

Maroochy Caloundra Acid Sulfate Soil Sustainable Land Management Project Volume 1 Report on Acid Sulfate Soil Mapping



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Accompanying maps and Volumes

- **Volume 2** Decoded borehole descriptions
- **Volume 3** Tabulated laboratory data
- Acid Sulfate Soils. Maroochy Caloundra acid sulfate sustainable land management project-**Map 1**. 1:25 000 scale.
- Acid Sulfate Soils. Maroochy Caloundra acid sulfate sustainable land management project-**Map 2**. 1:25 000 scale.

SUMMARY

This report presents the findings of acid sulfate soil (ASS) mapping undertaken on the Sunshine Coast of southeast Queensland. The work was carried out by the Department of Natural Resources and Mines as part of a three year Natural Heritage Trust funded project.

The *Maroochy Caloundra Acid Sulfate – Sustainable Land Management Project* involved mapping eight coastal lowland areas within the catchments of the Maroochy and Mooloolah rivers. Previous broad scale mapping and a detailed waterway pH inventory were used to identify the areas.

Approximately 7934 hectares (ha) of land less than 5 m AHD was mapped throughout the survey areas. Of this, 2011 ha was found to have a low probability of ASS occurrence. Land underlain by ASS totalled 5923 ha and consisted of both sulfidic sands and clays. This was divided into potential acid sulfate soils (PASS), which accounted for 5325 ha and actual acid sulfate soils (AASS), which accounted for 598 ha. AASS was distinguished by pH values less than 4 and the varying occurrence of jarosite. Whilst ASS layers were identified at varying depths, a large proportion (1257 ha or 21%) were encountered within 1 metre (m) of the surface. A further 2034 ha were encountered at 1 to 2 m depth.

During the course of the project, 656 boreholes were described and 5750 samples taken for chemical analysis. Oxidisable sulfur values were obtained using several analytical methods and ranged from 0% S to a maximum of 7% S across mapping areas and soil texture groups. Average oxidisable sulfur values for sulfidic clays across all areas averaged 0.9% S whilst for sulfidic sands the average was 0.2% S.

1. INTRODUCTION

During the 1990's, several serious environmental events in the lowland areas of Northern New South Wales sparked concern about acid sulfate soils (ASS). Little was known about the areal extent or the severity of risk of these problem soils in Queensland. As a consequence, the Department of Natural Resources and Mines (NR&M) undertook to investigate the situation. With the aid of Natural Heritage Trust funding, broad scale (1:100 000) mapping was undertaken to identify the location of sulfidic sediments in southeast Queensland. These initial investigations indicated that ASS underlay large areas of southeast Queensland coastal lowlands.

The large areas of acid sulfate soil identified on the Sunshine Coast raised concerns amongst local community and government organisations about the effects of ASS disturbance on the soil and water quality in the Maroochy and Mooloolah River catchments. This in turn raised questions about managing future sustainable land use. As a consequence, Natural Heritage Trust funding was granted to Maroochy Landcare to address these issues.

A major part of the project entailed the undertaking of detailed acid sulfate soil mapping. This work was undertaken by NR&M's Queensland Acid Sulfate Soil Investigation team (QASSIT). The mapping concentrated on areas identified by project stakeholders as being acid sulfate soil hotspots as determined by local waterway pH inventories. The following areas were identified : Meridan Plains to Parrearra, Mountain Creek, Maroochydore, Kunda Park (Eudlo Creek), Pacific Paradise to Mount Coolum, Mount Coolum to Peregian Beach South, Yandina to Dunethin Rock and Lake Weyba.

2. ESSENTIAL OUTCOMES AND USE OF REPORT

This reporting has been divided into three parts:

- **Volume 1:** Presents information on ASS along with the methodology and results from the mapping program. It is accompanied by two (**map 1 and map 2**) 1:25 000 scale maps that portray the areal extent of actual and potential ASS as well as the locations of all boreholes.
- **Volume 2:** Presents decoded descriptions of all boreholes encompassing soil profile morphology and field ASS testing.
- **Volume 3:** Presents tabulated laboratory data together with selected soil profile morphological properties, for example, texture and presence of jarosite. This data commonly includes:
 - ASS analysis for each soil horizon and/or every 0.5 m down the profile to depth of sampling;
 - Interpreted information including the labelling of all samples that exceed the ASS texture-based action criteria, recommended in national guidelines as requiring treatment.

3. DESCRIPTION OF THE STUDY AREA

The project area encompassing the eight mapping areas lies within the local authority boundaries of Maroochy Shire and Caloundra City in southeast Queensland (Figure 1). Figure 2 shows a three dimensional view of the Sunshine Coast and the eight individual study areas.

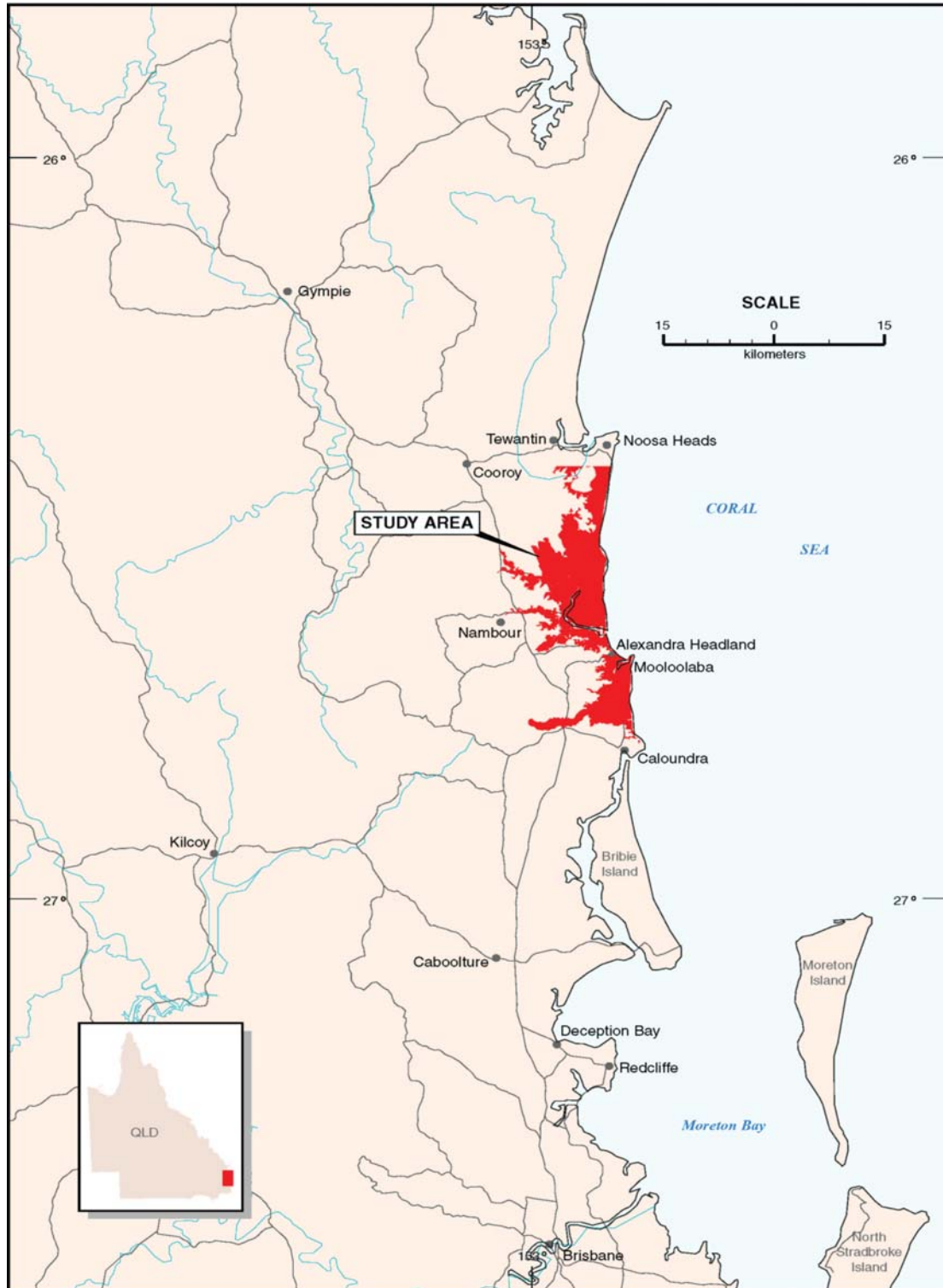


Figure 1. Map showing general study area

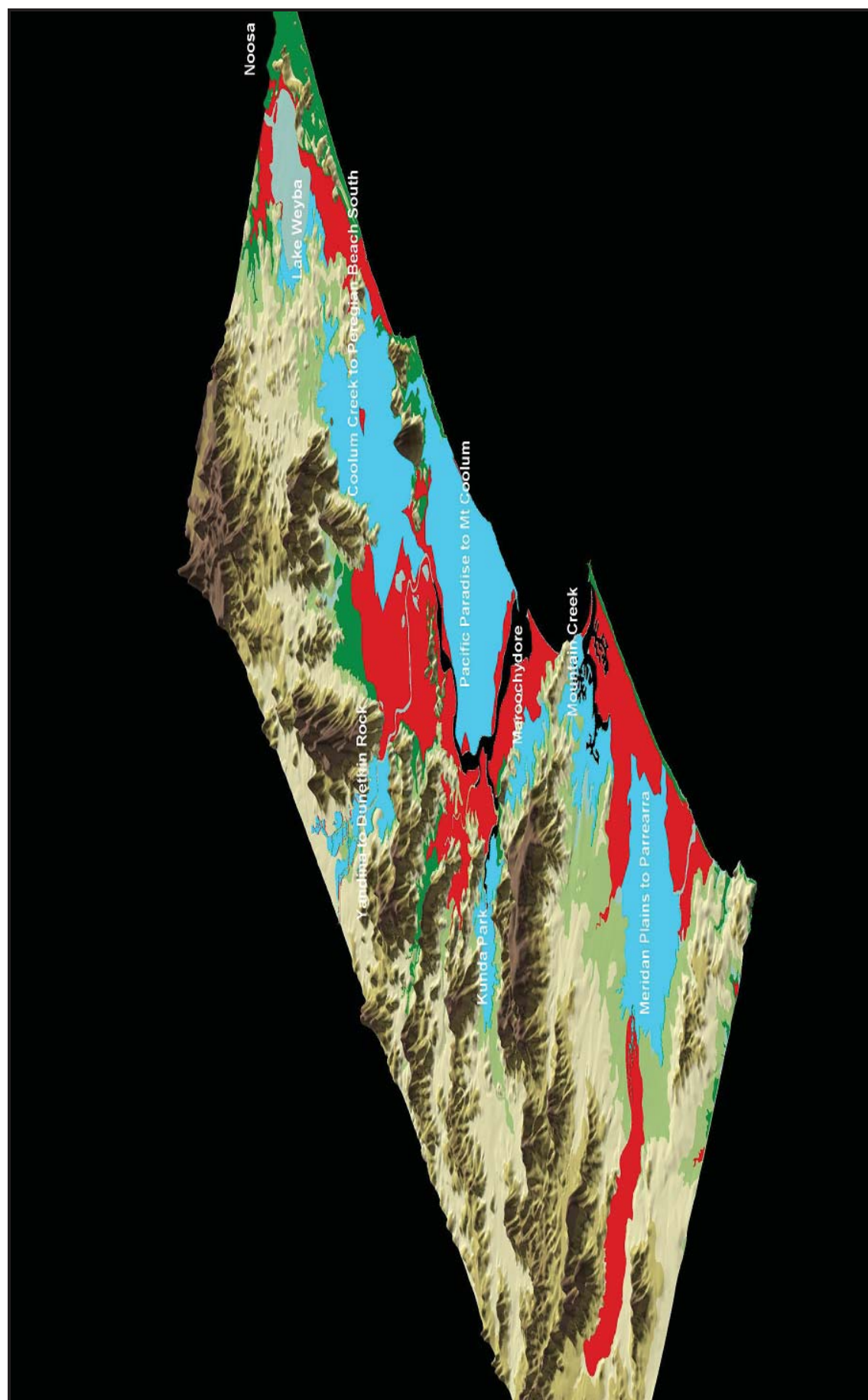


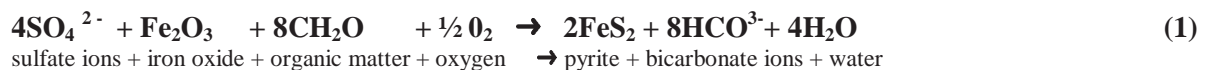
Figure 2. Eight mapping areas (light blue). Red denotes other areas of broad scale ASS mapping

4. ACID SULFATE SOILS – AN OVERVIEW

4.1 Description and formation

The term ‘acid sulfate soil’ (ASS) is a generic term given to sediments principally of marine origin that contain iron sulfides, mainly pyrite (FeS_2). The textures of these soils can range from sands to loams and clays. Over the last 140 000 years and in particular the last 10 000 years (the Holocene Epoch), sea level fluctuations (coinciding with periods of glaciation) have produced conditions along the Australian coastline that were conducive to the formation of pyrite. Dent (1986), states that ‘pyrite accumulates in waterlogged soils that are both rich in organic matter and flushed with dissolved sulfate usually from seawater’.

The formation of iron sulfides occurs under anaerobic conditions when sufficient organic matter from decaying plant material exists in sediments to provide the energy for sulfide-forming bacteria. These bacteria use the organic matter along with sulfate from seawater and iron from fresh water sediment to produce the iron sulfides (pyrite) as well as bicarbonate ions. Flushing such as that provided by tidal regimes removes bicarbonate ions and assists in the formation of pyrite, as described by equation 1.



Identification of PASS and AASS

When iron sulfides are exposed to the atmosphere (eg. through excavation and drainage), oxidation occurs, resulting in the production of sulfuric acid (H_2SO_4). Under these conditions, potentially toxic quantities of acid, iron, aluminium and heavy metals are released into the surrounding environment. Normally AASS occur in upper layers more prone to oxidation such as the zone of watertable fluctuation. AASS often overlie PASS which remain in a reduced state below the watertable.

In the field, PASS are usually grey to dark olive grey in colour (2.5Y41 to 5Y41 to 5GY31 in the Munsell soil colour chart). They are typically wet, fine textured soils (eg. mangrove muds), but may be sandy or more rarely, gravelly. AASS are usually browner than PASS due to their oxidised nature. They often show significant red and orange mottles, indicating their oxidised state. AASS are generally but not exclusively characterised by a yellow coloured mottle called jarosite, which is strong evidence that sulfuric acid has been released (Plate 1). Jarosite is formed as an intermediate product of the oxidation process and as a result is most often observed in old root channels (where the oxygen has reached the pyrite as the root decomposed), in soil cracks, and on banks or cuttings. Jarosite requires strong oxidising conditions, a potassium source and a pH of approximately 3.7 or lower to form (Ahern and McElnea 2000). As there are few natural situations that cause pH to drop to these levels, jarosite is one of the better indicative signs of AASS.

Field pH (pH_F) and field pH peroxide (pH_{FOX}) tests also help identify AASS and PASS layers. The addition of hydrogen peroxide to an ASS sample triggers accelerated oxidation of pyrite, liberating the acid that would form slowly under natural oxidising conditions. The strength of reaction to peroxide and the pH decrease from pH_F to pH_{FOX} are key indicators of ASS. PASS have pH_F of 4.0 to 7.5 and pH_{FOX} of 0.9 to 3.0, whilst AASS generally have a pH_F and pH_{FOX} below 4.0.

The equations below describes the oxidation process in more detail.



Plate 1. AASS displaying oxidised layers and jarosite (yellow) mottles

4.2 Oxidation of iron sulfides (pyrite)

Oxidation of pyrite, the main source of the acidity in ASS, can be described by the following equations. The initial step in pyrite oxidation is the production of elemental sulfur and ferrous ion (Fe II) (White and Melville 1993):



The sulfur is then oxidised to sulfate and acid (sulfuric acid):

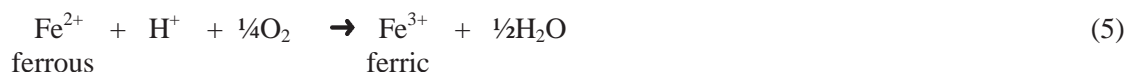


The complete reaction of pyrite to ferrous ion (Fe II) and sulfate can be written as:



This initial pyrite oxidation reaction tends to be very slow but given an oxygen supply, is inevitable. As the ferrous ion is soluble, it can be transported large distances into streams or it can stay in the original site area.

The ferrous ion may also in turn be oxidised to the ferric ion [which further reacts depending on the pH of the solution or soil; low dissolved oxygen and extreme acidity can both cause fish kills].
—see equations (5), (6) and (7) below:



The generation of Fe^{3+} from Fe^{2+} can be a rate-limiting step in the oxidation of pyrite without the presence of bacteria but *Thiobacillus ferrooxidans* can accelerate this reaction ten to ten thousand fold. Optimum conditions for the growth of the bacteria are a temperature around 30°C and pH of approximately 3. The reaction in equation (5) also removes dissolved oxygen from waterways.

The ferric ion is highly reactive and may oxidise more pyrite. The ferric ion component has several actions, none of which are beneficial to the environment:

At pH >4, Fe^{3+} is precipitated as ferric hydroxide $\text{Fe}(\text{OH})_3$ and releases even more acid into the surroundings. The precipitate is seen as a rusty discolouration on bridges or as floccules on the sea-bed (often at distances from the site of production). This reaction produces additional acidity and removes dissolved oxygen (DO) from the waterways.



