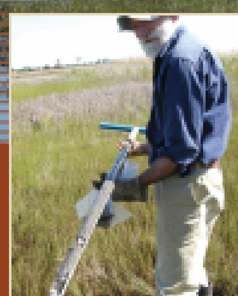
NSW DPI

Acid Sulfate Soils

Priority Investigations for the Lower Hunter River Estuary



REPORT TO THE DEPARTMENT OF ENVIRONMENT, WATER, HERITAGE AND THE ARTS

NSW DEPARTMENT OF PRIMARY INDUSTRIES

Australian Government

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August 2008

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Cover Photos: Birdlife in Hexham Swamp (background); Soil sampling at Tomago Wetland (left foreground); Iron flocculate as evidence of acid sulfate soils in Fishery Creek, Hexham Swamp (middle foreground); Hydraulic conductivity test (K_{sat}) pit at Tomago Wetland. Photos by J Fredrickson.

Executive Summary

Acid sulfate soils are a naturally occurring feature of estuaries along the Australian coastline. Changes to land use on floodplains, for example wetland drainage, have led to the oxidation of sulfidic soils, resulting in acid leaching from the soil causing water quality problems. Acidic water impacts upon downstream receiving waterways and their associated aquatic-dependent ecosystems, including migratory birds.

The detailed distribution of acid sulfate soils in the Lower Hunter River estuary is largely unknown, as is the impact these soils are having on important features of the estuary, such as Ramsar wetlands of international importance. This report details the results of a study into the distribution and severity of acid sulfate soils in the Lower Hunter River estuary, as well as providing recommendations for future research and on ground works in view of the findings. This study entitled ‘Acid Sulfate Soils Priority Investigations in the Lower Hunter River Estuary’ was funded by the Australian Government’s Coastal Catchments Initiative, and was undertaken by NSW Department of Primary Industries.

The acid sulfate soils investigation used a range of methods to assess soils across a range of representative sites in the Lower Hunter, including soil profile coring, laboratory analysis of soil samples, and tests for soil hydraulic conductivity (K_{sat}) and electrical conductivity (EC). In addition, detailed elevation information was provided by LiDAR technology, which was in turn used to update the Acid Sulfate Soil Risk Maps for the study area.

Sites tested include Kooragang Wetland (Ash Island site) and Shortland Wetlands (which are both listed as Ramsar Wetlands of International Importance), as well as nearby Tomago Wetland, Hexham Swamp and Fullerton Cove.

Analysis of soil chemistry at these sites has revealed that while acid sulfate soils occur in all five of the sites, there are differences in the degree of oxidation and consequently the risk of acid discharge. A summary of the results and recommendations is as follows:

Fullerton Cove

This site is considered the highest priority site for acid sulfate soil management of the five sites assessed. A system of constructed drains has allowed active management of surface drainage, leading to a lowered water table and oxidation of the potential acid sulfate soil (sulfide) layer in the subsoil. During core sampling the sulfide layer was discovered only 50cm from the soil surface in some areas, resulting in a high risk rating. Acid water is entering the drainage system which in turn is being discharged into the estuary via the Fullerton Ring drain floodgates. It is recommended that no additional deep drains are constructed in the area affected by shallow acid sulfate soils.

By opening the floodgates, neutralising tidal water could be reintroduced into the drains to buffer acid discharge before it reaches the estuary. Private landholders have expressed a willingness for floodgate opening, however wish to retain the use of the land for farming. In places where the land adjacent to the drain is low lying, associated works such as bunding and/or raising of the levee bank will be required.

Tomago Wetland

Tomago Wetland is considered the second highest priority site for acid sulfate soil management. Surface water is drained by a series of constructed drains, which discharge into Fullerton Cove via two sets of floodgates. At times these drains would receive acid discharge, produced from oxidised sulfidic subsoil as well as from surface sulfide accumulation in areas intermittently submerged by freshwater. It is recommended that estuarine water be allowed to flush the drains at Tomago, to neutralise acid discharge before it reaches the estuary. This could be achieved by opening the two sets of floodgates to allow the water level in the drains to rise and fall with the tide. One floodgate (the western floodgate) is already being opened under an existing project. It is recommended that an investigation into the opening of the eastern floodgate also be undertaken.

Results indicating high stored acidity in the northern boundary of Tomago Wetland confirm that caution should also be applied when undertaking drain maintenance activities to avoid exposing additional sulfidic soils to oxygen.

Hexham Swamp

The large area of Hexham Swamp ranges in its acid sulfate soil risk from low through to high. A sulfide layer of variable elevation was detected in the southern part of the swamp, and high risk areas were found adjacent to Ironbark and Fishery Creeks. These creeks receive large volumes of stormwater runoff from the surrounding hills, and this accumulates in surface ponds that pose the additional risk of surface sulfide accumulation.

Ironbark Creek floodgates currently inhibit tidal flows into Hexham Swamp. It is recommended that these floodgates be opened to allow tidal water into the creek system to neutralise any acid discharge before it reaches the estuary. The impact of urbanisation of the areas fringing Hexham Swamp need to be properly investigated to ensure acid effects are not amplified.

Weather conditions and time constraints prevented detailed investigation into the northern and western parts of the swamp. Further study is needed to conclusively identify key sources of acid.

Kooragang Wetland (Ash Island)

All sites at Kooragang have been ranked as medium risk. This is due to the deeper nature of acid sulfate soil at most sites, the natural water regime of the site and the absence of artificial drainage lines. The lack of artificial drains is an advantage in that most of the potential acid sulfate soil layer has never, and is unlikely to be (under the current wetland management) oxidised. The potential acid sulfate soil layer at Swan Pond, however, is on the soil surface, being an active site of sulfide creation. The priority for this site, and other permanently wet sites like it in the southern end of the wetland, is to keep the site wet to avoid oxidation of a significant amount of acid.

