Department of Environment
and Resource Management

Moreton Bay Regional Council acid sulfate soils

Pine Rivers area

July 2011

Prepared by:
JS Walton[1], JA Manders[2], KE Goulding[1]
Department of Environment and Resource Management
Resource Assessment and Information, South-East Region[1]
Queensland Acid Sulfate Soils Investigation Team (QASSIT), Brisbane[2]

Published by the Queensland Government, July 2011

Citation of this document should take the form:
Walton, J.S, Manders J.A, Goulding KE (2011). *Moreton Bay Regional Council Acid Sulfate Soils - Pine Rivers Area*. Department of Environment and Resource Management, Queensland, Australia.

#29839
July 2011
MAS_1
ISBN: 9311662191731
Volume 1

Acknowledgements

The authors wish to thank:

- Moreton Bay Regional Council for providing funding to make this project possible.
- Michael Messer and Erin Porter from Moreton Bay Regional Council for initiating this project.
- All landowners who supported the study by providing access to their properties.
- Jeremy Manders, Lauren O'Brien, Lauren Eyre, Fiona McCartney, Kate Goulding, John Loi, Suzette Argent, Mark Sugars, Peter Wilson, and Maria Zann (DERM) for field work assistance.
- Sonya Mork and Dan Yousaf from the Natural Resource Sciences Chemistry Centre (DERM) for soil laboratory analysis.
- Sheryl Crofts (DERM) for cartographic expertise.
- Lauren O'Brien, Sue-Ellen Dear, Lauren Eyre (DERM) and David Walton for report formatting and proofing.

Front cover photo taken from Dohles Rocks Road, Griffin looking towards the Pine River mouth.

Contents

List of figures

List of tables

List of photos

Map

(Located in the back pocket of the report)

Moreton Bay Regional Council Acid Sulfate Soils - Pine Rivers Area (Scale 1:25 000)

DERM Ref No: A1_508422

Volume 2

(The appendices and supplements are presented as "*Moreton Bay Regional Council Acid Sulfate Soils - Pine Rivers Area, Volume 2"* and are recorded on the DVD which accompanies this report.)

Appendix 1. MAS summarised analytical data (A3)

Appendix 2. MAS analytical data (A3)

Appendix 3. MAS borehole descriptions

Appendix 4. SEA summarised analytical data (A3)

Appendix 5. SEA analytical data (A3)

Appendix 6. SEA borehole descriptions

Supplement 1. Acid sulfate soils map (PDF version)

Supplement 2. Site photos

Supplement 3. Moreton Bay Regional Council Acid Sulfate Soils - Pine Rivers area, (PDF version of report)

Summary

Mapping of acid sulfate soils (high priority areas) has previously been undertaken in selected locations for Moreton Bay Regional Council (MBRC) by the Queensland Acid Sulfate Soils Investigation Team (QASSIT) from the Department of Environment and Resource Management (DERM). The purpose of this project is to expand on the existing mapping, thereby providing information to enable Council to broadly identify the extent of the acid sulfate soils (ASS) hazard within other low lying areas of the region. This survey of ASS was funded by MBRC and DERM.

The survey involves an area of some 3086 hectares (ha) along the lower reaches of the North and South Pine Rivers and Hays Inlet in the MBRC area. The survey area is centred on Griffin and extends from Rothwell in the north, Brendale to the south and Petrie in the west. Mapping was undertaken at 1:25 000 scale intensity within 1700 ha of the survey area, excluding tidal lands unlikely to be disturbed, land unable to be accessed, and land subject to intensive disturbance such as residential development, extractive industries, and industrial land uses.

Within the detailed survey area 86 boreholes were sampled. Results from 30 older boreholes conducted as part of previous 1:100 000 scale mapping were also considered in the current survey. Borehole depths ranged from 0.8 m to 9.8 m (average depth of 3.6 m) with all soil profiles described according to national standards (The National Committee for Soil and Terrain, 2009) and field pH tests carried out at 0.25 m intervals according to The Sampling Guidelines (Ahern et al. 1998). Collected samples were submitted for laboratory analysis, with all laboratory analyses carried out in accordance with the Acid Sulfate Soils Laboratory Methods Guidelines (Ahern et al. 2004). Selected samples were also re-analysed from 19 of the older boreholes within the study area.

The accompanying 1:25 000 scale ASS map displays the depth to the occurrence of ASS. Map units were allocated a mapping code and a depth code according to the depth at which the first potential acid sulfate soil (PASS) or actual acid sulfate soil (AASS) layer was encountered, based on field and laboratory data. Colours on the acid sulfate soil map display the depth and associated risk. Of the 1700 ha subject to detailed mapping, 1057 ha were found to contain ASS. Of this 1057 ha, AASS were present in 690 ha, ranging from surface horizons down to three metres depth. Existing acidity levels of up to 0.64 % S (equivalent) were found; often within the upper 0.5 m of the soil profile. Potential acid sulfate soils (PASS) were present in 367 ha, with potential acidity levels of up to 3.77 % S present at various depths from the surface to greater than seven metres. 575 ha contained AASS and PASS within the same soil profile, with PASS often overlain by AASS or in partially oxidised horizons with AASS.

These results indicate the need for caution in planning and managing developments in the Pine Rivers area to avoid costly damage to the environment, human health and local infrastructure. The results of this survey will be used for the planning and assessment of major activities and development involving soil disturbance and drainage within the Pine Rivers area. All disturbances must address the requirements of the State Planning Policy 2/02; and the latest versions of the Queensland ASS sampling and soil management guidelines. At the time of publication, the Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland (Ahern et al. 1998) and the Soil Management Guidelines (Dear et al. 2002) were the latest versions of these documents. It should also be recognised that the scale of the mapping undertaken in this report is intended for general planning purposes only. Property-scale surveys, which include an appropriate number of boreholes, will be required for future development in the study area. The information collected for this study can be used for education relating to ASS management, to provide further information for research into *Lyngbya majuscula* algal blooms, and to inform residents, developers and Council operations about the likelihood of ASS within the region.

1 Introduction

Mapping of ASS (high priority areas) has previously been undertaken for Council by DERM's Queensland Acid Sulfate Soils Investigation Team (QASSIT), in the low-lying areas of Bribie Island, Donnybrook, Toorbul and Beachmere. This project expands on the existing mapping to provide information within other low lying areas of the region, and will enable Council to broadly identify the extent of the ASS hazard. The resulting data will inform Council’s development assessment process via future amendments to the planning scheme/s. Additionally, the information can be used for education relating to ASS management, to provide further information for research into Lyngbya, and to inform residents, developers and Council staff about the likelihood of ASS within the region.

1.1 Overview of acid sulfate soils

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

Disturbed ASS can release acid, aluminium, iron and heavy metals into drainage waters, affecting aquatic plants and animals (Sammut et al. 1996). Concrete and steel infrastructure including pipes, foundations and bridges are susceptible to acidic corrosion leading to accelerated structural failure. Undisturbed ASS may appear as grey silty sands, black high plasticity silty clays and organic peat materials with pH values close to neutral (pH 6.5–7.5). In this state they are termed potential acid sulfate soils (PASS) because they have the potential to oxidise and produce sulfuric acid. If ASS are exposed to oxygen, the sulfides oxidise and sulfuric acid is produced (for example: one tonne of iron sulfides can produce about 1.5 tonnes of sulfuric acid when oxidised). In this state they are known as actual acid sulfate soils (AASS). AASS are highly acidic (pH <4), and often contain a straw yellow coloured mineral called jarosite. The term acid sulfate soil includes both actual acid sulfate soil (AASS) and potential acid sulfate soil (PASS).

PASS are generally located below the permanent water table and remain inert when maintained in a saturated state without oxygen. If appropriate planning is in place to avoid both direct disturbance and indirect exposure via lowering of the groundwater table, development can proceed without negative impacts upon PASS materials. If disturbance of ASS is to occur, a detailed assessment of the risk associated with the proposed activities must be undertaken and appropriate management strategies developed to prevent negative impacts on infrastructure and the environment.

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

1.2 Acid sulfate soil disturbance risks

The production of AASS can be rapidly accelerated by the way we use and modify our land and groundwater resources. These effects are long lasting and may result in regular fish kills and serious, deleterious impacts on water quality in highly sensitive fish nursery areas. Infrastructure itself can increase the risks associated with ASS. Water table drainage, tidal exclusion via floodgate culverts and levees and placement of linear infrastructure such as roads and rail corridors that exclude or reduce tidal influence over lands containing ASS can result in disturbance of ASS.

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

1.3 Acid sulfate soil management

There are a variety of management options available to treat acid sulfate soils. Selection of an appropriate management option will depend on the activity proposed, the physical and chemical characteristics of the ASS, the hydrological circumstances and the environmental sensitivity of the site. Preferred management methods are as follows:

Avoidance

The disturbance of ASS should be avoided wherever possible. PASS are inert when left in waterlogged, undisturbed conditions. Avoidance is often the most environmentally responsible and cheapest option.

Minimisation of disturbance

If ASS cannot be avoided, their disturbance should be minimised. Strategies that aim to minimise the disturbance of ASS include:

- redesign of earthworks for sites with a variable distribution of ASS so that areas with high levels of sulfides are avoided
- limiting disturbances on-site so that only shallow disturbances are undertaken
- redesign of existing surface drains so that they are shallower and wider and do not penetrate sulfidic layers
- minimising groundwater fluctuations by avoiding activities such as dewatering, deep drainage and the installation of groundwater extraction bores. It is advisable to seal off surrounding sediments using sheet piling during unavoidable excavation and then use basement tanking to exclude groundwater.

Neutralisation

Neutralisation of ASS involves the physical incorporation of neutralising/alkaline materials into the soil. Agricultural lime is the best choice for ASS application. Thoroughly mixing the appropriate amount and type of lime into disturbed ASS will neutralise any acid produced. Agricultural lime has an alkaline pH and buffers acid produced whilst raising the soil pH to acceptable levels. Hydrated lime is often more appropriate for treating acid waters due to its higher solubility, but requires additional workplace health and safety issues due to its high alkalinity. Once the acid water has been treated to pH 6.5–8.5, dissolved oxygen levels are acceptable, and metals (particularly iron) have been reduced to appropriate levels, it can usually be safely released from the site at a controlled rate to prevent significant changes to the quality of offsite waters (previous approval required). The amount of neutralising agent required depends on soil and water test results and the neutralising capacity of the lime source.

Hydraulic separation

Hydraulic separation is suitable for coarse-textured sediments (i.e. sandy material) containing iron sulfides and is often associated with dredging activities. Mechanical methods, such as sluicing or hydrocycloning, are used to hydraulically separate the sulfides from the coarser textured materials. This is an effective form of management in areas when the sediments contain less than 10–20 per cent clay and silt, and have low organic matter content. The separated sulfidic material extracted via the process requires specific management involving either neutralisation or strategic reburial.

Strategic reburial

Strategic reburial involves the placement of PASS into a void, where the soils can be permanently maintained in anaerobic (wet, oxygen-free) conditions at all times. The void can be covered with surface water (e.g. within the base of a lake), or covered by groundwater and compacted soil. The risks associated with this technique depend in part on the nature of the material to be buried. If material is not reburied quickly and is allowed to dry, oxidation and acid production will occur. Any excavated material that has started to oxidise will require neutralisation prior to placement below permanent water.

1.4 Policy context

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

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

1.5 Survey area

The survey area is situated within MBRC, on the northern outskirts of Brisbane in South East Queensland (Figure 1). The survey area includes non-urban and future urban zones within the areas of:

- Brendale
- Deception Bay
- Griffin
- Joyner
- Kallangur
- Lawnton
- Mango Hill
- Murrumba Downs
- North Lakes
- Petrie
- Rothwell
- Strathpine.

These areas have been selected based on future development patterns that are likely to occur, and where ASS are likely to be present. The area has a sub-tropical climate, with hot, humid summers and mild dry winters with cool nights. The average annual rainfall (based on Brisbane observations) is 1149 mm, with the majority falling in summer and early autumn between December and March. The landscape of the survey area is dominated by alluvial and estuarine plains fringed by sedimentary and metamorphosed rock formations.

The North Pine and South Pine Rivers converge to form the Pine River about seven kilometres upstream of its mouth where it discharges into Bramble Bay, part of the Moreton Bay Marine Park. Tidal influence is experienced as far as Young's Crossing on the North Pine River, approximately 17 km from the mouth. The tidal limit on the South Pine River is located over 13 km upstream (outside the study area) from its confluence with the North Pine River (Moreton Bay Regional Council, 2011). In the north of the study area, Saltwater Creek and Freshwater Creek feed into Hays inlet before discharging into Bramble Bay.

The survey area encompasses approximately 3086 ha of land predominantly less than five metres Australian Height Datum (AHD) in the lower reaches of the North and South Pine Rivers, and Hays Inlet. Excluding disturbed land associated with extractive industries and development, undisturbed tidal lands, and land unable to be accessed due to wet weather and time constraints, the area subjected to detailed mapping as part of this project was 1700 ha.

1.6 Mapping scale and intensity

Mapping scale is directly related to survey intensity, that is, the number of soil profiles and associated information collected per unit area. Within the detailed mapping area, the mapping was carried out at approximately 1:25 000 scale, which translates to between four and twenty fully described and sampled soil profiles per square kilometre (one per 5–25 ha). The sites are located using free survey techniques at relatively even spacing depending upon landform, or at wider intervals in tidal areas or undisturbed wetlands where ASS are consistently present. Areas of disturbed land that are likely to contain ASS have also been identified but because of the difficulties associated with assessment or accessibility, limited or no field verification has been carried out in these areas. In the study area disturbed land most commonly includes extractive industry sites and current development sites. Areas with fewer sites such as these have been mapped at a lower intensity of 1:100 000 or greater. The mapping intensity of the different map units are shown in the intensity diagram of the ASS map in Supplement 1.

