QNRM03370

ACID SULFATE SOILS

KEPPEL SANDS – YEPPOON AREA

CENTRAL QUEENSLAND COAST

D J Ross

Queensland Government
Natural Resources and Mines

ACID SULFATE SOILS

KEPPEL SANDS – YEPPOON AREA

CENTRAL QUEENSLAND COAST

D J Ross

Department of Natural Resources & Mines
Queensland 2003

QNRM03370

ISBN 1 920920 03 X

Department of Natural Resources & Mines
PO Box 1762
ROCKHAMPTON QLD 4700

Contents

List of figures

List of tables

List of maps

Summary

Medium intensity mapping of acid sulfate soils has been undertaken for a section of the Central Queensland coast from Keppel Sands to Yeppoon. The mapping identifies areas of both actual acid sulfate soils and potential acid sulfate soils and their respective depth of occurrence. The majority of land containing acid sulfate soils between Keppel Sands and Yeppoon is situated at an elevation of < 5m AHD (Australian Height Datum), however there is land with acid sulfate soils at an elevation of > 5m AHD. Much of this land above 5m AHD consists of sand deposits between Kinka and Tanby.

Between Keppel Sands and Yeppoon, the area of acid sulfate soils is 5,177 ha. This area contains approximately 1,627 ha of actual acid sulfate soils and 3,550 ha of potential acid sulfate soils. Other mapping units indicating areas of land where acid sulfate soils could occur, total 1,057 ha.

Descriptions of the acid sulfate soil map units are presented in this report. The self-neutralising capacity of acid sulfate soils which contain carbonate materials is also discussed. Chemical data for selected depth samples are appended. Sample site location is illustrated on the accompanying Sampling Sites map. The distribution of acid sulfate soils is shown on the Acid Sulfate Soils map.

Further interpretation of the acid sulfate soil mapping has enabled the production of an acid sulfate soils hazard map in which land is classified into four classes of acid generation potential. The four classes are very low, low, moderate and high. The distribution of soils with potential for acid generation is shown on the Acid Sulfate Hazard map.

The acid sulfate soils range in texture from fine sands to heavy clays, are seasonally wet or saturated and have a shallow or perched watertable. Associated landforms include tidal flats, elevated marine plains, beach ridge and chenier plains. Ironbark communities are recorded on low-lying extratidal flats at Zilzie and Coowonga.

Acid sulfate soil layers occur in the soil surface at some sites and fifty-five percent of the area assessed has these layers within 0.5m of the soil surface. Layers of high acid generation potential occur within 1m depth of the soil surface over much of the area.

Oxidisable sulfur levels of up to 6.4% and potential acidities to 4,019 mol H^+/t were recorded on supratidal flats or saltpans. These levels exceed the highest levels previously recorded for the southern portion of the Central Queensland coast area. Intertidal flats or mangrove mudflats had up to 5.7% oxidisable sulfur and potential acidities to 3,173 mol H^+/t, which also exceed previously recorded levels for this landform. High levels of sulfur at shallow depth are associated with the mangrove genus *Rhizophora*. Total actual acidity levels measured by the POCAS method are typically low throughout the survey area.

1. Introduction

Acid sulfate soils (ASS) are soils which contain sulfides or an acid producing soil layer as the result of the oxidation of sulfides. They commonly occur on low-lying coastal land at elevations less than 5m AHD (Australian Height Datum) and are usually contained in saturated soil or sediment. Excavating soil or sediment, extracting groundwater or the filling of land cause disturbance of acid sulfate soils. When exposed to air, sulfides oxidise to produce sulfuric acid. Disturbed land can release acid, aluminium, iron and heavy metals into drainage waters affecting aquatic plants and animals. Concrete and steel infrastructure including pipes, foundations, house slabs and bridges are susceptible to acidic corrosion leading to accelerated structural failure (Ahern *et al.*1998a).

Both actual acid sulfate soils (AASS) and potential acid sulfate soils (PASS) occur throughout the survey area. Actual acid sulfate soils are soils or sediment containing highly acidic soil horizons or layers affected by the oxidation of soil materials that are rich in iron sulfides, primarily pyrite. This oxidation produces hydrogen ions in excess of the sediments capacity to neutralise the acidity, resulting in soils or sediments of pH 4 or less. Potential acid sulfate soils are soils or sediment containing iron sulfides or sulfidic material that have not been exposed to air and oxidised. The field pH of these soils or sediment in their undisturbed state is pH 4 or more, and may be neutral or slightly alkaline (Anon. 2002).

The survey area is located at Yeppoon on the Central Queensland coast (Figure1). It is comprised of a number of relatively small coastal catchments draining into Keppel Bay. These coastal catchments contain areas of extensive grazing, urban development and support wetlands, recreational fishing, boating and the tourist trade. Excluding the low rises, steep hills and headlands of country rock, the survey area is approximately 6,200 hectares in area. Joskeleigh Road at Keppel Sands forms the southern boundary of the survey area while the northern boundary is essentially defined by Fig Tree Creek at Yeppoon. Much of the western boundary generally follows the landward extent of known marine influence.

A reconnaissance survey of acid sulfate soils along the southern part of the Central Queensland coast (Ross 2002) had identified acid sulfate soils at several locations from Keppel Sands to Statue Bay in the current survey area, and that information is used in the map compilation. Prior to the current survey, acid sulfate soil mapping was restricted to an area of the Capricorn International Resort land immediately north of the township of Yeppoon (Ross *et al*. 2000). This mapping project has been undertaken at the same mapping scale 1:50 000, which represents a medium intensity survey with the suitability of information limited to planning purposes. Map unit description and chemical data from laboratory analyses are presented in this report.

A number of land use activities associated with potential acid sulfate soil disturbance are present in the Keppel Sands -Yeppoon area. These include housing and resort development, the construction of roads, bridges and boat ramps, sand extraction, aquaculture, and ponded pasture on marine plains. The mapping project was initiated in partnership with Livingstone Shire Council in response to increasing development pressure along the coastal strip and the likelihood of ASS disturbance through future development.

Figure 1. Location of the survey area.

2. Survey area

The majority of the coastline between Keppel Sands and Yeppoon consists of sandy beaches separated by a number of prominent rocky headlands. The longest sandy beach (about 6km) is situated in the southern part of the survey area south of Coconut Point. These beaches are dissected in part by a number of tidal creeks and clayey inlets, the largest being Cawarral Creek just north of Keppel Sands. Elevated foredunes with residential development are a distinctive feature of the coastline at several locations, including Keppel Sands, Kinka and Lammermoor. Narrow to broad areas of sand ridges and extensive areas of tidal flats occur landward of the beach zone.

Coastal landforms made up of marine sediments (foredunes, sand ridges, cheniers and tidal flats) are mainly the result of Holocene (last 10,000 years) sea level rise and fluctuations. Areas of older, Pleistocene, (>10,000 years) degraded sand ridges occur at Keppel Sands and Kinka. Sediments supplied to the nearshore zone come mainly from the Fitzroy River. The drowned sandy coastal plain which now forms the seabed of Keppel Bay, is a secondary source of sediment (Beach Protection Authority 1979). Deep drilling in low-lying areas (elevation around 2m AHD) during the survey indicates thickness of the sediment to be > 6m at some locations, with much of this being pyritic.

Broad scale geological mapping has been undertaken for the survey area (Beach Protection Authority 1979, Willmott *et al*. 1986). The local country rock or pre-Quaternary bedrock consists mainly of sandstone, mudstone and chert of the Curtis Island Group. Sulfide bearing rock is not indicated. Most of the pyritic sediments are contained in Quaternary (Holocene) estuarine mud and sand deposits in mangrove flats, saltpans and coastal grassland, at elevations <5m AHD. Beach ridge sand deposits and chenier beach barrier deposits are also significant areas containing pyritic sediments. The distribution of older Quaternary (Pleistocene) sand deposits has been mapped by the Beach Protection Authority (1979). Both Holocene and Pleistocene beach ridge sand deposits generally occur on land above 5m AHD.

Wetlands within the survey area are seasonal with inundation mainly associated with summer rainfall. Average annual rainfall at Yeppoon is 1320mm and highly variable. There is some anecdotal evidence that average annual rainfall is considerably less at Keppel Sands, some 20km south. To alleviate the effects of drought, grazing properties in the Kinka area have in the past developed ponded pasture systems usually at the estuarine freshwater interface to prevent seawater incursion and to impound freshwater for pasture growth (Figure 2). An unseasonaly high winter rainfall event in early June 2002 prevented access to the Kinka wetlands for sampling.

Land use is mapped as part of the Water Park Creek Catchment for the Bureau of Rural Sciences national land use survey (Simpson and Leslie 2002). This mapping shows the dominant land use as grazing, with significant areas of rural residential land use. The embayment area occupied by the Cawarral Creek Fish Habitat Area is also substantial in size, with tidal creeks and tributaries used for recreational fishing. Mapping of tidal wetland plant communities along the central Queensland coast (Bruinsma 2000) indicates the estuaries of Coorooman and Cawarral Creeks to be dominated by the mangrove genus *Rhizophora* with almost equal proportions of *Rhizophora* and *Avicennia* communities occurring in the smaller Ross Creek estuary. Very high levels of acid producing potential are associated with the mangrove genus *Rhizophora*.

3. Methods

Sites for description and assessment were selected using a free survey technique (Reid 1988) with the aid of 1:25 000 scale colour aerial photographs and topographic image maps. The accompanying acid sulfate soil map has been compiled at 1:50 000 scale and meets the sampling requirements for medium intensity soil mapping. Soil boundaries that indicate the presence of both actual acid sulfate soils (AASS) and potential acid sulfate soils (PASS) at various depth categories are marked on the map. Acid sulfate soil information collected during previous surveys (Ross 1999, 2002) was used in the compilation. The map reference was adopted from the Queensland Acid Sulfate Soil Investigation Team (QASSIT) with minor modification to suit the survey area results. Site and soil description follows the Australian Soil and Land Survey Field Handbook (McDonald *et al*. 1990).

Much of the sampling was undertaken using 75mm diameter stainless steel Dormer hand augers. Sands at foredune and beach ridge sites were hand augered to the watertable or to 5m depth where the watertable was absent. Hydraulically driven stainless steel push tubes (75mm diameter) combined with tapered gouge augers (73, 60 and 48mm diameter) and push rods were used to sample sites with clay sediments and vehicle access. Undisturbed continuous cores were taken at 48 sites to depths of up to 7.2m with the QASSIT track mounted Geoprobe coring machine (Figure 3).

Field pH tests were carried out using a WP81 pH-conductivity meter fitted with an IJ44 pH electrode. Field pH (pH_F) and field pH peroxide (pH_{FOX}) measurements were determined at 0.25m intervals to the depth of sampling in accordance with QASSIT guidelines (Ahern *et al*. 1998a). With the exception of calcareous sands and shelly clayey sediments, the pH_{FOX} test was an extremely reliable indicator of potential acid sulfate soils. The presence of oxidisable sulfur in calcareous sands and shelly clayey sediments is usually indicated by an increase in pH after peroxide oxidation ($pH_{FOX} > pH_F$).

Following field pH tests, samples for laboratory analysis were selected at each site from the upper depth of occurrence of the acid sulfate soil layer, for confirmation of the depth category for mapping. The lower depth of occurrence of the ASS layer was also usually sampled at each site. More frequent sampling down the soil profile occurred at Geoprobe cored sites. Selected samples were placed in a portable refrigerator / freezer and packed frozen for dispatch to Brisbane by overnight air express. Shell coarse fragments and carbonate concretions were manually removed from clayey samples and sieved from dried sandy samples.

Selected soil samples from each site were analysed for peroxide oxidisable sulfur, total actual acidity and total potential acidity using the Peroxide Oxidation-Combined Acidity and Sulfate (POCAS) method (Ahern *et al*. 1998b). Laboratory results are given in the Appendix. Thirty-eight samples analysed by the POCAS method were subsequently analysed by the Chromium Reducible Sulfur method C_{RS} (Sullivan *et al*. 2000). In addition, thirty samples were analysed for inorganic carbon (Leco carbonates) and calcium carbonate content (ANC method) to determine the self-neutralising capacity of PASS soils with carbonate materials.