It is likely that sites in the central area of the wetland (around Phoenix Flats) are exporting some acid through ground water seepage. It is important to maintain tidal influence on the island via the swales and creeks crossing the island to neutralise any acid before it reaches the Hunter River. Should any actual or potential acidic spoil need to be excavated (for example, to maintain flows in the swales or construction of engineering projects) spoil must be tested and assessed, and required liming rates determined and applied.

In the north of Ash Island, on elevated ground, there is a moderate level of stored acidity. Under current water management (i.e. no constructed drains) this acid remains relatively harmless. It is important that drainage of this area is not altered, and no drains constructed, to prevent mobilisation of the stored acid.

Shortland Wetlands

Much of Shortland Wetlands is elevated and therefore not affected by acid sulfate sediments. Low lying areas such as Ironbark Marsh and the Canoe trail, however, are subject to acid sulfate soil risk. At present management of Ironbark Marsh involves near permanent inundation with freshwater. Similarly soil profiles adjacent to the Canoe trail are submerged, preventing sulfides from oxidising. In several locations the potential acid sulfate soil layer is close to the surface. Any future earthworks in the area will require additional testing of soils and assessment of risks of exposing this layer.

The opening of Ironbark Creek floodgates would play a positive role in the future management of this site. Once tidal water is allowed into the creek system, any acid could be neutralised before it reaches the estuary. Neutralisation would also prevent surface sulfide accumulation in freshwater wetlands from becoming a risk.

Further Recommendations

Numerous other wetlands in the Lower Hunter Estuary have been modified for farming and other human activities. The presence of acid sulfate soils in these wetlands is largely unknown, as is the impact of any acid being exported from these sites. These sites need to be assessed for their potential to generate acid.

Many of the wetlands in the Hunter region are owned and managed by private landholders conducting beef cattle / horse grazing. A series of Wet Pasture Management workshops were held under this current project to demonstrate to landholders techniques in keeping their formerly drained wetlands in a wetter condition. At the workshops landholders were shown how to improve pasture productivity, while also providing immense benefits for managing acid sulfate soils by retaining groundwater levels. This work could be further expanded in the region, with support given to landholders to provide the necessary infrastructure and training in its use.

Using the detailed elevation data acquired under this project, it is also feasible to model the changes to coastal wetland vegetation communities such as saltmarsh, which are likely to migrate inland following predicted sea level rises of up to 88cm by 2100. The movement of saltmarsh and associated communities will provide the impetus for the corresponding translocation of faunal communities including migratory birds. This technique can be used to model where the Ramsar wetlands are likely to be under various sea level change scenarios and determine suitable areas for potential saltmarsh migration.

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1 Background

1.1 Location

The Lower Hunter Estuary is located north of Newcastle, at the lower reaches of the Hunter River (see location map, figure 1). The Hunter River catchment is an area of more than 2 million hectares, bordered in the north-west by the Liverpool Ranges, to the west by the Great Dividing Range, and to the north and north-east by Mt Royal Range and the Barrington Tops. The Hunter River itself covers a distance of 467 km, starting north of Muswellbrook. From the headwaters the river flows south where it is joined by its major tributary, the Goulburn River, and then east to Newcastle where it discharges into the Tasman Sea.

1.2 Geology

The Hunter Valley's geology is made up of sediment trapped during the Permian period (~250 million years ago) including coal, conglomerate shales, fluvial sandstones, and Triassic period (~200 million years ago) including shales, and sandstones.

During the Quaternary period (1.8 million to present) sands and fluvial sediments were deposited, dependent on the varying sea levels. During periods of lower sea levels (up to 120 m below present day levels), the estuary and coastline extended 25km further seaward. During periods of sea level rise, vast quantities of marine sand were transported landward across the inner continental shelf as landward moving (transgressing) sand sheets and barriers.

This process has created the Hunter estuary as a barrier estuary (McManus *et al*, 2000; Chapman, *et al*, 1982). The estuary itself has two distinct barriers: the *Outer* and *Inner* Barriers (see figure 2). The *Outer Barrier* consists of a belt of beach, dune, estuarine and lagoonal sediments from the Holocene age (i.e. sediments deposited within the last 10,000 years). The eastern edge of the Outer Barrier forms the present day coastline.

