2 Lower Hunter Acid Sulfate Soils Priorities Investigation Project

2.1 Project Background

The disturbance of coastal ASS represents a significant major threat to coastal and marine ecosystems and has the potential to impact on threatened species such as birds, fish and frogs found occurring in the Ramsar sites in the Hunter. Previous observations were that over-drained wetland sites in the estuary have been responsible for chronic discharges of ASS-related poor water quality.

The poor water quality within and emanating from these sites (related to the oxidation and export of acid leachate) may be critically affecting the Ramsar wetlands in the lower estuary through direct impacts of acid and poor water quality and indirectly through loss of wetland habitats and the degradation of associated food sources.

It is vital to prevent further disturbance and to identify management options to mitigate the impacts of disturbed ASS. Improved management at these locations has been hamstrung by a lack of detailed information in a number of areas, including:

- Elevation of the landscape
- Hydraulic conductivity
- Soil conductivity
- Depth and quality of ASS layer in key areas

Given the increasing population size in the Hunter it is likely that future development pressure in this region is to intensify over future years. The excavation of underlying acid sulfate soils will lead to a continuing degradation of coastal wetlands. Through site specific field studies and research, this project identifies high risk areas in order to notify the appropriate local government / state & federal authorities and to assist in the planning process. The project is funded by the Australian Government's Coastal Catchment Initiative.

2.2 Project Aims

1. Provide detailed investigations and assessments of actual and potential ASS at five key sites in the Lower Hunter Estuary.

2. Assess ASS impacts on Lower Hunter Ramsar wetlands.

3. Provide management options for mitigating the impacts of ASS in the Lower Hunter Estuary region.

4. Build on existing programmes in the region, for example Coastal Catchments Initiative, Bringing Back the Fish, Kooragang Wetland Rehabilitation Project, Tomago Rehabilitation Project, Hexham Swamp Project.

5. Communicate project outcomes and facilitate community education through holding a series of workshops.

2.3 *Project Methods*

2.3.1 Study Sites

In the initial stages of the Lower Hunter Acid Sulfate Soils Investigations Project, a Technical Advisory Panel, consisting of key stakeholders determined five sites for the study (figure 20):

1. Kooragang Wetland, Ash Island
2. Shortland Wetlands
3. Hexham Swamp
4. Tomago Wetland
5. Fullerton Cove

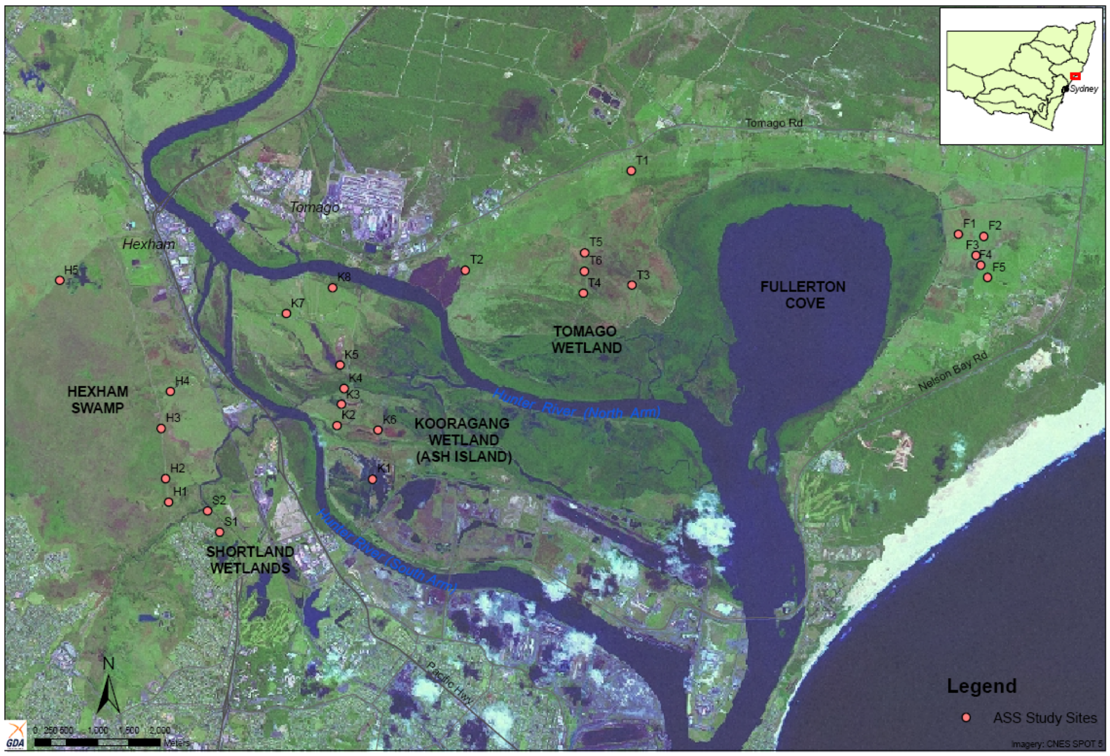

Figure 20: Map of Lower Hunter Estuary Study Sites

2.3.2 Kooragang Wetland (Ash Island)

Ash Island is located between the North and South Arms of the Hunter River near Hexham. Much of the island consists of a series of wetlands reserved for conservation, as well as some industrial reclaimed land (on the south east corner of the island). This project focuses on the wetlands within the conservation reserves, and excludes the industrial land. The wetlands feature expanses of mangrove and saltmarsh (see figure 21) in the inter-tidal areas, and act as a buffer between the internationally recognised, Ramsar listed Hunter Estuary Wetlands and the major industrial and urban areas of Newcastle.