4. Description of the soil map units

The depth to an actual acid sulfate soil (AASS) layer and/or potential acid sulfate soil (PASS) layer on relatively undisturbed land is shown on the accompanying soil map by an alphanumeric code. The alpha component A refers to an AASS layer, the alpha component S to a PASS layer while the numerical component (for example 0,1,2 etc) refers to the depth at which these layers occur. Additional information is provided (by code) for areas of soils with a strongly acid soil layer, those containing carbonate materials or an association with wetlands, and those formed on sediments of Pleistocene age. Other map units indicate ASS on disturbed lands or areas where there was limited assessment due to restricted access. The distribution of land where there is a low probability of ASS occurring below or above an elevation of 5m AHD is also shown on the map.

Between Keppel Sands and Yeppoon, the area of land mapped with acid sulfate soils is 5,177.5 ha. This area contains approximately 1,627 ha of land with AASS and 3,550 ha of land with PASS (Table 1). Other map units indicating areas of land where ASS are likely to occur, total 1,057.3 ha.

4.1 Actual Acid Sulfate Soils

A0 (AASS layer within 0.5m depth, no PASS layer)

These soils occur on narrow extratidal flats near the Cawarral Creek boat ramp, and on the landward margin of supratidal flats (saltpans) along Coowonga Road. The associated vegetation is narrow-leaved ironbark (*Eucalyptus crebra*) and paper-barked tea tree (*Melaleuca quinquenervia*). The soils are typically strongly acid at shallow depth, contain jarosite, and have no measurable actual or potential acidity in selected samples analysed by the POCAS method. At some locations these strongly acid layers overlie a cemented brown hardpan or cemented gravel layer which was not penetrable by sampling equipment.

A0S0 (AASS layer and PASS layer within 0.5m depth)

Mapping unit areas designated with the codes A0S0 and A0S0/S0 total 1,315 ha in area and represent 80% of the area of actual acid sulfate soils. The dominant landforms are infrequently inundated supratidal flats (bare saltpans). Some areas contain more frequently inundated intertidal flats with mangrove cover (potential acid sulfate soils), hence the /S0 association. The largest areas occur in the Cawarral Creek inlet. There are also substantial areas mapped behind Causeway Lake and Kemp Beach (Figure 4).

Common soil profile features are a thin brown structured surface horizon grading to a greyish brown clay subsoil with abundant pale yellow jarosite mottles. The lower unoxidised sulfidic layers are dark grey or greenish grey in colour with organic fragments. The soil surface cracks when dry and the fine granular surface in highly saline areas is susceptible to wind erosion.

The highest levels of pyritic sediments occur in these map units with S_{POS} values recorded up to 6.4% with a corresponding total potential acidity (TPA) value of 3,512 moles of hydrogen per tonne of soil (mol H^+/t). Total actual acidity (TAA) values of the jarosite layer are typically low (<50 mol H^+/t).

Figure 2. Pondage bank excluding tidal water to Kinka wetlands (spring tide).

Figure 3. Geoprobe core sampling, chenier plain, Keppel Sands.

Figure 4. Supratidal flat (saltpan) behind Kemp Beach.

Table 1. Areas of map units.

Map Unit	Map Unit Area (ha)	Percentage of Area Assessed
Actual acid sulfate soils		
A0	7.2	0.1
A0S0	960.4	15.4
A0S0/S0	354.8	5.7
A0S1	45.7	0.7
A0S2	55.2	0.9
A1S1	31.4	0.5
A1S2	125.8	2.0
A2S2	28.1	0.5
A3S3	18.8	0.3
Total	**1627.4**	**26.1**
Potential acid sulfate soils		
S0	727.3	11.7
$S0_N$	13.0	0.2
S0/S1	958.6	15.4
S1	369.5	5.9
$S1_N$	17.4	0.3
S1/S2	124.5	2.0
$S1_N/S2_N$	81.9	1.3
S1/S3	33.9	0.5
$S1_NS4/S2_N$	152.5	2.4
$a0S2_w$	10.1	0.2
$S2_N$	98.6	1.6
$S2_N/S3_N$	198.1	3.2
$S2_N/S3_NS4$	66.0	1.1
$S2_NS4$	55.6	0.9
S3/S4	31.6	0.5
$S3_NS4$	9.3	0.1
$S3_N/S4_N$	242.3	3.9
$S4_N$	53.2	0.8
$S4_NS5$	21.6	0.3
S4/S5+	4.5	0.1
S^P4	29.2	0.5
S^P4/S^P5	71.1	1.1
$S5_N$	64.7	1.0
S^P5/S^P5+	115.6	1.9
Total	**3550.1**	**56.9**
Other map units		
S_{LAN}	142.4	2.3
S_{LAW}	137.9	2.2
S_{DL}	45.9	0.8
LP	113.2	1.8
LP5	617.9	9.9
Total	**1057.3**	**17.0**
Total	**6234.8**	**100.0**

A0S1 (AASS layer within 0.5m depth, PASS layer 0.5 to1m depth)

The A0S1 map units are relatively small in area and mostly represent the slightly elevated margins of extensive areas of supratidal flats that were sufficiently large enough to map at the operative scale. The mapped areas are situated near Svendsen Road Zilzie, adjacent to and behind Causeway Lake and along the western margin of the Kemp Beach saltpan. Marine couch (*Sporobolus virginicus*) is usually a feature as the areas are slightly elevated.

The soil profiles range in texture from fine sandy loams to heavy clays but have in common a moderately thick surface horizon and layers containing jarosite. The variable oxidisable sulfur content of the soils is related to soil texture, ranging from 0.32% in fine sandy loams to 2.4% in heavy clays. TAA values range from 31 to 104 mol H^+/t, and TPA values from 285 to 1,460 mol H^+/t.

A0S2 (AASS layer within 0.5m depth, PASS layer 1 to 2m depth)

This single map unit is situated behind the foredunes of Kemp Beach. It extends along the coastline from an area west of Bluff Point to a drainage line in the Capricorn Coast National Park- Rosslyn Head Section. The landform is classed as a marine plain as it is situated above current tidal influence. Marine couch occupies the section of clay plain adjacent to the Livingstone Shire Council water main. The sandier section adjacent to the foredunes contains a range of vegetation types including dwarf blue gum (*Eucalyptus tereticornis*), paper-barked tea tree, wattle (*Acacia* sp.) and cabbage tree palm (*Livistona decipiens*).

A structured grey heavy clay with a black surface layer occupies much of the area of marine couch grassland. The woodland area has weakly structured grey sandy clay soils overlying fine sand at shallow depth. Jarosite in these soils often extends from 0.4m to 1.2m depth and the shallow groundwater is strongly acid. Deep drilling indicates the thickness of pyritic sediments of approximately 4m, and an underlying light grey cemented hardpan possibly of Pleistocene age. Oxidisable sulfur levels in the clay substrate range from 0.53 to 2.74% with TPA values up to 1,785 mol H^+/t, and in the fine sand substrate to 0.4% with a corresponding TPA of 268 mol H^+/ t.

A1S1 and **A1S2** (AASS layer 0.5 to 1m depth, PASS layer 0.5 to 2m depth)

These map units dominantly represent the low-lying marine couch plains located adjacent to or west of Causeway Lake. Some areas have pondage banks and are not affected by tidal influence while others are unlikely to receive tidal waters due to tidal restrictions by the weir of The Causeway. The drainage depression and man made wetland area adjacent to the old Yeppoon-Emu Park road at Lammermoor is also represented by these map units, and a few small areas near Coorooman Creek inlet.

The soil profiles near Causeway Lake are typified by a dark to black organic enriched surface horizon of high clay content, which cracks when dry. However, gravels can be present in the soil surface horizon and mottled grey clay subsoil where the soils adjoin low rises of country rock. Sediments below the grey clay subsoil are permanently reduced and are predominantly dark grey to greenish grey silty clays (Figure 5). The oxidisable sulfur content of these sediments range from 1.0 to 2.6%, and potential acidity 573 to 1205 mol H^+/t respectively. The sandy sediments at Lammermoor have much lower levels of oxidisable sulfur (0.12%) and potential acidity (70 mol H^+/t), to the depths sampled.

A2S2 and **A3S3** (AASS layer 1 to 3m depth, PASS layer 1 to 3m depth)

Actual acid sulfate soils occur within two major drainage lines of an extensive area of beach ridge plain dominated by potential acid sulfate soils at Kinka. The associated vegetation is paper-barked tea tree and cabbage tree palm. The soils are quite variable in surface texture ranging from fine sand through peaty sand to clay. Depth to the actual acid sulfate soil layer varies from 0 to 3m, and layering is common with depth. The more common profile consists of a dark structured clay soil (non acid sulfate soil) overlying a buried sandy acid sulfate soil within 1 to 2m depth. Jarosite is present in the lower part of this buried sandy layer and the shallow watertable is strongly acid.

The levels of oxidisable sulfur and TPA in the sandy substrate of the more easterly situated drainage line range from 0.49 to 0.98% and 280 to 603 mol H^+/t respectively. The other drainage line to the west is formed in older sand sediments. Lower levels of oxidisable sulfur and TPA were recorded in the upper sand substrate of this drainage line. These range from 0.09 to 0.21% and 65 to 190 mol H^+/ t respectively. Deep drilling through the watertable in this drainage line shows the potential acid sulfate soil layers to continue to below 6m depth with oxidisable sulfur levels to 0.59% and potential acidity values to 382 mol H^+/t. High levels of actual acidity (TAA to 135 mol H^+/t) can occur in the organic enriched (peaty) soil surface horizons of these drainage lines.

4.2 Potential Acid Sulfate Soils

S0 (PASS layer within 0.5m depth)

The S0 map units occur intermittently throughout the survey area from Keppel Sands to Mulambin and make up 20% of the area of potential acid sulfate soils. They are associated with frequently inundated intertidal flats (locally called mangrove mudflats) and all of the units adjoin tidal inlets or tidal creeks. Mangrove cover is a characteristic feature. Closed thickets of the mangrove genus *Rhizophora* are common in the Cawarral Creek inlet and open to closed thickets of *Avicennia*/*Rhizophora* are more common elsewhere.

The soils are saturated dark grey, grading to greenish grey silty clays with a greyish brown surface horizon. Organic materials feature in the surface layer and underlying silty clay sediment. The potential acid sulfate soil layer can occur in the soil surface layer of these map units. For example site CQA374 (Appendix), 0-0.2m depth sample contains 0.93% oxidisable sulfur and TPA of 380 mol H^+/t. Very high levels of oxidisable sulfur (1.8-3.3%) and total potential acidity (1023-1765 mol H^+/t) are recorded in map units of the Cawarral Creek inlet with *Rhizophora*. The levels elsewhere range from 0.4 to 1.2% oxidisable sulfur and 145 to 643 mol H^+ per tonne of soil.

S0$_N$ (PASS layer within 0.5m depth with carbonate materials)

This unit covers a small area of mangrove mudflat (intertidal flat) at Shoal Bay and a small area of saltpan (supratidal flat) west of Causeway Lake. The soils are distinguished from those of the previous S0 unit by the presence of carbonate materials (mainly in the form of very fine shell) throughout the soil profile. Like the previous unit the PASS layer can be found in the soil surface layer but has no measurable acid generation potential. Similarly, lower PASS layers have no measurable acid generation potential. Oxidisable sulfur values range from 0.3 to 0.74% in soils throughout this unit.

S0/S1 and **S1** (PASS layer 0 to1m depth)

The S0/S1 and S1 map units occupy an area of 1,328 hectares or 37% of the total area of potential acid sulfate soils. Extensive areas occur in the southern portion of the survey area from Keppel Sands to Coowoonga. Much of the landform here and at Ross Creek, Yeppoon is dominated by intertidal flats with mangrove cover and slightly elevated areas of supratidal flats (saltpan) with samphire (*Arthrocnemum* spp.). In the Zilzie area the map units mostly represent low-lying drainage areas of a beach ridge plain that have been banked to exclude tidal influence and promote grass cover. Elsewhere, the units are represented by a modified (banked) saltpan at Shoal Bay, intertidal flats adjacent to Causeway Lake and those of Fig Tree Creek Yeppoon.

In the Keppel Sands to Coowonga area, the soils range from fine sandy clays to medium clays. The greyish brown soil surface horizons usually have distinct brown or orange mottles and organic materials are common in the dark grey or greenish grey substrate. The highest level of oxidisable sulfur (5.7%) and acid generation potential (3,137 mol H^+/t) in the survey area, associated with an intertidal flat, was recorded adjacent to Coorooman Creek at Coowoonga. Very high levels of oxidisable sulfur (3.7%) and acid generation potential (2,345 mol H^+/t) were recorded on an intertidal flat at Ross Creek Yeppoon. Substantial levels of oxidisable sulfur (>1%) are generally associated with the S0/S1 and S1 map units elsewhere. However, in the banked drainage area at Zilzie, adjacent to shelly beach ridge sands, much lower levels are common (0.09 to 0.4% oxidisable sulfur, 19 to 92 mol H^+/t) in fine sandy clay soils overlying layers of fine sand, coarse sand and shell.