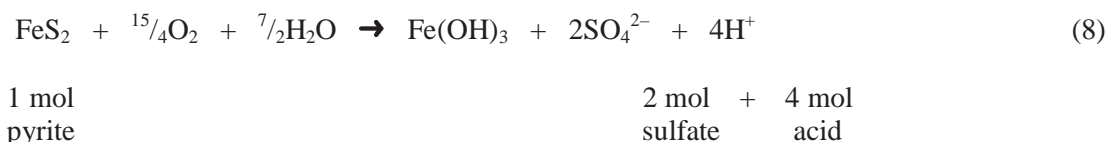
At low pH (<4), Fe^{3+} can remain soluble and very importantly when it remains in the ASS, it speeds up the pyrite oxidation process, while helping to liberate large amounts of additional acid:



Note: This reaction, equation (7), does not require oxygen to oxidise pyrite and can occur within an existing acid sulfate soil that has generated ferric ions, even when oxygen is denied by re-flooding or deep burial. For this reason, existing AASS require liming even if being buried.

At different points in time, the acid levels in the solution will vary and therefore one or more of the above reactions [(4) to (7)] may be operating. One of the important factors in moderating the pH is the buffering capacity of the soil—which is dependent on the types and quantities of the clay minerals present, the form of any carbonates present (fine or coarse), and the rate at which the chemical reactions occur. For example, if **lime** (or fine shell remnants) is present, then the lime will neutralise **some** of the acid.

The **overall reaction for the complete oxidation of pyrite** is given by Dent (1986):



4.3 Impacts

Oxidation of waterlogged sulfidic sediments has occurred naturally over time such as when watertable levels drop during periods of extreme drought. Sulfuric acid release would however have been slow and the natural buffering capacity in undisturbed landscapes would have reduced the likelihood of environmental damage. However when large amounts of sulfidic sediments are artificially drained or excavated, acid can be produced rapidly and in large quantities. The acid attacks the insoluble aluminium (Al) in the clay lattice of soils, releasing Al^{3+} into the water where it becomes extremely toxic to fish and vegetation. (It is rarely concentrated enough to affect humans through short-term skin contact). The impacts of ASS are widespread and can be divided into three broad categories: agronomic impacts; engineering impacts and environmental impacts.

Agronomic impacts

ASS pose chemical, biological and physical problems for crops (Dent 1986). The severe acidity produced by the sulfuric acid causes pH levels less than 3. These acid conditions enable heavy metals to become soluble causing plant toxicities of aluminium, iron III and manganese and deficiencies of phosphorus, calcium and potassium. Farm productivity can also be reduced by ASS, as nutrient availability for pastures can be severely restricted by acidic conditions allowing unpalatable acid tolerant weeds such as phragmites to invade paddocks (Plate 2). Grazing animals living in these areas may consume too much aluminium and iron as a consequence (Sammut and Kelly 2000).



Plate 2. ASS disturbance resulting in cane deaths and growth of acid tolerant phragmites species

Engineering impacts

In the undisturbed state, sulfidic clays act as super-saturated gels that have very low bearing strength (Dent 1986). This makes them unsuitable for foundation support. The sulfuric acid produced following exposure of sulfidic sediments corrodes steel and concrete (Plate 3). The iron in pyrite oxidises to form iron hydroxides, which can choke drains for significant distances downstream of the acid source, (Plate 4).



Plate 3. Acidified water from disturbed ASS attacks concrete and exposes the aggregate



Plate 4. Iron hydroxides choking drain

Environmental impacts

ASS disturbance has a very real potential impact on water quality and aquatic life. Acid leached into water bodies increases the solubility of aluminium and releases various forms of soluble and precipitated forms of iron. Aluminium in particular has severe effects on gilled organisms causing death and disease of fish and crustaceans. Fish diseases include red spot (Epizootic Ulcerative Syndrome), which occurs when the protective mucous covering the fish is removed by acid water. This allows a fungus to enter the skin and create large red ulcers on the body (Plate 5).

A decrease in the growth rates and productivity of aquaculture species such as oysters has also been attributed to acid release from disturbed ASS (White *et al.* 1996). Certain forms of the iron released from ASS disturbance can deplete oxygen in aquatic habitats, which in turn can cause or contribute to the death of aquatic species. The release of acid can also acidify poorly buffered soils such as those dominated by sand. This can restrict growth and kill intolerant native plants.



Plate 5. Fish displaying red spot disease (Epizootic Ulcerative Syndrome)

5 GEOMORPHOLOGY AND ACID SULFATE SOILS.

5.1 Background

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, it is useful to look further back in time to gain a better understanding of their deposition. While the whole process relating to Pleistocene ASS is still to be clarified, landholders should be aware that they need to assume that land can (and in some cases will) have ASS buried below apparently benign strata. The key features are (i) the limits of sea level inundation and (ii) the conditions for soil deposition in these areas. These are explored below.

During the previous interglacial period within the Pleistocene epoch (120 000 to 140 000 years B.P), 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. The dark blue areas seen in Figure 3 indicate the approximate area of this flooding. After this high, sea level receded and then fluctuated between 80 m and 140 m below present (Hekel and Day 1976). During this time, rivers and creeks cut deep channels through the previously deposited fluvial and estuarine sediments removing some and isolating others.

The most recent sea level rise (post glacial marine transgression) commenced approximately 19 000 years ago. At this time sea level was estimated to be 140 m lower than present with the shoreline up to 40 kilometres east of where it is today (Jones 1992). At the commencement of the Holocene (10 000 years ago), sea level was approximately 25 m below present and still rising (Thom 1981). Present sea level was reached around 6500 years ago (Thom and Roy 1985). There is evidence to suggest that minor rises of up to 1 metre occurred along the southern Queensland coast sometime after this with sea level returning to its present position around 4000 years ago (Jones 1992).

The rapid rate of sea level rise during the Holocene epoch 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 (Graham and Larsen 1999). The depth of sediment deposited depends on the size of the local river system and the depth of down cutting that occurred during the Pleistocene low sea levels. The pale blue areas in Figure 3 indicate possible high Holocene sea level.

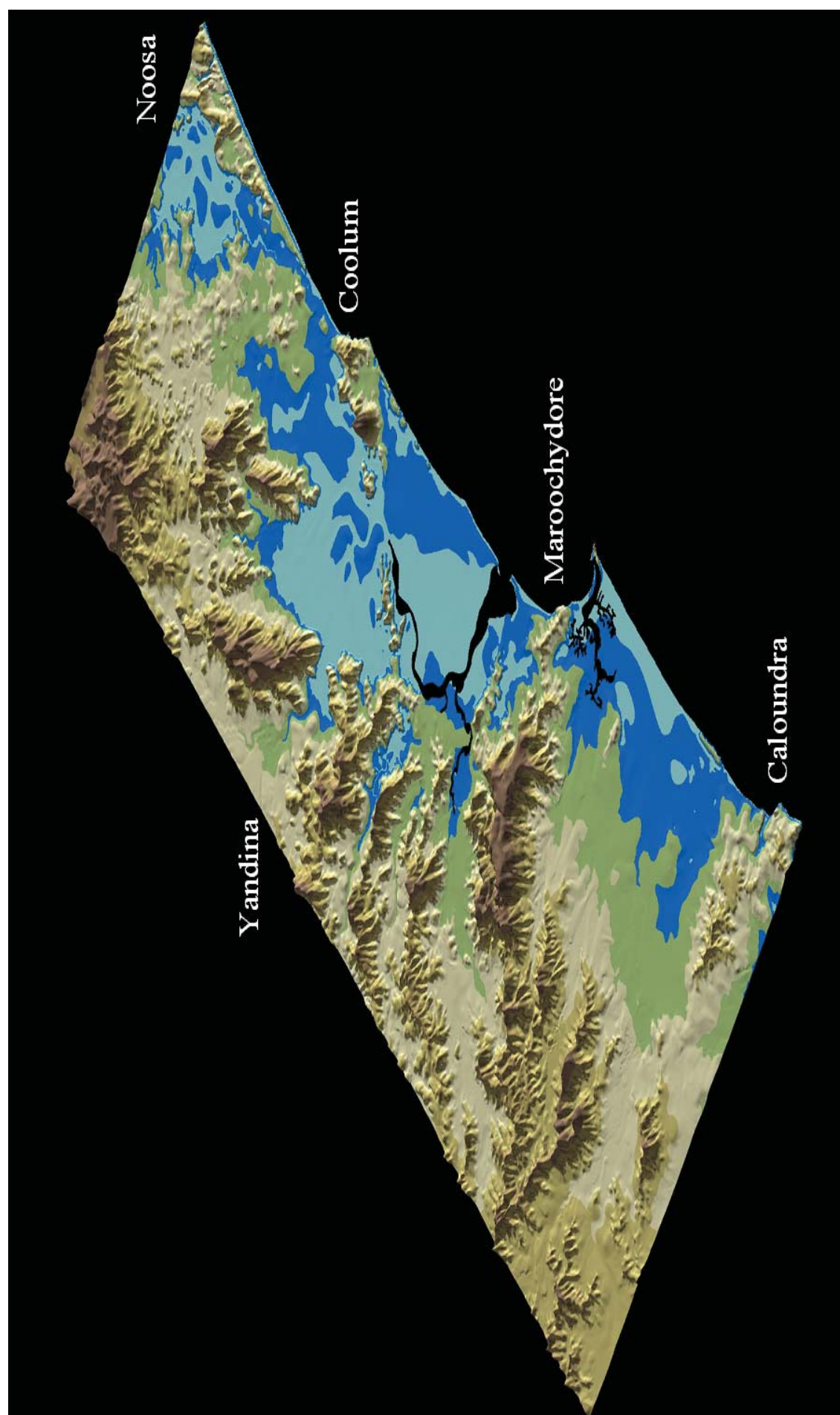


Figure 3. Likely areas of inundation by Pleistocene high sea level (dark blue) and Holocene high sea level (light blue)

5.2 Geomorphology of estuaries

Understanding the geomorphology of an area is an integral part of mapping ASS as it enables more educated placement of boreholes. The following provides a basic insight into the coastal processes that have enabled acid sulfate soil formation in the Maroochy Mooloolah areas of the Sunshine Coast.

Dalrymple *et al.* (1992), define an estuary 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. According to Dalrymple *et al.* (1992), ideal estuaries can be divided into three energy zones (Figure 4):

- (A) an outer zone dominated by marine processes ie. 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.

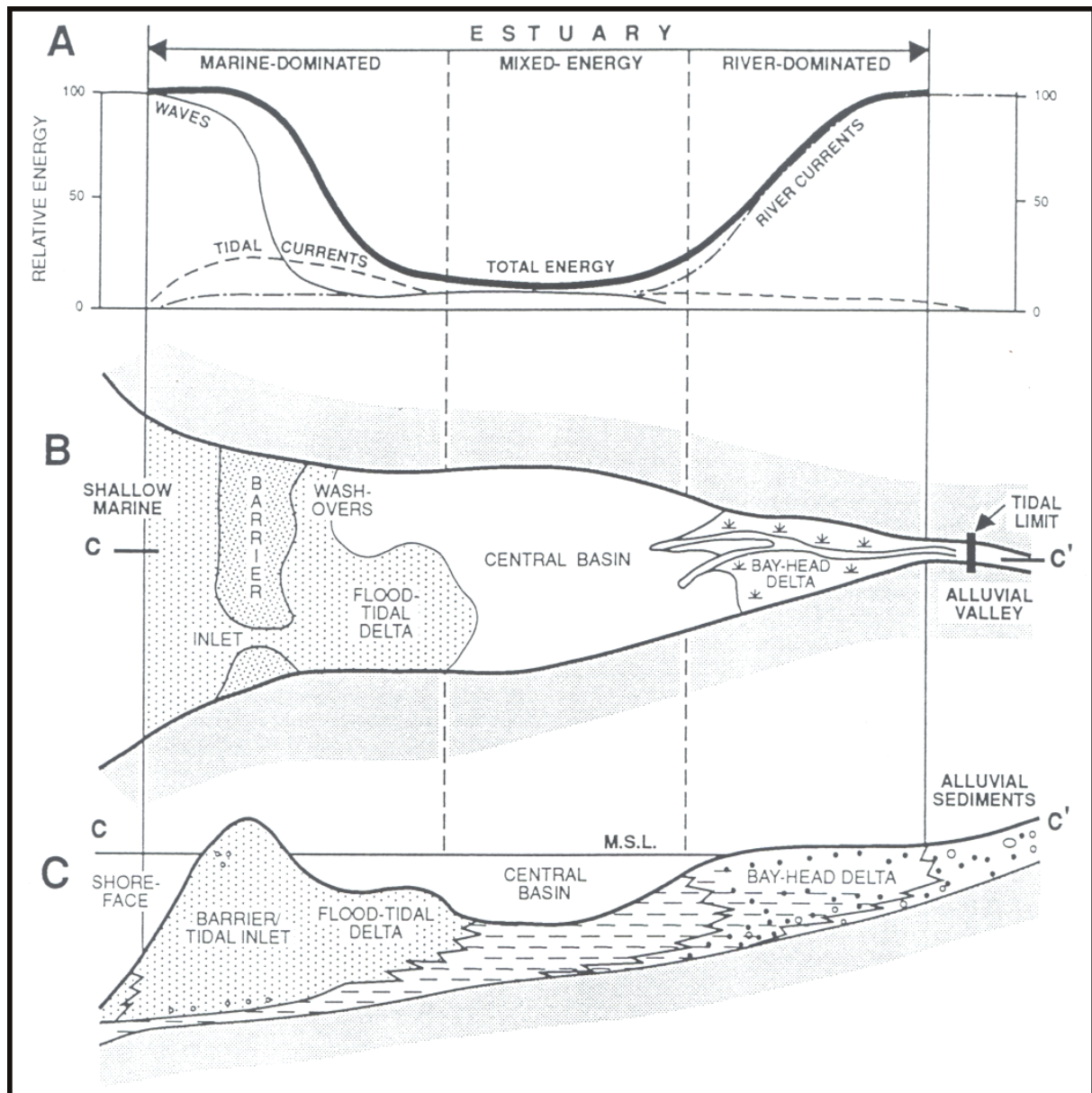


Figure 4. Estuary energy zones as described by Dalrymple *et al.* (1992)

The coastal classification of Roy (1984) subdivides estuaries into wave and tide dominated types. The Maroochy and Mooloolah river estuaries are of the wave-dominated type.

In wave dominated or barrier type estuaries, the mouth of the system experiences relatively high wave energy. The high wave energy, in combination with tidal currents causes sediment to move along shore and onshore into the mouth of the estuary where a barrier such as a spit or submerged sand bar forms. These barriers then prevent much of the wave energy from entering the estuary (Dalrymple *et al.* 1992). In general, marine sands are deposited as **tidal deltas** behind the **barrier** by incoming tides. Whilst in the upper reaches (dominated by river energy), fluvial sediments are deposited as **bay head or fluvial deltas**. The area of neutral energy (**central basin**) between the two is generally filled with finer sediment such as clays and silts (shown diagrammatically in Figure 4).

With time and a sufficient sediment supply, estuaries eventually fill with sediment and mature (Roy 1984). The central basins (or lagoons) are filled and river processes begin to build alluvium out over the top of the marine sediments during flood events.

5.3 Reference to the Sunshine Coast

High wave energy environments, dominant south easterly winds and swells along with plentiful sand supplies have meant that the southeast Queensland coast has been suited to the development of wave dominated barrier estuaries both during the Pleistocene and the Holocene.

Due to the fact that Pleistocene high sea levels were several metres higher than those of the Holocene, it is not uncommon to find remnants of Pleistocene deposits on the Sunshine Coast. Areas underlain by layers of indurated sand (termed coffee rock) are often good indicators of these deposits (Plate 6). Optical luminescence dating undertaken on a sample of coffee rock from area 6 confirms this. They cover large areas of the coastal strip from Lake Weyba to Pacific Paradise in Maroochy Shire and from Mooloolaba to Currimundi creek in Caloundra City.



Plate 6. Typical layer of Pleistocene age indurated sand (coffee rock)

Examples of the three energy zones described by Dalrymple *et al.* (1992) within wave dominated estuaries are quite evident in the Maroochy River system more so than the Mooloolah. The examples below relate to the Maroochy system (refer Figures 5 and 6).

Tidal deltas

Over the last 6500 years, it seems that the mouth of the Maroochy River has been restricted to an area between its current position and the southern end of the Maroochy airport. The pre-existing Pleistocene beach ridge deposits north of the airport are likely to have played a barrier role. As the estuary entrance of the Maroochy has moved, tidal delta sands have been deposited in an area bounded by the current river channel to the south and west and Mudjimba Beach Road to the north.

Central basin

As mentioned earlier, central basins usually develop in the deepest part of the estuary in between the higher energy regions of the fluvial and flood tide deltas (Dalrymple *et al.* 1992). In this very low energy environment, only very fine fluvial sediments of silt and clay are deposited. After the cessation of Holocene sea level rise, a large protected body of water remained behind the barriers in the area west of Mt Coolum. This essentially became a large coastal lagoon. Deposition processes then slowly began to fill the estuary (including the lagoon) with sediment. Hence central basin clays now dominate the area north and south of the river bounded approximately by the Coolum-Yandina Road, the Sunshine Motorway and Bli Bli. The clays are of a gel-like consistency and can be particularly inaccessible to vehicles during wet periods. In an evolutionary sense, the Maroochy River estuary is very mature (Roy pers.comm.) because the basin has been totally filled with mud to sea level.

