

Acid Sulfate Soils of Halifax North Queensland



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Volume 1

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Front cover Photo Site 120, Located in sugarcane north of Halifax. Hinchinbrook Island is pictured in background.

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Maps

(Located in the pocket in the back of report)

Acid Sulfate Soils of Halifax, North Queensland (1:25 000)

DERM Ref No:IAS-I-A1-508171

(The appendices and supplements sections are presented as "Acid sulfate Soils of Halifax, North Queensland Volume 2 and are recorded on the DVD which accompanies this report.)

Volume 2

Appendix 1	Summarised Analytical Data (A4)
Appendix 2	Analytical Data (A3)
Appendix 3	Decoded Borehole Descriptions
Supplement 1	Acid Sulfate Soils Map – Acid Sulfate Soils of Halifax, North Queensland (PDF version)
Supplement 2	Site Photos
Supplement 3	Acid Sulfate Soils of Halifax, North Queensland Report (PDF version)

Summary

This survey of acid sulfate soils was funded by the Commonwealth Government as part of the Natural Heritage Trust Extension, Coastal Catchment Initiative. The survey involves an area of some 2032 ha around Halifax, North Queensland and contributes to a statewide program to identify acid sulfate soil (ASS) hazard areas.

The survey area is centred on the cane lands of the Herbert River delta surrounding the township of Halifax. Mapping was undertaken at a 1:50 000 scale intensity.

Within the survey area 58 boreholes were sampled. Borehole depths ranged from 0.9 m to 12 m (average depth of 5.6m) with all soil profiles described according to national standards (McDonald et al. 1990) and field pH tests carried out at 0.25 m intervals according to Sampling Guidelines (Ahern et al. 1998). Collected samples were submitted for laboratory analysis using the Suspension Peroxide Oxidation Combined Acidity and Sulfur (SPOCAS) method (Ahern et al. 2004) and/or the Chromium Reducible Sulfur (SCR) method (Sullivan et al. 2004). All laboratory analyses were carried out in accordance with the Acid Sulfate Soils Laboratory Methods Guidelines (Ahern et al. 2004).

The accompanying 1:25 000 scale ASS map displays the depth to the occurrence of ASS. Map units were allocated a mapping code (S) and a depth code according to the depth at which the first potential acid sulfate soil (PASS) layer was encountered based on laboratory data. Colours on the ASS map display the depth and associated risk.

Of the 2032 hectares of ASS mapped, 16 hectares were found to contain actual acid sulfate soils (AASS) with existing acidity up to 0.13 %S at shallow depth in the top 1.5 m. Of the remaining 2010 hectares, PASS only were found, with up to 2.9 %S at various depths ranging from the surface to greater than 10.8 m below the surface.

These results indicate the need for caution in planning and managing developments in the area so as to avoid costly damage to the environment, human health 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).

It is suggested that major activities involving soil disturbance and drainage within the Halifax 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. Additional boreholes will be required if QASSIT sampling guidelines are to be met for site specific future development in the study area

1 Introduction

1.1 Brief Overview of Acid Sulfate Soils

Acid sulfate soil (ASS) is the name given to naturally occurring sediments (sands, silts, or clays) that commonly occur in low-lying, poorly drained coastal land at elevations less than 5 m AHD. These sediments contain sulfides—primarily iron sulfides or pyrite (FeS_2). Excavating soil or sediment, extracting groundwater or filling land may cause disturbance of ASS resulting in the oxidation of sulfides and the subsequent production of sulfuric acid. This can have major environmental, health, and engineering impacts.

Disturbed land can release acid, aluminium, iron and heavy metals into drainage waters affecting aquatic plants and animals (Sammut et al. 1996). Concrete and steel infrastructure including pipes, foundations and bridges are susceptible to acidic corrosion leading to accelerated structural failure.

Undisturbed ASS range from grey silty sands, black high plasticity silty clays and organic peat materials with pH values close to neutral (pH 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. If ASS are exposed to air, the sulfides oxidise and sulfuric acid is produced (for example: one tonne of iron sulfides can produce about 1.5 tonnes of sulfuric acid when oxidised). In this state they are known as actual acid sulfate soils (AASS). AASS are very acidic (pH <4), and often contain a straw yellow coloured mineral called jarosite. The term ASS includes both AASS and potential acid sulfate soil (PASS).

PASS are generally located below the permanent water table and remain inert when maintained in a state of permanent saturation. If appropriate planning is in place to avoid both direct disturbance and indirect exposure via lowering of the groundwater table, harmony between the built environment and the constraints presented by PASS materials can be readily established.

Occurrence of AASS in the profile can be the result of natural processes such as prolonged drought causing lowering of the natural groundwater table. As a result AASS and PASS can be found in the same soil profile, with AASS generally overlying PASS. Consequences of these natural occurrences, whilst widespread are generally mild in effect due to the limited or thin oxidation front, slow transport of acid via groundwater and the natural buffering potential present in many soils.

1.2 Local Acid Sulfate Soils Disturbance Risks

The production of AASS can be rapidly accelerated by the way we use and modify our land and groundwater resources. In North Queensland, the largest and most extreme environmental consequences have been experienced through changes to the natural hydrology including lowering of natural groundwater tables and tidal exclusion. These effects are long lasting and may result in regular fish kills and serious deleterious impacts on water quality in highly sensitive fish nursery areas. Infrastructure commonly attributable to extreme levels of environmental harm include table drainage tidal exclusion via floodgate culverts and levees, and linear infrastructure such as roads and rail corridors that exclude or reduce tidal influence over lands containing ASS. Disturbance to ASS through overuse of groundwater is believed to be occurring, particularly within shallow coastal sand aquifers. Whilst these groundwater disturbances can be widespread, water in these areas is used primarily for irrigation as opposed to potable supply. As a result, the impacts from overuse of groundwater in North Queensland remain widely underreported and poorly documented.

Most urban impacts to ASS in North Queensland have occurred through lack of knowledge and consideration of ASS as a development constraint. Close consideration of site limitations should be undertaken by relevant authorities, particularly when planning or assessing development in areas containing shallow or strong ASS.