Figure 21: Kooragang Wetland tidal habitat (photo: J Fredrickson)

The eastern side of the Kooragang Wetland (Ash Island) site is dedicated as a National Park under the NSW *National Parks and Wildlife Act* 1974, as part of the newly created Hunter Wetlands National Park (previously Kooragang Nature Reserve). The western side of the island is managed by Hunter Central Rivers CMA, leased from the State Government for the purposes of the Kooragang Wetland Rehabilitation Project.

Kooragang Wetland Rehabilitation Project (KWRP) is one of the largest active coastal rehabilitation projects in Australia. Note: the KWRP project area includes Ash Island, Tomago and Stockton Spit sites. The project was initiated in 1993 to compensate for the loss of fish, shorebird and other wildlife habitat caused by 200 years of draining, filling and clearing in the Hunter River estuary. Kooragang Wetland is now home to over 180 species of birds (including 24 species of migratory shorebirds), 15 species of frog, 10 species of bat and 300 species of indigenous plants, including 26 threatened species and one threatened community (HCRCMA, 2008a).

The original focus in rehabilitating Kooragang was to restore tidal flows to creeks to improve fisheries and wading bird habitat, while also providing habitat for endangered species such as the green and golden bell frog and the Australasian bittern. Other rehabilitation works include revegetation of rainforest on higher, non-tidal areas, and the development of Kooragang City Farm to research and demonstrate sustainable agricultural practices that are in harmony with natural ecosystems, especially wetlands (HCRCMA, 2008a).

Soil inspections were carried out along a transect at a range of elevations in key representative wetland areas. These investigations build on previous studies, which provide some site specific ASS depth information.

2.3.3 Shortland Wetlands (Hunter Wetlands Centre)

Shortland Wetlands is located north east of Newcastle close to Shortland urban area. The wetlands are a natural drainage depression, a remnant of extensive tidal and floodplain wetlands that once extended east of Ironbark Creek. There have been extensive changes to the natural flow regime resulting from the construction of floodgates on Ironbark Creek and a drainage canal from Sandgate Road to Ironbark Creek, the establishment of a garbage dump, the construction of a power transmission line and associated access roads and development of a sporting complex (The Wetlands Centre, 2002).

The site was established as a conservation reserve in 1985, and is now owned by Shortland Wetlands Centre, Ltd, trading as The Wetlands Centre Australia, a company limited by guarantee and owned by its members. It operates as a not-for-profit conservation organisation and is managed by a volunteer Board of Directors.

Since the establishment of the wetlands, site restoration has included the creation of new ponds (figure 22), development of tracks, building of structures and interpretation to support education uses. Management plans using a catchment management approach were developed and implemented to guide restoration work, on-going management and public access. A long-term revegetation plan has been implemented to improve degraded habitat and introduce new habitat types (The Wetlands Centre, 2002).

Much of Shortland Wetlands is elevated high above sea level. Hence, soil investigations focused on low lying land in the north west corner of the wetlands close to Ironbark Creek.

Figure 22: Freshwater Pond at Shortland Wetlands (Source: J Fredrickson)

2.3.4 Hexham Swamp

Hexham Swamp covers an area of 3800 hectares. These rich estuarine wetlands have become degraded over the last 30 years since floodgates were constructed on Ironbark Creek. Lack of tidal flushing, vital to the health of an estuarine wetland, has dramatically changed the swamp's environment. A freshwater system has largely replaced the extensive mangroves and saltmarsh communities which once thrived throughout the swamp, significantly reducing vital aquatic and terrestrial habitat for native species (see figure 23).

A project is underway (the Hexham Swamp Rehabilitation Project) which will see the staged opening of these floodgates to increase tidal flushing of the swamp. A restored estuarine habitat will encourage the return of migratory wading birds, fish and prawns. The project also involves the purchase of land within the swamp by the Hunter-Central Rivers CMA. A total 800 hectares of private and public grazing land may become inundated when the floodgates are opened.

Hexham Swamp is listed in the Directory of Important Wetlands in Australia, and under State Environmental Planning Policy No.14 - Coastal Wetlands. Also, international agreements on migratory wading bird habitat in the Swamp have been signed by Australia with China and Japan.

Much of Hexham Swamp is gazetted National Park, part of the Hunter Estuary National Park. Fringing areas are owned by private landholders, QLD Railcorp and other land more recently purchased by Hunter Central Rivers Catchment Management Authority. There are numerous utilities easements in areas of the swamp.