Bay head or fluvial deltas

Bay head deltas develop where rivers enter estuarine water bodies and deposit their sediment load (Roy *et al.* unpublished). Sediments of terrestrial origin are deposited especially during flood times and fill the estuary from the upper reaches. These materials eventually fan out and move over the central basin clays. In the Maroochy system the fluvial delta is hard to define due to the maturity of the system, however it most likely occurs in the vicinity of the Yandina Creek to Dunethin Rock and Bli Bli area. The fluvial delta sediments range from coarse sands in the levees adjacent to the river to clays with increasing distance from the river.

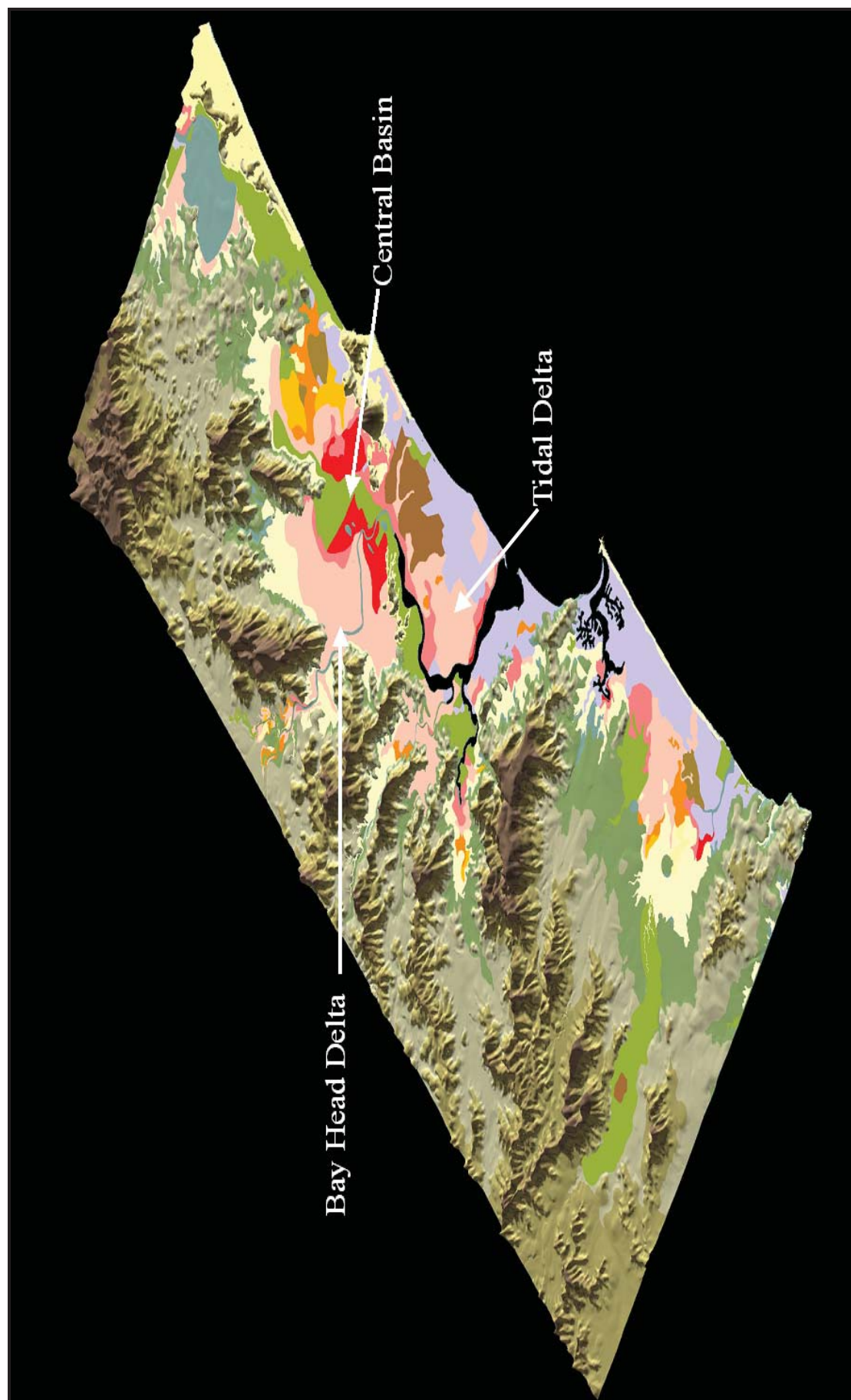


Figure 5. General estuary energy zones of the Maroochy River system

6. ACID SULFATE SOIL ASSESSMENT

6.1 Pre-fieldwork planning and assessment

All available geological, geomorphological and topographical information for the study area was collated and assessed. With this background knowledge, stereoscopic aerial photograph interpretation was carried out using colour and black and white photos at scales of 1:40 000, 1:25 000 and 1:18 000. This enabled the identification of landform and vegetation patterns that are likely to be associated with surface or buried sulfidic sediments thereby determining appropriate sites for field assessment.

Colour topographic image maps of 1:25 000 scale were used to identify the 5 m AHD contour line that represents the postulated landward limit of ASS occurrence to be field validated. The selected field assessment sites were marked on these maps at an approximate density of 16 sites per km² in accordance with 1:25 000 scale free soil survey mapping (Reid 1988).

6.2 Field survey methodology

Soil cores were generally taken to a maximum depth of 5 m (where possible) at each site selected in the pre-field phase. Early in the project the maximum sample depth was commonly 3 m but this was extended as new sampling equipment was designed. Site conditions or observations made during fieldwork sometimes led to the selection of alternate or additional sites. Several deeper boreholes were drilled to approximately 10 m in an attempt to find if any sulfidic sediment existed underneath layers of coffee rock.

Sampling equipment

ASS vary widely in texture and wetness and occur in situations where access is difficult. A variety of sampling equipment was therefore needed to obtain suitable soil cores (see Plates 1 to 7 in Appendix 1). Manual equipment used for sampling ASS includes spades, Jarret and sand augers, piston samplers and gouge augers.

Mechanical sampling equipment used included hydraulic push tubes, spiral (cork screw) augers, hollow flight screw augers, vacuum vibro corers, and the Geoprobe¹ (which uses direct push and percussion of a solid barrel with a removable sample liner). Typically, drier often non-sulfidic soils overlay wet sulfidic sands and clays, requiring a combination of manual and mechanical equipment to extract an uncontaminated core.

6.3 Field sampling procedures

The field sampling procedures, as set out in the guidelines of Ahern *et al.* (1998) and Ahern *et al.* (2000a) were closely followed to ensure reliability and uniformity of field and laboratory testing.

Over 650 soil profiles were described using the nomenclature of McDonald *et al.* (1990). Soil profile properties described include horizon depth, colour (Munsell 2000), mottles (including jarosite), texture, coarse fragments (eg. shell) and pH. Soil field pH tests were recorded at 0.25 m intervals, firstly in a 1:5 soil water paste (pH_F), and secondly after the addition of 30% hydrogen peroxide (pH_{FOX}). A significant depression in pH after reaction with the peroxide is a good field indicator of the presence of PASS.

¹ Geoprobe is a registered trademark of Kejr Inc., Salina, Kansas.

It must be noted the field pH tests as an indicator of ASS should be used with caution and should always be supported with the appropriate laboratory analyses as per the Queensland Department of Natural Resources and Mines' (NR&M) *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland* (Ahern *et al.* 1998) (obtainable from NR&M). Hey *et al.* (2000) provides a detailed assessment of the procedure and of the field pH test considerations needed when undertaking field tests to determine ASS risk.

A critical component of the soil profile description is the recognition of soil horizons. A soil horizon² is a layer whose morphological properties make it distinct from the horizon above and below it. The implication is that each layer will likely be homogenous in all its properties.

All profiles were sampled for laboratory analysis 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. Samples were placed in sealed plastic bags and refrigerated immediately using portable car fridge/freezers. Upon returning to the laboratory, samples were dried, ground and analysed according to the standards set out in Ahern *et al.* (1998).

6.4 Laboratory analysis

The main assessment for pyrite content carried out on all samples was **Total Oxidisable Sulfur ($S_{TOS}\%$)**, (Ahern *et al.* 2000b). This method assesses the amount of total sulfur (S_T) in all forms including pyrite (by X-Ray Fluorescence spectroscopy), and then subtracts the sulfur that is extracted by 4M hydrochloric acid. The latter (S_{HCl}) estimates the sulfur in non-pyritic forms such as that adsorbed on clay particles, in jarosite, and in water-soluble form. The difference gives an estimate of pyritic sulfur and hence is the potential of the soil to release acid if aerated under wetting and drying conditions, ie. $S_{TOS} = S_T - S_{HCl}$.

The **POCASm method** (Ahern *et al.* 2000c) was used as a confirmatory assessment to validate the S_{TOS} results on a selection of samples. These samples were selected because they have attributes that in effect mean that the S_{TOS} method alone may not give a complete assessment of the environmental risk posed by the soil. Unlike the S_{TOS} method, the POCASm method measures both sulfur content and acidity. It also measures cation content (eg. Ca), allowing an estimate of self-neutralising capacity. Analytes from the POCASm method include total actual acidity (TAA), total potential acidity (TPA), total sulfidic acidity ($TSA = TPA - TAA$), peroxide sulfur (Sp , potassium chloride extractable sulfur ($Skcl$) and peroxide oxidisable sulfur ($S_{pos} = Sp - Skcl$). By measuring actual acidity, the POCASm method allows the identification of soils that pose immediate environmental threat.

A limited number of samples (mainly surface) were also analysed by the **Chromium Reducible Sulfur (S_{CR}) method**, recently modified by Sullivan *et al.* (2000). This approach gives a better approximation of pyrite content in highly organic sediments. This method measures reduced inorganic S compounds including pyrite (and other iron disulfides), acid volatile sulfides (AVS) and elemental S. The method can be made specific to the iron disulfide fraction with appropriate pre-treatments to remove AVS and elemental S fractions. It is unaffected by the presence of organic matter and has good precision and accuracy, especially at low levels. S_{CR} is preferred over all methods for low analysis sands and for highly organic or peaty soils because of its specificity to reduced inorganic S.

Where more than one analytical method has been used to determine % S, the S_{CR} result is taken first followed by POCASm and then $S_{TOS}\%$.

² In traditional soil surveys, the term applies primarily to the material that has undergone some form of pedological development, and hence only the upper one to two metres are considered. In ASS mapping, a greater depth of material is described and so horizons with little or no pedological development are encountered. In this context, an important distinction is made between horizons and sedimentary facies. A facies can be considered to be one, or a group of horizons that have a distinct mode of deposition or source of sediment.

6.5 Database recording

All field and laboratory data has been entered into the NR&M Soil and Land Information Database (SALI), which was designed specifically for land resource surveys within NR&M. Terminology and codes used in the database are fully compliant with the *Australian Soil and Land Survey Field Handbook* (McDonald *et al.* 1990). Volume 2 of this report provides decoded profile descriptions of all boreholes described in the survey.

An important function of the database is to collate both soil profile morphology data and laboratory analysis results by horizons. All data from each soil profile can therefore be displayed in tabular format, and data from each horizon can be seen as a distinct 'layer' of information (Volume 3).

6.6 Interpretation of field and laboratory data

The determination of which samples (and hence which soil horizons/layers) constitute an actual and/or a potential acid sulfate soil is based on an assessment of field morphological properties, field pH tests and laboratory results.

The % S of the sample is used to calculate **potential acidity**. Soil colour, mottles and coarse fragments such as shell in the same horizon are noted to cross check with the % S result. % S values which exceed the texture based ASS action criteria (Ahern *et al.* 1998) of 0.03% S for sands; 0.06% S for loams to light clays, or 0.1% S for medium to heavy clays were used as the determinants of potential ASS³.

The above rules are built into the database and hence the S_{TOS}% result for each sample is automatically ascribed a code (according to texture) if it exceeds the action criteria. The upper depth of the first horizon in which the action criteria is exceeded is assigned a 'depth to sulfide' code, such that:

- S0 indicates that the action criteria is exceeded between 0 and 0.5 m.
- S1 indicates that the action criteria is exceeded in the 0.5–1.0 m interval.
- S2 indicates that the action criteria is exceeded in the 1 to 2 m interval.
- S3 indicates that the action criteria is exceeded in the 2 to 3 m interval.
- S4 indicates that the action criteria is exceeded in the 3 to 4 m interval.
- S5 indicates that the action criteria is exceeded in the 4 to 5 m interval.

A **field pH value of 4.0 or less** was used as the determinant of AASS. If a field pH of less than or equal to 4.0 is registered, then the horizon is assigned a depth code similar to the depth to sulfide code however instead of having an 'S' prefix it will have an 'A' prefix. For example an horizon with a pH of less than or equal to 4.0 that occurs between 0 and 0.5 m depth will be assigned '**A0**'.

It is not uncommon to find actual acid sulfate soil overlying potential acid sulfate soil. In these cases the 'A' code and the 'S' code are combined. For example '**A0S2**' denotes a pH less than or equal to 4.0 occurs between 0 and 0.5 m and PASS occurs at 1 to 2 m.

Due to the wealth of pH data obtained during the project and the importance of pH to agriculture it was also decided to indicate areas where pH values of between 4 and 5 were recorded. In these cases the same depth codes were used preceded with a lower case '**a**'. For example a profile registering a field pH of between 4.0 and 5.0 at a depth of 0.5 to 1 m will be labelled '**a1**' and if this overlays PASS at 2–3 m it will be '**a1S3**'.

³ The texture based ASS action criteria of 0.03, 0.06 and 1% for sands, loams to light clays and medium to heavy clays respectively only apply to disturbances less than 1000 tonnes. For disturbance >1000 tonnes 0.03 % applies regardless of texture

6.7 Mapping

Following the collation of field and laboratory data in the database, clear overlays to fit the 1:25 000 topographic image maps were compiled from the GIS. In this working copy the location of each field site is marked on the map along with its accompanying PASS or AASS ‘depth’ code if applicable eg. S2 (PASS) occurs between 1 and 2 m below the land surface.

For the production of the 1:25 000 scale published map, a boundary is marked on the overlay which delineates land where AASS and/or PASS is predicted to be present. The basis for delineation of map units is:

- areas dominated by AASS and/or PASS profiles; linked with
- interpretation of landform types associated with Holocene estuarine deposition; and
- surface elevation particularly below 5 m.

The main mapping categories depict land with AASS and/or PASS present within certain depth categories. PASS depth categories have been coloured using shades of red, pink, orange and brown with red being used for the shallowest depth. Where AASS exists a yellow dot overlay is also used. Other categories such as the S_{DL} category deal with various types of disturbed land where ASS is likely to be present but ground truthing was not possible or not undertaken—see reference on the map supplied with this report.

It was also necessary to develop a category to cater for recent findings of Pleistocene age sulfidic sediments. These often occur at depths greater than 5 m below some quite impenetrable layers. Whilst for all intents and purposes these are still ASS they were generally considered outside the scope of this mapping project. Where these sediments were encountered they have been denoted with a superscript ‘p’ such as in S^p5 (see map reference).

Chemical analysis results showed varying levels of sulfides in some seasonally wet areas. These areas were associated with *Melaleuca* sp. and *Casuarina glauca* and were often underlain by PASS at depth. Although the chromium reducible sulfur method showed many of these high surface results to be due to organic sulfur as opposed to pyritic sulfur, there were some that remained high after being adjusted for S_{CR}. Due to the broad scale of mapping it was impossible to differentiate these areas. Thus a superscript ‘w’ has been used to flag wet areas associated with *Melaleuca* sp. and *Casuarina glauca* eg. S_{2w}. Surface disturbance in these areas should be avoided until more detailed investigation is carried out.

The 1:25 000 scale map also shows the location of each field site. Further information regarding the interpretation and use of QASSIT acid sulfate soil maps can be found in **Appendix 2**.

7. RESULTS OF MAPPING AND LABORATORY ASSESSMENT

Acid sulfate soil assessment across the eight individual study areas covered 7934 ha of land. Of this 5923 ha of land was identified as being underlain by ASS. This includes 5325 ha of PASS and 598 ha of AASS. Dominant soil types included Sulfidic and Sulfuric Hydrosols as well as Semiaquic and Aquic Podisols. Table 1 presents a summary of the amount and depth of AASS and PASS discovered in each mapping area. Each area is labelled according to the order in the results section (7) eg. Area 1 is Meridan Plains to Parrearra, Area 2 is Mountain Creek etc.

Table 1. Areas in ha of AASS (red) and PASS (black) for each mapping area

Map Unit	Area 1	Area 2	Area 3	Area 4		Area 5		Area 6		Area 7		Area 8	Total
0–0.5m	36	33	18			21		404	19	18			549
0.5–1m	29	27	47	5	67	258		65	188	22			708
1–2m	533	29	12	60		837		271		37	145	110	2034
2–3m	126		24	29		15		285		33			512
3–4m	18			25				356		8			407
4–5m	100							163					263
>5m						598							598
S						96		203		17			316
SDL	161	160	50					165					536
LP	683	119	215	174				450		220		150	2011
Total	1686	368	366	360		1825		2569		500		260	7934

Each mapping area (refer Figure 3 and 1:25 000 ASS maps) has been discussed individually. Small sections of the 1:25 000 ASS map, pie charts and photographs have been used to aid discussion. For simplicity, the pie charts show the depth (in metres) to the first occurrence of an ASS layer. PASS layers, which include disturbed land (**S_{DL}**) and land where ASS occurs but no depth category is given (**S**) are coloured pink whilst AASS layers are coloured red. Areas identified as land with low probability of ASS (**LP**) are also shown and coloured pale yellow (refer to 1:25 000 map legend). Layers of hard indurated dark coloured sands have been referred to by their local name ‘coffee rock’.