Impacts from repeated ASS exposure around urban centres are cumulative and may lead to deleterious impacts on ground and surface water quality around and under our coastal towns and cities. Of considerable concern are the impacts these disturbances have on built infrastructure. Experience has shown that infrastructure most at risk include road culverts, bridge footings, building foundations and pilings, basement car parks and all buried services. The costs for early replacement of this infrastructure places heavy strains on the financial stability of local authorities, service providers and government with the ultimate financial liability borne by the general public by way of charges, taxes and rate contributions. Combined with this, are the engineering challenges faced when attempting to reinforce or replace foundations and footings under existing buildings and increasing delays to our transportation system as bridges, pipes buried infrastructure are replaced well short of their expected service life spans.

1.3 Policy Context

In Queensland, concern over mounting engineering and environmental costs from improper management of ASS has led to development of the State Planning Policy 2/02, Planning and Managing Development involving Acid Sulfate Soils (SPP2/02). The policy targets assessable high risk development and enables case by case assessment under a framework of guidelines for best practice.

Mapping areas where there is a high risk of ASS exposure is the next pro-active level of ASS Management. Mapping offers critical information relating to the general location, depth and strength of ASS in targeted areas. The maps and associated reports and laboratory data can readily be used at all levels of government for informed strategic planning, development assessment applications and by the private sector for commercial decision making with on ground survey and management requirements. In this manner, mapping supports and encourages the preferred “avoidance” outcomes of the SPP2/02.

Within the Wet Tropics area, seven areas were identified by a Far North Queensland Water Quality Improvement Plan (WQIP) committee as requiring ASS mapping. These included the areas around the Daintree River, Port Douglas, Cairns, Russell / Mulgrave Rivers, Hull / Tully / Murray Rivers, Johnston / Moresby Rivers and the Ingham area. Of these areas, the Ingham area was prioritised for special ASS mapping by the project steering committee.

This report details the 1:50 000 scale ASS mapping undertaken by the Department of Environment and Resource Management in the Halifax Area (Attachment 1).

2 Survey Area

Halifax was chosen as the survey area because of the close proximity to marine fish habitat areas, a history of fish kills in Gentle Annie Creek and the establishment of levees and drains on farms to minimise tidal inundation. The elevation and history of the area suggests that ASS are likely to be present and may have experienced disturbance.

This survey is centred on the sugarcane land surrounding the township of Halifax, located on the southern bank of the Herbert River (Figure 1). The Herbert River catchment covers an area of 9843 square kilometres. Flowing for 340 kilometres in a generally south-eastern direction, the Herbert River drops from the Atherton Tableland to the coastal plain spreading out to become the Herbert River delta. The river passes the townships of Ingham and Halifax before entering the Coral Sea near Lucinda, at the southern end of the Hinchinbrook Channel, 130 kilometres north of Townsville.

Halifax is situated on the northeast wet tropical coast of Queensland and experiences hot and humid summers and mild dry winters. The annual rainfall from the township of Ingham to the coast varies from 1105 to 3423 millimetres (mean 2066 millimetres) with the majority falling in summer between January and March. The land used within the study area is dominated by sugarcane cultivation. Halifax township and the sugarcane growing area is confined by the Herbert River on the west and mangroves to the north

and east. Regular floods in the lower catchment areas (including the survey area) causes damage to infrastructure and sugarcane.

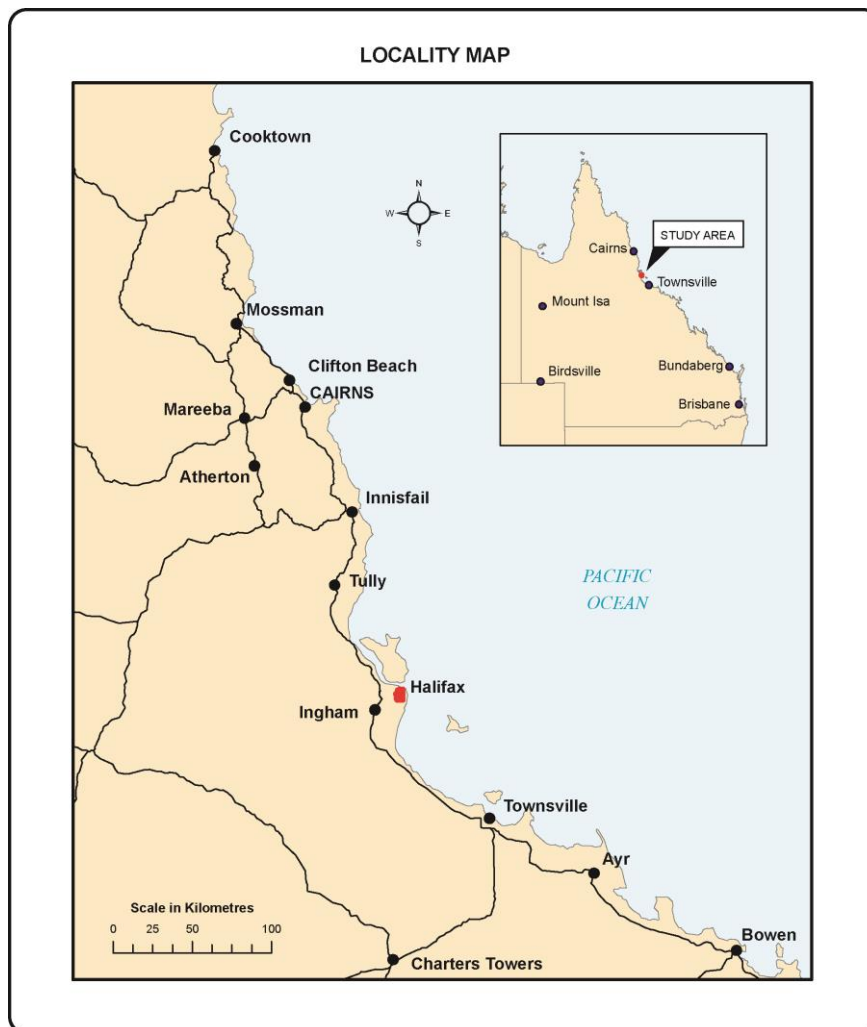


Figure 1. Locality Map

3 Mapping Scale Intensity

Mapping scale is directly related to survey intensity, that is, the number of soil profiles and associated information collected per unit area. The mapping in this report is carried out at approximately 1:25 000 scale which requires four (4) to twenty (20) fully described and sampled soil profiles per square kilometre (one per 5 ha to 25 ha). The sites are located using free survey techniques at spacing's of 200 to 400 meters depending upon landform or at wider intervals in tidal areas where ASS are consistent. The remaining areas are at a broader scale of mapping, that is at 1:50 000 which implies four (4) boreholes per square kilometre and 1:100 000 scale which implies one (1) borehole per square kilometre; however the 1:100 000 mapping was completed mainly by aerial photograph interpretation.