The mapping process is a way of presenting extremely complex three-dimensional soil data in a two-dimensional format, so that it can be input to planning or management decisions. At the 1:25 000 scale, it is possible to identify areas of high hazard, with mapping units that indicate the presence of both AASS and PASS at various depth intervals. This information is vital for strategic planning decisions relating to current or future use of subject lands. However, mapping at 1:25 000 scale is not of sufficient intensity to replace any site based assessments required under the SPP2/02 Planning and Managing Development Involving Acid Sulfate Soils.

Figure 1: Extent of acid sulfate soil survey, Pine Rivers area

2 Geology

The project area lies within the larger Pine River Drainage Basin, which is mostly underlain by Palaeozoic metamorphic rocks dominated by quartz phyllite (Bunya Phyllite) (Hofmann, 1980). Mesozoic sediments (Landsborough Sandstone) are present in the catchment of the North Pine River (Hofmann, 1980). Tertiary rocks are limited in occurrence and are present mainly as sedimentary rocks of the Petrie Formation (Hofmann, 1980). The study area itself is dominated by Quaternary sediments fringed by the above sedimentary and metamorphosed rock formations. The Quaternary sediments are described in detail in following sections.

Geological mapping (Cranfield et al., 2008) shows the project area to be characterised mainly by Holocene undifferentiated coastal plains and tidal flats, and to a lesser extent Holocene lowest and second river terraces. An extract of the geology mapping is shown in Figure 2, with Table 1 listing the major geologies and rock types within the study area.

Table 1: Major geology units of the study area (Cranfield et al., 2008)

Qa – Quaternary alluvium: clay, silt, sand, gravel; floodplain
Qha – Holocene alluvium: clay, silt, sand; active stream channels and low terraces
Qha/1 – Holocene alluvium: lowest river terrace; gravel, sand, silt, clay
Qha/2 – Holocene alluvium: second river terrace; sand, silt, clay gravel
Qhal – Holocene alluvium: linear depressions (ox-bows); mud, clay
Qhav – Holocene alluvium: levee banks; sand, gravel, silt
Qhc – Holocene miscellaneous unconsolidated sediments: undifferentiated coastal plains: mud, sand, commonly with a veneer of Qha
Qhct – Holocene miscellaneous unconsolidated sediments: tidal flats; sand, mud, grades offshore into Qhms
Qhe – Holocene miscellaneous unconsolidated sediments: estuarine channels and banks; sandy mud, muddy sand, minor gravel
Qpa – Pleistocene alluvium: high level alluvium; silt, clay, sand, gravel
Qpa/1 – Pleistocene alluvium: stranded river terrace (above floodplain); clay, silt, sand, gravel
Qr – Quaternary colluvium: residual soil, colluvium; sand, soil, clay, rock debris
RJl – Triassic-Jurassic arenite (Landsborough Sandstone): lithofeldspathic labile and quartzose sandstone, siltstone, shale, minor coal, ferruginous oolite marker

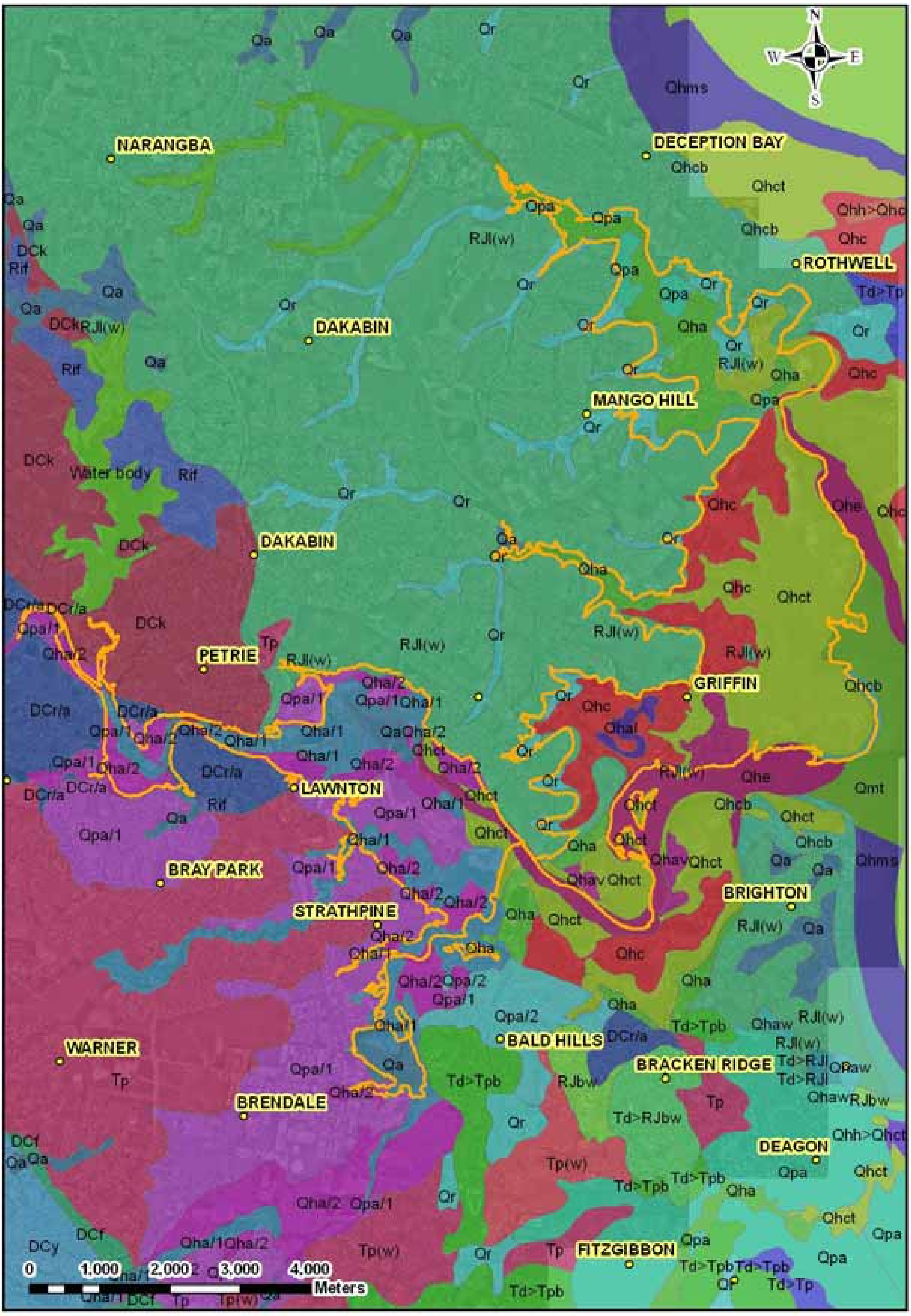

Figure 2: Geology of the study area (sourced from 1:100 000 scale mapping by Cranfield et al., 2008)

3 Geomorphology

Typically the sediments in which ASS are formed were laid down during periods of high sea level similar to current levels. These high sea levels (which correlate with interglacial periods), have occurred twice in the last 150 000 years. Although it is generally recognised that the majority of ASS occur in sediments deposited in the last 10 000 years (Holocene epoch), it is useful to look further back in time to gain a better understanding of their deposition.

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

The most recent sea level rise (the post glacial marine transgression) commenced approximately 19 000–18 000 years ago. At this time sea level was estimated to be 140 m lower than present with the shoreline up to 40 km east of where it is today (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) with present sea level being reached around 6 500 BP (Thom and Chappell, 1975). There is evidence to suggest that minor rises of up to 1.5 m occurred along the southern Queensland coast sometime after this with sea level returning to its present position around 4000 years ago (Lang et al., 1998).

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

3.1 Geomorphology of estuaries

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

An estuary is defined as the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes (Dalrymple et al., 1992). The marine processes (waves and tides) decrease in intensity up the estuary while the fluvial processes decrease in strength down the estuary. According to Dalrymple et al. (1992), ideal estuaries can be divided into three energy zones (Figure 3):

- A—An outer zone dominated by marine processes i.e. waves and tidal currents
- B—A low energy central zone where incoming marine energy is balanced by river energy
- C—An inner river dominated zone.

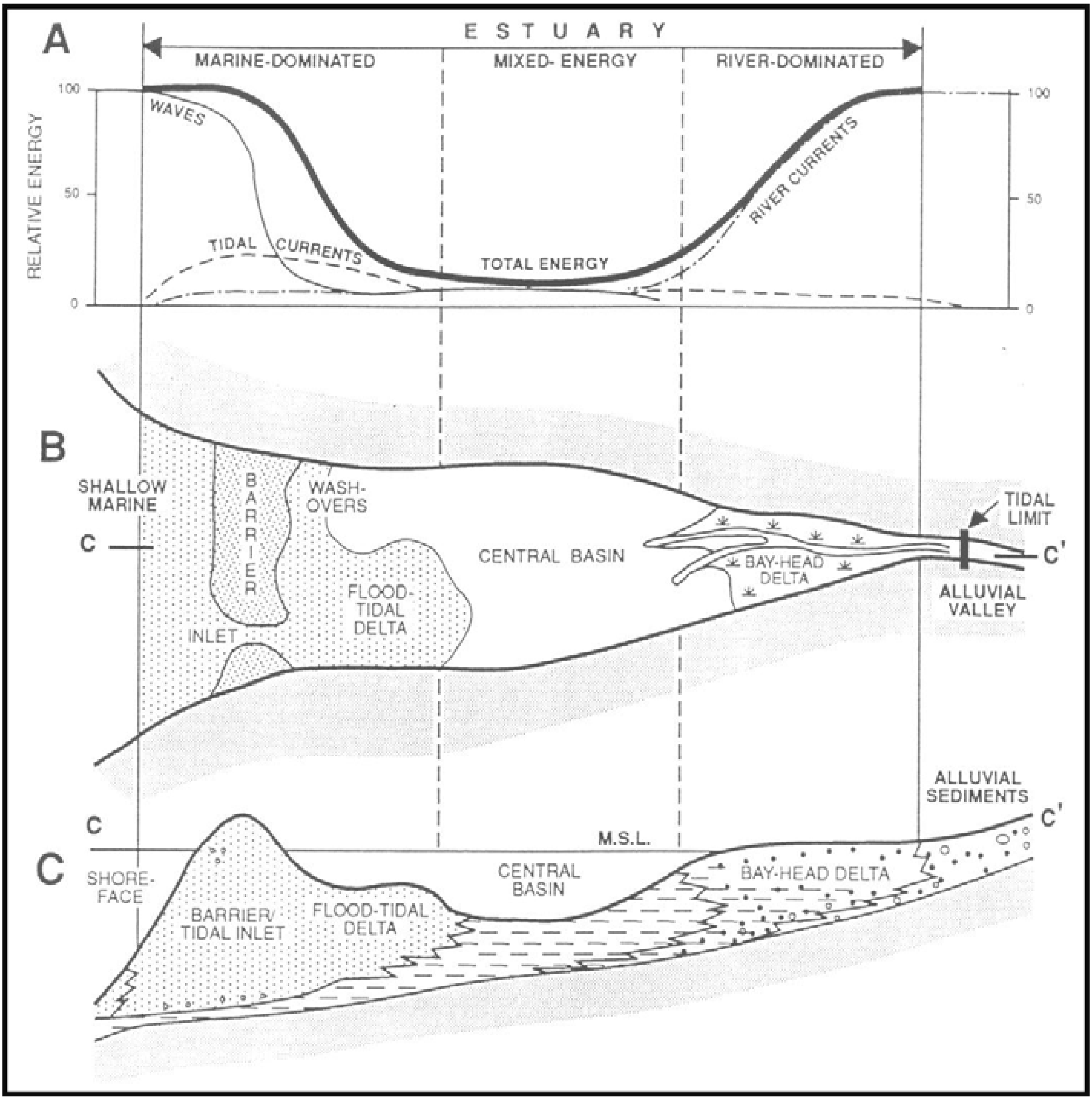

Figure 3: Estuarine energy zones as described by Dalrymple et al. (1992)

The coastal classification of Roy (1984) subdivides estuaries into wave and tide dominated types. On a broader scale, Moreton Bay is a wave dominated estuary, however with respect to the study area, the Pine River is a tide dominated estuary (OzCoasts, 2011).

In wave dominated or barrier type estuaries such as the Logan-Coomera Floodplain of southern Moreton Bay, 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). Marine sands are typically deposited as tidal deltas behind the barrier by incoming tides. 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 3).

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.

A tide-dominated estuary represents a bedrock coastal embayment that has been partially in filled by sediment derived from both the catchment and marine sources, in which tidal currents, rather than waves, are the dominant force shaping the gross geomorphology (Ryan et al., 2003). Tide-dominated estuaries generally consist of a landward-tapering funnel shaped valley, bounded by various intertidal sedimentary environments such as intertidal flats, mangroves, salt marshes, and salt flats (Ryan et al., 2003). Tide-dominated estuaries evolve by infilling of the valley with land and marine-derived sediment gradually in a seaward direction (Dalrymple et al., 1992). Infilling is characterised by the expansion of intertidal flats and salt flats around the margins of the estuary, and expansion and merging of tidal sand banks in the tidal channels (Harris, 1988), reflecting the deposition of sediment trapped within the estuary (Ryan et al., 2003).

3.2 Geomorphology of the study area

With respect to the study area, the large barrier islands at the eastern margin of Moreton Bay protect the Pine River estuary from the high energy ocean swells. As a result, the Pine River is a predominantly tide dominated system, although smaller waves can form during times of high winds. This is demonstrated by scarps in the east and south-east facing margins of the Landsborough Sandstone ridges and outcrops between Griffin and Mango Hill. They appear to be stranded marine cliffs, which were shaped by wave action during the period of highest Pleistocene sea levels (Hoffman, 1980).