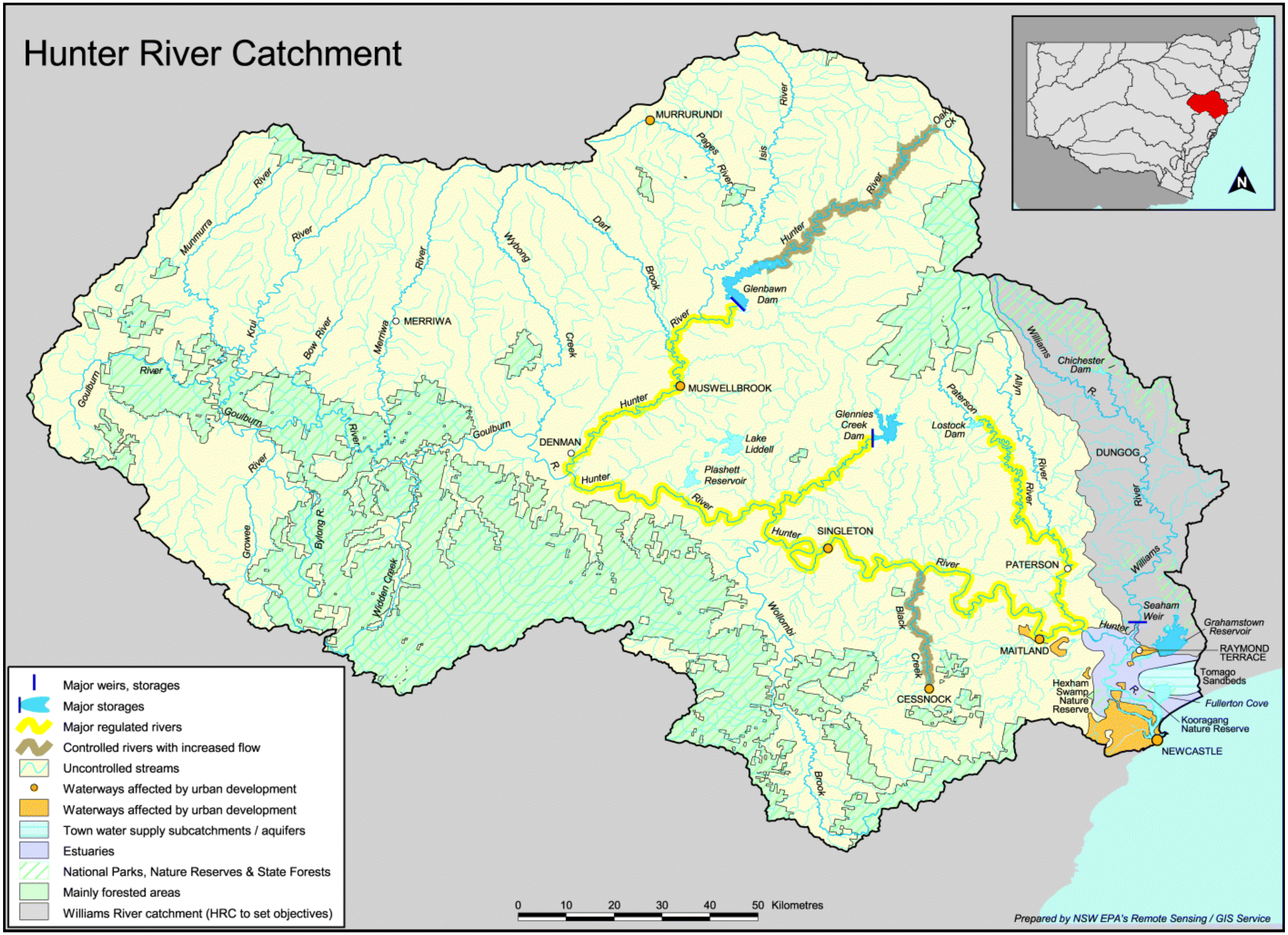

Figure 1: Map of the Hunter Catchment and land uses (source: NSW Dept Environment and Climate Change).

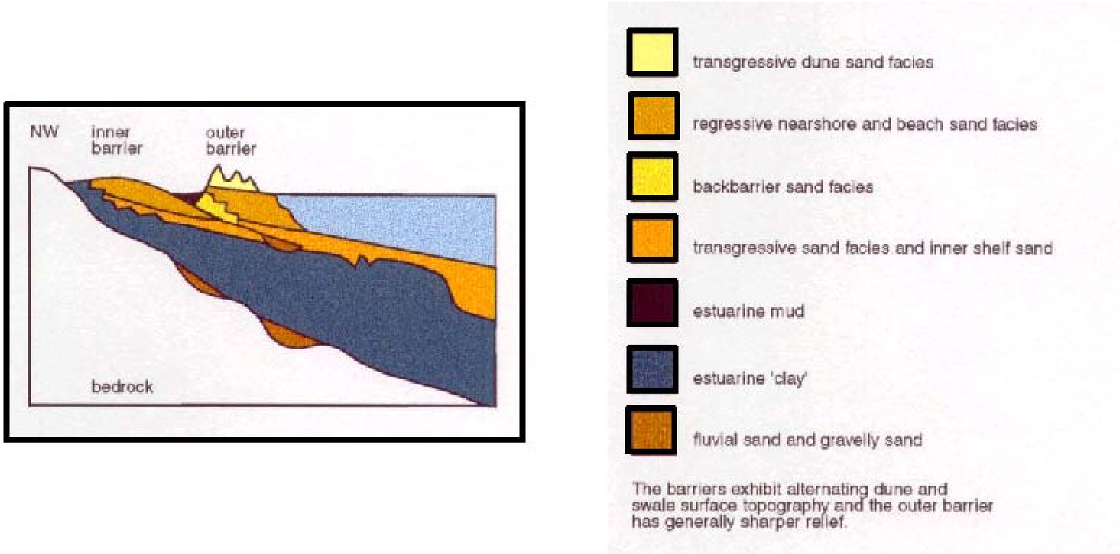

Figure 2: Inner and outer barriers off Newcastle Bight (source: Chapman *et al*, 1982)

The Inner Barrier is a second belt of marine sediments, located landward of the Outer Barrier. In between the Inner and Outer Barriers the estuary has formed, Tilligerry Creek extends south west from Port Stephens, and Fullerton Cove forms a basin connected to the Hunter River (see figure 3).