This is one of two mapping areas in the Mooloolah River floodplain area. Approximately 1686 ha of land was assessed and 145 boreholes completed. ASS accounted for 1003 ha (Figure 6) with 683 ha of low probability (LP) land also identified. Of the 1003 ha, PASS occupied 967 ha and AASS 36 ha. Average oxidisable sulfur contents in PASS layers varied across the area according to texture, with the sands averaging 0.16% S (maximum 1.6% S) and the clays averaging 1% S (maximum 7% S). The 7% S result was obtained via the S_{CR} method and was the highest recorded in any area.



Landward of the relatively narrow beach ridge plain deposits is a back barrier swamp that supports a large stand of *Melaleuca quinquinervia* (labelled **a0S2w** Figure 6). Soils are generally Sulfidic Hydrosols with profiles consisting of dark organic surface soils to 0.3 m over non-sulfidic sandy clay loam to silty light clay layers to approximately 1.3 m. Below this, PASS layers of sulfidic clayey sands and silty light clays extend to depths of 10 m or more. The majority of PASS across the study area occurred at 1–2 m (533 ha Figure 7). Oxidisable sulfur results (using the TOS method) exceeded the action criteria in the surface 0–0.1 m samples of most boreholes. However subsequent testing

using the S_{CR} method reduced many to below action criteria. This indicates that most of the oxidisable sulfur is in fact organic sulfur which does not oxidise to produce sulfuric acid.

Moving further landward up the Mooloolah River floodplain toward Meridan Plains, the soils are predominantly terrestrial floodplain sediments probably deposited well before the Holocene sea level rise. Most of the area does not have underlying PASS and has been mapped as LP (Figure6). A couple of small areas were however identified beneath layers of alluvium with PASS layers at 2–3 m and 3–4 m. These occurred adjacent to the Mooloolah River (S3 and S4 units Figure6). Soils in these LP units are generally Redoxic Hydrosols with profiles consisting of dark heavy clays containing coarse red and orange mottles. Several sites undertaken further up the catchment near the Bruce Highway at elevations of 15 m identified PASS layers of Pleistocene age at depths of 14 m.

AASS occupied 36 ha in a strip adjacent to Currimundi Creek (A0S0 Figure8) at the southern end of the mapping area. They consisted of sulfidic clays with jarosite mottles in the top 0.5 m. Surface soil pH values were in the pH 3–4 range and extended to 1.7 m in one borehole (1121).

It is notable that surface soil pH values of pH 4–5 were encountered across a large proportion (1052 ha Figure 7) of the mapping area as denoted by the ‘a0’ prefix on many of the map units. These low values are not necessarily due to ASS. They are in fact quite common in sandy coastal wetland environments as the sands have minimal buffering capacity and are easily leached.

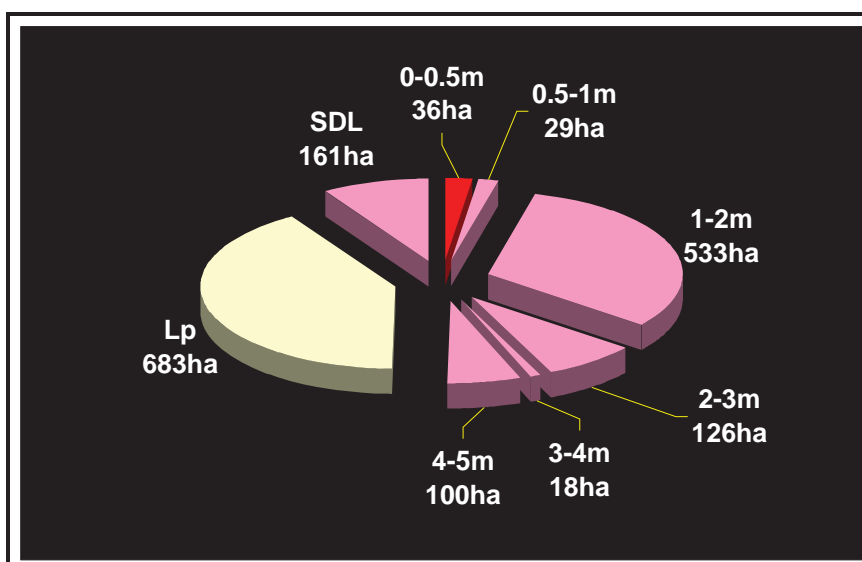


Figure 7. Proportions of AASS (red), PASS (pink) and low probability land (yellow) Area 1

7.2 Mountain Creek (Area 2)

The Mountain Creek mapping area was the second on the Mooloolah River floodplain. The area covered 368 ha (Figure 8) and included 26 boreholes. ASS was discovered beneath 249 ha of land with 119 ha being identified as low probability land for ASS. PASS accounted for 216 ha and AASS 33 ha. Oxidisable sulfur contents varied in PASS layers according to soil texture with sands averaging 0.19% S (maximum 1% S) and clays averaging 0.9% S (maximum 4.7% S).

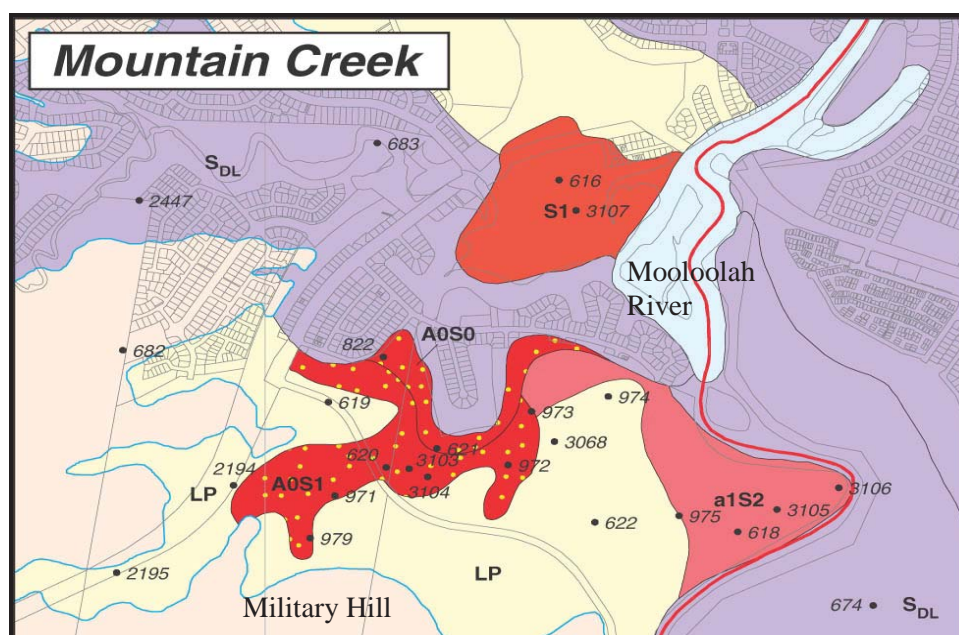


Figure 8. Area 2 – Mountain Creek

The area is basically a small basin that has formed where Mountain Creek joins the Mooloolah River. Military Hill a sandstone outcrop immediately to the south has protected the area to some extent from the higher velocity flows of the Mooloolah River allowing the basin to fill with sulfidic muds and sands. At the time that fieldwork was taking place, most of the area was in the process of being developed. Combined with previous disturbance in the area this created difficulty in the final mapping.

AASS were discovered in small areas (Figure 9) denoted as AOSO and AOS1 units in Figure 8. They consisted predominantly of sulfidic silty light clays that commence at the surface. In the AOSO unit jarosite was evident on the surface after recent clearing and extended to a depth of 1 m. Below this were layers of reduced sulfidic clays (PASS) to depths of approximately 5 m.

A small supratidal flat of approximately 27 ha in size (S1 unit Figure 8) was found to have PASS layers of silty light clay at 0.5–1 m. PASS layers of clayey sands continued below this extending to 2.5 m. Non sulfidic residual heavy clays formed from sandstone were encountered below 2.5 m.

A further small area (29 ha) of PASS was discovered at a depth of 1–2 m beneath a small terrace adjacent to the Mooloolah River at the eastern edge of the area. Sands dominate the soil profiles as the area is exposed to higher velocity water during Mooloolah River flood events. (Figure 9). Maximum thickness of ASS layers was in excess of 5 m, in one borehole, with the average being 2–3 m.

The low probability land to the west consists of Aquic and Semiaquic Podisols which comprise sands to 1 m over coffee rock, the depth of which was not determined due to its hardness. The low probability land to the south has similar Podisols profiles. The coffee rock however was penetrable and was underlain by heavy mottled clays at shallow depth. These clays have formed on the foot slopes of Military Hill.

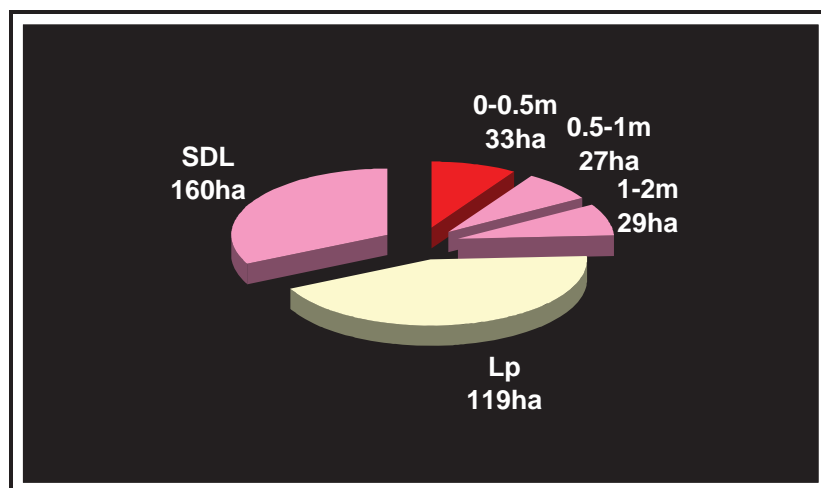


Figure 9. Proportions of AASS (red), PASS (pink) and low probability land (yellow) Area 2

7.3 Maroochydore (Area 3)

In the Maroochydore area (Figure 10), approximately 366 ha of land were mapped and 35 boreholes completed. Figure 11 shows that of the 366 ha mapped PASS accounted for 151 ha and low probability land for 215 ha. No evidence of AASS was found which is more than likely a direct result of the poor drainage and minimal disturbance of the area. Oxidisable sulfur values in clays averaged 0.9% S (maximum of 2.9% S) and 0.13% S in sands (maximum of 0.6% S).

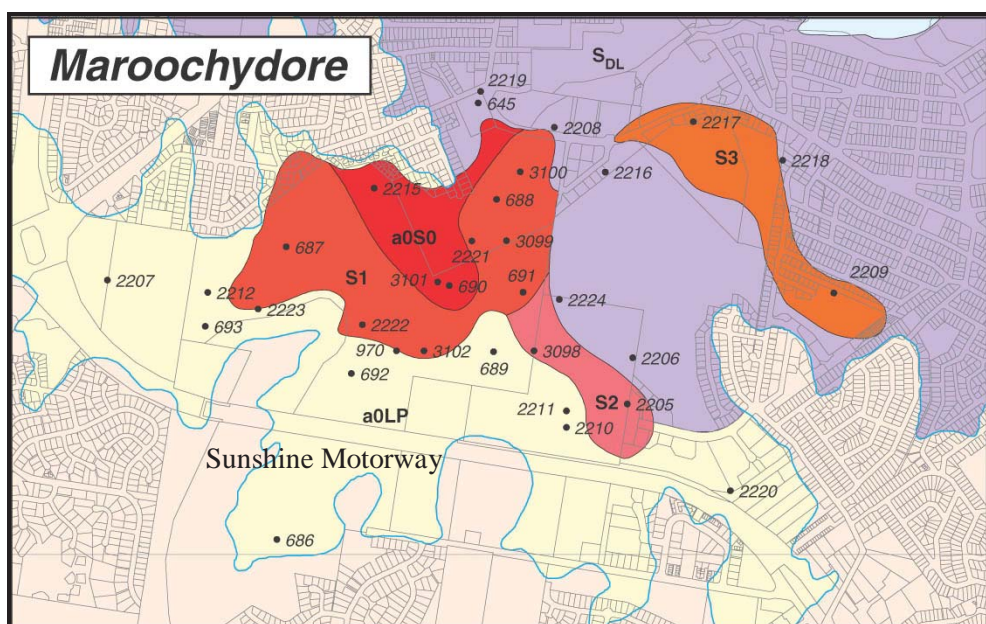


Figure 10. Area 3 – Maroochydore

The area is basically a small drainage basin that feeds into the Maroochy River. The very low landscape position and high water table has meant that this area has been largely undisturbed apart from small scale cropping on the drier fringes.

Due to the low landscape position, most PASS layers (65 ha) were encountered within the top metre (a0S0 and S1 units Figure 10). This was particularly so in the centre of the basin where soils (classified as Sulfidic Hydrosols) consisted of silty light clays from the ground surface. These extended to 7.2 m in borehole 2221. The average however in most boreholes was 2–3 m. Mottled heavy clay formed from the sandstone underlaid all profiles.

Aquic Podosols were encountered in boreholes 2218 and 2209. Coffee rock layers discovered in these boreholes at depths of 1–2 m did not possess the same degree of the strength as that seen in other areas. PASS layers consisting of sulfidic sands and clays occurred at depths of 2–3 m.

Much of the low probability land (Figure 10) consisted of mottled sandy clays grading at depth to decomposing sandstone. Surface soils were consistently acidic with pH values in the pH 4–5 range. This is partly due to the highly weathered nature of these soils and low base status of the sandstone parent material.

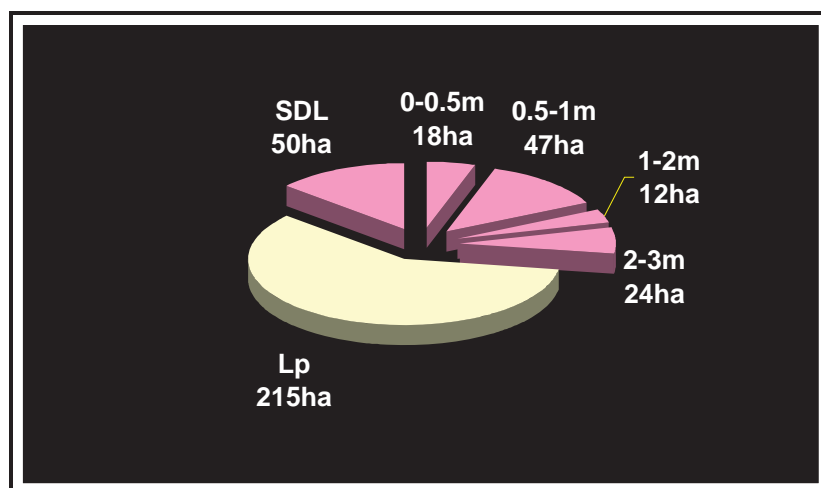


Figure 11. Proportions of PASS (pink) and low probability land (yellow) Area 3

7.4 Kunda Park (Area 4)

The Kunda Park area encompassed 360 ha of the lower reaches of Eudlo Creek, (a small tributary of the Maroochy River) and included 62 boreholes (Figure 12). Land use on the alluvial plain is dominated by sugar cane farming. Sulfidic clays averaged 1.4% S with a maximum recorded value of 3.7% S whilst sulfidic sands averaged 0.3% S with a maximum of 1.6% S. ASS accounted for 186 ha with low probability land occupying 174 ha around the fringes of the alluvial plain. Of the 186 ha of ASS mapped, 181 ha were PASS and 5 ha were AASS (Figure 13).

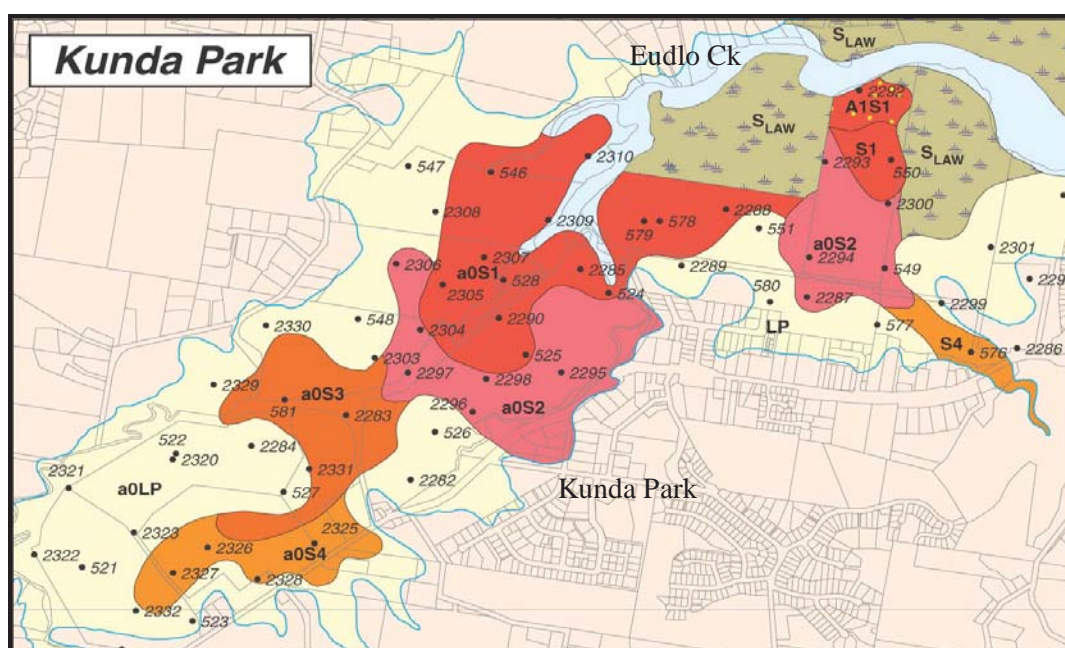


Figure 12. Area 4 – Kunda Park

Elevations varied from 5 m in the upper reaches of Eudlo Creek to <1 m in the lower sections. In the lower sections of the floodplain PASS occur at shallow depths, generally <1 m (67 ha Figure 13) as denoted by the S1 areas on Figure 12. Soils are generally Sulfidic Hydrosols with profiles consisting of dark sandy clay loams to 0.6 m overlying sulfidic silty light clays that can extend to depths of approximately 4 m. Shells were encountered in layers below 1.5 m in borehole 2292. The only area of AASS mapped also occurred in these shallow areas with jarosite being evident in a small band from 0.5 m–0.7 m (borehole 2292). In general the depth to PASS layers increased according to the depth of alluvial overburden in the upper reaches of the floodplain (Figure 12). The alluvial overburden generally consists of red and orange mottled heavy clays interspersed with varying layers of alluvial sand and gravel. Maximum depth at which PASS layers were encountered was 3–4 m.