The resultant mapping provides map boundaries that indicate the presence of both AASS and PASS at various depth intervals.

Mapping at 1:25 000 scale provides a clearer indication of the depth at which ASS occurs; the texture or particle size of the differing layers and the concentration of sulfides present. This information is vital for strategic planning decisions relating to current or future use of subject lands on a broader regional level.

Mapping at 1:25 000 scale is not of sufficient intensity to replace any site based assessments required under the SPP 2/02 Planning and Managing Development involving Acid Sulfate Soils.

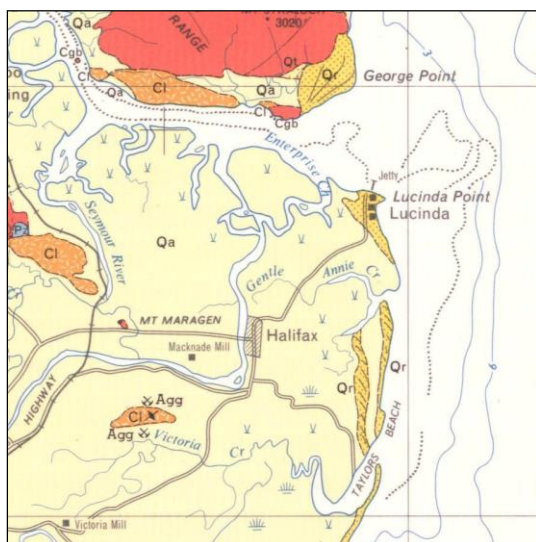
4 Brief Environmental History

Land cover and land use in the Herbert River catchment has changed substantially since European settlement. Sugarcane was first established in the Ingham area in the 1880's. In the 1930's Halifax along with the port at Lucinda was a thriving centre having a direct rail link with the port of Lucinda and access to the Hinchinbrook Channel and the Great Barrier Reef. Sugar cane expanded across the Herbert River delta with Ingham now the major business center for the region.

Prior to settlement, the area was dominated by Melaleuca communities and fringing saltpans/saltwater couch and mangroves. By the 1940's the Melaleuca communities in Halifax had been converted to sugarcane. Some hydrological modification of the flood plain has occurred with a series of bund walls and floodgates constructed to keep tidal inundation and storm surges out of low lying land while allowing for flood water to escape. The area of mangrove communities has remained relatively stable since the 1940s, while the area of sugarcane within the catchment has more than tripled between 1943 and 1996.

5 Geology

The Herbert River catchment includes a range of geological types such as granites, basalts, acid volcanics and weathered tertiary sediments. The geology and physiography of the hinterland of the catchment is favourable for a large and steady supply of sediment to the coastal zone. The finer material delivered to the coast may be carried far from the coast and deposited on the continental shelf. The coarser sediment is deposited at the mouth of the Herbert River to be later transported onshore. The total sediment loads for the Herbert River Catchment from the National Land and Water Resources Audit (NLWRA; 2001) suggests that there is ~665,000 t/yr of sediment leaving the Herbert River mouth. The discharge of sediment is highly seasonal with most occurring during major flood events in the summer months. A section of the Ingham 1:250 000 geological map (**Figure 2**) shows the alluvial deposition (Qa) and seawards beach ridges (Qr) on the coast (de Keyser 1965). Note that the location of the main Herbert River channel exiting near Lucinda Point has changed since 1965 (when this geological map was produced) to a more northerly direction.



Legend

- Qa Alluvium, soil, lagoonal deposits
- Qt Scree, talus
- Qr Beach, sand and dunes, showing of old shore lines
- Cl Massive rhyolitic to dacitic volcanics, some andersite
- Pz Blue grey quartzite; white tuffaceous(?) sandstone

Figure 2. Section of Ingham 1:250 000 Geological Map, de Keyser et al. (1965)

6 Geomorphology

In general the sediments in which ASS form were laid down during periods of high sea level similar to those we know today. These high sea levels (which correlate with interglacial periods), have occurred twice in the last 150 000 years. Although it is generally recognised that the majority of ASS occur in sediments deposited in the last 10 000 years (Holocene epoch), it is useful to look further back in time to gain a better understanding of their deposition. There has been little tectonic activity along the eastern coast of Australia since ca. 130 000, which makes this region very well-suited to the study of sea-level change.

During the previous interglacial period within the Pleistocene epoch (140 000 to 120 000 BP), evidence suggests that sea levels rose several metres higher than present (Pickett et al. 1985). This caused the drowning of river valleys and low lying coastal areas. In general, shorelines and floodplains were pushed many kilometres west and estuaries similar to those of today were formed. After this sea level high, there was climatic variability during the latter part of the Pleistocene epoch (120 000 to 20 000 BP) imposed by global warming and cooling. The sea level receded and then fluctuated between 80 m and 140 m below present (Bloom et al. 1974). During this time, rivers and creeks cut deep channels through the previously deposited fluvial and estuarine sediments, removing some and isolating others. The climate from 27 000 to 10 000 BP experienced expanding semi-arid conditions with corresponding humid periods during interglacial cycles. This drier climate caused corresponding changes to flora and fauna.

The most recent sea level rise (the post glacial marine transgression) commenced approximately 19 000 – 18 000 years ago. At this time sea level was estimated to be 140 m lower than present with the shoreline up to 40 km east of where it is today. At the commencement of the Holocene (10 000 years ago), sea level was approximately 25 m below present and still rising (Thom 1981) with present sea level being reached around 6 500 BP (Thom and Chappell 1975). Around 4 000 BP there is evidence that a minor sea level rise occurred of approximately 1m along the southern Queensland coast, and then the sea level returned to its present position (Jones 1992). With higher tidal ranges in north Queensland, there is a significant likelihood that ASS was deposited at higher AHD levels than southeast Queensland.

The rapid rate of sea level rise during the Holocene exceeded the rates of coastal deposition and thus valleys and low lying coastal areas were drowned just as they were during the Pleistocene. Once sea level rise stabilised (termed still stand), new estuaries were formed and coastal deposition processes were able to commence filling the newly created subaqueous space.