$S1_N$ (PASS layer 0.5 to1m depth with carbonate materials)

This relatively small unit (17.4ha) is located north east of Joskeleigh Road at Keppel Sands. It occupies an area of saltpan (supratidal flat) immediately behind the low ridge of shelly foredune sand. The unit has some low mangrove shrubs in a shallow tidal channel and along the wetter western margin adjacent to beach ridge sands. The soil profile, overlying shelly greenish grey fine sand sediment, consists of fine sand which is not common on saltpans (supratidal flats) in the survey area. An oxidisable sulfur value of 0.09% was recorded in unoxidised fine sand sediment with no measurable acid generation potential.

S1/S2 (PASS layer 0.5 to 2m depth)

Much of the lower section of Pumpkin Creek from Joskeleigh Road to Keppel Bay comprises this single complex map unit. The unit contains the following landform elements, a tidal creek, mangrove mudflats (intertidal flats), bare saltpan (supratidal flats), marine couch grassland (extratidal flats) and low sand ridges (beach ridges). Moreton Bay ash (*Corymbia tessellaris*), paper-barked tea tree and cabbage tree palm are common on the low sand ridges. The soils range from bleached yellowish brown sands to mottled dark grey structured clays. The levels of oxidisable sulfur range from 0.32% in sand ridges to 1.1% in tidal clay flats, with corresponding potential acidities of 165 and 414 mol H^+/t.

$S1_N/S2_N$ (PASS layer 0.5 to 2m depth with carbonate materials)

Low-lying narrow sand ridges and broader adjoining flats (chenier plain) at Coconut Point are part of this mapping unit. Flat areas between sand ridges extending north of Joskeleigh Road at Keppel Sands comprise the remainder of the map unit. The flats have been banked at both locations to exclude tidal influence. A large part of the mapping unit area at Keppel Sands is bare saltpan with areas supporting samphires and marine couch on clayey surface soils. Remnant mangroves occur in former tidal channels. At Coconut Point, isolated mangroves 3 to 5m tall occur in former tidal channels.

The soils are mostly neutral to alkaline in soil reaction (pH 7 to 8.5), contain manganese segregations in the surface layers and subsoil, and very fine shell throughout. They range from pale brown calcareous sands on sand ridges to olive brown medium clays overlying fine sand on flats. Deep sampling on the Joskeleigh Road Reserve records the dark grey and greenish grey fine sand sediments to 5m depth, and overlying a layer of silty clay sediment from 5 to 6m depth. At Keppel Sands, the oxidisable sulfur levels range from 0.09 to 0.24%, and from 0.03 to 0.75% at Coconut Point. There is no measurable potential acidity in the samples taken at both locations.

S1/S3 (PASS layer 0.5 to 3m depth)

Situated behind the foredune at Lammermoor is a low-lying (<5m AHD) beach ridge plain, and narrow tidal flat associated with Williamson Creek. This beach ridge plain has landform and soil characteristics found in older sand deposits along the Yeppoon coastline (degraded ridge/swale system, acidic soil reaction, well-developed soil horizons and gravel at depth). The sand sediments may represent an older sand deposit but are likely to have had Holocene sea incursion due to their low elevation. Moreton Bay ash, wattle and red ash (*Alphitonia excelsa*) are major vegetation components of the sand ridges with paper-barked tea tree and swamp mahogany (*Lophostemon suaveolens*) occupying the wetter swales. Marine couch is dominant on the tidal flat and mangroves along the tidal channel of Williamson Creek.

The main features of the beach ridge sands are a bleached subsurface horizon underlain by a moderately thick layer (up to 2m) of water worn gravels, which in turn overlies grey marine or terrestrial clay. The gravels are predominantly chert and may represent the swash zone of the former shoreline. The potential acid sulfate soil layer occurs on the tidal flat at <1m depth and in the beach ridge sands from <1m to 3m depth, hence the S1/S3 mapping unit. Oxidisable sulfur in the sand deposits range from 0.05 to 0.39%, and potential acidities from 30 to 228 mol H^+/t. Higher levels to 0.47% and 400 mol H^+/t occur in the underlying marine clay. The oxidisable sulfur values and total potential acidities recorded on the tidal flat range from 0.32 to 1.88% and 118 to 1,143 mol H^+/t, respectively.

$S1_N S4/S2_N$ (PASS layer 0.5 to 2m depth with carbonate materials, PASS layer 3 to 4m depth)

This unit is comprised mostly of the slightly elevated flats (extratidal flats) situated between Pumpkin Creek and The Sandhills at Keppel Sands. It includes some areas of bare saltpan (supratidal flats) and very low sand ridges (about 1m elevation). Remnant vegetation is dominantly Moreton Bay ash, blue gum, paper-barked tea tree and cabbage tree palm. The soils range from yellowish brown calcareous sands through dark non-cracking clays to hardsetting olive brown texture contrast soils overlying fine sand. The potential acid sulfate soil layers for these soil types have oxidisable sulfur levels of 0.14 to 0.67%, and occur over a range of depths from 0.8 to 1.8m, with no measurable acid generation potential. However, deep coring provides evidence that these soils can be underlain at depth with potential acid sulfate soil layers with acid generation potential (318 mol H^+/t).

a0S2$_W$ (Strongly acidic layer within 0.5m depth, PASS layer 1 to 2m depth, wetlands)

Two relatively small areas of non-tidal wetland were assigned the a0S2$_W$ map code. They occur as back-swamps in beach ridge sands near Emu Park and Tanby. The dominant vegetation is paper-barked tea tree. The soils are well-structured organic enriched clays grading to sands. Field pH of the soil surface layers is strongly acidic (pH 4 to 5), with field peroxide pH test values <3 units of pH. Oxidisable sulfur in the soil surface layers range from 0.05 to 0.4% with potential acidities to 60 mol H^+/t. The sandy substrate at 1 to 2m depth has oxidisable sulfur values of 0.07 to 0.16% and potential acidity values of 33 to 113 mol H^+/t.

S2$_N$ (PASS layer 1 to 2m depth with carbonate materials)

The S2$_N$ map units are located adjacent to Coorooman Creek inlet in the southern part of the survey area. They are made up of slightly elevated areas of marine couch grassland (extratidal flats) with occasional very low sand ridges. The dominant soils are greyish brown non-cracking clays overlying grey and dark grey sandy sediments. Orange mottles feature in the clay subsoil and very fine shell throughout the subsoil and deep substrate. Pumice occurs in the thin (<1.2m) sand deposits on these clay flats. Oxidisable sulfur levels range from 0.04 to 0.53% in these map units with no measurable potential acidity. Deep coring below the shallow watertable indicates these chemical characteristics continue to below 5m depth.

S2$_N$/S3$_N$ (PASS layer 1 to 3m depth with carbonate materials)

Narrow, low-lying, shelly sand ridges (chenier ridges) at Keppel Sands, and an association of broader sand ridges (beach ridges) and sandy depressions (swales) at Zilzie, are the main landforms represented by this mapping unit. The vegetation of the Keppel Sands map unit consists of woodlands of Moreton Bay ash, quinine berry (*Petalostigma pubescens*), paper-barked tea tree and cabbage tree palm, with mangrove thickets restricted to the very narrow drainage depressions in the eastern part of the map unit. Remnant clumps of cabbage tree palm occur in the Zilzie map unit.

At Keppel Sands, the soils are neutral to alkaline, yellowish brown fine sands overlying layers of coarse shell, and grey to dark grey clay and fine sand. Oxidisable sulfur ranges from 0.06 to 0.19% with no measurable potential acidity. Similar yellowish brown fine sands occupy the Zilzie unit, but have much lower shell content. The sand ridges contain very low levels (to 0.07%) of oxidisable sulfur to 6m depth, and the adjacent sandy depressions very low to moderate levels (0.04 to 0.33%) and no measurable potential acidity, to 5m depth. Towards the western boundary of the Zilzie unit along Svendsen Road, the sands grade from an alkaline to acidic reaction trend below 3m depth where they overlie a layer of gravel and weathered country rock.

S2$_N$/S3$_N$S4 (PASS layer 1 to 3m depth with carbonate materials, PASS layer 3 to 4m depth)

The elevated area of the north-facing embayment between Shoalwater Creek and Ritamada Headland is occupied by a chenier plain. Moreton Bay ash and cabbage tree palm are major vegetation components of the sand ridges. Paper-barked tea tree, silver-leaved tea tree (*Melaleuca dealbata*), swamp mahogany, cabbage tree palm and blue gum occupy the wetter flats or drainage depressions. Neutral to alkaline yellowish brown sands occur on low ridges with oxidisable sulfur levels to 0.45% at 2 to 3m depth, with no measurable acid generation potential. Below 3m depth the underlying shelly clay sediment contains low levels of acid generation potential (70 mol H^+/t). Low levels (28 to 34 mol H^+/t) of acid generation potential also occur in the clayey sediments which lie below shelly sands of the wetter flats or drainage depressions.

$S2_N S4$ (PASS layer 1 to 2m depth with carbonate materials, PASS layer 3 to 4m depth)

This unit occupies the major drainage depression at the junction of the Keppel Sands and Joskeleigh Roads, Keppel Sands. Its northern extent in the Keppel Sands Environmental Park is subject to tidal influence from spring tides. Cabbage tree palm and paper-barked tea tree are the dominant vegetation types with isolated occurrences of blue gum. The soils are essentially very dark grey to black non-cracking clays overlying layers of sand, gravel, shell and silty clay at variable depths. Oxidisable sulfur levels between 1.5 and 3m depth range from 0.03 to 1.09% with no measurable potential acidity. Low levels of potential acidity (48 mol H^+/t) can occur in sediments below 3m depth.

S3/S4 (PASS layer 2 to 4m depth)

Much of the Koorana Crocodile Farm, at Coowonga, is located on this unit. The unit consists of a low sand plain with sand ridges, surrounded by tidal flats. Blue gum, Moreton Bay ash and paper-barked tea tree woodland is the dominant vegetation on areas of uncleared sand ridges. The soils of the sand ridges are neutral to acid, bleached fine sands with layers of rounded gravel. Depth to the potential acid sulfate soil layer on the sand ridges varies from 2.8 to 3.3m. Oxidisable sulfur values in the fine sandy substrate range from 0.19 to 0.43% with potential acidities of 78 to 235 mol H^+/t. Limited sampling on an adjacent ridge flat indicates an actual acid sulfate soil at shallower depth with negligible oxidisable sulfur (0.007%) and low potential acidity (33 mol H^+/t).

$S3_N S4$ (PASS layer 2 to 3m depth with carbonate materials, PASS layer 3 to 4m depth)

High levels of acid generation potential occur in this relatively small map unit, below shelly sand and gravel deposits. The map unit is located at Shoal Bay, immediately behind sandy and clayey intertidal flats with mangrove cover. Remnant vegetation consists of isolated clumps of cabbage tree palm and paper-barked tea tree. The soils are essentially alkaline pale brown sands with abundant shell and gravel to 3m depth. Oxidisable sulfur levels of up to 0.48% are recorded with no measurable potential acidity. Below 3m depth, the clayey sediment contains 0.9 to 1.5% oxidisable sulfur and potential acidities of 475 to 799 mol H^+/t.

$S3_N/S4_N$ and **$S4_N$** (PASS layer 2 to 4m depth with carbonate materials)

These mapping units make up 296 ha or 8.3% of the area of potential acid sulfate soils. They are located adjacent to the present coastline at Kinka, and landward of the chenier deposits at Keppel Sands. The units represent part of the younger (Holocene) yellow brown beach ridge sand deposits, form a series of very narrow ridges and swales, and are distinguished by the presence of shell and relatively neutral pH. Much of the land surface is above 5m AHD. Moreton Bay ash and coastal Banksia (*Banksia integrifolia*) are common on the sand ridges, with silver-leaved tea tree, long-leaved tea tree (*Melaleuca leucadendron*) and cabbage tree palm dominant in the sandy depressions or swales. Oxidisable sulfur values range from 0.05 to 0.14% on ridge sites and from 0.02 to 0.15% in swale sites. No measurable potential acidity is recorded for ridge and swale sites to 6m depth.

