Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales

Department of **Environment & Climate Change** NSW

Northern Rivers CMA CATCHMENT MANAGEMENT AUTHORITY

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Cover: Acid discharges from Ghinni Ghinni Creek into the Manning River. Photo: Michael Dove.

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HOW TO USE THE GUIDELINES

The Acid Sulfate Soils Manual was published in 1998[1], providing a comprehensive compendium of information and processes relevant to forward planning and development control in ASS areas. However, limited information was available regarding how to address the existing broadacre agricultural problems. These Guidelines have been prepared in order to meet that need.

ASS remediation strategies have evolved greatly in recent years, largely due to rapid developments in the understanding of scientific and technical issues. At the same time, the objectives of floodplain management have expanded to include a broad range of sometimes competing issues across the floodplain landscape[2], underlining the need for coordination of floodplain objectives and works across the floodplain landscape. The opportunities and benefits of ASS remediation are likely to be greatest in the lowest elevation floodplain sites, including the (former) freshwater backswamps and saline wetlands, and these areas are the focus of these Guidelines.

The objectives of these Guidelines are to:
- provide a landscape-based framework for designing the most effective ASS remediation projects, and
- provide land managers with adequate information to design, implement, manage and monitor an ASS remediation project.

The approach taken in these Guidelines is that the remediation strategy adopted should flow from the characteristics and measurable properties of the landscape. The Guidelines examine the science underlying the remediation strategies discussed, and place the requirements of each strategy in the context of the physical limitations of the landscape.

The Guidelines are organised in five main parts. Part 1, **Acid Sulfate Remediation and Floodplain Management**, introduces the relevant government policy framework within which ASS remediation projects must be carried out. The two key aims of ASS remediation are set out in the context of a land capability framework, in order to provide a more strategic approach to ASS remediation efforts and sustainable floodplain management generally.

The Guidelines then discuss those techniques that have proved to be practical and are already in common use:
- neutralisation and dilution by floodgate management/modification
- neutralisation and dilution by restoration of tidal flows to predominantly former estuarine areas
- wet acid containment (ponded pastures), and
- dry acid containment.

The limitations of each of these remediation strategies are explained. It is concluded that each strategy has its strengths and drawbacks. Depending on the measure of success applied, there is no strategy currently available that is likely to produce an immediate and complete solution to the problem, and the best that can be achieved is a minimisation of further oxidation and a progressive reduction in the incidence and severity of acid discharges over time.

Part 2, **Developing a Remediation Plan**, provides information for preparing remediation projects, including information on remediation objectives, strategies, options and targets, and key information requirements.

Part 3, **Implementing a Remediation Plan**, then moves to operational issues, including the contents of the implementation plan, the types of water control structures and floodgate designs used, legal issues and communications plan.

Part 4, **Monitoring a Remediation Plan**, discusses soil, groundwater and surface water monitoring and modeling, ecological and other monitoring, recording of works and land management changes, performance standards, review, responding to the data with adaptive management, and contingency planning.

Part 5, **Securing Land Management Change in a Remediation Project**, discusses means of encouraging and importantly, securing change, on coastal floodplains. Securing change is an essential consideration for sustainable projects, being a key issue in maintaining the outcomes of remediation projects into the future, and is likely to become increasingly important in proposal assessment into the future.

The **Appendices** include: a simple field test for estimating saturated hydraulic conductivity; discussion of Government policy; legal liability exposure associated with remediation projects (including duty of care) and the various consents and approvals that may be required; Glossary and Definitions; Acronyms; Acts cited; Case law cited; References and an Index.

For locating information within the Guidelines, users may:

- familiarise themselves with the structure of the document through the Table of Contents
- use the index, or
- with a digital version, carry out a search on keywords.

Where appropriate, these Guidelines should be read in conjunction with the *ASS Manual* 1998 or its successor for more detailed information on issues including those relating to planning, assessment and soil testing.[3]

The Guidelines are intended to be used by those who are involved in ASS remediation, including local council and government agency personnel, consultants, industry advisors, researchers and community organisations.

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ACID SULFATE REMEDIATION AND FLOODPLAIN MANAGEMENT

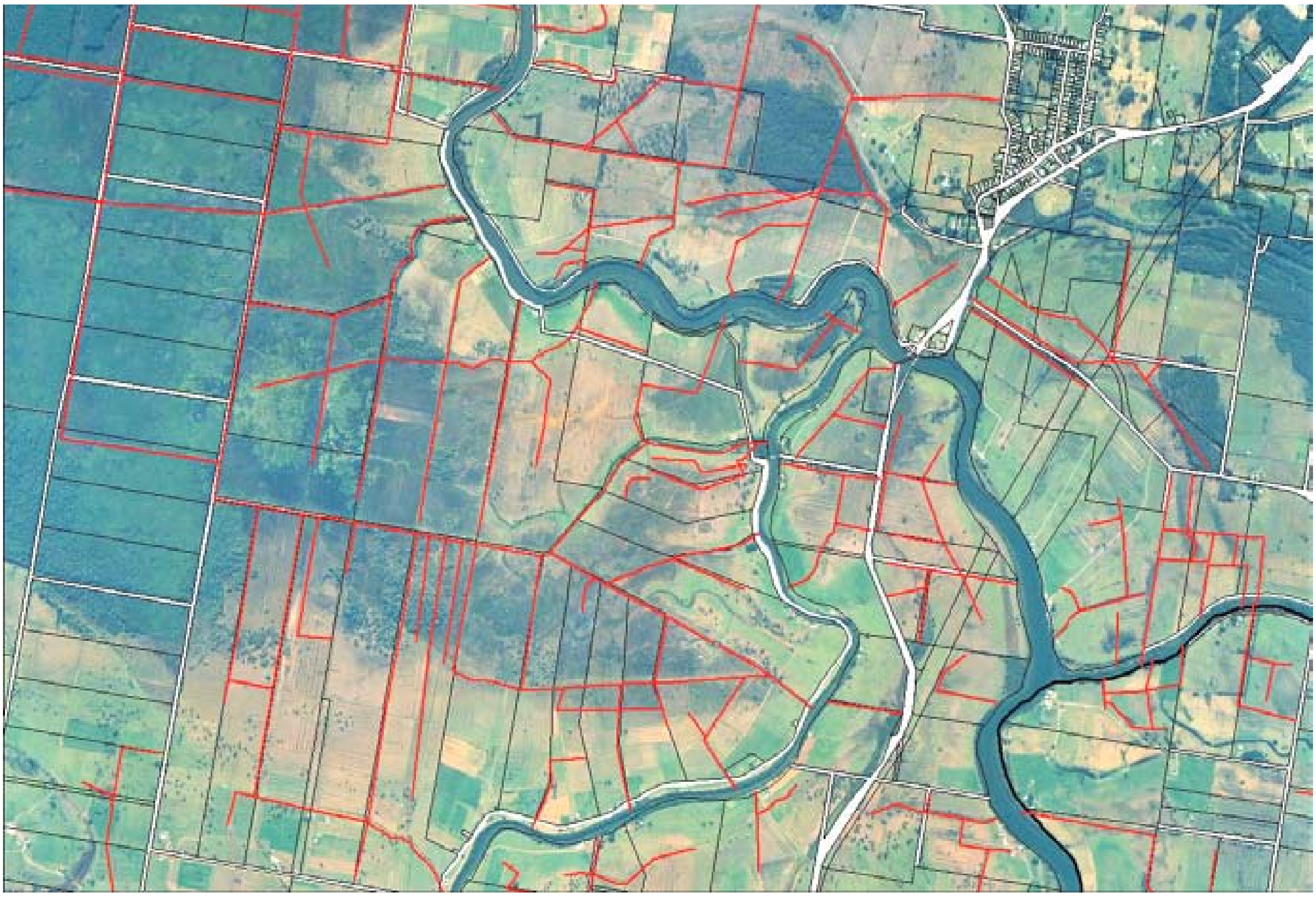
INTRODUCTION

Drainage of wetlands and backswamps on NSW coastal floodplains dates back to the latter half of the nineteenth century when the first drainage unions were formed.[4] However, few unions were formed, and their impact was limited. More ambitious swamp drainage schemes were carried out with Government support from the early 1900s under the Water and Drainage Act 1902, although these too often failed economically. It was not until after major flooding occurred in 1949 and the early 1950s that a number of large flood mitigation and drainage schemes were carried out, supported and/or undertaken by successive local and State governments (Plate 1).

Plate 1. Drainage works on the Macleay River floodplain in 1963

Photo: Kempsey Shire Council

Figure 1. Deep drainage network at Moto Swamp on the lower Manning River floodplain



Source: DECC drain network mapping. Deep drains marked in red

The floodplains of rivers on the north coast of NSW have now been extensively drained, with large networks of floodgated drainage channels owned and operated by local councils, drainage unions and private landholders (Figure 1). From the Manning to the Tweed, there are some 5 039 km of drains >0.5 m deep on ASS.[5] Drain inverts are typically -0.5 to -1.0 m Australian Height Datum (AHD) but can be as low as -1.8 m AHD[6], resulting in the removal of both surface and near-surface groundwater.

Important changes in patterns of land ownership on the floodplains accompanied the drainage schemes. Landowners were able to farm backswamps more intensively, and assisted by relatively high prices for agricultural commodities in the post-war period, were able to subdivide properties into smaller holdings that often comprised lower floodplain land only. These landholders now rely on an effective drainage and flood mitigation system for the continuation of current agricultural production systems.

The main period of major drain construction has passed, although more recent changes to drainage patterns have been carried out due to economic change, mainly concerning the tea-tree and dairy industries. In both cases, new works have generally been confined to shallow, wide drains, and the main focus now in agricultural areas is on the redesign of existing works and alternative ways of operating control structures.

Despite the publication of a number of scientific works[7], it was not until 1987 that the link between acid sulfate soils and a history of water quality problems and fish kills was generally recognised. In March of that year, following drought-breaking rains, a 23 km stretch of the Tweed River turned clear revealing a large kill of aquatic organisms, and ASS management emerged as a major issue.[8] Further acid events on other floodplains during the ensuing years (Plate 2) impacted on fisheries including oyster producers.

Plate 2. Acid discharge from Fernbank Creek into the Hastings River

Photo: Scott Johnston

Plate 3. An ASS scald in the Tuckean

Photo: Michael Wood

ASS can have acute impacts such as low pH; iron and aluminium toxicity; water deoxygenation; massive kills of aquatic life, including large numbers of fish and benthos; and chronic impacts including: diseases; reduced hatching, survival and growth rates across a wide range of aquatic species; habitat degradation; reduced aquatic food resources; reduced migration potential of fish; reduced fish recruitment; altered water plant communities; weed invasion by acid-tolerant plants; and secondary water quality changes. Other potential impacts include: the release of heavy metals from contaminated sediments; human and animal health impacts from polluted water; adverse impacts on land arability such as acid scalds (Plate 3) and damage to built structures such as bridges. Oxidation and subsequent reactions also change the soil fabric, fabric: oxidation products such as aluminium ions flocculate the clays, which do not redisperse during rewetting, leading to irreversible shrinkage and lowering of ground surfaces. ASS have economic impacts on most industries on the NSW coastal zone, including recreational fishing, commercial fishing, oyster and other aquaculture industries, sugar cane, tea-tree, grazing and dairy. ASS can also impact urban infrastructure such as water pipes, bridge footings and floodgates.[9]

Initially, efforts to address the problem focused on identifying mechanisms and strategies to prevent or minimise further disturbance and oxidation, including amendments to the development control process. The 1st and 2nd National Conferences[10] presented major advances in the understanding and management of ASS, and in 1998 the Acid Sulfate Soils Manual was published.[11] . However, limited information was available for addressing the existing problems, and it was recognised that further guidance specifically relating to the remediation of broadacre ASS areas was required.

The NSW Government endorsed the NSW Acid Sulfate Soil Strategy in August 1998.[12] In relation to remediation, the Strategy includes the need to identify priority hot spot areas for rehabilitation; review mechanisms to ameliorate acid discharges from these areas; and identify financial incentive mechanisms to encourage greater landholder ownership and management of the issue. The National Strategy for the Management of Coastal Acid Sulfate Soils[13] also includes rehabilitation of disturbed acid sulfate soils and acid drainage as an objective, and provides general direction in relation to remediation.

Plate 4. Belmore Swamp on the Macleay River floodplain

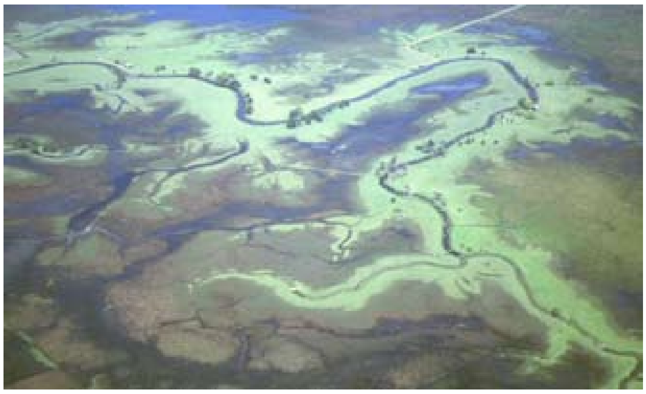


Photo: Mitch Tulau

The then Department of Land and Water Conservation (DLWC) carried out the first phase of the NSW strategy for remediation in 1999 by identifying priority 'hot spot' areas for rehabilitation. Of the approximately 600 000 ha underlain by ASS in NSW, some 20% was considered to have the highest priority for remediation.[14] Almost all of these 'hot spot' areas are large, flat, low elevation backswamps (Plate 4). The vast majority of this land was found to be privately owned, the main land uses being cattle grazing, and sugar cane and tea-tree cultivation, and most of these areas contained a number of landholdings, presenting challenges for co-operative floodplain planning.

Knowledge relating to the remediation of such areas was further discussed when a Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils was held at Southern Cross University in 1999[15] and draft remediation guidelines were prepared the following year.[16] Since then, a wide variety of approaches have been explored, with varying degrees of success. A great deal of practical knowledge was gained from the ASS Hot Spots Program in 2001-2004, in which seven of the most highly degraded and environmentally damaging ASS areas were selected for remediation. This was the largest single program ever undertaken to remediate ASS in NSW, covering over 18 000 ha, and involving hundreds of landholders and numerous public authorities.[17] More recently, the need for remediation of former wetland areas has been furthered by the call for carbon sequestration in the context of global warming.

The need for an integrated, standardised approach to managing coastal ASS has been a key issue.[18] The Northern Rivers Catchment Management Authority (NRCMA) commissioned these Guidelines in order to provide such an approach.[19]

REMEDIATION AIMS

A comprehensive approach to ASS remediation encompasses the objectives of both preventing and minimising the creation of further oxidation products, while managing those already produced. ASS remediation therefore encompasses the following aims:

- reducing the production of further acid and other oxidation products[20], and
- reducing the export of existing acidity and other oxidation products.

Reducing the Production of Further Acid

The *in situ* production of further acid and other oxidation products is primarily related to water table management. One of the main ways in which production may be reduced is to ensure that watertables remain above ASS layers, where possible. Any works undertaken as part of a remediation strategy should be consistent with the Drainage Guidelines[21] of the *ASS Manual* in relation to the depth to the sulfidic layers, discussed below (see Table 6).

Reducing the Export of Existing Acidity

In relation to the management of existing oxidation products, the objective is to:

- contain
- neutralise
- dilute, and/or
- chemically reduce

those products.[22]

These approaches are expressed in a number of remediation strategies, being:

- neutralisation and dilution by floodgate management/modification
- neutralisation and dilution by restoration of tidal flows to predominantly former estuarine areas
- wet acid containment strategy (WACS) (ponded pastures) and
- dry acid containment strategy (DACS).

REMEDIATION STRATEGIES

The main remediation strategies commonly practiced on a broadacre basis on NSW floodplains, and therefore considered in these Guidelines are summarised in Table 1 and discussed in further detail below.

Table 1. Common issues and limitations for selected remediation strategies

	Remediation Strategies			
	Neutralisation/dilution Strategies		**Containment Strategies**	
	Floodgate management/ modifications	Restoration of estuarine areas	Dry acid containment strategy (DACS)	Wet acid containment strategy (WACS)
Objectives	• Neutralise and dilute acidity and other oxidation products by exchanging drain and receiving waters • Provide, and restore, fish passage	• Neutralise and dilute acidity and other oxidation products by restoring a regular exchange of saline waters • Prevent further oxidation • Rehabilitate saltwater wetland and aquatic habitats	• Contain acid and other oxidation products within the subsoil by maximising the time that influent drain to groundwater gradients prevail by lowering the groundwater • Continue sustainable cropping	• Contain acid and other oxidation products within the soil and surface water by maximising the time that influent drain to groundwater gradients prevail by raising water levels in the drain • Reduce oxidation products by increasing organic matter • Prevent further oxidation • Rehabilitate freshwater wetlands • Provide a grazing resource
Position in the estuary	• Lower-mid estuary	• Lower estuary	• Upper-mid estuary	• Upper-mid estuary
Methods/ works	• Manual opening or modification of headworks	• Removal or modification of headworks • Removal of tide exclusion works	• Evapotranspiration from crops, assisted by pumping surface water • Reduction in drain density and depth (seepage area) • Land grading	• Installation of Water Control Structures (WCS) • Modification of headworks • Construction of artificial levees
Land elevation	• Above maximum tidal planes	• Below maximum tidal planes	• Sufficient to not affect underlying ASS (>0.5 m above ASS)[23]	• Containment up to local mean high tide[24]
Soils	• Low K_{sat} [25]	• Low—high K_{sat}	• Low K_{sat}	• Low—high K_{sat}
Location	• Artificial drain or creek	• Former estuarine flat	• Cropping areas	• Fresh water wetlands, wet grazing areas
Issues	• Risk of overtopping • Potential for saline groundwater intrusion • Potential for tidal flushing and poor discharge water quality • Sensitivity and significance of the receiving waters • Characteristics of wetlands • Engineering considerations • Little change in acid flux	• Capacity to restore tidal waters • Impacts on neighbouring land and waters	• Impacts on groundwater • Not effective in larger local rainfall-discharge events	• Capacity to contain catchment waters • Capacity to harvest freshwater from creeks • Impacts on neighbouring land • Not effective in larger local rainfall-discharge events • Perceived impacts on grazing capacity
Physical limitations	• Elevation and tidal planes • Soil K_{sat} at tidal elevations • Neutralising/buffering capacity of receiving waters	• Elevation and tidal planes • Neutralising/buffering capacity of receiving waters	• Elevation and depth of freely drained soil above the PASS and water table • Soil K_{sat} within the acid export window	• Elevation and tidal planes

Neutralisation/Dilution Strategies

Neutralisation strategies involve the reaction of the acid with a neutralising agent, usually agricultural lime or the bicarbonate in seawater.[26] The two most common such remediation strategies are liming of soil and drain waters and the opening of floodgates to estuarine waters.

Dilution is based on the notional concept that the pH of water increases by one pH unit for every ninefold increase in the volume of fresh neutral water.[27]

Liming of Soils and Drain Waters

Liming of soils, particularly spoil mounds, and drain waters was one of the first strategies used to address the effects of ASS. However, liming of surface soils is largely ineffective because of the limited penetration of most neutralising materials, and because acid discharge occurs predominantly from the subsoils and groundwaters.[28]

Notwithstanding this, there are instances where liming of drain banks at the point of groundwater discharge has demonstrated beneficial results, with increases of >3 pH units reported.[29] Also, liming can be effective where subsurface cuts are required.[30]

In terms of liming and treating waters, there are often significant technical and mechanical problems, physical limitations and chemical issues. The main practical problem is dissolving agricultural lime - without specialised application methods, lime may fall out of suspension and/or become coated with iron oxides.[31]

Limitations

As a result, the capacity of liming to neutralise acidity in waters is limited (except at very low pH) and may quickly diminish during even minor discharge events.[32] The iron floc that precipitates when the water pH is raised above 4.5 can coat plants, monitoring equipment, the base or walls of dams, drains, pipes, piezometers and creeks, and may become a major water pollution issue in its own right (Plate 5). Drain water liming systems can also require significant resources for repair and maintenance. The ongoing cost also remains a key issue and can quickly become prohibitive, depending on scale.[33]

Although liming in drain waters is a useful tool to ameliorate one aspect of the drain water quality problems in ASS landscapes (i.e. raising pH), other major water quality problems such as deoxygenation and soluble iron/iron floc pollution are not addressed by liming.[34] Generally, liming is limited and strategic only, such as to assist scald revegetation[35] and treating drain spoil.[36]

Plate 5. Iron floc caused by liming with hydrated lime at Partridge Creek on the Hastings

Photo: Thor Aaso

Neutralisation/Dilution by Floodgate Management/Modification

Floodgate management and/or modification is widely practiced, especially on the North Coast where the majority of floodgates are located.[37] Potentially, there are many benefits from managing and/or modifying floodgates, including allowing better quality water upstream during non-flood times, reducing exotic drain vegetation by introducing saltwater to drains and providing increased fish passage.[38]

As far as ASS management is concerned, the objective is the neutralisation and dilution of acidity and other oxidation products, often referred to as 'flushing', by providing a regular exchange of drain and receiving waters.

Limitations

Capacity for Neutralisation and Dilution

The neutralising capacity of the receiving waters is a key factor that determines the extent to which admitting these waters can ameliorate acidic water.[39] The ionic profile of the receiving waters will vary greatly between sites and flow conditions, but generally, suitable sites will tend to be located in the lower parts of estuaries. Further upstream, the feasibility of neutralisation would be limited to drier periods, when saline wedges extend further upriver.

As far as the dilution component is concerned, this strategy requires sufficient catchment flow to be available for dilution[40], whilst regulating the discharge of oxidation products. In other words, generally there must also be a containment component built in to the strategy as well. Alternatively, there must be sufficient tidal exchange for dilution. An additional consideration is the extent to which the drain and creeks waters are likely to mix, this being related to tidal flux, or potential for tidal flushing at the site.

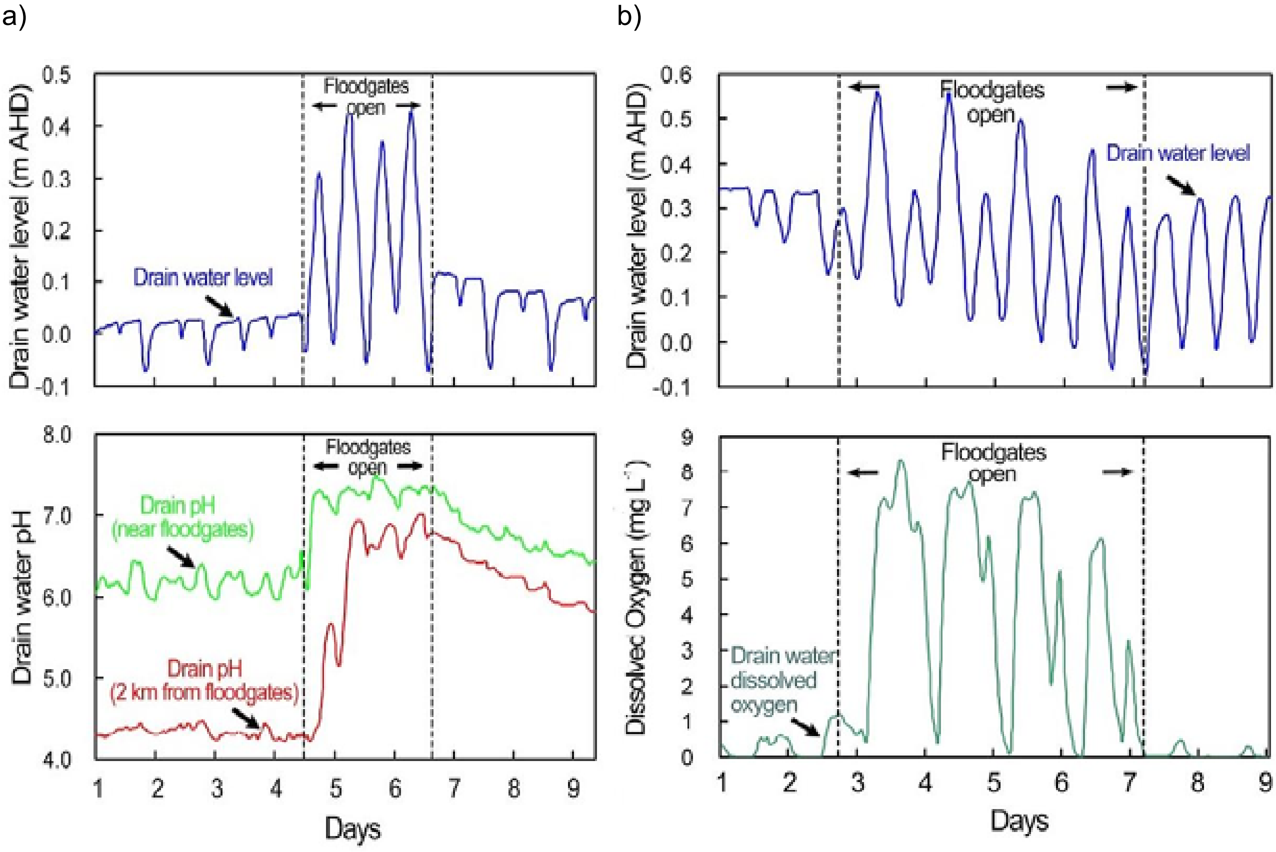
Floodgate management/modification has the capacity to effect improvements in certain water quality parameters in drains, specifically pH and DO, in non-flood times[41], but ASS management requires a strategy that is also effective during discharge conditions. Furthermore, this strategy does not typically affect the total export of deoxygenated water, black water and metals.[42]

In most of the worst degraded ASS areas, sufficient neutralising capacity in receiving waters and sufficient tidal flow is generally not present.[43] In high flows, continued acute acidic discharge would be a likely outcome in many sites. Unless carefully managed in terms of timing and/or volumes released, for example by controlling discharge on an ebb tide, this strategy amounts to a default 'do nothing' option of continuing pollution in the hope that the estuary can deal with the pollution.

This premise should be confirmed by research and monitoring focusing on the potential for pollutants to be effectively diluted and mixed, and the potential for chronic effects, before it is adopted. The characteristics of the receiving waters must be assessed over a sufficiently long period in order to determine to what extent tidal flushing may improve key water quality parameters such as pH, DO, MBO formation and metals.[44]

When floodgates are closed (i.e. returned to normal flapgate mode of operation), water quality parameters can rapidly revert (Figure 2). It has also been found that if tidal flows are introduced to drains that intersect ASS areas with high K_{sat}, average drain water levels will increase slightly, but oscillate, with groundwater gradients driving seepage, potentially resulting in enhanced lateral outflow of acid groundwater, especially in the period after floodgate closure.[45]

Figure 2. Short-term improvement in drain water pH (a) and DO (b) after floodgate opening
(From Johnston *et al*. 2003a.)



Land Surface Elevations and Tidal Levels

The risk of overtopping agricultural land with saline water is probably the greatest concern for landholders interested in opening floodgates, due to the potential impact on agricultural productivity.[46] Detailed elevation data in relation to local tidal planes are essential for assessing the potential for overtopping in low elevation areas, including backswamps.[47] . Alternatively, a trial opening methodology can be used where detailed tidal levels are unavailable.

It should be noted however that low pressure systems and storm surges vary tidal heights from those predicted, particularly in the lower estuary. Site assessment should also take into account the potential for other tidal anomalies up to 0.5 m on the coast[48], and the impacts of climate change, including potential for sea level rise.[49] It is expected that floodgate management will become increasingly limited by the potential for tidal overtopping of agricultural land as a result of sea level rise.

Hydraulic Conductivity

A significant agricultural risk is the potential for the intrusion of saline water into groundwater through the drain banks. The risk of lateral salt seepage depends largely on the macroporosity and hydraulic conductivity of the soil, and the long term groundwater gradient, such that soils with higher K_{sat} are more at risk from intrusion than those with lower K_{sat}.[50] It is considered that there is less risk of salt seepage if K_{sat} >1.5 m/day, more risk if >15 m/day.[51]

Soils with a high K_{sat} will be more prone to lateral water movement in both directions - acidic groundwater flowing through the soil to the drain, and also saline intrusion from the drain into adjacent soil and groundwater.

High K_{sat} in sulfuric horizons is generally due to high densities of interconnected macropores[52] and planar voids (Plate 6a & 6b). There appears to be wide variability in K_{sat} on coastal floodplains.[53] Without a reliable means of predicting the variation of K_{sat}, a precautionary approach should be taken, and more permeable materials assumed in ASS backswamps, prior to the carrying out of site-specific investigations on a site-by-site basis.

Assessment of soil hydraulic conductivity requires some technical expertise, though simple field-based methods have been developed.[54] The risks of saline intrusion into subsoils should be adequately assessed prior to any floodgate modification. Pits tests should be carried out according to Appendix 1, and relevant site data recorded.[55]

Plates 6a & 6b. High macroporosity in a soil from Partridge Creek on the Hastings

Photos: Thor Aaso

Many floodgates have only been opened infrequently and briefly, often to clear drains of aquatic vegetation, or as a flood mitigation device to help floodwaters discharge quickly. In the sugar industry, many cane farmers adopt a controlled opening approach, and allow brackish water into their main drains provided that the maximum elevation in the main drain does not reach that level where near surface soil has large K_{sat}, or causes brackish water to enter field drains.[56]

Opening floodgates in artificial drains may introduce estuarine flows to areas that were not formerly tidal. In these situations, the assessment of the site must recognise that the magnitude of the proposed change is therefore potentially much greater. For projects that aim to restore tidal flows to former estuarine wetlands, the potential for the intrusion of saline water into adjacent groundwater may be a major issue.[57]

Management of In-Drain Vegetation and Monosulfidic Black Oozes

Floodgate management/modification can assist in the management of monosulfidic black oozes (MBOs) (Plate 7). MBOs are major sources of titratable acidity and metals, and are a major contributor to high chemical oxygen demand (COD), causing low dissolved oxygen (DO), and acidification of floodwaters.[58] These sources of potential acidity can sometimes be substantial[59] and on a whole of floodplain basis the impacts can be profound.[60]

Plate 7. A core of MBO from a drain

Photo: Scott Johnston

The key issues in the management of MBOs are managing existing sources and preventing the creation of more MBO. MBO formation is facilitated in organic, anaerobic conditions, so any strategy that reduces organic material and increases the oxygen content of the water, is expected to reduce the formation of MBOs due to lower availability of organic matter from weeds.[61] Note however, that initial opening to saltwater and dieback of freshwater vegetation can lead to even lower DO levels in drain waters and increased MBO formation.

Depending on the site, seasonal growth of weeds in fresh conditions, with dieback of weeds and reformation of monosulfides in the dry season, may occur. The improvement of the water column from tidal flushing may therefore be transient.[62] Where MBO formation is substantial and inevitable, a containment strategy is preferred. Weed growth may be minimised by the use of riparian vegetation and shading, which reduces the organic matter for MBO formation and water temperatures, and increases habitat and bank stability.

MBO management by floodgate management/ modification would tend to be more effective in sites where the frequency and duration of freshwater conditions is minimal, i.e. in lower estuary sites with smaller catchment inputs. Lower estuary sites with predominantly saline drain waters combined with generally open floodgates do not form MBOs.[63] Clearing drains of fresh water vegetation may also increase the efficiency of drains, thereby exacerbating ASS problems, and reduced habitat for aquatic organisms.

Impacts on Wetland Vegetation

Floodgate management strategies to introduce tidal inundation need to be supported by an understanding of the geomorphic context of wetlands, their hydrology and natural salinity regimes. Many sites, such as artificial drains and associated freshwater backswamps were not previously tidal. The nature of any areas likely to be impacted, whether predominantly fresh or saline, should always be determined prior to the introduction of tidal flows.

Impacts on Aquatic Systems

An additional outcome from opening floodgates is increased fish passage and habitat. However, artificial drains are not prime habitat for most species, especially commercial species.[64] In fact these environments may present significant risks, for example if fish become trapped behind the floodgates in potentially toxic low DO or high acid conditions, or by being trapped in drainage systems once groundwaters begin to discharge.[65]

Chronic impacts on fisheries from the drainage of ASS areas may also occur, but are more difficult to demonstrate. Chronic, low levels of acid sulfate discharge may affect the migration behaviour of commercial species, which could have potential effects on stock sizes.[66] Concerns have been raised in relation to carbonate usage in receiving waters, especially the cumulative impacts.[67]

Receiving waters commonly contain valuable and sensitive aquatic ecosystems and many industries, such as the oyster industry, are dependant on these ecosystems functioning in a healthy state. Both acute effects, including the potential for enhanced export of acid and other pollutants, and chronic impacts, such as depletion of bicarbonate available to shellfish such as oysters, need to be assessed and taken into account.[68] Generally, the more sensitive the receiving waters, the more containment strategies are preferred over other options.

Furthermore, it has been found that for various reasons, many floodgates often remain closed, in which case neither fish passage nor ASS objectives are achieved. This underlines the benefits of 'fix-and-forget' approaches and automatic tidal gates, which can also provide for fish passage.[69]

Restoration of Estuarine Areas[70]

A driving force for the return of tidal inundation to former estuarine wetland areas is restoration of estuarine wetlands and important fish habitat areas. In terms of ASS management however, the objectives are neutralisation and dilution of acidity and other oxidation products, and encouragement of more anaerobic sediment conditions by raising water tables. Seawater reflooding usually involves manual opening or modification of floodgates, or removing levees which have excluded saltwater from the site.[71]

Limitations

Elevation and Tidal Planes

Accurate, high resolution land elevation data is essential in order to predict the area of wetland and surrounding country likely to be affected by tidal flows, and the depth to which inundation would occur. However, strictly speaking, estuarine ecological zones are related not to AHD, but to tidal planes.[72] An alternative to obtaining elevation data therefore is to carry out a trial opening in order to ascertain the upper limits of tidal inundation and determine the impact on adjacent private properties.[73]

Impacts on Wetland Vegetation

This strategy will necessarily lead to the introduction or expansion of salt-tolerant vegetation to the site, and is most appropriate when a principal or additional objective is the rehabilitation of a saltwater wetland.[74]

The nature of wetlands to be rehabilitated, whether predominantly fresh or saline, should always be determined prior to the introduction of tidal flows to wetlands, including by reference to the original survey plans of each affected portion.[75]

The introduction of saline water to vegetation not adapted to high Electrical Conductivity (EC), or periodic inundation to areas subject to more frequent tides, may cause salt scalding (Plate 8).

Plate 8. A saline/ASS scald in the Moto backswamp on the Manning River floodplain

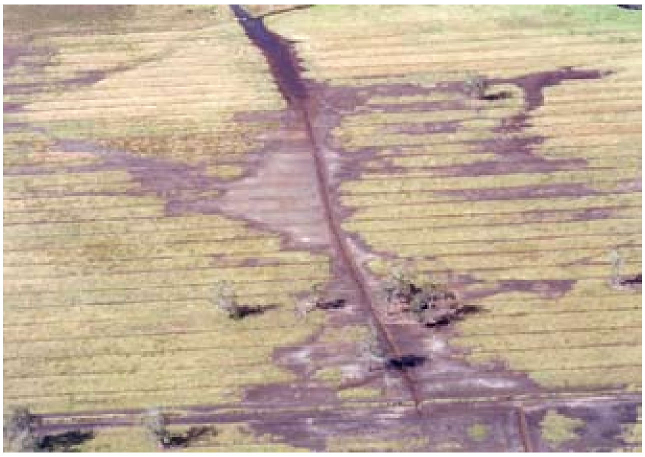


Photo: Glenn Atkinson

The implications of introducing tidal flows to a freshwater backswamp needs to be carefully assessed, as ecological consequences may result, is contrary to the *Wetlands Management Policy 1996*[76] and may be prohibited by law in some cases.

Furthermore, freshwater wetlands may be protected, including from salt water reflooding, by planning instruments such as State Environmental Planning Policy (SEPP) No. 14 – Coastal Wetlands. Endangered ecological communities such as Freshwater Wetlands on Coastal Floodplains and Swamp Oak Forest are also protected under the *Threatened Species Conservation Act 1995 (TSC Act 1995)*.[77]

In other cases it may be feasible, and legal, to introduce brackish or saline tidal flows to freshwater wetlands. Such a move should still be taken with full understanding of the consequences, as significant dieback of freshwater species will generally occur. Controlling water quality parameters such as DO, pH, biological oxygen demand (BOD) and COD will be crucial to maintaining water quality, including MBO formation.[78] formation. Potential effects on adjacent vegetation and ecosystems must also be recognised and addressed.

Impacts on Water Quality

Impacts of tidal inundation on resident and discharge water quality will depend on the quality and quantity of estuarine water admitted to the wetland and the exchange regime, and will be highly site specific. The introduced waters must contain sufficient neutralising capacity, and sufficient tidal exchange for dilution, and the strategy will therefore generally be more effective in the lower reaches of estuaries.

Implications for Land Use

Remediation efforts at sites on the north coast illustrate the problems facing broadacre remediation projects of this type. The introduction of saline water may require a permanent change in land use.[79] In the case of Yarrahapinni, an ambitious proposal for full restoration of tidal exchange was delayed due to the need to acquire large holdings of potentially affected land (Plate 9), whereas at Little Broadwater, the land has remained under existing tenure and continues to be managed for agricultural production, thus limiting the volumes and quality of water that may be admitted to the wetland.[80] The constraints on management options can also affect operational farm management issues such as access.

Plate 9. The former Yarrahapinni Broadwater on the Macleay floodplain

Photo: Peter Haskins

Containment Strategies

An understanding of how acid and other oxidation products enter waterways is necessary in order to assess the potential for successful containment strategies. The most important acid discharge pathway is groundwater seepage, with surface run-off generally contributing relatively little to acid discharge.

The major factors in controlling acid discharge rates from groundwater seepage and the dynamics and export pathways for oxidation products are:

- saturated hydraulic conductivity (K_{sat}) in sulfuric horizons and
- the groundwater gradient[81]

such that sites with very high K_{sat} and large groundwater gradients have higher acid export rates and metal concentrations.