6.1 Geomorphology of Estuaries

Understanding the coastal geomorphology of an area is an integral part of mapping ASS. The following provides a basic insight into the coastal processes that have enabled ASS formation in the mapping area.

An estuary is defined as the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes Dalrymple et al. (1992). The marine processes (waves and tides) decrease in intensity up the estuary while the fluvial process decrease in strength down the estuary.

According to Dalrymple et al. (1992), ideal estuaries can be divided into three energy zones (Figure 2):

- (A) an outer zone dominated by marine processes i.e. waves and tidal currents;
- (B) a low energy central zone where incoming marine energy is balanced by river energy; and
- (C) an inner river dominated zone.

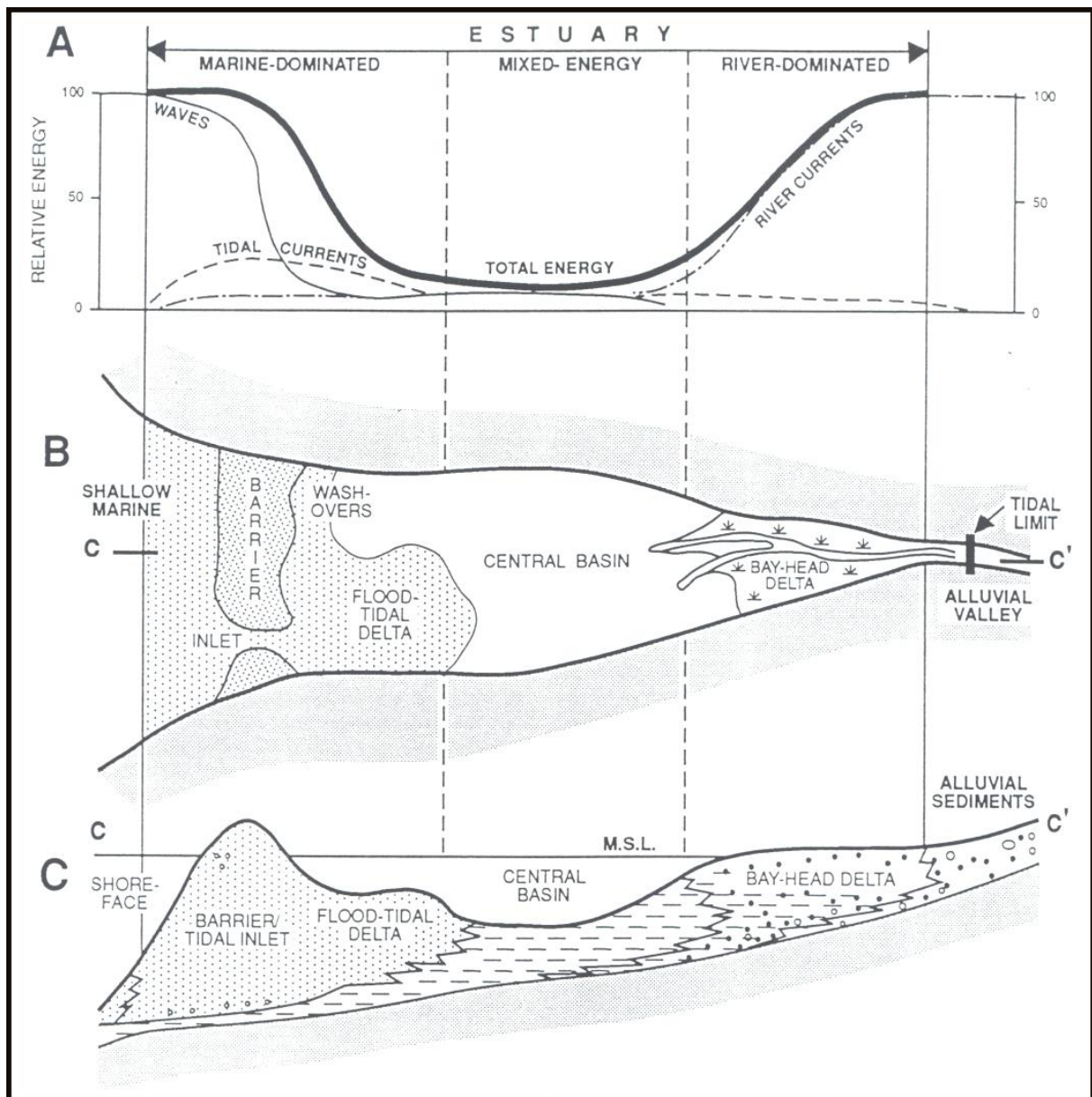


Figure 3. Estuary energy zones as described by Dalrymple et al. (1992).

6.2 Local Coastline Evolution

The following material is adapted from Hopley (1970) and White (2000).

The different geological layers which include the bedrock, Pleistocene and Holocene deposits of the Herbert River delta provide an understanding of the evolution and the deposition of marine sediments within the delta. The present Herbert River swings north at Ingham whereas the older bedrock channel continues towards the east, probably crossing the coast just north of Allingham. The bedrock channel is gorge-like having a depth greater than 75 meters beneath Ingham and 90 meters before it cross the coast. The Pleistocene deposits consisting of mostly mottled red and brown clays are of greatest thickness along the course of Palm Creek. The major course of the river during this time follows the course of the bedrock buried beneath. Pleistocene material is approximately 8.5 meters below the surface at Halifax (Site 128) but drops away towards the coast.

The Herbert River has changed course significantly over the last 10,000 years and occupied a number of channels to the north and south of its' current location. Since the last sea-level rise ceased (6000 years b.p.), the Herbert River has occupied many courses from Cattle Creek at the far southern end of the delta, through the Trebonne, Palm and Gentle Annie Creeks to the present Seaforth Channel. The older courses end in

foredunes and the more recent at the current beach-front. There has been a major course change about every 1000 years and the river has moved north more than 30 kilometres. The processes which caused the channel changes are still active today. The different courses and estuary mouths of the Herbert River are illustrated in **Figures 4 and 5**. (from White, 2000).