S4$_N$S5 (PASS layer 3 to 4m depth with carbonate materials, PASS layer 4 to 5m depth)

This small unit fringes the northern boundary of Causeway Lake at Mulambin. It consists of a low-lying drainage depression with some sand ridges near Neville Street. Paper-barked tea tree, blue gum and cabbage tree palm are the major vegetation types of uncleared areas. The soils are neutral to alkaline sands with concretionary carbonate in the subsoil, and are classified formally as Calcarosols (Isbell 1996). At 3 to 4m depth, the sands have oxidisable sulfur levels that meet the action criteria requiring treatment, but have no measurable potential acidity. Below 4m depth the sands are underlain by clay sediments with oxidisable sulfur levels of 0.19 to 1.37% and potential acidities to 555 mol H^+/t.

S4/S5+ (PASS layer 3 to > 5m depth)

A foredune area at Lammermoor is the only area of foredune sand in the survey area found to contain acid sulfate soils, within a sampling depth of 5m. This foredune system consists of an elevated ridge and well-developed swale or depression immediately adjacent to and parallel to the beach, and more elevated ridges landward with reworked sands. Trees of coastal she-oak (*Casuarina equisetifolia*) occur adjacent to the beach. Pale brown and yellowish brown sands with abundant shell occur in the swale to 3.5m depth. The potential acid sulfate soil layers occur in the underlying layers of sandy clay, coarse sand and gravel. Oxidisable sulfur levels range from 0.34 to 0.48%, and potential acidity is low (43 mol H^+/t).

S^{P}4 (PASS layer 3 to 4m depth, Pleistocene age sediments)

The landform of this map unit is a flat to gently sloping sandplain, mostly above 5m AHD. It contains minor drainage depressions, and indicates an older age sand deposit, in comparison with the landform of other sands in the sequence of beach ridge sands at Kinka. The unit is situated about 2km inland from Kinka Beach. Pink bloodwood (*Corymbia intermedia*), coastal Banksia, Moreton Bay ash and paper-barked tea tree are common vegetation types. The soils are acid, bleached, fine sands with brown subsoils, occasionally cemented, and overlie grey to greyish brown fine sands below 3m depth. Oxidisable sulfur and potential acidity levels are low, to 6m depth. These range form 0.03 to 0.07% and 10 to 53 mol H^+/t, respectively.

S^{P}4/S^{P}5 (PASS layer 3 to 5m depth, Pleistocene age sediments)

This map unit is situated adjacent to and immediately east of the S^{P}4 unit. Local relief is generally low in this degraded beach ridge/swale system. Pink bloodwood is the dominant tree species. Swamp mahogany, coastal Banksia, paper-barked tea tree and Moreton Bay ash are co-dominant species. The soils are slightly acid to acid bleached fine sands with yellowish brown subsoils. These subsoils overlie grey to olive brown saturated sands below 3m depth in the swales, and below 4m depth on ridge crests. Oxidisable sulfur levels range from 0.04 to 0.08% in the swales with corresponding low levels of potential acidity (to 47 mol H^+/t), to 5m depth. Higher levels (0.37%, 199 mol H^+/t) can occur in the swales below 5m depth. Low levels of oxidisable sulfur and potential acidity were recorded for ridge crest sites to 6m depth (0.04 to 0.08% and 18 to 45 mol H^+/t respectively).

$S5_N$ (PASS layer 4 to 5m depth with carbonate materials)

Sampling within this map unit indicates the potential acid sulfate soil layer to occur within the same depth range (4 to 5m) for both sand ridges and swales, irrespective of the local relief. The widely spaced low sand ridges and shallow swales are evident along Alfred Street at Kinka. Pink bloodwood, Moreton Bay ash, paper-barked tea tree and coastal Banksia are common vegetation types. The soils are neutral to slightly acid yellowish brown fine sands (Figure 6) and overlie grey to dark grey sands below 4m depth with finely divided shell fragments. Oxidisable sulfur levels from 4.5 to 6m depth range from 0.03 to 0.12% with no measurable potential acidity.

S^P5/S^P5+ (PASS layer 4 to > 5m depth, Pleistocene age sediments)

The landform and vegetation of this unit is very similar to that of the adjacent $S5_N$ unit described above. However, a higher more elevated sand ridge occurs in the western part of the map unit. The soils are slightly acid to acid, and have well-developed profiles with bleached fine sand layers over yellow brown fine sand. Below 3m depth there is frequently further bleached fine sand layers over bright yellow and reddish yellow fine sand. These grade to grey and greenish grey fine sands, occasionally with shell fragments and rounded pebbles. Oxidisable sulfur levels below 4m depth range from 0.04 to 0.27% with low levels of acid generation potential (15 to 43 mol H^+/t). Deep drilling indicates the potential acid sulfate soil layer to occur at depths greater than 6m, at some sites including the elevated sand ridge.

4.3 *Other Map Units*

S_{LAN} (Limited field assessment and landform indicating ASS with carbonate materials)

Much of the land south of Coconut Point, mapped as S_{LAN}, is occupied by the new Great Barrier Reef International Resort development. The landform consists of a low-lying narrow foredune and beach ridge plain. The sand deposits are the young (Holocene), yellow brown, neutral to alkaline sands with shell. The S_{LAN} map code indicates limited field assessment in a landscape where there is a reasonable probability of acid sulfate soils occurring, with carbonate materials that may compensate for the potential acidity.

S_{LAW} (Limited field assessment and landform indicating ASS, wetlands)

These map units are the back-swamp areas situated in the embayment south-west of Ritamada Headland and are locally referred to as the Kinka wetlands. They are enclosed by low rises of country rock, beach ridges adjacent to Young Avenue, chenier ridges along the Emu Park Road, and by pondage banks. Limited sampling of grey mottled heavy clays near the Emu Park-Ritamada Road junction indicates negligible levels of oxidisable sulfur and no acid generation potential at these sampling sites.

S_{DL} (Acid sulfate on disturbed land)

The S_{DL} map units are restricted to the urban area at Yeppoon and total 45.9 ha in area. The landform is largely man-made with a layer of brown to reddish brown gravelly clayey fill over estuarine sediments or local alluvium. The presence of acid sulfate soils is variable in these map units. For example, non-acid sulfate soils were found at the Council Depot and reserve at Yeppoon Inlet, to 5m depth. In the open tidal drain, along Arthur Street near the Council Depot entrance, very high levels of oxidisable sulfur and acid generation potential were found (4.7% S_{POS} and 2,452 mol H^+/t), at 2.2m below the ground surface. Potential acid sulfate soils occur in the low-lying tidal affected area of the Sewerage Treatment Plant at relatively shallow depth (0.8-1m). Along the road reserve near Yeppoon Creek, acid sulfate soils are recorded at greater depth 2.4- 2.6m.

LP (Land predominantly < 5m AHD with low probability of ASS occurrence)

A low ridge of foredune sand at Keppel Sands, low rise of country rock at Zilzie, and a seasonally wet plain at Tanby comprise this mapping unit. Isolated clumps of coastal she-oak occur on the low ridge of foredune sand at Keppel Sands. The soils are shelly brown sands and the limited sampling depth (1.5m) restricted by the watertable indicates non-acid sulfate soils to this depth. A sand veneer overlies the low rise of country rock on Svendsen Road Zilzie. Samples taken on the ridge crest of weathered clay below the sand veneer indicate low levels of non-pyritic acidity. There is some anecdotal evidence the LP map unit at Tanby was subject to tidal influence prior to construction of the weir of The Causeway. Limited sampling in this unit, opposite the Tanby Turf Farm, indicates non-acid sulfate soils in greenish grey, cemented sandy sediments to a depth of 3m.

LP5 (Land predominantly > 5m AHD with low probability of ASS occurrence)

Approximately 618 ha of land predominantly above 5m AHD is mapped as having a low probability of acid sulfate soil occurrence. The land consists of sand deposits which can have a watertable and may have the potential to contain pyritic materials. Foredune systems adjacent to the current shoreline, from Keppel Sands to Yeppoon, are the dominant landform. Several foredune areas are developed for urban uses and were not sampled. There are also substantial areas of beach ridge plain at Mulambin and Keppel Sands (The Sandhills).

The soils of the foredune area and adjoining beach ridge plain at Mulambin are essentially neutral to alkaline yellowish brown fine sands with shell fragments to 5m depth, and have no measurable oxidisable sulfur in the few sites sampled. Similar soils and laboratory results were found in foredune areas at Kinka Beach and Emu Park.

No watertable was encountered to 5m depth in the few sites sampled in the older sand deposit of The Sandhills at Keppel Sands. The soils are slightly acid to acid yellowish brown fine sands overlying bleached fine sands and alternating layers rounded gravel and sand (Figure 7). Nil to negligible levels of oxidisable sulfur occur in these sands and gravelly sands to 5m depth.

$S5_N$ (PASS layer 4 to 5m depth with carbonate materials)

Sampling within this map unit indicates the potential acid sulfate soil layer to occur within the same depth range (4 to 5m) for both sand ridges and swales, irrespective of the local relief. The widely spaced low sand ridges and shallow swales are evident along Alfred Street at Kinka. Pink bloodwood, Moreton Bay ash, paper-barked tea tree and coastal Banksia are common vegetation types. The soils are neutral to slightly acid yellowish brown fine sands (Figure 6) and overlie grey to dark grey sands below 4m depth with finely divided shell fragments. Oxidisable sulfur levels from 4.5 to 6m depth range from 0.03 to 0.12% with no measurable potential acidity.

S^P5/S^P5+ (PASS layer 4 to > 5m depth, Pleistocene age sediments)

The landform and vegetation of this unit is very similar to that of the adjacent $S5_N$ unit described above. However, a higher more elevated sand ridge occurs in the western part of the map unit. The soils are slightly acid to acid, and have well-developed profiles with bleached fine sand layers over yellow brown fine sand. Below 3m depth there is frequently further bleached fine sand layers over bright yellow and reddish yellow fine sand. These grade to grey and greenish grey fine sands, occasionally with shell fragments and rounded pebbles. Oxidisable sulfur levels below 4m depth range from 0.04 to 0.27% with low levels of acid generation potential (15 to 43 mol H^+/t). Deep drilling indicates the potential acid sulfate soil layer to occur at depths greater than 6m, at some sites including the elevated sand ridge.

4.3 *Other Map Units*

S_{LAN} (Limited field assessment and landform indicating ASS with carbonate materials)

Much of the land south of Coconut Point, mapped as S_{LAN}, is occupied by the new Great Barrier Reef International Resort development. The landform consists of a low-lying narrow foredune and beach ridge plain. The sand deposits are the young (Holocene), yellow brown, neutral to alkaline sands with shell. The S_{LAN} map code indicates limited field assessment in a landscape where there is a reasonable probability of acid sulfate soils occurring, with carbonate materials that may compensate for the potential acidity.

S_{LAW} (Limited field assessment and landform indicating ASS, wetlands)

These map units are the back-swamp areas situated in the embayment south-west of Ritamada Headland and are locally referred to as the Kinka wetlands. They are enclosed by low rises of country rock, beach ridges adjacent to Young Avenue, chenier ridges along the Emu Park Road, and by pondage banks. Limited sampling of grey mottled heavy clays near the Emu Park-Ritamada Road junction indicates negligible levels of oxidisable sulfur and no acid generation potential at these sampling sites.