Between 140 000 years ago and 120 000 years ago the sea level reached a peak four to six metres higher than the present day levels. It was during this period that the most recent Pleistocene sediments were deposited, including thick mud in the paleochannels of Northern Moreton Bay, encompassing the Pine Rivers area. There was little change until 28 000 years ago, when for a period of 10 000 years, the sea level continued to drop. This resulted in the removal of sediment from the Brisbane and Pine Rivers, forming wide river valleys (Evans et al., 1992). During the Pleistocene, valley incision reached 38 m below current sea level at the at Pine River mouth (Hoffman, 1980). Following the end of the Pleistocene 10 000 years ago, the shoreline continued to move westward with the rise in sea levels. The beginning of this Holocene transgression was marked by the deposition of estuarine sediments (Hofmann, 1980). During this period fluvial deposition was limited to the reaches of the North and South Pine Rivers. It is probable that 3880 years ago progradation began in the Pine River valley following the peak of the Holocene transgression (Hofmann, 1980).

Hofmann (1980) identified four different Quaternary units within the valley. These units are:

- the Strathpine deposits (Pleistocene), which are a fluvial unit grading into silt and clay forming an extensive terrace
- an estuarine unit of sand and silty mud containing shells and timber fragments, which fills erosional depressions in the Strathpine deposits and extends further upstream than recent tidal deposits
- a unit of recent alluvial channel and floodplain deposits encroaching on the estuarine deposits
- a unit of marine sand which overlies the seaward end of the estuarine deposits.

These units have been correlated to the most recent geology mapping (Cranfield et al., 2008) and now described in more detail.

Pleistocene (Strathpine) deposits

The Pleistocene deposits within the study area include the Qpa and Qpa/1 units. The Qpa/1 units correlate with the Strathpine deposits to the west of the Bruce highway. The Strathpine deposits are thought to be the result of a single alluvial cycle and may be as thick as 31 m in places. They overlie weathered bedrock deposits and consist of a coarse gravel base grading through sands into silt and clay. It is estimated that the Strathpine deposits could range in age from 120 000 to 130 000 years old (Hofmann, 1980).

Laboratory analysis of these deposits did not indicate the presence of pyrite and so they are considered non-ASS. While they may have once contained pyrite, they are generally considered to have fully oxidised during the long periods of low sea levels following their deposition.

Holocene estuarine deposits

The estuarine deposits are found overlying the eroded clay surfaces of the Strathpine deposits at the Pine River mouth and extend up the valleys of the North and South Pine Rivers. Further upstream they are overlain by recent floodplain deposits. They are mapped as Qhc and Qhct in the most recent geology mapping (Cranfield et al., 2008). Their thickness varies from 0.3–18 m depending on the level of erosion of the underlying Strathpine deposits. The sediments are generally representative of a low energy depositional environment. They are mainly highly plastic, dark grey mud and very fine sandy silt. At the base of the deposits are coarse to very coarse grained sands along with pebbles, patches of mud and large pieces of timber. At the river mouth the sediments at the base of the deposit are finer and consist of grey, fine to medium grained sands. Using a sample of *Eucalyptus propinqua* collected from the estuarine deposits, they have been dated to 8390 ± 150 years old, which indicates the arrival of the Holocene transgression in the Pine River valley (Hofmann, 1980).

Laboratory analysis of these sediments indicates that they are ASS, with the clays generally containing the highest sulfide levels. Clays are often present at the bottom of the profile and sometimes contain shells. These clays are often overlain by loamy and sandy textured sediments. The deep clay sediments would have been deposited in a low energy semi aqueous environment, similar to the central basin in Figure 3. This low energy environment provides the ideal conditions for ASS formation. As the estuary matures sandy textured sediments tend to dominate as the energy levels increase.

Holocene alluvium

The Holocene alluvium are channel or floodplain deposits overlying estuarine deposits or eroded Strathpine deposits. They are mapped as Qa, Qha, Qha/1, Qha/2, Qhal, and Qhav in the most recent geology mapping. The maximum depth of Holocene alluvium is between five and six metres (Hofmann, 1980). The sediments vary from silt and clay with medium plasticity in back swamps to sand found in levees. Plant debris is also common in these deposits. The colour of the sediments is brown or grey-brown. Above the North Pine River the floodplain deposits occur discontinuously to Petrie. However, they occur continuously along the South Pine River to just above its mouth. Channel deposits of sand and gravel extend into the Pine River estuary and have been sampled as far downstream as Dohles Rocks. The Holocene alluvium represents the youngest deposit in the area, as indicated by the occurrence of the Holocene alluvium over the Strathpine and Estuarine Deposits (Hofmann, 1980).

The Holocene alluvium are considered freshwater deposits and are not ASS, however they often overlie estuarine sediments which are ASS. Sand and gravel mines in the area target these Holocene and also Pleistocene alluvial deposits, which have been extensively mined in the North Pine River and in the South Pine River south of the study area.

Marine sands

Marine sand has been transported from Moreton Bay into the Pine River and overlies older estuarine deposits. It is mapped as Qhe on most recent geology mapping (Cranfield et al., 2008) and can reach depths of five to six metres. The sediments consist of grey to brown, fine to medium grained sand containing shell fragments. Marine sands form several lines of beach ridges and cheniers both to the north and south of the Pine River mouth, as well as being found in the lower Pine River. The age of the marine sand deposits varies from 1500 to 10 000 years old according to the various deposition events in the area (Hofmann, 1980). Wave energy dominates in the deposition of the marine sands, as greater energy is required to transport sands. Accordingly they are found towards the mouth of the river and in the upper part of the soil profile, where wave energy has a greater effect.

The marine sands are often ASS and can be found at the top of the profile in numerous boreholes in the Griffin and Hays Inlet area.

4 Methodology

The methodology used in the preparation of all DERM special acid sulfate soil maps meet the following requirements:

- State Planning Policy 2/02: Planning and Managing Development Involving Acid Sulfate Soils
- State Planning Policy 2/02 Guideline; Planning and Managing Development Involving Acid Sulfate Soils
- Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland (Ahern et al., 1998)
- Acid Sulfate Soils Laboratory Methods Guidelines (Ahern et al., 2004)
- Australian Soil and Land Survey Field Handbook, Third Edition (The National Committee on Soil and Terrain, 2009).

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

4.1 Mechanical sampling equipment

Mechanical sampling was undertaken with either a Geoprobe^{TM} model 6610DT coring machine or a vehicle mounted hydraulic coring rig. The Geoprobe^{TM} (Photo 1) is a track-mounted machine that obtains a 38 mm soil core in 1.5 m long removable clear PVC liners. Soil cores are photographed before being sampled and assessed. The Geoprobe^{TM} is the preferred method of mechanical sampling because it is able to sample all soil types from dry and wet sand to soft sticky muds and also hard alluvial soils. The Geoprobe^{TM} will also sample gravels, although damage to the drilling equipment can occur.

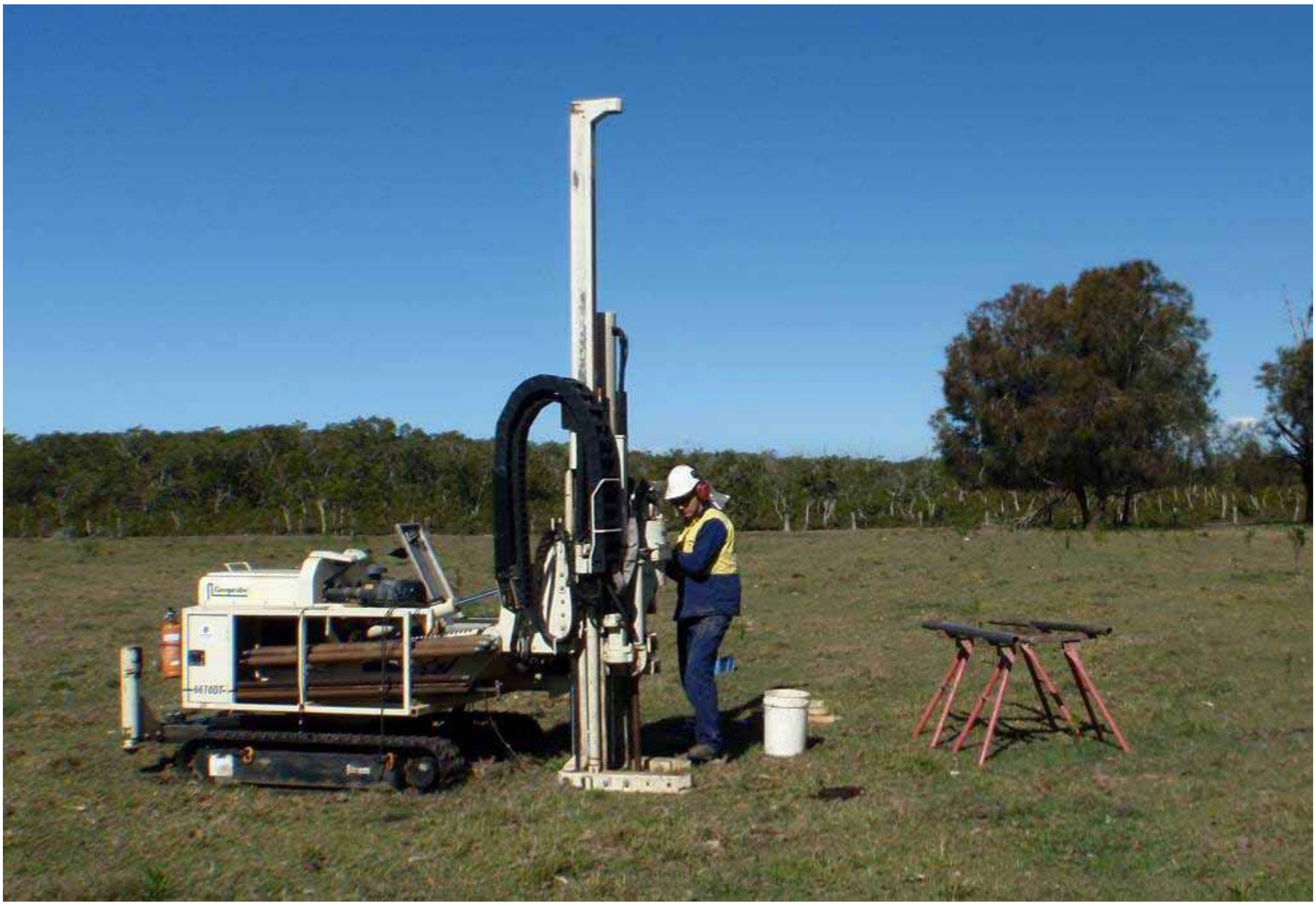

Photo 1: Geoprobe^{TM} sampling equipment in action, Griffin, South East Queensland.

Mechanical sampling of soil cores with the Geoprobe^{TM} are taken to a depth of five to six metres where possible or until non-marine soils are encountered. When the Geoprobe^{TM} was not available, the vehicle mounted hydraulic coring rig (Photo 2) was often used. Hollow steel tubes are pushed into the soil to a maximum depth of 1.8 m to retrieve an intact soil core of 50 mm diameter, then a 2.5 m tapered gouge auger attached to the push rig (Photo 3) and/or hand augers were used to sample further to the required depth.

Photo 2: Hydraulic coring rig with steel tube

Photo 3: Hydraulic coring rig with tapered gouge auger

4.2 Manual sampling equipment

Using mechanical equipment in densely vegetated and waterlogged areas (e.g. mangroves and swamps) is often impractical. Hand operated sampling equipment was used in areas where vehicle access was restricted. In association with the hydraulic coring rig, hand augers were also used for sampling soil at depth.

Sand augers (Photo 4) were used for sampling in very sandy friable soils and the more versatile 'Dormer No. 4 Auger' (Photo 4) was used in most moist sands and soft muds. To obtain an adequate volume of sample, a 75 mm diameter, single slot tube was used. These augers penetrate to a depth of approximately 30 centimetre (cm) before filling the auger. The auger is then reinserted to obtain further samples from the same sample hole. Where the soil type is suitable, it may be possible to auger 5–10 metres using the auger and a series of one metre extension rods. The tapered gouge auger (Photo 5) was used to take undisturbed samples from very soft material with significant clay content. Typically, the gouge 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. A 2.5 m long tapered gouge auger of 75 mm diameter at the top was also used. The auger is pushed into the soil either by hand or by hydraulic coring rig (Photo 3), then turned to cut the core and then withdrawn. It can be used at the surface or down an augured hole. 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. However, 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.