Soil investigations covered a range of sites across the large wetland area, building on previous soil studies carried out as part of the Hunter Water pipeline relocation project.

Figure 23: Hexham Swamp, freshwater reed beds are a dominating feature of the landscape (photo: J Fredrickson)

2.3.5 Tomago Wetland

The study area covers about 1200 ha, consisting of mixed pastureland and degraded, formerly tidal, wetland drained by an irregular network of channels with stormwater drainage controlled by floodgates. The wetlands are separated from the adjacent tidal mangrove forest of Fullerton Cove and the Hunter River by a perimeter drain and levee (figure 24).

Tomago Wetland is drained by a series of drains (e.g. North-South Drain, Eastern Drain), which carry water south to the Fullerton Ring Drain. The ring drain discharges at two sets of floodgates, one of which has recently been fitted with Smart Gates, which allow the gates to be remotely operated (figure 25). This is part of the Tomago Rehabilitation Project which aims to restore the former wetland by allowing tidal inundation to occur, improving habitat for migratory shorebird roosting, as well as juvenile fish and crustaceans (DECC, 2005).

Spoil from the drains' excavation has been used for construction of the perimeter levee and minor levees along the drains.

Tomago Road to the north follows the edge of an elevated sandy ridge about 2-3 metres above sea level, the land slopes downward to the south very gradually with higher areas at 1m AHD at the western end. In the centre further east the elevation drops to 0m AHD with patches below this, about 1km south of the main road (see Tomago Digital Elevation Model in Appendix 3).

Most soil inspections were located at sites of lowest elevation in order to detect any sulfidic subsoil layer without having to excavate too deeply. These investigations build on a previous study (completed as part of the Tomago Rehabilitation Project), which provide some site specific information at the north end of the North-South Drain.

Figure 24: Aerial view of Tomago Wetland, with Fullerton Cove and Stockton Beach in the distance (Source: DECC, 2005).

Figure 25: Tomago Floodgates fitted with Smart Gates. The square doors on the gates can be remotely opened and closed (photo: J Fredrickson)

2.3.6 Fullerton Cove

Fullerton Cove is a large, shallow embayment north of Ash Island. It has a maximum depth of two to three metres at its centre and at low tide large areas of mudflats are exposed. It occupies a broad depression between two systems of large sand dunes, the younger dune system runs along the coast behind the beach north-east of Stockton, and the other inland system (Tomago Sand-beds) runs east-west between Williamtown and Tomago. Fullerton Cove village is located to the east of the cove. The village is a rural area consisting of a narrow line of private properties running either side of Fullerton Cove Road. Low lying land on private property adjacent to the Cove are the focus of this study.

Figure 26: Fullerton Cove Ring Drain (photo: J Fredrickson)

A long raised levee bank, constructed in the 1920's, prevents tidal flooding across the study area from the Fullerton Cove embayment. The shoreline is protected by a belt of mangroves up to 1.5 km wide, west and south of the levee bank. Within the mangrove forest, sediment deposition since the bank was constructed has raised the level of the tidal flats above the level of the floodplain on the landward side. It is also possible that drying out of the soils and subsequent peat fires (during dry spells) have caused the land to subside in the decades since the floodplain was drained. Parts of the farmland are now approximately 0.5m lower than the mudflats in the mangrove forest. Surface run-off from farmland drains into a series of drains feeding into the main drain running parallel to and inside the raised levee. It discharges through floodgates at the southern end of the study area (figures 26 and 27).

The Fullerton Cove study area covers about 1000 - 1500 ha of almost level floodplain, parts of which are below sea level. The broad depression continues eastwards to Tilligerry Creek, but soil inspections were confined to a representative cross-section east of Fullerton Cove Road.

Figure 27: Fullerton Floodgates (photo: J Fredrickson)

2.4 Acid Sulfate Soil Risk Maps

In 1995, as a first step towards identification and future management of acid sulfate soils in NSW coastal areas, a series of Acid Sulfate Soil Risk Maps was prepared by a team of soil surveyors from the Department of Land and Water Conservation (now part of NSW Dept of Environment and Climate Change -DECC).

More recently DECC has begun updating the ASS Risk Maps (Edition 3) in light of more advanced elevation models (LiDAR) and research on Pleistocene / Holocene sea level changes becoming available. As part of the Acid Sulfate Soils Priorities Investigations Project, the ASS Risk Maps covering the Lower Hunter River region have been updated early on in the process. The revised ASS Risk Map is presented in Appendix 2.

The Acid Sulfate Soil Risk Maps predict the distribution of acid sulfate soils based on an assessment of the geomorphic environment. This assessment has involved aerial photo and LiDAR interpretation, extensive field work and associated laboratory analyses of soil samples.