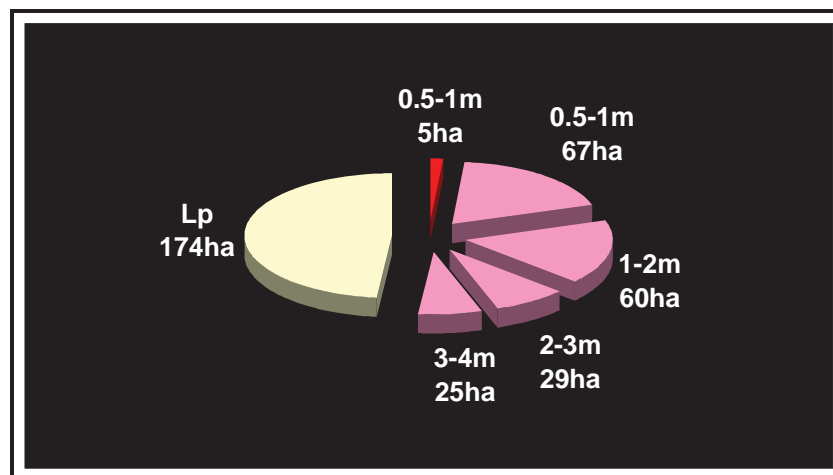


Figure 13. Proportions of AASS (red), PASS (pink) and low probability land (yellow) Area 4

7.5 Pacific Paradise to Mt Coolum (Area 5)

The Pacific Paradise to Mt Coolum mapping area included 168 boreholes and covers approximately 1825 ha (Figure 14). Oxidisable sulfur contents varied throughout the area with clays averaging 0.65% S (maximum 1.8% S) and sands averaging 0.13% S (maximum 1%). Most work concentrated on the sugar cane growing areas to the west of Pacific Paradise, although some boreholes were also undertaken to verify the extent of ASS beneath developed land to the east (SDL unit Figure 14).

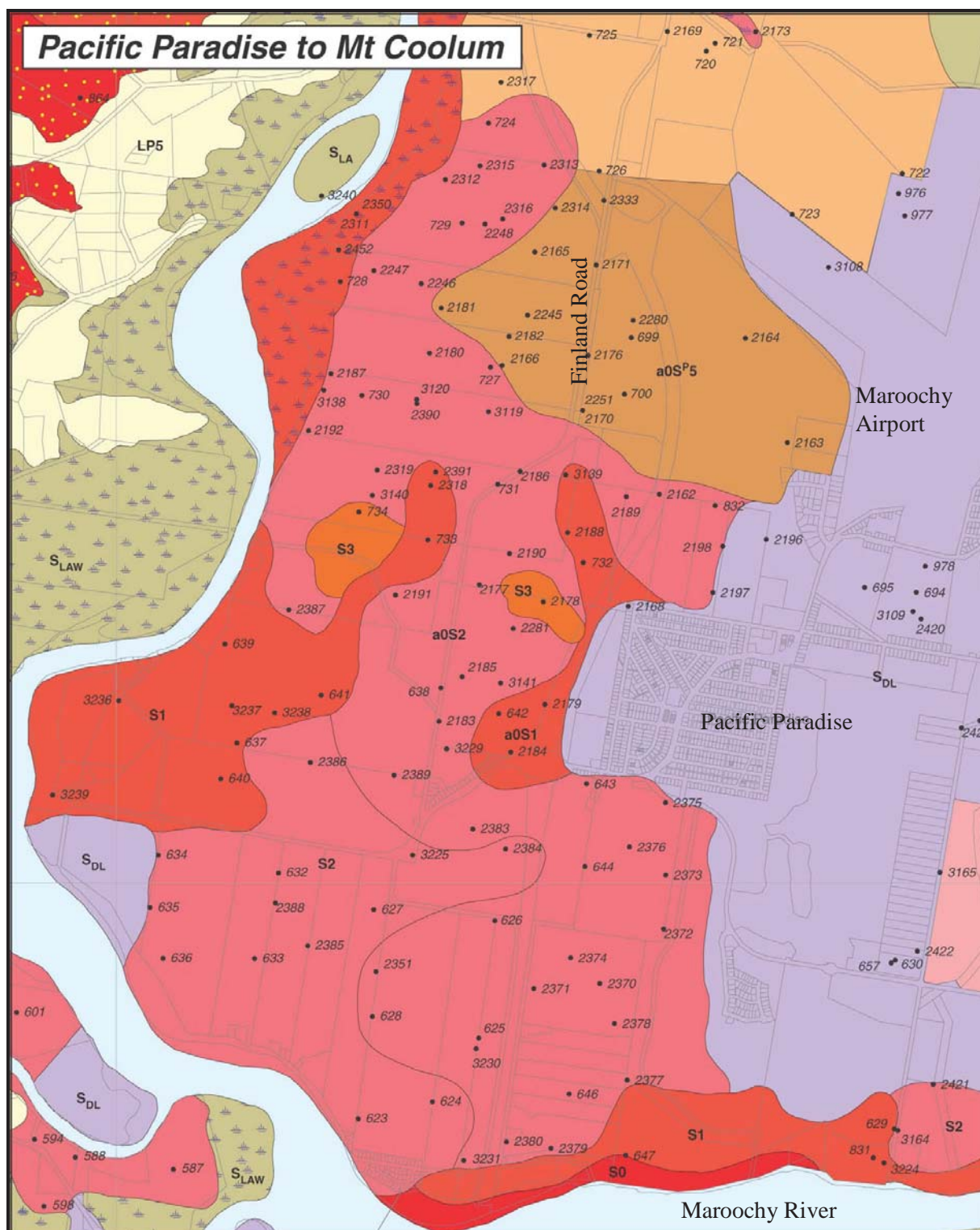


Figure 14. Area 5 – Pacific Paradise to Mt Coolum

PASS consisting of sulfidic sands and clays of Holocene or Pleistocene age underlies the majority of the mapping area. AASS were not encountered in any of the boreholes although iron oxide staining was evident in some drains around Pacific Paradise. The thicknesses of PASS layers extend to 20 m depth in an old in filled channel of the Maroochy River at Pacific Paradise.

Holocene tidal delta sands (classified as Sulfidic Hydrosols), dominate the area between the Maroochy River and Pacific Paradise. Elevations were in the order of 1–2 m. PASS layers were predominantly encountered at 1–2 m below the surface and accounted for a large proportion of the study area (837 ha Figure 15). Profiles have dark sandy loam/clay loams over pale grey poorly sorted sands to 1.5 m. The dark grey sulfidic sand PASS layers commence at 1.5 m. They extend to depths of at least 5 m and often contain shell fragments at depths below 2.5 m.

Shallower occurrences of PASS were encountered at 0–0.5m and 0.5–1m under supratidal flats adjacent to the Maroochy River and accounted for 280 ha (Figure 15). Elevations were generally less than 1 m and profiles comprised sulfidic silty light clays to depths of at least 5 m with shell fragments present below 1.5 m.

North of Pacific Paradise, remnant Pleistocene beach ridge sands dominate. Like other areas where these sediments were found, the Pleistocene sediments are characterised by elevations of 2–3 m AHD. Soils are generally Aquic Podosols with dark sandy surface layers to 0.3 m over bleached white sands to 0.8 m over hard black coffee rock. The coffee rock is generally quite impenetrable however in those boreholes where it was penetrated it was found to be 1–2 metres thick. Below this are brown sands, which extend to depths of 10 m. A large area (598 ha Figure 15) of PASS was identified at depths of 4–5 m in the area immediately west of the Maroochy airport (a0S^P5 Figure 14). PASS was identified at approximately 10 m in the **SDL** unit to the east.

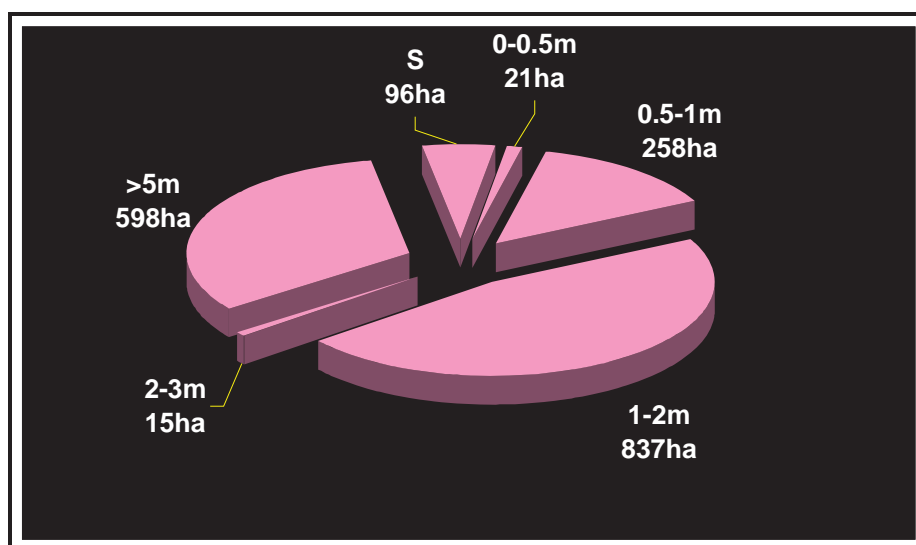


Figure 15. Proportions of PASS (pink) Area 5

The Mount Coolum to Peregrin Beach South area covered approximately 2569 ha and included 165 boreholes (Figure 16). 2119 ha of ASS and 450 ha of low probability land was encountered. AASS accounted for 469 ha and PASS 1650 ha (Figure 17). Oxidisable sulfur contents in clays across the area averaged 1% S (maximum 2.5% S) whilst the sands averaged 0.13% S (maximum 1.5% S).



As with other areas to the south, sediments of both Holocene and Pleistocene ages were encountered. In general terms, the Yandina–Coolum Road is the approximate division between the two. Elevations across the area vary from 2–3 m AHD north of the road falling gradually south of the road to < 0.5 m AHD near the Maroochy River.

Disturbance in the lower areas (<1 m AHD) have led to the formation of large areas (Figure 17) of AASS at shallow depths (A0S0, A0S1 and A1S2 units Figure 16). Profiles are classified as Sulfuric Hydrosols and display dark light clay surface soils to 0.3 m over dark grey oxidised sulfidic silty light clays. Jarosite mottles are prevalent to 0.8 m and pH values are in the 3–4 range. Below this, PASS layers of dark grey silty light clay extend to depths of approximately 5 m. Shells (bivalves) are common below 2 m.

Pleistocene sand deposits dominate to the north of the Yandina–Coolum Road (**a0SP5** and **a0SP4** units Figure 16). This was confirmed by optical luminescence dating of a sample taken from 1–2 m depth in borehole 3148. The dating returned an age of approximately 170 000 years BP. Ground surface elevation at the site was 2.8 m. Soil profiles can be classified as Aquic or Semiaquic Podzols and comprise of acidic (pH 4–5) grey sandy surface to 0.2 m over bleached white sands to 0.7 m over coffee rock to approximately 2 m. Below this are brown sands overlying PASS layers of dark grey sands at 3–5 m. Dark grey silty clays often occur at depths >5 m. These sediments extended to a depth in excess of 11 m at site 2408. Plate 7 shows an example of sulfidic silty clays beneath coffee rock.

It can be seen on Figure 16, that the areas of **a0SP5** and **a0SP4** are separated by a unit of **a0S3** that has PASS layers at 2–3 m. Profiles consist of grey sandy clay loams to approximately 1 m overlying grey brown sands to 2.5 m where PASS layers of grey sands commence. Underlying these sands at depths of approximately 6 m are residual mottled heavy grey clays that have formed on sandstone. It seems that this area has been a watercourse probably during the Holocene. Any coffee rock deposits were removed allowing infilling by Holocene sediments.

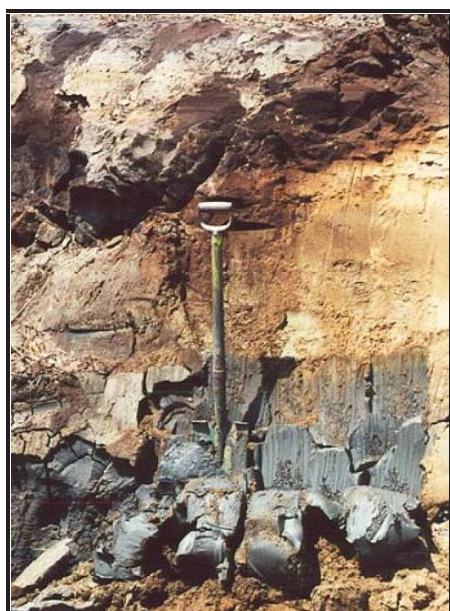


Plate 7. Sulfidic clay under Pleistocene coffee rock.

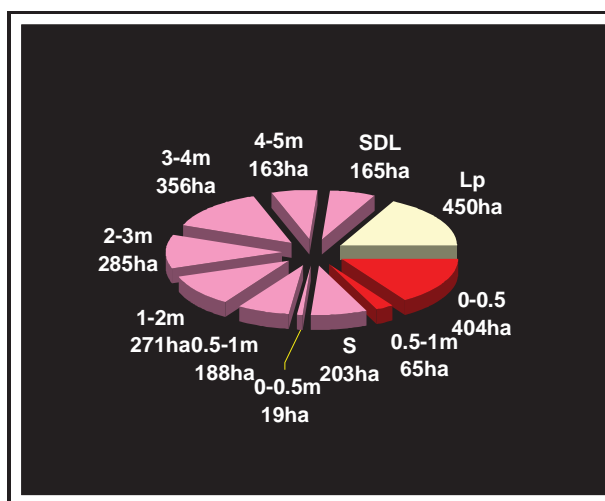


Figure 17. Proportions of AASS (red), PASS (pink) and low probability land (yellow) Area 6.

7.7 Yandina to Dunethin Rock (Area 7)

The Yandina to Dunethin Rock mapping area covered approximately 500 ha of floodplain and included 45 boreholes (Figure 18). Approximately 280 ha of ASS was identified along with 220 ha of low probability land (Figure 19). The ASS included 225 ha of PASS and 55 ha of AASS (Figure 19). Oxidisable sulfur levels in clays averaged 1.1% S (maximum 2.4% S) whilst in sands the average was 0.6% S (maximum 1.1% S).

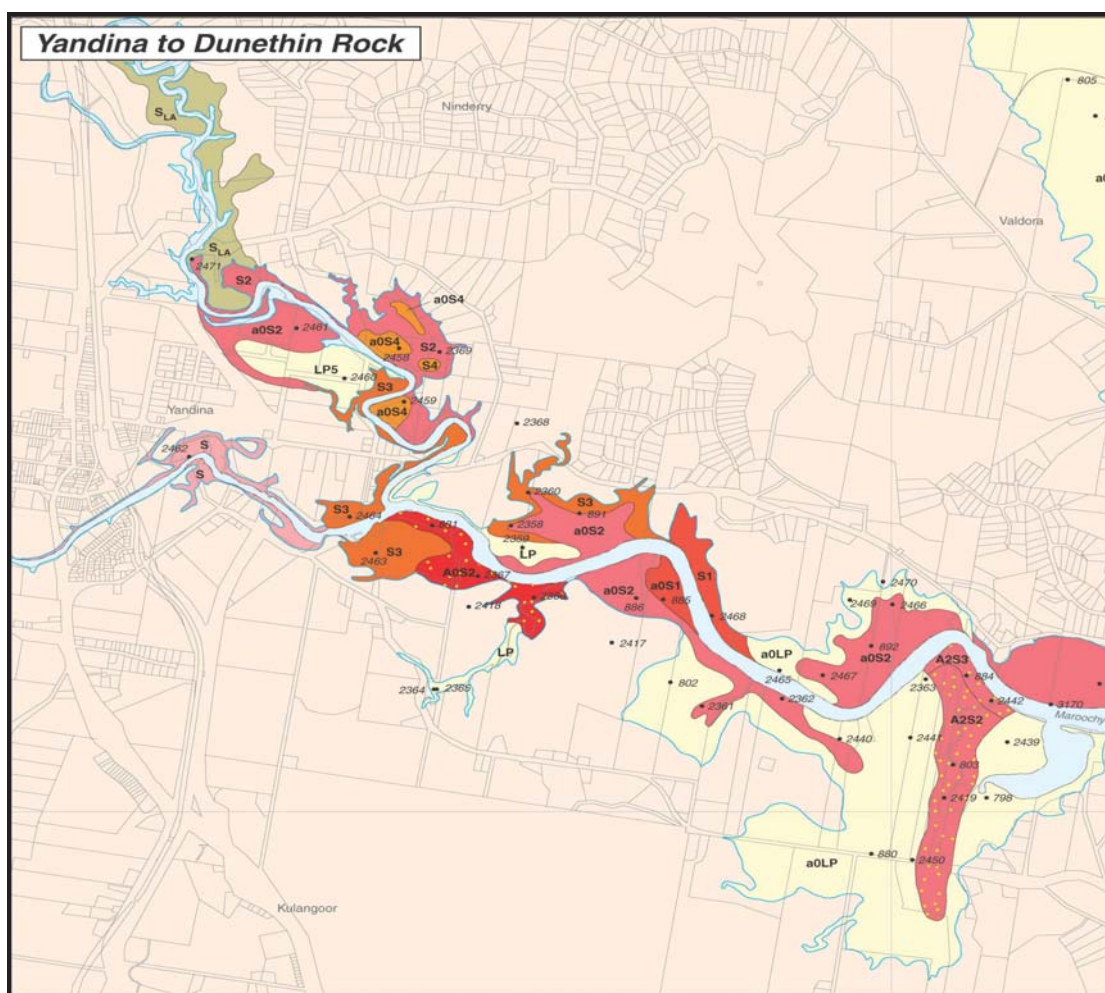


Figure 18. Area 7 – Yandina to Dunethin Rock

Fluctuations in the course of the Maroochy River over time and the higher flow velocities in this confined section of the River have resulted in variability of PASS sediments in both depth and texture. In the upper reaches (west of a point approximately half way between Yandina and Dunethin Rock), PASS sediments have been buried by various depths of clay alluvium. On the lower river terraces, mottled grey heavy clay alluvial layers overlie PASS layers of dark grey silty light clays at depths of approximately 1.3 m. Below this, coarse gravels and cobbles are often encountered in a sulfidic matrix.