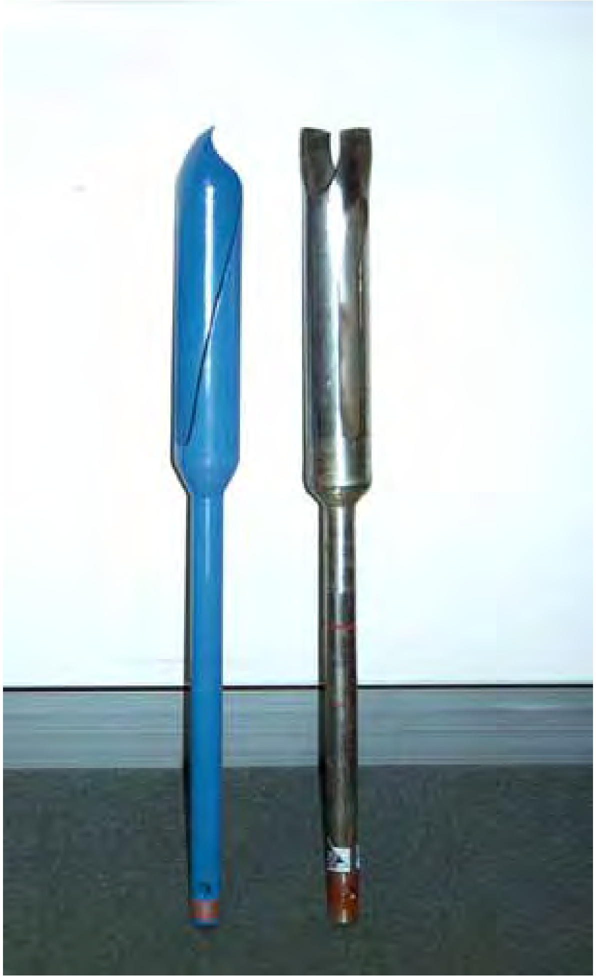

Photo 4: Dormer No 4 auger and sand auger

Photo 5: Tapered gouge auger

4.3 Location of sites, profile description and sampling

The location of sample sites was based on the free survey technique (McKenzie et al., 2008) with the aid of 1955 black and white aerial photos, a colour 2009 mosaic of aerial photos, Light Detection and Ranging (LiDAR) elevation information and geology mapping. Information gathered as part of the previous 1:100 000 scale mapping in this area, and information submitted to the department as part of development applications were also reviewed to assist in locating sites. Site conditions or observations made during fieldwork determined the selection of alternate or additional sites. The location of each site was recorded in Standard Map Grid coordinates to an accuracy of no less than 3 metres using a GPS unit. Within the survey area 86 boreholes were sampled between April and September 2010. Results from 30 older boreholes conducted as part of previous 1:100 000 scale mapping were also considered in the current survey. Use of the SEA sites in this report will reference the 'SEA' project code before the site number; MAS sites taken for the purpose of this mapping project will not reference the 'MAS' code.

The soil profiles were described using the nomenclature of the Australian Soil and Land Survey Field Handbook, Third Edition (The National Committee on Soil and Terrain, 2009), and Munsell Soil Colour Chart (Munsell, 2000). Soil properties recorded included horizon depth, colour, field pH, field pH after oxidation with 30 per cent hydrogen peroxide, mottles, texture and coarse fragments (e.g. shell, partly decomposed plant material). Soil pH was recorded at 0.25 m intervals down the profile, firstly in a soil and water paste (pH_F), and secondly after oxidation with 30 per cent hydrogen peroxide (pH_{FOX}) (Ahern et al., 1998).

The level of effervescence produced during the pH_{FOX} test was also recorded (Volume 2, Appendix 3 Borehole Descriptions). A large difference (e.g. 3–4 pH units) between pH_F and pH_{FOX}, together with significant effervescence is a reliable indicator of PASS.

The profile was sampled according to the Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland (Ahern et al., 1998) at the following intervals (except where these crossed horizon boundaries): 0–0.1 m, 0.2–0.3 m, 0.5–0.6 m, 0.8–1.0 m and then at intervals of 0.5 m below one metre depth. Soil samples were collected from each of the boreholes, which ranged in depth from 0.8–9.8 m (average depth of 3.6 m). In total, 865 samples were collected. Samples were placed in sealed plastic bags and refrigerated immediately. Upon returning to the laboratory, samples were dried at 80°C for 48 hours and fine ground (<1 mm) before laboratory analysis. Fifty four samples from older boreholes conducted as part of the previous 1:100 000 ASS mapping project were also re-analysed using current methods.

4.4 Database recording

All field and laboratory data were entered into the DERM Soil and Land Information (SALI) database, designed specifically for land resource surveys. Terminology and codes in SALI are consistent with the Australian Soil and Land Survey Field Handbook, Third Edition (The National Committee on Soil and Terrain, 2009). Refer to Volume 2, Appendices 3 and 6 for the Borehole descriptions.

Eighty six boreholes sampled for the purpose of this report were entered into the SALI database under the MAS (Moreton Acid Sulfate) project code. Thirty existing boreholes located within the study area were conducted by QASSIT as part of 1:100 000 scale acid sulfate soil mapping between August and October 1997. These were entered into the SALI database under the SEA (South East Acid) project code.

4.5 Laboratory analysis

Laboratory analyses were performed to quantify net acidity (i.e. existing acidity plus potential acidity less any naturally occurring acid buffering capacity). Two laboratory methods were used to determine the net acidity with all laboratory analysis carried out in accordance with the Acid Sulfate Soils Laboratory Methods Guidelines (Ahern et al., 2004). The choice of laboratory method was based on whether the soil layer in question was deemed AASS, or possibly PASS, according to field morphology. Refer to the Glossary for detailed explanation of laboratory terms and acronyms.

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

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

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

The Peroxide Residual Acid Soluble Sulfur (S_{RAS}) method (Method 23R) is described by Ahern et al. (2004). After peroxide digest and TPA titration the soil residue may contain insoluble sulfur (e.g. in jarosite or similar relatively insoluble iron and aluminium hydroxy sulfate compounds) which was either present initially in the soil or formed during peroxide oxidation. This sulfur represents a store of retained acidity (not measured in the TPA titration) that may be estimated after overnight (16 hrs) 4M HCl extraction of the washed soil residue.

On soil where the presence of jarosite is suspected (e.g. if pH_{KCl} <4.5 or jarosite has been noted in accompanying field sampling notes), it is strongly recommended that residue analysis for sulfur is performed.

The SEA sites were originally analysed in 1997 using the Total Oxidisable Sulfur (S_{TOS}) and POCASm methods. The S_{TOS} method is no longer used and the POCASm method has been replaced by the SPOCAS method.

The main assessment for pyrite content carried out on all SEA samples was Total Oxidisable Sulfur (S_{TOS}), (Ahern et al. 2000a). 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, i.e. $S_{TOS} = S_T - S_{HCl}$. The S_{TOS} gives an estimate of sulfidic sulfur and hence the potential of the soil to release acid if aerated under wetting and drying conditions. It gives no measure of existing acidity.

The POCASm method (Ahern et al. 2000b) 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. The POCASm method was an earlier version of the SPOCAS method.

Out of the 865 samples collected for this project, 574 were submitted for laboratory analysis. In addition, 54 samples collected as part of the SEA 1:100 000 scale mapping project were re-analysed using the current S_{CR} and SPOCAS methods in order to provide more accurate data on the presence or absence of ASS.

4.6 Determination of PASS or AASS status

The determination of which soil horizons constitute an ASS was based on an assessment of field morphological properties (e.g. texture, soil colour, mottles and coarse fragments such as shell), field pH test results and laboratory results that met or exceeded the texture based action criteria displayed in Table 2.

Table 2: Texture-based action criteria (source Ahern et al., 1998)

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

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

5 Results

5.1 Map units of the study area

The extent of ASS present is shown in Figure 4 and the attached ASS map (Supplement 1) displays the map units identified in the study area. Table 3 shows the total area of each map unit along with the percentage occupied by each unit of the 3086 ha total project area and 1700 ha detailed mapping area. Note that most of the AASS found in the survey area (690 ha) has PASS layers in the same horizon or below it, meaning that further disturbance has the capacity to release more acid and heavy metals. Approximately 62 per cent (1057 ha) of the detailed mapping area contains layers of ASS—most of which is within two metres of the surface. This does not include developed land because a depth to ASS layer is difficult to obtain in these areas due to disturbance. Apart from elevated land west of Petrie, land mapped as S_{LA} (likely to contain ASS, limited assessment) is expected to contain ASS in the top one metre.

Figure 4: Extent of ASS in the project area

Table 3: Areas of acid sulfate soil mapping units in the Pine Rivers area

Map unit*	Map unit area (ha)	Percentage of study area	Percentage of detailed mapping area
Actual acid sulfate soils (AASS)			
A0	103.4	3.35%	6.08%
A0S0	72.4	2.35%	4.26%
A0S1	8.6	0.28%	0.51%
A0S2	96.0	3.11%	5.64%
A0S2$_{W}$	51.1	1.66%	3.01%
A0S3	30.3	0.98%	1.78%
A1	11.4	0.37%	0.67%
A1S1	22.2	0.72%	1.31%
A1S2	179.2	5.81%	10.54%
A1S3	42.5	1.38%	2.50%
A1S4	22.5	0.73%	1.33%
A2S2	7.6	0.25%	0.45%
A2S3	20.3	0.66%	1.19%
A2S4	3.0	0.10%	0.18%
A3S3	9.5	0.31%	0.56%
A3S4	10.3	0.33%	0.60%
Total	690.2	22.39%	40.61%
Potential acid sulfate soils (PASS)			
S0	45.5	1.00%	1.82%
S1	30.9	0.59%	1.06%
S2	18.1	0.28%	0.51%
S2$_{W}$	8.6	0.04%	0.08%
S3	1.3	1.51%	2.74%
S4	46.6	0.16%	0.29%
S5	4.9	2.12%	3.85%
S5+	65.4	1.00%	1.82%
a0S0	70.1	2.27%	4.12%
a0S0$_{W}$	20.0	0.65%	1.18%
a0S1	10.9	0.35%	0.64%
a0S2	17.1	0.55%	1.01%
a0S3	19.1	0.62%	1.12%
a1S2	6.3	0.20%	0.37%
a1S3	1.9	0.06%	0.11%
Total	366.6	11.40%	20.72%

Land likely to contain acid sulfate soils, limited assessment			
S_{LA}	903.7	29.28%	
S_{DL}	379.0	12.28%	
Total	1282.7	41.56%	
Land with a low probability of ASS			
a0LP	225.9	7.32%	13.29%
a1LP	224.3	7.27%	13.19%
a2LP	18.8	0.61%	1.11%
LP	152.9	4.96%	9.00%
LP5	21.2	0.69%	1.24%
Total	643.2	20.85%	37.83%
Total project area	**3086.1**		
Total detailed mapping area	**1700**		

* The soil map units areas are delineated by:

- the depth of soil at which acidity is first encountered; 'A' refers to an AASS layer (pH <= 4), while 'S' refers to a PASS layer. The numeric component of the map code refers to the depth at which these layers occur [0 = (0–0.5 m), 1 = (>0.5–1.0 m), 2 = (>1–2 m), 3 = (>2–3 m), 4 = (>3–4 m), 5 = (>4–5 m)]
- the codes can be used separately (e.g. A0, S0, S1); but where a map unit contains both AASS and PASS layers, then the codes are combined (e.g. A0S0, A0S1)
- additional information is provided by code “a” for areas with strongly acidic (pH >4 and =<5) soil layers
- subscript w indicates areas associated with Melaleuca sp. wetlands and occasionally Casuarina glauca communities. Oxidisable sulfur per cent in surface layers may be highly variable and often exceeds the 'Action Criteria'. This may include sulfur from organic compounds and modern accretion of sulfides in a wet, organic rich environment.

5.2 Summary of borehole data

Table 4 below presents a summary of the laboratory data for each of the new sites, as well as the map code. Potential acidity ranged from 0 to 3.77 % S. Existing acidity, which is a combination of actual and retained acidity, ranged from 0 to 0.63 % S. Full laboratory results from the MAS and SEA sites are included in Appendix 2.

Table 4: Summary of borehole data from MAS sites

Site number	Site code	Maximum potential acidity (%S)	Liming rate – potential acidity (kg $CaCO_3$/t)[1]	Maximum existing acidity (%S)	Liming rate – existing acidity (kg $CaCO_3$/t)
1	A1S3	2.78	130.10	0.20	9.45
2	A2S3	0.17	7.96	0.07	3.30
3	a0LP	0.02	0.94	0.00	0.00
4	A1	0.02	0.94	0.17	8.10
5	a0S1	3.77	176.44	0.08	3.90
6	A1S2	1.35	63.18	0.15	7.13
7	a2LP	0.02	0.94	0.00	0.00
8	A0	0.02	0.94	0.17	8.10
9	a1S0	2.23	104.36	0.15	6.90
10	A0	0.02	0.94	0.24	11.33
11	a1LP	0.02	0.94	0.06	2.85
12	A0	0.02	0.94	0.70	32.64
13	A0	0.05	2.34	0.50	23.26
14	A2S4	0.77	36.04	0.12	5.70
15	A0S3	3.75	175.50	0.51	23.86
16	S5+	0.69	32.29	0.00	0.00
17	S5+	0.06	2.81	0.00	0.00
18	S1	0.08	3.74	0.02	0.75
19	A3S3	1.84	86.11	0.14	6.60
20	S4	0.08	3.74	0.03	1.50
21	A2S2	2.44	114.19	0.32	14.93
22	A3S4	0.08	3.74	0.14	6.76
23	S2	1.52	71.14	0.01	0.68
24	A0S2	1.97	92.20	0.35	16.58
25	LP	0.02	0.94	0.00	0.00
26	S0	0.71	33.23	0.00	0.00
27	S0	0.34	15.91	0.04	1.67
28	S2	0.77	36.04	0.00	0.00
29	S5+	2.09	97.81	0.00	0.00
30	S1	0.12	5.62	0.00	0.00
31	A2	0.02	0.94	0.09	4.38

---

[1] Rates are expressed in units of $CaCO_3$/t and are intended only to provide an indication of probable treatment levels required upon disturbance. Such rates are in practice calculated from the soil’s Net Acidity, and adjusted upwards to accommodate a safety factor, the soil's bulk density, and the characteristics of the ameliorating agent available