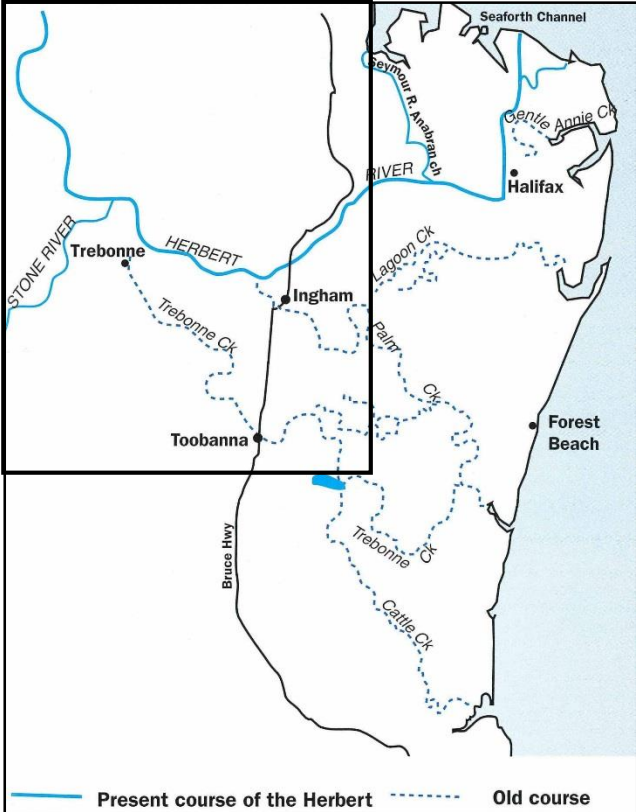


Figure 4. Prior courses of the Herbert River (White 2000).

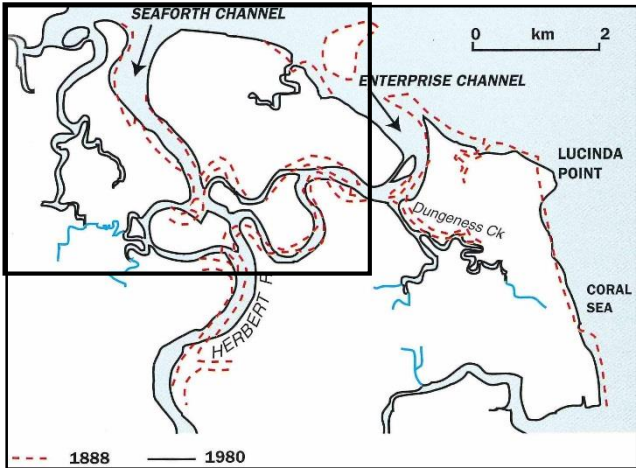


Figure 5. Prior mouths of the Herbert River. (White 2000)

Beach ridges have developed to the north of each of the older courses under the influence of the northwards littoral drift. The progradation of the Herbert River delta has meant that the earlier beach ridge systems have been engulfed or fragmented by the migration of the Herbert River such as Gentle Annie Creek which has incised the earlier ridges. The series of sand ridges from Allingham to Lucinda has enclosed the intertidal lagoon between Halifax and Lucinda allowing the subaqueous space to infill and be colonised with mangroves.

7 Acid Sulfate Soil Landscape Features

7.1 Bundwalls, Floodgates and Watertables

Watertables in wet tropical climates are generally close to the soil surface all year round with only a limited drop in watertables (if any) over the dry season. ASS are generally not subject to significant oxidation from natural watertable fluctuations and do not produce large volumes of acid in their natural state.

Along the Queensland coast bund walls and floodgates have been used to protect land for sugarcane growing, grazing, urban development and other land uses. The construction of bund walls and floodgates keeps tidal inundation and storm surges out of low lying land while allowing for flood water to escape. The location of bund walls vary and can be located in either the intertidal, supratidal or extratidal zone. The lower in the landscape they are placed, the greater the chance for disturbance and acidification of ASS.

Most bund walls have been in place for many years and often ASS material has been used in the construction of the wall. ASS material has been obtained by either creating a large deep drain on the outside of the wall or a shallow wide depression on the inside of the wall. Vegetation often takes a long time to establish on bund walls made out of ASS material and jarosite is usually present on the surface or just below.

A drop in watertable levels as a result of bund walls and floodgates will cause the oxidation of ASS layers located close to the soil surface and consequent production of acid. This acid may be leached out of the soil during the first rainfall events of the wet season, usually thunderstorms from October to December and transported to waterways quickly where drains have been installed. The result may be environmental harm, such as fish kills and stress on vegetation such as mangroves and salt marshes. The texture of the ASS will influence the rate that acid may be leached out of the soil. Sandy soils will be exhausted more quickly than clay soils but they may contain less acid than clay soils. The high water content of ASS when soils dry out causes the elevation of the land to drop. Thereby making it impossible in some cases to remove the bund wall and floodgates. When floodgates fail due to debris or vandalism seawater can inundate the land causing loss of value to agriculturally productive areas.

Drains and creeks intersecting the floodplain allow for the draining of flood water and also act as transport corridors for the release of acid water. The water temperatures in the drains and creeks during the summer months increases causing greater levels of algal growth and microbial activity. This can lead to stagnation, low levels of dissolved oxygen and increased risk of fish kills. Water quality quickly deteriorates in drains that do not have regular tidal exchange. Floodgates that allow controlled tidal exchange will have the following desired effects:

- neutralise any existing acidity and restore neutral pH to the watertable
- higher watertable levels preventing ASS oxygenation and release of heavy metals
- decrease algae and aquatic weeds growth
- increased dissolved oxygen levels and prevention of odours from stagnant water
- increased fish passage and decrease in mosquito breeding areas
- prevention of fish kills and red spot disease

8 Methodology

The methodology used in the preparation of all NRW Special Acid Sulfate Soil Maps meet the requirements in the following:

- ▶ *State Planning Policy 2/02: Planning and Managing Development Involving Acid Sulfate Soils*
- ▶ *State Planning Policy 2/02 Guideline; Planning and Managing Development Involving Acid Sulfate Soils*
- ▶ *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland (Ahern et al. 1998)*
- ▶ *Acid Sulfate Soils Laboratory Methods Guidelines (Ahern et al. 2004)*
- ▶ *Australian Soil and Land Survey Field Handbook (McDonald et al. 1990)*

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 and sites in a virtually virgin state. The following equipment was used to sample ASS.

8.1 Mechanical Sampling Equipment

Mechanical Sampling was undertaken with a Geoprobe™ model 54DT coring machine. The Geoprobe (**Plate 1**) is a track-mounted machine that obtains a 38 mm soil core in 1.2 m long removable clear PVC liners. Soil cores are photographed for the record before being sampled and assessed. The Geoprobe is the preferred method of mechanical sampling because it is able to sample all soil types from dry and wet sands to soft sticky muds and also hard alluvial soils.