The maps have four primary map classes:

1. **High Probability of Occurrence**: Landform elements in which the geomorphic processes have been suitable for the formation of ASS have been classed as having a High Probability of Occurrence. ASS in these environments are widespread or sporadic. They may also be very close to the surface or buried by many metres of alluvium or windblown sand. Bottom sediments of estuaries, rivers, creeks and lakes are also considered areas of High Probability of Occurrence. Environments associated with this map class are all closely related to Holocene deposits.
2. **Low Probability of Occurrence**: Where environments have not generally been suitable for ASS formation, or ASS are highly localised or sporadic, they have been classed as having a Low Probability of Occurrence. ASS may be close to the surface or buried by many metres of alluvium or windblown sand. The majority of these landforms are not expected to contain ASS. Soil materials are often Pleistocene in age.
3. **No Known Occurrence**: Acid sulfate soils are not known or expected to occur in these environments. In general, landforms above 10 m AHD were classed as having No Known Occurrence of ASS. Below this level other landforms were also placed into this map class based on an assessment of the geomorphic processes occurring there. Some of these environments include elevated Pleistocene and Holocene dunes, low hills with in situ bedrock soils, drainage plains or fluvial dominated plains and levees. These environments are not expected to contain ASS.
4. **Disturbed Terrain**: Disturbed terrain indicates areas which have been mined or filled or have been subjected to other significant soil disturbance activities.

Where there is a probability of occurrence of acid sulfate soils (ASS), the depth to the ASS layer is provided. A guide is also given to land use activities which may create an environmental risk if carried out without acid sulfate soils investigation. The mapping has been designed to provide information on acid sulfate soil distribution and indicate land uses which are likely to create an environmental risk by disturbing ASS. The maps will assist with land management and the environmental planning of landscapes in coastal NSW.

The highest risk category is where the iron sulfide layer is within 0.5 m of the soil surface (Naylor *et al.,* 1998). Figure 28 shows the areas of high risk and the estimated total acid sulfate soils in coastal NSW, based on 1995 ASS Risk Mapping. The Hunter catchment has the fourth highest area of both high risk ASS and total ASS areas of all NSW catchments. The area of acid sulfate soils in figure 28 is larger in the northern catchments of NSW than in the southern catchments, reflecting the change in river morphology between coastal embayments in the north and flooded river valleys in the south (White, *et al.*, 1999).

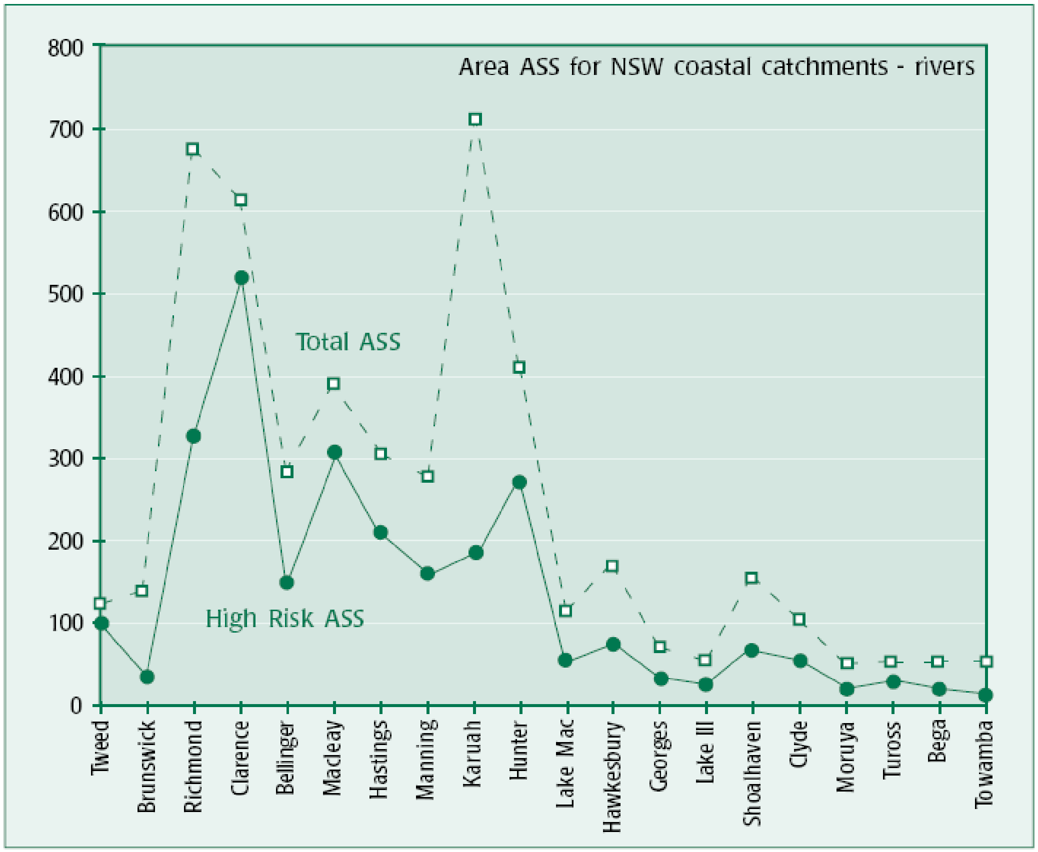

Figure 28: Area of high risk and total acid sulfate soils in NSW coastal catchments from 1995 mapping data (Source: White, *et al*, 1999)

2.5 Elevation (LiDAR)

Knowledge of local elevations and the production of detailed maps enable assessments of the potential for surface water movements across low lying areas. This enables land managers to then re-assess the amount of water being returned to the wetlands and identify areas where the provision of water control structures may be of benefit.