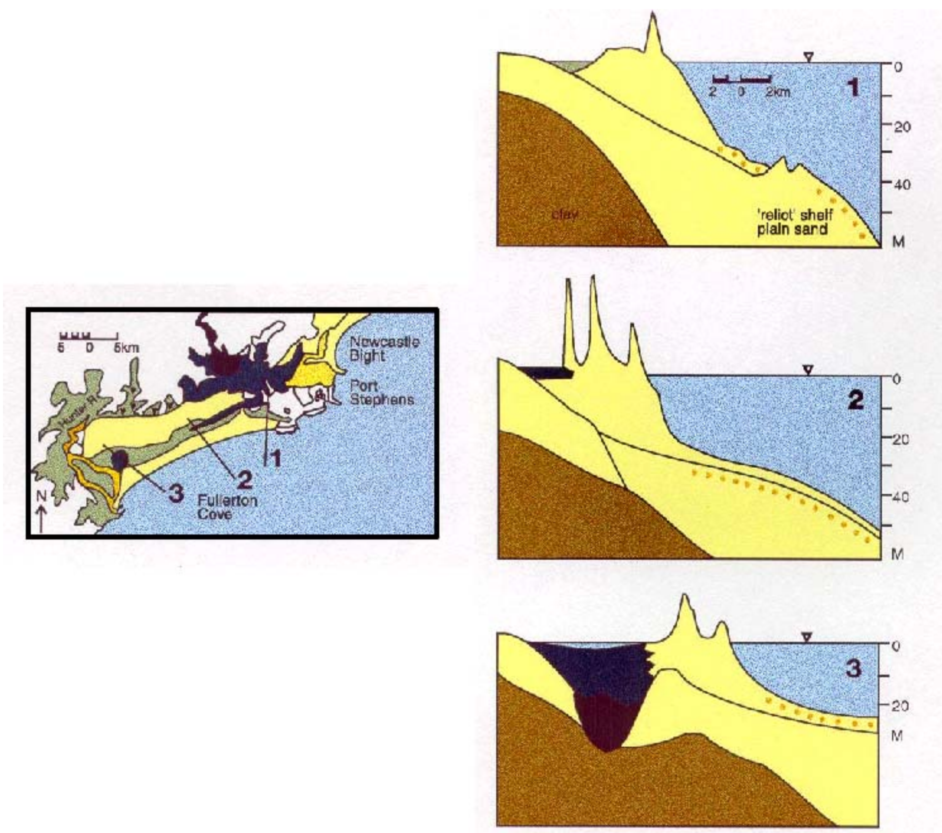

Figure 3: The development of tidal channels and lakes between the inner and outer barriers in the Lower Hunter and Port Stephens (source: Chapman *et al*, 1982)

1.3 Climate

The Hunter region's climate tends to be dominated in summer by sub-tropical influences and in winter by mid-latitude influences. The Hunter region lies in a transition zone, between sub-tropical climates of northern New South Wales and southern Queensland and the mid-latitude climates of Victoria and Tasmania.

The average temperature ranges from 18 to 27^{0}C in summer and 7 to17^{0}C in winter. The average rainfall is about 1100mm per year, with more falling in the summer, often as extreme rainfall events, and less rain in winter. Dominant winds are affected by the topography with prevailing winds in winter from the north-west. In summer, the prevailing winds are from east to south-east, followed by north-east breezes in the afternoon (McManus *et al*, 2000).

1.4 Tidal Regime and Flood Mitigation

The tidal variation in the estuary (adjacent to Kooragang Wetland) is 0.1m to 2m Australian Height Datum (AHD). The tidal limit is located 45 km from the sea at Oakhampton (near Maitland). Since major flooding in the 1950s the estuary has undergone significant changes resulting from extensive flood mitigation and drainage schemes. Floodgates and drainage networks have been constructed to prevent tidal exchange and remove surface water from reclaimed farmland on the floodplain. Surface water (stormwater) is also removed at a more rapid rate. Changes to channel morphology have resulted in the reduction in the channel length between Maitland and Morpeth from 24 to 9.6 km.

In the Port of Newcastle, located at Newcastle, dredging maintains a river depth of around 15 metres enabling access for large ships, which mainly export coal.

On average the Hunter River discharges 1.8 million megalitres of water to the sea per annum. Most of the water in the Hunter catchment comes from the north-eastern part of the catchment (HCRCMA, 2008b).

The Hunter River upstream of the Hunter–Goulburn confluence has both regulated and unregulated sections. The main stem of the river is regulated by the Glenbawn Dam that helps to control flooding and provides a secure source of water for industry, town and irrigation use. Glenbawn Dam stores 750,000 megalitres and has a flood mitigation capacity of 120,000 megalitres (HCRCMA, 2008b).

1.5 Flora

The Lower Hunter region is part of a transition zone for many plant and animal species between the sub-tropical influences of the north and the cooler, less fertile conditions to the south. As a consequence, the vegetation is unique when compared to the neighbouring regions. The flora of the Hunter Valley floor is remarkably diverse, with approximately 2000 species of vascular plants (DECC, 2006).

Of the 61 vegetation communities that occur in the Lower Hunter, 19 communities are considered to be regionally significant including ten listed endangered ecological communities. The Lower Hunter Region currently has 26 threatened plant species including eight endangered and 18 vulnerable species (DECC, 2006). Vegetation in the region has been largely cleared for agriculture, mining and urban purposes. The vegetation remaining on the valley floor is often highly fragmented and affected by weeds, feral animals and altered fire regimes.

1.6 Fauna

The Lower Hunter contains fauna habitats of national and international significance. The Hunter Valley marks a transition zone for many fauna species between the sub-tropical influences of the north and the cooler, less fertile conditions to the south. The estuary supports a rich faunal diversity (figure 4). A total of 27 of these species are classified as threatened, as listed in Appendix 1. Kooragang Wetland Rehabilitation Project has compiled a complete list of animal species recorded in and around the wetlands, including:

- 185 birds (28 are migratory species)
- 45 fish and decapod crustaceans (14 are listed as commercial and recreational species)
- 15 frogs including the endangered Green and Golden Bell Frog
- 10 bats
- 17 non-marine molluscs
- A variety of terrestrial mammals, reptiles, spiders and insects.