On the higher terraces a greater depth of alluvium buries the PASS. Profiles generally consisted of brown sandy clay loams to 1 m over yellowish brown sands (probably stranded levee deposits). PASS layers of grey sands were encountered at depths of 2–4 m according to surface elevation.

In the lower half of the mapping area, PASS were generally encountered at depths of 1–2 m (194 ha, Figure 19). Profiles were generally classified as Sulfidic Hydrosols and consisted of dark alluvial clays overlying dark grey silty light clay PASS sediments to a depth of approximately 5 m.

AASS were found in two small pockets, one near Dunethin Rock where the AASS layer occurred between 1 and 2 m. The other occurred in the surface on the southern side of the Maroochy River where the southern branch joins the main River. Here the AASS layer occurred in the top 0.5 m. No jarosite was present however pH values were in the pH 3–4 range. Both areas contained PASS below the AASS.

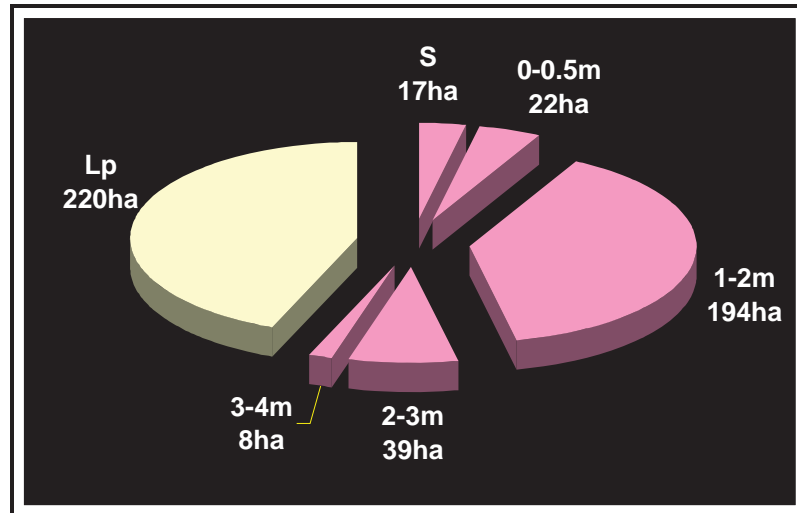


Figure 19. Proportions of PASS (pink) and low probability land (yellow) Area 7

7.8 Lake Weyba (Area 8)

The Lake Weyba mapping area only covered 260 ha as ASS were to the immediate margins of Lake Weyba (Figure 20). This Figure consisted of 110 ha of ASS and 150 ha of low probability land. No AASS was identified. Soil profiles consisted of dark sandy light clays to 0.2 m over grey sandy light clay to 0.5 m over a PASS layer of dark grey sulfidic sandy light clay. At borehole 801 this extended to 1.7 m. In other boreholes PASS was encountered in only a thin band at about 1 m depth and graded quickly into residual mottled grey heavy clays formed from sandstone. In borehole 801 dark grey sulfidic sands were encountered at 0.5 m. Sulfidic clays across the area averaged 0.4% S (maximum 0.6% S) and the sands averaged 0.13% S (maximum 0.4% S).

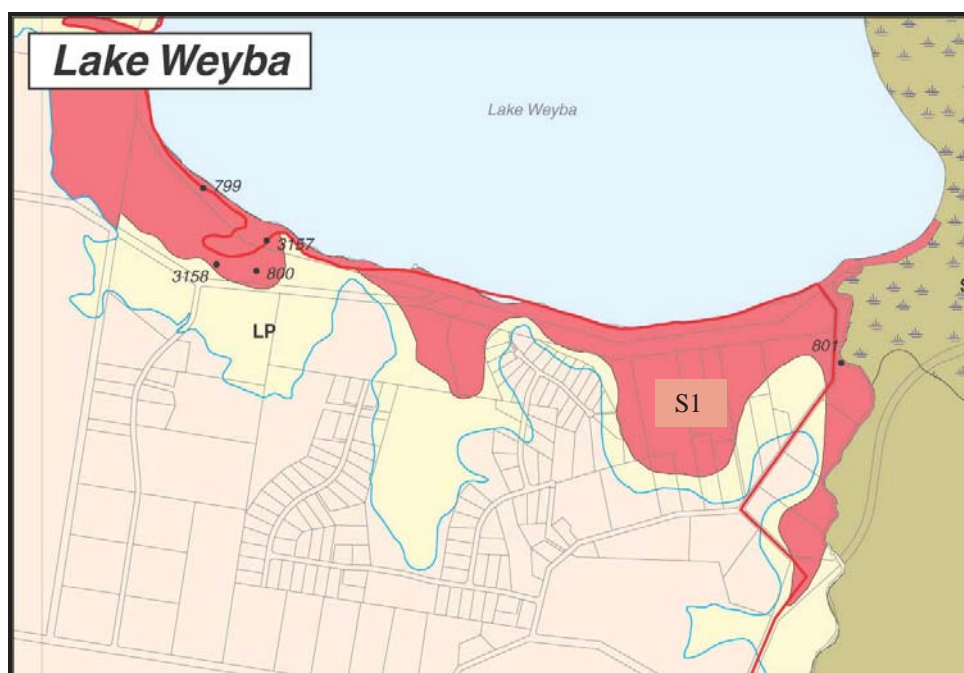


Figure 20. Area 8 – Lake Weyba

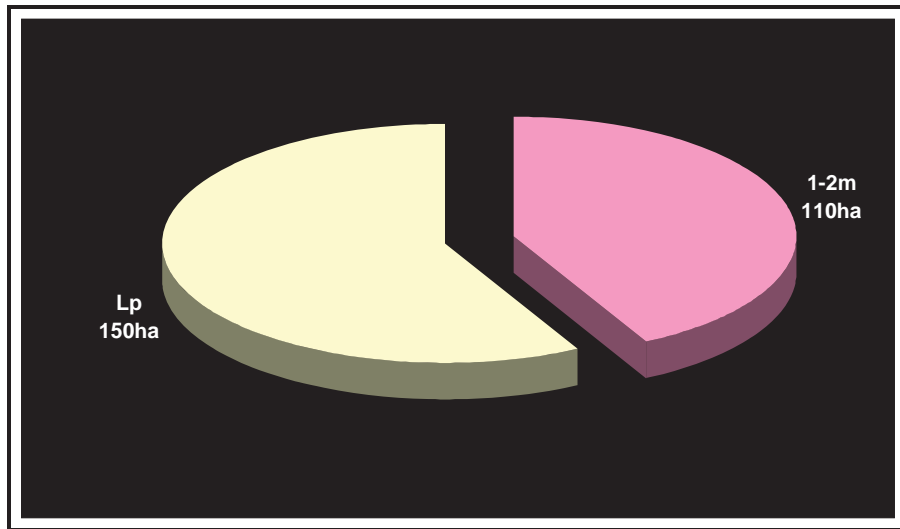


Figure 21. Proportions of PASS (pink) and low probability land (yellow) Area 8

8. MANAGEMENT PRINCIPLES OF ACID SULFATE SOILS

8.1 Background

The sustainable management of coastal areas and waters requires a deliberate approach to problems associated with ASS. This implies that individual landowners develop management plans to properly manage these problem soils on their land—but such efforts will be suboptimal (despite goodwill) if the cumulative nature of man-induced impacts from disturbing ASS are not approached as a total area issue. Often the cumulative impacts of many small discharges of acid can be just as damaging as a large release of acid from a single source or event.

All stakeholders benefit from a cooperative assessment of the situation. Government departments and agencies provide supportive advice and information (of which this report is a clear example)—but there is also a growing set of regulations/legislation (state planning policy) that places responsibility for any environmental harm with the landowner. Changes in land use can trigger changes in ASS. This applies to urban developments as well as the agricultural industry. In very practical terms, a landowner needs to manage his property to minimise his risk. This applies as much to existing land use as it does to new developments.

Agriculture, needs to modify the landscape if it is to be efficient. This is not usually a problem, but when farms are established on ASS then this can inadvertently set in train adverse consequences. It is prudent for those landowners to examine their existing situation; if remedial management is needed then action is better earlier than later.

8.2 Factors to be considered in managing new land disturbances

Where new developments are being established and if these are located in acid sulfate soil areas, then the landowner needs to be wary. Disturbing or dewatering ASS via drainage can initiate the oxidation process that releases large volumes of sulfuric acid and often results in the release of toxic levels of heavy metals. The result is a dysfunctional environment both *in situ* and in downstream areas. Some ASS are best left undisturbed, both on economic and environmental grounds.

The policy applied to an ASS disturbance is that all pollutants (for ASS this usually involves acid, water soluble iron, aluminium and sometimes heavy metals) must be contained and managed within the site boundary or at least treated to acceptable levels prior to discharge to a natural /external water body. As pH affects the solubility of the main ASS pollutants, pH control of all 'site water bodies' is usually the cheapest and primary control expected. When water discharge is licensed or approved in the management plan then discharge must only occur when pH is in the approved range (usually 6.5–8.5).

Although natural waters (eg. tea tree swamps) may have lower pH values than pH 6.5, once ASS have been disturbed at a site, then potential exists for soluble forms of aluminium to be mobilised (which can be most toxic to fish around pH 5.2; Sammut *et al.* 1996). Because aluminium species in solution are pH dependent and the chemistry is complex in natural waters, raising the pH well above pH 5.2 (eg. pH >6.5) ensures a substantial reduction in the total soluble aluminium concentration and a change in the ionic species present.

Use of stream, river or estuarine water as a primary agent to neutralise acidity is currently **not acceptable** as this removes bicarbonate from the water, which may adversely affect shell formation on crustaceans and the health of benthic communities. On all except minor disturbances, site management plans should incorporate complete bunding of the site to control runoff water using non ASS material in the walls of the bund.

Neutralising the acid with various forms of alkaline material (eg. agricultural lime CaCO_3) can ameliorate the acidity of the soil or water. Calcium sulfate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$; gypsum), a product of the reaction, is sparingly soluble and usually forms crystals in the soil, limiting sulfate export to

waterways. (Note there are a number of factors which affect the quantity of lime or other neutralising agents which should be used—see for example Ahern and Watling 2000).

8.3 Management techniques

Not all management techniques are appropriate to the specific situation. Selection of an appropriate management option will depend on the physical and chemical characteristics of the ASS, the hydrological circumstances and the environmental sensitivity of the site. Where a significant disturbance of ASS is being proposed, a soil scientist or engineer experienced in ASS management should be consulted.

As ASS can vary in their physical and chemical characteristics, they do not all respond to mitigation strategies in a consistent way. To avoid costly errors, both environmentally and financially, soil investigations at a high intensity should be undertaken to map the distribution of ASS prior to developing mitigation strategies. Such detailed investigations are necessary not only to understand the risks associated with disturbing these soils, but also to determine the most feasible mitigation options.

The chief areas of concern on existing ASS lands are the bund walls and spoil heaps containing ASS; floodgates; and deep, frequent drains that lower the water table and efficiently export acid and/or contaminants. Most of these existing situations can be improved by:

- selective application and incorporation of modest quantities of lime or other neutralising material to spoil heaps, paddocks, and sides of drains. These will need renewing annually where substantial acid producing potential exists in the soil;
- treating spoil with lime when cleaning out clogged drains;
- resisting the temptation to deepen drains—broad and shallow is environmentally friendly, easier to mow/keep clean and can move as much surface water if designed correctly;
- if deep drains exist, using temporary boards to keep the water table high once the major surface water is removed. This means ASS layers are kept wet and protected from oxidation;
- reducing the number of drains and use laser levelling to remove excess surface water (it is important that laser levelling does not expose an ASS layer);
- not ploughing too deeply or deep ripping if an ASS layer is close to the surface;
- lime slotting between the paddock and drain is currently being trailed in the Pimpama area and may prove useful. (Cook *et al.* 2002).
- Using specially designed weed cleaning buckets for drains to minimise disturbance of drain sediments which can contain monosulfides. These are black oozy sediments that oxidise rapidly on exposure to oxygen produces large quantities of acid (Bush *et al.* 2002).

Avoidance

ASS are benign when left in a waterlogged, undisturbed environment. Avoidance, by not disturbing or developing in areas affected by ASS is often the most environmentally responsible and cheapest option. A detailed assessment of the distribution of ASS in an area is recommended to avoid disturbing ASS.

If an assessment indicates serious ASS on the proposed site, then total avoidance should be the first option ie. the most sensible option may be to find an alternative site. Selection of alternative, non ASS sites is preferred to remediation of impacts caused by disturbance of ASS.

If total avoidance is not feasible, than alteration of proposed activities is the next best option ie. Redesign works to minimise the need for excavation or disturbance of ASS (and hence required remedial action).

Liming

A tried and tested approach to managing ASS is to neutralise them with agricultural lime (aglime). This product has a slightly alkaline pH and reacts with any acid produced, raising the soil pH to safer levels. According to Ahern and Watling (2000), neutralisation products such as aglime are preferred due to the lower risks of contaminating surrounding waterways or groundwater.

Due to the fact that pH affects the solubility of iron and aluminium, measures to control the pH of site soil and water bodies are expected in any management plan. It is noted that the most cost effective, long term approach to managing ASS is usually pH control. McElnea and Ahern (2000) in long term leaching column research have shown that pH control through lime application controlled the leaching of iron and aluminium. If ASS are disturbed, management plans involving the treatment of lime should incorporate a safety factor of at least 1.5 to 2. Some countries insist on a safety factor of 3, Canada being an example.

Table 2 below describes conversion rates for calculating liming rates (adopted from Table 4 of the QASSIT guidelines (Ahern *et al.* 1998). Realistically, the lime is rarely pure, and the lime may not be fully mixed within the soil body. The release of alkalinity from carbonate minerals is generally determined by solution equilibrium, whereas the release of acidity from sulfide oxidation is kinetically controlled. Thus, the availability of carbonate for acid neutralisation is solubility limited, whereas the concentration of acidity may accumulate with time. Therefore, even though a material may have a theoretical excess of acid neutralising capacity, the type of carbonate and leaching regime may promote acid generation and limit neutralisation, resulting in acid drainage.

Using chemical calculations, a soil with 1% S as pyrite would produce 30.59 kg H₂SO₄/tonne of soil—this would require 31.2 kg/tonne of soil of pure lime (CaCO₃). Incorporating a safety factor of 1.5 gives a lime requirement of 46.8 kg per tonne of soil to neutralise the acid (the resultant product, calcium sulfate, may be precipitated or crystallise out of the solution).

Table 2: Conversion rates for calculating liming requirements on acid sulfate soils

Oxid. Sulfur S (%)	moles H ⁺ /kg (S% x 0.6237)	moles H ⁺ /t or moles H ⁺ /m ³ (S% x 623.7)	kg H ₂ SO ₄ /tonne or kg H ₂ SO ₄ /m ³ (S% x 30.59)	kg lime/tonne soil or kg lime/m ³ Safety factor = 1.5	Cost/ha/m depth of soil @ \$70/t for lime \$
0.01	0.0062	6.237	0.306	0.47	228
0.02	0.0125	12.47	0.61	0.94	655
0.03	0.0167	18.71	0.92	1.4	983
0.05	0.0312	31.19	1.53	2.3	1778
0.1	0.0624	62.37	3.06	4.7	3276
0.2	0.1247	124.7	6.12	9.4	6552
0.3	0.1871	187.1	9.18	14.0	9828
1.0	0.6237	623.7	30.6	46.8	32 774
5.0	3.119	3119	153.0	234.0	163 800

Note: Assumes a bulk density of 1.0 g/cm³ or 1 tonne/m³ (range can be 0.7–2.0 and as low as 0.2 for peats). Where bulk density is >1 g/cm³ or 1 tonne/m³ then the safety factor will increase for lime rates/m³ soil (eg. if BD=1.6, then 1 m³ of soil with 1.0 % S_{POS} will require 75 kg lime/m³ instead of 47 kg). In some areas bulk lime delivered may be less than \$70/tonne but it can be considerably more in some areas due to transport costs.