LiDAR (Light Detection and Ranging) is remotely flown from aircraft, using lasers to pinpoint elevations within 0.15m resolution. LiDAR efficiently produces high definition, high accuracy terrain, and elevation and canopy models. In densely vegetated areas LiDAR routinely provides a more rapid and detailed terrain model than photogrammetry for broadscale projects.

As described in Figure 29 the technology involves a laser scanner mounted in an aircraft. The laser scanner emits a laser beam which is reflected from the ground. The laser scanner records the time difference between the emission and reflection. Combined with accurate information about the position and orientation of the aircraft during flight, the elevation of the 'scanned' area can be determined. Modern laser scanning systems are capable of emitting up to 100,000 pulses per second, providing a dense grid of points covering the ground surface and capable of penetrating vegetation. It is then possible to model not only the ground surface below trees but also the tops of trees and buildings.

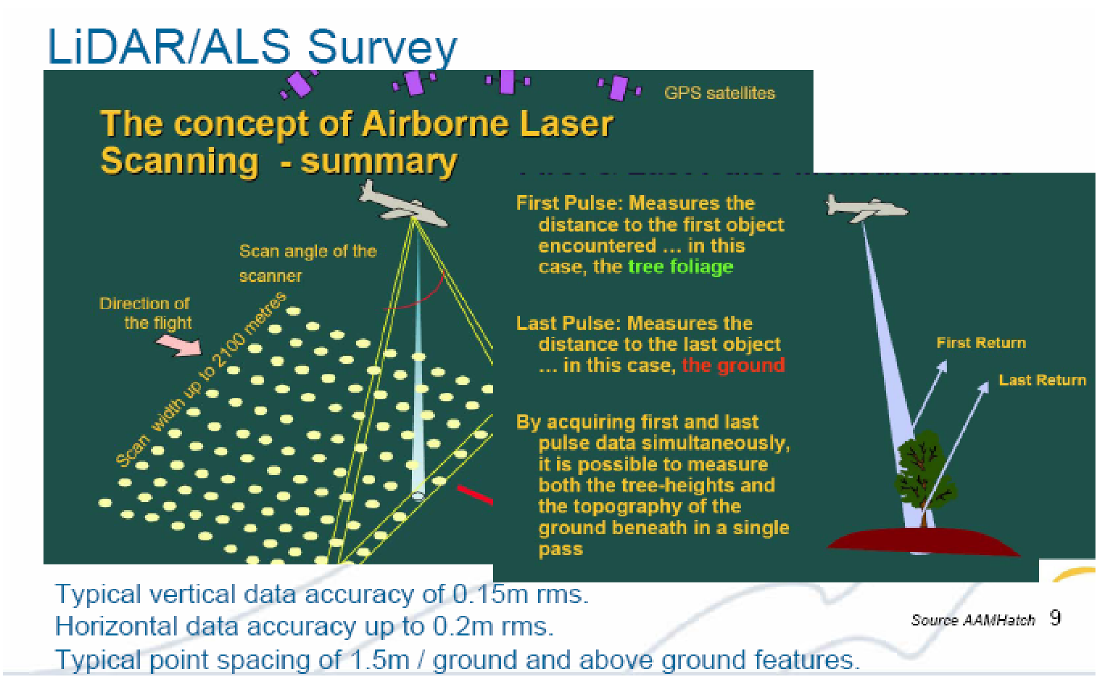

Figure 29: LiDAR Airbourne Laser Scanning (Source: AAMHATCH in Hudson and Douglas, 2007).

The necessary elevation information for this project was provided by LiDAR data for the Lower Hunter Region which was purchased and negotiated through licensing agreements with the original data holders. The LiDAR data (in Digital Elevation Model format) was used to identify appropriate sampling sites, and formed the basis for the Acid Sulfate Soil Risk Mapping.

The Digital Elevation Model for the Lower Hunter Region is provided in Appendix 3. The Digital Elevation Model reveals that the study sites identified by this project are between -1 to 2m elevation AHD. Further discussion into the relevance of elevation in ASS assessment is provided in Section 3 (Results).

2.6 Soil and Water Sampling

Soil and water sampling was carried out using methods as detailed in *Australian Soil and Land Survey Field Handbook* (McDonald *et al*, 1990) and sampling, handling and transport of soil samples were undertaken according to *Acid Sulfate Soils Laboratory Methods Guidelines* (Ahern, *et al,* 2004).