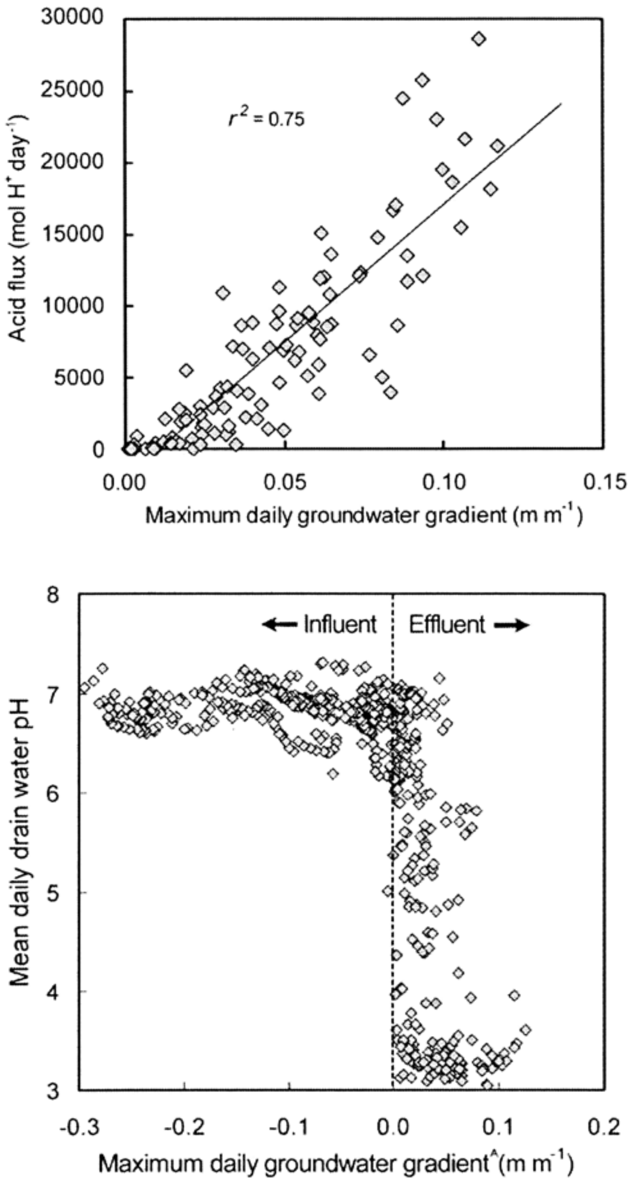
Darcy's equation explains the relative importance of the various factors affecting long term acid export via groundwater seepage:

- $A_{gw} = C_{gw}.K.H_e.t_d.A_s$ where A_{gw} is acid export via groundwater seepage
- C_{gw} is the mean concentration of acidity in the sulfuric horizon groundwater (mol H^+/m),
- K is the saturated hydraulic conductivity of the sulfuric horizon (m/day),
- H_e is the mean effluent groundwater gradient towards the drain (m/m),
- t_d is the duration (days) that the mean daily groundwater gradient was effluent (Figure 3), and
- A_s is the area of the drain walls subject to groundwater seepage.

High K_{sat} in sulfuric horizons is generally due to high densities of interconnected macropores and planar voids. High K_{sat} presents a significant limitation to strategies involving management or modifications to floodgates. (Conversely, low hydraulic conductivity is critical to strategies involving containment in the soil profile - see below).

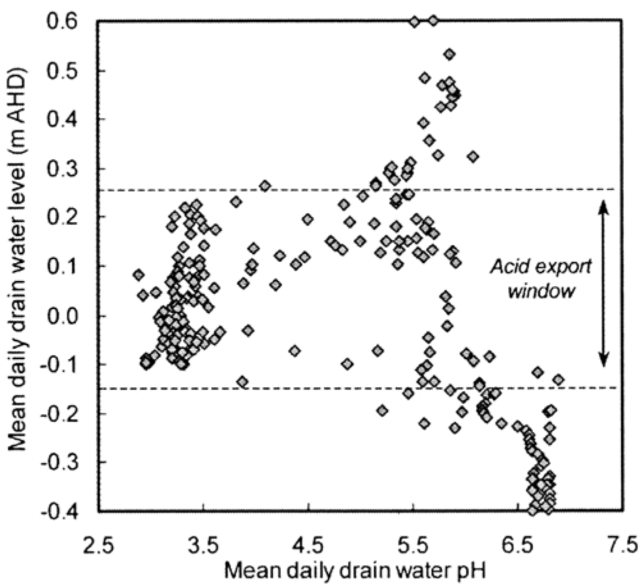
The groundwater gradient is influenced by the rainfall:evapotranspiration ratio and the difference in elevation between the groundwater surface and the drain water.[82] The importance of gradient is illustrated in Figure 3, which explains why the key to ASS remediation is hydrological manipulation.

Figure 3. Groundwater gradient v acid export and drain water pH
(from Johnston *et al*., 2003a, 2004)



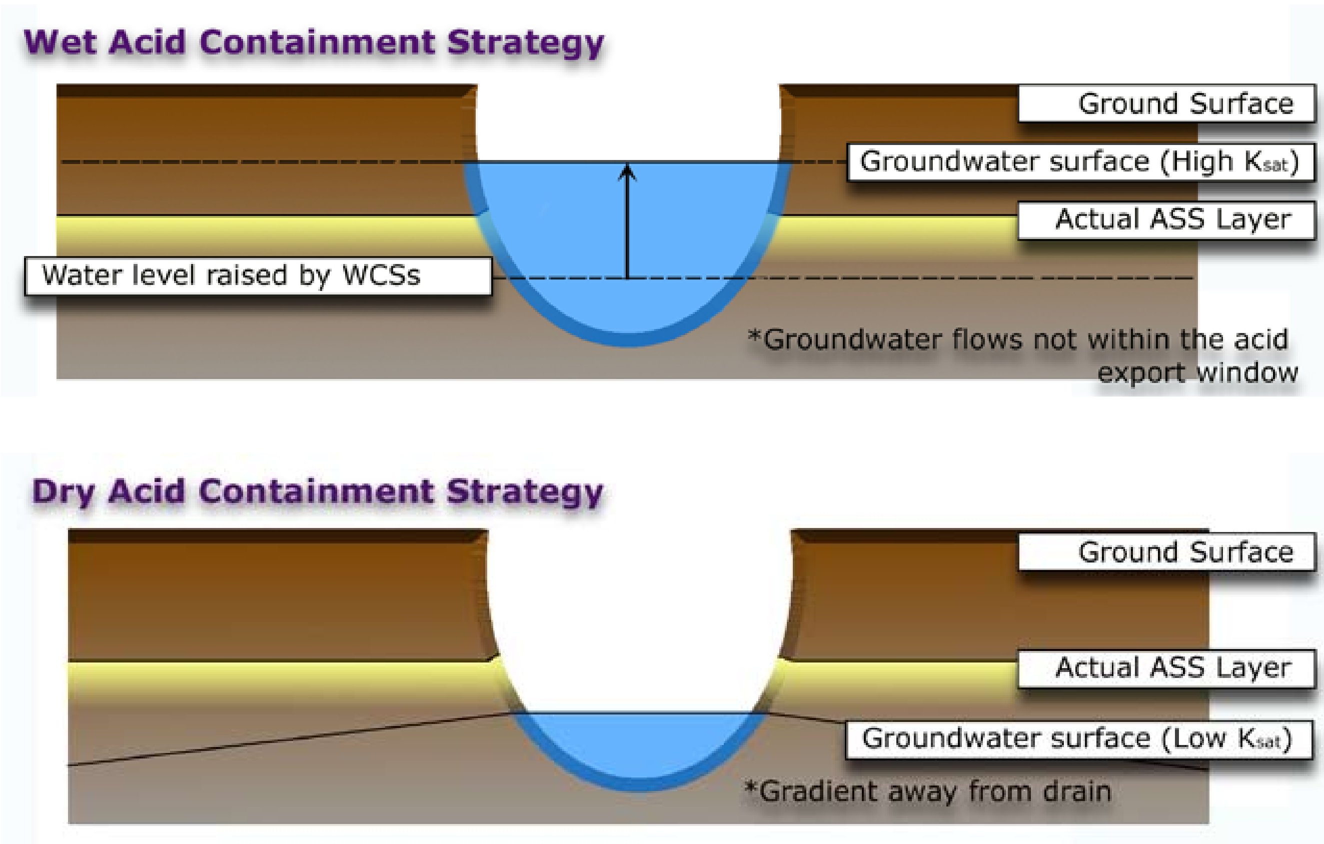
The relationship between hydraulic conductivity and groundwater gradient, in the context of land surface elevation, depths to ASS layers and tidal levels, is brought together in the concept of the ‘acid export window’. Most drainage of groundwater-derived acidity occurs when the watertable is within the acid export window. The acid export window is determined by the height difference between the top of the actual acid sulfate soil (AASS) layer (i.e. acidified soil, often also the soil surface in ASS backswamps) and the daily low tide level in the backswamp drain. Depths to actual and potential ASS layers are critical measurements, because the elevation of these layers in relation to tidal amplitude determines the thickness and therefore the duration of the acid export window (Figure 4).[83]

Figure 4. Water level v drain pH, showing the acid export window
(from Johnston *et al*. 2004)



In terms of containment strategies, two main approaches are used, one where water tables are maintained relatively high, known as ‘wet acid containment strategy’ (WACS) and a low water table model, ‘dry acid containment strategy’ (DACS).[84] In both cases, the hydraulic objective is to reduce effluent gradients from the soil to the drain in favour of influent gradients, from drain to soil. In one case (dry acid containment), the influent is achieved by lower groundwater levels. In the other (wet acid containment), the influent is achieved by higher drain levels (Figure 5).[85]

Figure 5. Wet and dry acid containment



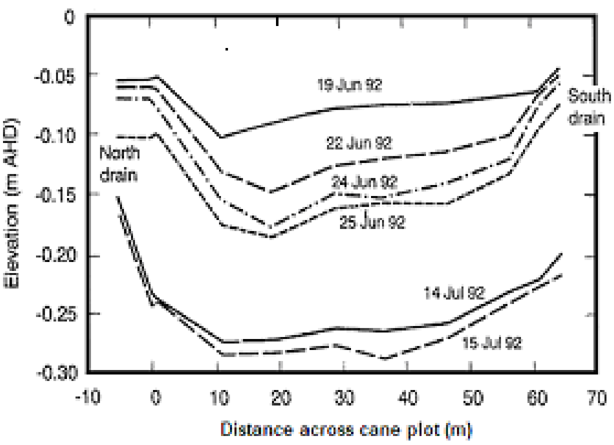
Dry Acid Containment

In some soils (with low K_{sat}), evapotranspiration plays a dominant role in lowering watertables during dry periods (at least in drained situations) (Figure 6). If groundwater levels are lower, a larger rainfall event would have to occur before ground water rose to, and began discharging from, the actual ASS layer[86] and the 'acid export window'[87]. Evapotranspiration from cane creates an influent, rather than an effluent, groundwater gradient, and as a result, more oxidation products are contained.[88]

The hydraulic objective of the DACS is therefore to allow evapotranspiration to reduce the groundwater elevation so as to increase the ASS profile storage of incoming rainfall and thereby reduce the number and magnitude of events discharging existing acidity. In these circumstances, drains may act not as 'drains' at all, but as irrigation channels for groundwater recharge.[89] It has been found that satisfactory drainage to the depth required can often be achieved with fewer field drains, supplemented by more efficient laser-graded surface drainage.[90]

Beginning on the Tweed, and later extending to other floodplains, sugar cane growers have been able to fill in many field drains by investing in land grading.[91] Reports suggest that acid discharges have been reduced[92], and a reduction is supported by modeling and application of Darcy's equation, because the critical factors controlling the export of acidity are drain spacing and depth.

Figure 6. Fall of the watertable due to evapotranspiration under sugar cane (from White *et al*. 1997[93])



DACS may be usefully paired with floodgate opening because, when tidal flows are introduced to drains, modal drain water levels will increase slightly, and higher drain water levels mean that the groundwater does not need to be lowered to the same extent to negate an effluent gradient. However, in very low elevation sites, the risk of overtopping limits the feasibility of floodgate management or modifications. A further risk is that evapotranspiration may impact on ASS (see below).

Limitations

Elevation and Depth to ASS

DACS and cropping will rely on various depths of freely drained soil above the water table[94], which should be kept above the PASS. The DACS relies on accurate water table control, and is therefore not recommended in situations where this cannot be achieved. The potential for low water table management to reduce effluent groundwater gradients has also prompted research into its relevance for other land uses, such as forestry.[95]

However, concerns have been raised regarding the potential for plantations or encroachment of trees into former backswamp areas to lower groundwater, increase titratable acidity and metals, and redistribute these towards the surface. This would especially apply in environments that prior to drainage were not, or were only sparsely, treed.[96]

Planning should also take into account the potential for sea level rise. It is expected that DACS, and the cultivation of any crop requiring a freeboard of drained soil, will become increasingly reliant on drain and groundwater pumping into the foreseeable future.

Hydraulic Conductivity

Low hydraulic conductivity is critical to DACS, because the greater the K_{sat}, the less effective is the crop in creating the required influent groundwater gradient. Similarly, the greater the K_{sat}, the greater is the potential for saline intrusion. Detailed soil and ground water investigations must therefore be carried out to determine the efficacy of this strategy for a site.[97]

Investment in Works

Substantial investment may also be involved in land grading and drainage redesign, and as such DACS may be limited to high return crops or sites where substantial external funding can be obtained.

Impacts on Groundwater

The magnitude of the existing acidity problem is large in many sites.[98] It has therefore been proposed that the primary and most pressing management issue is the management and containment of this existing acidity[99], rather than reducing the potential for further oxidation in transitional and PASS layers. In reducing the frequency and severity of discharge events by maximising the available soil moisture store, it has been noted that further oxidation could occur in transitional and PASS layers.[100]

The rates of formation and discharge, and therefore net accumulation rates, will vary from site to site, and in some cases, the ratio between existing acidity and the risk of further production might not favour DACS. Conversely, production of further acidity may be relatively insignificant in some locations. Further research and site-specific risk assessment should be carried out into the magnitude and significance of existing acidity and the risks of enhancing acid production. The NSW policy framework recognises the need to protect groundwater resources.[101] Therefore, the long term impacts on groundwater need to be acknowledged, and steps taken to reduce those long term impacts, such as watertable management that is more appropriate to the site and elevation.

Wet Acid Containment

The objective of the wet acid containment strategy (WACS) is to contain acid and other oxidation products within the soil and surface water by maximising the time that influent groundwater gradients prevail by raising water levels in the drain. It has been shown that weirs can be used to contain acid and to reduce the rate of discharge from the groundwater to the drain.[102] Containment methods range from sills and dropboards in drains to more substantial in-drain water control structures (WCSs) such as weirs and penstocks, to more comprehensive modification of drainage systems including completely filling drains and reinstating natural drainage lines.[103]

Containment of acid by WACS may involve in-drain containment only, or the creation of surface water of varying duration and depths in backswamps, also known as 'freshwater ponding' or 'ponded pasture'. Floodgates may also be actively managed to introduce fresh water to backswamps to improve pastures at beneficial times of the year. The ideal location for WCSs is the levee toe, which is also often a boundary to soils with predominantly lower macroporosity and lower K_{sat}.[104]

Depending on design and management factors, the installation of structures or modifications to floodgates may have implications for fish and water passage, water quality maintenance and crop management.[105]

Limitations

Land Surface Elevations

Land surface elevations over the backswamp or other natural geomorphic containment unit are necessary in order to predict the maximum water level to which water may be contained and the seasonal water regime that may apply in backswamps. Elevation data may also be used to identify low points in levees, and define specifications of headwork modifications. Where appropriate, a well-monitored trial may assist with delineation of affected land. Planning should also take into account the long term potential for sea level rise. Depending on the geomorphic characteristics of the natural containment basin, the ability to contain acid and other oxidation products may involve progressively higher containment structures, and possibly the raising of artificial and natural levees.

Effectiveness in Addressing Acid Production and Export

'Wet pasture' management or 'reflooding' was initially seen in terms of its assumed ability to prevent further oxidation.[106] Doubts have been cast on the effectiveness of 'reflooding' as a remediation technique, due to: concerns over the potential for Fe^{3+} to act as an oxidant in the absence of oxygen; the lack of labile organic carbon left in the sediments to drive reduction reactions; the presumed increased frequency of acidic discharges; and the potential for reformed surficial sulfides to oxidise during the dry season. It was concluded that reflooding with freshwater 'may not be a panacea'.[107]

Many of these concerns could not be properly examined due to the lack of relevant research directed to floodplain grazing systems. It was not until later that one of the key concerns, regarding Fe^{3+} as an oxidant, was examined. It was found that the rate of sulfide oxidation generally decreased markedly when placed under water. Furthermore, sulfide reformation was rapid when organic materials were present[108], and could resume rapidly once appropriate hydrological conditions were restored.[109] Organic material provides for reduction reactions that lock up acidity.

Water quality in fresh water backswamps depends on a number of factors including:

- depth of water and degree of stratification
- vegetation and grazing management
- the size of the acid store
- the presence and size of acid scalds, and
- the amount of labile organic matter present.

By retaining water, wet acid containment reduces the acidity discharge in small to medium events. Although groundwater rich in oxidation products is positioned higher in the profile, enhanced discharge in any given event need not occur, depending on management of drain water levels. However, substantial acidity in the deeper groundwater remains[110], and when discharged by major rainfall events, drain waters can still become extremely acid.[111] Nevertheless, it has been found that WCSs may be an effective means of reducing acid discharge where groundwater seepage is the main export pathway, mainly by reducing the frequency and volume of flows (Figures 7 and 8).[112]

Figure 7. Acid export flux from groundwater seepage v surface run-off
(from Johnston *et al.* 2003a)

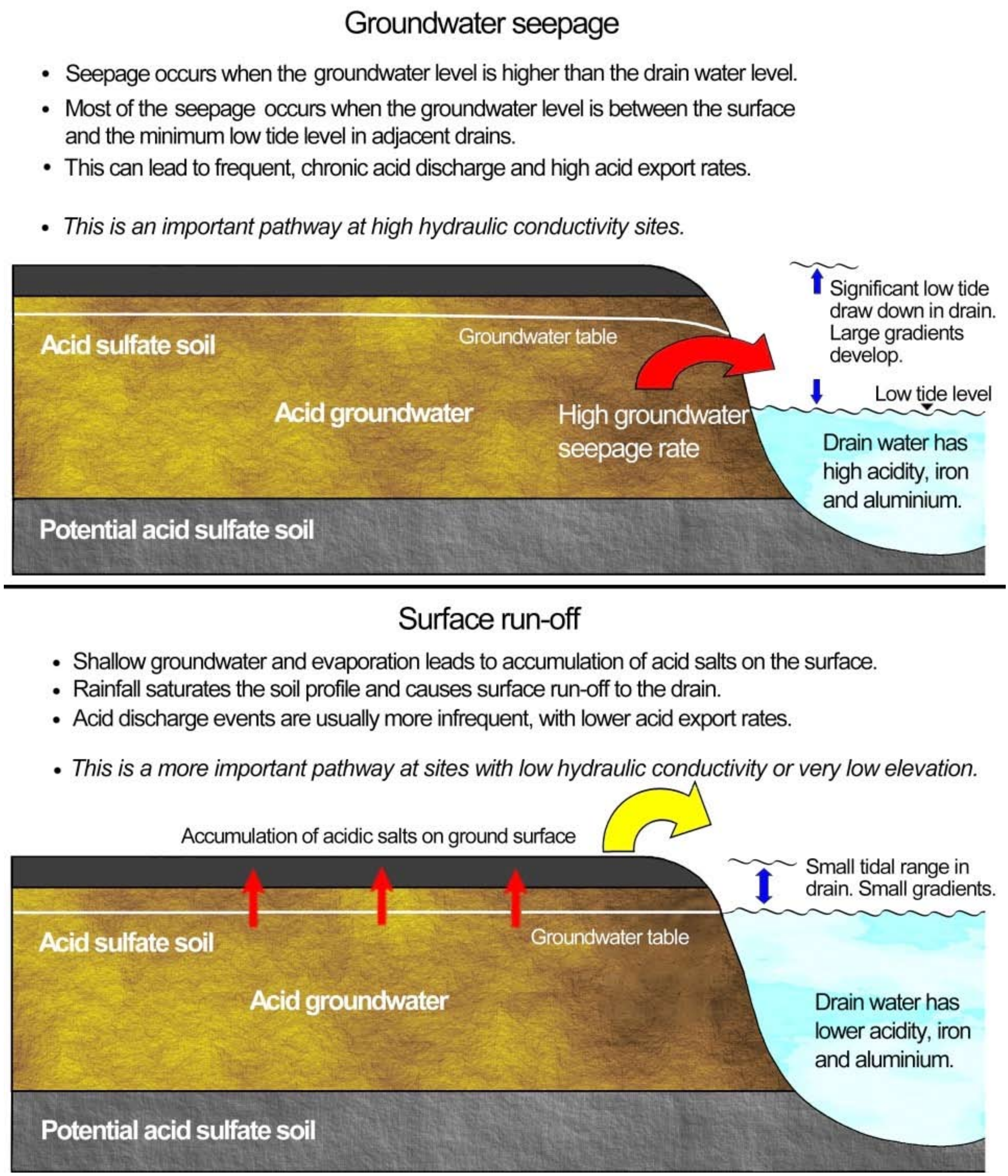
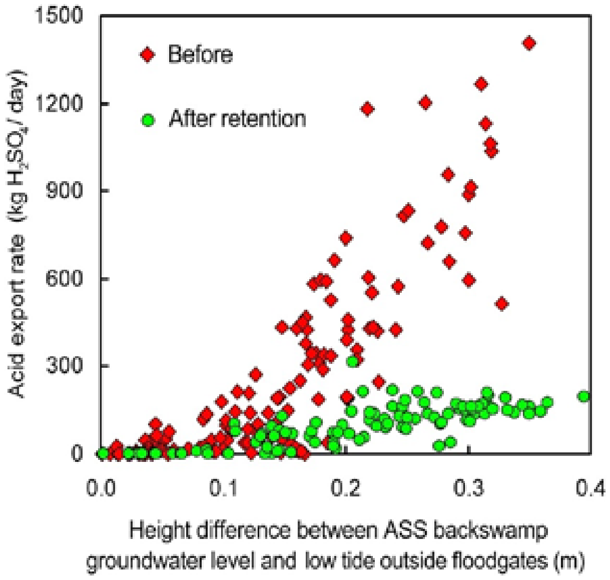


Figure 8. Acid export rate v height difference
(from Johnston *et al*. 2003a)



Long term data from Little Broadwater, managed as a freshwater containment strategy, also indicates an improvement in the pH of water discharged from the wetland during high rainfall events, a faster recovery time, and a decrease in acidity flux in response to the controlled opening and active management of floodgates.[113]

Addressing the Export of Related Products

Water quality issues such as low DO and black water events may often be related to the mismanagement of the same ASS environments. The common problem is the nature of the connection between the backswamps and the river, so that chemical processes that would normally have been contained in backswamps are being transferred to the estuary.

In-drain WCSs can provide a trap and sink for MBOs, although they may also potentially increase discharge during acute events. Drain infilling solves both the continued formation of in-drain MBOs and their export, although they can still form on land surfaces in wet environments where oxidation has liberated sulfate and iron species. For these reasons, drain infilling is preferred to the installation of WCSs.

Plate 10. Drain infilling at Cudgen

Photo: Tweed Shire Council

Without significant changes to the modified hydrology of floodplain backswamps, drainage-enhanced, estuarine deoxygenation events are likely to occur episodically into the future.[114]

The review of the 2001 North Coast flood and associated fish kills suggested that the most strategic remediation approach for improving drainage water quality would be to slow the rate at which mobilised iron and dissolved organic carbon enter the drainage system from the floodplain by retaining water and encouraging inundation tolerant vegetation on very low, highly acidic, low-value backswamps.[115] This would favour the reduction of iron species, enable build-up of a thick organic surface layer, reduce the transport of acidic products to the soil surface by reducing groundwater evaporation, and reduce the seepage of iron and aluminium-rich groundwater. It has been suggested that the appropriate level of containment would be approximately local mean high tide level (about 0.5 m on backswamps with a mean surface elevation of approximately 0 m AHD).[116]

However, while freshwater ponding may result in near surface, anoxic, reducing conditions below the surface, the sediments generally remain extremely acidic, with elevated salt and trace metal concentrations.[117] Acid stored in the sediment can still be released rapidly into solution, with acid discharge events highly responsive to rainfall in terms of response times and severity of water quality degradation.[118]

Reformation of Surficial Sulfides

In ASS backswamps a surface layer of pyrite may reform in the top 10–20 cm of the soil.[119] During dry weather the reformed pyrite oxidises, and an upward evaporative flux occurs, causing an accumulation of acidic solutes in near surface soils, particularly when the groundwater is approximately 10–20 cm below the surface of scalds. During rain, the surface salts then dissolve, causing a sudden drop in pH in the first flush of surface water into the drains.[120]

It has been recommended that the best way of ameliorating the acidic surface conditions is to raise and maintain higher water levels, thereby keeping pyrite layers in a reduced state for longer periods.[121] In order to prevent a pyrite layer concentrating towards the surface, wet conditions would need to be maintained[122], although the details concerning issues such as depth and hydroperiod are not clear. The accumulation of acid salts is markedly reduced in vegetated areas, due to the reduced effect of capillary action from the hydrologic effect of the organic layer. The addition of organic matter content[123] into the surface of the soil is expected to help remediate ASS scalds by improving soil texture, preventing evaporation and binding aluminium. Surficial acid salt production may be a transitional phase in the earlier stages of WAC remediation.[124]

So long as the potential for surface pyrite reformation and oxidation is considered and a strategy devised for its management, wet acid containment is an option, not only for rehabilitating scalds, but also for high risk PASS areas.[125]

Reduction Processes

Transformations of Fe and S associated with schwertmannite ($Fe_8O_8(OH)_6SO_4$) reduction have been examined by waterlogging schwertmannite- and organic-rich soil material.[126] Waterlogging readily induced bacterial reduction of schwertmannite-derived Fe(III), producing abundant pore water FeII, SO_4^{2-} and alkalinity, such that the pH increased from pH 3.4 to pH~6.5. Reduction lead firstly to the formation of elemental S, and later also to formation of mackinawite (FeS), although pyrite (FeS_2) was a quantitatively insignificant reduction product.

Vegetation Management

Most floodplain areas, including those suitable for WACS are generally in private ownership and used for grazing, so vegetation management and productivity from re-wetted backswamps is a key issue for many landholders.

Wet pasture grazing in backswamps was a common land use prior to the deep drainage schemes implemented in the period between the 1950s and the 1970s, and information on wet pasture species is available[127], but despite this, there has been some resistance by farmers to wet grazing, mainly due to the unknown production and quality of the native wet pastures.

Research on water couch *(Paspalum distichum)*[128] has found that it can grow well in extreme ASS environments, and has high digestibility, high crude protein[129] and high energy at higher growth rates than couch (*Cynodon dactylon*), the dominant grass prior to ponding. Growth rates depend on the timing of rainfall, temperature, grazing pressure and water level. Shallow water <20 cm deep is optimal for water couch growth (Plate 11a & 11b). Water couch can therefore be a valuable pasture in backswamp areas, although it can be susceptible to overgrazing.[130]

An added benefit of ponding is that wet sites do not frost and had protection from fire.[131] Other key agronomic issues to be considered are: stocking rates and seasonality[132], stock exclusion from scalds, snails and fluke management, botulism, and impacts from stock drinking low pH water with elevated concentrations of metals. Nevertheless, many graziers are now retaining more water on their backswamps using a range of WCSs.[133]

Plates 11a & 11b. Seven Oaks on the Macleay River floodplain, in 1994 (a) and 2004 (b)

a)

Photo: Mitch Tulau (1994)

b)

Photo: Scott Henderson (2004)

Wet pasture management also recognises the crucial importance of peat in the hydrology and management of ASS in backswamp areas.[134] Backswamp areas should not be ploughed, except when part of an active and ongoing management plan to restore suitable vegetative cover.[135]

Freshwater ponding also may benefit acid management by slowing or reversing the encroachment of ASS backswamps with tree species, mainly *Melaleuca quinquenervia*, which can lead to accumulation of acidity, and enhanced titratable acidity and acidic metal cations in the soil and groundwater.[136]

INTEGRATED FLOODPLAIN AND ACID SULFATE SOIL MANAGEMENT

Regardless of the physical limitations of the site, such as those imposed by elevation, soils and the characteristics of the receiving waters, the most effective ASS remediation projects will be those that are integrated with other natural resource management objectives relevant to coastal floodplains and estuaries, in order to achieve holistic coastal floodplain management.[137] In many cases the ASS remediation strategy must be integrated with objectives such agricultural production, wetland rehabilitation, carbon sequestration, and restoration of habitat for fish, invertebrates and waterbirds.[138]

The most relevant policy documents that seek to guide floodplain management are discussed in Appendix 2.[139] Some of the main factors affecting the acceptability of different strategies and specific actions in practice will be social and economic issues discussed further in Chapter 2.

These policies should be considered in their totality, rather than pursuing one to the exclusion of others, as the lack of an integrated and comprehensive floodplain management strategy can result in some issues not being fully addressed, leading to piecemeal modifications or delaying project outcomes.[140] However, reconciling these issues may be a difficult task, especially if objectives and actions of policies appear to be contradictory.[141]

Capability Framework

Land Capability is a decision-making framework that can assist in identifying where the various policy objectives may be achieved concurrently, which policy objectives might be mutually exclusive and, if necessary, where certain objectives should take priority.[142] Land capability[143] is the ability of an area of land to sustain permanent agricultural or pastoral production without permanent damage. In the context of ASS management, there is a close nexus between land use in relation to land and soil capability, and soil condition. Land being used within capability will produce no oxidation products nor discharge beyond background levels. Any land management change should not result in the production of further acidity nor in increased export of that acidity into drains and waterways. A general framework for determining links between soil condition indicators, management practices, environmental consequences and land capability in ASS landscapes is presented in Table 2.

Table 2. Links between land capability and management practices

	Characteristics of ASS Land used within Capability	**Characteristics of ASS Land used beyond Capability**
MANAGEMENT PRACTICES	Watertable managed to minimise ASS discharge[144] Drain depth according to Drainage Guidelines (Table 6) Drain cleaning and MBO management according to best practice Vegetation cover consistent with the site hydrology	No watertable control, ASS discharge Drains intersect Actual ASS layer Drain cleaning and MBO management not according to best practice Vegetation cover not consistent with the site hydrology
SOIL CONDITION INDICATORS	Soil pH >4[145] Groundwater pH >4 Groundwater Titratable Sulfidic Acidity (TSA) low[146] Titratable actual acidity (TAA) low[147] Depth to oxidation front stable Thickness of Actual ASS layer stable	Soil pH <4 Groundwater pH <4 Groundwater TSA high[148] TAA high[149] Increasing depth of oxidation front Increasing thickness of Actual ASS layer
ENVIRONMENTAL CONSEQUENCES	Low acid discharge from site, oxidation products contained No or minimal new acid production No scalds, scalds revegetated	Significant acid discharges Substantial new acid production Scalds develop and grow

Elevation and Sea Level Rise

On coastal floodplains, elevation in terms of AHD is a key factor in determining land and soil capability, especially in relation to ASS, where the formation of key chemical components was influenced by sea level at the time of deposition. Generally, the lower the elevation, the greater are the limitations to drainage and sustainable cropping, and, to a lesser extent, grazing.

The elevation of the upper surface of ASS materials[150] is commonly found at about 0.2–0.4 m AHD[151] , although several factors may complicate this generalisation, including:

- variations in sea levels during estuarine depositional phases[152]
- the fact that estuarine deposition is related to local tidal planes, rather than AHD
- scour of estuarine materials by higher energy flows
- slumping and peat loss[153], and
- vertical translocation and precipitation of oxidation-reduction products.[154]

In these alluvial-estuarine landscapes, changes in the elevation of land surfaces and that of ASS materials may mean that it might not be possible to 'restore' pre-drainage hydrological conditions. Land capability in relation to elevation is also complicated by the fact that local water regimes are largely controlled by the elevation of natural levees. Nevertheless, elevation remains a useful approximation to land and soil capability that is easily and accurately mapped. The relevance of elevation (and depth to ASS) is discussed in more detail in the context of the major remediation strategies below.

The feasibility of long term remediation strategies, and therefore appropriate land uses, must also consider climate change and sea level rise. Sea level rise will affect the feasibility of various floodplain management strategies, and particularly some ASS remediation strategies, due to subtle variations in elevation on the floodplain and the extreme sensitivity of some strategies to sea level change.

For example, sea level rise will result in:
- changes of vegetation zonation in tidal saltwater wetland environments[155]
- increased mean elevation of groundwater
- reduction of the hydraulic head available for drainage
- increased potential for incursion of estuarine water into fresh groundwaters
- increased potential for tidal penetration and overtopping of agricultural land and freshwater wetlands
- reduced viability of various agricultural practices, and
- increased reliance on interventions such as levees and pumping.

Changes and limitations of this type need to be factored into any floodplain management strategy, including any ASS remediation strategy, if it is to be considered sustainable. A key information requirement in this context is that of high resolution land elevation data, so that the magnitude and geographical extent of changes consequent upon sea level rise can be accurately modeled and mapped.

Greenhouse Gases

Coastal floodplains and wetlands are potentially significant sinks for global carbon, whilst drainage and subsequent rapid oxidation of the accumulated carbon is thought to result in accelerated carbon emissions. Soils represent an important store of terrestrial carbon that is relatively stable and can enhance primary productivity. The average residence time for carbon in soils is much longer than vegetation, and some inert forms such as charcoal and clay organic matter (OM) complexes can have residence times into the thousands of years.

However, most research into soil organic matter has concentrated on the change from undisturbed forest soils to disturbed cropping land uses. There are fewer instances of research into sequestration of soil OM under grasslands, although there is some recent evidence to suggest that well-managed grasslands may be good sequesters of soil OM.[156] Similarly, published estimates of carbon flux from Australian coastal wetlands are few.

The picture is complex, with factors such as change in land use and cover, restoration of degraded and eroded lands, reduction of grazing intensity or changed grazing practices, fertilisation, liming, irrigation, fire management, promotion of certain plant species, and promotion of earthworms or other soil biota all potentially relevant.[157]

Patterns of CO_2 flux have been examined in the context of sugar cane cultivation on ASS, where the net result is one of sequestration.[158] It is not yet clear how these data compare to alternative land uses contemplated by these Guidelines, such as various forms of wetland rehabilitation.

However, coastal floodplains and wetlands may be sources of a range of other green house gases with much higher global warming potentials, such as methane (CH_4), nitrous oxides (N_2O), hydrogen sulfide (H_2S), sulfur dioxide (SO_2) and methyl halides. It is thought that production of nitrous oxides may be stimulated by soil wetness[159], with the soil type also apparently important: emissions from cropped ASS appear to be much higher than from non-ASS soils. The emission factor, being the proportion of N in applied fertilizer that is emitted as N_2O also appears to be much higher from ASS.[160]

Methane emissions also responded to soil wetness, but are probably produced deeper in the soil profile, in the anaerobic zone.[161] However, the flux patterns are complex: methane emissions also depended on details of the farm management system.[162] How these results relate to ASS remediation strategies is not yet fully understood.[163]

DEVELOPING A REMEDIATION PROJECT

PRELIMINARY ISSUES

Organisational Issues

The most comprehensive and effective remediation projects are those that adopt an integrated approach, and seek to modify environmental management using the natural water-landscape units as a basis for planning.

In relation to ASS remediation, this will often be on a whole of backswamp basis. Issues of consultation, collaboration and consent are therefore fundamental to any ASS remediation project. Landholders, researchers, councils and government agencies cannot individually effectively address the challenges of ASS management and remediation. Individual landholders can initiate useful improvements in ASS management on their own properties, for example, by modifying or filling in drains, but the outcomes can be maximised by coordinating efforts within the context of a larger plan.[164]

Key ingredients of a comprehensive remediation solution will include collaboration, resources and sustained commitment for purposes including securing funding, coordinating research and monitoring, establishing a basis for community consultation, preparing and implementing the plan, and ensuring effective communication.

Organisations for Coordinating Remediation Projects

ASS remediation projects may be carried out by:
- councils and county councils[165], and committees of council[166]
- Private Drainage Boards (formerly known as drainage unions)[167]
- Crown reserve trusts[168]
- State agencies and
- various other incorporated associations.

Each of these types of organisations has different powers, degrees of autonomy and responsibilities, and it is important to ensure that the particular organisation has the powers necessary for carrying out the required functions. These functions will vary from case to case, but may include providing extension services, carrying out certain land management tasks or dealing in land.

In some cases an appropriate organisation may already exist, although its powers and other characteristics may need to be examined in order to determine its suitability for a particular task.

Local Government

Role of Local Government

Local government has a key role in remediation projects because these will often involve flood mitigation and drainage infrastructure managed and operated by councils. In such cases, remediation proposals cannot be advanced in isolation from local government's participation, their views on the operation of those works and, very often, their capacity to bear the burden of responsibility for the maintenance of any modified works. Many councils have demonstrated a sustained commitment to ASS management by appointing project officers to project coordination roles. In the case of major projects, a commitment from local government will generally be essential.[169]

Delegations

Under s. 355 of the *Local Government Act 1993 (LG Act 1993)*, a council may exercise its functions:
- by a committee of the council
- partly or jointly by the council and another person or persons, or
- by a delegate of the council.

'Section 355 committees' have been a commonly utilised form of devolvement, and many councils have established s. 355 committees and delegated the authority to modify and/or operate certain floodgates and other structures. Some councils opt to avoid the formal committee processes, and rather use the same section to establish groups of landholders simply as delegates of council.[170] In either case, when operating council structures, s.355 delegates do so according to a Floodgate Management Plan that is endorsed by council. These delegated bodies have the benefit of council support, including technical and, where available, funding support.[171]

Private Drainage Boards

Private Drainage Boards[172], formerly known as drainage unions, were formed in order to drain land and mitigate the effect of floods[173], and have broad powers to construct works, maintain and effect extensions and alterations to works, and make drains through adjacent land, with the consent of the board for the purposes of mitigating the effects of flood or tides.[174] The *Water Management Act 2000* requires the board to maintain in a state of efficiency the works under its charge, and renew such works where necessary.[175]

These powers have been interpreted broadly to include remediation work, in fact drainage boards have often been particularly effective because of their ability to coordinate action at a suitably local level, that of the backswamp. The framework for the administration and operation of Private Drainage Boards is now provided under the *Water Management Act 2000 (WM Act 2000)*, which has broadened their role by requiring the environmental objectives of the Act to be met.[176]

Crown Reserve Trusts

A Crown Reserve Trust is a not-for-profit corporation established under the *Crown Lands Act 1989 (CL Act 1989)* for the purposes of managing a Crown reserve. The trust is responsible, under the oversight of the Minister, for the care, control and management of a specific Crown reserve. The form of the trust may vary, and may be managed by either corporate managers, a community/local organisation, a local council, the Ministerial Corporation, a community Trust Board, or an administrator. Members of trust boards are appointed by the Minister administering the *CL Act 1989*.[177]

A reserve trust enjoys a certain level of autonomy in its care, control and management of the Crown reserve. A trust's powers may include, determining the management of the land (subject to Crown consent), employing people or outsourcing expertise when special skills are required, entering into management or maintenance contracts, and setting entry fees. The Department of Lands provides each trust with operational support, financial assistance and guidance.[178]

Others

Other groups involved in managing remediation projects have included State agencies, incorporated associations such as Landcare groups, other Non Governmental Organisations (NGOs), and developers, who may be required to undertake a project with a remediation component as a condition of development consent.