The base of all permanent and temporary treatment pads should be limed with a precautionary amount of fine aglime at a minimum rate of 2.5 t/ha to help neutralise any acidic leachate generated. The ASS requiring treatment should then be spread on the treatment pads in layers that allow drying, such as 200 mm to 300 mm thick. After the soils are suitably dried, fine aglime is spread at 1.5 to 2 times the theoretical acid production potential, and is thoroughly mixed into the soil, before final compaction. These soils may need to be worked several times to ensure sufficient mixing. Supervision of earthworks is the key to success (see Ahern and Watling 2000 for further details).

In the case of sugar cane lands, caution needs to be taken in relation to over liming of cane land in one application as this can cause some fertility problems as sugarcane tends to prefer slightly acid soils.

As mentioned above, the preferred ameliorant is aglime. Other forms of alkaline materials suitable for soil amelioration with a low solubility, include dolomite, magnesite and burnt magnesite. A problem with the magnesium compounds is that magnesium sulfate is produced during neutralising reactions. Magnesium sulfate is quite soluble and if large quantities are involved it may result in environmental concerns in waterways. Calcium sulfate does not have this problem because of its lower solubility.

These differing alkaline materials have different neutralising values, which affect the tonnage required. Other factors to consider include the fineness of the product (coarse material is less effective), and whether the current Ca:Mg balance in the soil will be significantly altered (Mg dominant soils tend to disperse, causing surface crusting and infiltration problems).

9. CONCLUSIONS

Eight areas comprising 7934 ha of land was mapped. Approximately 5923 ha of acid sulfate soils were identified, consisting of 5325 ha of potential acid sulfate soils (PASS) and 598 ha of actual acid sulfate soils (AASS). Although the depth to AASS and PASS layers varied, 1257 ha were encountered within one metre of the surface and a further 2034 ha at 1 to 2 m depth.

This study has shown that AASS, which are currently producing sulfuric acid exist in four of the eight mapping areas. These pose an immediate environmental threat via acidification of soils and adjacent waterways particularly in the Mount Coolum to Peregrine Beach South area. Liming treatment is suggested for these localities.

The study has also demonstrated that much of the remaining lands below 5 m AHD have underlying potential acid sulfate soils. Care needs to be exercised especially in areas where these layers are encountered within 1 m of the ground surface as any significant lowering of water tables could trigger the oxidation process and result in the formation of more AASS.

An interesting and important scientific finding of this survey was the discovery of sulfidic sediments below layers of Pleistocene aged coffee rock. The depths at which these sulfidic sediments occur (often >5 m below the surface) mean that risk of disturbance is low except where deep excavations are required. It is therefore unwise to base decisions on ASS occurrence on the age of overlying materials.

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11 DEFINITIONS AND CONCEPTS USED IN THIS DOCUMENT

Acid Sulfate Soil (ASS): a soil or soil horizon which contains sulfides or an acid soil horizon **affected** by oxidation of sulfides. This is the definition used in Queensland's Environmental Protection Policy. Acid sulfate soils are the common name given to naturally occurring sediments and soils containing iron sulfides (principally iron disulfide or their precursors). The exposure of the sulfide in these soils to oxygen by drainage or excavation leads to the generation of sulfuric acid.

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

Actual Acid Sulfate Soil (AASS): soils containing highly acidic soil horizons or layers resulting from the aeration of soil materials that are rich in iron sulfides, primarily pyrite. This oxidation produces hydrogen ions in excess of the sediments capacity to neutralise the acidity resulting in soils of pH of 4 or less when measured in dry season conditions. These soils can usually be identified by the presence of yellow mottles and coatings of jarosite.

Potential Acid Sulfate Soils (PASS): soils which contain iron sulfides of sulfidic material which have not been exposed to air or oxidised. The field pH of these soils in their undisturbed state can be pH 4 or more and may be neutral or slightly alkaline. However they pose a considerable environmental risk when disturbed, as they will become very acidic when exposed to air and oxidised.

Action Criteria: Refers to % S values of soil samples which exceed QASSIT Guidelines (Ahern and Powell 1998) and are therefore classed as ASS. These soils may require remedial treatment such as application of Aglime if disturbed or drained. The action criteria used as the determinant of potential ASS are:

0.03% S for sands.

0.06% S for loams to light clays.

0.1% S for medium to heavy clays.

Note that where excavations exceed 1000 tonnes, the action criteria of 0.03% Oxidisable Sulfur applies, regardless of soil texture.

Aglime: A neutralising agent used to treat acidic soils; by composition, it is commonly 95-98% pure calcium carbonate CaCO_3 ; it is insoluble in pure water, with a pH of approximately 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 bench marks and tide gauges, and set a mean sea level as a zero elevation.

Anaerobic: conditions whereby oxygen is excluded, usually by waterlogging.

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

EIS (Environmental Impact Statement): or EIA (Environmental Impact Assessment): the EIS is the written report generated from the EIA which is the study commissioned by the proponent of a project to identify and quantify any impacts (both on and off site) that the proposed project may have on the existing environment.

GIS (Geographical Information System): Computer based mapping system which uses software that allows the manipulation and visualisation of spatial data.

Groundwater: subsurface water in the zone of saturation, including water below the water table and water occupying cavities, pores and openings in underlying soil and rock.

Groundwater flows: the natural or artificially produced movement of groundwater in the zone of saturation.

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

Jarosite: an acidic pale yellow iron sulfate mineral: $\text{KFe}_3(\text{OH})_6(\text{SO}_4)_2$, is the most conclusive indicator of AASS. 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.

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

Pleistocene: a period of time extending from 1.8million years ago to about 10,000 years ago, an epoch of the Quaternary period.

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

Water table: portion of the ground saturated with water; often used specifically to refer to the upper limit of the saturated ground.

Chemical acronyms used for analytical procedures

POCAS: Peroxide Oxidation-Combined Acidity and Sulfate Method.

POCASm: Peroxide Oxidation-Combined Acidity and Sulfate Method (modified).

SPOCAS: Suspension Peroxide Oxidation-Combined Acidity and Sulfate Method.

pHF: Field pH. (pH of soils and deionised water).

pHFOX: Field pH. (pH of soils and hydrogen peroxide).

pHKCl: pH of a 1:5 solution of soil and 1M KCl.

SCR: Chromium Reducible Sulfur.

TAA: Total Actual; Acidity.

TPA: Total Potential Acidity.

TOS: Total Oxidisable Sulfur.

TSA: Total Sulfidic Acidity.

APPENDIX 1 – SAMPLING EQUIPMENT

Hand Operated Sampling Equipment

Jarret Auger

The Jarret auger has a 100 mm (4 inch) diameter and will penetrate the soil surface, approximately 200 mm before the auger head is filled. Its use is restricted to a range of soil textures in the dry and moist state but will not retrieve dry sands. Where the soil type is suitable, it may be possible to auger 5–10 metres using the Jarret auger and a series of 1-metre extension rods (Plate 1).

Augers for sands and soft sediments

Sand augers are useful for sampling in very sandy friable soils however in our experience, the ‘Dormer No. 4 Auger’ is more versatile as it successfully recovers most moist sands and soft muds. To obtain an adequate volume of sample, a 75 mm diameter, single slot tube is commonly used. These augers penetrate to a depth of about 30 cm before filling the auger. The auger is then reinserted to obtain further samples from the same sample hole (Plate 2).

Tapered gouge auger

The tapered gouge auger is designed to take undisturbed samples from very soft material with a significant clay content. Typically, the auger is an open-faced, stainless steel tube that tapers from a diameter of 50 mm at the top, to 20 mm at the bottom. The auger is pushed into the soil, turned to cut the core and then withdrawn. It can be used at the surface or down an augered hole however re-sampling is limited due to hole collapse. The open face tube allows easy removal of soil from the auger, and the tapered end improves sample retention for wet soils. The tapered gouge auger produces a highly representative sample of the profile. Moreover, once the gouge auger has been pushed down once, it cannot be pushed down into the same hole again, as the tapering effect will lead to cross-contamination in the next soil sample (Plate 3).

Push tube with tapered tip

The push tube consists of a 50 mm diameter PVC or stainless steel tubing that is pushed into the soil surface to obtain a sample. This technique is good for a range of soil textures but is generally not used for saturated sands, as sample loss can be a problem. However, adding a sealable cap before extraction may improve retention by reducing suction. This is a particular problem in dry clays and saturated sands.

Piston sampler

The Piston sampler is similar in principle to a large yabbie pump. It is used to obtain undisturbed samples in saturated sands or soft muds below the watertable. The piston sampler is a push tube with a manual suction and piston mechanism to improve retention. As the stainless steel tube is pushed down, the piston is pulled up then held while the tube is withdrawn. The piston sampler is limited by the length of the piston due to wall collapse on withdrawal. Using a suitable sized poly pipe for casing will reduce the incidence of wall collapse and can increase the depth of excavation on saturated sands. However, care is needed to avoid contamination (Plate 4).

Mechanical Sampling Equipment

There are many limitations associated with the sampling of coastal soils. Sand below the watertable is difficult to sample, while sites containing gravel layers are the most challenging and best sampled using an excavator. Moreover, the greater the sampling depth below the watertable, the more difficult sampling is likely to be. To overcome this difficulty, specialised mechanical equipment has been developed for ASS sampling. A brief outline of the benefits and limitations of conventional and specialised drilling equipment appears below.

Hydraulic push tube

A hydraulic push tube is normally mounted on the rear of a 4WD vehicle or trailer. The steel push tube usually has a diameter of 50 mm and has a hardened tapered tip that is hydraulically pushed into the soil. Although the equipment performs well in loams, clay loams and some clays, but sticky clays are difficult to remove from the tube, and wet sands are likely to fall out. (Plate 5).

Spiral (cork screw) auger

The spiral auger is of similar design to a posthole auger. The spiral auger has serious limitations as it is difficult to obtain a sufficient amount of clean, uncontaminated sample. Cleaning is also laborious and the spiral auger is therefore generally unsatisfactory for ASS sampling.

Hollow flight screw auger incorporating an internal split tube sampler

The hollow flight auger is useful for undisturbed sampling. It uses a hollow screw auger with an internal sampler that can be withdrawn regularly. The internal sampler is fitted with a 'split tube' that obtains suitable cores, though compression of muds and sample loss of sands below the watertable does occur. A 'catcher' often improves retention on saturated sands.

Backhoe/excavator

Backhoes and excavators provide an excellent view of the soil profile and are very good at recovering gravels. Sampling can be easily obtained at measured intervals down the excavated face. A backhoe or excavator is advantageous for sites containing abundant shell as it allows a larger sample to be collected without shattering the shell. This overcomes a common problem with most sampling techniques as visible shell should be removed prior to laboratory analysis. Once below the watertable however, wall collapse is a substantial problem compromising effective sampling and personal safety. Work place safety issues must be addressed when excavating pits. The possibility of hydrogen sulfide gas poisoning should be a consideration when entering a pit.

Wash bore drilling combined with a driven Standard Penetration Test (SPT) split tube sampler

This form of equipment is used mainly for engineering purposes rather than for detailed soil investigations as it is difficult to log and sample the profile adequately. It is often used for deep drilling on saturated sands where a bentonite and polymer solution is continually pumped under pressure to hold the borehole walls intact. Sample contamination can be a substantial problem due to mobilisation of fine sediment within the profile. Some well-equipped drilling rigs can also use a Standard Penetration Test (SPT) sampler or a thin walled 50 mm diameter tube (designated U50—undisturbed, 50 mm diameter) when wash boring. 'Gemco' is one of the brands commercially available in Australia.

Core sampling employing a vacuum and vibration technique

The Vacuum-Vibro Corer (based on principles used by some off-shore drilling rigs) has been developed and modified by DNR to more effectively sample wet sands, muds, and soft soils commonly encountered in ASS environments (Plate 6).

The VVC consists of a 60 mm diameter, 5–6 m stainless steel tube which is mounted on the back of a trailer, 4WD utility or truck. Using both vibration and vacuum the tube is inserted into the soil to obtain a continuous, intact sample. The tube, containing the sample is then winched up whilst the vacuum is maintained. A combination of compressed air and vibration is then used to extrude the sample into a clear, plastic sleeve. The sample can then be described and sampled easily.

If the upper profile is hard and dry, a hydraulic push tube or manual augering device may be required until soft moist material is encountered at depth.

Geoprobe

The Geoprobe is a track mounted, self-propelled all-terrain vehicle that improves accessibility to notoriously difficult ASS sampling sites. The Geoprobe is a hydraulically powered percussion machine that can sample to depths of up to 30 m. The Geoprobe obtains continuous soil samples that are contained in 1.2 m removable clear polymer liners. The samples can be logged immediately or sealed and frozen for later logging. The Geoprobe retrieves soft sands and muds with minimal compaction (Plate 7).



Plate 1. Jarett soil auger



Plate 2. Dormer soil and Dormer sand augers



Plate 3. Dormer tapered gouge auger



Plate 4. Piston sampler



Plate 5. Hydraulic push rig



Plate 6. Vibro suction corer



Plate 7. Geoprobe

APPENDIX 2

Interpretation and Use of NR&M Acid Sulfate Soils Maps

***Note:** This document should be provided with all NR&M mapping products and referred to in the printed acid sulfate soils reports accompanying mapping products. It should be included with digital product packages (CD ROMs etc) to provide information essential for the correct use of ASS maps and reports produced by NR&M, and to limit liability for misuse of NR&M products.*

DISCLAIMER:

While every care is taken to ensure the accuracy of this product, the Department of Natural Resources and Mines (NR&M) makes no representations or warranties (expressed or implied) about its accuracy, reliability, completeness or suitability for any particular purpose and disclaims all responsibility and all liability. Any representation, statement, opinion or advice, expressed or implied from this product is made in good faith and on the basis that the State of Queensland, its agents and employees are not liable (whether by reason of negligence, lack of care or otherwise) to any person for any damage, expense or loss whatsoever which has occurred or may occur in relation to that person taking or not taking (as the case may be) action in respect of any representation, statement or advice referred to above.

1. Background

Acid sulfate soils (ASS) are marine or estuarine sediments that contain iron sulfides, commonly pyrite. When exposed to air by disturbance or drainage, the iron sulfides oxidise producing significant quantities of sulfuric acid (battery acid). This acid results in the release of toxic quantities of iron, aluminium and heavy metals from the soil. These pollutants can seep into waterways, killing fish, other aquatic organisms and vegetation. Concrete and steel structure may also be severely corroded, requiring replacement.

Environmental harm from ASS has been well documented, particularly in New South Wales, and there is significant and growing anecdotal evidence of fish kills and other environmental damage in coastal areas of Queensland affected by ASS. As part of the Queensland Department of Natural Resources and Mines (NR&M), the Queensland Acid Sulfate Soils Investigation Team (QASSIT) has undertaken a number of projects to map the location and extent of ASS in coastal Queensland.

This document is aimed at ensuring the correct use and interpretation of maps and data published by NR&M as a result of these projects. NR&M ASS maps are available in hard copy and electronic forms at a range of scales – 1:100 000, 1:50 000, 1:25 000. The variation in map scale relates directly to borehole or site intensity, and hence reliability of map boundaries. This document also provides a general description of the field sampling and mapping procedures used by NR&M. Users of mapping products do not always understand the limitations of the data (particularly in relation to mapping scale), and the serious consequences that can result from using the information out of context or attempting to extrapolate beyond the data limits. To pre-empt such misuse, it has been necessary to include a cautionary statement such as the one below, with all products.

Example of paragraph in an ASS report:

“Users of mapping products such as ASS maps must be aware of the limitations implied in the scale of mapping undertaken. At a scale of approximately 1:25 000, the mapping is suitable for use in regional farm management and development planning. Individual property planning or developments will require more detailed ASS investigations at scales of at least 1:10 000, depending on the type and location of development. Map unit boundaries may be updated as additional field and laboratory data becomes available. End users of NR&M mapping products should become acquainted with the methodologies used and the limitations of the product.”

It must be emphasised that users of mapping products should seek competent advice before undertaking action—whether exploratory or remedial action. Often the consequences associated with disturbed ASS can still be producing adverse effects 30 years after an event (Cook *et al.* 1999).

2. Mapping Acid Sulfate Soils

ASS are relatively common in Queensland coastal areas and are generally found in low-lying areas less than 5 m Australian Height Datum (AHD), and mapping exercises tend to also concentrate on these localities. Field sampling and mapping of ASS is more technically challenging than standard agricultural soil mapping. For example, ASS are three-dimensional bodies of sandy or muddy sediments, of varying depth and pyritic concentration. These sediments may be covered with more recent, non-estuarine sediments (alluvium), and they may also be oxidised to some depth, depending on natural or man-made watertable fluctuations.

ASS which have already undergone some oxidation and display existing acidity ($\text{pH} \leq 4$) are termed **actual ASS (AASS)**. ASS which have not yet been oxidised are termed **potential ASS (PASS)**. Often actual ASS immediately overlie potential ASS, and the lower level of watertable fluctuation is usually the boundary between the two (Smith *et al.* 2000).

Due to the potentially hazardous properties of ASS, it is necessary to target mapping according to likely occurrence, and potential future disturbance of ASS. As a result, mapping scale may vary across a single map from 1:100 000 to 1:25 000, depending on the likelihood of finding ASS in the area. A greater likelihood of finding ASS generally necessitates a greater mapping intensity.

The basis for field sampling and mapping of ASS has been:

- Identification of landform types associated with Holocene estuarine deposition; principally via stereoscopic air photo interpretation (API); and
- Surface elevation below 5 m AHD (based on maximum Holocene sea levels).