Site number	Site code	Maximum potential acidity (%S)	Maximum liming rate – potential acidity (kg $CaCO_3$/t)	Maximum existing acidity (%S)	Maximum liming rate – existing acidity (kg $CaCO_3$/t)
32	S1	3.34	156.31	0.00	0.00
33	a1S3	0.45	21.06	0.09	4.43
34	S2	0.06	2.81	0.00	0.00
35	a1LP	0.02	0.94	0.04	1.65
36	a0S0	2.30	107.64	0.08	3.83
37	LP	0.02	0.94	0.00	0.00
38	A0S3	1.39	65.05	0.16	7.33
39	A2S2	1.70	79.56	0.10	4.89
40	LP	0.02	0.94	0.00	0.00
41	S2	2.87	134.32	0.00	0.00
42	a0LP	0.02	0.94	0.19	9.02
43	a0LP	0.02	0.94	0.10	4.58
44	A0	0.02	0.94	0.52	24.30
45	a0S0	0.19	8.89	0.14	6.60
46	A0S0	0.08	3.74	0.64	29.73
47	A0S4	0.59	27.61	0.13	6.11
48	A1S2	0.99	46.33	0.12	5.75
49	S3	0.62	29.02	0.00	0.00
50	S0	3.22	150.70	0.00	0.00
51	A1	0.02	0.94	0.08	3.57
52	A1S4	1.06	49.61	0.09	4.40
53	S4	0.13	6.08	0.00	0.00
54	a0S3	1.88	87.98	0.02	0.85
55	A2S4	0.96	44.93	0.12	5.49
56	a1LP	0.02	0.94	0.12	5.40
57	a2LP	0.02	0.94	0.07	3.23
58	a1LP	0.02	0.94	0.08	3.83
59	a2LP	0.02	0.94	0.03	1.50
60	A1S3	1.06	49.61	0.14	6.63
61	a0S2	1.12	52.42	0.14	6.66
62	a0S2	0.44	20.59	0.11	5.10
63	a0S2	0.56	26.21	0.03	1.36
64	A0	0.09	4.21	0.61	28.55

Site number	Site code	Maximum potential acidity (%S)	Maximum liming rate – potential acidity (kg $CaCO_3$/t)	Maximum existing acidity (%S)	Maximum liming rate – existing acidity (kg $CaCO_3$/t)
65	a1LP	0.02	0.94	0.08	3.53
66	A1	0.02	0.94	0.11	5.09
67	A0S2	0.49	22.93	0.17	8.18
68	A1S2	0.51	23.87	0.16	7.45
69	a1LP	0.02	0.94	0.13	5.85
70	A0	0.02	0.94	0.31	14.42
71	A1S3	0.38	17.78	0.16	7.36
72	A0	0.02	0.94	0.17	8.18
73	S1	3.36	157.25	0.00	0.00
74	a0LP	0.03	1.40	0.18	8.48
75	a0LP	0.02	0.94	0.09	4.35
76	A0S0	0.13	6.08	0.35	16.51
77	A0	0.05	2.34	0.43	20.03
78	A0S2	0.43	20.12	0.26	12.06
79	A0S3	0.23	10.76	0.12	5.57
80	A1S2	0.47	22.00	0.07	3.33
81	a0LP	0.02	0.94	0.03	1.35
82	a0LP	0.02	0.94	0.04	1.73
83	A0S2	3.30	154.44	0.27	12.76
84	S2	3.19	149.29	0.00	0.00
85	a0LP	0.03	1.40	0.05	2.33
86	A0S1	0.41	19.19	0.63	29.44

5.3 Characteristics of the mapping area

For discussion purposes, the study area has been divided into five geographical areas, primarily on a sub-catchment basis (Figure 5). Within each area, the different geomorphological conditions are described, including selected site details and photos. The elevation of the land above Australian Height Datum (AHD) has been estimated for each site using LiDAR (Light Detection and Ranging) data which is an optical remote sensing technology that measures properties of scattered light to find the range of a distant target. At each site the depth to the PASS layer can be subtracted from the LiDAR elevation to give the depth of the PASS occurrence relative to AHD. The five areas are:

- Saltwater Creek (Area 1) including Sites 3, 7 and 83
- Western Hays Inlet and Freshwater Creek (Area 2) including Sites 67, 48 and 73
- Griffin (Area 3) including Sites 60 and 86
- South Pine River (Area 4) including Sites 20, 36 and 38
- North Pine River (Area 5) including Sites 29, 30 and 39.

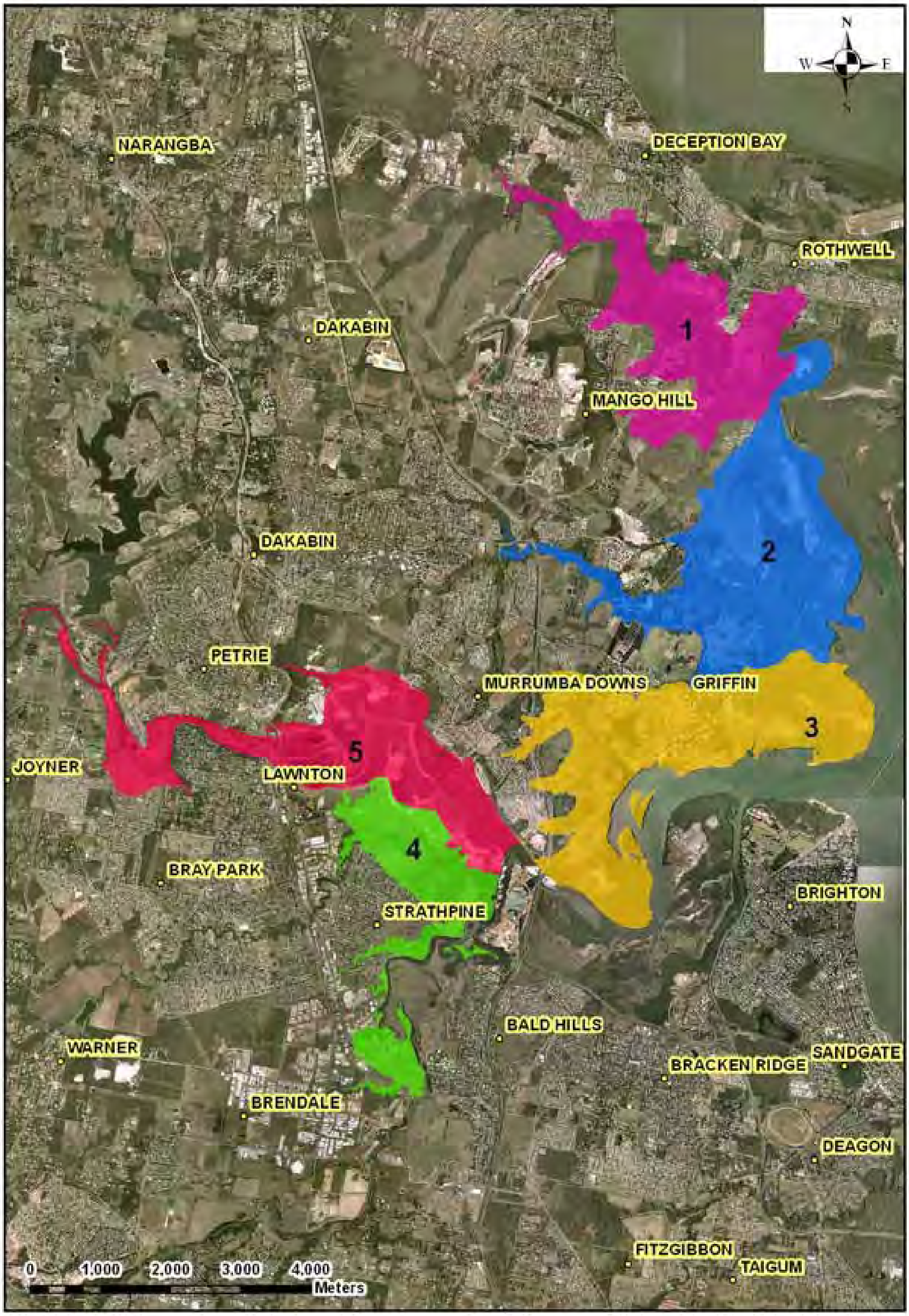

Figure 5: Project sub-areas

Hays inlet lies between the Redcliffe Peninsula in the east and Mango Hill/Griffin to the west. Saltwater Creek and Freshwater Creek discharge into Hays Inlet. During the Holocene period it became a broad, open tidal embayment however it is now largely filled with sediment. In the north of the study area, Area 1 and Area 2 cover the western part of Hays Inlet. The eastern part of Hays Inlet is not in the study area.

Saltwater Creek (Area 1)

Within the study area, Saltwater Creek extends from Deception Bay/North Lakes in the north-west past Anzac Avenue in the south-east where it joins Hays Inlet. It represents a creek valley which has filled with estuarine and terrestrial sediments. Prior to the Holocene transgression, Saltwater Creek incised the pre-existing Pleistocene deposits and Landsborough Sandstone during periods of low sea level. It includes a development site in the south still in the early stages of development. In addition to 5 sites investigated at this location, ASS information submitted for the proposed development was reviewed to assist in the delineation of the mapping units.

Area 1 covers 538 ha; of which 278 ha is ASS. Of the ASS component, the majority (219 ha) is AASS; with a relatively small area (58 ha) of PASS. Of the AASS areas most are partially oxidised, or have oxidised horizons over unoxidised horizons with further potential acidity (170 ha). Land mapped as having a low probability of ASS occurrence (259 ha) is a mix of Pleistocene deposits, quaternary residual colluvial deposits and Landsborough Sandstone. This low probability land is often naturally acidic due to weathering or organic acids being present. Site 3 is representative of the Pleistocene sediments and has a surface elevation of 1.7 m AHD (Photo 6). This soil classifies as a Natric Grey Kurosol, with dark brown clay loam to 0.15 m over mottled grey clays of light to medium heavy texture to at least 3.8 m depth. Field textures indicate that the clay is sodic to at least 2.3 m. This area is mapped as a0LP, indicating land with a low probability of ASS occurrence, with the top 0.5 m of soil having pH between 4.0 and 5.0.

Photo 6: Site 3 location

Photo 7: Site 3 soil profile to 3.8 m

Site 7 is representative of the Landsborough Sandstone soils in this area and has a surface elevation of 4.4 m AHD (Photo 8). It is classified as a Mesotrophic Grey Kurosol. The soil profile consisted of very dark brown sandy loam to 0.33 m over light grey sandy clay loam to 0.76 m, over light grey mottled light medium clay to at least 2.65 m. The top 0.3 m has been ploughed and disturbed during previous farming operations. It is not ASS and has a map code of a0LP.

Photo 8: Site 7 location

Photo 9: Site 7 soil profile to 2.65 m

To the east of Anzac Avenue, A0S0 is the dominant ASS mapping unit (59 ha), indicating AASS and PASS in the top 0–0.5 m. AASS are also present in the top 0.5 metres of most of the remaining ASS mapping units. The depth to PASS varies across the area, from 0–0.5 m in SEA Site 1020 to 3–4 m depth in Site 14. A0S0 represents mainly supratidal and extratidal flats with elevations of approximately 1.2–1.5 m AHD.

SEA Site 1020 is generally representative of the A0S0 area. The surface elevation of SEA Site 1020 is about 1.4 m AHD, with PASS present from 1.3 m AHD. Site 83 is similar, the difference being a greater depth to PASS (1.3 m). The elevation at Site 83 is 1.5 m AHD. Site 83 was classified as a Sulfuric Extratidal Hydrosol and was sampled by hand auger to a depth of 3.6 m. The soil profile consisted of black silty clays to 0.2 m, over brown to greenish grey silty clays. Soil is sulfuric (AASS) to a depth of at least 2.3 m, with existing acidity levels up to 0.27 % S. It is sulfidic (PASS) from 1.3 m, with very high oxidisable sulfur levels up to 3.3 % S. ASS are present to a depth of at least 3.4 m at Site 83 and 2.5 m in SEA Site 1020. Vegetation is primarily *Sporobolus virginicus* (Salt Couch), with *Allocasuarina littoralis* (Black She oak) also present.

Photo 10: Site 83 location

Photo 11: Site 83 soil profile to 3.6 m

West of Anzac Avenue the inlet narrows, with the remnant non-ASS Pleistocene surface becoming more prominent. An area (51 ha) of low lying land along the watercourse is mapped as A0S2$_W$ in this area, associated with a swamp vegetated primarily by *Melaleuca quinquenervia*. Only 1 site (76) was investigated toward the edge of this area due to inundation with water. The surface elevation of Site 76 was 1.8 m AHD, with soil sampled to a depth of 1.0 m by hand auger. Site 76 is classified as a Sulfuric Redoxic Hydrosol, with sulfidic (0.127 % S) dark sapric clay loam to 0.2 m, over black sapric light clay to 0.4 m, over grey light medium clay. Soil is AASS (existing acidity up to 0.32 % S) below 0.4 m depth, which is unusual given that AASS usually overlies PASS. It appears that monosulfides may be present in the surface, affecting existing and potential acidity levels.

While PASS were not encountered at depth at Site 76, it is considered that closer to the centre of the channel, PASS are likely to be encountered between 1–2 m depth. Inundation by water however prevented access to this area.

Photo 12: Site 76 location

Photo 13: Site 76 soil profile to 1.0 m

Surface elevations increase further upstream and accordingly so does the depth to ASS. Site 1 is in an area mapped as A1S3 and Site 2 is in an area mapped as A2S3. Site 2 is furthest up Saltwater Creek and has a surface elevation of 3.4 m, with PASS encountered from 2.75 m depth (0.65 m AHD) to 4.1 m (–0.7 m AHD). Around 1 m of non-estuarine sediments overlay AASS then PASS. Site 2 was classified as a Sulfuric Redoxic Hydrosol and was sampled to a depth of 4.3 m. The soil profile consisted of grey to dark grey light to heavy clays to 1.75 m depth (sulfuric from 1.25 m), over sulfidic sand (0.166 % S) to a depth of 4.25 m. Below this depth, the underlying sandstone was encountered. Vegetation was dominated by *Melaleuca quinquenervia*.