(HCRCMA, 2008a)

Figure 4: Fauna found in the Lower Hunter Estuary: Green and Golden Bell Frog (DECC), Freshwater Mullet (Gunther Schmida) and Grey Shrike Thrush (DPI)

Of particular note, the Hunter estuary is one of the most important sites in New South Wales for migratory shorebirds, regularly hosting more than 1% of the world's population of Bar-tailed Godwits and Eastern Curlews. The estuary is also home to a range of fish and crustaceans, many of which are commercial and recreational species such as the Hunter school prawn (HCRCMA, 2008a).

Lists of species found in the Hunter estuary are provided in Appendix 1.

1.7 Wetlands

The Lower Hunter Estuary contains significant wetland areas that are of significance for migratory shorebirds, in particular wetlands at Kooragang (Ash Island), Shortland, Tomago, Hexham and Fullerton Cove. The location of these wetlands is shown in figure 5. The Hunter estuary contains the second largest area of mangroves in NSW (DECC, 2006). It is important as both a feeding and roosting site for a large seasonal population of shorebirds and as a waylay site for transient migrants. The Hunter estuary also provides important nursery habitat (spawning grounds) for marine organisms including commercial species of fish and prawns.

The Hunter estuary wetlands are listed internationally under the Ramsar Convention because of their unique mix of wetland types, importance for maintaining biological diversity and conservation of migratory shorebirds.

Figure 5: Lower Hunter Estuary Wetlands

Imagery: CNES SPOT 5

1.7.1 Ramsar Wetlands

The Ramsar Convention or 'Convention on Wetlands of International Importance' aims to promote and protect wetlands throughout the world. The convention was developed in the Iranian city of Ramsar in 1971 as a means to call international attention to the rate at which wetland habitats were disappearing, in part due to a lack of understanding of their important functions, values, goods and services. As it is a convention, the governments that join are expressing a commitment to preventing and repairing the loss and degradation of wetlands. Australia became a signatory in 1971 and now has more than 60 Ramsar sites, covering an area greater than the size of Tasmania.

The Hunter Estuary Wetlands Ramsar site comprises:

- Kooragang Nature Reserve - designated to the Ramsar list in 1984, and
- Shortland Wetlands - listed as part of the Ramsar site in November 2002.

To be listed as a Ramsar site, wetlands must contribute to internationally accepted criteria. The full ranges of criteria used to assess international significance are based on the wetland's zoology, botany, ecology, hydrology or limnology and importance to waterfowl.

Kooragang and Shortlands contribute to four of these criteria:

- **Criterion 1: Representative, rare or unique wetlands**

Shortland Wetlands is unique in that it has, within its 45 hectare site, a combination of high conservation value near-natural wetlands (melaleuca swamp forest, freshwater reed marsh, coastal estuarine mangrove-lined creek) and high conservation value artificial wetlands (constructed freshwater lagoons, coastal estuarine casuarina-lined channel, model farm dam).

It is the only complex of this type found within the Sydney Basin bio-geographic region. The melaleuca swamp forest in particular represents a wetland type that, although once very widespread, is poorly represented in the Sydney Basin bio-geographic region.

Figure 6: Melaleuca swamp forest at Shortland Wetlands (Photo: B Rampano)

- **Criterion 3: Populations important for maintaining biological diversity**

Kooragang Nature Reserve is ecologically diverse and represents a significant genetic pool for wetland species in the Sydney Basin bio-geographic region. 112 species of vascular plants have been identified at Kooragang Island, forming many distinct habitat types.

The mangrove and saltmarsh areas are particularly good examples of these plant communities (see figure 7). The most significant wetland plant community at Shortland Wetlands is the melaleuca swamp forest, dominated by broad-leaved paperbark (*Melaleuca quinquenervia).*

Figure 7: Tidal mangrove forest (Photo: J Fredrickson)

The Hunter Estuary Wetlands are also important for maintaining a high diversity of birds within the bio-geographic region.

- **Criterion 4: Species at a critical stage in their life cycles or a refuge in adverse conditions**

Kooragang Nature Reserve is widely recognised for its importance in the conservation of migratory birds. At least 38 species of migratory birds recorded at Kooragang and 21 species of migratory birds at Shortland Wetlands are presently listed under international treaties including the Japan-Australia and China-Australia Migratory Bird Agreements (JAMBA and CAMBA).

Kooragang Nature Reserve regularly supports 15 species of migratory shorebirds, while Shortland Wetlands regularly provides habitat for at least seven species of migratory shorebirds. In 2000, 4800 migratory shorebirds were recorded in the Hunter Estuary.

Kooragang and Shortland Wetlands also support a large number of species at a critical seasonal stage of their breeding cycle. The site provides refuge for a number of species during periods of critical inland drought. These species include:

- freckled duck (*Stictonetta naevosa*)
- pink-eared duck (*Malacorhynchus membranaceus*)
- Australian pelican (*Pelecanus conspicillatus*), pictured (figure 8)
- glossy ibis (*Plegadis falcinellus*).

The site is also important for local resident ducks, herons and other waterbirds, with up to 2000 ducks recorded at Shortland Wetlands during dry periods.

Fig 8: Australian Pelican (Photo: DPI) Fig 9: Eastern Curlew (Photo: J Thornton)

- **Criterion 6: Regularly supports 1 per cent of the individuals in a population of one species or subspecies of waterbird.**

Kooragang Nature Reserve regularly supports between 2 per cent and 5 per cent of the East Asian-Australasian Flyway population of eastern curlew *(Numenius madagascariensis*), pictured (figure 9), with counts ranging from 320 to 900 birds between 1989 and 2000.