S_{DL} (Acid sulfate on disturbed land)

The S_{DL} map units are restricted to the urban area at Yeppoon and total 45.9 ha in area. The landform is largely man-made with a layer of brown to reddish brown gravelly clayey fill over estuarine sediments or local alluvium. The presence of acid sulfate soils is variable in

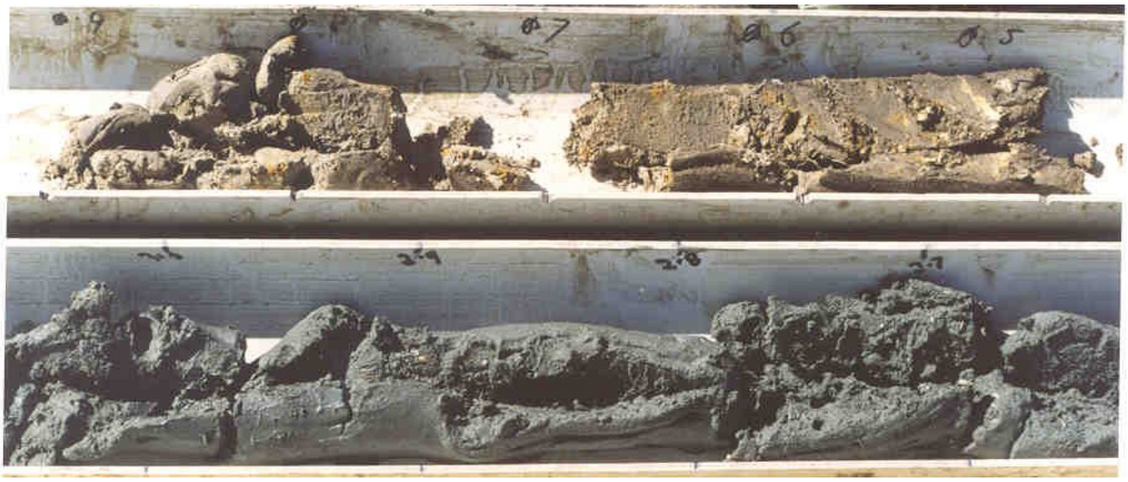

Figure 5. Greyish brown AASS layer over greenish grey PASS layer, Coorooman.

Figure 6. Yellowish brown sands grading to dark grey sand (PASS layer), Kinka.

Figure 7. Freely drained sands with gravel layers below 4m depth, The Sandhills.

Thirty samples throughout the survey area with finely divided naturally occurring carbonate were analysed by two methods to determine the calcium carbonate content and hence self-neutralising capacity (Table 3). These samples were from map units with the N subscript. Oxidisable sulfur values for their respective texture category exceeded the action criteria requiring treatment, but no measurable acid generation potential was recorded. The inorganic carbon content or carbonates determined by the use of a Leco furnace provides a rapid approximate measure of calcium carbonate content. The Acid Neutralising Capacity (ANC) method has the potential to overestimate calcium carbonate content and hence the soils neutralising capacity.

The calculated Net Acid Generation Potential (NAGP) using the ANC result for all samples listed in Table 3 is zero. Ahern and McElnea (2000) do not recommend using NAGP as a risk assessment method because an overestimate of ANC could seriously underestimate potential acid risk. Based on the inorganic carbon (Leco carbonates) value, four samples of medium texture listed in Table 3 theoretically contain insufficient carbonate to be classed as completely self-neutralising. Lime treatment would be required of the respective soils. Much of the area represented by the remaining samples or self-neutralising soils consists of the younger (Holocene) beach ridge sand deposits, chenier beach ridge deposits and areas of extratidal flats at Coorooman.

The accompanying acid sulfate soils map is essentially a map of *depth* to the acid sulfate soil layers. An indication of risk, depending on the type of disturbance, can be inferred from the depth to an actual acid sulfate soil and/or potential acid sulfate soil layer. For example, draining land with actual and potential acid sulfate soil layers at very shallow depth (< 0.5m), within the A0S0 mapping units could be considered a high risk activity. However, there is no indication of the level of sulfides, actual acidity or acid generation potential provided at 1:50000 scale of mapping. Mapping unit areas with the same depth code can contain quite variable levels of sulfides, existing and potential acidity and consequently varying levels of risk.

An assessment of risk (Ahern *et al*. 1998a, Dear *et al*. 2002) is expressed in terms of treatment categories based on laboratory results, soil texture and weight of material to be disturbed. The treatment categories represent increasing levels of risk management for increased levels of sulfide concentration and quantity of disturbed soil or sediment. However, there appears to be no generally acceptable rating scheme of sulfide concentration and acid generation potential for undisturbed acid sulfate soils. Russell *et al*. (1996) used a rating scheme of total sulfidic acidity levels (Low 31-63, Moderate 63-126 and High > 126 moles H^+/t) in an assessment of acid sulfate soils on disturbed land near Cairns, North Queensland. An expanded scheme of hazard ratings was applied to laboratory results in a reconnaissance survey of acid sulfate soils along the Central Queensland coast (Ross 2002).

Acid sulfate soil risk maps which predict the distribution of acid sulfate soils, based on an assessment of the geomorphic environment, have been produced for coastal areas of New South Wales (Flewin *et al*. 1996). The maps identify the areas at risk and likely depth to the occurrence of acid sulfate soils. Three risk classes are used (High, Low and No Known Occurrence) and these can be related to land use activities that may expose acid sulfate soils creating an environmental risk. There is no known formal acid sulfate soil risk or hazard maps for coastal areas of Queensland. Unlike risk maps, hazard maps are based on more objective criteria with limited interpretation.

Table 2. Peroxide oxidisable and chromium reducible sulfur for selected depth samples.

Site No	Depth (m)	Texture [1] Category	S_{POS} [2] (%)	S_{CR} [3] (%)
CQA310	2.8-3.0	Coarse	0.127	0.256
CQA313	0.0-0.2	Medium	0.369	0.027
CQA313	0.5-0.7	Medium	1.377	1.196
CQA313	1.3-1.5	Medium	0.979	0.974
CQA315	4.0-4.2	Coarse	0.053	0.051
CQA317	4.3-4.5	Coarse	0.031	0.043
CQA317	4.8-5.0	Coarse	0.092	0.097
CQA320	2.1-2.3	Coarse	0.099	0.097
CQA320	2.6-2.8	Coarse	0.083	0.096
CQA323	2.3-2.5	Coarse	0.071	0.083
CQA324	0.0-0.2	Medium	0.048	0.000
CQA324	1.3-1.5	Coarse	0.168	0.176
CQA324	1.7-1.9	Medium	0.128	0.147
CQA328	0.9-1.1	Fine	0.074	0.027
CQA328	2.8-3.0	Fine	1.125	1.044
CQA329	0.7-0.9	Fine	2.460	2.196
CQA329	1.6-1.8	Fine	2.361	2.184
CQA330	0.8-1.0	Fine	1.020	0.849
CQA330	1.5-1.7	Fine	1.287	1.191
CQA331	3.5-3.7	Medium	0.480	0.451
CQA331	3.9-4.0	Medium	0.341	0.027
CQA332	0.0-0.2	Medium	0.173	0.158
CQA332	0.8-1.0	Coarse	0.057	0.081
CQA333	0.9-1.1	Medium	0.288	0.288
CQA334	0.8-1.0	Medium	0.182	0.119
CQA334	1.3-1.5	Medium	0.346	0.328
CQA335	0.6-0.8	Fine	1.218	1.030
CQA335	1.4-1.6	Fine	0.961	0.980
CQA337	0.3-0.5	Fine	0.056	0.057
CQA337	0.8-1.0	Medium	0.532	0.436
CQA338	1.5-1.7	Coarse	0.098	0.112
CQA338	1.8-2.0	Coarse	0.037	0.060
CQA339	0.8-1.0	Coarse	0.205	0.256
CQA339	1.5-1.7	Coarse	0.050	0.068
CQA341	0.8-1.0	Fine	0.138	0.153
CQA341	1.6-1.8	Fine	0.533	0.531
CQA342	0.6-0.8	Fine	0.079	0.070
CQA342	1.1-1.3	Fine	0.639	0.595

[1] Ahern *et al*. (1998a).
[2] Peroxide oxidisable sulfur (Ahern *et al*. 1998b).
[3] Chromium reducible sulfur (Sullivan *et al*. 2000).

Table 3. Oxidisable sulfur and acid generation potential for selected samples with carbonate materials.

Site No	Depth (m)	Texture[1] Category	S_{POS} [2] %	TPA [3] mol H^+/t	Inorganic [4] Carbon %	ANC [5] $CaCO_3$ %	EA [6] mol H^+/t
CQA277	0.8-1.0	Medium	0.235	0	0.10	0.5	53
CQA303	4.3-4.5	Coarse	0.140	0	1.79	14.4	0
CQA303	5.8-6.0	Fine	0.394	0	0.23	2.4	0
CQA309	4.6-4.8	Coarse	0.143	0	0.58	5.6	0
CQA310	2.8-3.0	Coarse	0.127	0	2.97	22.3	0
CQA312	5.8-6.0	Coarse	0.050	0	0.45	3.9	0
CQA314	7.0-7.2	Medium	0.263	0	0.22	1.9	0
CQA331	3.9-4.0	Medium	0.341	0	0.14	1.6	86
CQA333	0.9-1.1	Medium	0.288	0	0.61	5.2	0
CQA338	2.8-3.0	Coarse	0.135	0	0.81	6.4	0
CQA339	0.8-1.0	Coarse	0.205	0	0.39	3.7	0
CQA339	4.6-4.8	Fine	0.141	0	0.10	0.7	0
CQA345	4.8-5.0	Medium	0.148	0	0.57	5.4	0
CQA348	0.8-1.0	Medium	0.768	0	0.32	2.9	186
CQA345	0.7-0.9	Medium	0.471	0	0.27	2.4	0
CQA361	3.3-3.5	Medium	1.092	0	0.68	6.1	0
CQA380	1.3-1.5	Fine	0.526	0	1.60	13.1	0
CQA395	1.4-1.6	Coarse	0.468	0	3.24	25.9	0
CQA396	0.5-0.7	Coarse	0.577	0	2.99	28.0	0
CQA398	0.8-1.0	Medium	0.589	0	2.08	18.6	0
CQA401	1.8-2.0	Medium	0.536	0	0.70	5.2	0
CQA408	2.8-3.0	Fine	0.334	0	0.29	3.1	0
CQA437	4.6-4.8	Coarse	0.199	0	1.75	14.4	0
CQA440	4.8-5.0	Fine	0.242	0	0.54	5.6	0
CQA441	4.6-4.8	Medium	0.675	0	0.12	1.8	432
CQA448	3.8-4.0	Coarse	0.136	0	0.52	4.7	0
CQA450	3.8-4.0	Coarse	0.078	0	0.96	7.8	0
CQA450	5.8-6.0	Coarse	0.060	0	0.10	0.6	0
CQA475	1.0-1.2	Fine	0.370	0	0.59	6.1	0
CQA480	1.5-1.7	Coarse	0.155	0	1.68	13.0	0

[1] Ahern *et al*. (1998a).
[2] Peroxide Oxidisable Sulfur (POCAS method).
[3] Total Potential Acidity (POCAS method).
[4] Carbonates (Leco furnace).
[5] Acid Neutralising Capacity (0.1N HCl).
[6] Calculated Excess Acidity for inorganic carbon content (safety factor of 1.5).

The potential acid generation of particular areas of land is illustrated on the accompanying acid sulfate soil *hazard* map. Four classes of acid generation potential are used (Very Low, Low, Moderate and High) based on the concentration of sulfides (peroxide oxidisable sulfur content, S_{POS}) and corresponding acid generation potential (total potential acidity, TPA). The criteria used to establish the classes (Table 4) is essentially a revised acid sulfate soil hazard rating scheme applied to laboratory results in a previous survey (Ross 2002).

Depth to the acid sulfate soil layer is not used in the class criteria because the higher concentrations of sulfides and acid generation potential mostly occur at shallow depth and are associated with clayey sediments. Lower concentrations of sulfides and lower acid generation potential generally occur at greater depth and are characteristically associated with sandy sediments. The hazard map should be read in conjunction with the accompanying acid sulfate soil map. For convenience in use, the depth to the acid sulfate soil layer with significant potential acidity has been placed on the mapping units of the hazard map. For example, where a potential acid sulfate soil layer rich in carbonate overlies a potential acid sulfate soil layer with net potential acidity, the depth to the layer with net potential acidity is given.

Table 4. Acid sulfate hazard classes.

Class	**Criteria**
Very Low	S_{POS} < 0.03% and TPA = 18 to 80 mol H^+/t S_{POS} > 0.03% and TPA = 0 to <18 mol H^+/t Low probability areas
Low	S_{POS} > 0.03% and TPA ≥ 18 to < 200 mol H^+/t
Moderate	S_{POS} > 0.35% and TPA ≥ 200 to <1000 mol H^+/t
High	S_{POS} > 1.5% and TPA > 1000 mol H^+/t

6. Acknowledgments

The author gratefully acknowledges the substantial financial support from Livingstone Shire Council (LSC) for this mapping project and the assistance from LSC staff, in particular, Linda Hine for project facilitation and David Pearson for field assistance and data entry. Col Ahern (QASSIT, NR&M) provided specialised equipment for deep sampling. Geoprobe core sampling was undertaken by Ian Hall (QASSIT, NR&M). Niki Latham and Ian Grant (Analytical Services, NR&M) determined the laboratory results. The maps were prepared and produced by John Simpson (Central West GIS Group, NR&M). Most landowners were cooperative in allowing access to their properties. Deborah Ashby (NR&M) formatted the text. Don Malcolm (QASSIT, NR&M) and Bruce Forster (NR&M) reviewed the document.