Plate 1. Geoprobe model 54DT track-mounted coring machine

Mechanical sampling of soil cores are taken to a depth of 5 to 6 m (or to -1m AHD) where possible or until non-marine soils are encountered.

8.2 Hand Operated Sampling Equipment

Access of mechanical equipment in mangrove areas is often impractical due to the softness of the substrate, the density of the vegetation and a requirement to keep disturbance to a minimum. A hand operated sampling tapered gouge auger was used at sites 82 and 136.

8.3 Location of Sites, Profile Description and Sampling

The location of sample sites was based on the free survey technique (Reid 1988) with the aid of aerial photos (latest and oldest) and Light Detection and Ranging (LiDAR) elevation information or best elevation data available. Site conditions or observations made during fieldwork determined the selection of alternate or additional sites. The site location of each site was recorded in Standard Map Grid coordinates to an accuracy of no less than 3 meters using a GPS unit.

The soil profiles were described using the nomenclature of the *Australian Soil and Land Survey Field Handbook* (McDonald et al. 1990). Soil properties recorded included horizon depth, colour, field pH, field pH after oxidation with 30% hydrogen 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 (Volume 2 Appendix 1). A large difference (eg. 3–4 pH units) between pH_F and pH_{FOX} , together with significant effervescence is a reliable 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 at 80°C for 48 hours and fine ground (<1 mm) before laboratory analysis.

8.4 Database Recording

All field and laboratory data were entered into the NRW Soil and Land Information (SALI) database, designed specifically for land resource surveys. Terminology and codes in SALI are consistent with the *Australian Soil and Land Survey Field Handbook* (McDonald et al. 1990). Decoded borehole descriptions can be seen in Volume 2 Appendix 3.

Laboratory analysis

Laboratory analyses were 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 actual or possibly potential according to field morphology. Two laboratory methods were 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). Refer to Glossary (Page 48) for detailed explanation of laboratory terms and acronyms.

A summarised version of the laboratory data displaying actual acidity, potential acidity, net acidity using the Suspension Peroxide Oxidation Combined Acidity and Sulfur (SPOCAS) acid base accounting methods is provided in Volume 2, Appendix 1. Full details of laboratory analyses are available in Volume 2, Appendix 2. Selected samples were analysed for full SPOCAS analysis to determine actual acidity and self neutralising capacity. The samples selected for analysis were based on the morphological data collected at the site.

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 forms of inorganic S, while not determining organic sulfur. While sufficient for most PASS samples the method however does not measure existing acidity.

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).

8.5 Determination of PASS or AASS

The determination of which soil horizons constitute an 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

(PASS) were assessed using S_{CR} and S_{POS} analytical results. (AASS) were determined by the presence of jarosite, TAA results as well as field pH (pH_F) and/or laboratory (pH_{KCl}) values of 4 or less. Neutralising capacity was assessed using a combination of ANC_E , Ca_A , Mg_A , TPA, ANC_{BT} and pH. (See Glossary for definitions of symbols).

9 Results

9.1 Map Units of the Study Area

The mapping process is a way of presenting extremely complex 3-Dimensional soil data in a 2 dimensional format, so that it can be input to planning or management decisions. At the 1:25 000 scale, it is possible to identify areas of high hazard. The attached ASS map displays the map units identified in the study area.

Table 2 shows the total area of each mapping unit along with the percentage occupied by each unit. The entire area of 2032 area is underlain by layers of ASS, but these vary in depth and severity. It is noted that the AASS found in the survey area (16 ha) has PASS layers below it (meaning that further disturbance has the capacity to release yet more acid and heavy metals).

Table 2. Area of individual map units

Map Unit*	Map Unit Area (ha)	Percentage of Area Assessed (%)
Actual acid sulfate soils		
A1S1	16	0.8
Potential acid sulfate soils		
S0	886	43.6
a0S1	26	1.3
S1	137	6.7
a0S2	356	17.5
S2	57	2.8
a0S3	68	3.3
a0S5	469	23.1
S5	12	0.6
Total	2010	98.9
Acid Sulfate on disturbed land		
SDL	6	0.3
Total Area	2032	100.0

*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 (pH ≤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. S0, S1); but where a map unit contains both AASS and PASS layers, then the codes are combined (eg. A1S1);
- additional information is provided by code “a” for areas with strongly acidic (pH >4 and ≤5) soil layers.
- SDL

9.2 Characteristics of the Mapping Area

The following selection of sites represents the different geomorphological conditions encountered in the study area. Site and profile photos are supplied for some of these.

The main S5+ mapping unit represents a relic beach ridge barrier formation now covered with alluvium, which gradually drops in height towards the north and east, dipping below the surrounding shallow PASS units. Gentle Annie Creek and other relic creeks have incised into the main section of the S5+ unit leaving shallow PASS deposits over the beach ridge barrier sands.

Site 128 (**Plate 2**) is located east of Halifax township on the eastern edge of the S5+ unit. The soil profile (**Plate 3**) shows alluvial clay loam to light clay from the surface to 2.25m, over coarse sands which extend to 8.15m, over a dark marine silty clay loam from 8.15m to 8.35m and mottled Pleistocene material from 8.35m to 9.3m. A sulfide concentration of 0.49 %S (S_{CR}) which is above the action criteria (Table 1), was recorded at 7.0m to 7.2m. The morphology of the site indicates a relic beach ridge barrier formation with some low energy marine influence at the bottom of the sand deposit. The silty clay loam horizon at 8.15m to 8.35m contains 0.46 %S (S_{POS}), and shell with neutralising capacity. No PASS was found in the Pleistocene layer.