Identification of PASS and AASS

In the field, PASS are usually grey to dark olive grey in colour (5Y41 to 5GY31 in the Munsell soil colour chart). They are typically wet, fine textured soils (eg. mangrove muds), but may also be sandy or more rarely, gravely. When PASS remain in their undisturbed, natural, waterlogged state, they are environmentally ‘benign’. However, if exposed to oxygen, the iron sulfides in the PASS will oxidise, and sulfuric acid will be produced. Basically, the PASS becomes AASS.

AASS are usually browner (10YR51 to 2.5Y33 in the Munsell soil colour chart) than PASS because they have been partly or fully oxidised. They often show significant red and orange mottles, indicating their oxidised state. AASS generally contain a straw-coloured mottle called jarosite, $\text{KFe}_3(\text{OH})_6(\text{SO}_4)_2$, which is strong evidence that sulfuric acid has been produced, since jarosite requires very acidic conditions ($\text{pH} < 3.7$) to form and stay visible.

Field pH (pH_F) and field pH peroxide (pH_{FOX}) tests also help identify AASS and PASS layers. In the pH_{FOX} test, the addition of hydrogen peroxide to an ASS sample triggers accelerated oxidation of pyrite, liberating the acid that would form slowly under natural oxidising conditions. The strength of reaction to peroxide and the pH decrease from pH_F to pH_{FOX} are key indicators of PASS. PASS usually have pH_F values greater than 4 (usually around neutral) and $\text{pH}_{\text{FOX}} < 3$, and show a strong reaction to peroxide. AASS generally have a pH_F and pH_{FOX} below 4. For more detailed information on conducting and interpretation of field pH tests, refer to Hey *et al.* (2000).

Site description and sampling

Site description, sampling, field testing and laboratory analysis is carried out in accordance with the latest version of the *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland* (Ahern *et al.* 1998) (referred to as the *Queensland Sampling Guidelines*). A range of manual and mechanical sampling equipment specially designed to cater for the recovery of intact cores from saturated sands, soft plastic muds and other ASS material is used. Soil cores are generally between 2 and 6 metres in depth and preferably extend to the depth of the non-marine sediment layers. Traverses of deeper

boreholes are used in key areas, to improve understanding of the coastal geomorphology, and develop a clearer picture of the historical development of ASS.

Morphological descriptions of each site are recorded according to the nomenclature of McDonald *et al.* (1990) and site locations are recorded in standard Australian Map Grid coordinates to an accuracy of 3 metres. All data is stored in NR&M's Soil and Land Information [SALI] database.

Samples (weighing approximately 0.5 kg) are collected at 0.5 m intervals down the soil profile, or within each soil or sedimentary layer. Samples are bagged, labelled and frozen in the field in preparation for future laboratory analysis. Field tests (pH_F and pH_{FOX}) are conducted at 0.25 m intervals down the soil profile in the field and results are tabulated. Upon arrival at the laboratory, samples are either frozen or oven-dried at 85°C for 48 hours for laboratory analysis.

Decoded site descriptions and chemical data are usually supplied in the appendices of the project reports. They show the texture and other characteristics of each soil layer, which layers have PASS, AASS or pH between 4 and 5, and the results of laboratory analysis.

Mapping categories

For initial mapping, all sites assigned with map unit codes are overlayed or printed onto topographic maps. Homogenous areas are then delineated according to the following criteria:

- **Presence of or 'depth to' AASS layer**—defined as soil pH less than or equal to 4
- **Presence of or 'depth to' PASS layer**—defined as any soil layer in which the oxidisable sulfur (S%, a measure of pyrite content) exceeds the appropriate *action criteria* (see below)
- **Presence of or 'depth to' to acidic layer**—defined as layers with pH >4 to ≤5; this level of acidity can be due to natural organic acidity or past oxidation of ASS

Note: 'Depth to' categories are shown only at 1:50 000 and 1:25 000 mapping scales. The density of boreholes in 1:100 000 mapping does not provide sufficient reliability to allow this level of detail, so these maps only indicate the presence of ASS, with no 'depth to' categories shown.

Action criteria

Action criteria refer to the amount of existing and potential acidity in the soil that triggers the need for management if the soil is disturbed. Action criteria vary according to soil texture (Table 1). For more details regarding action criteria refer to the *Queensland Sampling Guidelines* (Ahern *et al.* 1998).

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

Type of Material		Action criteria if 1 to 1000 tonnes of material is disturbed		Action criteria if more than 1000 tonnes of material is disturbed	
		Existing + Potential Acidity		Existing + Potential Acidity	
Texture range (McDonald <i>et al.</i> 1990)	Approx. clay content (%)	Equivalent sulfur (S%) (oven-dry basis)	Equivalent acidity (mol H ⁺ /tonne) (oven-dry basis)	Equivalent sulfur (S%) (oven-dry basis)	Equivalent acidity (mol H ⁺ /tonne) (oven-dry basis)
Coarse texture <i>Sands to loamy sands</i>	≤5	0.03	18	0.03	18
Medium texture <i>Sandy loams to light clays</i>	5–40	0.06	36	0.03	18
Fine texture <i>Medium to heavy clays and silty clays</i>	≥40	0.1	62	0.03	18

Selection of type of laboratory analysis

ASS are chemically very complex soils, making analysis and interpretation particularly difficult. It is always important, but especially so for detailed investigations, that the correct type of analysis is carried

out on ASS samples. The Chromium Reducible Sulfur (S_{CR}) method is the preferred method for low analysis sands and for highly organic or peaty soils because of its specificity to reduced inorganic sulfur (ie. pyrite). Analysis by the Peroxide Oxidation Combined Acidity and Sulfate (POCAS) method and the more recent Suspension POCAS (SPOCAS) method gives best results for samples containing amounts of shell or carbonates, or those showing existing acidity. The Total Oxidisable Sulfur (TOS) method is a useful low cost method to analyse ASS. On occasions, analysis by all three methods may be necessary. For more information regarding laboratory analysis and interpretation of ASS chemical data refer to McElnea and Ahern (2000).

3. Limits of Various Mapping Scales

The scale of mapping has important ramifications with respect to the context in which maps are used. Map scale relates directly to site density, and hence reliability of map boundaries. For an indication of the reliability of each map unit, users should refer to the **intensity diagram on the map, or the UMA scale code** (in the UMA database), which is calculated from the number of boreholes present within each unit—as indicated in the box below. The UMA database is maintained as part of the geographic information system (GIS) files, and includes data on individual map units, referred to as Unique Map Areas (UMAs). This includes the identity of the sites that occur in the UMA and a statement about its reliability.

The mapping scale of each UMA is calculated using the following formula: $(\sqrt{\text{ha/no. sites}}) \times 10^4$

For example, if there are four sites in a UMA of one square kilometre (ie. 4 sites per 100 ha), then the scale is: $(\sqrt{100/4}) \times 10^4 = \sqrt{25} \times 10\,000 = 50\,000$

In practice, the nominated scale covers a range of site densities. For QASSIT ASS maps:

- 1:100 000 implies approximately 1 borehole per 100 ha
- 1:50 000 implies approximately 1 borehole per 25 ha
- 1:25 000 implies approximately 1 borehole per 6.25 ha

The scale of a map is clearly marked on the map and accompanying information in the map key or in a supporting publication is provided on how the map may be used. Map users need to be aware of the limitations of interpretation from these mapping scales. The information is only intended for use and in presentation with information at that scale. Should digital information be integrated with data or a more intensive scale, then the legend of the printed map should make it clear that the ASS theme is only accurate to the relevant scale. Figure 1 below shows how variations in borehole density can determine the overall mapping outcome. The higher number of 1:50 000 and 1:25 000 boreholes can enable the identification of smaller more detailed units.

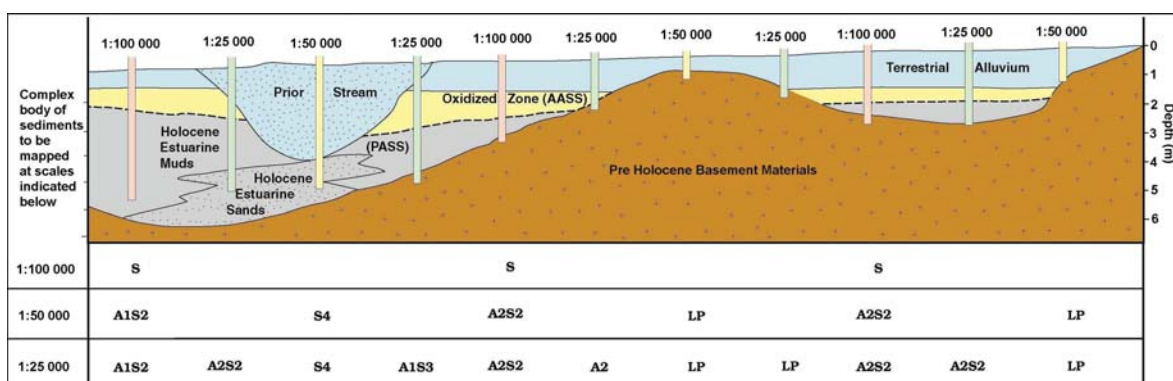


Figure 1. Borehole density diagram showing additional detail available for mapping at each scale.

The site intensity of 1:100 000, 1:50 000 and 1:25 000 maps is not appropriate for individual developments. Individual developments will require even more detailed ASS investigations at scales of at least 1:10 000, depending on the type and location of the development. ASS investigations for individual developments should be conducted according to the *Queensland Sampling Guidelines*.

1:100 000 Scale Mapping

At 1:100 000 scale, only the presence or absence of ASS is indicated. No information is given about the depth to ASS, and whether AASS or PASS are present. This scale of mapping is not appropriate for use on an individual property basis. Not only are boundaries not sufficiently accurate at the property level, it is not possible to make decisions about ASS management simply on the basis of its presence. Factors such as 'depth to ASS' and the amount of existing and/or potential acidity are needed for such decisions. For local authorities considering development applications, we advise that the only use of 1:100 000 mapping in these contexts should be as a mechanism to signal the need for further assessment. For example, a decision to prohibit an activity based solely on 1:100 000 scale map information would not be appropriate.

1:50 000 Scale Mapping

Mapping at 1:50 000 scale indicates the presence or absence of AASS and PASS and also gives an indication of depth to AASS and PASS. Although unsuitable for individual property planning, 1:50 000 is a useful scale for regional property management and development planning. It must be remembered though, it is based on approximately one quarter of the data used for 1:25 000 mapping. Therefore 1:50 000 scale map units are likely to be larger and contain more variability than 1:25 000 scale units (hence a lower level of confidence).

1:25 000 Scale Mapping

Due to increased site intensity, mapping at 1:25 000 scale indicates the presence or absence of AASS and PASS and the depth to AASS and PASS, with more detailed delineation and improved reliability of map units. This additional information can improve ASS management decisions regarding current or future land use. 1:25 000 is a reliable scale for individual property planning, however individual developments will require more detailed ASS investigations.

4. Map Legends and Map Unit Codes

The maps use colour to indicate the various categories of AASS and PASS. For relatively undisturbed areas mapped at 1:50 000 or 1:25 000 scale, the main mapping categories depict the varying depths to the first AASS and/or PASS layer. Map units represent areas where the depth to the first AASS or PASS layer is relatively uniform. These are coloured using shades of red, pink, orange and brown, with red indicating the shallowest depth (eg. S0 unit is coloured red, indicating that PASS occur 0 to 0.5 m below the surface). The base colour of individual map units is attributed according to the shallowest ASS layer, regardless of whether this represents 'actual' or 'potential' acidity. If AASS is present in the unit, this is represented by an overlay of yellow dots.

Each map unit is labelled with a map unit code, which indicates the characteristics of the unit. The basic codes used are:

- S** potential acid sulfate soil (PASS)
- A** actual acid sulfate soil (AASS)
- a** acid layer with pH >4 to ≤5

Each symbol (S, A, or a) is then followed by a numeric depth code ranging from 0 to 5. For eg.

- S0** indicates PASS between the soil surface and 0.5 m depth
- S1** indicates PASS at 0.5 to 1.0 m depth
- S2** indicates PASS at 1.0 to 2.0 m depth
- S3** indicates PASS at 2.0 to 3.0 m depth
- S4** indicates PASS at 3.0 to 4.0 m depth
- S5** indicates PASS at 4.0 to 5.0 m depth
- S5+** indicates PASS at depths greater than 5.0 m

Combined Codes. The codes above may be used alone or in combination ie:

- A1** AASS (pH ≤4) occurs at 0.5–1 m depth; no PASS present
- S4** PASS occurs at 3–4 m depth; no AASS present
- A1S3** AASS occurs at 0.5–1 m depth; PASS occurs at 2–3 m
- a0S2** pH 4–5 layer occurs within 0.5 m; PASS occurs at 1–2 m

Mixed Units. These are shown with both colours striped to indicate areas where the depth to ASS is too variable to be accurately mapped at the operative scale (eg. A1/A2).

Other Codes. For disturbed, urban or industrial lands or other areas where little or no field checking could be achieved, the maps show where ASS is likely to occur based on geomorphology and elevation data. Codes used are:

- | | |
|-----------------------|--|
| S | Land mapped at 1:100 000 scale where ASS occurs within 5 m of the surface. |
| S_{LA} | Limited field assessment, but reasonable probability of ASS occurring due to landscape position. Current land use prevents disturbance or access is restricted eg. National Parks and Reserves. |
| S_{DL} | Limited field assessment in disturbed lands likely to contain ASS eg. canal estate, marina, aquaculture, quarry, urban or industrial lands. |
| S^P | Indicates pyritic sediments of Pleistocene age. Found only recently, these sediments often occur in deep sandy soils (eg. Podosols) below quite impenetrable ‘coffee rock’ layers, at depths greater than 5 m. While these are still acid sulfate soils, they were generally considered outside the scope of the mapping project. |
| w | Indicates seasonally wet or swampy areas often associated with <i>Melaleuca spp.</i> and <i>Casuarina glauca</i> communities. ASS typically occur at depth. These areas show varying levels of sulfides near the surface, possibly due to organic sources of sulfur (see note on organic soils below). Subscript ‘w’ is used in conjunction with other codes such as S _{LAw} or S2 _w . |

Note: Soil disturbance in any areas designated one of the ‘S’ codes above—with no depth shown—should be avoided without more detailed investigation.

Codes for areas with low probability of ASS.

- | | |
|------------|---|
| LP | Areas below 5 m elevation with low probability of ASS occurring |
| LP5 | Areas above 5 m elevation with low probability of ASS occurring |
| NA | Land not assessed |

Borehole locations and data. For all scales, each fully described and sampled site is shown as a dot on the map. Site numbers are also shown at 1:50 000 and 1:25 000 scales.

5. Modification of ASS Codes Allocated by SALI-Chem

There are situations where the mapping codes, which are automatically assigned by NR&M’s soil chemistry database program [SALI-Chem], need to be modified in the light of supplementary data if they are to provide the most accurate information.

- **Modification of ‘depth to’ codes.** For each site, in order to allocate ‘depth to’ codes for AASS, PASS and acid soil layers (**A0**, **S2**, **a1** etc), SALI-Chem applies the appropriate action criteria (depending on soil texture) to the available laboratory data. The depth code assigned is based on the **upper depth of the horizon from which the sample was taken**. In some instances, these mapping codes may require modification to more accurately represent the site in question. For example, a soil horizon described in the field may stretch across depth categories (ie. from 0.4 m to 0.9 m depth), but upon later viewing of laboratory results, the sample from 0.5-0.6 m returns a result below the action criteria, while the sample from 0.8-0.9 m exceeds the action criteria. The database would automatically code this soil as an ‘**S0**’ profile, based on the **upper depth of the sampled horizon** (0.4 m). The mapping officer may choose to re-code the profile to ‘**S1**’, in order to reflect the observation that PASS was found only between 0.5 to 1.0 m (and not between the surface and 0.5 m).
- **Organic soils.** In soil chemistry terms, ASS are characterised by **inorganic acidity from sources such as pyrite**. However, sometimes a laboratory (or field) analysis will yield a natural pH of less than 4 despite the absence of significant levels of pyrite. This is most often caused by organic acidity, which is usually less hazardous, and typically occurs in surface or near-surface layers of Podosols, Organosols or Hydrosols. Where there appears to be no AASS influence near the surface, these soil units will be mapped as ‘**a**’, rather than ‘**A**’.

Organic matter can also contain significant amounts of sulfur which may trigger an 'S' code (in SALI-Chem) if samples are analysed by TOS or POCAS methods. Only Chromium Reducible Sulfur (S_{CR}) analysis can distinguish between pyrite and organic sulfur sources. As S_{CR} is not done for every site, the results from some surface organic soils have been discounted if the actual depth of PASS is obviously deeper than the surface layers. Data from adjacent sites, particularly those where S_{CR} analysis is available, may be used to adjust depth codes to reflect the perceived true depth (or absence) of PASS.

- **Jarosite and pH's > 4.0.** Although jarosite usually occurs in conjunction with soil pH below 4 (resulting in an 'A' coding), at some sites where jarosite is common (greater than 10%), natural pH may remain above 4.0 ('a' coding). This is believed to be due to natural variability within the soil matrix. Because the presence of jarosite is a reliable indicator of AASS, the site can be recoded from 'a' to 'A'.

6. Updating of Map Unit Boundaries

Soil maps are based only on the information available at the time of mapping. QASSIT may update boundaries for soil units on both digital and printed maps, as additional field and laboratory data becomes available. Map users should ensure that they have the most up-to-date mapping information available.

7. References

For further information on QASSIT mapping projects, please contact QASSIT:

Phone: (07) 3896 9819

Fax: (07) 3896 9782

Address: Block C, 80 Meiers Road, Indooroopilly Qld 4068

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