7. References

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

Ahern CR, Blunden B and Stone Y (eds) (1998b). *Acid Sulfate Soils Laboratory Methods Guidelines*. Acid Sulfate Soils Management Advisory Committee, Wollongbar, NSW, Australia.

Ahern CR and McElnea AE (2000). An Overview, Comparisons and Codes for Current Analytical Methods to Determine Acid Sulfate Soil Risk. 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, Queensland.

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

Beach Protection Authority (1979). *Capricorn Coast Beaches*. A Detailed Study of Coastline Behaviour along the Capricorn Coast of Queensland, Australia.

Bruinsma C (2000). *Queensland Coastal Wetlands Resources: Sand Bay to Keppel Bay*. Department of Primary Industries Queensland. Information Series QI00100.

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.

Flewin TC, Naylor GA, Chapman G, Atkinson CL, Murphy MJ, Tulau MJ, Milford HB and Morand DT (1996). Maps Make Acid Sulfate Soil Manageable. In: *Proceedings 2nd National Conference on Acid Sulfate Soils*. RJ Smith and Associates and ASSMAC, Australia.

Isbell RF (1996). *The Australian Soil Classification*. CSIRO Publishing, Melbourne.

Mc Donald RC, Isbell RF, Speight JG, Walker J and Hopkins MS (1990). *Australian Soil and Land Survey Field Handbook*. 2nd edition, Inkata Press, Melbourne.

Reid RE (1988). Soil Survey Specifications. In: RH Gunn, JA Beattie, RE Reid and RHM van de Graff (editors) *Australian Soil and Land Survey Handbook, Guidelines for Conducting Surveys*. Inkata Press, Melbourne.

Ross DJ (1999). *Land Suitability Assessment and Soils of the Calliope and Yeppoon Areas, Queensland*. Department of Natural Resources Queensland. Land Resources Bulletin 990066.

Ross DJ (2002). *Acid Sulfate Soils, Tannum Sands to St Lawrence, Central Queensland Coast*. Department of Natural Resources and Mines, Queensland. QNRM02008.

Ross DJ, Malcolm DT and Hall IR (2000). Pyritic sediments in geological map units of Pleistocene age on the Central Queensland Coast. 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, Queensland.

Russell DJ, Smith CD, Best E, Helmke SA and Hales PW (1996). Water Quality Trends from an Acid Sulfate Soil Source, Cairns, North Queensland. In: *Proceedings 2nd National Conference on Acid Sulfate Soils*. RJ Smith and Associates and ASSMAC, Australia.

Simpson J and Leslie MJ (2002). Field Report – Land Use Mapping, Water Park Creek Catchment, Central Queensland. Central West GIS Group, Department of Natural Resources and Mines, Queensland.

Sullivan LA, Bush RT, McConchie D, Lancaster G, Clark MW, Lin C and Saenger P (2000). Chromium Reducible Sulfur – Method 22B. 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, Queensland.

Willmott WF, O`Flynn ML and Trezise DL (1986). *Rockhampton Region Queensland 1:000000 Geological Map Commentary*. Department of Mines, Queensland.

APPENDIX

Chemical data for selected depth samples

ABBREVIATIONS

AMG Australian Map Grid Zone 56 in AGD84 datum

S_{POS} Peroxide oxidisable sulfur

TAA Total actual acidity

TPA Total potential acidity

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
249	1.5-1.7 1.8-2.0	Fig Tree Creek	268190mE 7439750mN	Creek Bank	0.001 0.009	0 0	0 0
250	0.8-1.0	Fig Tree Creek	268454mE 7439609mN	Tidal Creek	0.018	0	30
251	0.7-0.9 1.2-1.4	Fig Tree Creek	268699mE 7439582mN	Intertidal Flat	0.989 1.776	21 64	575 1033
252	0.5-0.7 1.3-1.5	Fig Tree Creek	268800mE 7439510mN	Intertidal Flat	0.334 0.051	0 0	116 0
253	0.2-0.4 0.8-1.0	Ross Creek	268612mE 7438903mN	Intertidal Flat	0.024 0.558	0 0	0 200
254	0.1-0.3 1.6-1.8	Fig Tree Creek	269372mE 7439596mn	Intertidal Flat	1.046 1.213	0 0	473 128
255	0.5-0.7 1.2-1.4	Fig Tree Creek	269040mE 7439651mN	Intertidal Flat	1.498 1.375	45 37	813 798
256	2.8-3.0 5.3-5.5	Yeppoon	268500mE 7439109mN	Plain	0.005 0.007	0 0	0 0
257	0.8-1.0 2.3-2.5	Yeppoon	268720mE 7438998mN	Extratidal Flat	0.482 1.293	0 14	230 660
258	0.6-0.8 1.2-1.4	Ross Creek	270205mE 7438621mN	Supratidal Flat	1.841 2.141	17 22	998 1135
259	0.4-0.6 1.1-1.3	Ross Creek	269348mE 7438464mN	Supratidal Flat	1.981 2.076	44 18	1153 1095
260	0.2-0.4 0.7-0.9	Ross Creek	269371mE 7438403mN	Extratidal Flat	0.025 0.009	0 0	0 0
261	0.2-0.4 1.8-2.0	Ross Creek	269085mE 7438450mN	Intertidal Flat	3.723 1.170	67 0	2345 590
262	0.8-1.0	Ross Creek	269238mE 7438271mN	Extratidal Flat	0.008	0	10
263	0.4-0.6 1.4-1.6	Ross Creek	269409mE 7437353mN	Tidal Creek	1.322 2.976	0 29	725 1740
264	0.3-0.5 0.7-0.9	Ross Creek	269053mE 7438054mN	Supratidal Flat	2.440 1.172	37 10	1418 583
265	0.2-0.4 1.6-1.8	Ross Creek	269118mE 7438148mN	Intertidal Flat	4.330 1.825	39 0	2580 970
266	0.2-0.4 1.4-1.6	Ross Creek	269060mE 7437788mN	Intertidal Flat	2.754 2.746	21 0	1660 1530
267	1.3-1.5	Ross Creek	269005mE 7437631mN	Drainage Depression	0.009	0	0
268	1.1-1.3 1.8-2.0	Lammermoor	271044mE 7437365mN	Drainage Depression	0.128 0.034	16 37	70 50
269	1.3-1.5	Lammermoor	271156mE 743721mN	Drainage Depression	0.004	0	13
270	0.8-1.0 2.3-2.5	Lammermoor	271221mE 7436999mN	Swale	0.046 0.004	0 0	30 13
271	2.3-2.5 2.8-3.0	Lammermoor	271310mE 7436878mN	Swale	0.002 0.475	0 102	15 400
272	0.0-0.2 0.8-1.0	Lammermoor	271478mE 7436571mN	Extratidal Flat	0.061 1.887	0 44	0 1143
273	2.0-2.2	Lammermoor	270851mE 743698mN	Drainage Depression	0.009	0	0
274	2.4-2.6 5.3-5.5	Lammermoor	270887mE 7437032mN	Drainage Depression	0.002 0.005	0 0	0 0
275	2.3-2.5	Lammermoor	270840mE 7437099mN	Drainage Depression	0.001	0	0
276	0.0-0.2 2.3-2.5	Lammermoor	270976mE 7437419mN	Drainage Depression	0.009 0.001	13 0	13 0

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
277	0.0-0.2	Lammermoor	271676mE	Tidal Creek	0.182	0	0
	0.8-1.0		7436520mN		0.235	0	0
278	1.8-2.0	Lammermoor	271567mE	Drainage	0.003	0	0
	4.8-5.0		7436196mN	Depression	0.000	0	0
279	1.3-1.5	Lammermoor	271506mE	Extratidal	0.324	0	118
			7436345mN	Flat			
280	4.5-4.75	Statue Bay	273883mE	Beach Ridge	0.000	0	0
			7434798mN				
281	1.0-1.2	Statue Bay	273512mE	Extratidal	0.089	12	36
	2.4-2.6		7434480mN	Flat	0.710	0	357
282	0.6-0.8	Statue Bay	273233mE	Extratidal	0.764	41	428
	2.8-3.0		7434986mN	Flat	0.939	22	500
	3.8-4.0				0.538	0	223
	4.8-5.0				0.009	0	0
283	0.3-0.5	Statue Bay	272504mE	Supratidal	0.244	27	143
	1.1-1.3		7434987mN	Flat	2.936	84	1723
285	0.5-0.7	Statue Bay	272391mE	Extratidal	0.322	104	285
			7434855mN	Flat			
287	0.5-0.7	Statue Bay	272450mE	Intertidal	1.042	0	470
	1.0-1.2		7434419mN	Flat	2.611	37	1455
	1.6-1.8				1.722	19	893
288	0.56-0.7	Statue Bay	272311mE	Extratidal	0.776	0	378
			7434512mN	Flat			
289	0.4-0.6	Statue Bay	272659mE	Supratidal	1.585	47	955
	0.8-1.0		7435471mN	Flat	5.000	71	2828
290	0.8-1.0	Statue Bay	272685mE	Supratidal	3.886	61	2233
	1.6-1.8		7435682mN	Flat	0.730	15	385
291	0.2-0.4	Statue Bay	273090mE	Supratidal	0.253	47	145
	0.8-1.0		7435702mN	Flat	5.048	184	3055
292	0.5-0.7	Statue Bay	273449mE	Plain	0.073	14	45
	1.3-1.5		7435741mN		0.535	0	316
293	1.2-1.4	Statue Bay	273372mE	Drainage	0.445	146	553
	2.5-2.7		7435806mN	Depression	0.016	35	45
294	2.0-2.2	Mulambin	273611mE	Beach Ridge	0.002	0	0
	2.8-3.0		7432806mN		0.000	0	0
	4.6-4.8				0.000	0	0
295	1.0-1.2	Mulambin	273285mE	Extratidal	0.203	0	48
	1.4-1.6		743290mN	Flat	0.402	0	183
296	2.3-2.5	Mulambin	273241mE	Drainage	0.020	0	0
			7433034mN	Depression			
297	2.5-2.7	Mulambin	273275mE	Beach Ridge	0.011	0	0
	3.0-3.2		7433421mN		0.029	0	0
	4.8-5.0				1.374	0	555
298	2.8-3.0	Mulambin	273480mE	Swale	0.028	0	0
			7433421mN				
299	4.8-5.0	Mulambin	273413mE	Beach Ridge	0.000	0	0
			7433280mN				
300	2.6-2.8	Mulambin	273191mE	Beach Ridge	0.015	0	0
			7433569mN				
301	0.4-0.5	Mulambin	272560mE	Supratidal	0.076	0	0
	0.8-1.0		7433694mN	Flat	0.224	0	38
302	1.2-1.4	Mulambin	272710mE	Extratidal	0.407	22	233
			7433682mN	Flat			
303	2.8-3.0	Mulambin	273390mE	Swale	0.019	0	0
	4.3-4.5		7434011mN		0.140	0	0
	4.8-5.0				0.009	0	0
	5.8-6.0				0.394	0	0