Funding

Implementing an effective remediation project will generally require substantial resources, and most proponents will need to access external funds to carry out the project. The process of securing funds should be commenced as soon as possible after the project objectives and project detail sufficient to propose a preliminary budget has been decided - securing funding may take some time.

The local Catchment Management Authority can provide further information about accessing funding, and guides to community grants from Federal, State and NGO sources are available.[179] Often funding may need to be drawn from a number of sources, related to various components of the project, such as works, research and monitoring. Funding should be committed for each stage or component of the project before proceeding.

Targeting of Remediation Projects

ASS problems are generally greatest at lower elevations, so the focus of remediation projects should generally be confined to High Risk ASS land at an elevation of < 2 m AHD. These lands are identified on the ASS Risk Maps as codes 0 (0–1 m AHD) and 1 (1–2 m AHD)[180], and include all the ASS 'hot spots'.[181]

Consultation

Project stakeholders are those who may be affected by the project, or who may have a relevant interest in the project outcomes. This principle is especially relevant on coastal floodplains, where changes to farm management and drainage can affect adjoining landowners' properties and the environment generally.

Proponents should discuss any remediation options with affected landholders and drainage unions, industry groups (such as cane growers, fishers' cooperatives), councils or county councils and State agencies, Landcare or similar groups, Aboriginal land councils, and relevant experts from universities and/or other institutions. Each of these can contribute useful inputs to a project, while failure to include even one of these stakeholder groups may limit the effectiveness of a project.[182]

The stakeholders affected by the project should be involved from the outset and in all phases, including identifying the objectives for the remediation plan and options for achieving the objectives, and implementing and monitoring the remediation plan.

The process of stakeholder and community consultation may be potentially lengthy, especially where proposals for land management change are substantial, or where there are key information gaps. However, the process must be carried out thoroughly, as a failure to consult and involve all stakeholders appropriately may undermine the success of the project or cause delays. In some cases, failure to consult with landholders and any other interested parties prior to undertaking remediation works may have legal consequences.[183]

The remediation plan should clearly enunciate who may be affected by the project, who may have an interest in the project, and what their roles and responsibilities may be. It may be desirable, and in some cases necessary, to formalise roles and responsibilities.[184] A record of all consultations, including contact with parties not identified as stakeholders, should be maintained.

IDENTIFYING THE PROBLEMS

Identifying the issues underlying the problem correctly is a key step and one on which the success of the project depends. Preconceived perception of the problem can undermine the whole approach, possibly leading to piecemeal solutions.[185] Once the issues are identified, determining the actual causes may be a difficult task, and one which has often been compounded by poor or incomplete data[186] and the fact that effects of ASS impacts can often manifest themselves many kilometres from the source of the problem.

A problem statement should clearly identify the apparent issues, including those indicators set out in the *ASS Manual*[187] and their location, and provide a brief history of the site, such as specifying when drainage and other works including any floodgates, were installed or modified, and when problems were first noticed.

Resource and Site Data

Any relevant research or monitoring carried out on the site or any research or monitoring sufficiently related to the issue by universities, State agencies, local councils or landholders should be identified and evaluated. Existing information may include water quality data (particularly from data loggers)[188], soil information[189], information, ecological monitoring or research, and historical environmental data.[190]

Depending on the expertise available to the project proponents, it may be beneficial to seek external evaluation of existing information. In evaluating the information, the risks of inappropriately extrapolating data across landscapes should be recognised. Data obtained from similar geomorphic landscapes and soils are generally considered to be of most value.

INTEGRATING WITH OTHER OBJECTIVES

In many cases the ASS remediation strategy must be integrated with objectives, such agricultural production, wetland rehabilitation, and restoration of habitat for fish, invertebrates and waterbirds. Land capability maps, elevation data, and other data relating to the physical aspects or ecologic values of the site should be consulted.

Relevant social and economic issues (see below) must also be considered at this point. The type of land use, and particularly the economics of land use, is commonly a major constraint on the choice of remediation strategy. For example, industries returning low gross margins per hectare, such as grazing, generally cannot justify a high cost strategy based on expensive works, such as land reshaping, land grading, sustained in-drain neutralisation of acid water and regular surface liming, as are routinely carried out in higher return cane growing areas. Conversely, cropping industries which generate high returns are unlikely to prefer strategies such as wet acid containment (freshwater ponding) or restoring estuarine areas, at least not in the absence of significant compensation.

The costs of the various options taken into account include not only the actual costs, such as costs of works and those associated with changes in production, but also opportunity costs, such as the costs of not carrying out remediation, both in relation to wetlands and aquatic ecosystem health and productivity. Options may be ranked on environmental, social and economic criteria.

In doing so, some compromises may have to be made. Table 3 lists some of the common trade-offs that may need to be taken into account in determining the appropriate strategy(s).

Table 3. Trade-offs between different management actions
(based on Johnston *et al*. 2003a)

	Remediation Strategies			
	Neutralisation/dilution Strategies		**Containment Strategies**	
	Floodgate management	Restoration of estuarine areas	DACS	WACS
Outcome	• Improved fish passage/habitat • Some in-drain neutralisation/ dilution • Reduced aquatic weeds	• Improved fish passage/habitat • Other wetland values • Neutralisation/ dilution	• Reduced acid discharge	• Reduced acid discharge • Improved drought refuge and productivity • Enhanced biodiversity • Carbon sequestration
Trade-off	• Still seasonal acid discharge • Drain more saline • Risk of overtopping/ saline intrusion	• Potential loss of farm land, productivity and income	• Potential subsoil acid production	• Potential barrier to fish passage/habitat • Potential for trapping of fish • MBO accumulation behind WCS • Change in farming type to wetter system • Reformation of surficial sulfides • Seasonal mosquito risk

ASSESSING THE SITE

Site assessment should be carried out with reference to the limiting factors identified for each of the main remediation strategies discussed in Chapter 1. However, all remediation projects are likely to require some information on each of the following matters, irrespective of the remediation strategy being employed:

- physical site characteristics, including soil properties, land surface elevations and tidal amplitudes
- characteristics and management of drainage systems
- hydrology and water quality, and
- social and economic issues including current and historic land use and tenure.[191]

Each site must be assessed independently to determine appropriate strategies and options, rather than applying a fixed formula. Every site is unique in terms of its key features, including: soils, geomorphology and elevation; drainage history and land use, and the quantity, quality and relevance of data and other information that may be available for the site. However, a number of common issues and limitations for the main remediation strategies are listed in Table 1.

Physical Characteristics of the Site

Characterising the site in terms of its geomorphic landform element(s), land capability, soil properties and land surface elevations is an essential first step in deciding appropriate remediation strategies. Appropriate strategies will differ between, for example, a low elevation backswamp (e.g. WACS), a higher elevation alluvial plain (DACS), and an intertidal estuarine flat (saltwater wetland restoration). A benefit of geomorphic mapping and characterisation is the development of a focus on the physical geography and limitations of a site, rather than on current land uses and appearance of the landscape.[192]

Soil Properties

Soil characteristics and properties should be described for each layer and horizon. Soil information should be collected according to pp. 20-21 of the ASS Assessment Guidelines in the *ASS Manual*[193], the *Australian Soil and Land Survey Field Handbook*[194], and the *Soil Data Entry Handbook for the NSW Soil and Land Information System* (SALIS).[195]

Soil characteristics and properties relevant to ASS remediation may include both chemical properties such as TAA, TPA, Scr % and neutralising capacity, as well as physical characteristics such as hydraulic conductivity, the stratigraphy of the various soil materials, and the distribution of ASS in the area, including any hot spots or scalds. Important properties such as pyrite content and inherent neutralising capacity, and other chemical properties should be assessed by laboratory testing carried out according to the Laboratory Methods Guidelines.[196] A critical measurement in designing remediation is the depth to actual and potential ASS, because the elevation of these layers in relation to tidal amplitude determines the thickness and therefore the duration of the 'acid export window'.[197]

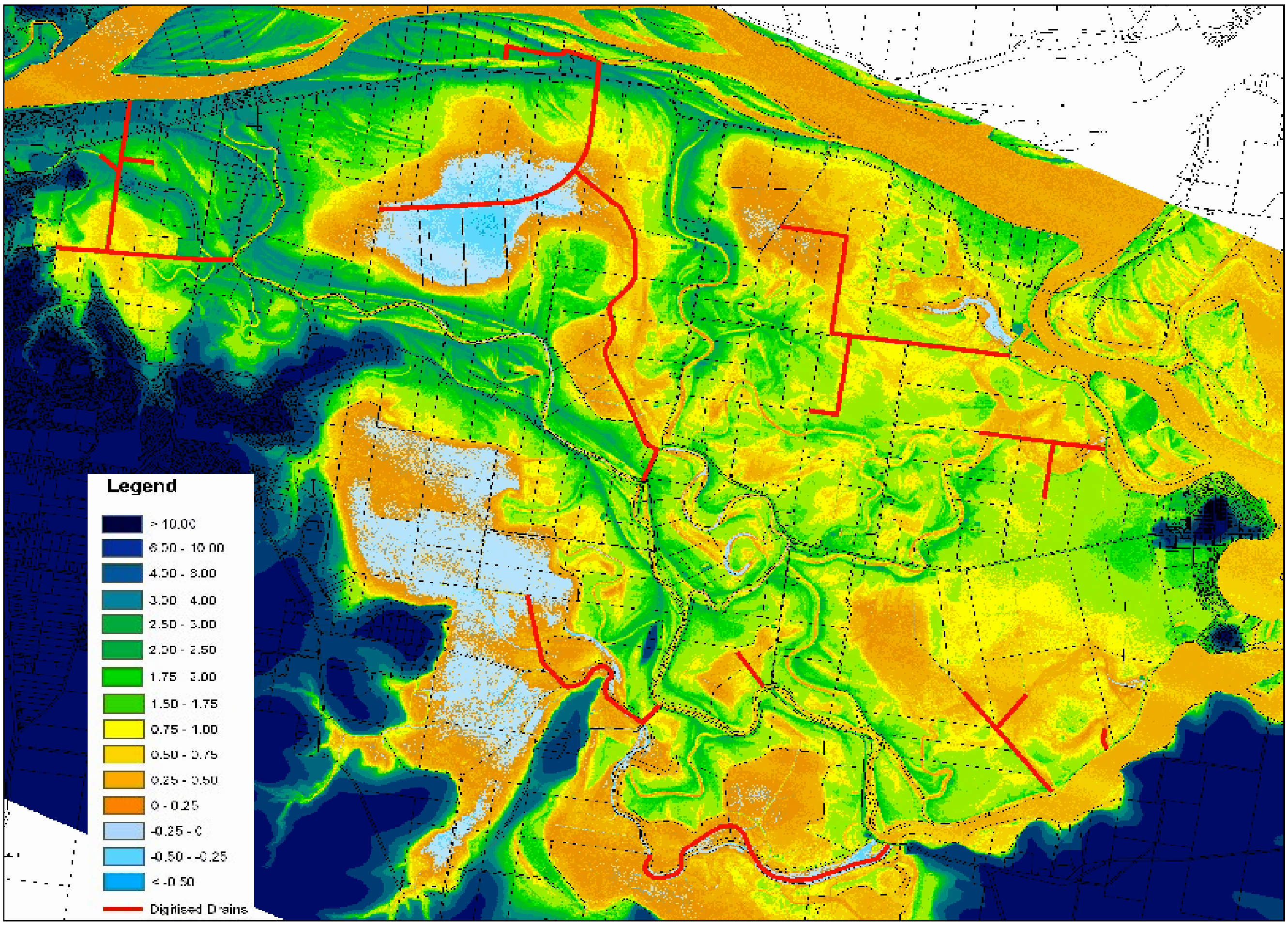
Indicative information in relation to soil properties, including the depth to actual and potential ASS and stratigraphy is available from the hot spot reports[198], ASS Risk Maps[199], soil landscape reports[200], or for specific areas or profiles, the NSW Soil and Land Information System (SALIS).[201]

Land Surface Elevations and Tidal Amplitudes

High resolution data is required for project planning on coastal floodplains, where increments of a few centimetres are often required to determine feasible remediation strategies. The most accurate, highest resolution spatial elevation data is generated by Airborne Laser Survey (ALS)[202] (Figure 9). Point elevation data from ground-based Differential Global Positioning System (GPS) may be required where the elevation of specific features such as drain and floodgate inverts is required. Detailed and accurate land elevation input data is required for computer modeling of the area of inundation under different scenarios. Failure to capture accurate, high resolution elevation data can result in unexpected water management outcomes, or project delays.[203]

Various techniques are available to measure tidal levels.[204] Accurate data can only be obtained by field truthing over selected tidal cycles.

Figure 9. Elevation map of the Shoalhaven generated using ALS
(from Lawrie and Eldridge (2006). Note that the backswamps are at or below sea level



Characteristics and Management of Drainage Systems

Drains may be owned and managed by a range of organisations and individuals, and details of ownership and responsibilities can be complex. The basic rule is that the ownership of fixed structures attaches to that of the land, whereas the ownership of moveable structures does not.[205]

There are generally three categories of drains: council-owned drains, Private Drainage Board drains, and private (individual landholdings) drains. Drains constructed under flood mitigation schemes on the Tweed, Richmond, Clarence, Macleay, Hunter and Shoalhaven, as well as many other major drains, are council assets. Councils will generally hold mapped information concerning these structures, sometimes including details such as floodgate specifications and invert levels.

Many major drains were constructed by drainage unions, now known as Private Drainage Boards.[206]. Drainage Boards retain control over the management and maintenance of board works, but ownership of the land remains with the landholder, there being no easements created by the *Water Management Act 2000 (WM Act 2000)* to sever the works from the surrounding land. Details on board boundaries and management responsibility of drainage structures are available from the board concerned or from DWE.

The last category of works covers those drains constructed, owned and managed by individual landholders. These drains are located within property boundaries, and are generally of smaller dimensions than council or board drains, to which the private drains may be connected.

DECC has mapped drainage networks, including the locations of most floodgates and other structures, within ASS landscapes on the NSW north coast.[207] Drains are mapped at a scale of 1:25 000 and coded for width, depth and spoil height. An inventory of floodgates was carried out by NSW Fisheries[208], and a number of councils have carried out inventories of their own council drainage structures.[209] The elevations of drain and floodgate inverts should be determined by ground survey using differential GPS.

Hydrology and Water Quality

Hydrologic factors of relevance may include: the discharge from the site (estimated monthly discharge, upland discharge); hydraulic conductivity, which affects the relationship between groundwater drainage and its relationship to drainage surface water (connectivity) and the potential for the intrusion of saline water into groundwater, or lateral salt seepage; the water quality in the drainage systems; discharge rates of oxidation products; buffering capacity and exchange rates of receiving waters; and the ability to harvest freshwater from receiving waters.

Social and Economic Issues, Land Use and Tenure

Social and economic factors may include: current and possible future trends in land and water uses, and farmers' future plans for the land; the importance of off-farm income to the landholder(s) concerned; landholders' knowledge of alternative farming systems, and their ability and willingness to adopt change; the proportions of backswamp to drier levee or other higher elevation country owned by the farmer(s); the degree of investment in infrastructure by government and landholders; and social-economics of any estuarine production affected by the site.

A requirement to consider the social and economic impact of a 'development' flows directly from s. 79C(1)(b) of the *EP&A Act 1979*.[210]

In many situations, issues related to endangered terrestrial ecological communities and species within the site, endangered aquatic communities and species in affected waterways, and wetlands and pastures and their condition, may constrain remediation objectives or targets.[211]

Most floodplain areas, including ASS backswamps, generally include a large number of landholdings, and often several types of tenure including freehold, various Crown land categories[212], and sometimes areas of National Park or Nature Reserve. The size and shape of holdings (including the proportion of properties not liable to flooding) may also affect the potential scope of an ASS remediation plan. Information on some matters relating to land tenure is available from the local council or the Department of Lands.

SPECIFYING TARGETS

Targets are observable or measurable attributes that can be used to determine whether a project meets its intended objectives. Clear and practical, short and long term targets for remediation should be identified. These targets provide a sound basis for:

- identification, inclusion and involvement of stakeholders in the project
- development of sound principles for the management of the project
- development of appropriate indicators to aid and trigger particular management decisions
- establishment of appropriate monitoring necessary to enable the assessment of the success of the project, and
- consideration of any trade-offs necessary between short and long term targets or between targets or outcomes in relation to particular issues or in particular parts of the catchment.

Targets should, where possible, be expressed in quantitative and unambiguous terms, and systems should be put in place so that progress towards targets and objectives can be tracked in a verifiable, statistically robust and transparent manner, while recognising that both the objectives and any monitoring programs take into account the variability inherent in natural ecosystems.

Targets may be expressed in terms of water quality improvements or in terms of measurable soil properties.[213] An alternative approach, due to the variability of water quality and acid discharges, may be to set targets on works or other remedial actions carried out, such as: the following lengths of drains filled, shallowed or modified; numbers of floodgates modified and/or subject to active management; or area of contained or leveed ASS land, reflooded or subject to higher watertable management.

PREPARING A REMEDIATION PLAN

Level of Detail

The amount of information and level of detail in the plan should match that required to develop and monitor a scientifically valid and legally defensible plan, and will therefore vary depending on the magnitude of potential impacts.

In many cases, detailed investigations may be necessary to understand the risks associated with each remediation strategy. The higher the risks (including those due to scale or permanence), the more detailed the supporting studies will need to be. Similarly, if a proposed management strategy is largely unproven or potentially carries higher risk, site specific experiments or pilot projects may be required prior to proceeding. Caution is urged where uncertainty exists about the ability of a strategy to adequately manage ASS or where sensitive environments may be adversely affected by acid discharges.[214]

In more straightforward cases, especially those involving relatively minor works or impacts, a more limited range of matters for consideration may be appropriate. For some routine works, such as agricultural drain infilling and liming, a brief generic plan may suffice.

Qualifications

The process of plan preparation, including environmental assessments, should be undertaken by suitably qualified persons, with relevant qualifications in agricultural or environmental science, and practical experience in ASS management.[215]

Contents of the Remediation Plan

The Remediation Plan should include the following sections.

Table 4. Remediation plan template

Section	Contents
Background and Purpose of the Plan	Geomorphology and history of the site and issues
Processes of Plan Development	Details on consultation and technical review, concept plan, management plan, implementation plan
Project Stakeholders	List of individuals, groups and organisations that are involved in the project, their roles and responsibilities
Funding	Sources, timing, codependency if applicable, in-kind contributions and implied future commitments to maintenance and repairs
Links with Other Plans	Details of plans, projects and processes that relate to or overlap with the objectives of the present plan
Site Characteristics	Details on relevant issues such as: climate; topography; hydrology/tidal influences; wetlands; flora and fauna; geomorphology/soils; groundwater and surface water characteristics; drainage and flood mitigation works and their management and impacts; Aboriginal cultural and heritage sites; land zoning, land tenure, land use and infrastructure
Major Options of the Plan	An explanation of what strategies are possible at the site, in the context of the site characteristics
Strategies and Objectives	An explanation of which main remediation strategies are to be used, objectives and intended outcomes
Works Proposed	Details of the types of works, their location and specifications, including a reliable map (Figure 10)
Consents and Approvals	Details of all consents and approvals that may be required
Land Management Changes	Details of proposed non-works changes, their location and specifications
Performance Indicators	Quantifiable indicators that may be used to measure the success or otherwise of the project; includes water quality indicators and works indicators
Implementation Plan	Plan detailing actions, priority, what is required for each action, the estimated cost and any approvals required. Details who is designated to carry out each task. Individual actions organised on a time line or flow chart
Contingency Plan	Explanation of the nature of risk, the perceived threat rating and duration of threat, proactive measures proposed and the proposed response
Communications Plan	Outline of the target audience(s), and the communications methods to be employed, timing and duration
References and Appendices	All references included in the plan, and any data sets, such as water quality data, soils information, and relevant metadata about such data sets

Remediation Principles

In preparing the plan, the following principles be should be applied (Table 5).

Table 5. General principles applicable to remediation projects

Location and targeting of funding
• The focus of remediation projects should be high risk ASS land at an elevation of < 2 m AHD, including ASS hot spots.
Remediation aims
• Remediation measures should not result in the production of further acidity[216] nor in increased export of acidity into drains and waterways
Objectives and targets
• Where possible, remediation projects should meet multiple policy objectives.[217] • Proposed remediation strategies should clearly state the remediation objectives, or combination of objectives. • The remediation plan should include clear and achievable short- and long- term targets, and where possible, targets should be expressed in quantitative terms. • Systems should be put in place so that progress towards targets and objectives can be tracked in a verifiable, statistically robust and transparent manner. • The benefit:cost ratio should be maximised.
Consultation and socio-economic issues
• The remediation project should involve all relevant stakeholders from the outset. • The remediation project should maximise public benefit, whilst recognizing the rights of existing users. • In developing the remediation plan, appropriate consideration and weighting should be given to social and economic factors.
Plan preparation
• The process of plan preparation should involve the skills and experience of a multi-disciplinary team. • The process of plan preparation, including environmental assessments, should be undertaken by suitably qualified persons with relevant qualifications, and practical experience in ASS management • The amount of information and level of detail in the plan should match that required to develop and monitor a scientifically valid and legally defensible plan.
Engineering and practical issues
• Any modifications to drainage works should be practical, technically sound and reliable. • Generally, preference should be given to strategies that require lower levels of intervention, and maintenance.[218] • Responsibility for ownership and ongoing maintenance of the structure must be determined prior to the approval and/or commencement of works to ensure that the structure will continue to be adequately maintained.
Legal issues
• The project must be legally sound, including any relevant consents and approvals obtained, and common law obligations and duties adhered to. • All projects should be subject to a risk assessment to determine the level of environmental risk.
Monitoring and adaptive management
• The remediation plan should include a monitoring program for soils and the surface and subsurface water quality, and any other relevant matters. • The monitoring data should be compiled, reviewed regularly against any relevant standards and performance targets[219], and used to evaluate the effectiveness of the plan or its implementation. • If the remediation strategies appear to be ineffective, the plan or the targets should be reviewed. • High risk projects should generally incorporate a staged approach with appropriate monitoring. • A contingency plan must be developed prior to approval or commencement of the project, in order to manage impacts should the remediation strategies fail. • The remediation plan should include details of maintenance requirements, including likely duration, frequency, responsibilities and funding sources.

IMPLEMENTING A REMEDIATION PROJECT

IMPLEMENTATION PLAN

The implementation component of the plan should detail what needs to be done (including consultation, actions related to land management changes, and any works components), and who is designated to carry out each task. It is important to relate the individual actions to a time line or flow chart. This will ensure that critical actions, such as securing of any consents or obtaining survey data prior to constructing water control structures, are in place at the appropriate time.

Constructions and Modifications

This section should include discussion of works that may be required as part of the remediation project. In the case of installation of in-drain water control structures, the implementation plan should detail:
- relevant specifications of the structure(s) proposed
- the reasons for the modifications, and
- a reliable map showing the location(s) of the structures to be modified.

In the case of drainage works, the implementation plan should detail:
- the existing drainage in the area
- the drains to be retained
- the drains to be modified
- the details of modifications
- the reasons for the modifications, and
- a map of existing drainage and that proposed to be modified.[220]

In the case of modifications to existing floodgates, the implementation plan should detail:
- relevant specifications of the existing structure(s)
- the details of modifications
- the reasons for the modifications, and
- a map showing the location(s) of the structures to be modified (Figure 10).

Operation and Maintenance

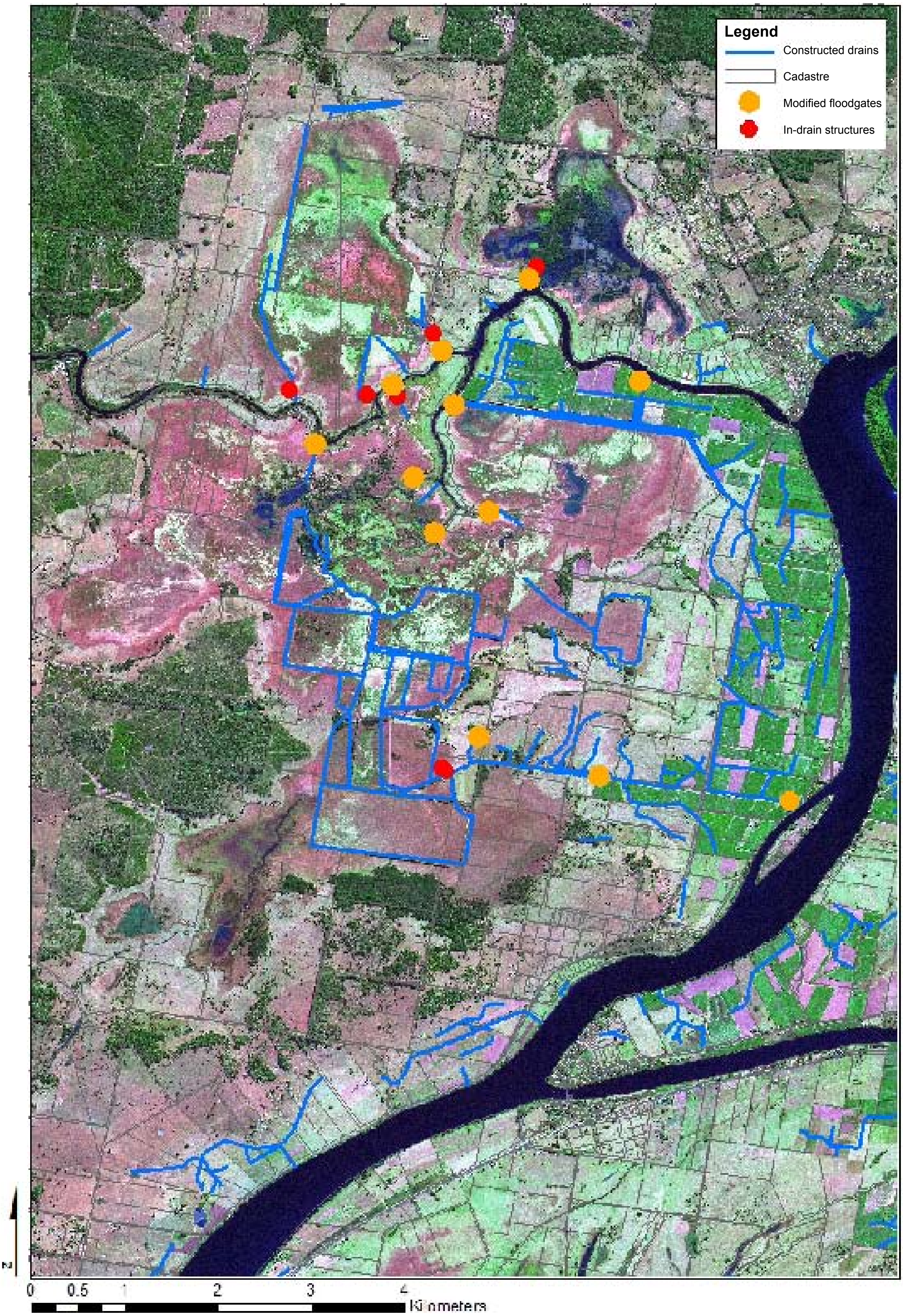
The operation and maintenance component of the plan should include:
- management activities or tasks
- a timetable for activities and resource availability
- an inspection checklist
- a list of contacts for approvals and advice
- OH&S matters
- a description of monitoring activities, and
- an emergency management plan.

Drain maintenance is only part of an ASS remediation strategy to the extent that it allows a more precise management of drain and groundwaters consistent with the principles contained in these Guidelines. Drain maintenance is not part of an ASS remediation strategy if the work carried out has the effect of draining land and groundwaters to lower levels. Proponents need to check with their local council about planning requirements and relevant legislation before undertaking any drain maintenance works. Drain maintenance in ASS areas should be carried out consistent with appropriate guidelines.[221]

Depending on the land management practices in a remediation area, weeds, noxious and otherwise, may become a problem. Weeds affecting saltmarsh and other saline areas are discussed in the Saltwater Wetlands Manual.[222] The operation, maintenance and monitoring of constructed freshwater wetlands is comprehensively covered in *The Constructed Wetlands Manual*.[223]

In cases where access may be affected, plan should detail:
- potential changes to access (replacement of crossing, culverts, etc)
- the location of new access, and
- the responsibilities of specific parties for works, timeframes, costs and future maintenance.

Figure 10. Example map from Everlasting Swamp showing location and nature of proposed works (after Wilkinson 2004.)



WATER MANAGEMENT WORKS

General Criteria

Useful summaries of floodgate designs, modifications available and operational aspects of floodgate management devices are available[224], although the suitability of each type for a particular location needs to be determined on a case-by-case basis. Design criteria that could be applied to floodgate modifications include the following considerations.[225]

The structures should:
- maintain the efficiency of the flood mitigation system during flooding
- be capable of controlling maximum and minimum water levels and avoid unintended inundation of neighbouring land
- be able to be operated during higher flows
- be easy to install
- be low maintenance and durable, vandal resistant
- be easy to operate and be compliant with OH&S, and
- be reasonably costed.

'Fix-and-forget' designs are preferred to high-tech, high maintenance and/or labour-intensive designs.[226]

Drainage System Design and Landgrading

Criteria for Modification of Existing Drains and Construction of New Drains[227]

A strong preference should be given to reducing the overall number and depth of drains and wherever possible, reconfiguring existing drains to reduce the impact on the environment. Existing deep drains should be widened and shallowed (Plate 12a & 12b). Where drained areas with shallow ASS already exist and are subject to an approved drainage management plan, any modifications to the drainage must comply with the provisions of the approved plan. Modification of existing drains must be in accordance with the Drainage Guidelines in the *ASS Manual*.[228]

Plates 12a & 12b. Drain before and after shallowing

There must be a very strong justification for the construction of any new drains or the deepening, extension or retention of any existing drainage works. As a general principle, new drainage works must ensure that no further acid is produced or discharged as a result of their construction, operation or maintenance. Guidelines for the modification of existing drains and the construction of new drains have been prepared (Table 6).

Table 6. Drainage guidelines
(adapted from Robertson *et al*. 1998)

1. Where areas are "scalded" or degraded and devoid of vegetation, no further drainage should be undertaken. The drainage design should avoid drainage of soil layers that contain deposits of jarosite. Any drainage of jarositic soil will result in acid drainage waters. Remediation strategies should be developed which may include alternative drainage management including the removal of existing drains.
2. Where any ASS is < 0.5 m below the soil surface, these areas should be left undrained. Generally these areas are best left waterlogged and planted with species such as swamp grasses.
3. Where any ASS is between 0.5 and 2.0 m from the surface, drainage should only be attempted with properly designed drains and treatment of any acidic discharge. • If ASS is 0.5 to 1 m below the soil surface, then surface drainage and land grading should be limited to cuts < 0.3 m. Irrigated pastures or crops should be considered. • If ASS is 1 m to 1.5 m below the soil surface, then surface drainage and land grading should be limited to cuts < 0.5 m. Subsurface drainage may also be possible in heavy clay soils and should be limited to 0.5 m depth. • if ASS is > 1.5 m below the surface, surface drainage, subsurface drainage and land grading should be limited to cuts no greater than 1 m.

The base of drains should generally be above the upper surface of any ASS layer in order to provide for higher ASS levels than predicted, the movement of ASS oxidation products in the capillary fringe, and to provide a seasonal ground water buffer against drought. The drainage design should avoid drainage of both sulfidic and sulfuric soil layers. A preliminary indication of the presence of and depth to sulfidic sediments can be determined from the ASS Risk Maps, followed by a preliminary soil assessment, and if necessary, from more detailed assessment (see Assessment Guidelines[229]). Generally, areas mapped with elevation codes 0 or 1 on the ASS Risk Maps should generally be excluded from further drainage. Drainage works should not be carried out in adjacent areas (such as levees) where they may impact on these areas.

Variation from this *"rule of thumb"* would only be justified in specific situations, if a full environmental assessment had been undertaken by a suitably qualified consultant and a plan of management prepared demonstrating that an ASS problem will not result and that any potential impacts can be managed.[230] Guidelines on land grading are also included in the Drainage Guidelines of the *ASS Manual 1998*.[231] Remediation works that include drainage works or land grading should only be undertaken in locations where the elevation of the land provides for the requisite soil depths above ASS layers.[232]

Drains should be wide and shallow in order to maximise floodwater discharge capacity whilst minimising disturbance of any ASS layers. Batters of 1 in 5 or flatter are recommended (up to 2:1 for side batter against a fence). Drains should be only large enough as is necessary to remove excess storm or floodwater and should be designed to have a minimum impact on farming operations. The grade should be between 1 in 600 and 1 in 2 000 with design velocities less than 0.6 m/s for loam and silty soils and less than 1.2 m/s for clay and gravel soils. Drains should not permanently contain ponded water, and therefore should be shallower than the invert level of the floodgate.[233]

Land Grading

To increase the efficiency of drainage, land can be laser leveled to remove isolated depressions and achieve an adequate slope (e.g. a minimum grade of 1 in 1 500). Land grading is expected to improve water quality by efficiently shedding local rainfall, rather than allowing it to infiltrate into the soil and displace acidified groundwater into drains. Some of the main benefits of improved surface drainage by land grading are that it enables farmers to reduce the numbers, density and total lengths of drains, and it increases run-off that reduces discharge of acid groundwater. Land grading of large areas will remove the need for many smaller field drains, but still requires a substantial existing drain to receive the overland water flow from the land graded area.[234]

The plan should be designed so that sulfuric or sulfidic materials are not exposed during land forming. Proponents need to check with their relevant council about planning requirements and relevant legislation before undertaking any earthworks in ASS areas.[235]

In-Drain Water Control Structures

The purpose of in-drain water control structures is to elevate drain water levels and reduce the hydraulic gradient from the groundwater table to the drain in order to reduce the acid discharge rate into drains, or to limit the upstream ingress of brackish water into low-lying agricultural land. A range of water control structures may be constructed, from rudimentary sandbag weirs to fully automated systems.[236] Some of the more common types are discussed below.

Criteria for Water Control Structures

Some general criteria may be applied to water control structures.[237] Ideally, the structures should:

- be designed to suit local conditions
- maintain the efficiency of the flood mitigation system during flooding
- be capable of controlling minimum water levels
- include flexibility to trial different water levels
- be low maintenance and durable
- be compliant with OH&S
- be vandal resistant
- be cost effective
- have approval from the relevant owner(s) of a drain prior to the installation of any WCS or modification to the drain design
- comply with relevant legislation in terms of installation and management.

Examples of in-drain water control structures are illustrated in Plates 13a, 13b, 13c and 13d. Note that not all meet the criteria above.

Plate 13. In-drain Water Control Structures
From top: a) temporary sandbag weir in the Upper Maria River

Photo: Tim Morris

b) earthen sill with crossing at Seven Oaks

Photo: Tim Morris

c) concrete weir at Maloney's Drain, Shark Creek

Photo: Phil Hirst

d) dropboard at North Oxley Island

Photo: Mitch Tulau

Sandbag Weirs

Sandbag weirs are commonly used in trials (Plate 13a). A major benefit is that they are adjustable, although not easily. They are also removable, which may be either an advantage or a disadvantage. They are, however, prone to leakage and failure, and should not be installed when potential flows are above 2 cusecs.

Earthen Sills

Earthen sills are essentially the filling in to the required level of a short section of drain. The design and construction costs are low, and they are generally easy to install. Pipes or a spillway may need to be included in the design so that the crest does not remain wet and prone to erosion. (Plate 13b). Armouring may be required in higher flow situations, especially > 2 cusecs, or where stock may be tempted to use the sill as a drain crossing. However, sills are not easily modifiable.

Concrete Weirs

Fixed concrete weirs are a semi-permanent solution. Weirs control minimum water levels, and may incorporate dropboards to include water level flexibility (Plate 13c). They are the lowest maintenance and most durable in-drain structure, and, depending on the design, may be used in larger drains with flows above 5 cusecs.

Dropboards

Dropboards are very simple and generally inexpensive systems that can be installed as an in-drain structure, such as at the end of a pipe, and modified to raise or lower water levels (Plate 13d). They are generally inexpensive to install. In some cases, the headworks of flood mitigation works were originally constructed with slots for the purpose of installing dropboards. In other situations, a dropboard structure may have to be retrofitted, and as such the cost will vary. Dropboards may be useful in cases where the capital expenditure required for drain filling/reshaping is difficult to justify.[238] A series of dropboards can be installed to provide a range of upstream water levels. Dropboards have both the advantage and disadvantage of being able to be modified or removed. However, dropboards can sometimes being difficult to remove and reseal, and depending on the design, should not be used in larger drains with flows above 2–5 cusecs.

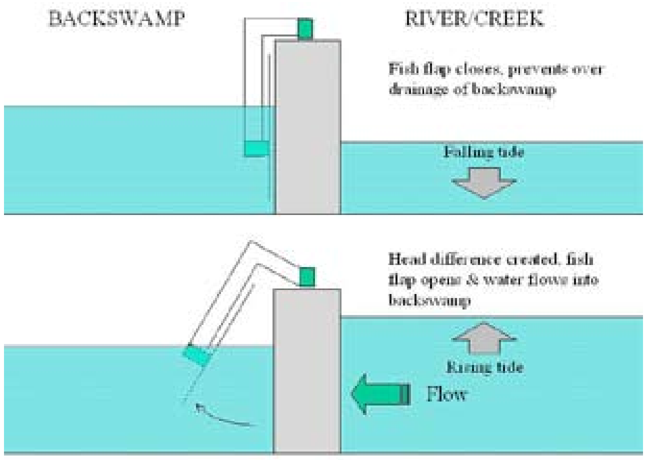
Structures with Fish Flaps

In-drain water retention structures, or headworks, may incorporate a fish flap that provides for fish passage (Plate 14), and therefore meets the dual objectives of preventing over-drainage of the backswamp, whilst allowing some fish passage. This is essentially a reverse floodgate. Unlike an automatic tidal gate (see below), which closes when water is higher on the outside of the gate, to prevent overtopping on the backswamp side, a fish flap structure opens when water is higher on the downstream side and closes on a falling tide to retain water in the swamp.

Plate 14. A water retention structures with a fish flap at Little Broadwater

Source: Clarence Valley Council

Figure 11. Operation of the fish flap
Source: Clarence Valley Council



Headworks Design and Modifications

Criteria for Design and Modification of Floodgate Structures

The following principles generally apply to the management of floodgate structures:

- maintain the efficiency of the flood mitigation system during flooding
- allow controlled back flows (fresh or saline) through the drains
- groundwater tables should be maintained at or above any sulfidic (including partially oxidised) sediment layer and the hydraulic groundwater gradient should be directed from the drain to the groundwater if drain waters are fresh and soils have low K_{sat}
- management of gates should not result in the production or discharge of further oxidation products
- approval from the relevant owner/operator of a floodgate must be obtained prior to operation of the floodgate, and public water management structures must only be operated under delegation according to an approved operational protocol
- management of structures should be carried out in consultation with all affected landowners relevant councils or government authorities, and any other person or organisation who may be materially affected
- strict attention to OH&S matters is required, and
- modification and management of water control structures must comply with relevant legislation.