Plate 2. Site 128 Map Unit S5+. PASS Depth ~6.5m

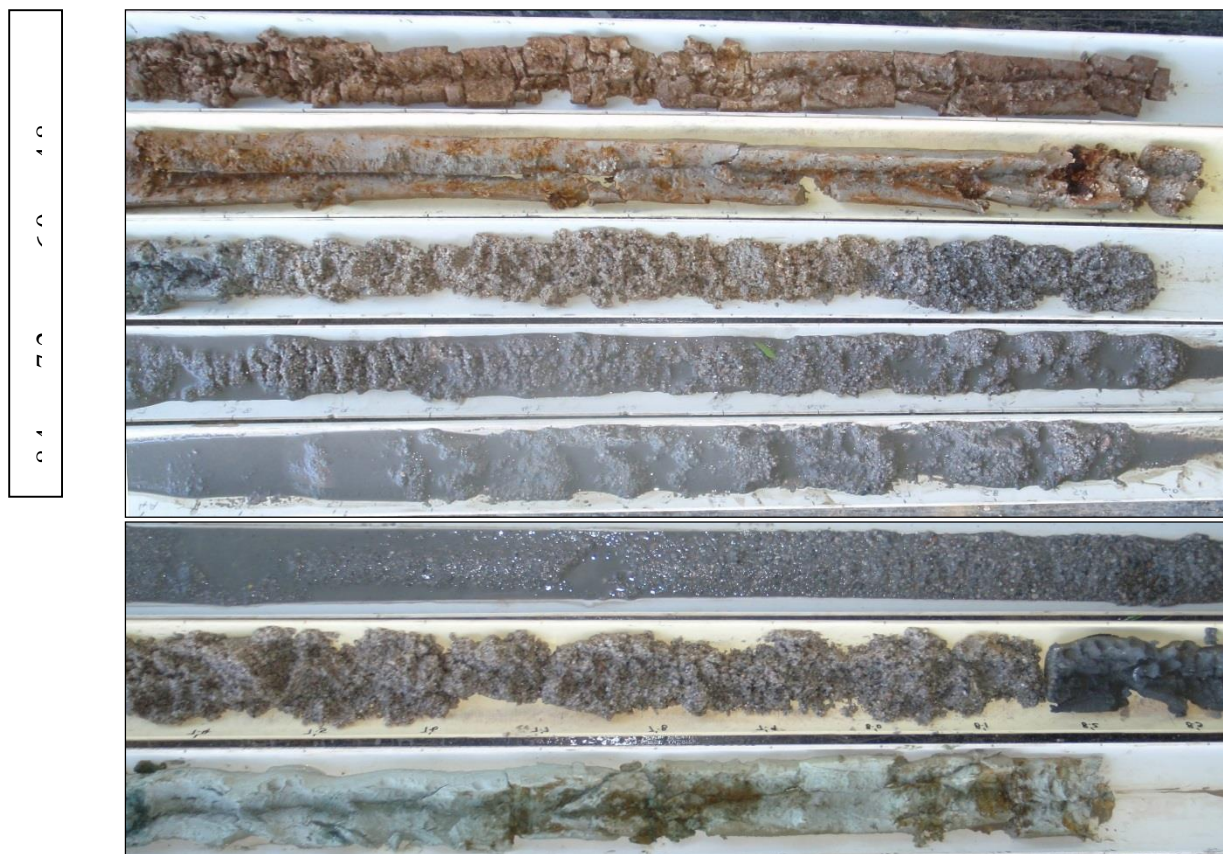


Plate 3. Site 128 Soil Profile

Site 79 (**Plate 4**) is located within the S5+ map unit and is representative of the relic beach ridge barrier formation. The soil profile (**Plate 5**) shows an alluvial clay layer from the surface to 0.4m, over coarse sands to 9.45m, over dark marine clay to the depth of the borehole at 10.8m. No Pleistocene layer was reached. The beach sand was below the action criteria. The dark marine clay muds below 9.45m recorded a sulfide concentration of 0.5 %S (S_{POS}), and shell with neutralising capacity. A PASS layer of clay loam/light clay texture was consistently found below the barrier sands.



Plate 4. Site 79 Map Unit S5+. PASS Depth 9.45m



Plate 5. Site 79 Soil Profile

Site 81 (**Plate 6**) is located within the S2 unit east of the S5+ relic beach ridge barrier. A bund wall in the left of the photo is protecting the sugarcane from tidal influence. The soil profile (**Plate 7**) shows alluvial mottled clay to 1.1m. Below 1.1m to 1.8m are PASS marine silty/sandy light clays with sulfide concentrations from 0.7 %S to 1.6 %S (S_{CR}). A PASS sand layer from 1.8m to 2.1m contains 0.27 %S (S_{CR}). Below 2.1m the profile transitions into the relic beach ridge barrier sand formation free of sulfides.



Plate 6. Site 81 Map Unit S2. PASS Depth 1.1m



Plate 7. Site 81 Soil Profile

Site 82 (**Plate 8**) is located within the S0 unit to the east of the bundwall and Site 81 (**Plate 6**). The site was sampled using a gouge auger within mangroves. The soil profile (**Plate 9**) shows a clay loam surface to 0.3m over silty light clay to 0.9m. Mottles are evident from 0.15m to 0.65m. **Plate 10** shows a close up of the surface to 0.2m. The surface to 0.1m contains a PASS layer with a sulfide concentration of 0.08 %S (S_{CR}).



Plate 8. Site 82 Map Unit S0. PASS Depth 0.0m



Plate 9. Site 82 Soil Profile (sampled by gouge auger)



Plate 10. Site 82 Soil Profile close up of 0.0m to 0.2m

Site 131 (**Plate 11**) is located within the channel and the upper reaches of Gentle Annie Creek. A road crossing approximately 175m downstream restricts the movement of tidal water upstream and may limit the extent of mangroves to this site. The soil profile of Site 131 (**Plate 12**) shows a profile with a fibric peat surface (0.0m to 0.15m), over silty light clays (0.15m to 1.1m), and loamy sands continue beyond 1.9m. A sulfide concentration of 0.15 %S (S_{CR}) was measured in the fibric peat surface (0.0m to 0.15m) and 0.93 %S (S_{CR}) in the silty light clay horizon from 0.45m to 1.1m. Relic beach ridge barrier sands occur from a depth of 1.1m. The relic beach ridge barrier has been incised by the channel of Gentle Annie Creek which deposited PASS material from the surface to 1.1m. This site demonstrates that mangroves do not have to be currently existing at the site for PASS material to be present in the surface material.