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
304	2.0-2.2	Mulambin	273683mE 7434150mN	Drainage Depression	0.008	0	0
305	4.8-5.0	Mulambin	273195mE 7433897mN	Foredune	0.000	0	0
306	4.8-5.0	Mulambin	273822mE 7433062mN	Foredune	0.000	0	0
307	0.9-1.0	Kinka	273560mE 7432259mN	Intertidal Flat	0.067	0	0
308	3.0-3.3	Kinka	273524mE 7431692mN	Foredune	0.000	0	0
309	2.8-3.0 3.4-3.6 4.6-4.8	Kinka	273603mE 7431145mN	Swale	0.000 0.036 0.143	0 0 0	0 0 0
310	2.8-3.0 4.2-4.4 4.8-5.0 5.8-6.0	Kinka	273530mE 7431147mN	Swale	0.127 0.063 0.158 0.030	0 0 0 0	0 0 0 0
311	3.0-3.2	Kinka	273420mE 7431160mN	Swale	0.000	0	0
312	3.8-4.0 4.6-4.8 5.8-6.0	Kinka	273223mE 7431188mN	Swale	0.000 0.020 0.050	0 0 0	0 0 0
313	0.0-0.2 0.5-0.7 1.3-1.5	Kinka	273001mE 7431210mN	Drainage Depression	0.369 1.377 0.979	135 74 58	513 963 603
314	3.2-3.4 4.3-4.5 4.6-4.8 5.8-6.0 7.0-7.2	Kinka	272870mE 7431225mN	Swale	0.000 0.003 0.011 0.273 0.263	0 0 0 0 0	0 0 0 63 0
315	3.8-4.0 4.0-4.2	Kinka	272648mE 7431255mN	Swale	0.014 0.053	0 10	13 43
316	4.3-4.5 4.5-4.7 5.8-6.0	Kinka	272640mE 7431960mN	Swale	0.000 0.000 0.000	0 0 0	0 0 0
317	4.3-4.5 4.8-5.0 5.3-5.5 5.8-6.0	Kinka	272009mE 7431673mN	Sandplain	0.040 0.092 0.042 0.073	10 0 0 0	30 15 0 0
318	2.0-2.2 2.5-2.6	Kinka	272382mE 7429943mN	Swale	0.000 0.056	0 0	0 18
319	3.6-3.8 3.8-4.0 4.7-4.9 5.0-5.2 5.8-6.0	Kinka	272454mE 7430438mN	Swale	0.000 0.087 0.087 0.371 0.042	0 0 0 10 0	0 47 28 199 20
320	2.1-2.3 2.6-2.8 3.25-3.5 4.0-4.2 5.8-6.0	Kinka	272468mE 7430661mN	Drainage Depression	0.099 0.083 0.070 0.002 0.593	0 0 0 0 28	65 55 40 0 382
321	5.8-6.0	Kinka	272490mE 7430873mN	Beach Ridge	0.000	0	0
322	2.8-3.0 3.8-4.0	Kinka	271680mE 7431014mN	Sandplain	0.000 0.000	14 0	20 0
323	2.3-2.5	Kinka	271753mE 7430790mN	Drainage Depression	0.071	0	53

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
324	0.0-0.2	Kinka	271624mE	Swamp	0.048	67	60
	1.3-1.5		7430675mN		0.168	0	113
	1.7-1.9				0.128	0	70
325	4.3-4.5	Kinka	271714mE	Sandplain	0.005	0	0
	4.8-5.0		7430624mN		0.031	0	13
	5.8-6.0				0.012	0	10
326	2.8-3.0	Kinka	271971mE	Sandplain	0.000	0	0
	3.3-3.5		7430124mN		0.057	0	18
	3.8-4.0				0.037	0	10
	4.8-5.0				0.032	0	43
	5.8-6.0				0.025	0	0
327	0.4-0.6	Kinka	271500mE	Swamp	0.023	15	20
	1.2-1.4		7430358mN		0.060	0	0
328	0.9-1.1	Kinka	271022mE	Plain	0.074	0	13
	2.8-3.0		7430739mN		1.125	0	573
329	0.7-0.9	Kinka	271112mE	Plain	2.460	55	1460
	1.6-1.8		7431171mN		2.361	23	1313
330	0.8-1.0	Kinka	272335mE	Plain	1.020	63	645
	1.5-1.7		7431945mN		1.278	60	790
331	3.5-3.7	Lammermoor	271221mE	Foredune	0.480	0	43
	3.9-4.0		7437432mN		0.341	0	0
332	0.0-0.2	Kinka	274516mE	Intertidal	0.173	0	0
	0.8-1.0		7429599mN	Flat	0.057	0	0
333	0.9-1.1	Kinka	274831mE	Supratidal	0.288	0	0
			7428954mN	Flat			
334	0.8-1.0	Kinka	275669mE	Supratidal	0.182	0	50
	1.3-1.5		7428964mN	Flat	0.346	0	0
335	0.6-0.8	Kinka	274463mE	Supratidal	1.218	11	645
	1.4-1.6		7428513mN	Flat	0.961	0	15
336	0.0-0.2	Emu Park	277137mE	Swamp	0.012	0	0
	2.2-2.4		7426759mN		0.009	0	0
337	0.3-0.5	Keppel Sands	271958mE	Intertidal	0.056	0	0
	0.8-1.0		7418876mN	Flat	0.532	0	275
338	1.5-1.7	Keppel Sands	272284mE	Drainage	0.098	0	0
	1.8-2.0		7417474mN	Depression	0.037	0	0
	2.8-3.0				0.135	0	0
	4.6-4.8				0.018	0	0
339	0.8-1.0	Keppel Sands	272448mE	Supratidal	0.205	0	0
	1.5-1.7		7417479mN	Flat	0.050	0	0
	2.8-3.0				0.037	0	0
	3.8-4.0				0.807	0	318
	4.6-4.8				0.141	0	0
340	3.8-4.0	Keppel Sands	271630mE	Swale	0.000	0	0
			7418836mN				
341	0.8-1.0	Keppel Sands	271548mE	Supratidal	0.138	0	0
	1.6-1.8		7418608mN	Flat	0.533	0	260
342	0.6-0.8	Keppel Sands	271413mE	Intertidal	0.079	0	0
	1.1-1.3		7418704mN	Flat	0.639	0	283
343	4.8-5.0	Keppel Sands	271419mE	Sandplain	0.000	0	0
			7418750mN				
344	4.8-5.0	Keppel Sands	271421mE	Beach Ridge	0.005	0	0
			7417656mN				
345	3.5-3.6	Keppel Sands	272325mE	Beach Ridge	0.013	0	0
	4.8-5.0		7417452mN		0.148	0	0
	5.8-6.0				0.102	0	0
346	1.5-1.7	Keppel Sands	272952mE	Extratidal	0.556	0	303
	1.9-2.0		7417160mN	Flat	0.501	10	273

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
347	1.6-1.8	Keppel Sands	273153mE 7417251mN	Beach Ridge	0.318	0	165
348	0.8-1.0	Keppel Sands	273160mE 7417058mN	Intertidal Flat	0.786	0	0
349	1.7-1.9	Keppel Sands	272516mE 7416745mN	Extratidal Flat	0.050	0	0
351	1.1-1.3	Keppel Sands	273946mE 7418604mN	Bench	0.004	0	0
353	1.9-2.0	Keppel Sands	273880mE 7418705mN	Plain	0.266	0	0
354	0.7-0.9	Keppel Sands	273574mE 7418598mN	Supratidal Flat	0.471	0	0
355	1.6-1.8	Keppel Sands	273440mE 7418408mN	Beach Ridge	0.255	0	0
356	0.3-0.5 0.8-1.0	Keppel Sands	274001mE 7417720mN	Intertidal Flat	0.169 0.232	0 0	0 0
357	0.3-0.5 0.8-1.0	Keppel Sands	274009mE 7417820mN	Intertidal Flat	0.332 0.459	0 0	80 145
358	3.8-4.0	Keppel Sands	272286mE 7418014mN	Swale	0.090	0	0
359	2.8-3.0	Keppel Sands	271156mE 7415774mN	Drainage Depression	0.000	0	0
360	1.3-1.6 3.8-4.0 4.8-5.0 5.8-6.0	Keppel Sands	271977mE 7415826mN	Beach Ridge	0.000 0.011 0.051 0.075	0 0 0 0	0 0 0 0
361	2.6-2.8 3.3-3.5 3.6-3.8 4.8-5.0	Keppel Sands	271800mE 7415741mN	Drainage Depression	0.620 1.092 0.909 2.149	0 0 0 0	0 0 0 48
362	2.4-2.6 3.4-3.6	Emu Park	276437mE 7425939mN	Plain	0.000 0.000	0 0	0 0
363	0.0-0.2 1.6-1.8	Emu Park	277005mE 7427218mN	Swamp	0.053 0.069	0 0	0 33
364	1.8-2.0	Emu Park	276085mE 7425572mN	Extratidal Flat	0.005	0	0
365	0.6-0.8 1.0-1.2	Emu Park	276214mE 7425508mN	Intertidal Flat	0.883 0.573	0 0	378 185
366	0.6-0.8 1.4-1.6	Emu Park	276141mE 7425537mN	Supratidal Flat	0.722 0.831	0 0	245 253
367	0.8-1.0	Emu Park	276498mE 7425690mN	Extratidal Flat	0.000	0	0
368	0.6-0.8	Emu Park	276391mE 7425300mN	Supratidal Flat	0.426	0	195
369	1.8-2.0	Emu Park	276746mE 7425052mN	Supratidal Flat	0.006	0	0
371	0.6-0.8 1.0-1.2	Emu Park	276526mE 7424532mN	Supratidal Flat	0.540 2.097	15 23	230 973
372	0.5-0.7	Emu Park	274491mE 7425830mN	Stream Channel	0.027	0	0
373	0.3-0.5	Emu Park	274623mE 7425579mN	Supratidal Flat	3.516	77	1925
374	0.0-0.2 0.4-0.6 1.1-1.3	Emu Park	274643mE 7425525mN	Intertidal Flat	0.935 3.318 2.458	0 26 17	380 1413 1285

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
375	0.4-0.5	Emu Park	274886mE	Supratidal	3.190	10	1515
	1.0-1.2		7425397mN	Flat	1.782	0	705
376	2.0-2.2	Keppel Sands	272999mE	Swale	0.096	0	0
			7416827mN				
380	0.8-1.0	Keppel Sands	273606mE	Intertidal	0.796	0	0
	1.3-1.5		7416964mN	Flat	0.526	0	0
381	1.2-1.3	Keppel Sands	273174mE	Beach Ridge	0.007	0	0
			7415799mN				
382	1.5-1.7	Keppel Sands	273212mE	Beach Ridge	0.001	0	0
	2.8-3.0		7415952mN		0.061	0	0
383	1.5-1.7	Keppel Sands	2735534mE	Beach Ridge	0.004	0	0
	2.6-2.8		7416201mN		0.195	0	0
384	0.3-0.5	Keppel Sands	270732mE	Extratidal	0.006	0	0
	1.3-1.5		7417123mN	Flat	0.002	0	0
385	0.4-0.6	Keppel Sands	270036mE	Supratidal	1.468	22	848
			7419067mN	Flat			
386	1.3-1.5	Yeppoon	268590mE	Plain	0.006	0	0
	2.4-2.6		7438856mN		0.866	39	518
	3.0-3.2				1.500	12	768
387	0.2-0.4	Emu Park	276117mE	Intertidal	3.301	20	1765
	0.8-1.0		7424927mN	Flat	3.256	0	1713
388	0.2-0.3	Emu Park	276211mE	Supratidal	2.246	0	1255
	0.8-1.0		7424791mN	Flat	2.206	0	1233
390	1.8-2.0	Kinka	275020mE	Sandplain	0.007	0	0
	2.8-3.0		7429145mN		0.489	0	0
	3.8-4.0				1.487	0	799
	4.5-4.7				0.945	0	475
391	0.8-1.0	Zilzie	271796mE	Supratidal	1.185	20	680
	1.3-1.5		7421435mN	Flat	1.122	17	573
392	1.1-1.3	Zilzie	272025mE	Levee	0.006	0	0
	1.8-2.0		7421235mN		0.001	0	0
393	1.3-1.4	Zilzie	274106mE	Drainage	0.873	11	493
	1.5-1.6		7422172mN	Depression	1.707	0	0
394	0.0-0.2	Kinka	275540mE	Intertidal	0.548	0	0
	1.3-1.5		7429147mN	Flat	0.336	0	0
395	1.4-1.6	Coconut Point	275829mE	Drainage	0.468	0	0
			7423047mN	Depression			
396	0.5-0.7	Coconut Point	275629mE	Drainage	0.577	0	0
	1.3-1.5		7422997mN	Depression	0.751	0	0
397	1.0-1.2	Coconut Point	275326mE	Drainage	0.028	0	0
			742796mN	Depression			
398	0.0-0.2	Coconut Point	275614mE	Tidal Creek	0.113	0	0
	0.2-0.4		7422773mN		0.369	0	0
	0.8-1.0				0.589	0	0
399	0.3-0.5	Coowonga	271667mE	Intertidal	0.791	10	410
	0.8-1.0		7420524mN	Flat	0.764	0	0
400	0.8-1.0	Coowonga	271558mE	Supratidal	1.031	34	608
	1.6-1.8		7420785mN	Flat	0.720	0	358
401	0.8-1.0	Coowonga	271579mE	Extratidal	0.013	0	0
	1.5-1.7		7420524mN	Flat	0.425	0	0
	1.8-2.0				0.536	0	0
	2.4-2.6				0.362	0	0
	4.6-4.8				0.107	0	0
402	1.5-1.7	Coowonga	271533mE	Beach Ridge	0.004	0	0
	2.8-3.0		7419888mN		0.199	0	0
403	0.8-1.0	Coowonga	271370mE	Supratidal	1.828	24	1043
	1.6-1.8		7420382mN	Flat	1.185	0	615