Floodgate Lifting Devices

Floodgate lifting devices may be installed to enable manual opening of gates, allowing for either saltwater backflows into drains or freshwater flows into backswamps. Winches are manually operated devices, involving a pulley system to lift the gate, which allows for tidal flushing.[239] . Floodgate lifting devices have been used for some time, having been included in the design of many of the earlier flood mitigation scheme works, often comprising a side winch operating on pulleys hung off a frontal log beam.[240]

Examples of floodgate lifting devices are illustrated in Plates 15a, 15b and 15c.

Plate 15. Floodgate lifting devices
From top: a) Lifting devices on headworks on the Belmore River on the Macleay

Photo: Mitch Tulau

b) Lifting devices at Rocky Mouth Creek on the Richmond attached to a side-mounted winch by a gantry

Photo: Mitch Tulau

c) Front lift from a safety walkway at Camp Creek on the Clarence

Photo: Clarence Valley Council

Automatic Tidal Gates

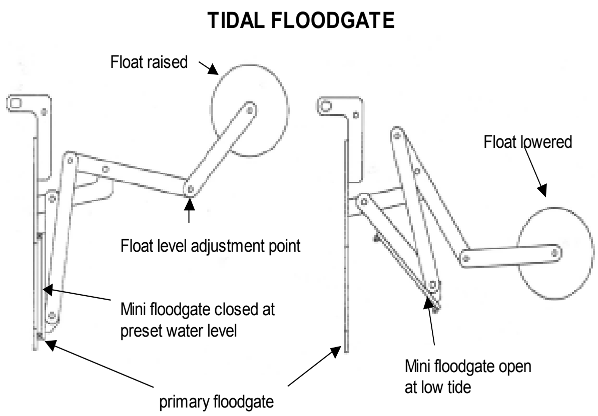
Automatic tidal gates generally involve a flapgate set into the main floodgate (Plate 16). The flapgate is regulated by a float system, so that as the float rises to a set level on the downstream side due to high water, the flap is closed; when the outside water level falls, the flap is opened (Figure 12). The level of the float can be calibrated to regulate exchange through the flap without permitting tidal inundation of low-lying land.

Automated systems are also recommended for the purposes of improving and maintaining fish passage.[241] Many landholders use a winch/tidal gate combination. A winch allows the landholders to open the system, for example to avert any threat of a black water event, and also assists with gate/tidal gate maintenance and adjustment.

Plate 16. Automatic tidal gate

Photo: Clarence Valley Council

Figure 12. Operation of the tidal floodgate
Source: Aaso *et al*. (2002b)



Water Retention Gates

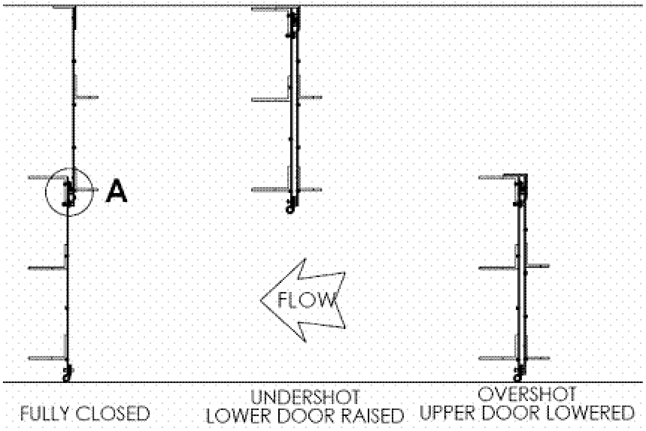
Gates that can be used to retain water in backswamps for environmental and grazing purposes include sluicegates, penstocks and bottom-hinged weir gates. Sluicegates can be opened from either the top or the bottom, to allow flows in either direction by either top or bottom flows.[242] By allowing the upper sill height to be easily and accurately adjusted, the operator can allow the height of the water level behind the gate to be controlled. A mini-sluicegate is an adjustable window comprising a sliding panel, usually controlled by a screw jack, set in an existing floodgate.

Top and bottom gates[243] (Plate 17, Figure 13) are designed such that the top half of the door may be raised or lowered to regulate water level, with the lower door raised to accept water at lower levels, or to discharge water during higher catchment flows. These gates are easy to install and may be operated manually or with electric actuators, and are an economical alternative to many other options.

Plate 17. Top and bottom gate on the Coldstream River on the Clarence River floodplain

Photo: Clarence Valley Council

Figure 13. Operation of top and bottom gate
Source: Clarence Valley Council



Penstocks are usually more substantial structures, usually vertically opening, which can be used to maintain higher water levels upstream, including retaining water in the drain or on backswamps. However, vertical lift gates are often difficult to open and close with strong currents. Landholders may not always be able to close these types of gates when required, increasing the risk of saline overtopping.[244] Penstocks are only occasionally used in coastal rural floodplains.[245]

Bottom-hinged weir gates (Plate 18) enable the water elevation to be controlled within a large height range, and the top decanting mechanism enables the upper water column, which typically is of better quality, to be preferentially discharged.[246] Bottom-hinged gates can also allow a staged raising of groundwater and surface water levels to allow vegetation communities to adapt.

Plate 18. Water retention gate at Partridge Creek on the Hastings River floodplain

Photo: Thor Aaso

LEGAL ISSUES

Exposure

In undertaking a remediation project, participants such as council employees and other public officials, as well as participating landholders, may be exposed to claims, including those of negligence or nuisance, from those who may claim to be affected by the project. Liability can attach through the common law of nuisance (in relation to damage to land and water) or negligence (in relation to injury to person), or through regulation. The sources of potential liability and defences available are discussed more fully in Appendix 3.

Risk Assessment

The risks of potential impacts arising from modifications to floodgates or drains or changes to the operation of floodgates should be investigated and monitored.

One of the key issues in risk assessment is whether the party(ies) responsible took sufficient action in response to the risk.
The reasonableness of the steps taken to prevent injury calls for consideration of:

- the magnitude of the risk
- the probability of its occurrence, and
- the expense and difficulty of taking more effective action to alleviate the risk.

All projects should be subject to a risk assessment to determine the level of environmental risk. Issues associated with risk of disturbance of ASS are covered in the *ASS Manual*[247], consistency with which is a key element of demonstrating that actions and their impacts have been reasonable. In the context of remediation projects, steps to address the risk may include thorough site assessment, staging of the project and careful monitoring of the impacts at each stage, and implementation of adaptive management, if required.[248]

Where there is uncertainty about the methodology proposed, it may be preferable to stage the plan, for example to develop a first stage as an interim plan/pilot project, implement this stage of the plan and use the monitoring data for the development of the second stage or the final plan. Staging should generally be used where significant hydrologic modification of the site is involved.

Risk of injury to person during construction, operation and maintenance and OH&S matters are discussed in Appendix 3.

Risk Assessment Relevant to Floodgate Management/Modifications

Environmental and Agricultural Risks

Environmental and agricultural risk assessment relevant to floodgate management/modifications may include the following matters:

- the risk of incursion of saline water into groundwater and wetlands.[249] If there is risk of lateral salt seepage, monitoring of salinity and acidity both downstream and upstream will help decide whether, and for what period, to open floodgates. If saline water begins to enter areas where it is not desired, changes to the operation of floodgate should be implemented.
- the risk of estuarine pollution including low pH and DO, and consequent fish kills or impact on water users including oyster growers, during discharge events.
- the potential impacts from dieback of freshwater vegetation and the resultant short-term decline in water quality.
- the risk of low water quality from MBOs being mobilised or otherwise being discharged into the estuary.

Water Levels and Overtopping

The risk of impacts from saline water overtopping land should also be investigated.[250] Changes in the elevation of drain waters should be monitored over a range of tidal cycles. Estimated daily tidal ranges are available from Manly Hydraulics Laboratory (MHL).[251] Risk from storm surge may need to be addressed in lower estuary situations.

Risk of Structural Failure

The hydraulic forces associated with tidal and flood flows can be large, and unless taken into consideration, can impact on headwork and drain stability, maintenance and longevity.[252]

Storms and Floods

Flooding can result in erosion or sedimentation in the vicinity of structures. In addition, logs, litter and other debris can be deposited and consequently damage or impair the operation of any works. Inspection should be undertaken as soon as possible after storm and flood events to note and repair any such defects.

Using a Staged Approach

Any project to introduce tidal flows should incorporate a staged approach.[253] Stage 1 of the project may be the partial opening of a single floodgate and the subsequent monitoring of its impacts on issues including the area of wetland and surrounding country likely to be affected by re-inundation, the existing native vegetation and wildlife habitat, the existing fishing and oyster growing activities in receiving waters, the groundwater, and the social and economic well-being of the local community.[254]

Table 7. Risk assessment relevant to floodgate management/modifications

Factors in Deciding the Level of Risk	Level of Environmental Risk		
	Nil to low	Medium	High
Saline incursion	• K_{sat} <1.5 m/day	• K_{sat} 1.5–15 m/day	• K_{sat} >15 m/day
Enhanced acid discharge	• Large catchment flows • Higher elevation ASS > 2 m AHD • No in-drain MBOs • High buffering/ neutralising capacity receiving waters • Opening staged	• Medium catchment flows • Medium elevation ASS 1–2 m AHD • Moderate in-drain MBOs • Moderate buffering/ neutralising capacity receiving waters	• Small catchment flows • Low elevation ASS <1 m AHD • Significant in-drain MBOs • Low buffering/ neutralising capacity receiving waters • Opening not staged
Dieback of freshwater vegetation	• Drain not connected to a freshwater wetland	• Drain connected to a freshwater wetland, but water level managed by attenuation or a weir	• Drain connected to a freshwater wetland, with hydraulic connection to allow salt ingress
Overtopping and water levels	• Water levels attenuated, maximum drain water level < land surface		• Water levels not attenuated, maximum drain water level > land surface
Structural failure	• Small catchment, structure designed for maximum expected flows • Maintenance schedule adhered to	• Medium sized catchment, structure designed for modal flows • Maintenance when defects noted	• Large catchment, structure designed for average flows • No or little maintenance schedule adhered to

Risk Assessment Relevant to Installation of In-Drain Water Control Structures

Environmental and Agricultural Risks

Environmental and agricultural risk assessment may include matters such, as the risk of estuarine pollution and consequent fish kills during discharge events, pollution of waters including low pH and DO due to floodgate opening and polluted water entering the estuary, low water quality from MBOs being mobilised or otherwise being discharged into the estuary, and impact on water users including oyster growers, commercial/recreational fishers, and persons engaged in contact sports.

Risk of Structural Failure

The hydraulic forces associated with tidal and flood flows can be large, and unless taken into consideration, can impact on headwork and drain stability, maintenance and longevity.

Table 8. Risk assessment relevant to installation of in-drain water control structures

Factors in Deciding the Level of Risk	Level of Environmental Risk		
	Nil to low	Medium	High
Acid discharge	• Large catchment flows • Higher elevation ASS > 2 m AHD • In-drain MBOs managed • In-drain vegetation, OM mimimised • High buffering/ neutralising capacity receiving waters	• Medium catchment flows • Medium elevation ASS 1–2 m AHD • Moderate in-drain MBOs • In-drain vegetation, OM managed • Moderate buffering/ neutralising capacity receiving waters	• Small catchment flows • Low elevation ASS <1 m AHD • Significant in-drain MBOs • In-drain vegetation, OM not managed or minimised • Low buffering/ neutralising capacity receiving waters
Overtopping and water levels	• Drain water levels managed by a low elevation or adjustable weir, maximum drain water level < land surface elevation	• Maximum drain water level approximates land surface elevation	• Maximum drain water level > land surface elevation
Structural failure	• Small catchment, structure designed for maximum expected flows • Maintenance schedule adhered to	• Medium sized catchment, structure designed for modal flows • Maintenance when defects noted	• Large catchment, structure designed for average flows • No or little maintenance schedule adhered to

Consents and Approvals[255]

A consent (generally from a local government authority), or an approval or permit of some kind (from a State or Commonwealth Government agency) may be required for certain works or activities, such as:
- works which disturb ASS or lower the water table
- development in SEPP 14 Coastal Wetlands
- development in the Coastal Zone
- works on public land
- works on public roads
- connecting a private drain to a public drain
- dredging and reclamation
- fish passage and fishways
- works likely to affect fish habitat, mangroves and seagrasses
- works in Marine Parks
- excavation of 'waterfront land'
- clearing native vegetation
- projects affecting threatened species
- interference with groundwater
- harvesting water from drains and creeks
- polluting works, and
- impacts on archaeologic and heritage items.

In some cases, including public utility undertakings and certain development by the Crown, where existing use rights can be demonstrated, and works carried out in accordance with the sugar industry best practice guidelines[256], consent is not required. These matters are discussed more fully in Appendix 3.

COMMUNICATIONS PLAN

ASS remediation and changes to floodplain management have the potential to impact on both neighbouring landholders and downstream water users. Impacts may include increased flooding or inundation, salt intrusion, temporary changes in water quality, and aspects of the vegetation. Consequently, the need for and nature of the remediation measures need to be communicated widely in the local area so that the proposal is clearly understood by landholders.

A communications strategy plan should be developed that enables target audiences to be identified, allows a consistent message to be developed and promoted, allows messages to be tailored towards specific information gaps, and coordinates the parties responsible for actions and completion dates.

Target groups for the communications strategy include, landowners, local councils, government agencies, the broader community, and industry groups and funding bodies.

Landowners are the key to the success of the project because they often have a detailed understanding of certain aspects of the site and its history, the remediation plan will generally require landowner agreement for implementation, support of researchers and extension officers, and in many cases because some works will require management and maintenance.

The support and understanding of the broader community is also important, as remediation project sites are often of interest to the community, these areas often having long been considered environmentally significant.

Media may include electronic media, printed material, workshops and field days, meetings, and interpretative signage.

A communications strategy will require regular review.

MONITORING A REMEDIATION PROJECT

GENERAL GUIDELINES

Each ASS remediation project should include a monitoring program designed to provide feedback on the effectiveness of the management strategy and to provide an early warning of any environmental degradation or impact, and to evaluate and modify the management of the project as necessary.[257]

The most effective monitoring programs will aim to provide data that may be used to provide answers to specific questions directly related to the project objectives and targets. Monitoring and evaluation strategies should provide data that can assist in determining whether the objectives.

In some cases, the type and resolution of data required will be predetermined by reporting and/or regulatory requirements, agreements with funding bodies, etc, but in all cases, there should be a direct relationship between monitoring design and the remediation project's objectives and targets, in terms of water quality, hydrologic and/or ecologic outcomes.

As a minimum, a monitoring program for soils and the surface and subsurface water quality should outline:

- parameters to be monitored
- monitoring locations
- monitoring frequency
- analyses to be conducted and by whom, and
- contingency and reporting procedures.[258]

However, the precise details will be determined by factors such as the characteristics of the site, project objectives and design, resources available, and the regulatory context. The level of monitoring should match that required to monitor a scientifically valid and legally defensible plan, and will therefore vary depending on the magnitude of potential impacts. For some projects, an in-drain data logger with occasional spot sampling may be all that can be achieved, and may be all that is necessary. At the other end of the scale, a monitoring program may take on the appearance of a research project in its own right.[259]

A less intensive, more commonly achievable strategy may include:

- one or two water quality monitoring stations measuring pH, DO, EC, ORP, temperature and water level
- a flow meter to measure discharge and enable flux to be calculated, with
- supplementary spot water quality sampling
- a photographic archive from fixed photo points, and
- groundwater data from piezometer transects with detailed soil reports.[260]

There have been occasions when monitoring data has not been put to optimal use. Under-utilisation of data has occurred for a range of reasons, including poor monitoring design, poor or suspect data due to inadequate maintenance, and commonly, insufficient resources to analyse or react to the data. A risk, especially with longer term monitoring that does not have clear objectives and outcomes, is that 'ownership' of the program will similarly lose focus. Being clear about who is responsible for undertaking the monitoring program, and to what purpose(s) the data will be put, is a prerequisite for success.

Baseline Monitoring

Quantifying soil and water quality changes and relating these to on-ground works requires systematic pre- and post-works monitoring.[261] Monitoring must commence prior to any works or changes to groundwater, drain and/or land management being implemented in order to compile a reasonable idea of baseline conditions. The period of this baseline monitoring should commence as soon as is practicable after approval to proceed is received. Due to climatic variability, and the hydraulic properties of the soils and landscapes, an understanding of the relationships between water quality and hydrology is difficult to achieve over short periods.

SOIL MONITORING[262]

Objectives

The purpose of monitoring soil is to detect and examine changes in the concentration of products of oxidation-reduction reactions within the soil profile. These changes may relate to issues such as any surface concentration of monosulfides, or increases in deeper acidity. An additional parameter that may be measured, especially in the context of WACS, is sequestration of organic carbon.

Monitoring Design

Location of Monitoring

The Assessment Guidelines in the *ASS Manual*[263] provide advice in relation to the number of soil sampling sites per area and the depth of sampling in the context of development projects. Compliance with these Guidelines is mandatory, unless departure can be justified, in relation to development. However, they may not always be relevant to remediation monitoring design. Demonstrating change in some soil properties is difficult, often due to the inherent variability of soil properties generally, and both monitoring design and processing of data may require geostatistical techniques.

The monitoring task is further complicated by the nature, distribution and sometimes transience of key chemical properties throughout the profile. Conversely, in some cases, one well-chosen sample may suffice. As always, the most important criterion is that the site(s) chosen be representative, and this entails an understanding of the landscape at a landform element level.[264] This will normally require accurate elevation data.

Profile Description

Fine resolution, comprehensive profile descriptions will be required. In order to provide a consistent format, and to ensure that all relevant soil descriptive information is assessed, soil profile description should be carried out according to the *Australian Soil and Land Survey Field Handbook*[265], and the *Soil Data Entry Handbook for the NSW Soil and Land Information System* (SALIS).[266]
The location of each sampling site should be clearly marked on a map at a scale of at least 1:25 000 with grid references and elevation (m AHD, preferably to one decimal point) for each sample site.

Data Collection and Parameters Measured

The type of remediation strategy and the level of investigation required will largely determine the suite of parameters to be measured, as different strategies will cause different hydrologic and chemical changes in the soil profile. Characteristics and properties measured may include:
- depth to ASS/PASS, and, for each layer
- TAA, TSA, TPA
- chromium reducible sulfur (Scr)
- pH;

ORP (Eh)
- organic carbon (OC)
- bulk density, and
- mineralogical changes.[267]

Soil Carbon and Gases

Soil carbon flux is a dynamic process that involves interactions with other minerals and biological processes, and is therefore controlled by moisture, temperature, type and rate of biological activity, soil properties such as texture and structure, landscape position, vegetation and land use. Soil organic matter (OM) comprises living OM (phytomass, microbial and faunal biomass), and non-living OM (dissolved OM, particulate OM, humus, and inert OM). Account may need to be taken of all these different soil OC components in order to provide adequate indicators of changes occurring within the more labile soil OC pools. However ease of measurement and ultimate costs are potential limits to detailed measurement of soil OC pools, and care must be taken to determine the appropriate analytical method.

Assessment of soil organic carbon can be carried out by soil survey and monitoring according to the relevant methods and in conjunction with modeling and remote sensing, depending on scale.[268]

Loss and sequestration of carbon and a range of other green house gases with much higher global warming potentials, such as methane (CH_4), nitrous oxide (N_20), hydrogen sulfide (H_2S), sulfur dioxide ($S0_2$) and methyl halides, are significant for estimating greenhouse gas emissions in the context of land management change. Fluxes of carbon and gases have been examined by a range of methods, including the use of chambers and micrometeorological techniques.[269]

GROUNDWATER MONITORING

Objectives

Groundwater seepage into drains is the most significant pathway for acid discharge from ASS landscapes.[270] The manipulation of groundwater is therefore often a key objective of many remediation projects[271], so the monitoring groundwater dynamics is of crucial importance. Groundwater chemistry can respond quickly to changes produced by watertable manipulation[272], so the hydrological and chemical components of groundwater monitoring should be closely linked.

The objective of groundwater monitoring is to provide an understanding of the relationships between the groundwater level regimes, other groundwater dynamics, including issues of connectivity and gradient, and groundwater chemistry, and to relate these to drain water levels and chemistry.

Monitoring Design

A series of piezometers should be installed with capacitance probes to monitor the watertable.[273] Bores may be clustered or nested, involving a multiple bore installation comprising piezometers screened at varying depths to intersect different aquifers or aquifer levels. The Groundwater Guidelines in the *ASS Manual*[274] should be consulted for the correct installation, sampling and monitoring of groundwater piezometers. See also the comments on monitoring design in relation to soils above.

Location of Monitoring

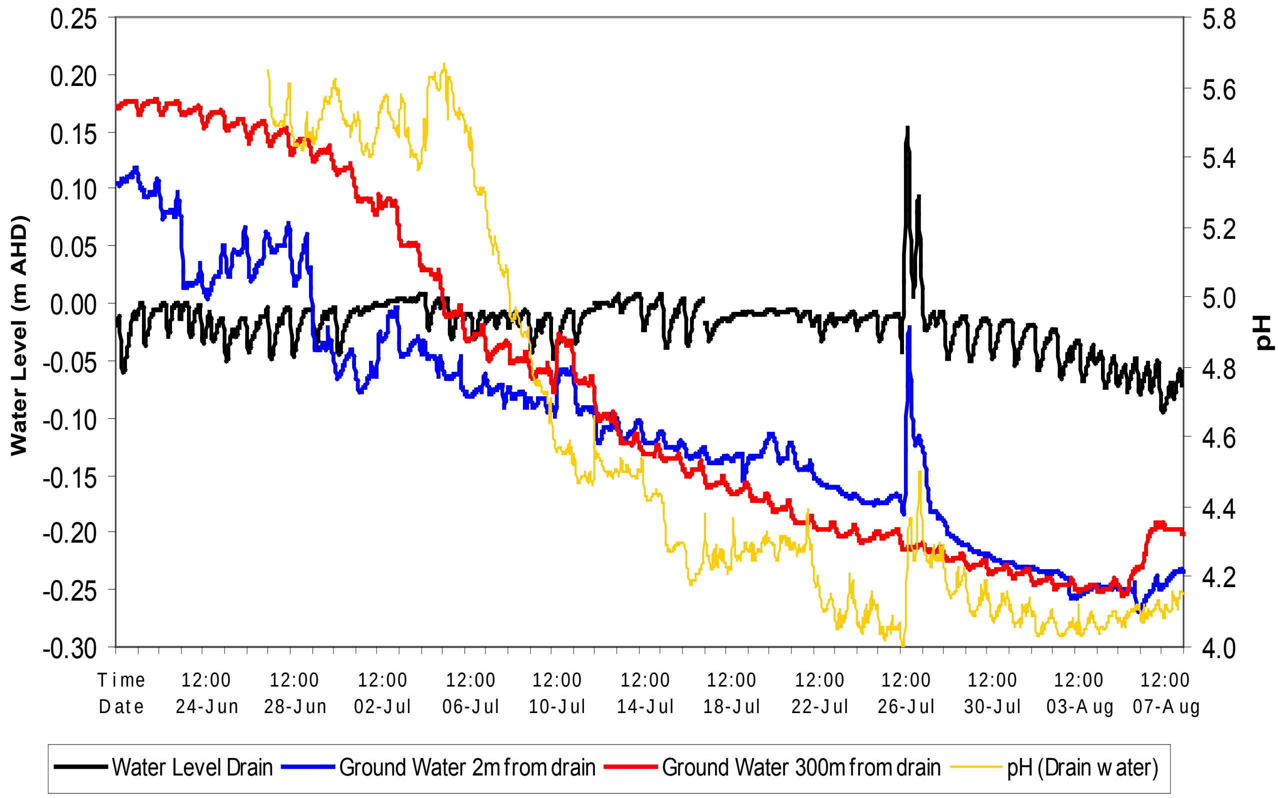
A network or transect of piezometers should be installed perpendicular to the drain or stream, and along the suspected direction of groundwater flow, where changes in the slope of the groundwater table is suspected (e.g. near drains and streams), in areas of groundwater extraction or high irrigation, on either side of water control structures such as floodgates or weirs, and in low-lying backswamp or scalded areas.

It is important to space piezometers closer together where large changes in the elevation of the groundwater are expected (e.g. close to drains) and further apart where significant change in groundwater elevation is not expected (e.g. in the middle of a paddock).[275] Installation of wells should also use geomorphic/stratigraphic information from the site investigation, and be surveyed to the AHD baseline. The location of each borehole should be clearly marked on a map with 13-digit grid references for each sample site in GDA, with elevation accurate to at least 10 cm.

Data Collection and Parameters Measured

The groundwater elevation should be logged by capacitance probe and data logger for pH and EC (and potentially DO and ORP), preferably at least hourly. Data should be presented in an easily readable format, such as that shown in Figure 14.

Figure 14. Groundwater monitoring data from the Clarence
Source: Scott Johnston



Sampling for parameters including titratable acidity, metals (and potentially DO and ORP) should be linked to logged data, and gathered according to a formal schedule, although it may also be event-triggered[276], with the monitoring frequency adjusted to take account of the rate of change. The schedule should be varied only if events, such as flood, inundation or fire make access unsafe or undesirable.

Collection of rainfall data at remediation sites is crucial as it allows relationships to be drawn between rainfall inputs to watertable fluctuations, groundwater quality and discharge. Rainfall data may be collected by logged tipping bucket gauges.[277]

For fine resolution work, examining transformations and exchange of nutrients, metals and metalloids between the sediment and water, pore waters may be sampled by sediment pore water 'peepers'.[278] Sediment water interface samples may be collected using a syringe and needle.

WATER QUALITY MONITORING

Objectives

The two main components of monitoring water are water level regime and water quality. The objective of water monitoring is to provide an understanding of the relationships between the drain and surface water levels and chemistry and to relate these to groundwater levels, dynamics and chemistry.

Monitoring Design

Location of Monitoring

Water monitoring includes that in the drain or other receiving waters, as well as any other permanent or temporary surface waters. The appropriate number of monitoring and sampling locations and the frequency of sampling will be defined by the scale and nature of the works, the characteristics of the drainage network and the nature of the potential impacts. For example, in a branched drainage network, monitoring locations may target suspected source areas, and allow comparison with catchment or ambient water quality. Again, the monitoring program must be systematic in terms of timing and location.[279]

Monitoring locations may be needed:
- upstream of the site
- within the site
- immediately upstream of a floodgate or other water control structure[280], and
- immediately downstream of a remediation discharge point.

The downstream point is the most critical, as it provides the best measure of the overall performance of the remediation project. Monitoring sites must also be sufficiently proximate to the areas affected by on-ground works.[281]

Complementing continuous monitoring of water with spot sampling at several other locations may provide a greater understanding of the dynamics and processes of acid discharge. Areas with ponded surface waters will also need to be monitored.

Data Collection and Parameters Measured

The parameters measured will depend on the type of remediation strategy being employed and the level of investigation required, and will be site-specific.

A typical suite of parameters may include:
- EC
- pH
- DO

oxidation-reduction potential (ORP)(Eh)
- temperature
- soluble Fe
- soluble Al
- bicarbonate
- turbidity
- water level
- flow, and
- visual issues, such as colour.[282]

In order to gain a comprehensive understanding of drain or stream or drain water quality dynamics, three sources of information are therefore required:
- a data logger monitoring program, being semi-continuous measurement of certain chemical parameters
- manual sampling and laboratory analysis of a suite of water quality parameters, and
- continuous measurement of flow in drains.

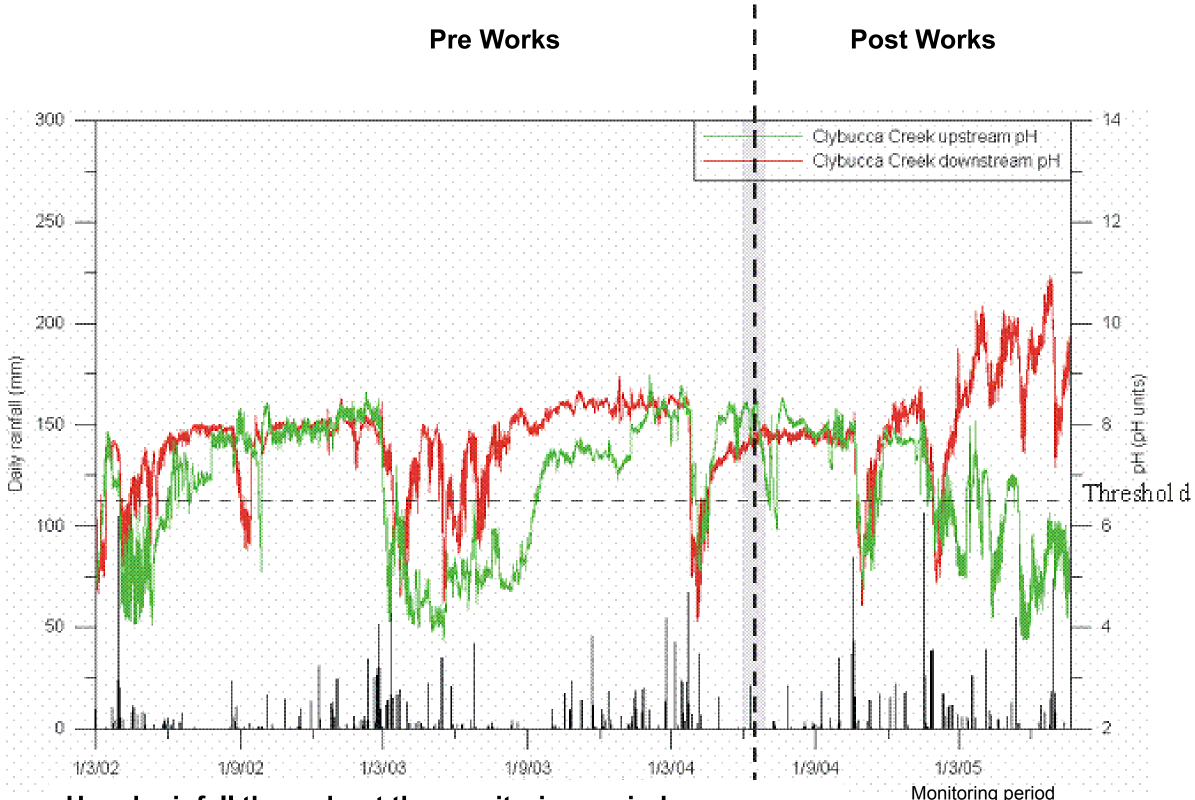
In addition, visual issues such as colour of water, floc etc are all relevant observations that are useful along with the foregoing.

Data Logging

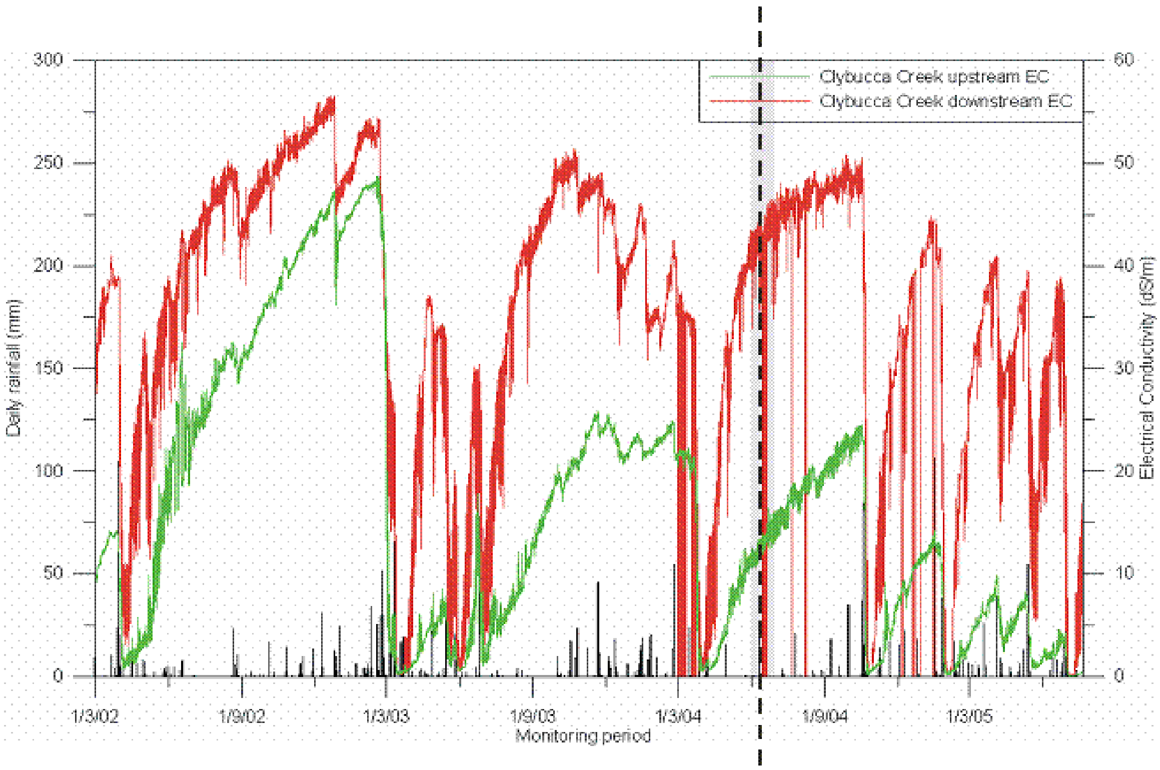
Monitoring by data logger is generally effective in providing high temporal resolution data on the dynamics of certain water quality parameters, and is especially important for an understanding of the nature and magnitude of changes in response to rainfall. The parameters usually datalogged are EC, pH, ORP, DO and temperature. EC is generally a robust, reliable parameter, as is pH, provided an appropriate maintenance schedule is observed.[283]

ORP or 'redox' of an aqueous solution is commonly datalogged. However, the accurate measurement of redox is also known to be quite difficult in ASS landscapes, and the long-term measurement of redox may also be impractical in ASS environments due to maintenance requirements.[284] The accurate measurement of DO by membrane sensors is highly problematic in ASS landscapes[285], largely due to the deposition of iron precipitates or contamination by H_2S. Optically based sensors such as Luminescent Dissolved Oxygen (LDO) overcome the problems of the membrane sensors, and are becoming more commonly used. Data should be presented in an easily readable format, such as that shown in Figure 15.

Figure 15. Water quality monitoring data from Clybucca
Source: Bush *et al*. (2006), p. 26



pH and rainfall throughout the monitoring period



EC and rainfall throughout the monitoring period

Manual Sampling and Laboratory Analysis

Drain water samples should be collected and analysed for those parameters for which reliable information cannot be obtained by automatic equipment. Samples should be collected either manually or by an automatic device[286] at selected logging sites according to a formal schedule, with the frequency increased during higher flows, ranging from at least daily during high flow periods, to every 4-10 days during periods of low flow.[287]

The program should be varied only if events such as flood, inundation, or fire make access unsafe or undesirable. Samples should be representative of the water column and should consider the potential for stratification within the column.[288] It may be appropriate to depth profile on a seasonal basis to determine whether stratification is likely to occur. Where stratification is likely, samples should not be bulked.[289] Laboratory analyses should be undertaken in accordance with the *Laboratory Methods Guidelines* (2004).[290]

Oxidation-reduction Potential

ORP is an important measurement because changes to the redox status govern the transformation and release of adsorbed ions. Changes in ORP will determine chemical transformations that are important in ASS remediation, such as formation of acidity or monosulfides, and the precipitation of iron in the water column and the production of iron flocs.

Dissolved Oxygen

Low DO levels can cause faunal kills, and result in reducing conditions within sediments, and may be related to solubility and mobility of nutrients and toxicants in the water column. DO is therefore an important parameter for assessing the impacts on water quality from ASS areas. However, logged data from membrane sensors that are not maintained frequently may be unreliable.[291] Optically based sensors such as Luminescent Dissolved Oxygen (LDO) overcome the problems of the membrane sensors, and are gaining widespread acceptance. At some sites, supplementary manual sampling may need to be carried out.[292] BOD and out. BOD and COD may be calculated from water samples in order to assist with determination of the factors impacting on oxygen levels.

Titratable Acidity and Soluble Iron and Aluminium

pH is poor indicator of acidity flux, because drainage waters from ASS frequently contain considerable stored titratable acidity associated with dissolved aluminium and iron. pH therefore generally underestimates acidity[293], to the extent that estimates of acidity flux based on pH can understate acidity export by a factor of 2 to 10.[294] The titratable acidity of waters is therefore required to quantify acidity export.[295]

Flow

Flow is fundamental to the calculation of acid discharge. Flow measurement, particularly at floodgates, requires robust instrumentation able to cope with high flow and physical impacts.

Other

Other parameters that may be measured or calculated in certain instances include $Cl:SO_4$ ratio[296], ratio[8], the occurrence of key minerals[297], MBO, bicarbonate, dissolved organic carbon, and turbidity.[298]

Modelling Discharge

Acid discharge patterns from ASS are highly variable due to temporal variations in rainfall, tidal flows, interactions between soil chemical properties and vegetation, and biologically mediated iron redox reactions. Given this complexity, the data requirements to accurately estimate acid discharge from backswamp systems are considerable. An alternative approach is to model the two components of acid discharge, acid discharge via groundwater seepage to drains, and acid discharge in surface run-off.

Data requirements for site characterisation may include factors such as[299]: the area of backswamp with actual ASS; vegetation types in backswamp; groundwater acidity[300]; K_{sat} of the actual ASS horizon; surface water quality and flow; water table height (in AHD) in the drain and downstream of floodgates; the length of drains in the ASS backswamp; daily rainfall and evapotranspiration in the backswamp; ground surface elevation to estimate surface water storage; and the elevation of inverts of drains, floodgates and WCSs.

EQUIPMENT MAINTENANCE AND DATA INTEGRITY

Data is only as good as the accuracy and maintenance of the equipment being used. Regular maintenance and calibration are required due to the extremely aggressive impacts that ASS oxidation products have on water quality monitoring sensors. Membrane-based DO and ORP measurements are the least robust, and are often prone to substantial drift, leading to erroneous results. If these are to be datalogged, equipment requires calibration and cleaning on a weekly basis.[301] Similarly, all probes and sensors may require regular cleaning and maintenance according to the specifications. Any water quality monitoring program or contract should include clear maintenance protocols.