Source: DECC (2008)

1.8 Acid Sulfate Soils

1.8.1 Formation of Acid Sulfate Soils

Acid sulfate soils (ASS) are naturally occurring soils and sediments rich in quantities of sulfide minerals, predominately iron pyrite (FeS_2). These soil layers have the potential to generate sulfuric acid when the FeS_2 material is exposed to oxygen, causing great environmental harm. The formation and oxidation of ASS is a constant and continual process of the natural sulphur cycle. There are a number of activities that can lead to oxidation of these soils, including floodwater mitigation drains, dredging, coastal sandmining, road construction, urban development, tourism attractions, aquaculture and agricultural ventures.

ASS occur naturally over extensive low-lying coastal areas, predominately below five metres AHD (Dear *et al*, 2002). Following the last ice age, rising sea levels of the Holocene age inundated these low lying areas and floodplains. Sulfate contained within the sea water reacted with land sediments containing iron oxides and vegetation and other matter. The anoxic conditions created by the inundating sea water and the activity of certain bacteria led to the development of these iron sulfide minerals. NWPASS (2000) identifies five conditions that are necessary for the formation of iron sulfides. These are:

- a supply of dissolved sulfate, with concentration greater than 10 mg/L,
- a supply of readily decomposed organic matter,
- an adequate source of iron,
- generally oxygen-free conditions, and
- tidal flushing to remove soluble reaction products.

As long as the sulfidic soils remain below the water table, oxidation cannot occur and the soils are quite harmless and can remain so indefinitely (NWPASS, 2000). This portion of the soil profile is referred to as Potential Acid Sulfate Soil (PASS).

The Coastal ASS Atlas (ASRIS, 2008) estimates that Australia contains 95,000 km^2 of coastal ASS which equates to two billion tonnes of sulfidic material (potentially 3 billion tonnes of sulfuric acid) of which:

- 74,000 km^2 is on coastal land
- 21,000 km^2 is below the low tide mark as submerged or bottom sediments
- 1,000 km^2 is disturbed and acidified.

ASS is also found in coastal areas of Africa, the Far East, Latin America and Asia and occupies approximately one million square kilometres around the globe (Cooper, 2000). Additional information on methods for locating and assessing the risk of ASS in NSW is provided in section 2.4 Acid Sulfate Soil Risk Maps.

Atmospheric exposure of PASS allows the sulfidic material (previously benign) to be oxidised. Soluble Fe^{2+} is converted to insoluble Fe^{3+}, generating a yellowish-brown precipitate of $Fe(OH)_3$, an iron flocculate that discolours the water and the surface of vegetation upon which it settles. Furthermore, the oxidation of iron pyrite produces soluble iron (III) sulfate, $Fe_2(SO_4)_3$, and sulfuric acid, H_2SO_4 given by the equation:

$$4\ FeS_2 + 15\ O_2 + 2\ H_2O \rightarrow 4\ Fe^{3+} + 8\ SO^{2-}{}_4 + 4\ H^+$$

$$\text{i.e. } 2\ Fe_2(SO_4)_3 + 2\ H_2SO_4$$

Therefore the pollutants associated with the disturbance of acid sulfate soils include the acidification of shallow soils and the leaching of sulfuric acid and yellowish brown iron flocculate into natural waterways (as seen in Fisheries Creek at Hexham Swamp in figure 10). The concentrated acid can liberate toxic heavy metals, further adding to the pollution (Baird, 1998). The presence of aluminium is indicated by a milky-grey colouration in affected waters.

The oxidised acid sulfate layer is referred to as Actual Acid Sulfate Soil (AASS) and is generally of pH 3.5 or less, and the depth with which these oxidised components are noticed is referred to as the sulfuric horizon. The AASS layer can be indicated by the presence of jarosite mottles within the subsurface soil layers (figure 11). Jarosite is a yellow straw coloured iron based mineral. Oxidation products such as aluminium ions flocculate the clays, which do not redisperse during rewetting, lead to irreversible shrinkage and lowering of ground surfaces (White *et al*, 1997).

Figure 10: Iron flocculate in Fishery Creek at Hexham Swamp

Figure 11: Jarosite mottles within clay subsurface layer at Tomago Wetland
(photos: J Fredrickson)

To varying extent, soils have the natural ability to buffer or resist a change in pH caused by the oxidation of ASS. Clays with a high cation exchange capacity tend to have a higher buffering capacity than sands or other soils with low cation exchange capacity (Dear *et al*, 2002). This buffering capacity can be increased when organic materials such as vegetation and root systems are contained within the soil profile, along with the occurrence of calcium or magnesium carbonates, the shells of marine organisms deposited during periods of higher sea levels.

1.8.2 Soil properties of Acid Sulfate Soils

Certain soil profile features, as well as chemical and physical properties, have an essential role in producing acidity. All ASS have a sulfidic layer, or had one in the past in some cases. This is the potential acid sulfate soil (PASS) layer. It usually contains over 0.1% reduced inorganic sulfur (sometimes less if the layer is sandy). It normally occurs in the deep subsoil where waterlogged conditions prevail. When air reaches the layer it dries out, and it starts to oxidise. This process can be accompanied by the formation of jarosite. Further oxidation can degrade jarosite to other iron oxide or hydroxide minerals that are orange, yellowish-brown or reddish-brown in colour. These minerals often form hard concretions along root channels (hollow and/or tubular in shape), where air passes through the soil.