The intention of the soil morphological assessment and soil profile descriptions were to establish the depth to sulfuric (actual ASS containing jarosite and iron oxide mottling) and sulfidic (potential ASS containing pyrite, shells or with a positive peroxide test) horizons. For these purposes, a truck mounted, hydraulically-operated auger was used to penetrate through the dense surface layers where necessary. A gouge auger was then deployed to sample the softer sediments to a depth of up to 1.5 metres (see figures 30 and 31).

Figures 30 and 31: methods of soil sampling - soil coring and the gouge auger (photos: J Fredrickson).

The soil profile descriptions and sampling included the following:

- Record of each borehole location using GPS and record of surface elevation.
- Soil profiles were described mostly using undisturbed cores, so that depth of each horizon and the presence of shells and jarosite mottles could be accurately determined.
- The morphological properties outlined in table 1 were described, and samples for the laboratory tests outlined below were collected from each horizon. Approximately 0.5 kg of soil per sample was collected for laboratory analysis ensuring that a sealed plastic bag is used and clearly labelled with project/site number and depth of sample. As soil properties can change rapidly with depth, narrow depth intervals (10 or 15cm) were used for sampling down the profile. Up to 6 intervals were sampled from each profile.
- Field pH peroxide test (pH_{FOX}) at 10cm depth intervals down the profile, to determine the presence of any oxidisable PASS layer (see figure 32).

- Record of groundwater depth from the soil surface.

- Collection of a groundwater sample for laboratory analysis. In some cases water was also sampled from the nearby drain and / or surface water close to the site.

- Samples were immediately frozen after collection and dispatched to Wollongbar Diagnostic and Analytical Services Laboratory (NATA (National Association of Testing Authorities) accredited laboratory) for detailed analysis.

- Profiles were located mainly in areas not previously described.

Figure 32: Peroxide is applied to soil samples to test for the presence of oxidisable sulfur. The gas produced during the reaction is sulfur dioxide and water vapour. This vigorous reaction is from subsoil at Tomago Wetland (Photo: S Walsh)

A ranking system is used in this report (after Lawrie and Eldridge, 2006), whereby a **high risk** is assigned to areas where the soil has some or all of the following features:

- PASS layer within a metre of the soil surface
- high TAA level within the top metre of the profile (over 100 moles H^+/tonne)
- very low pH (below 4 within the top metre)
- high concentration of sulfate in the soil and groundwater
- exchangeable aluminium percentage over 50% within the top metre
- sandy texture or porous, crumbly structure that is highly permeable
- location in close proximity to an artificial drain or natural drainage line
- poorly drained surface where ponding persists for many days after rain, and where the vegetation turns black and putrid when waterlogged.

A **low risk** is assigned in areas where the soil has some or all of the following features:

- soil where the reduced inorganic sulfur content is very low, or zero
- PASS layer which is very deep in the profile and is likely to be permanently waterlogged
- profile in an elevated position (over 2m AHD) or lacking any water table within the root zone, or remote from any drain or natural drainage line.

2.6.1 Soil Analysis

The following tests were carried out on the soil samples collected in this study:

- Chromium Reducible Sulfur (S_{cr}%) (Method 22b ASSMAC, Ahern *et al*, 2004)
- Total Carbon (%) (by Dumas combustion – Method 6B3 Rayment & Higginson,1992)
- Soil pH ($CaCl_2$) (Method 4B1 Rayment & Higginson, 1992)
- Total Actual Acidity (TAA) (Method 21F ASSMAC, Ahern *et al,* 2004)
- Electrical Conductivity (EC) (Method 3A1 Rayment & Higginson, 1992)
- Soluble Chloride (Method 5A Rayment & Higginson, 1992)
- Soluble Sulfate
- Exchangeable Aluminium

The Chromium Reducible Sulfur (S_{cr} %) test was chosen as it is one of the few tests which can give an accurate estimate of the quantity of reduced inorganic sulfur (i.e. the unoxidised iron sulfide) in the soil. This test has been shown to be specific to reduced sulfur and is not influenced by the presence of organic sulfur or sulfates in the soil. As such it is ideal for analysing for the presence of PASS material in the soil.

Total Carbon (%) was tested to show variation down the profile, and is important in assessing the soil materials given the extent of peat accumulation in this landscape setting as well as the importance of organic matter in the formation and breakdown of the sulfide minerals by soil micro-organisms.

Soil pH was measured using the $CaCl_2$ method, as this is a more robust test than the pH water method, and more meaningful for relating pH to plant growth. The ASSMAC acid sulfate soil manual defines an 'Actual Acid Sulfate' soil as an acid soil resulting from the aeration of materials rich in iron sulfides with a pH of 4 or less (pH_{water}). Soil pH ($CaCl_2$) results are often around 0.5pH units less than pH water test result for the same soil. This has to be factored in when interpreting soil pH results.

Total Actual Acidity (TAA) is a measure of the total amount of acidity present in the soil, expressed as moles of H+ / tonne of soil. As such it is a more accurate indicator of acidity through the profile than the pH measurement.

Electrical Conductivity (EC) (measured on a 1:5 soil/water suspension) provides a measure of the salt levels and has important implications for plant growth.