Photo 14: Site 2 location

Photo 15: Site 2 soil profile to 4.3 m

The dominant clay textures and general high levels of potential acidity of up to 3.77 % S in Area 1 indicate a low energy depositional environment, particularly in the lower reaches. In general, the average upper elevation of ASS deposits appears to be about 1.6 m AHD in Area 1. High level PASS extends from Site 15 well up Saltwater Creek to at least Site 1. As the inlet narrows north of Anzac Avenue, terrestrial sediments become more prevalent and are mixed in the soil profile along with estuarine sediments. These terrestrial sediments are present often as coarse sands derived from the surrounding sandstone. At Site 1, potential acidity levels of up to 1.76 % S were found, which is very high for sands.

High existing acidity levels are present in Site 13. It appears that an artificial drain located 60 m to the west may have lowered the local watertable, allowing in-situ ASS to oxidise. Information collected as part of this survey and submitted as part of development application south of Site 13 indicates soil disturbance in this area has resulted in significant oxidation of ASS, with extremely high levels of existing acidity in some locations. Significant levels of potential acidity remain as well. Some remediation works have already been undertaken and more are proposed as part of the earthworks planned for this development. While human disturbance is likely to have contributed to oxidation of ASS and generation of existing acidity in some areas, AASS are also present in areas which don’t appear to have been disturbed. Accordingly, AASS in this area may be a natural occurrence in undisturbed locations.

Western Hays Inlet and Freshwater Creek (Area 2)

Area 2 comprises the western part of the Hays Inlet plain between Saltwater Creek and north of Griffin, along with Freshwater Creek which extends west past the Bruce Highway. Two barriers have been constructed on the creek to apparently limit or exclude tidal incursion further up the creek system. Based on air photos, they appear to have been constructed some time after 1958. The majority of the area comprises intertidal flats, mangroves, salt marshes, and salt flats. Closer to the bedrock in the west, the older tidal deposits form a coastal plain predominantly above present sea level.

Area 2 encompasses an area of 798 ha, including 446 ha of undisturbed tidal lands (S_{LA}) likely to contain ASS. Approximately 187 ha are mapped as AASS and 37 ha are PASS. All the AASS are partially oxidised or AASS are present over PASS. 109 ha have a low probability of ASS being present. The western fringe of the relic tidal plain appears to be old estuarine deposits with no potential acidity remaining (a0LP) as in Site 81. Shell is present at depth, with actual acidity possibly from previous oxidation of sulfides. Further west along the scarp are quaternary residual colluvial deposits and Landsborough Sandstone mapped as low probability.

North of Freshwater Creek, A0S2 (89 ha) is the dominant map unit, with A1S2 (92 ha) most prevalent south of Freshwater Creek. Site 67 (1.7 m AHD) is representative of A0S2 and was sampled to a depth of 2.7 m. It was classified as a Sulfuric Redoxic Hydrosol, with black clay loam to 0.2 m depth over greyish brown to dark grey clayey sand to 2.0 m depth. Below this depth is dark greenish grey sandy light clay to 2.5 m over greenish black sandy light medium clay to 2.7 m depth. AASS are present from 0.2–1.6 m depth and PASS from 1.8 m (up to 0.4 percent S), with the non-ASS pre-Holocene basement at 2.5 m depth. Shell was encountered from 2.2–2.5 m depth, with acid neutralising material present in some samples at similar depths throughout the area. Vegetation at this location was predominantly *Allocasuarina littoralis* and *Sporobolus virginicus*.

Photo 16: Site 67 location

Photo 17: Site 67 soil profile to 2.7 m

Site 48 is representative of the A1S2 unit. Elevations in the extratidal flats of this map unit are around 1.5–1.9 m AHD. Site 48 (1.6 m AHD) is a Sulfuric Redoxic hydrosol, with brown and grey clay loams to 0.55 m over grey sandy clay loams to 3.6 m depth. Below this depth are very dark grey silty light clays and clay loams. Shell is present from 2.3–5.75 m. Existing acidity of 0.12 % S is present along with jarosite at 0.55 m depth. Potential acidity is present from 1.7 m with a maximum level of 0.99 % S at 4.3 m depth. Site 47 had significant levels of acid neutralising material in shell bearing sediments from 2.6 m depth. Vegetation was primarily *Melaleuca quinquenervia* along with a Eucalyptus species, possibly *Corymbia citriodora* (Spotted Gum).

Photo 18: Site 48 location

Photo 19: Site 48 soil profile to 5.9 m

The generally lower potential acidity levels of the plain, compared with Saltwater Creek, and coarser soil textures such as loams and sands indicate a higher energy depositional environment. This is consistent with the open nature of the embayment at the commencement of the Holocene, when tidal energy would have been high particularly at the margins of the embayment and wave energy would have also influenced the nature of sediment deposited and rates of pyrite accumulation.

In Freshwater Creek, however very high levels of potential acidity of up to 3.36 % S are present, consistent with a low energy tidal inlet, and similar to Saltwater Creek. These areas are mapped as S1 and S2w, with potential ASS present from a depth of 0.6 m (1.2 m AHD) at Site 73 and 1.5 m (1 m AHD) at Site 84. Site 73 is a Sulfidic Oxyaquic Hydrosol, with black sandy clay loam from 0.1–0.4 m over grey clayey sand to 1.0 m over grey clays to 4.2 m. The surface elevation is 1.8 m AHD, with *Melaleuca quinquenervia* the dominant vegetation in this location.

Photo 20: Site 73 location

Photo 21: Site 73 soil profile to 4.2 m

AASS are widespread in Area 2. Significant soil disturbance or drainage does not appear to have occurred; accordingly actual acidity appears to be a natural occurrence. However it is possible that the tidal barriers in Freshwater Creek may have altered the local groundwater hydrology, allowing oxidation of ASS. With respect to the large S_{LA} area, ASS are likely to be present from the surface, consistent with Site 50 which is an intertidal flat mapped as S0. Shell is present in most boreholes in the A1S2 and A0S2 units towards the base of the estuarine sediments. Some acid neutralising capacity (ANC) is present in samples containing shell, and in some locations there is sufficient ANC to account for potential acidity and render the soil self neutralising. It should be noted that caution is required in estimating the neutralising capacity of the soil. With respect to laboratory analysis, even though large shell is removed from the sample before grinding, remaining shell is finely ground. This makes it more reactive during laboratory analysis. As a result, laboratory results can overestimate the field capacity of the shell to neutralise acid. For this reason a fineness factor of least 1.5 must be applied when calculating the net acidity for samples containing ANC.

Griffin (Area 3)

The Griffin area is bounded by the Pine River in the south, Bramble Bay to the east, the Bruce Highway in the west and Freshwater Creek to the North. It is a coastal plain over 1 km wide in places, fringed by Landsborough Sandstone. The western areas contain back swamps in a low energy depositional environment, whereas the east is a higher energy tidal environment. This area covers 816 ha, of which 409 ha was subject to detailed mapping. The remainder is primarily tidal land mapped as S_{LA}, with ASS likely to be present from the surface. Of the 409 ha detailed mapping area, 250 ha (68 per cent) are ASS. Of this 250 ha the majority (217 ha) is AASS, and the remaining 33 ha PASS. Approximately 138 ha have a low probability of ASS being present. This land is largely comprised of soils derived from Landsborough Sandstone and is located around the margins of the area.

In the eastern part of Griffin, A1S2 and A1S3 are the dominant mapping units. Site 60 is representative of A1S3 and was classified as a Sulfuric Redoxic Hydrosol. The surface elevation at Site 60 is 1.9 m AHD. Site 60 encountered black, grey and greyish brown loams to 1.5 m over dark grey loamy sands to 2.95 m. These overlay dark clay loams and clays to 6.0 m. Existing acidity of 0.14 % S is present in the sandy loams at 0.65–0.95 m depth, with PASS present from 2.3 m depth and a maximum potential acidity of 1.06 % S in the silty light medium clay between 5.4–6.0 m. Below 2.3 m depth, the finer texture sediments and higher pyrite content are evidence of a low energy depositional environment. The area is largely cleared, however there are numerous *Eucalyptus tereticornis* trees remaining.

Photo 22: Site 60 location

Photo 23: Site 60 soil profile to 6.0 m

In the west, A0 is the most prevalent mapping unit. This area has shallower deposits of ASS which appear to have fully oxidised. An exception is Site 86, which is included in an area mapped as S_{DL}. Earthworks have been undertaken in this area to widen existing drainage lines, with spoil spread on adjacent land. Site 86 was classified as a Sulfuric, Oxyaquic Hydrosol, with 0.5 m of AASS fill, over partially oxidised undisturbed AASS and PASS. The natural profile consisted of black clay loam from 0.5–0.9 m, over dark grey clays to 3.0 m. High levels of existing acidity (0.47 % S) were found in a sample at 2.6–2.8 m depth, along with reserves of potential acidity (0.41 % S). If it hadn't been disturbed, this area would have probably have been mapped as A0S3, consistent with land to the north-east. The elevation at Site 86 is 1.8 m AHD.

Photo 24: Site 86 location

Photo 25: Site 86 soil profile to 3.0 m

Soil textures in the east of Griffin are predominantly coarse to medium in the upper part of the profile, reflecting the higher energy depositional environment of the previously tidal energy dominated open estuary. Consistent with this are the generally lower levels of oxidisable sulfur. However in the western area textures are finer, reflecting the lower energy environments of the bays. Closer to the Bruce Highway in the south, ASS are found at greater depth of predominantly 3–4 m, represented by the S4 and A1S4 map units. Site 54 represents a levee of the Pine River, with gravel encountered to a depth of 3.0 m. Both Sites 54 and 55 have dark marine muds at depth indicating an incision by the Pine River, whereas an adjacent Site 53 to the north-west was not incised and has Pleistocene deposits at a similar depth.

The Landsborough Sandstone outcrop southeast of Site 86 was an effective barrier preventing the Pine River from incising the land to the west and north of this outcrop during the Pleistocene epoch. Prior to deposition during the

Holocene, the area from Site 86 north to and including the A0S3 unit is likely to have been incised only by a local creek. Site 44 and SEA Site 1002 located north of the outcrop have only AASS overlying shallow weathered sandstone, they are separated by a later incision and deposition of PASS.

A maximum potential acidity result of 1.12 % S was found at Site 61 but most samples were below one % S. Closer to the Bruce highway, Site 54 encountered potential acidity up to 1.88 % S. However this site is not representative of the broader Griffin area. Existing acidity is very high in some locations, with a TAA of 0.43 % S in the top 0.5 m at Site 46. An even higher TAA of 0.54 % S was present at Site 64 in the top 0.5 m however this site had fill on the surface from nearby excavation of a drainage line which was likely to have oxidised more than if it was undisturbed.

South Pine River (Area 4)

This area is extends south from the Lawnton sand and gravel quarries at the junction of the North and South Pine Rivers past the north coast railway line at Brendale. The five-metre contour extends approximately 3.5 km further upstream in this area; however this area was not mapped as part of this project. Area 4 includes Four Mile Creek at Lawnton and covers 339 ha, including 42 ha of land mapped as S_{LA} and S_{DL}. Part of this area has been disturbed for road construction and earthworks associated with playing fields, parks and gardens. This land is mapped as S_{DL}. Area 4 contains 182 ha of ASS, of which 61.5 ha are AASS and 121 ha PASS. The widespread distribution of sand and gravel deposits in the area indicates that it is part of the fluvial delta of the South Pine River, where deposition of terrestrial sediments dominates over tidal estuarine deposition.

In the south near Gympie Road a number of elevated areas including river terraces are present. These areas are represented by the S4 mapping unit and generally have surface elevations of between 3–4 m AHD. Site 20 encountered around 2.5 m of terrestrial alluvium comprising of brown clay loams and clays, over dark greenish grey sandy estuarine PASS sediments to 6.2 m depth. The terrestrial alluvium was classified as a Eutrophic Brown Kandosol, with the estuarine sediments classified as a Sulfidic Oxyaquic Hydrosol. Within these sandy sediments potential acidity levels are low, typical of a high energy depositional environment dominated by fluvial deposition. A maximum potential acidity of 0.08 % S was present in the sands. The surface elevation of Site 20 is four metres AHD.

Photo 26: Site 20 location

Photo 27: Site 20 soil profile to 6.4 m

Remnant meander patterns of the South Pine River are mapped as A3S3. Site 19 is a Chromosolic Redoxic Hydrosol, and is similar to Site 20, with alluvium over estuarine sediments. It differs by lower surface elevations in the map unit of 2.2–3.0 m AHD, and by the presence of AASS and PASS in olive grey and dark greenish grey silty clays above the estuarine sands. High level (1.84 % S) PASS was encountered in sandy light clay at 3.3 m depth. The surface elevation of Site 19 is 2.2 m AHD.

Site 21 (2.4 m AHD) is typical of the high level AASS over PASS present in this area, mapped as A1S2. TAA of 0.32 % S was found at 1.8 m and potential acidity of 2.44 % S at 4.8 m in coarse sand, which is extremely high for sand. However sorting of the sand and fine sediment may have occurred during drilling with the Geoprobe^{TM}, possibly concentrating the pyritic sediment in the sample, and/or a clay lens may have been present.

Closer to Four Mile Creek north of Harvey Street is a scroll plain of the South Pine River mapped as a1S3. Alluvial sediments of 2.1 m depth overlay pyritic estuarine sediments (Site 33). The S2 map unit represents a supratidal flat below approximately 1.4 m AHD in elevation. Site 32 within this map unit encountered high level PASS up to 3.34 % S at 1.2 m depth in silty light clay. The silty clay textures and high sulfide content demonstrate that these sediments were laid down in conditions favourable for pyrite formation, such as a quiet estuarine environment with high tidal exchange.