ECOLOGICAL MONITORING

Ecological monitoring is an essential component of ASS remediation projects in cases where the project is integrated with ecologic or other relevant land or water management objectives, such as restoration of a wetland. Equally, wetland and/or ecologic indicators can be employed as surrogate measures of project outcomes, for example, improvements in aquatic ecosystems in relation to water quality improvements.

It is beyond the scope of these Guidelines to provide a detailed guide to designing ecological monitoring programs. In most cases, ecological monitoring program design will be highly site-specific, and intended to provide data aimed at answering specific questions or issues. Experienced scientists within the assessing agencies should assist by providing a clear set of guidelines specific for each proposal. In terms of survey design, project objectives should be translated into hypotheses that can be tested with scientific rigour. In all cases, ecological monitoring project design should be integrated with other relevant research projects related to the ASS remediation project, for example, the monitoring of water quality in the context of vegetation change. The budget allocated for ecological studies should be proportional to the magnitude of impacts or the complexity of potential issues arising from the remediation project.[302] Ecological monitoring of a closely related site where remediation is not being undertaken may be required for purposes of comparison.

Terrestrial Ecological Monitoring

Monitoring protocols should be put in place to record any vegetation change in response to changed land management practices associated with an ASS remediation project. In this context, the main factors contributing to vegetation change are likely to be changes to water regimes, such as variations in water levels, DO, pH and salinity.

Common situations where a terrestrial ecological monitoring requirement should be triggered in the context of ASS remediation projects might include rehabilitation of scalds, freshwater wetland restoration and saline wetland restoration.

Vegetation monitoring should include species present, vegetation extent, density, height and productivity, where relevant. Monitoring should occur at a number of sites representative of the existing and anticipated community diversity of the affected site, as well as in marginal or other affected areas. Vegetation may be monitored using both remote techniques including satellite imagery, stereoscopic aerial photographic interpretation and oblique aerial photography, and on-ground techniques such as quadrat sampling and photography from set photo points.

Methodologies appropriate to the site and to the specific circumstances should be employed. A common approach for analysing quantitative ecologic data is principal components analysis, in order to both characterise the spatial patterns and to determine environment factors correlated with them. Some councils and other organisations have developed guidelines for carrying out flora and fauna surveys.[303]

Where vegetation change is an outcome of changed land management practices, such as increased reliance on species more adapted to changed water regimes, ecologic changes may be compared with an economic analysis of the property. These data will provide a measure as to how biodiversity credits might be costed against productivity sacrifices and/or alternatives.[304]

Aquatic Ecological Monitoring

Monitoring protocols should be also put in place to record any changes in vegetation or faunal populations in aquatic locations in response to changed water regimes, including changes to water level and quality, associated with an ASS remediation project.

Common situations where a monitoring requirement should be triggered include changes to the operation of floodgates[305] and saline wetland restoration.

Aquatic vegetation monitoring should include, where relevant, parameters such as vegetation type, extent and condition. Monitoring should occur at a number of representative sites. Vegetation may be monitored using both remote techniques including satellite imagery and aerial photography, and on-ground techniques such as quadrat sampling, and photography from set photo points.

Various methodologies for assessing river health are available, for both fresh and estuarine waters[306], however a comprehensive strategy would target a range of relevant species, including invertebrates.[307]. Methodologies appropriate to the site and to the specific circumstances should be employed.

REPORTING WORKS AND LAND MANAGEMENT CHANGE

Determining acidic discharge is a complicated, expensive and often labour-intensive means of determining significant environmental improvements in ASS landscapes, not least because it may be some time before sustained water quality improvements are achieved.

An alternative approach is to use a proxy or surrogate method, such as recording and reporting on-ground works and the implementation of land management changes, where the relationship of those works and changes to water quality improvements are known. A demonstrated linkage between management practices, soil condition indicators and environmental consequences means that benefits can be recognised and recorded where the environmental consequences of land use are not readily measurable. The correlative relationships between works and water quality may need to have been demonstrated, generally through experimental evidence.

Indicators may include matters such as:
- length of drainage filled or modified, and as a percentage of that required or proposed
- numbers of headworks or floodgates modified and/or subject to active management, with quantification of the change in groundwater regime, and as a percentage of that required or proposed, and
- area of contained or leveed ASS land, reflooded or subject to higher watertable management, and as a percentage of that required or proposed.

Suitable indicators related to water quality improvements may include:
- data on floodgate opening times, duration, and extent of opening
- length of drains infilled
- invert levels of infilled section
- number and/or area impacted by WCSs
- effective invert levels of WCSs and the proportion of time that groundwater is maintained above the ASS layers
- any decrease in the area of ASS scalds, and
- area of land used within its land and soil capability.

These measures are essential inputs to understand issues such as the extent and causes of changed water quality, vegetation terrestrial change, and farm economies. Accurate measurement of the extent of altered hydrology is also key data for the purposes of consultation and negotiation.[308]

ADAPTIVE MANAGEMENT AND CONTINGENCY PLAN

Adaptive Management

The monitoring data should be compiled and reviewed regularly against baseline data, appropriate standards and agreed performance targets, and used to evaluate the effectiveness of the plan and to modify the management of the remediation project as necessary. For example, monitoring should determine whether or not water discharged from a site complies with the requirements of the relevant water quality legislation, the *ANZECC Guidelines* (2000) and any specific water quality objectives set for receiving waters.

Performance outside agreed standards or targets may require remedial action. This remedial action may involve changes to the way the management plan is implemented, changes to the management plan, or more significant changes to the design or operation of the proposal.[309] The degree of flexibility provided for under the plan and the circumstances under which departure from agreed practices may require a referral to project managers, council, agencies and/or any other individual or organisation, should be negotiated in advance.

Contingency Plan[310]

A contingency plan must be developed prior to approval or commencement of the project, in order to manage impacts should the remediation strategies fail. Generally, a contingency plan may have two phases, remedial action and restorative action. If monitored results indicate the agreed standards or performance indicator levels are not being achieved, immediate remedial action will be required. Examples may include additional liming, or closure of a floodgate.

When remedial action fails or monitoring results identify severe failure of the remediation strategy to meet agreed standards, the project may need to be placed on hold while further assessment is carried out.

The decision to implement contingency plans may be triggered by the proponent or by relevant government agencies. Prior to the actions being implemented, an assessment should be undertaken as to whether the problem is related to ineffective implementation. If this is the case, the management plan should be audited to ensure that it can be implemented effectively. Monitoring should increase to ensure compliance with standards or performance levels.

If the problem is found to be related to the management strategies themselves being ineffective, the remediation plan should be reviewed, including an assessment of the outcomes of remedial actions. Consultation with relevant government agencies should occur if changes to the management plan are proposed. In some cases a change to the management strategy may require a change to the approval.

External factors beyond the control of the project managers, such as major infrastructure development (e.g. highway upgrades on the floodplain), may arise in certain cases and require a complete revision of the project. An exit strategy may need to be developed if the project is to be abandoned.

The contingency plan should specify the party(ies) responsible for on-ground actions and identify key notification actions.

SECURING LAND MANAGEMENT CHANGE IN A REMEDIATION PROJECT

The final element in ensuring that remediation projects are effective is the establishment of some mechanism to ensure that remediation practices endure and do not cease with the completion of the project.[311] In the last decade or so, a great deal of creative discussion has taken place in relation to voluntary, property-right, market-based instruments.[312]

However, in practice, the range of options currently applicable to coastal floodplains is limited.[313] This section describes mechanisms for providing incentives to either facilitate or consolidate the outcomes from ASS remediation projects on private land.

ENCOURAGING CHANGE IN LAND MANAGEMENT

Most floodplain areas, including wetlands and ASS areas, are privately owned. This section outlines some of the ways that government organisations or NGOs may influence private land management by agreement with those who own or have interests in land.

Extension Services and Incentive Mechanisms

Some landholders need further encouragement before making the necessary changes. A broad range of options for providing incentives has been canvassed in the literature.[314] The main mechanism to remedy drainage issues is to support landholders with access to research-based extension advice and access to funding and to assist with implementing changes that are beneficial to both the farmer and the broader community and environment.

An incentive for farmers flows from being able to control floodplain surface and ground waters in order to deliver an economically beneficial result. Conversely, landholders may be reluctant to accept major changes in water management if there is not a demonstrated economic benefit. In backswamp areas particularly, the coordination of stakeholders may therefore be a complex and expensive task.

Funding for Works

One of the major impediments to more environmentally sustainable management of floodplains is lack of funding. There have been a number of targeted funding opportunities in the past, and major improvements can often be effected by minor works, with minimal cost to the landholder(s). This suggests that other factors are important besides the provision of works – farmers must also see benefits.

Incentives for Providing Environmental Services

A landholder may agree to manage land or structures in a particular way in return for some form of incentive or reimbursement. The theoretical framework for the provision of incentive payments is as follows: if the community expects a higher environmental standard than is being delivered under existing management, then the beneficiaries, the broader community, should pay, with government meeting at least some of the costs. Regulatory tools are available and may be applied where generally accepted environmental outcomes are currently not being met.[315] Despite the large amount of literature on the topic[316], and the potential for incentive mechanisms in cases where watertable modifications are likely to result in either loss of productivity or more difficult management of existing agricultural activities, the use of economic instruments has not been widely utilised in broad-acre agricultural situations on NSW coastal floodplains. Payment mechanisms have been trialed at a few locations.[317] Apart from the difficulties in raising equity and administering schemes, governments have generally been reluctant to enter into long-term arrangements of this type[318], with the risk that raised expectations may be unsupported.

Rate relief is commonly proposed as a viable mechanism for rewarding progressive farmers. However, as local government is constrained in granting exemptions by s. 555 of the *LG Act 1993*, existing exemption schemes are limited.[319] However, councils can offer differential rates, say for lands that are managed for conservation.

Carbon Trading

Carbon trading, or more generically emissions trading, is the trading of contractual commitments or certificates that represent specified amounts of carbon-related emissions that either: are allowed to be emitted; comprise reductions in emissions (new technology, energy efficiency, renewable energy); or comprise offsets against emissions, such as carbon sequestration (capture of carbon in biomass).[320] A workable emissions trading scheme is being developed.[321]

Facilitating Change by Land Acquisition

The acquisition of private land in order to effect land management changes may be the most economically viable means of implementing remediation strategies. Acquisition may be undertaken by public authorities[322], or by NGOs. State and local governments have facilitated the rehabilitation of wetlands and the remediation of ASS areas by acquiring land at a number of sites.[323]

An objective of an acquisition program must be to secure hydrologic control over the site. That is, an acquisition program will only achieve the objective of expanding the remediation options available if the whole hydrologic basin, or backswamp, including key water control structures, is included. Acquisition and gazettal under the *National Parks and Wildlife Act 1974* also removes the application of SEPP 14.[324]

However, a number of important policy considerations must be assessed before acquisition is practised on anything but a very selective and strategic basis, and it may be argued that governments have an obligation to trial strategies that are less disruptive to a given local socio-economic climate before resorting to those options that are likely to be more intrusive.

In some cases, land may be acquired pursuant to a developer contributions plan prepared under s. 94 of the *EP&A Act 1979*. SEPP 1 has also been used to modify development prescriptions relating to land in exchange for contribution of the remaining land.[325]

It is important to note that conversion to public ownership is not an end in itself, and the remediation project must still be secured in an appropriate form. It may be preferable following government purchase to sell or lease the land, possibly with some form of covenant or management agreement in place.[326]

The leasing of land by the landholder to a statutory authority or an NGO may be an alternative means of securing the necessary land management assurances for the required period short of acquiring ownership, although a short lease period would not necessarily support major changes in land management.

SECURING CHANGE IN A MANAGEMENT PLAN

Remediation projects will commonly involve substantial investment of public funds, time and energy. In order to ensure that this investment is brought to maximum effect, arrangements may be required to ensure that the project outcomes endure. The most appropriate way to formalise the objectives, processes and land management outcomes is through a management plan.[327]

General Comments

A management plan will vary in scope and context. Some will have a statutory basis, in which case the scope and specific provisions of the Act will determine the matters that the plan may address. For example, Conservation Agreements entered into under the *NPW Act 1974*, and Property Vegetation Plans entered into under the *Native Vegetation Act 2003* relate to the objectives of the respective Acts. In the common case where a remediation project requires a consent or some other form of approval for works under one or more of a number of Acts[328], the management plan may comprise one of the conditions of consent.
A management plan may also form the basis of contractual arrangements between purchasers and providers on a commercial, or industry basis.
A plan may prescribe the terms and conditions under which the landholder agrees to certain land management prescriptions. Matters that may be addressed in a management plan will depend on the purpose and context of the plan, including the scope and the specific provisions of any relevant Act, but may potentially include matters such as stocking rates and seasonality, construction and operation of water control structures, the nature and level of funding support, and compliance matters.

Floodgate Management Plans

Local councils may delegate certain of their functions, including management of drainage works and flood mitigation works, to committees of council or to landholders.[329]

Delegated management actions are carried out according to a Floodgate Management Plan that sets out:

- the aims of floodgate management[330]
- the principal tasks and responsibilities for floodgate management
- a description of the structure, location and ownership
- the parties involved in the development of the management plan
- guidelines for opening and closing, in relation to levels and salinity
- a record of the timing and duration of openings and closings
- protocols for monitoring of water levels, water quality and groundwater
- vegetation responses
- a contingency plan, and
- contact details of all parties involved.

Flood security remains the primary function of the floodgate, and as such the gate must be closed if there is any threat of flooding. Floodgates may also need to be closed if any ‘adverse effects’ from opening are reported. Operators must liaise with all stakeholders including council staff in relation to the operation of the structure(s). The timing and durations of openings and closings must be recorded, as must any water quality data collected or other unusual changes.[331]

Agreements that ‘Run with the Land’

The most secure arrangements will ‘run with the land’, whereby provisions applying to the management of land or any fixed structures will continue to apply to that land even if the ownership of the land changes.

Covenants

Provisions of the *Conveyancing Act 1919* allow covenants, expressed in either positive or negative terms, to be attached to particular pieces of land, and these can be enforced against subsequent landholders. The covenant must benefit land that is held by a person wishing to enforce the agreement. Typically, the benefited land will be neighbouring land, with the covenant attached at the time of subdivision. Government departments and public authorities can enter into voluntary agreements relating to land use with landholders[332], or may dispose of land subject to a covenant.[333]

However, there are significant limitations to covenanting. Those who wish to enforce a restrictive covenant must own neighbouring land that is benefited by the covenant, as covenants can only be enforced by parties with a proprietary interest.[334] Proceedings must be taken in the Supreme Court of NSW.

Conservation Agreements

A Conservation Agreement may be entered into under the *NPW Act 1974* between the Minister and a land owner, in relation to certain areas including: those containing scenery, natural environments or natural phenomenon worthy of preservation; areas of special scientific interest; and areas for the study, preservation, protection, care or propagation of fauna or native plants or other flora[335], which may restrict the use of the area, or require the owner**owner** to not to carry out, or to carry out, specified activities.[336]

Also potentially useful is the *Threatened Species Conservation Amendment (Biodiversity Banking) Act 2006*, which amended the *TSC Act 1995*. The aim of the amendment is to protect biodiversity by imposing obligations on developers to protect and maintain biodiversity and allowing these obligations to be fulfilled through the purchase of ‘offsets’ from landholders undertaking certain agreed conservation actions.[337]

Property Vegetation Plans

A Property Vegetation Plan (PVP) may be entered into under the *Native Vegetation Act 2003*, between a landholder and the CMA, which may outline the management of native vegetation on the property. A PVP can include provisions relating to the restoration of native vegetation, including wetland vegetation. Activities, such as the remediation of ASS scalds for example, may form part of a PVP.

Landholders who have entered into a Property Agreement are eligible for financial assistance through the Native Vegetation Management Fund. The money will be allocated by the CMA according to priorities set out in the Catchment Action Plan and the relevant investment strategies. Activities that may be funded include: revegetation and rehabilitation of land with native vegetation, including control of grazing and fire.

Plans Registered on s. 149 Certificates

A Certificate prepared under s. 149 of the *EP&A Act 1979* provides information on matters related to the development potential of a parcel of land, including the planning restrictions that apply to the land. Some councils have taken steps to secure management by registering the remediation management plan on the s. 149 certificate. Prospective owners therefore have prior knowledge of the works before purchase.[338]

APPENDICES

APPENDIX 1 HYDRAULIC CONDUCTIVITY – SIMPLE FIELD TEST FOR SHALLOW COASTAL ACID SULFATE SOILS

Johnston, S.G and Slavich, P.G. (2003). Hydraulic conductivity – simple field test for shallow coastal acid sulfate soils. NSW Agriculture, Wollongbar.

Outline of the Method, its Limitations and Uses

This is a simple, semi-quantitative field method for assessing the likely range of saturated hydraulic conductivity (K_{sat}) in shallow acid sulfate soils (ASS). It has been developed for extension officers, landholders and field workers who work with ASS. It is based on established field based methods for assessing K_{sat} in shallow pits.[339] K_{sat} is a critical variable affecting the hydrology and acid export dynamics of drained ASS. Assessment of K_{sat} is important in order to design appropriate management strategies for broad acre ASS remediation projects.

K_{sat} is notoriously variable, particularly in ASS, which undergo unique, one way structural changes due to chemical dissolution and physical ripening processes. While K_{sat} can often be low (<1 m day^{-1}), recent work has demonstrated that K_{sat} can be extraordinarily high (>100 m day^{-1}) in the sulfuric horizons in some drained ASS backswamps.[340] High values are generally associated with extensive soil macropore networks. The spatial heterogeneity of K_{sat} in shallow coastal ASS aquifers means that realistic field scale estimates based on small scale methods (i.e. slug tests, permeameters, particle size analysis) can be subject to significant errors.[341] This is particularly true when groundwater flow is dominated by macropores whose size and spatial variability are high relative to the size of area sampled.[342] For this reason, tests which average aquifer response over larger areas (i.e. pit bailing or tidal signal damping) are more likely to be representative of actual field K_{sat} values.

This method is designed to complement existing methods. It has a number of advantages and limitations, which are listed below. These should be understood before conducting the test.

Advantages

- It allows rapid, semi-quantitative assessment of K_{sat} in shallow ASS environments.
- It is simple to conduct, only very basic equipment required.
- It avoids complex mathematics.
- Data collected in this method can be used[343] to derive a quantitative measurement of K_{sat}.[344]
- It is useful as an extension tool to undertake with landholders.
- It can help assess whether lateral groundwater seepage (to the drain/from the drain) is likely to be an issue (i.e. during opening of floodgates).
- It can help assess what hydrological pathway (groundwater seepage or surface runoff) may dominate the acid flux at a given site.

Limitations

- It can only be used to assess K_{sat} in shallow soil horizons (i.e. <0.6 m below surface).
- It can only be used when the water table is below the ground surface, but no deeper than 0.5 m from the surface.
- In this form it is semi-quantitative only and provides a K_{sat} estimate within certain ranges (i.e. low/high/extreme).
- It requires the user to stay within defined ranges for pit size, water levels and bail out volumes.

Equipment Required

- A flat shovel
- Stopwatch
- 50 cm ruler with 1 mm graduations
- 10 L bucket
- Recording data sheet (provided with this method)
- Pen/pencil
- Two people.

Soil Features to Note

Soil texture, structure and visible soil features such as macropores are important. Macropores can play a very important in water movement through ASS. The existence of clearly visible soil pores rapidly discharging groundwater after bailing the pit can be an excellent indicator of high K_{sat} soils. When excavating the pit notes should be made on the following features.[345]

- Soil texture
- Ripeness
- Macropores – size, shape, density, orientation
- Water flow via visible pores
- Peat, organic matter, root material.

Locating the Pit

Choose sites that are representative of the area you wish to assess. The number of tests you conduct should be related to your data needs. If you want some idea of the variability of K_{sat} it will be important to construct at least several pits across the site.

Pit Construction

While the data analysis component of this test avoids complex mathematics, it has been field calibrated only within a certain range of pit dimensions and water table heights. This point is important. Pit excavation should follow these instructions closely. Failure to do so will compromise the accuracy of the test.

The pit should be as square as possible with vertical sides and a 'flat' (as possible) bottom (see Figure 16 for pit geometry), with a minimum size of 30 cm x 30 cm (W x B), a maximum size of 50 x 50 cm (W x B), and a maximum depth of pit from surface (D) of 60 cm. B and W should be as equal as possible (i.e. a square pit). A minimum of 10 cm water depth is required in the bottom of the pit (L) at equilibration with surrounding water table. The ratio L/W must be between 0.2 and 0.75. This is important as the data processing is calibrated to these ranges. See Table 9 for example pit dimensions that generate an acceptable L/W ratio. 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.

Figure 16. Example of pit geometry

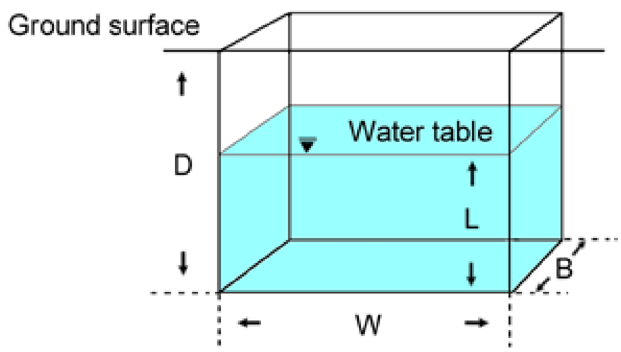


Table 9. Example of pit dimensions
(L, W) which generate acceptable ratios of L/W (0.2 to 0.75)

	L (cm)					
W (cm)	**10**	**15**	**20**	**25**	**30**	**35**
30	0.33	0.50	0.67	-	-	-
40	0.25	0.38	0.50	0.63	-	-
50	0.20	0.30	0.40	0.50	0.60	0.70

Recording Field Information

When recording L (where L = average depth below water table to base of pit, see Figure 16) make at least 10 random measurements across the pit. More can be made if required. The mean of these measurements will be used in the data analysis component of this test. This will help reduce errors from having an uneven pit base. Record pit dimensions on the record sheet provided with this method as per the example of pit geometry provided in Figure 16). The mean of several measurements of B and W may be required if the pit is slightly uneven. Use your discretion.

Conducting the Test

Dig the pit so that the dimensions accord to the instructions outlined in 'Pit construction' above. Observe and record soil features. Wait until pit water level has reached equilibration with surrounding water table.

Record the pit dimensions, water table depth parameters on the record sheet provided with this method.

Insert the 50 cm ruler vertically into sediment in the base of the pit in one corner where you can easily read it. Make sure the ruler is stable. Record the raw equilibrium water level depth on the ruler. (i.e. L might be ~20 cm but you insert the ruler several cm so the raw water level reading on ruler before bailing is 24 cm).

Rapidly bail out the water in pit using 10 L bucket. Be slow and steady during the last bail to minimise 'sloshing' and water level oscillation in the pit.

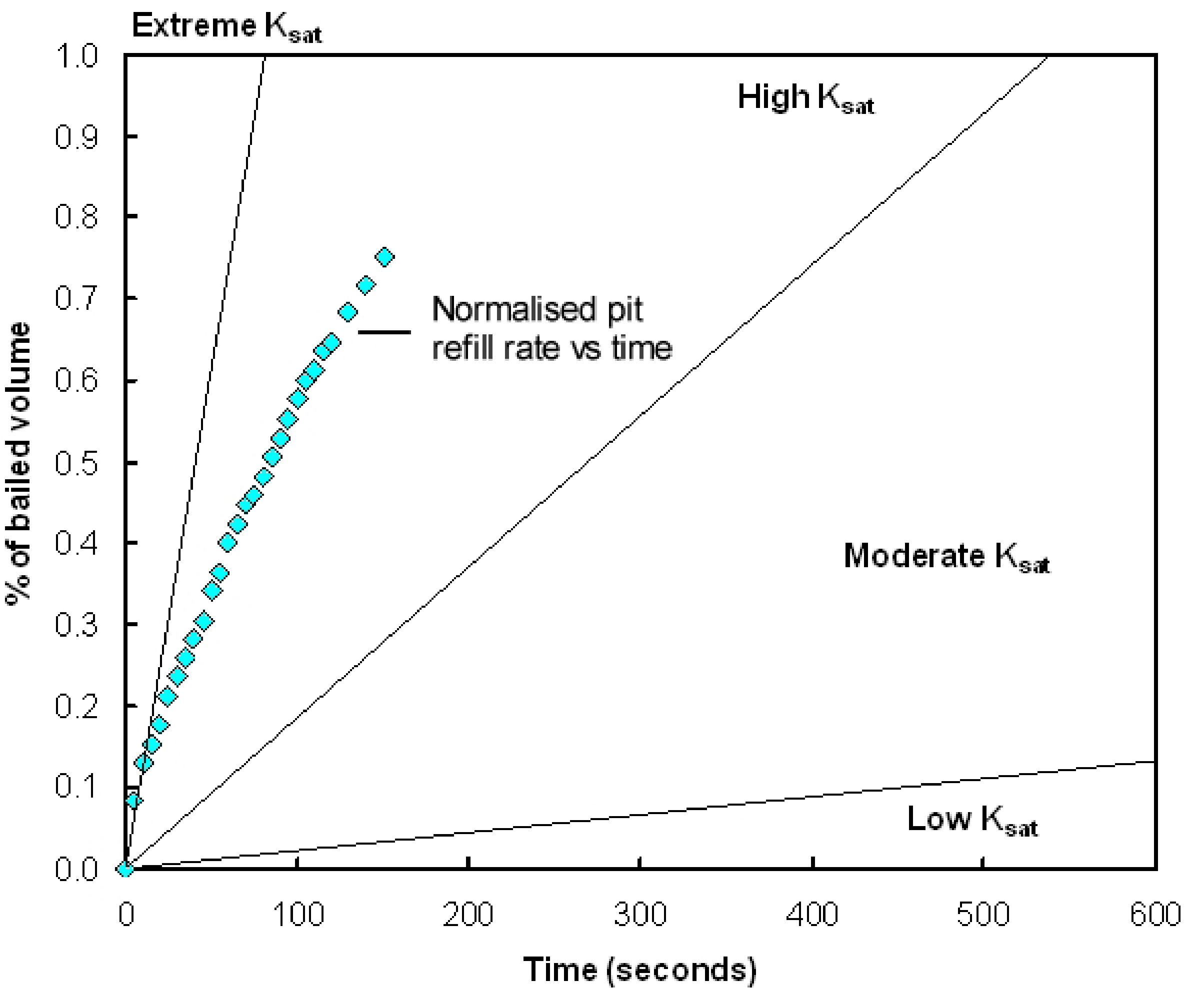
Have one person start the stopwatch immediately after the last bail and begin counting the seconds out loud. Have the other person watching the water level on the ruler and recording the level from zero seconds onwards. Record the water level approximately every 5 seconds (on record sheet) for a minimum of 3 minutes or until at least ~80% of the pit bail out volume is replaced, up to a maximum of 30 minutes if required. If the pit infill rate is slow, then record the water level at time intervals, which are long enough to allow accurate measurement (i.e. rise in water level of at least 1 mm per time increment). Wait until equilibrium level is obtained and repeat the test at least once.

Data Entry and Plotting

The data you record should be entered onto the Excel spreadsheet provided with this method. Instructions for data entry are provided within the spreadsheet.[346] The spreadsheet also calculates the ratio L/W and the percentage of the pit water volume you bailed out so that you can check to see if it is within the ranges listed above under 'Pit construction'.

The spreadsheet will perform very simple calculations and plotting automatically. *No responsibility is taken if you alter the calculations in any way!* After you enter your data the resultant plot will show the normalised pit refill rate v time and should look something like Figure 17. The plot line will fall into one of four pre-set categories listed below which *approximate the following K_{sat} ranges.*[347]
Low = < 1.5 m day^{-1}
Medium = 1.5 to 15 m day^{-1}
High = 15 to 100 m day^{-1}
Extreme = < 100 m day^{-1}

Figure 17. An example of pit refill data after plotting in spreadsheet



Interpreting Data and Assessing K_{sat}

The example pit refill data shown in Figure 17 shows a K_{sat} in the high range (i.e. between approximately 15 to 100 m day^{-1}). If a sites K_{sat} falls in the high or extreme range, then depending on other factors (i.e. elevation of acid groundwater horizons relative to local low tide levels), there is a very real probability that groundwater seepage may be a major hydrological pathway of acid export.

High or extreme range K_{sat} also means that if floodgates are opened and saline water introduced into a drain there is a high probability that substantial lateral movement of this saline water away from the drain could occur. However, this will also be dependant 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.

Availability of this Method

This method, including these instructions, recording sheets and Excel spreadsheet, is available on CD from NSW Agriculture at Wollongbar Agricultural Institute. Alternatively, copies of the above can be downloaded for free at www.agric.gov.au/reader/floodgates_guidelines.

APPENDIX 2 GOVERNMENT POLICY CONTEXT

National Strategy for Ecologically Sustainable Development

The *National Strategy for Ecologically Sustainable Development* (NSESD)[348], is the key national policy framework document for integrating economic, social and environmental objectives, and has been adopted by State and Territory Governments through the Inter Governmental Agreement on the Environment (IGAE).[349]

The goal of the Strategy is:
"development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends".[350]
The core objectives are:
- to enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations
- to provide for equity within and between generations, and
- to protect biological diversity and maintain essential ecological processes and life-support systems.

The guiding principles include:
- decision-making processes should effectively integrate both long and short-term economic, environmental, social and equity considerations
- where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation
- the need to develop a strong, growing and diversified economy which can enhance the capacity for environmental protection should be recognised
- cost effective and flexible policy instruments should be adopted, such as improved valuation, pricing and incentive mechanisms, and
- decisions and actions should provide for broad community involvement on issues which affect them.

The goal, objectives and principles should underpin the interpretation and administration of all other relevant government policies.

Rivers and Estuaries Management

The *State Rivers and Estuaries Policy*[351] establishes the framework for the management of the State's rivers and estuaries and related ecosystems. Its objectives are:
- to manage the rivers and estuaries of NSW in ways which slow, halt or reverse the overall rate of degradation in the systems
- to ensure the long term sustainability of their essential biophysical functions, and
- to maintain the beneficial use of these resources.

A number of component policies are set up under the policy, including the *Estuary Management Policy*, the *Wetlands Management Policy* and the *Weirs Policy*.

The general goal of the *Estuary Management Policy*[352] is to achieve an integrated, balanced, responsible and ecologically sustainable use of the State's estuaries, which requires recognition of the social and economic importance of the State's estuaries. The Policy promotes
- the long term sustainable use of NSW rivers and estuaries
- the replacement of environmentally degrading processes with more efficient and less degrading alternatives
- the protection of estuarine habitats and ecosystems in the long term, and
- the rehabilitation of environmentally degraded areas including restoration of their biophysical functions.

The key mechanism of the Policy is the estuary management planning process which involves the preparation and implementation of a balanced, long term management plan for the sustainable use of each estuary and its catchment, in which all values and uses are considered, and which defines management strategies for:
- conservation of aquatic and other wildlife habitats
- conservation of the aesthetic values of estuaries and wetlands
- prevention of further estuary degradation
- repair of damage to the estuarine environment, and
- sustainable use of estuarine resources, including commercial uses and recreational uses as appropriate.

Wetlands Management and Migratory Birds

Both Commonwealth and State policies share a common goal to conserve and rehabilitate wetlands. The *Wetlands Policy of the Commonwealth Government of Australia 1997* aims to:

- meet Australia's commitments as a signatory to relevant international treaties in relation to the management of wetlands and migratory birds[353], and
- ensure that the activities of the Commonwealth Government promote the conservation, ecologically sustainable use and enhancement of wetland functions, including guiding government decision-making in relation to wetlands on Commonwealth land, and providing guiding principles for all levels of government to encourage sustainable use and management of wetlands. The *Directory of Important Wetlands in Australia* identifies significant wetlands.[354]

The Australian Government is committed to conserving migratory waterbirds through a number of international agreements such as the Ramsar Convention and the Convention on Migratory Species, and throughout the East Asian-Australasian Flyway, bilateral migratory bird agreements with Japan, China and Korea. The agreements list terrestrial, water and shorebird species which migrate between Australia and the respective countries, and require the parties to protect migratory birds including by conserving habitats.

The NSW W*etlands Management Policy 1996*[355] aims to:

- identify degraded wetlands
- actively rehabilitate degraded wetlands and their habitats and processes as far as is practicable
- halt and where possible reverse the loss of wetland vegetation, declining water quality and falling natural productivity, and
- ensure that adequate water is available to restore wetland habitats. In so doing, water entering wetlands should be of sufficient quality so as to not degrade the wetlands.[356]

Areas of conservation significance include SEPP14 wetlands, and other areas identified locally as having conservation value. However, these protections are directed towards remnants, following major works in the post-World War II period.

Freshwater wetlands, particularly the more open freshwater wetlands, which include most backswamps, are in particularly short supply.[357]

Fish Habitat

NSW Policy and Guidelines for Aquatic Habitat Management and Fish Conservation 1999 has been prepared by NSW DPI to guide stakeholders on the protection and management of aquatic habitats in NSW. It is targeted at local and state government authorities, proponents of developments and their advisers, and individuals or non-government organisations concerned with the planning and management of our aquatic resources. It can be used to inform land use and natural resource management planning, development planning and assessment processes, and is a valuable educational tool to improve awareness and understanding of the importance of aquatic habitats and how impacts can be mitigated or managed.

As with other in-stream structures, floodgates can prevent fish access to spawning and feeding areas, fragment fish populations and interrupt genetic flow, reduce flow levels below those needed for fish survival, alter temperature, salinity and water quality regimes downstream, and restrict the access of fishers.
NSW DPI applies the *Aquatic Habitat Management and Fish Conservation Policy and Guidelines* to encourage landholders to maintain floodgates in an open position during non-flood conditions.[358] The policy is also given expression partly through the approvals processes in the *Fisheries Management Act 1994*.[359]

Weirs

The *NSW Weirs Policy 1997*[360] is a one of a suite of policies prepared in the context of the Council of Australian Governments (COAG) water reforms and concern over environmental flows. The policy addresses the environmental impact of 'weirs', which includes floodgates and related structures.[361] The general approach is that the construction of new weirs is discouraged, and weirs that are no longer providing significant benefits should be removed.

On the unregulated rivers of the coast, where estuarine wetlands and natural estuarine creeks have been isolated and drained by levee and floodgate structures, loss of fish habitat and the resultant decrease in fish stocks are major concerns.

However, some water control works can provide other benefits on coastal floodplains, including enhanced fisheries production, being an essential component of acid containment strategies.[362] The appropriate policy balance between ASS containment and fish passage is to foster removal or modification of levee headworks to provide improvements in drain water quality through dilution and neutralisation (where feasible), and to encourage fish passage within that section of the drain that intersects the higher elevation levee, non-acid sulfate, soils, through to approximately the levee toe-backswamp boundary, and within the ASS backswamp, to place the emphasis on ASS containment.[363]

A whole-of-catchment view should be taken to restoration and rehabilitation activities, with floodgate opening focusing on the most appropriate habitat from a fisheries perception, as opposed to simply focusing on those areas where landholders are willing to cooperate.[364] In this way, the benefits of expanded fish habitat can be maximised, while minimising the risk of estuarine pollution and consequent fish kills during discharge events.

Flood Mitigation and Agriculture

The *NSW Flood Prone Land Policy 1986*[365] includes the framework for the construction of flood mitigation works, and the maintenance of existing works. Previous schemes have provided a major increase in the area available to agriculture, including cropping, particularly on North Coast floodplains. However, it is now generally acknowledged that many 'flood mitigation' scheme works were 'over-engineered' - many of the drains are too deep, often intersecting ASS materials, and inverts of many headworks are too low. Similar levels of flood protection might have been achieved with shallower drains and smaller flood mitigation schemes. A key area for consideration is therefore the appropriate balance between the flood mitigation function of backswamps and more intensive agricultural land use, and the remediation of wetlands.

The *NSW Policy for Sustainable Agriculture 1998* identifies the criteria that agriculture must meet to be considered sustainable. It must:
"take full account of the costs of production, including environmental costs … ; protect and restore the natural resource base on which agriculture depends; [and] prevent adverse on-site and off-site impacts on the environment and any other sector of the community."[366]

In the area of coastal floodplain management, the policy is relevant to the two main objectives of ASS management, the need to reduce discharge of acid and other oxidation products, coupled with the need to prevent oxidation and pollution of the soil and the near-surface groundwater.

Groundwater Pollution

The *NSW State Groundwater Quality Protection Policy 1998*[367] *1998* seeks to slow and halt, or reverse any degradation of groundwater resources, including near-surface groundwaters. The policy framework also recognises the need to take a long term, rather than a short-term, view.[368] This is especially important in the ASS context, where changes to many of the physical and chemical properties of soils and groundwaters, as well as landscape elevation changes, are understood to be irreversible.

Climate Change and Sea Level Rise

The risk of climate change and related sea level rise[369] is acknowledged in the *NSW Coastal Policy 1997*[370], the *NSW Floodplain Development Manual*[371], the draft *Coastal Zone Management Manual*[372], the *Far North Coast Regional Strategy*[373], the draft *Mid North Coast Regional Strategy*[374] and the *South Coast*[375] *and Illawarra Regional Strategies*.[376] These policy positions are largely given expression through the development consent process.[377] The *Far North Coast Regional Strategy* includes actions for LEPs to assess and consider potential sea level rise. The implications of climate change and sea level rise on works associated with remediation projects should be addressed during the assessment process.[378]

However, the implications of climate change and sea level rise extend beyond development control and coastal recession to include land management responses to increased flooding of low lying areas and increased risk from storm surge. A more general policy was announced by COAG in 2006, when it committed all jurisdictions to develop strategies to adapt to the unavoidable impacts of climate change.[379] Mechanisms to effect policy in this area may include: funding decision-making processes; acquisition and covenanting; and various incentive mechanisms.

APPENDIX 3 LEGAL ISSUES

Exposure[380]

Damage to Land and Water

Nuisance

A nuisance[381] is an indirect interference with a person's interest in the use and enjoyment of land (and water). The law aims to maintain a balance between competing interests in land use. Cases are decided on the basis of 'reasonableness'. What is 'reasonable' will vary depending on the circumstances, but as a general rule, it can be said that it is never reasonable to cause damage to another's property.[382] The law will therefore generally protect adjoining properties from nuisances such as unwanted surface water[383], the contamination of groundwater used for drinking purposes[384], and water pollution affecting riparian occupiers.[385]

The remedy for damage to property is normally calculated according to actual damage caused.[386] The courts may also grant an injunction to have the nuisance discontinued. It is also important to note that an action in nuisance may succeed notwithstanding that the works were carried out in accordance with statutory powers and with the necessary approvals.[387]

Regulation of Pollution

Regulation of pollution is exercised under the *Protection of the Environment Operations Act 1997 (POEO Act 1997).* Most ASS remediation works will take place on 'non-scheduled premises', in which case the Appropriate Regulatory Authority (ARA) is local government[388], except for activities undertaken by a public authority, which the EPA will regulate.[389]

Local councils, or in the case of a State or public authority, the EPA[390], can regulate non-scheduled activities through clean-up notices[391], prevention notices[392] and enforcement powers.[393] Clean-up action may include action to prevent, minimise, remove, disperse, destroy or mitigate pollution, to ascertain the nature and extent of the incident, and prepare and carry out a remedial plan of action. There is no merit appeal from a clean-up notice, and some councils have made use of these notices in the context of ASS pollution.