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
404	1.3-1.5	Coowonga	271107mE	Extratidal	0.066	0	18
	2.8-3.0		7420527mN	Flat	0.295	0	0
405	0.3-0.5	Coowonga	271231mE	Intertidal	0.025	0	0
	0.8-1.0		7419099mN	Flat	1.605	0	873
	1.6-1.8				1.984	0	1090
406	0.8-1.0	Coowonga	271045mE	Swale	0.007	32	33
	1.3-1.5		7419292mN		0.002	0	0
407	2.5-2.7	Coowonga	270960mE	Beach Ridge	0.000	0	0
	3.3-3.5		7419364mN		0.430	0	235
	4.3-4.5				0.197	0	0
408	0.35-0.5	Coowonga	270613mE	Extratidal	0.043	0	0
	1.8-2.0		7420603mN	Flat	0.251	0	0
	2.8-3.0				0.334	0	0
409	0.8-1.0	Coowonga	270783mE	Flat	0.065	0	25
	1.8-2.0		7420053mN		0.519	11	280
410	0.35-0.5	Coowonga	270216mE	Intertidal	0.283	0	0
	0.8-1.0		7419516mN	Flat	0.809	0	320
411	0.8-1.0	Coowonga	270065mE	Supratidal	2.624	21	1520
	1.3-1.5		7419561mN	Flat	1.932	11	1075
412	0.6-0.8	Coowonga	269977mE	Supratidal	1.480	0	745
	1.1-1.2		7419741mN	Flat	1.400	0	703
413	0.1-0.25	Coowonga	270321mE	Extratidal	0.024	0	0
	0.3-0.5		7418799mN	Flat	0.007	0	0
414	0.0-0.2	Coowonga	269917mE	Flat	0.008	0	0
	1.8-2.0		7419174mN		0.000	0	0
415	2.8-3.0	Kinka	272514mE	Sandpit	0.000	0	0
			7429585mN				
416	2.3-2.5	Kinka	272824mE	Swale	0.000	0	0
			7429851mN				
417	0.0-0.2	Kinka	272705mE	Drainage	0.021	0	0
	0.6-0.8		7429624mN	Depression	0.002	0	0
418	1.5-1.7	Kinka	273544mE	Swale	0.000	0	0
			7430344mN				
419	2.0-2.2	Kinka	273479mE	Swale	0.000	0	0
	2.8-3.0		7429960mN		0.000	0	0
420	0.1-0.3	Coowonga	268724mE	Supratidal	0.346	0	125
	0.3-0.5		7421906mN	Flat	2.329	58	1253
	1.3-1.5				3.962	40	2240
421	0.35-0.5	Coowonga	268007mE	Tidal Creek	3.245	25	1720
	1.2-1.4		7422455mN		2.664	27	1375
422	0.45-0.6	Coowonga	267706mE	Intertidal	0.434	0	108
	1.2-1.4		7422575mN	Flat	1.889	0	835
423	1.3-1.5	Emu Park	277662mE	Foredune	0.008	0	0
			7425460mN				
424	0.3-0.5	Emu Park	270167mE	Supratidal	3.724	80	2203
	0.5-0.65		7426984mN	Flat	2.695	21	1400
425	0.3-0.5	Emu Park	270185mE	Intertidal	2.216	10	1073
	1.0-1.2		7426866mN	Flat	2.147	0	1035
431	2.8-3.0	Yeppoon	268370mE	Plain	0.000	0	0
	4.8-5.0		7439718mN		0.000	0	0
432	3.0-3.3	Lammermoor	271554mE	Beach Ridge	0.393	0	228
	3.8-4.0		7436610mN		0.093	0	43
	5.5-5.7				0.000	0	0
433	0.4-0.5	Keppel Sands	273913mE	Plain	0.003	0	0
	0.9-1.0		7418644mN		0.003	0	0
	1.4-1.5				0.000	0	0
	1.8-1.9				0.000	0	0

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
434	0.8-1.0	Keppel Sands	273895mE	Plain	0.000	0	0
	1.8-2.0		7418597mN		0.002	0	0
	3.8-4.0				0.000	0	0
435	1.3-1.5	Keppel Sands	273852mE	Plain	0.000	0	0
	2.0-2.2		7418590mN		0.016	0	0
	2.8-3.0				0.001	0	0
	3.8-4.0				0.000	0	0
436	1.1-1.3	Keppel Sands	273842mE	Plain	0.119	0	0
	1.3-1.5		7418643mN		0.008	0	0
	3.0-3.2				0.000	0	0
	4.5-4.7				0.000	0	0
437	2.8-3.0	Mulambin	273220mE	Drainage	0.015	0	0
	3.3-3.5		7433084mN	Depression	0.026	0	0
	4.6-4.8				0.199	0	0
438	3.8-4.0	Kinka	272072mE	Beach Ridge	0.000	0	0
	4.8-5.0		7430288mN		0.089	0	45
	5.8-6.0				0.042	0	18
439	2.6-2.8	Coowonga	270969mE	Beach Ridge	0.197	0	90
	3.8-4.0		7419577mN		0.212	0	78
	4.8-5.0				0.416	0	0
	5.8-6.0				0.723	0	0
440	1.8-2.0	Keppel Sands	273358mE	Plain	0.036	0	0
	2.8-3.0		7415456mN		0.047	0	0
	3.8-4.0				0.075	0	0
	4.8-5.0				0.242	0	0
	5.8-6.0				0.220	0	0
441	1.0-1.2	Keppel Sands	272814mE	Plain	0.005	0	0
	1.8-2.0		7417507mN		0.143	0	0
	2.8-3.0				0.061	0	0
	3.8-4.0				0.047	0	0
	4.6-4.8				0.675	0	0
442	1.8-2.0	Keppel Sands	272529mE 7416953mN	Beach Ridge	0.009	0	0
443	1.6-1.8	Kinka	275892mE	Beach Ridge	0.008	0	0
	2.6-2.8		7429248mN		0.452	0	0
	3.4-3.6				0.195	0	70
444	1.8-2.0	Kinka	275707mE 7428669mN	Plain	0.012	0	0
445	1.7-1.9	Yeppoon	268602mE	Plain	0.452	0	162
	2.2-2.4		7439392mN		4.778	46	2452
	2.6-2.8				1.999	0	1029
446	1.8-2.0	Yeppoon	269521mE	Plain	0.000	0	0
	2.8-3.0		7439318mN		0.006	0	0
	4.3-4.5				0.007	0	0
447	4.8-5.0	Kinka	273427mE	Beach Ridge	0.032	0	0
	5.3-5.5		7429738mN		0.064	0	0
	5.8-6.0				0.121	0	0
448	1.8-2.0	Zilzie	274005mE	Plain	0.109	0	0
	2.8-3.0		7421592mN		0.071	0	0
	3.8-4.0				0.136	0	0
	4.8-5.0				0.039	0	0
449	2.8-3.0	Zilzie	273394mE	Swale	0.046	0	0
	3.7-3.8		7420399mN		0.339	0	0
	5.0-5.2				0.255	0	10
	6.3-6.5				0.140	0	60
	7.0-7.2				0.007	0	0

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
450	3.0-3.2	Zilzie	273578mE	Beach Ridge	0.061	0	0
	3.8-4.0		7420414mN		0.078	0	0
	4.8-5.0				0.065	0	0
	5.8-6.0				0.060	0	0
451	1.8-2.0	Zilzie	271963mE	Extratidal	1.359	26	758
	2.8-3.0		7421437mN	Flat	0.630	0	348
	3.8-4.0				0.355	0	168
	4.8-5.0				3.063	0	1538
452	0.8-1.0	Zilzie	273965mE	Supratidal	3.525	65	2070
	1.3-1.5		7422650mN	Flat	3.707	50	2040
453	0.7-0.9	Zilzie	273970mE	Extratidal	3.507	48	1851
	1.3-1.5		7422600mN	Flat	3.836	57	2015
454	0.6-0.8	Zilzie	274280mE	Plain	0.096	12	38
			7422405mN				
455	0.8-1.0	Zilzie	273340mE	Extratidal	0.039	10	25
	1.6-1.8		7421906mN	Flat	0.470	31	305
456	0.4-0.6	Zilzie	274191mE	Extratidal	0.098	0	0
			7423782mN	Flat			
457	0.3-0.5	Zilzie	274180mE	Supratidal	4.382	50	2348
	1.3-1.5		7423851mN	Flat	6.446	48	3512
458	0.3-0.5	Zilzie	273650mE	Supratidal	2.826	29	1515
			7423190mN	Flat			
459	1.2-1.4	Zilzie	272198mE	Flat	0.009	0	0
			7421758mN				
460	1.0-1.2	Zilzie	272165mE	Flat	0.008	0	0
			7421481mN				
461	1.3-1.5	Zilzie	272944mE	Plain	0.005	0	0
			7421576mN				
462	1.8-2.0	Zilzie	273555mE	Beach Ridge	0.006	26	35
			7421861mN				
463	0.3-0.5	Zilzie	272490mE	Intertidal	0.236	0	123
			7420562mN	Flat			
464	0.35-0.5	Coorooman	270310mE	Intertidal	1.996	13	1048
	1.6-1.8		7424142mN	Flat	2.508	28	1274
465	0.35-0.5	Coorooman	270405mE	Supratidal	1.173	0	565
	1.6-1.8		7423803mN	Flat	3.628	29	1888
466	0.3-0.5	Coorooman	270551mE	Intertidal	0.596	0	258
	1.6-1.8		7423348mN	Flat	1.905	0	929
467	0.1-0.3	Coorooman	269958mE	Supratidal	0.889	0	485
	0.3-0.5		7423435mN	Flat	5.808	50	4019
468	0.3-0.5	Coorooman	268743mE	Intertidal	5.752	101	3173
	0.8-1.0		7424268mN	Flat	3.900	47	2170
	1.6-1.8				2.672	20	1383
469	0.9-1.1	Coorooman	268325mE	Extratidal	0.088	0	33
	1.3-1.5		7424299mN	Flat	1.199	23	650
470	0.3-0.5	Coorooman	267741mE	Tidal Creek	0.015	0	0
	1.4-1.6		7425076mN		1.812	18	930
471	0.8-1.0	Coorooman	267629mE	Stream	0.669	0	325
	1.6-1.8		7425475mN	Channel	3.231	0	1573
472	0.3-0.5	Kinka	270625mE	Supratidal	0.489	11	248
	1.6-1.8		7433408mN	Flat	1.481	0	675
473	0.3-0.5	Kinka	270812mE	Supratidal	0.543	18	313
	0.8-1.0		7432911mN	Flat	2.965	28	1530
	1.3-1.5				3.435	20	1763
474	0.2-0.4	Kinka	271034mE	Supratidal	0.367	20	220
	0.6-0.8		7433118mN	Flat	2.614	40	1425

Site No	Depth m	Locality	AMG Reference	Landform	S_{POS} %	TAA mol H^+/t	TPA mol H^+/t
475	0.4-0.5	Kinka	271360mE	Supratidal	0.745	0	0
	1.0-1.2		7432855mN	Flat	0.370	0	0
476	0.5-0.7	Kinka	271626mE	Intertidal	1.724	23	893
	1.6-1.8		7432540mN	Flat	0.874	0	0
477	0.3-0.5	Causeway	271984mE	Supratidal	0.194	40	135
	0.8-1.0		7432733mN	Flat	0.705	38	430
478	0.4-0.5	Causeway	272657mE	Supratidal	1.223	32	643
	1.6-1.8		7433010mN	Flat	0.802	15	415
479	3.0-3.2	Zilzie	273172mE	Beach Ridge	0.012	28	33
	3.3-3.5		7421676mN		0.014	44	55
480	1.0-1.2	Kinka	274358mE	Swale	0.031	0	0
	1.5-1.7		7429598mN		0.155	0	0
481	0.3-0.5	Zilzie	271465mE	Intertidal	0.625	0	270
	1.6-1.8		7421910mN	Flat	1.898	0	1023