Plate 11. Site 131 Map Unit S0. PASS Depth 0.0m

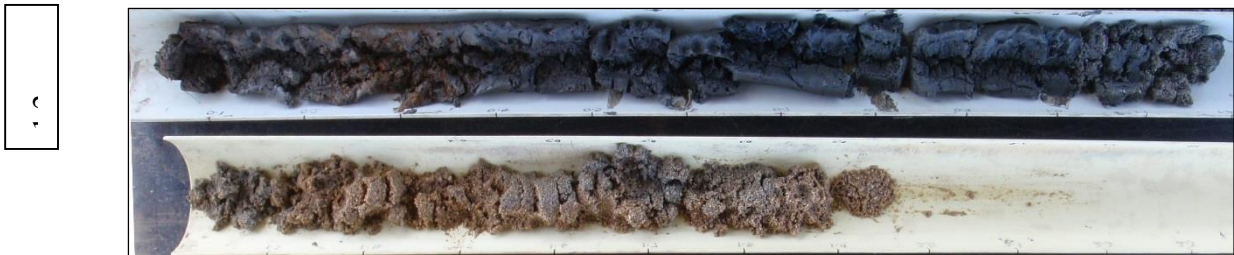


Plate 12. Site 131 Soil Profile

Site 93 (a0S2 unit) located to the west of Site 131 is situated within a relic creek channel. This site consists of a shallow deposit of PASS marine mud overlying barrier sands.

Site 130 is located in the northwest section of the S5+ unit. This site contains relic beach ridge sands to a depth of 10.6m. A thin deposit of PASS material from 10.6m to 10.8m contains 0.13 %S (S_{POS}) and sits directly above a mottled Pleistocene clay. Site 130 represents the northern most extent of the relic beach ridge deposits. To the north of this location the profiles are represented by a thin alluvial clay layer over PASS material consisting of sands and muds.

Site 103 (**Plate 13**) is located with the A1S1 unit to the north of Gentle Annie Creek. The soil profile (**Plate 14**) shows a mottled clay surface to 2.0m, over marine sand to 5.1m, over a sandy clay loam which extends beyond 6.0m. The horizon from 0.8m to 1.15m recorded a pH_F of 4.3, the presence of jarosite (**Plate 15**) and a retained acidity of 126 mol H^+/t ($S-S_{NAS}$). PASS in the clay layer from 1.15m to 2.0m recorded a sulfide concentration of between 0.23% (S_{POS}) to 1.3 %S (S_{CR}). The marine sand layer from 2.0m to 5.1m contains 0.2 to 0.05 %S (S_{CR}). The iron strips pictured in Plate 14 recorded a field reading of 100mg/L Fe^{2+} at 2.9m and 25mg/L Fe^{2+} at 4.3m. The profile was also analysed for DTPA extractable iron (Method 12A1-Fe); the results were Fe 431mg/kg at 1.9m, Fe 28 mg/kg at 2.8m and Fe 32 mg/kg at 4.5m.



Plate 13. Site 103 Map Unit A1S1. PASS Depth 1.15m.

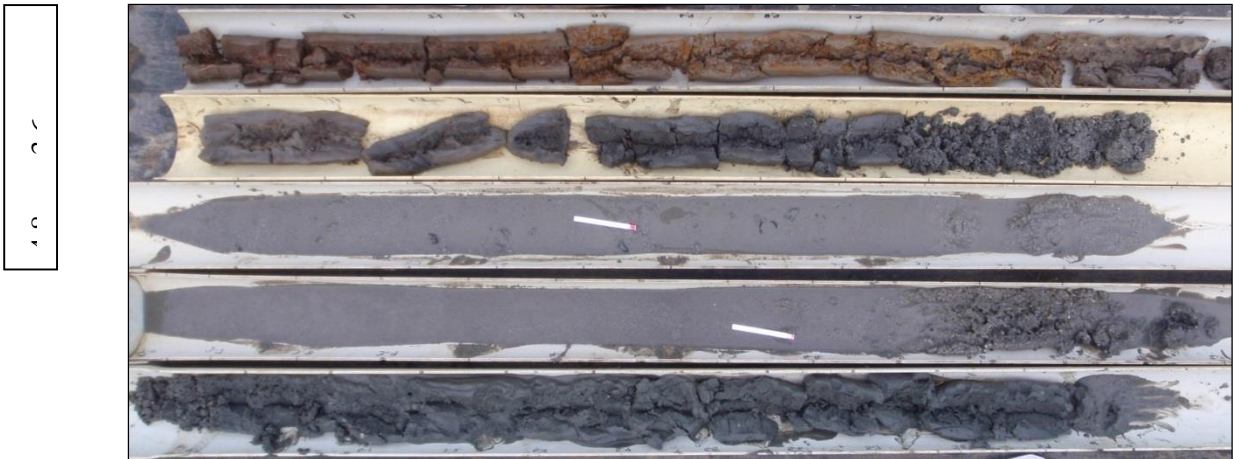


Plate 14. Site 103 Soil Profile



Plate 15. Site 103 Jarosite (0.9m to 1.0m)

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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, CaCO₃; 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.

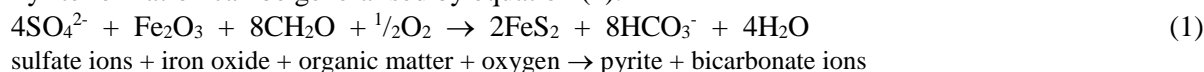
Ca_A: Reacted calcium. The calcium soluble after the peroxide digest and TPA titration that was not soluble following KCl-extraction and TAA titration. ($Ca_P - Ca_{KCl}$). It can be used (in combination with Mg_A) to provide an estimate of the soil carbonate content, but may be an underestimate if the 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.

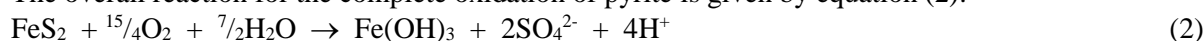
Ca_P: Peroxide calcium. Calcium measured following the TPA analysis, which includes soluble and exchangeable calcium, calcium from gypsum, as well as calcium (eg. from carbonates) dissolved as a result of acid produced due to oxidation of sulfides by peroxide.

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).

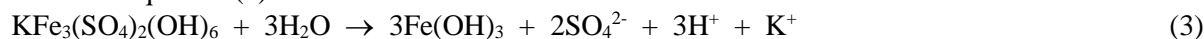
Pyrite formation can be generalised by equation (1):



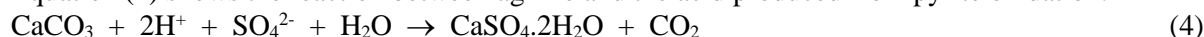
The overall reaction for the complete oxidation of pyrite is given by equation (2):



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.

DERM : Queensland Department of Environment and Resource Management.

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 approached 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.