Oxidation also changes the soil chemical properties. The pH falls and the levels of total actual acidity (TAA), sulfate and exchangeable aluminium increase. If the groundwater is saline, the ratio of chloride to sulfate dissolved in it decreases, as it does in the soil itself. A summary of soil and water chemical properties important for acid production is provided in table 1.

Acid accumulates in the soil profile as oxidation progresses, but its movement out of the soil depends on the soil's hydraulic properties, as well as movements in the water table. In estuarine areas these movements are affected by the tidal action, rainfall, movement of surface runoff, flooding and evapo-transpiration by plants growing in the soil (Hughes *et al*., 1998).

It is very difficult to quantify the influence of all these factors and accurately predict the frequency and volume of acid discharges. However, the risk of acidic water being discharged from the soil can be estimated semi-quantitatively (see section 2.6 Hydraulic Conductivity for more information).

Table 1: Summary of soil and water chemical properties important for acid production

Soil material/ horizon	Morphological property	Chemical properties tested
Potential acid sulfate soil (PASS)	depth, thickness, texture, permeability, peroxide response	Reduced inorganic sulphur content, pH, salinity, chloride & sulfate content, total actual acidity (TAA)
Actual acid sulfate soil (AASS)	depth, thickness, texture, presence of jarosite texture, permeability	pH, salinity, TAA, chloride, sulfate content, % exchangeable aluminium
Subsurface mottled zone	presence of iron concretions, texture, permeability	pH, salinity, TAA, chloride, sulfate content, % exchangeable aluminium
Surface soil	thickness, odour, texture, permeability	pH, salinity, TAA, chloride, sulfate, % exchangeable aluminium

1.8.3 Floodplain Alteration

Many coastal floodplains have an extensive network of floodgates, constructed drains and modified waterways. Floodgates prevent flood waters and tidal brackish water from inundating low areas of the floodplain. Constructed drains (figure 12) are used to remove stormwater from agricultural land, converting low lying swampy land into dryland farming areas, allowing agriculture to diversify and improve production.

Figure 12: Constructed Drain at Tomago Wetland, which carries stormwater from the wetland area (photo: J Fredrickson)

Drainage of low wetlands has commonly led to exposure of acid sulfate soils to air, either through excavation or by lowering the watertable via drainage and drought. The acid and associated iron and aluminium can then leach from the soil and accumulate in drains and waterways behind floodgates. Floodgates prevent inflow of saltwater and floodwaters, which would otherwise act to dilute or neutralise pollutants, and allow a concentrated discharge of acid water during the ebb tide (Johnson, *et al*, 2003). Figure 13 demonstrates how floodplain alteration can increase production of ASS.

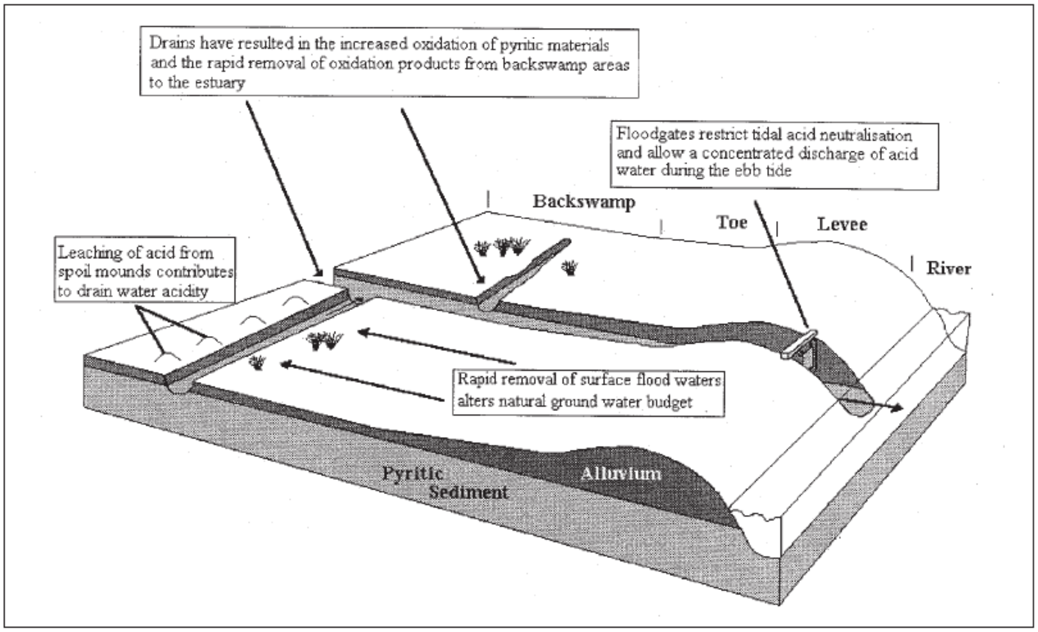

Figure 13: ASS production as a result of floodplain alteration (source: DLWC, 1998)

1.8.4 Rate of Production

The magnitude of effects of ASS will be determined by specific properties such as depth to the sulfuric horizon or PASS, and the subsoil concentrations of salts or minerals. NWPASS (2000) has identified the following factors as attributing to the rate of acid discharge:

- how fast atmospheric oxygen can enter the soil
- the amount and distribution of sulfides in the soil
- the distribution of soil water
- soil temperature and soil pH
- soil composition

Management strategies can be set in place in order to adjust hydrological flows and control oxidative processes, ultimately impeding or preventing the acidification process.