Prevention notices may be used if the ARA has reasonable grounds to believe that an activity is being conducted in an *"environmentally unsafe manner"*[394], which may require that plant be installed, repaired, altered, replaced, maintained or operated, or that the plant not be used, or its mode of operation be altered.[395] An appeal process is available.[396]

Injury to Person

Negligence and Duty of Care

The law of negligence is aimed at protecting people from personal injury, rather than addressing interferences with the land itself.[397] There are four elements to a negligence claim:
- the defendant must owe a duty of care to the plaintiff
- the defendant must have failed to discharge that duty
- the plaintiff must have suffered material injury, as a result of the defendant's failure, and
- there must be a strong element of proximity between the injury of the plaintiff and the failure of the defendant.[398]

Parties involved in establishing and operating works and other components of a remediation project, potentially including the proponent, consultants, works contractors, and the local government/assessment manager[399], may have a duty to take reasonable care not to harm people who come in contact with the project.

In deciding whether there has been a breach of the duty, the issues to be determined are whether a reasonable person to whom the duty attaches could have foreseen the risk of injury, and if so, whether the person took sufficient action in response to the risk. The reasonableness of the steps taken to prevent injury calls for consideration of the magnitude of the risk, the probability of its occurrence, and the expense and difficulty of taking more effective action to alleviate the risk.

Examples where the duty might be triggered in the context of ASS remediation might include the need for:
- appropriate training for operators of manual floodgate devices
- installation of guard railing and signage near both public and private traffic ways
- enclosure against accidental and/or unauthorised access to automatic or remotely operated water control structures

- appropriate fencing around construction sites including excavations and stockpiles
- erecting appropriate signage to warn of dangers, and
- adequate assessment of the risks such as mosquito risk[400] from a remediation project.

Regulation of Occupational Health and Safety

Insofar as workplaces are concerned[401], issues of negligence and duty of care have been codified in the *Occupational Health and Safety Act 2000 (OH&S Act 2000).*[402]

The Act requires employers to ensure the health, safety and welfare of their employees when at work by maintaining places of work under their control in a safe condition, providing and maintaining systems of work and working environments, that are safe and without risks to health, and providing the information, instruction, training and supervision necessary to ensure the health and safety of employees.[403]

An employer must also ensure that people (other than the employees) are not exposed to risks to their health or safety arising from the conduct of the employer's undertaking while they are at the employer's place of work.[404]

Minimising Risk

OH&S and Floodgate Management

A common situation where OH&S duties may arise is the active management of floodgates. Actively managed floodgates are a 'workplace' within the meaning of the Act, and for the purposes of the Act, volunteers carrying out a function on behalf of council may be treated as employees.[405] The obligation therefore falls with councils to ensure that any plant is safe to use, that operators can carry out their activities in a safe manner; and that adequate training has been delivered.

Training and Safety

A major limitation of manually operated devices such as winches from a practical point of view is that landholders or council operators must be on hand to raise and lower the gates, and this may not be possible at crucial times such as at night or during flooding.

Operators of any council structures must be trained in safe operating procedures.[406] Training should cover the following issues:
- responsibilities under the *OH&S Act 2000*
- responsibilities of operators
- safe operating procedures for the opening and closing gates, and
- insurance and liability issues.[407]

Councils are also obliged as a risk management procedure to ascertain the suitability of tasks to be undertaken by volunteers and their ability to safety carry out those tasks.[408]

Where floodgate lifting devices are incorporated in either conventional flap gates or automatic tidal gates, enclosure of the mechanisms may be required for both OH&S reasons and to prevent accidental or deliberate interference with their design function. Appropriately sited signage should indicate the potential risk of unauthourised operation of such devices.

Insurance

Insurance for Employees and Volunteers

Larger organisations, including councils, normally carry a range of insurance, including personal accident and injury insurance, for their employees. Some classes of insurance also cover volunteers whilst they are carrying out delegated functions on behalf of a council. It is important for both councils and their delegates to understand these insurances and their limitations.[409]

In terms of activities such as floodgate management, only those persons named as operators in the Management Plan or by delegation will be covered by council's relevant insurance policies, and only if they are carrying out council functions, such as management of floodgates, and risk minimisation and safety procedures, as specified in a Safe Methods Working Statement, are followed at all times. All operations of the floodgates must be recorded by dated entry in a log book.

Public Liability Insurance

Third party personal injury and property damage claims against organisations, their employees or volunteers are normally covered under that organisation's Public Liability insurance. Note that this insurance does not normally cover incidents where damage has been caused through acts of wilful recklessness or negligence.

Any incident which results in an injury, loss or damage to another person or their property, and which occurs as a consequence of an employee or volunteer carrying out their duties, must immediately be reported to the employer.

Defences Available to Public Authorities

A defence from claims is available to councils under ss. 731 and 733 of the *Local Government Act 1993 (LG Act 1993)*. Under s. 731, a council (including an employee of council or a member of a committee of the council or any person acting under the direction of the council or a committee of the council) is not exposed to any action, liability, claim or demand if the matter or thing was done in good faith for the purpose of executing an Act.[410]

Specific protection exists in relation to flood liable land, and land in the coastal zone, where the protection extends to the Crown, a statutory body representing the Crown and a public or local authority constituted by or under any Act, a councillor or employee of a council or any such body or authority, a public servant, and a person acting under the direction of a council or of the Crown or any such body or authority.

Any such person does not incur any liability in relation to advice given, or things done or omitted to be done in good faith relating to the likelihood of land being flooded or the nature or extent of flooding. This section applies to the carrying out of flood mitigation works, indeed to any other thing done or omitted to be done in the exercise of a council's functions under any Act.[411] Providing the Crown any such body or authority acts in 'good faith', protection under the *LG Act 1993* extends to both acts and omissions.[412] The notion of 'good faith' is difficult to define and will depend on the circumstances and context.[413] However, 'good faith' involves more than just honest ineptitude – where the damage is foreseeable, courts will ask whether reasonable steps were taken to prevent the damage.

If this test is met, an alleged nuisance may be defended if it is the inevitable consequence of the performance of a statutory duty or exercise of a power.[414] Note however that statutory and discretionary defences have been rejected in private nuisance[415] and criminal actions.[416]

Respondents may need to demonstrate that best management practices have been complied with. Best management practices will be consistent with the procedures, information or other actions outlined in this document unless acceptable reasons can be given for any inconsistency.

Consents and Approvals[417]

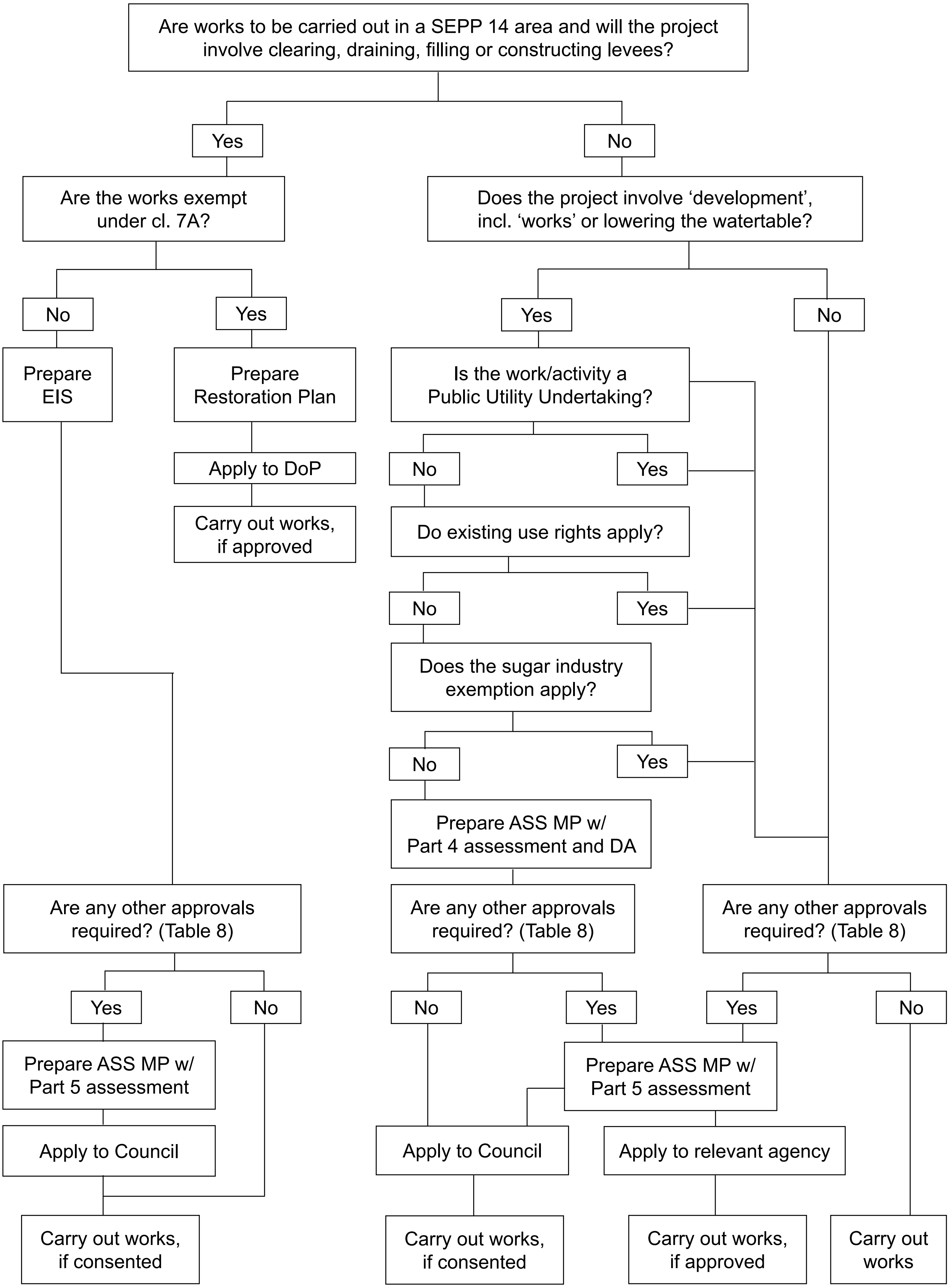
NSW Statutory Framework

The *Environmental Planning & Assessment Act 1979 (EP&A Act 1979)* provides the general framework for environmental planning & assessment in NSW. Part 3 of the Act provides the framework for the making of Environmental Planning Instruments (EPIs); Part 4 outlines processes for granting consent under EPIs; and Part 5 deals with assessment and determination where consent under an EPI is not required.[418]

The first step in determining assessment requirements for a 'development' is the Local Environmental Plan (LEP).[419] LEPs will also generally include, or include reference to, certain relevant Model Provisions[420], and include a Schedule that lists development that is excluded from the main operation of the plan, typically being public utility undertakings.[421] Development Control Plans (DCPs) can also be prepared in order to explain processes or provide more detail, than is possible within the LEP.[422]

State Environmental Planning Policies (SEPPs) may amend the details of existing LEPs, either by making certain development permissible that would otherwise be prohibited by the LEP, or conversely, by imposing development consent requirements that do not appear in the LEP.[423] Regional Environmental Plans (REPs) are often used to provide an overall planning framework, by setting the parameters for forward planning and development control by affected councils, such as the kinds of zones, objectives and matters that must be addressed.[424]

Figure 18. Simplified flow diagram of consents and approvals required



Environmental Assessment under the EP&A Act 1979

If development consent is required under an EPI, then the development assessment provisions of Part 4 of the *EP&A Act 1979* apply. In determining a development application (DA), a consent authority is to take into consideration matters as are of relevance to the development specified in s. 79C (1), including the likely impacts of that developmentdevelopment, including environmentalenvironmental impacts on both the natural and built environmentsenvironments, and social and economic impacts in the locality, and the suitability of the site for the developmentdevelopment.

If development consent is not required, assessment will generally be required under Part 5.[425] This will include projects where some other approval is required, or are to be carried out by a public authority.[426] A determining authority under Part 5 must examine and take into account to the fullest extent possible all matters affecting or likely to affect the environment by reason of that activity.[427] Development by the Crown, which includes a public authority (not being a council) or a public utility[428], is covered by Part 5A.

An adequate knowledge of the site is essential to minimise risk and maximise the effectiveness of the remediation program. The ASS Assessment Guidelines[429] and the ASS Management Plan Guidelines[430] in the *ASS Manual* (1998) detail a number of issues that may need to be assessed for projects in ASS areas.

Climate Change and Sea Level Rise

SEPP 71 requires consent authorities to consider *"the likely impact of coastal processes and coastal hazards on developments and any likely impacts of development on coastal processes and coastal hazards"*.[431] Similarly, the Standard LEP requires LEPs to *"recognise and accommodate coastal processes and climate change"* for development within the coastal zone[432], and requires that consent must not be granted unless the consent authority has considered *"the effect of coastal processes and coastal hazards and potential impacts, including sea level rise: (i) on the proposed development, and (ii) arising from the proposed development"*.[433] The effects of climate change and coastal flooding must also be considered under Part 3A of the *EP&A Act 1979*.[434]

Works that do not Require Consent or Approval

Public Utility Undertakings and Development by the Crown

Schedule 1 of the *Environmental Planning & Assessment Model Provisions 1980* contains a list of developments carried out by public utilities that are excluded from the controls in an LEP, where the Schedule 1 has been incorporated into the LEP.

These works include the carrying out of public utility undertakings, including drainage, involving the installation or erection, additions to or replacement or extension of, any plant or other structures[435], and the carrying out or causing to be carried out by a council engaged in flood mitigation works or by DWE of any work for the purposes of soil conservation, irrigation, aforestation, reaforestation, flood mitigation, water conservation or river improvement in pursuance of the provisions of the *Water Act 1912* , the *Irrigation Act 1912* , the *Farm Water Supplies Act 1946* or the *Water Management Act 2000*.[436]

Note that works carried out by public utilities require assessment under Part 5.

SEPP (Infrastructure) 2007 provides that certain infrastructure development carried out by or on behalf of a public authority may be carried out without consent. Development that is exempt under this policy includes flood mitigation work (including construction, maintenance and 'environmental management works') (cll. 49, 50), works on land reserved or declared under the *National Parks and Wildlife Act 1974* , the *Marine Parks Act 1997* or the *Fisheries Management Act 1994* or environmental management works on a public reserve controlled by a council (cl.65), soil conservation works (including works to avoid, manage or mitigate the effects of acid sulfate soils) (cll. 108, 109), and instream management or dredging to rehabilitate aquatic habitat or to restore tidal flows (cll. 128, 129).[437]

Existing Use Rights

The 'existing use rights'[438] provisions of the *EP&A Act 1979*[439] authorise the continuation of an existing land use regardless of any introduction by a subsequent EPI for a requirement that the use be prohibited or subject to development consent.[440] Even though a new planning instrument may seek to prohibit an existing use or make it subject to development consent, planning law protects the use until it is abandoned. A land use that is abandoned cannot be resumed.[441] This approach is justified on the grounds that preventing landholders from continuing with their current land use would impose too great a burden on them for past errors of past land use allocation and management, and would therefore be unfair and disruptive.[442]

The limits on existing uses are:

- any alteration or extension to .. a building or work
- any increase in the area of the use made of a building, work or land from the area actually physically and lawfully used immediately before the coming into operation of the relevant instrument[443]
- any enlargement or expansion or intensification of the use[444]
- the continuance of the use in breach of any consent in force under the *EP&A Act 1979*, or
- the continuance of the use where it has been abandoned (generally presumed where the use has ceased for a continuous period of 12 months).[445]

Existing use rights may impact on the need for consent in some situations relevant to ASS remediation, including in areas relating to clearing and vegetation management, and drain management.[446] However, the existing use right exemption only applies to development under the *EP&A Act 1979*, and does not extend to other Acts under which some other approval is required.

Sugar Industry Exemption

An exemption from the need to obtain development consent under the *EP&A Act 1979* for the carrying out of works applies to the sugar industry, under certain conditions. Growers are able to carry out works specified in a Drainage Management Plan, such as land grading, drain construction, drain maintenance or other earthworks that may disturb ASS or lower the water table. The drainage management plans are based on a 1999 soil sampling program that covered all ~700 cane farms in NSW and assessed the location, depth and intensity of ASS layers.

Plans must also be prepared in accordance with the NSW Sugar Industry Best Practice Guidelines for ASS. This document provides general operational requirements for works such as drainage and land grading, and links to the *ASS Manual*.[447]. The sugar industry Guidelines also specifies the compliance, audit and review process. The process is given effect through a Memorandum of Understanding between the Department of Planning and the NSW Sugar Milling Co-operative, of which all NSW cane growers are members.[448]

Consents Required

Works which Disturb ASS or Lower the Watertable

Most ASS areas in coastal local government areas are zoned 1 (a) Rural General (or a variant thereof). These zones invariably provide for agriculture (and ancillary activities) without consent. Of particular relevance to floodplain management, cl. 34(1) of the *Model Provisions 1980* provided that consent is required for work on land within a flood prone area. Most coastal councils adopted cl. 34 (1) of the Model Provisions 1980 (or a similar clause), and therefore would otherwise generally require consent for works on floodplains. However, in most agricultural cases, drainage works were generally exempt from consent requirements due to the operation of cl. 10 of *SEPP 4 – Development Without Consent*.[449] The exemption applies to development for a purpose that is ancillary or incidental to a purpose for which the land may be used, including drainage. Such development may be carried out without consent. In other words, most forms of agriculture are generally permissible without development consent; therefore drainage that is ancillary to agriculture would also not require development consent.[450]

However, this exemption has been progressively removed in those local government areas that have adopted an LEP amendment based on the 'Model ASS LEP'.[454] The LEP requires consent for works that might disturb ASS, as defined by the Table in the LEP and the attached ASS Planning Maps. The consent requirement includes works that may not otherwise need consent based on the existing provisions in the LEP. Works by councils, county councils and private drainage boards are also brought into the consent process.

Under these ASS clauses, a person must not, without the consent of the council, carry out works described in the Table in the LEP on land of the class specified, unless an exception applies or is obtained. 'Works' generally includes: (a) any disturbance of more than one (1) tonne of soil …, or (b) any other works that are likely to lower the watertable.[452]

Under the *EP&A Act 1979*, the environmental impacts of a proposal must be considered prior to development consent being granted. If development consent is required, a DA must be lodged with council accompanied by either a Statement of Environmental Effects (SEE) (if not designated) or an Environmental Impact Statement (EIS) (if designated).

Designated Development

Schedule 3 of the *Environmental Planning & Assessment Regulation 2000* lists a number of types of development that are Designated Development, and requires the preparation of an EIS. This requirement may be triggered by the type of development and its location in an *"area of high watertable, highly permeable soils or acid sulphate, sodic or saline soils"*.[453]

Development in SEPP 14 Coastal Wetlands

The aim of *SEPP 14 – Coastal Wetlands* is to ensure that the coastal wetlands are preserved and protected in the environmental and economic interests of the State.[454] The SEPP is a key instrument for the control of certain development on ASS backswamps and is based on mapped wetlands, a number of which are also ASS areas in need of remediation. Any proposal to fill, clear, drain, or construct levees around, a SEPP 14 wetland will generally require consent from the council, with concurrence from the Director-General of the Department of Planning. The SEPP 14 wetland maps should be checked to determine whether any proposals to carry out remediation works are within any SEPP 14 wetlands.[455] The maps should be examined carefully, and the boundaries surveyed if necessary, as the map line work may not reflect actual wetland boundaries on the ground at the present time.[456] The application must be accompanied by an EIS. These procedural requirements have sometimes prevented remediation works from proceeding.[457] Where there is scope for interpretation, it would be useful to go to the objectives of the SEPP.[458]

In the context of remediation projects, the two commonly triggered clauses are those relating to filling and clearing. There is no threshold for the scale of works, so the construction of an in-drain water control structure or the filling-in of even a short section of drain would normally trigger the need to prepare an EIS and submit it with the DA.[459]

Clearing may be deemed and indirect, for example as a consequence of changing the operation of headworks to effect a change in wetland water quality from fresh to estuarine water.[460] Conversely, an EIS may not be required if salt concentrations levels are to be kept within a threshold acceptable to most fringing aquatic communities.[461]

A special clause[462] removes the requirement to prepare an EIS for restoration projects carried out in order to remedy a breach of the SEPP, and substitutes a requirement to prepare a restoration plan in accordance with the Guidelines for Wetland Restoration Plans.[463] Where such restoration works are carried out within ASS areas, ASS remediation objectives may be included.[464]

Development in the Coastal Zone

SEPP 71 — Coastal Protection sets out additional matters for consideration in relation to development in the 'coastal zone'[465], and requires that development in 'sensitive coastal areas' be forwarded to the Minister for comment.[466] 'Sensitive coastal locations' include: land within 100 m above mean high water mark of the sea, a bay or an estuary; coastal lakes, Ramsar wetlands and World Heritage areas, marine parks and aquatic reserves; land within 100 m of any of the above; and land within 100 m of land reserved under the *National Parks and Wildlife Act 1974* or *SEPP 14 Coastal Wetlands*.[467]

Other Approvals and Integrated Development

In many cases works may not require development consent, but may require some other form of approval listed in s.91 of the *EP&A Act 1979*.[468] In many cases remediation works will require both development consent, and at least one other approval, in which case the proposal will be considered to be 'integrated development' and subject to a coordinated assessment and approval process. Special provisions in the *EP&A Act 1979* and the *Environmental Planning & Assessment Regulation 2000* detail the manner in which integrated development is to be dealt with by councils and other public authorities.

If another approval is required, the potential environmental impacts of granting the approval for the activity must be assessed by the responsible authority under that authority's legislative requirements and having regard to the matters for consideration as set out under Part 5 of the *EP&A Act 1979*. Advice should be sought from the responsible authority regarding the need for an approval and the appropriate level of environmental assessment.

Usually a Review of Environmental Factors (REF) is prepared by the proponent, so that the responsible authority can decide if an EIS is required based on the factors in the DUAP Guideline *Is an EIS Required?*[469] If the activity is likely to significantly affect the environment, under Part 5 of the *EP&A Act 1979*, an EIS must be prepared in accordance with cll. 71-73 of the *Environmental Planning & Assessment Regulation 2000*, and assessed prior to any approval being granted.

If an EIS is not required, the responsible authority should make a decision based on the issues assessed in the REF. A determining authority should take into account *"to the fullest extent possible"* the factors listed in cl. 82 of the *Environmental Planning & Assessment Regulation 2000* before approving a proposed activity.

Table 10. Consents and approvals that may be required

		Neutralisation/dilution strategies		Containment strategies	
Activity/works	**Consent/approval required**	**Floodgate management/ modifications**	**Restoration of estuarine areas**	**DACS**	**WACS**
Works which disturb ASS or lower the water table	LEP, ASS clause	• Normally exempt - public undertakings	• Ancillary works	• Redesign of drainage (exempt if BMP).[470]	• Constructing a WCS
Development in SEPP 14 Coastal Wetlands	*SEPP 14 - Coastal Wetlands*	• Clearing	• Clearing	• n/a	• Constructing a WCS • Filling • Leveeing
Development in the Coastal Zone	*SEPP 71 - Coastal Protection*	• Development in sensitive coastal locations	• Development in sensitive coastal locations	• Development in sensitive coastal locations	• Development in sensitive coastal locations
Works on public land	*Crown Lands Act 1989*, s. 155		• Filling on public lands		• Constructing a WCS • Filling on public lands
Works on public roads	*Roads Act 1993*, s. 138		• Filling on public roads		• Constructing a WCS • Filling on public roads
Connecting a private drain to a public drain	*Local Government Act 1993*, s. 68			• Connecting a drain	
Dredging and reclamation	*Fisheries Management Act 1994,* ss. 199-201.	• Drain maintenance		• Drain maintenance	• Constructing a WCS • Filling
Fish passage and fishways	*Fisheries Management Act 1994,* ss. 218, 219.	• Floodgate is to be altered		• Floodgate is to be altered	• Constructing a WCS • Weir to be constructed or altered
Works likely to affect fish habitat, mangroves and seagrasses	*Fisheries Management Act 1994,* ss. 204, 205.			• Redesign of drainage • Drain maintenance	• Constructing a WCS
Works in Marine Parks	*Marine Parks Act 1997*, ss. 19, 20.	• Development or activity in the locality of a Marine Park	• Development or activity in the locality of a Marine Park	• Development or activity in the locality of a Marine Park	• Development or activity in the locality of a Marine Park
Excavating Protected Land	*Rivers and Foreshores Improvement Act 1948,* Part 3A	• Works on Protected Land	• Works on Protected Land	• Works on Protected Land	• Works on Protected Land
Clearing native vegetation	*Native Vegetation Act 2003*	• Clearing riparian vegetation	• Clearing riparian vegetation		• Clearing • Clearing riparian vegetation
Projects affecting threatened species	*Threatened Species Conservation Act 1995,* *National Parks and Wildlife Act 1974,* s.118A *Fisheries Management Act 1994*, Part 7A.		• Works		• Works
Interference with groundwater	*Water Act 1912*, s. 112			• Interference with groundwater	
Harvesting water from drains and creeks	*Water Act 1912*, s. 112				• Harvesting water from drains and creeks

Works on Public Land

The *Crown Lands Act 1989* requires that approval be obtained for certain works, including drainage and filling on public lands. Section 155 provides that a person shall not, without lawful authority *"erect a structure on public land, or clear, dig up or cultivate public land, or interfere with any substance, whether on or in, or forming part of, public land"*.[471] Public land includes many foreshores, public (including 'paper') road reserves, and the beds of most rivers and estuaries.[472] An annual fee may be payable for situating a work on Crown land. Information in this regard should be sought from the Department of Lands.

Section 138 of the *Roads Act 1993* provides that a person must not erect a structure or carry out a work in, on or over a public road, or dig up or disturb the surface of a public road without a permit under s.139. 'Public roads' include 'paper' roads, or road easements, which provide for access to every portion in NSW. Inquiries should be directed to council in the first instance.

Connecting a Private Drain to a Public Drain

Under s.68 of the *Local Government Act 1993*, an approval must be obtained to connect a drain to a public drain. Information should be sought from the local or county council regarding the locations of public drains, although generally these will include major drains constructed under the various flood mitigation schemes. Details on council drainage assets can be obtained from the relevant council. Inquiries should be directed to the council.

Dredging and Reclamation

Part 7 Division 3 of the *Fisheries Management Act 1994 (FM Act 1994)* deals with 'dredging' and 'reclamation'.[473] 'Dredging work' means any work that involves excavating 'water land'.[474] Drain waters may therefore be waters for the purposes of ss. 199–201 of the Act.[475] Most of the deeper union and trust drains, and those constructed under the flood mitigation schemes would therefore be included, and drain cleaning resulting in the removal of sediment would generally fall within the meaning of 'dredging'. Furthermore, where drain maintenance involves harm to 'marine vegetation' (such as mangroves and seagrasses) in a 'protected area' (which includes Crown land and land vested in a public authority), a permit is required.

'Reclamation work' means any work that involves using any material (such as sand, soil, silt, gravel, concrete, oyster shells, tyres, timber or rocks) to fill in or reclaim water land, or depositing any such material on water land for the purpose of constructing anything over water land (such as a bridge), or draining water from water land for the purpose of its reclamation.[476] There is no threshold, so even minor filling, for example that associated with the installation of a water control structure, would generally be considered filling.

A person, or local government or public authority must not carry out dredging or reclamation work without a permit. However, this requirement does not apply to work authorised under the *CL Act 1989*, or work authorised by a relevant public authority (other than a local government authority).[477]

Fish Passage and Fishways

Section 219 of the *FM Act 1994*, passage of fish not to be blocked, provides that a permit is required if a floodgate, causeway or weir is to be constructed or altered, or an obstruction is otherwise created across or within a bay, inlet, river or creek, or across or around a flat, so that the free passage of fish could be obstructed. In relation to in-stream rehabilitation, structures can be classified as barriers to fish passage if works are across the full width of the waterway and create a headloss of greater than 100 mm, or works increase the mean velocity of stream flow by constricting the waterway area.[478] Works that create a headloss of greater than 300 mm will need to include specific features to facilitate fish passage where they occur on a natural waterway. This may include a full or partial-width rock ramp as part of the design.

Similarly, under s. 218 of the *FM Act 1994*, the Minister for Primary Industries may require a person or a public authority who constructs, alters or modifies a 'weir', including a floodgate, to provide fishways. Public authorities are also required to consult with DPI before they approve any such activity.

DPI (Fisheries) has prepared guidelines that specify the circumstances under which notification is required.[479] Notification is required if major works are carried out on floodgates that currently exclude fish, repairs to floodgates are required due to gradual deterioration, such that fish are able to pass through them, major repairs or modifications to floodgates on natural waterways, or any new floodgates (or other construction) which may impede fish passage are proposed.

Basic information requirements for remediation projects include a site map, water quality data, photo-points to indicate change, inundation record, and a copy of the management plan.

Notification is not required if repairs to floodgates are minor (e.g. flap, hinge and seal replacement as part of routine maintenance), repairs to floodgates are required due to vandalism or accident, repairs are required to floodgates that are already kept open, or floodgates that do not involve a waterway (e.g. flood control structures on storage floodways).[480]

Assessment can be on a site-by-site basis, or on a council basis through the development of an agreement with DPI (Fisheries). Some councils[481] have an annual permit that covers the operation of standard / routine works such as drain clearing for mangroves.[482]

A guideline for implementing the above policies is that structural flood mitigation should not occur if the site is in an area with ASS, contaminated sediments or will result in the draining of a wetland.[483] Inquiries and applications should be directed to DPI (Fisheries).

Works likely to Affect Fish Habitat, Mangroves and Seagrasses

Under ss. 204 and 205 of the *FM Act 1994*, a permit is required to harm mangroves and seagrasses, certain other marine vegetation in ‘public water land’, on an aquaculture lease or on the foreshore of either.[484] At the time of writing, an activity proposed in relation to an artificial drain must be assessed.[485]

Works in Marine Parks

When assessing development within a marine park, a consent or determining authority must obtain the concurrence of the relevant Ministers to the granting of the consent or approval.[486] When assessing a DA for development in the locality of a marine park, the consent authority must take into consideration any advice given to it by the Marine Parks Authority. A determining authority must not carry out, or grant an approval to carry out, an activity in the locality of a marine park unless the determining authority has taken into consideration any advice given to it by the Authority.[487]

Activities that Affect the Quantity or Flow of Water

An approval is required for a ‘controlled activity’ under the *Water Management Act 2000*[488], being:
- the erection of a building or the carrying out of a work (within the meaning of the *EP&A Act 1979*)
- the removal of material (whether or not extractive material) or vegetation from land, whether by way of excavation or otherwise
- the deposition of material (whether or not extractive material) on land, whether by way of landfill operations or otherwise, or
- the carrying out of any other activity that affects the quantity or flow of water in a water source.

A controlled activity approval is required to carry out a specified controlled activity at a specified location in, on or under waterfront land, being the bed of any river, estuary or lake, to 40 m inland of the bank.[489] Note however that under cl. 39A(1) of the *Water Management (General) Regulation 2004*, all public authorities[490] are exempt from the need to hold a controlled activity approval. Inquiries should be directed to DWE.

Clearing Native Vegetation

Under the *Native Vegetation Act 2003*, development consent is generally required from the Catchment Management Authority (CMA) for clearing of any vegetation on vulnerable land (which may include land within 20 m of a river), vegetation on land identified as being environmentally sensitive or liable to land degradation, or native vegetation on other land.

In terms of remediation projects, any clearing of native vegetation would generally be minor and ancillary to the construction of works. The types of clearing permitted without approval includes routine agricultural management activities (RAMAs), clearing of non-protected regrowth[491], sustainable grazing, and clearing certain groundcover.[492]

The range of routine agricultural management activities (RAMAs) that apply to protected riparian land is limited, although those that are potentially relevant to remediation projects may include any activity reasonably considered necessary to remove or reduce an imminent risk of serious personal injury or damage to property, the removal of noxious weeds under the *Noxious Weeds Act 199*, and the construction and maintenance of fencing to improve management of the protected riparian land.[493]

Clearing for RAMAs must be to the minimum extent necessary. Note that even if clearing approval is not required under the *Native Vegetation Act 2003*, approval may be required under other legislation such as the *EP&A Act 1979*. Note also that clearing listed in s. 25 does not require approval if it is authorised or permitted under other legislation. If consent may be required, project proponents should consult with the local CMA.

Projects Affecting Threatened Species

The *Threatened Species Conservation Act 1995 (TSC Act 1995)* aims to protect threatened species, which includes both listed endangered[494] and vulnerable species[495], endangered populations[496] and vulnerable and endangered ecological communities[497] (referred to collectively as ‘threatened species’).[498] It is an offence to harm[499] any animal that is a threatened species, population or ecological community[500], or to pick[501] any plant that is a threatened species, population or ecological community.[502] It is an offence to damage the habitat of an endangered species, population or ecological community.[503] A person also must not damage any critical habitat.[504]

In relation to aquatic species, Part 7A, s. 220ZW of the *FM Act 1994* provides for the licensing of actions that are likely to result in harm to a threatened species, population or ecological community, damage to critical habitat, or damage to a habitat of a threatened species, population or ecological community.

It is a defence if the alleged offence was essential for carrying out development or an activity authorised under Parts 4 or 5 of the *EP&A Act 1979*[505], in accordance with a licence granted under the TSC Act 1995[506], or authorised under the *Rural Fires Act 1997*.[507]

The *TSC Act 1995* links with the assessment provisions of the *EP&A Act 1979* and requires that consent authorities under Part 4 of the *EP&A Act 1979*, and determining authorities under Part 5 must consider the question of whether there is likely to be a significant effect on threatened species associated with a proposed development.[508] The likely magnitude of impacts is assessed using a threatened species test of significance.[509] The test is used to determine *“whether there is likely to be a significant effect on threatened species, populations or ecological communities, or their habitats”*.[510] If any one or more of the factors raised in s.5A are answered in the positive, indicating that a significant effect is likely, then the proponent must prepare[511] and submit an adequate[512] Species Impact Statement (‘SIS’) along with the DA[513] in accordance with the detailed requirements in the *TSC Act 1995*.[514] If a proposal involves critical habitat, a SIS must accompany the DA regardless of whether the s5A test identified potential significant impacts.

A licence may be granted authorising a person to harm animals, or pick plants that are threatened species, populations or ecological communities. Authorisation may also be granted to damage the habitat of threatened species, populations or ecological communities, or critical habitat.[515] A SIS must be submitted with the licence application if the proposal relates to critical habitat.[516] A SIS may be required in relation to other habitat.[517] Inquiries should be directed to the Department of Environment and Climate Change.

Also potentially relevant is the *Environment Protection and Biodiversity Conservation Act 1999 (Cth) (EPBC Act 1999)*, which is intended to protect matters of ‘national environmental significance’ (NES)[518]. The Act lists nationally endangered and vulnerable species, and critically endangered or endangered and vulnerable ecological communities.[519] It is an offence to kill, injure, take, trade, keep or move a member of a listed threatened species or a threatened ecological community unless authorised.[520]

Projects Affecting Ramsar Wetlands and Migratory Species

Under the *EPBC Act 1999*, any action that has, will have, or is likely to have a significant impact on a matter of NES, including a Ramsar wetland[521] and any migratory species listed under international treaties[522], is required to undergo an assessment and approvals process.[523]

Interference with Groundwater

Licences are required for the installation of wells or bores or extraction of ground water under the *Water Act 1912*.[524] Licence conditions may relate to the protection of the environment generally.[525] Licences are also required for the extraction of water from a natural waterbody or from drains that intersect the watertable. Inquiries and applications should be directed to DWE.[526]

Harvesting Water from Drains and Creeks

A water extraction licence may be required for extraction of freshwater from drain and creeks for production/environmental management purposes. Inquiries should be directed to DWE.

Polluting Works

A water pollution control licence, issued under the *POEO Act 1997*, may be obtained in order to provide a framework for regulation of water pollution for a non-scheduled activity. However, few ASS remediation projects of the kind discussed in these Guidelines will require licensing.[527]

Impacts on Archaeology and Heritage

The *NPW Act 1974* covers deposits, objects or material evidence relating to indigenous habitation. It is an offence to knowingly destroy, deface or damage a relic or an Aboriginal place without consent.[528]

Deposits, objects or material evidence relating to non-indigenous habitation is covered by the *Heritage Act 1977*.[529]

Miscellaneous Works

Examples of other works that may require a permit under the *FM Act 1994* include bridges, culverts, causeways (both piped and unpiped) or other road-crossings of waterways (temporary or permanent) which require placing material on the bed of the waterway (i.e. reclamation) and/or which may obstruct the free passage of fish, channelisation, relocation or realignment of waterways, foreshore or stream bed or bank stabilisation works (involving dredging or reclamation to halt erosion), or boardwalks or walking tracks that cross intertidal areas, mangrove wetlands, seaweeds or seagrasses.