Four Mile Creek

During the last glacial period of the Pleistocene, Four Mile Creek incised into the Pleistocene sediments, which were subsequently inundated during the Holocene transgression. The LP area is predominantly Pleistocene fluvial sediments which are non-ASS. The S_{DL} map units in this area are mostly land which has been subject to sand and gravel extraction. 1955 black and white aerial photos indicate that Rob Akers sports ground appears to have been filled over an old oxbow which is likely to have contained ASS. The most extensive map unit in this area is a0S0, which represents the intertidal and supratidal flats below around 1.4 m AHD. Site 36 is representative of this area, with PASS present in the top 0.5–3.0 m depth. Site 36 was classified as a Sulfidic Supratidal Hydrosol, with fibric peat to 0.2 m over dark grey clay to 3.0 m, over sand and sandy clay loams to 4.5 m. High level PASS (2.3 % S) was found from 0.8–2.5 m depth in dark grey fine sandy light clay. This overlies riverine coarse sand which doesn’t contain pyrite. The surface elevation of Site 36 is 1.3 m AHD. Vegetation was primarily Salt Couch, with some samphires and mangroves present.

Photo 28: Site 36 location

Photo 29: Site 36 soil profile to 4.5 m

At the western end of Four Mile Creek, PASS were present from 2.7 m depth at Site 38. This area is mapped as a0S3, with surface elevations ranging from around 2.0–2.8 m AHD. Site 38 is classified as a Kandosolic Redoxic Hydrosol, with dark brown to dark grey clays to 2.0 m over dark grey coarse sands to 2.8 m, then grey clay to 5.8 m. Existing acidity levels of 0.16 % S are present at 1.1–1.3 m and may be a result of previous oxidation of sulfides. High level PASS (1.39 % S) are present in the coarse sands between 2.7–3.6 m. Coarse gravels at this depth made sample recovery difficult however, and as limited sample was able to be recovered over the sample depth, sulfides are likely to have been concentrated in the sample. The area was largely cleared, however there were some *Eucalyptus tereticornis* trees present. The surface elevation of Site 38 is 2.5 m AHD.

Photo 30: Site 38 location

Photo 31: Site 38 soil profile to 5.8 m

North Pine River (Area 5)

This area extends west from the junction of the North and South Pine Rivers at Lawnton to beyond Young's crossing. Land in the west of Petrie and Lawnton above five metres AHD was included in the study area where geology mapping, aerial photography and elevation data indicate that land was likely to contain Holocene age sediments, and therefore could contain ASS at depth. A significant portion of Area 5 north of Lawnton Pocket Road comprises highly disturbed land subject to sand and gravel extraction, or used in association with the Amcor Paper Mill at Petrie. Area 5 covers 596 ha, of which 470 ha was excluded from detailed mapping due to this land being waterways, disturbed land, undisturbed tidal land or land that was unable to be accessed during the project. The S_{DL} mapping units which encompass the extractive industry and paper mill sites are likely to contain significant areas of ASS where geology mapping indicates Holocene alluvial deposits. However they were not investigated due to their highly disturbed state. Detailed mapping was undertaken on the remaining 126 ha.

The North Pine River is tightly constrained by the surrounding hard rock geology to the Gympie Road Bridge, where the landscape broadens into a fluvial delta. The broad extent of sand and gravel quarry operations in this area is evidence of the predominantly high energy depositional environment dominated by fluvial energy.

Approximately 103 ha were found to be ASS, of which 5.6 ha were AASS and 97.6 ha PASS. The depth to ASS ranged from the top 0.5 m to over 7 m depth. The main ASS map unit in this area is S5+, indicating PASS at depths greater than 5 m. Sites 16, 17 and 29 are found in this map unit, which represents the lower terrace of the North Pine River. Sites 16 and 17 encountered around seven metres of non-ASS alluvium before pyritic materials were found.

The pyritic samples were very firm and appear to be compacted estuarine sediments of Pleistocene age, or rock from the Rocksberg Greenstone formation or Kurwongbah Beds. These sediments could be naturally pyritic or pyrite could have formed in them close to the surface when they were inundated with estuarine waters. Site 29 however encountered high level PASS (2.09 % S) in dark greenish grey light medium clay at 5.9 m depth which is obviously estuarine sediment. Site 29 was classified as a Dermasolic Oxyaquic Hydrosol, with clays to 2.0 m depth over predominantly brown gravelly sand to 5.9 m, and then greenish grey clay, sand and clay to 7.45 m. Site 29 (S5+) had a surface elevation of 1.85 m AHD. However, surface elevations vary in this unit, based on the depth of overlying alluvial material.

Photo 32: Site 29 location

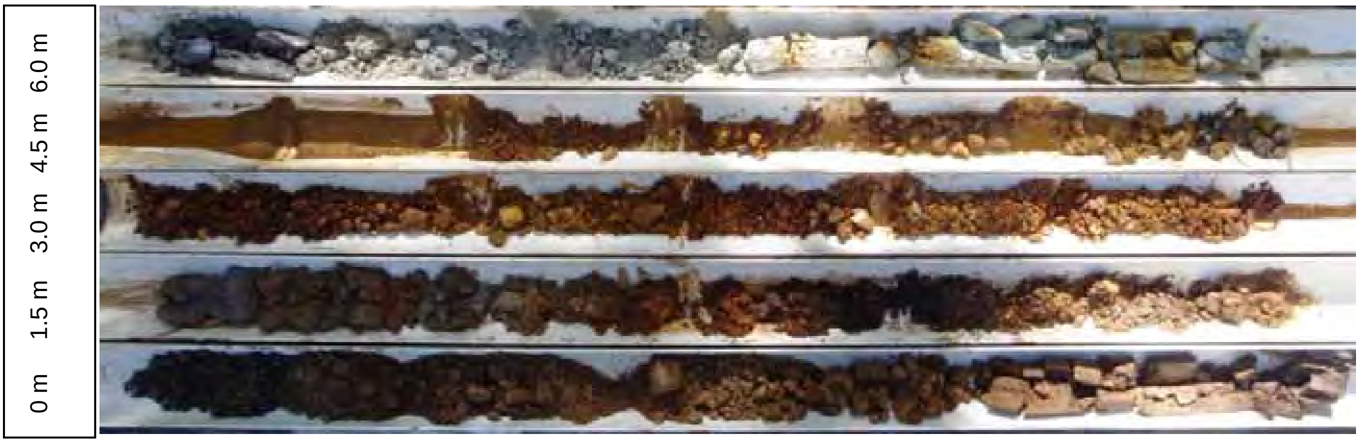

Photo 33: Site 29 soil profile to 7.45 m

The A2S2 units are located off the main channel of the river, shielded from its high energy flows. They are likely to be part of old channel meanders which have filled with sediment in low energy conditions. Site 39 (A2S2) is a Sulfuric Redoxic Hydrosol, with greyish brown to grey clays to 1.7 m over dark grey silty clay loam to 3.95 m, and olive sands to 4.5 m. High level PASS with potential acidity up to 1.7 % S was found in the silty clay loams from 1.85 m depth, underlying oxidised material from 0.95 to 1.85 m. The surface elevation at Site 39 is 1.9 m AHD, giving an elevation of 0.05 m AHD for PASS at this location.

Site 39 is located in a depression within Ron Thomason Park. A site location photo is not available for this site; however an extract from a 2009 aerial photo is included for reference.

Photo 34: Site 39 location

Photo 35: Site 39 soil profile to 4.5 m

The S1 and S2 units represent lower lying supratidal and intertidal flats adjacent to the river. Site 30 (S1) was located in a mangrove-vegetated intertidal flat adjacent to the Pine River and was classified as a Sulfidic Intertidal Hydrosol. Due to access constraints, this site was sampled using a hand auger and as a result a sample was not able to be recovered from below 0.8 m depth due to the presence of gravels. The soil profile of Site 30 consisted of very dark greyish brown clay loam to 0.1 m, over reddish brown light clay to 0.6 m, then dark greenish grey silty light clay to 0.8 m. The elevation at Site 30 is 0.9 m AHD and PASS was found from 0.6 m depth in the silty light clay. It appears that the Pine River has scoured part of the soil profile away in this location, with subsequent deposition of more recent Holocene sediments over the older gravels, which are likely to be similar to Site 29, approximately 50 m to the north.

Photo 36: Site 30 location

Photo 37: Site 30 soil profile to 0.8 m

Site 26 (S0) encountered PASS of 0.71 % S in a sample taken from 0.3 m depth. S0 represents a tidal creek next to the paper mill. Site 41 (S2) encountered high level PASS from 1.05 m depth in light clays, up to 2.87 % S.

East of the Gympie Road Bridge, the alluvium broadens into a bay head delta as per Figure 3. Bay head deltas are typically dominated by terrestrial sourced sediments and this characterises much of the soils in this area. Most of the Holocene alluvium in Area 5 contains several metres of non-ASS alluvium consisting of clays, loams, sands and gravels over estuarine sediments of varying texture. These areas are mapped with the notation S_{DL}, S4, S5 and S5+ reflecting the greater depth to ASS. The exceptions appear to be remnant channel meanders of the Pine River which have filled with younger ASS bearing sediments. These areas are mapped as S0, S1, and S2 areas, reflecting the shallower depth to ASS.

6 Recommendations

ASS are present across most of the study area. ASS (particularly AASS) are close to the surface (i.e. the top 1.0 m) in extensive areas, mainly between Griffin and Rothwell. ASS close to the surface present a greater hazard to the natural and built environment, which can be exacerbated by human activities. Intensive soil disturbance should be avoided where possible in these areas, due to the greater risk of adverse impacts, and the associated intensive, expensive environmental management likely to be required. Infrastructure in these areas is likely to experience corrosion. As a result they are likely to need additional maintenance and may have shorter than expected life spans.

West of the Bruce highway along the North and South Pine Rivers, ASS are often encountered at greater depth underlying non-ASS deposits. Intensive soil disturbance in these areas, particularly the S5+, S5 and S4 map units, is likely to be easier to manage. This is because the majority of earthworks commonly occur in the upper part of the profile, resulting in less disturbance of ASS at depth. Also, the risk of groundwater disturbance impacting upon ASS is often less of an issue in these areas. In areas such as the S5+, S5 and S4 map units where the original ground surface is higher (e.g. around five metres AHD), Council could impose a less stringent assessment regime for developments which involve shallow soil disturbance unlikely to disturb ASS at depth.

AASS are extensive, particularly east of the Bruce Highway. However it seems that a significant proportion of this land may be naturally acidic. Consequences of natural AASS, whilst widespread, are generally mild in effect due to the limited or thin oxidation front, slow transport of acid via groundwater and the natural buffering potential present in many soils. In the study area, options for remediation of these naturally acidic broad acre areas appear limited, are likely to be very difficult and expensive to implement, and may have little environmental or economic benefit. Accordingly, it is recommended that consideration of possible remediation strategies be focussed on areas where human activities are likely to have resulted in the formation of AASS, or at least exacerbated pre-existing acid production. Further investigation would be required for each area of possible remediation in order to adequately characterise the site and develop appropriate remediation strategies.

Historic earthworks in the development site north of Kinsellas Road East have exacerbated natural conditions, with very high levels of existing acidity in spoil and soil in which the groundwater regime has been altered. However, DERM understands that earthworks proposed as part of an approved development in this area will vastly improve current site conditions and reduce future impacts associated with ASS.

At Buchanan Road and Gynther Road Rothwell is an area mapped as A0 with high levels of existing acidity present from the surface. While some existing acidity is likely to have been present naturally in this area pre-disturbance, construction of drains along the road reserves is likely to have increased acid production due to lowering of the groundwater table. Aerial photography from 2009 and LiDAR information also indicate mounds of spoil present along the margins of the drain. If this material has not been treated, it is likely to be an additional source of acidity and metals. In addition, the drain provides a conduit for rapid release of the acidic drainage water into Hays Inlet. Maintaining high water levels in the drains by the use of floodgates could reduce acid generation and discharge, however monosulfides are likely to form in the drains and acidic drain water could be released in concentrated slugs during rain events. Alternatively, release of such contaminants into Hays Inlet could be reduced by filling of the drains and treatment of spoil. If it is not feasible to fill in the drains, it is recommended that they be re-profiled to be shallower and wider in order to reduce acid export.

To the east of Richard Road in Mango Hill are a number of areas adjacent to mangrove flats which have been disturbed by drains and topsoil stripping. These areas are mapped as containing AASS in the top metre and PASS in the top one to two metres. Aerial photography from 2009 and LiDAR information indicates scalded areas of spoil which are likely to contain AASS. These areas are likely to be releasing acidic, metal rich water into Freshwater Creek and Hays Inlet. Release of such contaminants could be reduced by filling of the drains and treatment of spoil. If it is not feasible to fill in the drains, it is recommended that they be re-profiled to be shallower and wider in order to reduce acid export. Tidal exclusion in salt marsh areas should be avoided as this restricts access of fish predators and tidal flushing of the larvae of the salt marsh mosquito *Ochlerotatus vigilax* (Skuse). This mosquito transmits diseases such as Ross River virus (RRV).

On Freshwater Creek, two tidal barriers have been constructed on the creek to limit or exclude tidal incursion further up the creek system. Based on air photos, they appear to have been constructed some time after 1958. It is not clear exactly what impact these works have had upon ASS in this location, however disturbance of ASS upstream of the barriers is indicated by regular iron staining on historic aerial photography over the years. This may indicate some oxidation of in-situ soil during dry periods, with the excluded tidal waters unable to assist in maintaining groundwater levels and neutralising acid production. Removal of the tidal barriers may eventually restore pre-existing conditions; however this would impact upon the local hydrology and freshwater vegetation which has established post construction of the barriers.