Measurements of Soluble Chloride and Soluble Sulfate concentration allow the relative influences of salt water intrusion from past king tides and the oxidation of the PASS layer, on Soil Salinity (EC) to be evaluated.

Exchangeable Aluminium is measured as a percentage of total Cation Exchange Capacity (i.e. the amount of cation exchange sites occupied by aluminium ions in the cation exchange complex). High levels of soluble aluminium are often toxic to non-native plants such as some pasture, crop and ornamental species, causing markedly stunted roots and reduced growth. Toxicity can be expected when exchangeable aluminium levels are >5% and soils are strongly acid.

These tests were chosen on the basis of an earlier study in the Shoalhaven catchment (Lawrie and Eldridge, 2006).

2.6.2 Water Analysis

The water samples were tested for the following properties:

- pH
- Electrical Conductivity (EC)
- Chloride
- Sulfate

Groundwater pH often reflects the extent of sulfide oxidation which has occurred in the soil profile. It has environmental implications for water quality and plant growth.

Electrical conductivity of the groundwater reflects the influence of freshwater percolation, salt water inputs from king tides and the oxidation of PASS material in the sediments, on groundwater salinity.

Chloride and Sulfate concentrations in the groundwater indicate the relative influences of tidal processes and sulfide oxidation.

Chloride / Sulfate Ratio The ratio of chloride to sulfate in the groundwater is another indicator of the presence of an acid sulfate soil. It is based on the fact that the ratio of Cl^- : SO_4^{2-} in sea water on a mass basis is 7.2. It is argued that a ratio of less than 4, and definitely less than 2, is a very strong indication that there is an extra source of sulfate other than sea water (i.e. from the earlier oxidation of pyrite in the soil).

2.7 Hydraulic Conductivity

Hydraulic conductivity (K) of the soil is a measure of the potential for groundwater movement both laterally and vertically through the soil profile. This critical parameter can greatly influence the behaviour of shallow groundwater and therefore potential management options for areas with acid sulfate soils (ASS). For example, the reintroduction of tidal flushing in a former wetland creek can benefit the system immensely. However, in some sites where the hydraulic conductivity is high (due to sandy soils or the presence of macro-pores), flushing with salt water can lead to detrimental impacts to wetland vegetation, surrounding productive pastures and potentially to the export of heavy metals associated with ASS / salt interactions.

On coastal floodplain ASS back-swamps K is also highly variable. For example, hydraulic conductivity may vary with depth as shown in figure 33. The sulfuric layer (horizon) is most significant from an acid export point of view as it may contain a large store of acid groundwater, and being closer to the surface, it is more likely to be intercepted by a constructed drain.

Figure 33: Schematic diagram of how hydraulic conductivity may vary with depth (source: Johnson and Slavich, 2003).

For this reason, some site specific knowledge of *K* is ideally required to identify management options for the remediation of ASS sites, particularly with regards to:

- Identifying pathways of acid export (groundwater vs surface water)
- Identifying different types of containment strategies
- Opening floodgates and potential for lateral salt seepage.

The method employed by the project to determine the likely range of saturated hydraulic conductivity (K_{sat}) involves the excavation of test pits and use of pit-bailing techniques (after Johnston and Slavich, 2003), where results are calculated using the method of Bouwer and Rice (1983).

Representative sites were chosen for the pits, in total 12 pits were excavated across the Lower Hunter floodplain, to the specific dimensions determined by Johnston and Slavich (2003) as follows:

- The pit should be as square as possible with vertical sides and a 'flat' (as possible) bottom (see figures 34 and 35). Avoid excessive smearing of pit faces.
- Minimum area of 30 cm x 30 cm (W x B).
- Maximum area of 50 x 50 cm (W x B).
- Maximum depth of pit from ground surface (D) = 60 cm.
- A minimum of 10 cm water depth is required in the bottom of the pit (L) at equilibration with the surrounding water table.
- The pit water level at equilibration with surrounding water table must be at least 5 cm below ground surface.
- Bail out between 50% to 90% of water volume in the pit.
- Time and record the rate of ground water infill until equilibrium is obtained.