Acts, Regulations and Case Law Cited[530]

New South Wales

Acts

Carbon Rights Legislation Amendment Act 1998
Clean Waters Act 1970
Conveyancing Act 1919
Crown Lands Act 1989
Drainage Act 1939
Drainage Promotion Act 1865
Drainage Promotion Act 1901
Environmental Planning & Assessment Act 1979
Farm Water Supplies Act 1946
Fisheries Management Act 1994
Irrigation Act 1912
Local Government Act 1993
Marine Parks Act 1997
Maritime Services Act 1935
National Parks and Wildlife Act 1974
Native Vegetation Act 2003
Occupational Health and Safety Act 2000
Protection of the Environment Operations Act 1997
Rivers and Foreshores Improvement Act 1948
Roads Act 1993
Rural Fires Act 1997
Threatened Species Conservation Act 1995
Threatened Species Conservation Amendment (Biodiversity Banking) Act 2006
Water Act 1912
Water and Drainage Act 1902
Water Management Act 2000

Regulations

Environmental Planning & Assessment Model Provisions 1980
Environmental Planning & Assessment Regulation 2000
Management of Waters and Waterside Lands Regulation –N.S.W.
National Parks and Wildlife (Land Management) Regulation 1995
State Environmental Planning Policy No 4 – Development Without Consent and Miscellaneous Complying Development.
State Environmental Planning Policy No. 14 – Coastal Wetlands
State Environmental Planning Policy No. 71 – Coastal Protection
State Environmental Planning Policy (Infrastructure) 2007
Water Management (General) Regulation 2004

Commonwealth

Acts

Environment and Biodiversity Conservation Act 1999

Case Law

Bankstown City Council v Alamdo Holdings Pty Ltd (2005), HCA 46, 7 September 2005.
Cambridge Water Co v Eastern Counties Leather (1991), New Property Cases 147.
Dorrestijin v South Australian Planning Commission (1984) 59 ALJR 105; 54 LGRA 99.
Fishwatch Inc v Sawtell, Sawtell, Gray, Stark, Lismore City Council, Richmond River City Council, the Minister Administering the Crown Lands Act and the Minister for Planning (1994), unreported, Land and Environment Court of NSW, No 402412 of 1994, 11 March 1996.
Garrett v Freeman (No. 2) (2006), Land and Environment Court of NSW 334, 15 June 2006.
Gartner v Kidman (1962), 108 CLR 72.
Kempsey Shire Council v Berne (1997), unreported, Land and Environment Court of NSW, No 40195 of 1996, 13 June 1997.
Kempsey Shire Council v Lawrence (1995), Supreme Court of New South Wales, Court of Appeal Nos. CA 40310/95.
Tagget v Tweed Shire Council, NSW Court of Appeal, unreported, 3 November 1993, No.40520/92.
Van Son v Forestry Commission of New South Wales (1995), 86 LGERA 108, (1995) 6 BPR 13,945; (1995) Aust. Torts Reports 81-333.
Vaughan-Taylor v David Mitchell-Melcann Pty Limited & Minister for Minerals and Energy (1991) 73 LGRA 366.
Walker v Minister for Planning (2007). NSWLEC 741, 27 November 2007.

APPENDIX 4
GLOSSARY AND DEFINITIONS

Australian Height Datum (AHD) – a common national plane of level corresponding approximately to mean sea level.

Acid sulfate soils (ASS) – naturally occurring sediments and soils containing iron sulfides (principally pyrite) and/or their precursors or oxidation products. The exposure of the sulfides to oxygen by drainage or excavation leads to the generation of sulfuric acid. Acid sulfate soils include actual acid sulfate soils or potential acid sulfate soils. Actual and potential acid sulfate soils are often found in the same soil profile, with actual acid sulfate soils generally overlying potential acid sulfate soil horizons.

Acidity – the concentration of free hydrogen ions in solution below pH 7. For further detail see Green *et al*. (2006b).

Actual acid sulfate soils (AASS) – soils or sediments containing highly acidic soil horizons or layers resulting from the oxidation of soil materials that are rich in sulfides, primarily pyrite. This oxidation produces acidity in excess of the sediment's capacity to neutralise the acidity resulting in soils of pH 4 or less.

Alkalinity – the concentration of free hydrogen ions in solution above pH 7.

Alluvial – describes material deposited by, or in transit in, flowing water.

Anaerobic – conditions under which oxygen is absent.

Aquifer – rock or sediment that is sufficiently permeable to hold and transmit quantities of water at useable rates.

Backswamp – a swampy area of floodplain, located distally from a river or distributory stream and at the lowest low elevation part of the floodplain, usually at or near the alluvial-bedrock boundary.

Benthos – the animals and plants that live on the floor of the sea or lakes.

Biological oxygen demand (BOD) – the amount of oxygen required by microorganisms to break down organic matter. Biochemical oxygen demand is the amount of oxygen required for biodegradation of compounds by micro-organisms growing under aerobic (oxygenated) conditions.

Bicarbonate – a salt of carbonic acid, containing the HCO_3^{-1} ion.

Black water – very dark coloured anoxic water draining from floodplain backswamps after flooding. This water is derived from the decay of organic matter and typically has a foul odour, high iron levels, no oxygen and a high capacity to strip further oxygen away from any other waters it may come into contact with.

Bore – a vertical hole lined with tubing, usually steel or PVC, which allows the inflow of groundwater for the purposes of extraction or monitoring.

Buffering – the capacity of a system to resist change in pH when material of a different pH is added to it (this addition can be more or less acid/alkaline than the system).

Bulk density – a measure of a soil's mass per unit volume of soil. Factors that influence the measurement include; organic matter content, the porosity of the soil, and the soil structure these factors will intern control hydraulic conductivity. The equation used is Bulk Density (p) = Mass of oven dried soil / Total volume. A soil that has a well developed structure will become less dense as porosity increases; as a result the bulk density of the soil will decrease.

Cation – a positively charged ion in solution.

Chemical oxygen demand (COD) – is the amount of oxygen required for the chemical oxidation of compounds in water.

Chronic impacts – impacts due to long exposure, as opposed to acute impacts.

Clay – soil material composed of particles finer than 0.002 mm. When used as a soil texture group, such soil contains at least 35% clay.

Clustered bores – a multiple bore installation comprising adjacent piezometers drilled and screened at varying depths to intersect different aquifers or aquifer levels.

Containment – remediation strategies that aim to slow the rate at which surface and/or groundwaters enter the drainage system.

Contingency – an allowance for unforeseen circumstances made in estimates, usually expressed as a percentage.

Cusec – cubic metres (of water passing a point) per second.

Dilution – reduction in the concentration of solutes.

Dissolved oxygen (DO) – a measure of the level of oxygen dissolved in water.

Disturb – to move. In the context of ASS, disturb also includes to oxidise.

Drain – a purpose-built structure, including any linear modification to the original ground surface, intended to facilitate the gravity-driven removal of surface and/or near-surface waters from land. Drain does not include furrows constructed as part of a remediation strategy based on ridges and furrows to encourage the re-establishment of vegetation.

Dropboard – simple board or plate generally installed as an in-drain structure, at the end of a pipe, or in a headwork structure and modified to raise or lower water levels.

Dry acid containment strategy (DACS) – a containment strategy whereby evapotranspiration lowers watertables, such that rainfall event would have to be larger before ground waters rise to, and began discharging; in other words, to increase the time that influent, rather than an effluent, groundwater gradients prevail.

Electrical conductivity (EC) – a measure of the ability of water to conduct an electric current between immersed electrodes. The value measured relates to the nature and amount of salts dissolved in the sample and increases with increasing concentration. Usually quoted in microSiemens per centimetre (μS/cm).

Estuarine – of, pertaining to, or formed in an estuary, being the part of a river in which water levels are affected by tides. Estuarine also relates to those soil materials which have been under the influence of brackish water during their deposition.

Evaporation – the loss of water from an exposed surface. Evaporation is driven by the differential partial vapour pressure of water in a body and the atmosphere, and is affected by factors including solar radiant energy, wind, and near-surface boundary conditions.

Evapotranspiration – the loss of water from an area of land through the transpiration of water by plants and evaporation from the soil.

Fabric – the appearance of the soil material under a lens, including the presence or absence of peds and soil pores and their arrangement.

Fish flap – essentially a reverse floodgate, so that the flap structure opens when water is higher on the downstream side and closes on a falling tide to retain water in the swamp.

Flocculate – to form into a precipitate.

Floodgate – structures, generally comprising a top-hinged flap, that prevent water moving upstream, or up-drain. The weight of the flap and the head pressure on the downstream side seal the flap against a planar surface. When downstream levels fall, the water head behind the floodgate forces the flap open to permit drainage. In this document, the term ‘floodgate’ is used to include ‘tide gate’.

Floodplain – flat land beside a river that is normally inundated when the river overflows its banks during a flood.

Freshwater ponding – the creation of surface water of varying duration and depths in backswamps.

Geomorphology – relating to the form of the Earth, the general configuration of its surface, and the changes that take place in the evolution of landforms.

Groundwater – water contained within the voids and spaces in rocks or soils.

Groundwater gradient – the change in hydraulic head (water level) per unit distance. This is the driving force for water flow through soils.

Headworks – a structure positioned at an exit point of a containment unit such as a backswamp in order to control the flow of water. Includes floodgates, penstocks and sluicegates.

Holocene – the epoch occurring from the end of the last glacial event, taken to be 10 000 years ago, to the present.

Horizon – the individual soil layer, based on texture and colour, which differs from those above and below.

Hydraulic conductivity – the rate of horizontal groundwater flow through a unit area of an aquifer under a unit hydraulic gradient. Hydraulic conductivities are usually reported as m/day. Values commonly range between <0.0001 m/day to 300 m/day in ASS environments.

Hydraulic gradient – the slope of the water table or potentiometric surface. The hydraulic gradient is determined from the decline in groundwater level at two measuring points divided by the distance between them.

Hydrology – the study of the distribution and movement of water.

Hydroperiod – the period of inundation of an area by water including induced flows, flooding and tidal flows.

Hot spots – drained, low elevation, high risk ASS areas, responsible for severe soil and/or water acidification impacts. Includes most backswamps. Receiving waterbody is environmentally susceptible to the above (e.g. due to fresh waters and/or poor tidal flushing, area of economic importance to aquatic industries and/or important aquatic habitat, otherwise area of environmental sensitivity, etc.)

Infiltration – the process by which water at the land surface passes into the soil and descends through the unsaturated zone.

Intertidal – located between high and low tide.

Invert – the level to which a floodgate can drain.

Iron floc – particulate material, either as in suspension or subsequent precipitates, of a range of iron compounds.

Jarosite – a mineral, principally $KFe_3(SO_4)_2(OH)_6$, that forms under strongly oxidising conditions at pH below 3.7. Pale yellow deposits precipitated around old root channels and on ped faces are often jarosite, and are one of the most commonly used features to identify ASS.

K_{sat} – the rate at which water flows through the soil under saturated conditions.

Land capability – the ability of an area of land to sustain permanent agricultural or pastoral production without permanent damage.

Land grading – works carried out to increase the efficiency of drainage or irrigation schemes to remove isolated depressions and achieve an adequate slope. Also known as laser leveling or land forming.

Landform element – part of the landform characterised by a distinctive slope, shape, size, form and the type of geomorphic processes active on it.

Levee – very long, low ridge located immediately adjacent to a stream or river channel, built up by overbank flow.

Marine vegetation – vegetation that at any time of its life must inhabit water other than fresh water.

Monosulfide – FeS, formed by the reduction of Fe^{3+} to Fe^{2+} by bacterial action, which then combines with dissolved sulfide ions to produce a finely divided black ooze.

Monosulfidic black ooze (MBO) – anoxic, black, organic gel-like sludges that forms on the base of drains in ASS areas and contains high concentrations of monosulfides.

Nested bores – a groundwater installation comprising a single large diameter hole containing multiple piezometer casings screened at varying depths to intersect different aquifers or aquifer levels.

Neutralisation – the chemical process of adding a basic substance to an acid in order to raise the pH of a soil or liquid.

Organic matter (OM) – matter derived from living organisms and that contain compounds of carbon.

Organic carbon (OC) – carbon derived from living organisms.

Oxidation – the process of chemical combination with oxygen, resulting in the removal of one or more electrons from an atom or ion, groups of atoms or another electron acceptor.

Oxidation-reduction potential (ORP) – also known as ‘redox’ of an aqueous solution, relates to the transfer of electrons between chemical species, and refers to environmental conditions generally denoting the presence (oxidising) or absence (reducing) of oxygen, and the potential of a soil to oxidise or reduce chemical substances. Measured in millivolts or Eh (1Eh unit = 1mV).

Peat – organic matter, partly decomposed, formed under saturated, essentially anaerobic conditions.

Penstock – a gate that controls the flow of water.

Permeability – the relative ease with which a porous medium can transmit a fluid.

pH – a measure of the acidity or alkalinity of a soil. The negative logarithm of the concentration of H^+ in the water expressed in gram ions per litre of solution. Unless otherwise specified, measurement is in terms of 1:5 soil:H_2O mixture.

Piezometer – a pipe in which the elevation and quality of the groundwater level can be determined.

Plain – a large, very gently inclined or level element of unspecified geomorphic origin.

Ponded pasture – pastures that require or can tolerate periods of shallow inundation, generally in backswamps.

Porosity – the percentage of a rock or soil that is represented by open voids or spaces

Potential acid sulfate soil (PASS) – soils or sediments that contain iron sulfides or sulfidic material which have not been exposed to air and oxidised. The field pH of these soils in their unoxidised state is >4 and may be neutral or slightly alkaline.

Precipitation – the change of phase from solution to solid.

Pyrite – the mineral, FeS_2, or iron disulfide.

Quaternary – a period of geologic time covering the Holocene plus the Pleistocene, between approximately 2 million years ago and the present.

Receiving waters – waters on the downstream, or outside, of floodgates or headworks and which receive waters from drainage systems under effluent flow conditions.

Red spot disease – a disease of fish characterised by red skin lesions, which may lead to death. Also called epizootic ulcerative syndrome.

Reduction – the reverse of the process of oxidation.

Rehabilitation – to improve or recover natural functions and processes to whatever degree is considered feasible without necessarily achieving the pre-disturbance condition.

Remediation – to remedy an identified problem.

Restoration – to return a degraded ecosystem to its natural or original state by completely removing the cause of degradation.

Riparian – pertaining to rivers and streams.

Salinity – the total soluble mineral (dissolved solids) content of water.

Salt seepage – the movement of brackish or saline creek or drain waters through banks into fresher groundwaters.

Scald – a bare area, usually in the lowest parts of a backswamp, where the vegetation has been killed by acidic and/or saline conditions, and often peats or other organic surface soil layers removed by oxidation.

Schwertmannite – the mineral $Fe_8O_8(OH)_6(SO_4)$, occurring as a secondary precipitate forming crusts on material inundated by acidic (pH 3.2) drainage water.

Sensitive receiving waters – waters which, under normal flow conditions, will receive flow from ASS areas, and in which the assimilation capacity of those waters is low, taking into account the buffering capacity, inherent neutralising capacity and volume of the receiving water, and the exchange rates of those receiving waters with other waters.

Sluicegate – gates can be opened from either the top or the bottom, and which allows flows in either direction, and which allows the height of the water level behind the gate to be controlled.

Soil landscape – an area of land that has recognisable and describable topography and soils that are capable of being represented on maps and of being described by concise statements.

Soil material – a three-dimensional soil entity that has a degree of homogeneity and lateral continuity. Each soil material is defined and described in terms of its morphological properties.

Sulfides – mineral compounds containing sulfur and a metal, often iron. Oxidation of iron sulfides (mainly pyrite) is the primary source of acidity in acid sulfate soils.

Sulfidic – a soil layer in which contains sulfides. Also known as potential ASS.

Sulfuric – a soil layer in which sulfides have been oxidised to form sulfuric acid. Also known as actual ASS.

Supratidal – refers to the zone of inundation located above mean high tide and below the highest high tide.

Swamp – those areas dominated by ground surfaces and soils that are wet at least seasonally. Soil parent material includes large amounts of accumulated decayed organic matter. Watertables are frequently close to the surface. Landform elements may include swamps, relic ox-bows, abandoned channels and some lagoons and swales.

Tidal anomaly – the difference between the predicted tidal data and the actual tide measured, usually due to changes in atmospheric pressure.

Tidal planes – ocean tidal levels expressed as a series of tidal planes relative to a convenient datum below which the tide seldom falls The commonly adopted tidal planes for most of the NSW coast are based on the levels for Middle Head in Sydney Harbour, where the datum is Zero at Camp Cove which approximates to Indian Spring Low Water (ISLW). Tidal predictions for Middle Head in Sydney Harbour are presented in NSW Tide Charts prepared by the Department of Commerce.

Tidal gate – similar to a floodgate, but primarily intended to exclude tidal waters from tidal land.

Topsoil – a part of the soil profile, typically the A1 horizon, containing material that is usually darker, more fertile and better structured than the underlying layers.

Titratable actual acidity (TAA) – acidity that is largely readily soluble and exchangeable acidity measured in the laboratory by titration of a 1 M KCl suspension. TAA is a measure of the soluble and exchangeable acidity already present in the soil, often as a consequence of previous oxidation of sulfides.

Titratable peroxide acidity (TPA) – the net result of the reactions between the acidifying and neutralising components in the soil (following peroxide digestion). A TPA of zero indicates that for a finely ground sample (under laboratory oxidation conditions), the soil's buffering/acid neutralising capacity exceeds (or equals) the potential acidity from oxidation of any contained sulfides.

Titratable sulfidic acidity (TSA) – the sulfidic acidity component, determined by the difference between TPA and TAA.

Turbidity – a measure of the light-scattering properties of water, and indicates how much material is suspended in the water.

Water control structure (WCS) – an in-drain structure or a headwork that can be used to control the level of water on the upstream side.

Watertable – the surface of a body of groundwater within an unconfined aquifer at atmospheric pressure.

Well – a shallow shaft that is larger in diameter than a bore, but usually no greater than 1.5 m wide. Commonly, wells are less than 20 m deep and may be partially lined with concrete cylinders.

Wet acid containment strategy (WACS) – a containment strategy whereby acid and other oxidation products are contained within the soil and surface water by maximising the time that influent groundwater gradients prevail by raising water levels in the drain.

Wetland – land that is inundated with slow-moving or stationary shallow water on a temporary or a permanent basis.

APPENDIX 5 LIST OF ACRONYMS

AASS	Actual acid sulfate soil
AHD	Australian height datum
ALJR	Australian Law Journal Reports
ALS	Airborne laser scanner
ANZECC	Australia New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ARA	Appropriate Regulatory Authority
ASS	Acid sulfate soil
ASSMAC	Acid Sulfate Soils Management Advisory Committee
BOD	Biological oxygen demand
BPR	Butterworths Property Reports
CALM	[Department of] Conservation and Land Management.
CAMBA	China – Australia Migratory Bird Agreement
CL Act	*Crown Lands Act 1989*
CLR	Commonwealth Law Reports
COAG	Council of Australian Governments
COD	Chemical oxygen demand
CRCC	Clarence River County Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVC	Clarence Valley Council
DA	Development Application
DACS	Dry acid containment strategy
DCP	Development Control Plan
DECC	Department of Environment and Climate Change
DIPNR	Department of Infrastructure Planning and Natural Resources
DLWC	Department of Land and Water Conservation
DNR	Department of Natural Resources
DO	Dissolved oxygen
DoL	Department of Lands
DUAP	Department of Urban Affairs and Planning
DWE	Department of Water and Energy
EC	Electrical conductivity
EDO	Environmental Defender's Office
EIS	Environmental Impact Statement
EP&A Act	*Environmental Planning & Assessment Act 1979*
EPA	Environment Protection Authority
EPI	Environmental Planning Instrument
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ESD	Ecologically Sustainable Development
FM Act	*Fisheries Management Act 1994*
GDA	Geodetic Datum of Australia
GPS	Global positioning system
HCA	High Court of Australia
IGAE	Inter Governmental Agreement on the Environment
IPCC	Intergovernmental Panel on Climate Change
JAMBA	Japan – Australia Migratory Bird Agreement
LDO	Luminescent Dissolved Oxygen
LEP	Local Environmental Plan
LG Act	*Local Government Act 1993*
LGERA	Local Government Environmental Reports of Australia
LGRA	Local Government Reports of Australia
MBO	Monosulfidic black ooze
MHL	Manly Hydraulics Laboratory
N	Nitrogen
NES	[Matter of] National Environmental Significance (NES)
NGO	Non-Governmental Organisation
NPW Act	*National Parks and Wildlife Act 1974*
NPWS	National Parks and Wildlife Service
NRCMA	Northern Rivers Catchment Management Authority
NSWGO	New South Wales Greenhouse Office
NSWLEC	New South Wales Land and Environment Court
NWPASS	National Working Party on Acid Sulfate Soils
NWQMS	National Water Quality Management Strategy
OH&S Act	*Occupational Health and Safety Act 2000*
ORP	Oxidation-reduction potential
P	Phosphorus
PASS	Potential acid sulfate soil
POEO Act	*Protection of the Environment Operations Act 1997*
PWD	Public Works Department
RAMA	Routine agricultural management activity
REP	Regional Environmental Plan
RFI Act	*Rivers and Foreshores Improvement Act 1948*
RoKAMBA	Republic of Korea – Australia Migratory Bird Agreement
SALIS	Soil and Land Information System
Scr	Sulfur, chromium reducible
SIS	Species Impact Statement
SCU	Southern Cross University
SEPP	State Environmental Planning Policy
TAA	Titratable actual acidity
TPA	Titratable peroxide acidity
TRG	Technical Reference Group
TSA	Titratable sulfidic acidity
TSC Act	*Threatened Species Conservation Act 1995*
WACS	Wet acid containment strategy
WCS	Water control structure
WM Act	*Water Management Act 2000*

REFERENCES

Aaso, T. (2004). Partridge Creek Acid Sulfate Soil Hot Spot Remediation Program Final Report. Port Macquarie-Hastings Council.

Aaso, T., Rogers, M., Hicks, W., Bowman, W. and Pensini, D. (2002a). Short and long-term management strategies for Partridge Creek, New South Wales, Australia. Unpubl.

Aaso, T., Breckell, G., and Cibilic, A. (2002b). Using automatic tidal floodgates for controlled tidal exchange in coastal floodplain drains in. eastern Australia Poster paper. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia.

Adam, P., Urwin, N., Weiner, P. and Sim, I. (1985). Coastal wetlands of New South Wales. A survey and report prepared for the Coastal Council of New South Wales.

Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment (JAMBA) 1974 ATS 1981 No. 6, UNTS 1241 p 385.

Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment (CAMBA) 1986 ATS 1988 No. 22, UNTS 1535 p. 243.

Ahern, C., Stone, Y. and Blunden, B. (1998a). Acid Sulfate Soil Assessment Guidelines. In: Stone, Y., Ahern, C., and Blunden, B. (1998). Acid Sulfate Soil Manual. ASSMAC, Wollongbar, NSW.

Ahern, C., Stone, Y. and Blunden, B. (1998b). Acid Sulfate Soil Management Guidelines. In: Stone, Y., Ahern, C., and Blunden, B. (1998). Acid Sulfate Soil Manual. ASSMAC, Wollongbar, NSW.

Ahern, C., Blunden, B. and Stone, Y. (1998c). Acid Sulfate Soils Laboratory Methods Guidelines. In: Stone, Y., Ahern, C., and Blunden, B. (1998). Acid Sulfate Soil Manual. ASSMAC, Wollongbar, NSW.

Ahern C. R., McElnea, A.E. and Sullivan, L.A. (2004). Acid Sulfate Soils Laboratory Methods Guidelines. Queensland Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia.

Andersson, K. (1995). The impact of sugar cane production on the acidity and humic substances of acid sulphate soils. B.Sc. thesis, School of Geography, UNSW.

Aretino, B., Holland, P., Matysek, A. and Peterson, D. (2001). Cost sharing for biodiversity conservation: a conceptual framework. Productivity Commission, Canberra.

Aslin, H.J. and Brown, V.A. (2004). Towards Whole of Community Engagement: A Practical Toolkit. Department of Agriculture, Fisheries and Forestry, Bureau of Rural Sciences, Canberra.

ASSMAC (1999). Financial assistance options to improve acid sulfate soil management and improve quality of drainage water. Discussion paper prepared by ASSMAC for Water CEOs. November 1999.

Atkinson, G.A. (1999). Soil landscapes of the Kempsey-Korogoro Point 1:100,000 sheet. Report and Map. DLWC.

Atkinson, G. (2006). Monitoring the acid sulfate soil indicator. Unpubl. paper. NSW Department of Natural Resources.

Atkinson, G. and Tulau, M.J. (1999). A framework for integrating ASS remediation strategies. In: Slavich, P. (ed.) (2000). Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp. 29-36.

Atkinson, G., Aaso, T. and Rea, S. (2002a). Drainage Network Mapping on the New South Wales North Coast. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia.

Atkinson, G.A., Currie, B.A. and Sayer, G.C. (2002b). Elevation survey of acid sulfate soil terrain using real time kinematic global positioning systems. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia, pp. 99-100.

Atkinson, G.A. and Gardner, G. (2003). Cattai Wetlands out of the Mire with Innovative Management and Funding Solutions. 12th Annual NSW Coastal Conference, 5-6 November 2003, Port Macquarie.

Australia-New Zealand Environment and Conservation Council (2000). Australian Guidelines for Water Quality Monitoring and Reporting. Available at: http://www.mincos.gov.au/pub_agwq.html and http://www.deh.gov.au/water/quality/nwqms/monitoring.html

Australian Society of Soil Science Incorporated (2006). Profile. The official newsletter of the Australian Society of Soil Science Incorporated. Issue 144, August 2006, Part 2, p. 5. Available at: http://www.asssi.asn.au/asssi/flash/content/news&events/documents/Profile144August2006_000.pdf.

Bates, G.M. (2002). Environmental Law in Australia. 5th edition. Lexis Nexis Butterworths.

Beattie, R. N., Nielsen, P.J., Rayment, G.E., Aitken, R.L., McQuire, P.J., and Quirk, R.G. (2001). Achieving self-regulation for drain maintenance in the NSW sugar industry. *Proc. Aust. Soc. Sugar Cane Technol*. 23: 51-57.

Beattie, R. (2005). 2005 NSW sugar industry audit report. NSW Sugar Milling Co-operative Ltd.

Beavis, S., Beavis, F., Sommerville, P. and Welch, S.A. (2005). Spatial and temporal variability of acidity at a coastal acid sulfate soil site II: a time for change. In: Roach, I.C. (ed.) (2005). Regolith 2005 – Ten Years of CRC LEME, pp. 22-26.

Becker, H. and Vanclay, F. (eds) 2003. The International Handbook of Social Impact Assessment, Cheltenham (UK): Edward Elgar.

Benkendorff, K. (n.d.). Ecological Factors in Environmental Impact Assessment. Position Statement by the Ecological Society of Australia. Available at: http://www.ecolsoc.org.au/Position_papers/EIA.htm

Blunden, B. and Indraratna, B. (2001). Pyrite oxidation model for assessing ground-water management strategies in acid sulfate soils. *J. of Geotechnical and Geoenvironmental Engineering* 127: 146-157.

Blunden, B., Indraratna, I. and Morrison, J. (1999). Management of acid generation in sulfidic soils by drain manipulation: a case study. In: Slavich, P. (ed.) Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp 59-69.

Boast, C.W. and Langebartel, R.G. (1984). Shape factors for seepage into pits. *Soil Science Society of America* 48: 10-15.

Bolton, K.G.E. (2001). A feasibility study of effluent reuse for acid sulphate soil management and wetland regeneration at West Byron. Prepared or Byron Shire Council

Bolton, K. (2003). Drain monitoring report [West Byron]. SCU.

Bolton, K.G.E. and Warner, A.P. (2002). Effluent reuse for acid sulfate soil management, wetland regeneration and carbon credits. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; p. 102.

Bolton, K.G.E., Sullivan, L.A., Rosicky, M.A., Ward, N.J., Balson, A. and Bruce, J.J. (2002). Changes in soil and water chemistry in response to effluent irrigation in a peat acid sulphate soil. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp 20-21.

Bouma, J. (1991). Influence of soil macroporosity on environmental quality. In: *Advances in Agronomy* 46: 1-37. (Eds D.L. Sparks, Academic Press.)

Bouwer, H. and Rice, R.C. (1983). The pit bailing method for hydraulic conductivity measurement of isotropic or anisotropic soil. *American Society of Agricultural Engineering* 26: 1435-1439.

Burton, E.D., Bush, R.T., Sullivan, L.A. and Mitchell, D.R.G. (in press). Reductive transformation of iron and sulfur in schwertmannite-rich accumulations associated with acidified coastal lowlands. *Geochimica et Cosmochimica Acta*.

Bush, R. (ed.) Proceedings, National Conference on Acid Sulphate Soils, 24-25 June 1993, All Seasons Greenmount Beach Resort, Coolangatta.

Bush, R.T., Fyfe, D. and Sullivan, L.A. (2002). Distribution and occurrence of monosulfidic black ooze (MBO) in Coastal Acid Sulfate Soil landscapes. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia.

Bush, R.T., Keene, A., Sullivan, L.A. and Bush, M.L. (2006). Water quality analysis of ASS hot spots. An investigation on behalf of the NSW Department of Natural Resources. Prepared by the Centre for Coastal Management, Southern Cross University.

Carson, L. (2001). Ideas for community consultation : discussion on principles & procedures for making consultation work. Report prepared for the NSW Department of Urban Affairs & Planning planFIRST MI12759. Available at: http://www.planning.nsw.gov.au/planfirst/pdf/principles_procedures_final.pdf#search=%22community%20consultation%20nsw%20gov%20au%22

Chapman, G.A. and Murphy, C.L. (1989). Soil landscapes of the Sydney 1:100,000 Sheet. Soil Conservation Service of NSW.

Cibilic, A. and Henderson, S. (2004). Comparison of wet and dry acid groundwater containment strategies. Poster, Estuaries and Change Conference, Ballina, 20-21 June 2004.

Clarence Floodplain Services (2006a). Floodgate operations training. Clarence Valley Council.

Clarence Floodplain Services (2006b). Clarence Floodplain Project Newsletter, Dec 06.

Coakes, S. (1999). Social impact assessment. A policy maker's guide to developing Social Impact Assessment programs. Bureau of Resource Sciences, Agriculture, Fisheries and Forestry Australia, Canberra.

Collins, R. (2006). Tweed research projects – Blacks Drain. Presentation to Northern Rivers Floodplain Network, Tweed, 20-21 July 2006.

Convention on Wetlands of International Importance Especially as Waterfowl Habitat 1971 (Ramsar Convention) ATS 1975 No 48, UNTS 996 p. 245.

Cook, F.J., Rassam, D.W., Blunden, B., Gardner, E.A. and Carlin, G.D. (1999). Irrigation and drainage: effects on acidity export from acid sulphate soils. In: Slavich, P. (ed.) Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp. 78-87.

Cook, F.J., Rassam, D.W., Gardner, E.A., Carlin, G.D. and Millar, G.E. (2000). Drained acid sulfate soils: pathways of acid export. In: Ahern, C.R., Hey, K.M., Watling, K.M. and Eldershaw, V.J. (eds) (2000). Acid Sulfate Soils: Environmental Issues, Assessment and Management, Technical Papers, Brisbane, 20 - 22 June 2000. Department of Natural Resources, Indooroopilly, Queensland, Australia.

Cook, F.J., Carlin, G.D., Dobos, S. and Millar, G.E. (2002). Oxidation rate of pyrite in acid sulphate soils: In situ measurements and modelling. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp. 36 – 37.

Cook, F.J., Dobos, S.K., Carlin, D.B. and Millar, G.E. (2004). Oxidation rate of pyrite in acid sulfate soils: in situ measurements and modelling. *Aust. J. Soil Research* 42: 499-507.

Curnow, P. and Fitz-Gerald, L. (2006). Biobanking in New South Wales: Legal issues in the design and implementation of a biodiversity offsets and banking scheme. Environmental and Planning Law Journal 23(4) August 2006: 298 - 308.

Davies, N. (2004). Initial hydrodynamic tidal survey for floodgate fish passage enhancement, Micalo Island. In: Walsh, S. and Copeland, C. (2004). North Coast Floodgate Project Final Report 2002-2004, pp. 66-78.

Dear, S.E., Moore, N.G., Dobos, S.K., Watling, K.M. and Ahern, C.R. (2002). Soil Management Guidelines. In Queensland Acid Sulfate Soil Technical Manual. Department of Natural Resources and Mines, Indooroopilly, Queensland, Australia.

Dear, S.E., Moore, N.G., Fahl, D., Dobos, S.K. and Watling, K.M. (eds.) (2004). Legislation and Policy Guide. In: Queensland Acid Sulfate Soil Technical Manual. Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia.

Deeley, D.M. and Paling, E.I. (1999). Assessing the ecological health of estuaries in Australia. Marine and Freshwater Research Laboratory, Institute for Environmental Science Murdoch University. LWRRDC Occasional Paper 17/99 (Urban Subprogram, Report No. 10), December 1999. Available at: http://www.precisioninfo.com/rivers_org/au/archive/?doc_id=9

Denmead, O.T., Macdonald, B.C.T., Bryant, G., Reilly, R., Griffith, D.W.T., Stainlay, W., White, I. and. Melville, M.D. (2005). Gaseous nitrogen losses from acid sulfate sugarcane soils on the coastal lowlands. *Proceedings Australian Society of Sugar Cane Technologists* 27: 211-219.

Denmead, O.T., Macdonald, B.C.T., Bryant, G., Wang, W., White, I. and. Moody, P. (2007). Greenhouse gas emissions from sugarcane soils and nitrogen fertilizer management: II. *Proceedings Australian Society of Sugar Cane Technologists* 29: 97-105.

Dent, D. (1986). Acid Sulphate Soils: A Baseline for Research and Development. Publication 39, International Institute for Land Reclamation and Improvement, Wageningen, Netherlands.

Department of Commerce (2006). NSW Tide Charts.

Department of Environment and Heritage (n.d.). Framework for Marine and Estuarine Water Quality Protection. Available at: http://www.deh.gov.au/coasts/pollution/cci/framework/pubs/framework.pdf

Department of Infrastructure, Planning and Natural Resources (2001). Acid Sulfate Soil Remediation Hot Spot Remediation Project Management Plan. December 2000.

Department of Infrastructure, Planning and Natural Resources (2005a). Floodplain Development Manual. The management of flood liable land. April 2005.

Department of Infrastructure, Planning and Natural Resources (2005b). Acid Sulfate Soil Hot Spot Remediation Project. Final Project Report to the Environmental Trust. August 2005.

Department of Land and Water Conservation (1996). NSW Wetlands Management Policy. DLWC, Sydney.

Department of Land and Water Conservation (1997). NSW Weirs Policy. NSW Government.

Department of Land and Water Conservation (1998a). NSW State Groundwater Quality Protection Policy. Government.

Department of Land and Water Conservation (1998b). Constructed Wetlands Manual.

Department of Land and Water Conservation (1999). Interim guidelines for targeted and general flora and fauna surveys under the Native Vegetation Conservation Act 1997. DLWC, Sydney.

Department of Land and Water Conservation (2000). Drain Network Mapping, unpubl.

Department of Planning (2006). Far North Coast Regional Strategy Draft. Available at: http://www.planning.nsw.gov.au/plansforaction/northcoast.asp

Department of Urban Affairs and Planning (1995a). Is an EIS Required?

Department of Urban Affairs and Planning (1995b). *Threatened Species Conservation Act*: Circular A13, 22 December 1995, 8 pp.

Department of Urban Affairs and Planning (1999). Guidelines, Wetland Restoration Plans.

Desmier, R., Macdonald, B.C.T., Melville, M.D. and Waite, T.D. (2002). Design, construction and performance of passive and active treatment systems to decrease the acidity export from acid sulphate soils in the Tweed Shire, NSW (Australia). In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia, pp. 71 - 72.

Donner, E.N.S. and Melville, M.D. (2002). The effects of floodplain land use on the chemistry and hydrology of coastal acid sulfate soils. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia, pp. 1-2.

Dwyer, P. (2004). Legislation overview. Increased coordination of floodplain legislation. In: Walsh, S. and Copeland, C. (2004). North Coast Floodplain Project. Final Report 2002-2004. NSW Department of Primary Industries, pp. 122-124.

Ecologically Sustainable Development Steering Committee (1992). National Strategy for Ecologically Sustainable Development. Department of Environment and Heritage. Available at: http://www.deh.gov.au/esd/national/nsesd/strategy/intro.html

Eddie, M.W. (2000). Soil landscapes of the Macksville - Nambucca 1:100,000 Sheet. Report and Map. DLWC.

Eddie, M.W. (n.d). Soil landscapes of the Camden Haven 1:100,000 Sheet. Report and Map. Draft. DNR.

Emery, K.A. (1985) Rural Land Capability Mapping, Soil Conservation Service of NSW, Sydney.

Environment Australia (2001). Directory of Important Wetlands in Australia. Third edition. Available at: http://www.environment.gov.au/water/wetlands/database/directory/index.html

Environmental Defender's Office (2006). Rural landholder's guide to environmental law in New South Wales. EDO and Hunter-Central Rivers Catchment Management Authority.

Environment Protection Authority (19997). State of the Environment Report 1997. Chapter 3.7. Available at: http://www.epa.nsw.gov.au/soe/97/ch3/15_4.htm

Environment Protection Authority (2000). State of the Environment Report.

Evans, G. (1999). Returning the Tide to Hexham Swamp, While Retaining Flood Protection. Proceedings, 39th Annual Conference NSW Floodplain Management Authorities, Tamworth May 1999.

Farrier, D. (1995a). Conserving biodiversity on private land: incentives for management or compensation for lost expectations? *The Harvard Environmental Law Review* 19 (2): 303-408.

Farrier, D. (1995b). Policy instruments for conserving biodiversity on private land. In: Bradstock, R.A., Auld, T.D., Keith, D.A., Kingsford, R.T. Lunney, D. and Sivertsen, D.P. (eds) (1995). Conserving Biodiversity: Threats and Solutions, Surrey Beatty & Sons, Sydney, pp. 337-359.

Farrier, D. (1995c). Off-reserve management and the conservation of biodiversity, with a particular reference to the management of land in private ownership. Consultant's Report to the Tasmanian Forests and Forest Industry Council, May 1995.

Farrier, D., Lyster, R., Pearson, L. (1999). The Environmental Law Handbook, 3rd edition. Planning and Land Use in New South Wales. Redfern Legal Centre Publishing.

Fleming, J.G. (1987). The Law of Torts, 8th edition, Law Book Company, Australia.

Framework for Marine and Estuarine Water Quality Protection (2002). Environment Australia.

Department of the Environment and Heritage, Canberra. Available at: http://www.biodiversity.ea.gov.au/coasts/pollution/cci/framework/pubs/framework.pdf

Gardner, A and Setter, T. (1998). Legal powers and responsibilities for managing diffuse pollution from agriculture: Regulating the flow of water – 'the common enemy'. *Australasian J. of Natural Resources Law and Policy* 5(2):187-224.

George, B.H. (1999). A role for afforestation in acid sulphate soil management. In: Slavich, P. (ed.) (2000). Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp 103-110.

George, B.H. and Heagney, G.A. (2002). Establishing trees in acid sulfate soil: early survival and growth; tree water use and acid generation. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp 135 - 136.

Glamore, W. (2004). Evaluation and analysis of acid sulfate soil remediation via tidal restoration. PhD thesis, University of Wollongong.

Glamore, W. C. and Indraratna, B. (2006). A multi-staged management strategy for restoring tidal flushing. Unpubl. Paper, Water Research Laboratory, School of Civil and Environmental Engineering, UNSW and Faculty of Environmental Engineering, University of Wollongong.

Goodrick, G. N. (1970). A survey of wetlands of coastal New South Wales. Tech. Mem. No5, CSIRO Div. Wildlife Research.

Graham, J., Duggin, J. and Frazier, P. (2004). Vegetation responses to tidal inundation of Little Broadwater wetland. Progress report: June 2004. Appendix 3 in: Walsh, S. and Copeland, C. (2004). North Coast Floodplain Project. Final Report 2002-2004. NSW Department of Primary Industries, pp. 57-65.