Disturbed areas containing AASS are present in Griffin to the west of Henry Road and Greens Road. On Greens Road, drains have been excavated in a low lying area, with spoil spread on adjacent land. Site 86 encountered high levels of existing acidity in spoil and underlying natural horizons. Accordingly, earthworks have exacerbated the AASS likely to have existed prior to disturbance. Costs associated with traditional neutralisation of spoil in this area are likely to be high. A possible alternative strategy could be to maintain high ground water levels in this area in order to reduce further oxidation of sulfides, limit the amount of acidic leachate from moving offsite, and encourage reduction of oxidation products.

Sand and gravel extractive industries have removed large volumes of sediment containing ASS. However concentrated pyritic fines and pyritic clays are likely to be present in base of the resulting ponds. Future disturbance of sediment in these ponds should be avoided and they should remain in saturated, anaerobic conditions in order to avoid oxidation of sulfides.

Further guidance on remediation of ASS can be found in the *Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales* (Tulau, M.J., 2007).

7 Conclusions

The project has identified the presence of AASS and PASS across the study area at varying depths and in a wide range of soil textures. ASS extend at least five kilometres up Saltwater Creek and the South Pine River, and extend close to Young's Crossing at Petrie, which is approximately 17 km from the mouth of the Pine River. AASS are widespread east of the Bruce Highway and are also present along the South Pine River, including Four Mile Creek. High levels of existing acidity were found in the eastern and southern parts of the study area, with high levels of potential acidity found across the study area.

Of the 3086 ha study area, 2340 ha was identified as likely to contain ASS. Large areas of tidal land likely to contain ASS (S_{LA}) in the top metre, large areas of disturbed land (S_{DL}) likely to contain ASS, and land above five metres AHD containing Holocene alluvium (S_{LA}) were not subject to detailed mapping as part of this study.

Of the 1700 ha subject to detailed mapping, 1057 ha were found to contain ASS. Of this 1057 ha, AASS were present in 690 ha from the surface to up to three metres depth. Existing acidity levels of up to 0.64 % S were found, often within the top 0.5 m. PASS were present in 367 ha, with potential acidity levels of up to 3.77 % S present at various depths from the surface to greater than seven metres. 575 ha contained AASS and PASS within the same profile, with PASS often overlain by AASS or in partially oxidised horizons with AASS. Some areas of AASS have obviously been affected by human activities which have disturbed soil and groundwater. However there are large areas of AASS which do not have obvious signs of soil disturbance and hence it appears that they may be naturally acidic.

ASS and AASS in particular are close to the surface (i.e. the top 1.0 m) in extensive areas, mainly between Griffin and Rothwell. Intensive soil disturbance should be avoided where possible in these areas, due to the greater risk of adverse impacts, and associated intensive, expensive environmental management likely to be required. Infrastructure located in these areas are likely to be affected by high acidity levels, leading to premature corrosion and degradation. Council and developers should assess ASS impacts when constructing and maintaining infrastructure in these areas. Other soil disturbance in these areas will need to be carefully managed to avoid exacerbating existing acid release and to avoid detrimental impacts upon the built and natural environment.

Some disturbed areas could benefit from remediation strategies in order to reduce adverse impacts upon the natural and built environment, however further investigations would be necessary in order to adequately characterise these areas and develop appropriate mitigation measures. Very high levels of existing and potential acidity are present in soil associated with an approved development site at Mango Hill; however this material will be treated as part of earthworks associated with the development. Sand and gravel extractive industries have removed large volumes of sediment containing ASS. However the resulting concentrated pyritic fines and pyritic clays are likely to be present in the ponds.

The results of this study indicate the need for caution in planning and managing developments in the Pine Rivers area to avoid costly damage to the environment, human health and local infrastructure. Activities involving significant soil and groundwater disturbance in the area must follow the requirements of the State Planning Policy 2/02; the Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland (Ahern et al., 1998) and the Soil Management Guidelines (Dear et al., 2002). It should also be recognised that the scale of the mapping undertaken in this report is intended for general planning purposes only and that property-scale investigations will be required if QASSIT sampling guideline requirements are to be satisfied for future disturbances in the study area.

References

Ahern CR, Ahern MR and Powell B (1998). *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils (ASS) in Queensland*. Department of Natural Resources, Indooroopilly, Queensland, Australia.

Ahern CR, McElnea AE, Latham NP (2000a). *Total Oxidisable Sulfur (TOS): An Instrument Based Analysis for Screening Potential Acid Sulfate Soils*. In: *Acid Sulfate Soils: Environmental Issues, Assessment and Management, Technical Papers*. Ahern CR, Hey KM, Watling KM and Eldershaw VJ (Eds), Brisbane, 20–22 June, 2000. Department of Natural Resources, Indooroopilly, Queensland, Australia.

Ahern CR, McElnea AE, Latham NP and Denny SL (2000b). *A modified acid sulfate soil method for comparing net acid generation and potential sulfide oxidation–POCASm*. In: *Acid Sulfate Soils: Environmental Issues, Assessment and Management, Technical Papers*. Ahern CR, Hey KM, Watling KM and Eldershaw VJ (Eds), Brisbane, 20–22 June, 2000. Department of Natural Resources, Indooroopilly, Queensland, Australia.

Ahern CR, McElnea AE and Sullivan LA (2004) (Eds). *Acid Sulfate Soils Laboratory Methods Guidelines*. Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia.

Bloom AL, Broecker WS, Chappell JMA, Mathews RK and Mesolella KJ (1974) *Quaternary sea level fluctuations on a tectonic coast. New 230Th/234U dates from the Huon Peninsula, New Guinea*. Quaternary Research, 4, 185–205

Cranfield LC, Donchalk PJT, Green PM, Grimes KG and Hutton LJ (2008). *Brisbane Geology 100 000 scale.* Department of Natural Resources, Mines and Energy, Brisbane.

Dalrymple RW, Zaitlin BA and Boyd R (1992). *Estuarine Facies Models: Conceptual basis and stratigraphic implications*. Journal of Sedimentary Petrology 62(6), 1130–46.

Dear SE, Moore NG, Dobos SK, Watling KM and Ahern CR (2002). *Soil Management Guidelines*. In *Queensland Acid Sulfate Soil Technical Manual*. Department of Natural Resources and Mines, Indooroopilly, Queensland, Australia.

Evans KG, Stephens AW and Shorten GG (1992). *Quaternary sequence stratigraphy of the Brisbane River delta, Moreton Bay, Australia*. Marine Geology 107, 61–79.

Harris, P. T., (1988) *Large-scale bed forms as indicators of mutually evasive sand transport and the sequential infilling of wide-mouthed estuaries*. Sedimentary Geology. 57:273–298.

Hofmann GW (1980). Quaternary sediments and geological history of the Pine Rivers area, Southeast Queensland. Queensland Government Mining Journal October, 1980. 502–12.

Jones MR (1992). *Quaternary Evolution of the Woorim–Point Cartwright Coastline*. Vols. 1 and 2. Marine

Geoscience Unit, Department of Minerals and Energy Project Report MA49/2.

Lang SC, McClure ST, Grosser M, Lawless M and Herdy T (1998). *Sedimentation and Coastal Evolution, Northern Moreton Bay*. In: Tibbets IR, Hall NJ and Dennison, WC. Eds (1998) *Moreton Bay Catchment*. School of Marine Science, The University of Queensland, Brisbane pp.81–92.

McKenzie NJ, Grundy MJ, Webster R and Ringrose-Voase AJ (2008). *Guidelines for Surveying Soil and Land Resources* (2nd edn) CSIRO Publishing, Melbourne.

Moreton Bay Regional Council (2011). *Waterways management, Pine Rivers District.* http://www.moretonbay.qld.gov.au/environment.aspx?id=1752.

Munsell (2000). *Munsell Soil Colour Charts*. Gretag Macbeth, Little Britain Road, New Windsor, NY.

OzCoasts (2011). *Pine River Estuary Search*. http://www.ozcoasts.org.au/search_data/detail_result.jsp

Pickett JW, Thompson CH, Kelley RA and Roman D (1985). *Evidence of high sea level during isotope stage 5c in Queensland, Australia*. Quaternary Research 24, 103–14.

Queensland Government (2002). *State Planning Policy 2/02 Planning and Managing Development involving Acid Sulfate Soils*. Department of Local Government and Planning and Department of Natural Resources and Mines, Brisbane, Australia.

Queensland Government (2002). *State Planning Policy 2/02 Guideline: Planning and Managing Development involving Acid Sulfate Soils*. Department of Local Government and Planning and Department of Natural Resources and Mines, Brisbane, Australia

Roy PS (1984). *New South Wales estuaries: their origin and evolution*. In Coastal Geomorphology in Australia. Thom BG (Ed). Academic Press, Australia. pp 99–121.

Ryan, DA, Heap, AD, Rake, L, and Haggier, DT, (2003) *Conceptual models of Australia's estuaries and coastal waterways: applications for coastal resource management*. Geoscience Australia, Record 2003/09, 136 pp.

Sammut J, White I and Melville MD (1996). *Acidification of an estuarine tributary in eastern Australia due to drainage of acid sulfate soils*. Marine and Freshwater Research 47, 669–84

Sullivan LA, Bush RT, McConchie D, Lancaster G, Clark MW, Lin C and Saenger P (2004). *Chromium Reducible Sulfur (SCR) – Method 22B*. In *Acid Sulfate Soils Laboratory Methods Guidelines*. (Eds CR Ahern, AE McElnea and LA Sullivan). Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia.

The National Committee on Soil and Terrain (2009). *Australian Soil and Land Survey Field Handbook (3rd edn)*. CSIRO Publishing, Melbourne.

Thom BG and Chappell J (1975) *Holocene sea levels relative to Australia*. Search, 6, 90–3.

Thom BG (1981). *Radiocarbon dating of a Holocene beach ridge sequence in southeast Australia. Duntroon, ACT*. Department of Geography, University of New South Wales.

Tulau MJ (2007). *Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales*. Department of Environment and Climate Change, NSW.

Glossary

Acid base account (ABA): A simple equation used to combine the results of several laboratory soil tests to produce a consistent and comparable measure of net soil acidity. The accounting system includes measures of freely available (actual) acidity, acidity released from low solubility chemical compounds (retained acidity) and sulfides vulnerable to oxidation (potential acidity), balanced against any acid neutralising capacity (ANC) if present in the soil. Except where the neutralising material in the soil is very fine, ANC on fine ground laboratory samples is usually an overestimate of effective ANC compared to its field reactions and kinetics. Hence a compensating 'fineness factor' is employed in the equation.

Acid neutralising capacity (ANC): The ability of a soil to counteract acidity and resist the lowering of the soil pH. In an ASS context, acid neutralising capacity is considered negligible if the soil's pH_{KCl} after processing (according to the latest Laboratory Methods Guidelines) is less than 6.5, and can be operationally defined by a range of lab tests. ANC is defined and measured according to the latest *Laboratory Methods Guidelines* (or AS 4969).

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

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

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

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

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

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

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

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

Alluvium: An extensive stream-laid deposit of unconsolidated material, including gravel, sand, silt, and clay. Typically it forms floodplains that develop into alluvial soils.

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

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

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

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

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

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

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

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

Pyrite formation can be generalised by equation (1):

$$4SO_4^{2-} + Fe_2O_3 + 8CH_2O + \frac{1}{2}O_2 \rightarrow 2FeS_2 + 8HCO_3^- + 4H_2O \quad (1)$$

sulfate ions + iron oxide + organic matter + oxygen → pyrite + bicarbonate ions

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

$$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \quad (2)$$

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

$$KFe_3(SO_4)_2(OH)_6 + 3H_2O \rightarrow 3Fe(OH)_3 + 2SO_4^{2-} + 3H^+ + K^+ \quad (3)$$

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

$$CaCO_3 + 2H^+ + SO_4^{2-} + H_2O \rightarrow CaSO_4.2H_2O + CO_2 \quad (4)$$

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

DERM: Department of Environment and Resource Management.

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

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

Facies: A distinct body of rock or unconsolidated sediment with particular features that reference its mode of formation.

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

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

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

In situ: From the Latin; literally, 'in the place'. In this document, the term refers to undisturbed soils or sediment, and often those soils or sediments directly adjacent to or affected by a disturbance. More generally, in soil science the term refers to untransported materials, or to processes that don't involve transport.

Jarosite: An acidic pale yellow (straw or butter coloured) iron sulfate mineral: $KFe_3(SO_4)_2(OH)_6$. Jarosite is a by-product of the acid sulfate soil oxidation process, formed at pH less than 3.7; commonly found precipitated along root channels and other soil surfaces exposed to air.

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

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

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

Monosulfides: The term given to the highly reactive iron sulfide minerals found in ASS that have the approximate formula 'FeS' and which are soluble in hydrochloric acid (as opposed to iron disulfides such as pyrite that aren't appreciably soluble in hydrochloric acid); formed as intermediates during the formation of pyrite. Monosulfides are highly reactive and oxidise rapidly. Includes amorphous FeS, mackinawite $\approx Fe_9S_8$ and greigite $\approx Fe_3S_4$.

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

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

% S: A measure of oxidisable sulfur (using the S_{CR} or S_{POS} methods) expressed as a percentage of the weight of dry soil analysed. Can also be used as an 'equivalent sulfur unit' when comparing the results of tests expressed in other units, or when doing acid base accounting.

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

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

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

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

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

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

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

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

QASSIT: Queensland Acid Sulfate Soils Investigation Team.

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

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

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

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

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

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

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

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

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

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

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

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

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

www.derm.qld.gov.au