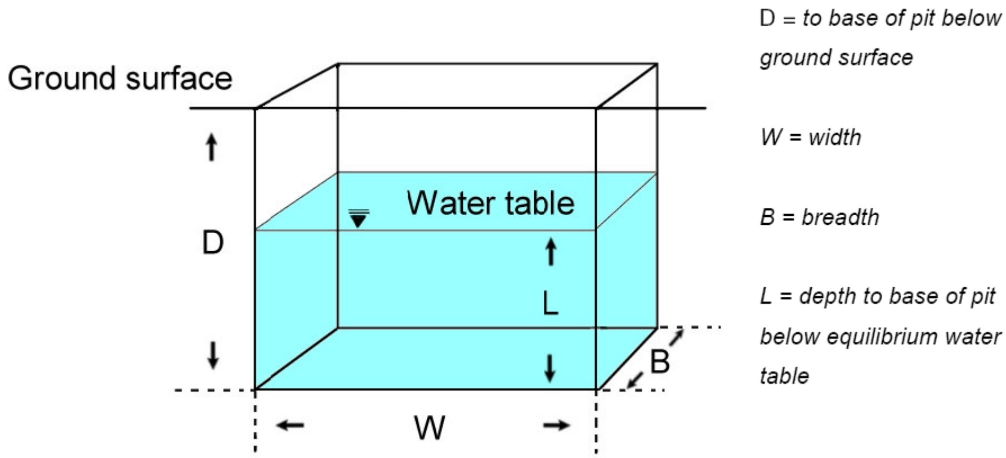

Figure 34: Example of pit geometry (Source: Johnson and Slavich, 2003).

Applying the Bouwer and Rice (1983) calculation methods to the data collected provides a quantitative assessment of K_{sat}. The K_{sat} measurement falls into one of four categories:

Low =	less than 1.5m/day
Moderate =	1.5 to 15m/day
High =	15 to 100m/day
Extreme =	greater than 100m/day

Figure 35 (left): Example of a hydraulic conductivity (K_{sat}) pit assessment at Hexham Swamp on the Lower Hunter Estuary floodplain (photo: J Fredrickson)

According to Johnson and Slavich (2003) if a site's K_{sat} falls in the high or extreme range, then depending on other factors (i.e. elevation of acid horizons relative to local low tide levels, whether the drain intercepts those high K_{sat} soil horizons, any 'pugging' and blockage of macropores at the drain bank face), there is a very real probability that groundwater seepage may be a major hydrological pathway of acid export. In this case, a containment strategy will likely be an important management option.

Acid groundwater may be contained by infilling or shallowing drains, or by using a retention structure to keep drain water levels high and stable and prevent the development of effluent groundwater gradients through tidal drawdown.

High or extreme range K_{sat} also means that if floodgates are opened and saline water introduced into a drain there is a possibility that this saline water could move laterally away from the drain over substantial distances. However, this will also be dependent on the driving head and will only occur *if the gradients are influent* (i.e. the drain water level is higher than the groundwater level).

If a site's K_{sat} falls in the low range then the risk of lateral salt water seepage if floodgates are opened is likely to be minimal.

If a site's K_{sat} falls in the medium range then further quantitative assessment of K_{sat} may be warranted in order to assess the risk of lateral salt water seepage due to floodgate opening. Monitoring the response of the water table adjacent to the drain during a freshwater floodgate opening event may also be useful (Johnson and Slavich, 2003).

2.8 Soil Conductivity

Apparent soil conductivity due to acid or marine salts was measured along a number of transects on the floodplain using a Geonics EM38 (electromagnetic induction meter), which was operated in accordance with the manufacturer instructions (McNeill, 1986).

The EM38 (pictured in figure 36) is a non invasive way of measuring the conductivity of a soil. This meter induces electromagnetic eddy currents into the ground and measures the magnetic field that is generated, which indicates how well it is conducted by the soil on the surface and to a depth of 1.5m.

Figure 36 (left): EM38 being used to measure soil electrical conductivity (salinity) (Source: S Walsh).

The strength of the current is related to the salt content in the soil, therefore higher salt contents result in higher conductivity readings. This is because most soil minerals are insulators, so in sufficiently moist soils electrical conductivity is mainly via the salts (electrolytes) in the soil water (Turnham, 2003).

The EM38 has a coil spacing of 1m and measures apparent soil EC in mS/m in either a vertical or horizontal dipole orientation. In the vertical orientation the EM38 is more responsive to changes in EC below 0.45m, whereas in the horizontal orientation the maximum response is to the surface and declines with depth.

Due to this difference in respective depth response functions, the vertical and horizontal EC readings can provide a useful measure of the trend in soil EC with depth. The mean of the vertical and horizontal readings provides a more effective integration of soil profile EC than either measurement alone (Slavich, 1990).

Conductivity results are measured on a scale of low, medium, high and very high as detailed in table 2.

Table 2: Soil Electrical Conductivity Rating

Apparent Electrical Conductivity (mS/m)	Low	Medium	High	Very High
Estuarine clay dominated landscapes (coastal floodplains)	< 100	100-200	200-400	>400

Source: Clay and Hirst (2004)

Apparent EC is a function of the average of EC across the transect and also the average of the horizontal and vertical readings.

2.9 Access Permission

Prior to entering sites to carry out field surveys, the owner or land manager was contacted seeking access permission.

Fullerton Cove sites are all on private land, and access required permission from private landholders.

Tomago Wetland and Hexham Swamp are managed by NSW Dept of Environment and Climate Change (National Parks) and access required permission (and at times a key to unlock gates) from Parks Rangers.

Kooragang Wetland is managed by Hunter Central Rivers CMA and NSW Dept of Environment and Climate Change (National Parks) and access required permission from Site Managers.

Shortland Wetlands Centre is managed by the Hunter Wetlands Centre and access required locked gate admission from Site Managers.