1.8.5 Effects and Implications

Acidification affects both soil and water, and it is now accepted that ASS oxidation has negative impacts on water quality, estuarine habitat, commercial and recreational fisheries, engineering structures, community infrastructure, agricultural productivity, real estate values, scenic amenity and tourism (Rosicky *et al*, 2002). As an example of the effects of acid sulfate soils on infrastructure is the corrosion of concrete bridge abutments (figure 14).

Figure 14: Concrete corrosion due to acid at Hexham Swamp
(photo: J Fredrickson)

Figure 15: Acid Plume from modified floodplains entering the Hastings River
(photo: DPI)

The impacts associated with ASS are both wide-ranging and severely damaging to the surrounding environment. Discharges of acidic water cause deleterious effects on fish, oysters and a multitude of other aquatic species.

Impacts on water quality associated with ASS are most noticeable after rain events following a period of drier conditions. Figure 15 shows a plume of acid in the Hastings River. Extended dry periods lower the watertable, further oxidising layers of potential ASS. Drought-breaking rains then flush significant quantities of sulfuric acid and toxic, heavy metals into waterways, resulting in fish kills (White *et al.* 1997), diseases such as epizootic ulcerative syndrome (red spot disease, see figure 16), and reproduction, recruitment and growth problems for aquatic organisms (Sammut, 1996).

Plants and sedentary gilled organisms that are unable to escape acidified waters are often killed or experience growth and reproduction problems. Water plant communities may alter, with the environment becoming more suitable for acid-tolerant plants, many of which are weeds. Oysters that suffer from either frequent or prolonged exposure to acidic conditions, cease feeding and experience breakdown of their shell, exhibit poor growth rates and display gill or organ damage (Sammut, 2000).

Aquatic habitats are also severely damaged as a result of acid water discharges. When mixed with less acidic stream water (pH > 4), the iron dissolved in acid water precipitates and can then smother plants and other benthic organisms (Sammut, 2000). High levels of aluminium are not only highly toxic to most aquatic organisms, but they also cause particles in the water column to flocculate and settle on the benthos. The resulting water clarity elevates temperature (up to 5^{o} C increase), allows acid-tolerant plants to saturate the water with oxygen (killing fish through gas bubble disease), and can increase incidence of fish suffering sunburn and melanomas (Sammut, 2000).

Figure 16: Lesions from red spot disease in sand whiting (photo: D. Callinan)

1.8.6 Avoiding disturbance of coastal ASS

Undisturbed ASS (buried and below the water table) poses little problem for the environment. Accordingly ASS affected areas should not be drained or excavated, and land management should be modified accordingly to avoid such practices where possible.

Measures suggested by the National Strategy for the Management of Coastal Acid Sulfate Soils (NWPASS, 2000) to prevent ASS problems becoming worse include:

Awareness: key land managers and developers must be aware of the problem, including the nature and distribution of ASS as well as its potential adverse impacts.

Education: community education is vital if practices are to be changed and adapted to achieve healthier environmental outcomes. Education of the community and rural industries in best management practice is an essential component of any attempt to limit the damage resulting from ASS and the attempts to remediate problem areas. Incentives and penalties are necessary in the more extreme cases as part of an ongoing education strategy.

Planning and development controls: planning controls must be tailored to minimise the risk of disturbing ASS and provide appropriate preventive measures without excessive cost. These may be linked with areas mapped as ASS risk.

1.8.7 Remediation of Degraded Areas

Having ensured that the oxidation of ASS does not increase, the next most crucial issue is to remediate existing areas of ASS and scalded areas. It is possible that there will already be a substantial quantity of acid stored in the soil profile that, if untreated, could continue to release acid into surrounding water bodies for a further 100 years or more (White *et al*, 1997).

Four main strategic options exist for the management of acid in the environment. These are containment, neutralisation, dilution, and transformation (Atkinson & Tulau, 1999):

Containment of acid within the soil profile in natural back-swamp depressions, artificial surface ponds or drains, prevents or minimises leakage into the environment. Higher water-tables behind containing structures creates intermittent to permanent wetlands and may have significant land management implications. This may represent the most viable option for dealing with acid discharges in the majority of cases but may not be conducive to the attainment of all objectives (Tulau, 2000).

Neutralisation strategies rely on the reaction of the acid with a known neutralising agent, typically either lime ($CaCO_3$) or the bicarbonate (HCO_3) in seawater (Dixon and Middleton, 2001). However neutralisation with lime is costly and has only short-term strategic applications. Neutralisation by seawater is more effective in lower estuaries where waters contain an adequate percentage of bicarbonate. In upper estuaries it may not be practical to rely solely on this buffering capacity to neutralise escaping waters, due to lower salinities.

Dilution involves the addition of freshwater to raise the pH, or allowing slow controlled acid leakage into the environment at an acceptable rate (Dixon and Middleton, 2001). As a management option, it is most effective when there is sufficient water available, or there are means to control the slow leakage of acid. It is therefore an appropriate strategy in larger rivers.

Transformation of acid by reduction into other stable compounds is the final means of dealing with acid discharges. Although valuable in terms of research, this method is yet to be verified in field situations (Atkinson and Tulau, 1999).

Figures 17-19 demonstrate these remediation techniques, as used to rehabilitate Bleechmore's back-swamp in the Clarence Catchment. By applying water to this ASS affected wetland, the acid was diluted and further oxidation of ASS was prevented, while also providing wet pasture benefits.

Figure 17: Bleechmore's back-swamp in the Clarence River catchment, NSW north coast. Before inundation the back-swamp was scalded by ASS.

Figure 18: In February 2007 freshwater was applied to the backswamp.

Figure 19: One month later the wet pasture had recovered, providing a viable food source for cattle, while also preventing further ASS oxidation.
Photos: Clarence Valley Council.