfides (actual ASS) and/or soil or sediment containing iron sulfides or other sulfidic material that has not been exposed to air and oxidised (potential ASS). This includes:

- non-oxidised and therefore non-acidic soils or sediments with significant amounts of oxidisable iron sulfides (ie. PASS);
- partially oxidised soils or sediments with variable ratios of existing acidity and unoxidised iron sulfides (ie. PASS/AASS); through to
- completely oxidised (no remnant sulfides) soils or sediments with significant existing acidity (ie. AASS).

The term acid sulfate soil generally includes both actual and potential ASS. Actual and potential ASS are often found in the same soil profile, with actual acid sulfate soils generally overlying potential acid sulfate soil horizons.

Actual acid sulfate soils (AASS): Soil or sediment containing highly acidic soil horizons or layers affected by the oxidation of soil material that are rich in iron sulfides, primarily pyrite. This oxidation produces hydrogen ions in excess of the sediment's capacity to neutralise the acidity, resulting in soils of pH 4 or less. These soils can sometimes be identified by the presence of secondary sulfate salts such as jarosite.

Potential acid sulfate soils (PASS): Soil or sediment containing iron sulfides or sulfidic material that have not been exposed to air and oxidised. The field pH of these soils in their undisturbed state is pH 4 or more, and may be neutral or slightly alkaline.

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

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

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

Aglime: A neutralising agent used to treat acidic soils; by composition, it is commonly 95–98% pure calcium carbonate, $CaCO_3$; it is sparingly soluble in pure water, with a pH of ~8.3; application rates will depend on the purity and fineness of the product.

AHD: Australian Height Datum. The datum used for the determination of elevations in Australia. The determination used a national network of benchmarks and tide gauges, and sets mean sea level as zero elevation.

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

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

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

Borehole: The actual hole created when an auger, push-tube or similar is inserted into the soil body; the portion removed (the core) will demonstrate the soil profile.

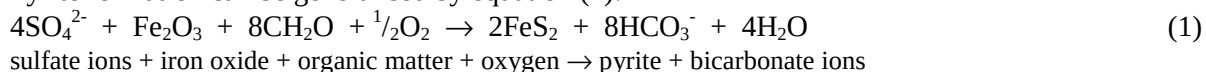
Ca_A: Reacted calcium. The calcium soluble after the peroxide digest and TPA titration that was not soluble following KCl-extraction and TAA titration. (Ca_P – Ca_{KCl}). It can be used (in combination with Mg_A) to provide an estimate of the soil carbonate content, but may be an underestimate if the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

Ca_{KCl}: Potassium chloride extractable calcium measured following the TAA analysis, which includes soluble and exchangeable calcium as well as calcium from gypsum.

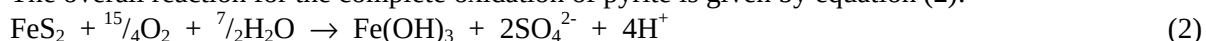
Ca_P: Peroxide calcium. Calcium measured following the TPA analysis, which includes soluble and exchangeable calcium, calcium from gypsum, as well as calcium (eg. from carbonates) dissolved as a result of acid produced due to oxidation of sulfides by peroxide.

Chemical equations: There is a wide range of chemical equations involved in acid sulfate soils. Some of these are detailed below. Further information (especially regarding the intermediate steps involved in pyrite oxidation) can be found in the *Acid Sulfate Soils Laboratory Methods Guidelines* (Ahern *et al.* 2004).

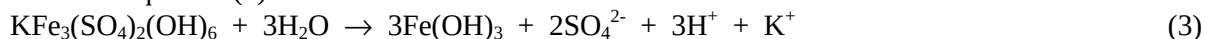
Pyrite formation can be generalised by equation (1):



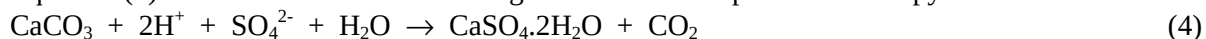
The overall reaction for the complete oxidation of pyrite is given by equation (2):



In moist environments, jarosite slowly decomposes (usually by hydrolysis) releasing iron and acid, as shown in equation (3):



Equation (4) shows the reaction between aglime and the acid produced from pyrite oxidation:



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

Disturbance of ASS: Any activity or action that will or is likely to expose ASS to oxidising conditions eg. movement, excavation or drainage of ASS.

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

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

Holocene: A period of time from about 10 000 years ago to the present, an epoch of the Quaternary time period.

Horizon: A soil layer that differs in physical, chemical or biological properties such as colour, texture, structure, consistency, pH etc from the layers above and below.

Jarosite: An acidic pale yellow (straw or butter coloured) iron sulfate mineral: $\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$. Jarosite is a by-product of the acid sulfate soil oxidation process, formed at pH less than 3.7; commonly found precipitated along root channels and other soil surfaces exposed to air.

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

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

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

Monosulfides: The term given to the highly reactive iron sulfide minerals found in ASS that have the approximate formula 'FeS' and which are soluble in hydrochloric acid (as opposed to iron disulfides such as pyrite that aren't appreciably soluble in hydrochloric acid); formed as intermediates during the formation of pyrite. Monosulfides are highly reactive and oxidise rapidly. Includes amorphous FeS, mackinawite $\approx \text{Fe}_9\text{S}_8$ and greigite $\approx \text{Fe}_3\text{S}_4$.

Net Acidity: The result obtained when the values for various components of soil acidity and acid neutralising capacity are substituted into the Acid Base Accounting equation. Calculated as: $\text{Net Acidity} = \text{Potential Acidity} + \text{Existing Acidity} - (\text{Acid Neutralising Capacity}/\text{Fineness Factor})$.

Neutralisation: The process whereby acid produced (by the oxidation of soil iron sulfides) is counteracted by the addition of an ameliorant such as aglime (CaCO_3); there are formulae for calculating the amount of ameliorant needed to bring the soil closer to a pH value of 7.

NR&M: Queensland Department of Natural Resources and Mines.

NRW: Queensland Department of Natural Resources and Water.

pH: A measure of the acidity or alkalinity of a soil or water body on a logarithmic scale of 0 to 14 units. A pH reading less than 7 indicates an acid, pH equal to 7 indicates a neutral substance, while pH more than 7 indicates an alkaline substance. Note that one unit change in pH is equivalent to a ten-fold change in acidity.

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

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

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

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

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

Pyrite: Pale-bronze or brass-yellow, isometric mineral: FeS_2 ; the most widespread and abundant of the sulfide minerals.

QASSIT: Queensland Acid Sulfate Soils Investigation Team.

Quaternary: A geological time period extending from 1.8 million years ago to present time; incorporates both the Pleistocene and Holocene time periods.

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

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

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

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

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

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

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

SPOCAS: An acronym standing for Suspension Peroxide Oxidation Combined Acidity and Sulfur method (Method Code 23), the peroxide-based method that supersedes the previous POCAS and POCASm methods.

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

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

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

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

Appendix 1

Decoded Borehole Descriptions

Appendix 2
Summarised Laboratory Data

Supplement 1
Acid Sulfate Soils Map – Beachmere Study Area