Green, R., Macdonald, B.C.T., Melville, M.D. and Waite, T.D. (2006a). Hydrochemistry of episodic drainage waters discharged from an acid sulfate soil affected environment. *J. Hydrology* 325: 356-375.

Green, R., Waite, T.D., Melville, M.D. and Macdonald, B.C.T. (2006b). Characteristics of acidity in acid sulfate soil drainage waters, McLeods Creek, Northeastern NSW, Australia. *Environmental Chemistry* 3: 225-232.

Gunningham, N. (2007). Incentives to improve farm management: EMS, supply-chains and civil society. *J. of Environmental Management* 82: 302-310.

Hashimoto, R. and Troedson, A. (2005). Quaternary Geology Mapping Project. Geological Survey of NSW.

Haskins, P.G. (1999). Active floodgate management. In: Slavich, P. (ed.) (2000). Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp 70-77.

Haskins, P.G. (2004). A DLWC perspective. In: Walsh, S. and Copeland, C. (2004). North Coast Floodplain Project. Final Report 2002-2004. NSW Department of Primary Industries, pp. 182-185.

Haskins, P.G. (2006). Environmental Services Scheme, Illalong Project – Clybucca (Kempsey), NSW. Proposal to Monitor Water Quality and Groundwater Levels. Unpubl.

Haskins, P.G. (in press). Clybucca Environmental Services Scheme Monitoring report.

Hastings Council (2002). Progress report. Remediation of acidic discharges from Partridge Creek, Hastings River, New South Wales. Progress report to the Commonwealth Acid Sulfate Soil Project. Progress report up to 30 June 2002.

Havilah, E.J. and Launders, T.E. (1996). Pastures for coastal floodplains with acid sulfate soils. In: Smith, R.J. and Smith, H.J. (1996). Proceedings of the 2nd National Conference of Acid Sulfate Soils, held at Coffs Harbour 5-6 September 1996. Published by Robert J Smith and Associates and ASSMAC, pp 152 - 159.

Haworth, R.J., Baker, R.G.V. and Flood, P.G. (2002). Predicted and observed Holocene sea-levels on the Australia coast: what do they indicate about hydro-isostatic models in far-fields sites? *J. of Quaternary Science* 17(5-6): 581-591.

Hazelton, P.A. (1992). Soil landscapes of the Kiama 1:100,000 Sheet. Report and Map. Soil Conservation Service of NSW.

Hazelton, P.A. and Tille, P.J. (1990). Soil landscapes of the Wollongong - Port Hacking 1:100,000 Sheet. Report and Map. Soil Conservation Service of NSW.

Henderson, S., Kemsley, R., Smith, B., Hayes, M., Devine, B., Tulau, M. and Atkinson, G. (2002). Broadacre acid sulfate soils remediation and management trials, Macleay River, New South Wales Australia. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; p. 141.

Hicks, W. (2001). Monitoring and evaluation strategy for CASSP East Trinity Demonstration. CSIRO.

Hicks, W.S., Bowman, G.M. and Fitzpatrick, R.W. (1999). East Trinity Acid Sulfate Soils, Part 1: Environmental Hazards. CSIRO Land & Water Technical Report. 14/99, p. 15. Available at: http://www.clw.csiro.au/publications/technical99/tr14-99.pdf

Hicks, W.S., Bowman, G.M. and Fitzpatrick, R.W. (2002). Assessing the acidity hazard of acid sulphate discharge waters. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp 34 – 35.

Independent Advisory Committee on Socio-Economic Analysis (IACSEA) (1998). Socio-economic Assessment Guidelines for River and Groundwater Management Committees.

Independent Advisory Committee on Socio-Economic Analysis (IACSEA) (2000). Glossary of Techniques for the Analysis of the Socio-economic effects of Water Reform.

Indraratna, B., Glamore, W.C. and Tularam, G.A. (2002). The effects of tidal buffering on acid sulphate soil environments in coastal areas on New South Wales. *Geotechnical and Geological Engineering* 20: 181-199.

Intergovernmental Panel on Climate Change (2001a). Climate Change 2001: IPCC third assessment report. Working Group I: The Scientific Basis. Available at: http://www.grida.no/climate/ipcc_tar/wg1/408.htm

Intergovernmental Panel on Climate Change (2001b). Climate Change 2001: IPCC third assessment report. Working Group II: Impacts, Adaptation and Vulnerability. 6. Coastal zones and marine ecosystems. 6.2. State of Knowledge. Available at: http://www.grida.no/climate/ipcc_tar/wg2/286.htm

Intergovernmental Panel on Climate Change (2007). The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf

Isaacson, L., Kirste, D., Beavis, S., and Welch, S.A. (2006). Controls of acid, salt and metal distribution at a coastal acid sulfate soil site. Regolith 2006 – Consolidation and dispersion of ideas. CRC Leme, pp. 166- 170.

Johnston, S. (1995). The Effects of Acid Sulphate Soils on Water Quality in the Maria River Estuary, NSW. Report prepared for Ocean Watch, DPW, DLWC, Hastings Council, CFAC and Kempsey Shire Council.

Johnston, S.G. and Slavich, P.G. (2003). Hydraulic conductivity – a simple field test for shallow coastal acid sulfate soils. NSW Agriculture, Wollongbar.

Johnston, S., Slavich, P. and Hirst, P. (2002). Sources of salinity in low elevation coastal floodplain soil landscapes and effects on cane yield. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp. 149 - 150.

Johnston, S., Kroon, F., Slavich, P., Cibilic, A. and Bruce, A. (2003a). Restoring the balance. Guidelines for managing floodgates and drainage systems on coastal floodplains. NSW Agriculture, Wollongbar NSW.

Johnston, S.G., Slavich, P.G., Hirst, P. (2003b). Artificial drainage of floodwaters from sulfidic backswamps: effects on deoxygenation in an Australian estuary. *Marine and Freshwater Research* 54: 781-795.

Johnston, S.G., Slavich, P.G., Hirst, P. (2003c). Alteration of groundwater and sediment geochemistry in a sulfidic backswamp due to *Melaleuca quinquenervia* encroachment. *Aust. J. Soil Res*. 41: 1343–1367.

Johnston, S.G., Slavich, P.G. and Hirst, P. (2003d). *Hydraulic conductivity in sulfuric horizons at Partridge Creek ASS hot spot*. Report prepared for Hastings Council by NSW Agriculture. Report number DAN13/1 July 2003.

Johnston, S.G., Slavich, P.G., Hirst, P. (2004a). The acid flux dynamics of two artificial drains in acid sulphate soil backswamps on the Clarence River floodplain, Australia. *Aust. J. Soil Res*. 42: 623–637.

Johnston, S.G., Slavich, P.G. and Hirst, P. (2004b). The effects of a weir on reducing acid flux from a drained coastal acid sulfate soil backswamp. *Agricultural Water Management* 69: 43-67.

Johnston, S.G., Slavich, P.G., Hirst, P. (2005a). Changes in surface water quality after inundation of acid sulfate soils, of different vegetation cover. *Aust. J. Soil Res*. 43: 1–12.

Johnston, S.G., Slavich, P.G. and Hirst, P. (2005b). Opening floodgates in coastal floodplain drains: effects on tidal forcing and lateral transport of solutes in adjacent groundwater. *Agricultural Water Management.* 74(1): 23-46.

Johnston, S.G., Slavich, P.G. and Hirst, P. (2005c). The impact of controlled tidal exchange on drainage water quality in acid sulphate soil backswamps. *Agricultural Water Management* 73: 87-111.

Jones, D (1998). Acid Sulfate Soils – The Environmental Timebomb. Unpubl. B. Sc. (Env)/ LLB thesis, Centre for Natural Resources Law and Policy, Faculty of Law, University of Wollongong, NSW.

Jones, D. (2000). Acid sulphate soils: the environmental time bomb. *Australasian Journal of Natural Resources Law & Policy* 7(1): 1-46.

Kempsey Shire Council (2004a). Clybucca Hot Spot Final Report.

Kempsey Shire Council (2004b). Yarrabee Park Wetland Draft Restoration Plan.

Kinsela, A.S. and Melville, M.D. (2004). Mechanisms of acid sulfate soil oxidation and leaching under sugarcane cropping. *Aust, J. Soil Res*. 42: 569-578.

Kroon, F., Bruce, A.M., Housefield, G.P. and Creese, R.G. (2004). Coastal floodplain management in eastern Australia: barriers to fish and invertebrate recruitment in acid sulphate soil catchments. NSW Department of Primary Industries - Fisheries Final Report Series No. 67, FRDC Project 98/215, Final Report.

Lawrie, R. and Eldridge, S. (2006). Reduction on acid discharge to the Shoalhaven-Crookhaven estuary. NSW DPI, Richmond.

Lee, E., Baird, M., Lloyd, I. (1998) State Environmental Planning Policy No.46 – Protection and Management of Native Vegetation. *Environmental and Planning Law Journal* 15(2):127.

Lipton, J.D. (1995). Common law liability for environmental damage' (1995) 69(11) *Law Institute Journal* 1120-1123.

Lloyd, R. (2004). Winches – Clarence. In: Walsh, S. and Copeland, C. (2004). North Coast Floodplain Project. Final Report 2002-2004. NSW Department of Primary Industries, pp. 134-140.

Macdonald, B.C.T., Quirk, R.G., Melville, M.D., Waite, T.D., White, I., Desmier, R., Smith, J., Tunks, M. and Beattie, R.N. (2002). Sugar cane and acid sulphate soils: techniques for reduction of acid discharge. *Proc. Aust. Soc. Sugar Cane Technologists* 24: 311-315.

Macdonald, B.C.T., Denmead, O.T., White. I., Melville, M.D. (2004). Natural sulfur dioxide emissions from sulfuric soils. *Atmospheric Environment* 38: 1473-1480.

Manly Hydraulics Laboratory (2006). Saltwater Wetlands Rehabilitation Manual. NSW Department of Natural Resources, NSW Department of Commerce, Manly Hydraulics Laboratory. Report No. MHL1441. Commerce Report No. 04nnn.

Marsden, J. (2005). Liabilities of civic leaders, elected personnel and senior staff and other legal aspects of flood plain management. Proceedings, 45th Annual NSW Floodplain Management Conference, Narooma.

Matthei, L.E. (1995). Soil landscapes of the Newcastle 1:100,000 Sheet. Report and Map. DLWC.

McDonald, R.C. and Isbell, R.F. (1990). Soil profile. In: McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1990). Australian Soil and Land Survey Field Handbook, 2nd edition, Inkata Press, pp. 103-152.

McKenzie, N. Henderson, B. and McDonald, W. (2002). Monitoring Soil Change. Principles and practices for Australian conditions. CSIRO Land & Water, CSIRO Mathematical & Information Sciences. CSIRO Land and Water Technical Report 18/02, May 2002. Available at: http://audit.ea.gov.au/anra/land/soil_change/AUS.cfm?region_code=AUS

Miford, H.B.(1996). Soil landscapes of the Coffs Harbour 1:100,000 Sheet. Report and Map. DLWC.

Milford, H.B., McGaw, A,J.E. and Nixon, K.J. (2001). Soil Data Entry Handbook the NSW Soil And Land Information System (SALIS), 3rd Edition. NSW Department of Land and Water Conservation, Parramatta. Available at: http://www.naturalresources.nsw.gov.au/care/soil/salis/pdfs/salis_soil_data_entry_handbook.pdf

Millham, N.P. and Howes, B.L. (1995). A comparison of methods to determine K in a shallow coastal aquifer. *Groundwater* 33: 49-57.

Mobbs, M. (1996). Incentives for keeping and restoring vegetation. A guide for Australian landholders and governments. Department of Primary Industries and Energy, Canberra.

Morand, D.T. (1994). Soil landscapes of the Lismore-Ballina 1:100,000 Sheet. Report and Map. CaLM.

Morand, D.T. (1996). Soil landscapes of the Murwillumbah 1:100,000 Sheet. Report and Map. DLWC.

Morand, D.T. (2001). Soil landscapes of the Woodburn 1:100,000 Sheet. Report and Map. DLWC.

Morgan, M. and Papworth, W. (2004). Broughton Creek Acid Sulfate Soil Hot Spot Final Report, June 2004. Shoalhaven City Council,

Mulvey, P. (1993) Pollution, prevention and management of sulfuric clays and sands. In; Bush, R. (ed) Proceedings of the First National Conference on Acid Sulfate Soils. 24-25 June. Coolangatta.

Murphy, C.L. (1993). Soil landscapes of the Gosford-Lake Macquarie 1:100,000 Sheet. Report and Map. Soil Conservation Service of NSW.

Murphy, C.L. (1995). Soil landscapes of the Port Stephens 1:100,000 Sheet. Report and Map. DLWC.

Murphy, C.L. (n.d.). Soil landscapes of the Buladelah 1:100,000 Sheet. Report and Map. DNR.

Murray, M., Bell, S., Hoye, G. (2002). *Flora and fauna survey guidelines: Lower Hunter Central Coast Region 2002*. Lower Hunter & Central Coast Regional Environmental Management Strategy, NSW. Available at: http://www.cessnock.nsw.gov.au/Cessnock/uploadedFiles/Council_Services/Building_and_Development/Development_Control_Plans/DCP56.pdf

National Parks and Wildlife Service (1996a). Threatened Species Conservation Act: Circular No.1: 24 January 1996, 8 pp.

National Parks and Wildlife Service (1996b). Information Circular No.2 – Threatened Species Assessment under the *EP&A Act*: The 8-part Test of Significance, NPWS, Hurstville, November 1996.

National Strategy for Ecologically Sustainable Development. (1992). Department of Environment and Heritage, Canberra. Available at: http://www.deh.gov.au/esd/national/nsesd/

National Working Party on Acid Sulfate Soils (1999). National Strategy for the Management of Coastal Acid Sulfate Soils. Prepared on behalf of the Standing Committee on Agriculture and Resource Management Council of Australia and New Zealand. Published by NSW Agriculture, Wollongbar Agricultural Institute, Wollongbar NSW.

Natural Resources Commission (2005). Recommendations State-wide Standards and Targets. September 2005. Attachment 2 Supporting Information for State-wide Targets.

Naylor, S.D., Chapman, G.A., Atkinson, G., Murphy, C.L., Tulau, M.J., Flewin, T.C., Milford, H.B., and Morand, D.T. (1997). Guidelines for the Use of Acid Sulphate Soil Risk Maps. Department of Land and Water Conservation.

NSW Agriculture (1998). Policy for Sustainable Agriculture. Available at: http://www.agric.nsw.gov.au/reader/nr-policy-nsw/enviropol.pdf?MIvalObj=3241&doctype=document&MItypeObj=application/pdf&name=/enviropol.pdf

NSW Department of Primary Industries (2007). Carbon trading. Available at: http://www.forest.nsw.gov.au/env_services/carbon/trading/Default.asp

Australian Greenhouse Office (2007). Emissions trading analysis. Available at: http://www.greenhouse.gov.au/emissionstrading/

NSW Government (1986). NSW Flood Prone Land Management Policy.

NSW Government (1992a). NSW Rivers and Estuaries Policy.

NSW Government (1992b). Estuary Management Policy.

NSW Government (1997). NSW Coastal Policy: A Sustainable Future for the New South Wales Coast. DUAP, Sydney.

NSW Government (2006). Coastal Zone Management Manual. Jan 2006. Draft, Appendix D10.

NSW Greenhouse Office (2006). Discussion paper; possible design for a national greenhouse gas emissions trading scheme. Information sheet No. 3. Available at: http://www.emissionstrading.net.au/__data/assets/pdf_file/1720/3_Climate_change_impacts_on_Australia.pdf

Northern Rivers Catchment Management Authority (2006). Catchment Action Plan (version May 2006).

Patterson, W. and Smith, R.J. (2000). Design improvements – rural drainage schemes. Paterson Consultants PL, Grafton, and Robert J. Smith and Associates, Alstonville.

Portnoy, J.W. (1999). Salt marsh diking and restoration: biogeochemical implications of altered wetland hydrology. *Environmental Management* 24(1): 111-120.

Proctor, W., Commerford, E., Hatfield Dodds, S., Stauffacher, M., Wilkinson, S, (2007). Motivating change in the catchment. A guide to revegetation design and incentives for catchment management bodies. CSIRO Land and Water. Available at: http://www.csiro.au/resources/MotivatingChange.html

Rawson, A. and McInnes-Clarke, S. (2002). Soil Organic Carbon Monitoring in the Lower North Coast of NSW Part 1 - Soil Quality Issues. DLWC.

Richardson, B.A. (1978). Fish kill in the Belmore River, Macleay River drainage, NSW, and the possible influence of flood mitigation works. Proceedings of the Floodplain Management Conference. 7-10 May 1980. Department of Natural Development and Energy, and the Australian Water Resources Council. AGPS, Canberra.

Roach, I.C. (ed.) (2005). Regolith 2005 – Ten Years of CRC Leme. CRC Leme.

Robertson, G., Creighton, G., Porter, M., Woodworth, J. and Stone, Y. (1998). Drainage Guidelines. In: Stone, Y., Ahern, C., and Blunden, B. (1998). Acid Sulfate Soil Manual. ASSMAC, Wollongbar, NSW.

Rose C. and Henderson, S. (2003) Native grasses in extreme environments – Water meadows in remediation of acid sulphate soil scalds. Proceedings of the 3rd National Conference of the STIPA Native Grasses Association, Sustainability and Beyond, Cooma.

Rose, C. and Rose, H. (2006). Productivity and forage quality of water couch (*Paspalum distichum*): an important native species in grazed coastal wetlands. Unpubl. Paper.

Rose C., Yerbury R. & Henderson S. (2002) Water couch – productive quality grass for acid sulphate soil remediation. In: Proceedings of the 5th International Acid Sulfate Soils Conference, August 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp. 177-178.

Rosicky, M.A., Sullivan, L.A. and Slavich, P.G. (2002). Pyrite concentration and surface reformation in and around acid sulphate soil scalds on the NSW coast. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp. 30-31.

Rosicky, M., Slavich, P., Sullivan, L.A. and Hughes, M. (2004a). Factors contributing to the acid sulfate soil scalding process in the coastal floodplains of New South Wales, Australia. *Aust. J. Soil Res*. 42: 587-594.

Rosicky, M., Slavich, P., Sullivan, L.A. and Hughes, M. (2004b). Soil properties in and around acid sulfate soil scalds in the coastal floodplains of New South Wales, Australia. *Aust. J. Soil Res*. 42: 595-602, at 599.

Rosicky, M., Slavich, P., Sullivan, L.A. and Hughes, M. (2006). Surface and subsurface salinity in and around acid sulfate soil scalds in the coastal floodplains of New South Wales, Australia. *Aust. J. Soil Res*. 44: 17-25.

Rumpf, C. (2002). Option Paper 2, Stuarts Point Water Sharing Plan. Protection Strategy – An update on investigations and alternative approaches. Department of Land and Water Conservation, Grafton.

Sammut, J., White, I. and Melville, M.D. (1994). Stratification in acidified coastal floodplain drains. *Wetlands (Australia)*, 13: 49-64.

Schmidt, J., Blunden, B., Macdonald, F., and Stone, Y. (1998). Acid Sulfate Soils Groundwater Guidelines In: Stone, Y., Ahern, C., and Blunden, B. (1998). Acid Sulfate Soil Manual. ASSMAC, Wollongbar, NSW.

Shortland Wetland Centre (1997). Environmental Impact Statement for the Proposed Restoration of Tidal Inundation of Yarrahapinni Wetland.

Slavich, P. (ed.) (2000a). Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999.

Slavich, P. (2000b). Executive Summary. In: Slavich, P. (ed.) (2000). Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp.vii-xi.

Slavich, P.G (2001). Technical review of the impacts of February 2001 Richmond River floods on water quality and fish kill. Draft of Executive Summary. Unpubl. Paper, NSW Agriculture. Wollongbar.

Slavich, P, Johnston, S. Atkinson, G. and Bowman, G. (2006). ASSESS. A model to estimate daily acid export from backswamps with acid sulfate soils. Unpubl. Paper.

Smith, C.D. and Martens, M.A. (2002). Overview of an acid sulphate soil remediation program at East Trinity. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia, p. 58.

Smith, J. (2002). Black sludges to red water: the oxidation of iron monosulfides. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp. 190-191.

Smith, J., van Oploo, P., Marston, H., Melville, M D., Macdonald, B.C.T. (2003). Spatial distribution and management of total actual acidity in an acid sulfate soil environment, McLeods Creek, northeastern NSW, Australia. *Catena* 51: 61-79.

Smith, R.J. and Smith, H.J. (1996). Proceedings of the 2nd National Conference of Acid Sulfate Soils, held at Coffs Harbour 5-6 September 1996. Published by Robert J Smith and Associates and ASSMAC.

Smith, R.J. (1998). Hastings, Floodgates and Drains. Possible Improvements in Management. R.J. Smith and Associates.

Smith, R.J. (1999). Managing backswamps. In: Slavich, P. (ed.) (2000). Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp.37-42.

Smith, R.J. (2001) A Manual for establishing landholder/sponsor management agreements for coastal backswamps. Prepared for Clarence River County Council.

Smith, R.J. (2004). Floodgate evolution overview. In: Walsh, S. and Copeland, C. (2004). North Coast Floodplain Project. Final Report 2002-2004. NSW Department of Primary Industries, pp. 128-133.

Smith, R.J. and Clarence River County Council (1999). Drain and Floodgate Maintenance Guidelines. CRCC.

Speight, J.G. (1990). Landform. In: McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1990). Australian Soil and Land Survey Field Handbook, 2nd edition, Inkata Press, pp. 9-57.

Stevenson, M. (2003). An internship study undertaken at the Wollongbar Agricultural Institute, December 2002 - February 2003. Southern Cross University.

Stone, Y., Ahern, C., and Blunden, B. (1998). Acid Sulfate Soil Manual. ASSMAC, Wollongbar, NSW.

Stone, Y. and Hopkins, G. (1998). Acid Sulfate Soils Planning Guidelines. In: Stone, Y., Ahern, C., and Blunden, B. (1998). Acid Sulfate Soil Manual. ASSMAC, Wollongbar, NSW.

Sullivan. L.A. and Bush, R (2000). The behaviour of drain sludge in acid sulfate soil areas: some implications for acidification of waterways and drain maintenance. In: Slavich, P. (ed.) (1999). Proceedings, Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Southern Cross University, 31 August – 2 September 1999, pp.43-49.

Sullivan, L.A. and Bush, R.T. (2002). Chemical behaviour of monosulfidic black oozes (MBOs) in water: pH and dissolved oxygen. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; pp. 14-15.

Sunshine Sugar (2000). Best Practice Guidelines For Acid Sulfate Soils.

Tasmanian Public Land Use Commission (1998). Tasmanian Regional Forest Agreement, Background Report Part F. Department of Agriculture, Fisheries and Forestry, Canberra. Available at: http://www.affa.gov.au/content/publications.cfm?ObjectID=43CC4A86-1F47-4F92-97E8E41120F964D3

Thom, B. (1999). Opening address, 9th Annual New South Wales Coastal Conference, Forster.

Tulau, M.J. (1997). Soil landscapes of the Bega - Goalen Point 1:100,000 sheet. Report and Map. DLWC.

Tulau, M.J. (1999a). Acid Sulfate Soil Management Priority Areas in the Byron-Brunswick Floodplains. Report. NSW Department of Land and Water Conservation, Sydney.

Tulau, M.J. (1999b). Acid Sulfate Soil Management Priority Areas in the Lower Richmond Floodplain. Report. NSW Department of Land and Water Conservation, Sydney.

Tulau, M.J. (1999c). Acid Sulfate Soil Management Priority Areas in the Lower Clarence Floodplain. Report. NSW Department of Land and Water Conservation, Sydney.

Tulau, M.J. (1999d). Acid Sulfate Soil Management Priority Areas in the Lower Hastings-Camden Haven Floodplains. Report. NSW Department of Land and Water Conservation, Sydney.

Tulau, M.J. (1999e). Acid Sulfate Soil Management Priority Areas in the Lower Manning Floodplain. Report. NSW Department of Land and Water Conservation, Sydney.

Tulau, M.J. (1999f). Acid Sulfate Soil Management Priority Areas in the Lower Tweed Floodplains. Report. NSW Department of Land and Water Conservation, Sydney.

Tulau, M.J. (1999g). Management of acid sulphate soils in New South Wales – Policy, Organisation and Regulation. *Australasian Journal of Natural Resources Law and Policy* 6(1): 1-32.

Tulau, M.J. (2000). Acid Sulfate Soil Remediation Guidelines. DLWC, Unpubl.

Tulau, M.J. (2002a). Agricultural drainage in acid sulfate soil backswamps in New South Wales, Australia – technical, regulatory and policy responses. In: Lin, C., Melville, M.D. and Sullivan, L.A. (ed.) (2002). Acid Sulfate Soils in Australia and China. Science Press, Beijing, China, pp. 158-176.

Tulau, M.J. (2002b). Soil landscapes of the Narooma 1:100,000 sheet. Report and Map. DLWC.

Tulau, M.J. (2005). Soil landscapes of the Eden-Green Cape 1:100,000 sheet. Report and Map. DIPNR.

Tulau, M.J. and Naylor, S.D. (1999). Acid Sulfate Soil Management Priority Areas in the Lower Macleay Floodplain. Report. NSW Department of Land and Water Conservation, Sydney.

Turak, E., Waddell, N. and Johnstone, G. (2004). New South Wales (NSW) Australian River Assessment System (AUSRIVAS) Sampling and Processing Manual 2004. Department of Environment and Conservation. Available at: http://ausrivas.canberra.edu.au/

van Breeman, N. (1973). Soil forming processes in acid sulphate soils. In: Dost, H. (ed.). Acid sulphate soils. Proc. Int. Symp. Acid Sulphate Soils, 13-20 August 1972, ILRI, Waginingen, Netherlands, pp. 66-129.

van Oploo, P. (2000). Soil and pore-water relations of a coastal acid sulfate soil in northern New South Wales, Australia. PhD thesis, UNSW.

Walker, P.H. (1960). Soil investigations in the Alumy Creek - Great Marlow Area, Grafton, N.S.W. CSIRO Division of Soils Tech. Mem. 6/60.

Walker, P.H. (1961). Groundwater Characteristics of the Kempsey District, NSW. CSIRO Division of Soils, Divisional Report 1/61.

Walker, P. H. (1963). A Reconnaissance of Soils in the Kempsey District, NSW. CSIRO Soils and Land Use Series No. 44, Melbourne.

Walker, P.H. (1972). Seasonal and Stratigraphic Controls in Coastal Floodplain Soils. *Aust. J. Soil Res*. 10: 127-42.

Walsh, S. (2004). Floodgate project. NSW Fisheries & the North Coast Floodgate Project. In: Walsh, S. and Copeland, C. (2004). North Coast Floodplain Project. Final Report 2002-2004. NSW Department of Primary Industries, pp. 125-127.

Walsh, S. and Copeland, C. (2004). Proceedings of the NSW Fisheries Floodgate Design & Modification Workshop, Ballina, Northern NSW, August 14th 2002, Executive Summary. In: Walsh, S. and Copeland, C. (2004). North Coast Floodgate Project Final Report 2002-2004, p. 119.

Walsh, S. and Copeland, C. (2004). North Coast Floodplain Project. Final Report 2002-2004. NSW Department of Primary Industries.

Walsh, S., Riches, M. and Huegill, J. (2002). North Coast Floodgate Project, Final Report. Report to the Natural Heritage Trust, NSW Fisheries, Ballina.

Ward, N.J., Sullivan, L.A. and Bush, R.T. (2004). The response of partially oxidised acid sulfate soil materials to anoxia. *Aust. J. Soil Res*. 42: 515-525.

WetlandCare Australia (2005). Tools for Sustainable Wetlands. Sustainable Wetlands on NSW Coastal Landscapes. Hunter Central Rivers Catchment Management Authority, Final Report, 30 November 2005.

White, I. and Melville, M.D. (1993). Treatment and containment of potential acid sulfate soils. Report to the Roads and Traffic Authority. Technical Report No. 53 CSIRO, Centre for Environmental Mechanics.

White, I., Melville, M.D., Wilson, B.P., Price, C.B. and Willett, I.R. (1993). Understanding acid sulphate soils in canelands. In: Bush, R. (ed.) (1993). Proceedings of the National Conference of Acid Sulfate Soils, Greenmount Beach Report, Coolangatta, 24-25 June 1993, pp. 130-148.

White, I., Melville, M.D., Wilson, B.P., and Sammut, J. (1997). Reducing acidic discharges from coastal wetlands in eastern Australia. *Wetlands Ecology and Management* 5: 55-72.

White, I. Melville, M., Macdonald, B., Quirk, R., Hawken, R., Tunks, M., Buckley, D., Williams, J. and Beattie, R. (2006). Minimising acid discharge into coastal rivers from canelands in NSW: a win-win in diffuse source discharge to coastal rivers. Proceedings, 9th International River Symposium, Brisbane, 4-7 September.

White, N., Faulkner, R., Frazier, P. and Wilkes, J. (2006). Rehabilitation and water quality of an estuarine wetland: Little Broadwater, NSW. Paper presented to: Catchments to Coast, the Society of Wetland Scientists 27th International Conference and the Australian Marine Sciences Association 44th Annual Meeting 9-14 July, 2006 Cairns Convention Centre, Queensland, Australia.

Wilkinson, G. (2004). Everlasting Swamp Acid Sulfate Soil Hot Spot Remediation Project. Final Report July 2004. Clarence Floodplain Services, Clarence Valley Council.

Williams, J.D. and Copeland, C.A. (1996). An overview of farmland management and wetland rehabilitation. In: Smith, R.J. and Smith, H.J. (1996). Proceedings of the 2nd National Conference of Acid Sulfate Soils, held at Coffs Harbour 5-6 September 1996. Published by Robert J Smith and Associates and ASSMAC, pp. 164-169.

Williams, R.J. and Watford, F.A. (1997). Identification of structures restricting tidal flow in New South Wales, Australia. *Wetlands Ecology* 5: 87-97.

Williams, R.J., Watford, F.A., Hannan, J. and Copeland, C. (1996). Audit of tidal control structures in NSW. In: Smith, R.J. and Smith, H.J. (1996). Proceedings of the 2nd National Conference of Acid Sulfate Soils, held at Coffs Harbour 5-6 September 1996. Published by Robert J Smith and Associates and ASSMAC, pp. 128-9.

Wilson, B.P. (2005). Elevations of sulfurous layers in acid sulfate soils: What do they indicate about sea levels during the Holocene in eastern Australia? *Catena* 62: 45-56.

Wilson, B. P., White, I. and Melville, M. D. (1999). Floodplain hydrology, acid discharge and change in water quality associated with a drained acid sulfate soil. *Mar. Freshwater Res*. 50: 149-57.

Wood, M., Rosicky, M., Slavich, P. and Sullivan, L.A. (2002). Key processes and roles in successful implementation of acid sulfate soil management in the Tuckean Swamp Northern NSW. In: Proceedings, 5th International Acid Sulfate Soils Conference, August 25-30th 2002. Twin Towns Services Club, Tweed Heads, NSW Australia; p. 203.

Yarrahapinni Wetlands Reserve Trust (1999). Yarrahapinni Wetlands Rehabilitation Project Stage One – The Trial Opening of a Single Flood Gate With Monitoring, Environmental Impact Statement, August 22, 1999.

Young, M.D., Gunningham, N., Elix, J., Lambert, J., Howard, B., Grabosky, P. and McCrone, E. (1996). Reimbursing the future. An evaluation of motivational, voluntary, price-based, property-right and regulatory incentives for the conservation of biodiversity. Biodiversity Series, paper No. 9, Biodiversity Unit, Department of Environment, Sport and Territories, Canberra.

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ENDNOTES

[1] Stone *et al*. (1998).
[2] See e.g. NRCMA (2006), pp. 146, 147.
[3] For information of soil testing and laboratory methods, see Ahern *et al*. (2004). For more detailed information on aspects of freshwater environments, see the Constructed Wetlands Manual (DLWC (1998b). See also the Saltwater Wetlands Rehabilitation Manual (Draft) (MHL & DNR (2006)).
[4] Under the *Drainage Promotion Act 1865* and later, the *Drainage Promotion Act 1901*.
[5] DLWC (2000).
[6] The invert is the level to which a floodgate can drain. -1.8 m AHD is therefore well below low tide.
[7] Walker (1960, 1961, 1963, 1972).
[8] Easton (1989).
[9] Tulau (2000).
[10] Bush (ed.) (1993), Smith & Smith (1996).
[11] Stone *et al*. (1998).
[12] See EPA (2000), Chapter 4 Land. Available at: http://www.epa.nsw.gov.au/soe/soe2000/cl/print_cl_4.5.htm. See also the *NSW Coastal Policy 1997* (NSW Government (1997) Strategic Actions 1.4.1 and 2.1.4.
[13] NWPASS (1999). Available at: www.dpie.gov.au/armcanz/pubsinfo/ass/ass.html
[14] Tulau (1999a, b, c, d, e, f), Tulau & Naylor (1999).
[15] Slavich (ed.) (2000a).
[16] Tulau (2000).
[17] DIPNR (2005b); Bush *et al*. (2006), p. 40; Morgan & Papworth (2004), p. 6.
[18] See e.g. Glamore & Indraratna (2006), p. 1.
[19] See e.g. NRCMA (2006). Appendix 8, p. 119.
[20] See e.g. Slavich (2000b).
[21] Robertson *et al*. (1998), p. 5.
[22] Atkinson & Tulau (1999).
[23] This is based on 0.5 m freeboard of drained soil required to grow cane. However, to this should be added the elevation >AHD of the upper level of ASS. Also, soil depth-elevation calculations should allow for the evapotranspiration and the effects of capillary action: Rosicky *et al*. (2006). Other crops may vary. See also fn 232.
[24] Johnston *et al*. (2003b), p. 783.
[25] It is considered that there is less risk of salt seepage if K_{sat} >1.5 m/day, more risk if >15 m/day: Johnston *et al.* (2003a) pp. 30-31.
[26] Neutralising materials are discussed in the Acid Sulfate Soil Management Guidelines (Ahern *et al*. (1998b), pp. 13 - 19.
[27] Note that this relationship does not hold if waters contain unhydrolysed iron and aluminium. Note also dilution only addresses the *concentration* of oxidation products - the total acid and metal loads on the receiving system remain basically unchanged.
[28] Johnston *et al*. (2004a).
[29] Measurements out at McLeods Creek indicated unlimed drain banks discharged at pH 3.7, while the nearby limed drains discharged at around 7.0 for up to 18 months before falling back to 3.7: Quirk, R. pers. comm., unpubl. data.
[30] e.g. under sugar industry Drainage Management Plans, lime must be applied where land grading is >100 mm deep.
[31] Ahern *et al*. (1998b), p. 27.
[32] See e.g. Aaso *et al.* (2002a), who found that at moderate flow, only a 27% decrease in acid discharge was achieved from the Partridge Creek backswamp. See also Desmier *et al.* (2002), concerning various techniques trialed at McLeods Creek.
[33] At East Trinity e.g., treatment of the drainage waters was originally budgeted at $55-70 million over the next 25 years: Smith & Martens (2002), p. 58.
[34] Sullivan & Bush (2002), p. 15.
[35] Rosicky *et al*. (2004a), p. 593.
[36] Application techniques and other issues associated with liming of drain waters have been examined by Ahern *et al*. (1998b), pp. 20-27.
[37] Williams & Watford (1997), Williams *et al*. (1996). By 2004, there were 89 sites being actively managed on the North Coast: Walsh *et al*. (2002); Walsh (2004), p. 127.
[38] Floodgates can also be modified/managed for wet acid containment strategy (WACS).
[39] See Ahern *et al*. (1998b), Table 7.1, p. 24.
[40] This data may be obtained by monitoring and modelling. See also MHL reports and summary data and references in Tulau (1999a,b,c,d,e,f); Tulau & Naylor (1999).
[41] Walsh & Copeland (2004), pp. 2, 22-25; see also Haskins (1999).
[42] Sullivan & Bush (2002), p. 15.
[43] e.g. at Shark Creek on the Clarence (Johnston *et al*. 2005c, p. 96), the buffering and dilution capacity of the tidal creek waters were rapidly exceeded once acidity began to be transported to the drain after rainfall. Also, the titratable acidity of the groundwater was found to exceed the buffering capacity of seawater by 25 times. This site is a typical mid-lower estuary low elevation backswamp with a poorly flushed distributory system, and these findings are most likely relevant to similar 'hot spot' sites. Even in lower estuary sites, such as East Trinity, it was necessary to modify floodgate structures to control discharge, enabling the treatment of acidified water: Smith & Martens (2002).
[44] See e.g. Johnston *et al*. (2005c), p. 96; see also Glamore & Indraratna (2006), p. 3, who modeled water quality changes expected from floodgate opening at a site on Broughtons Creek on the Shoalhaven. To calculate the potential for neutralisation and buffering of a volume of water (e.g. in a drain), see Ahern *et al*. (1998b), Table 7.1, p. 24. Note that when acidic surface waters or groundwaters are discharging, the volumes, flow rates and titratable acidity of those waters must also be considered.
[45] Johnston *et al*. (2005b,c).
[46] Johnston *et al.* (2003), p. 29.
[47] e.g., at East Trinity, an example of controlled reintroduction of tidal flows, the assessment included digital elevation and flood modelling: Smith & Martens (2002). See also Glamore & Indraratna (2006), p. 3.
[48] See e.g. an example from MHL: http://www.mhl.nsw.gov.au/www/sydres.htmlx. A series of major tidal anomalies also occurred in early 1999. Thom, B.: Opening address, 9th Annual New South Wales Coastal Conference, Forster. Tsunamis may also cause tidal anomalies, such as a 0.5 m anomaly on 17 May 1995: http://mhl.nsw.gov.au/www/tsunami.htmlx
[49] *Walker v Minister for Planning* (2007).
[50] Conversely, low hydraulic conductivity is critical to strategies involving containment in the soil profile (see below.
[51] Johnston *et al.* (2003a), pp. 30-31.

[52] Macropores may be of vegetative, faunal or pedogenic origin.

[53] See e.g. Table 3 in Johnston *et al*. (2005b), p. 43; Johnston *et al.* (2004a), pp. 632-633; Johnston *et al.* (2005b). See also Kinsela & Melville (2004), who believed that higher K_{sat} figures are the exception. The importance of saturated hydraulic conductivity (K_{sat}) was also raised by Cook *et al*. (1999). See also Cook *et al*. (2000). The impact of machinery has been noted at McLeods Creek (White *et al.* (1993), Figs 6, 7, 8, pp. 138-9), and at Blacks Drain, also on the Tweed, where subsoil K_{sat} appears to be much lower under a road along the drain bank (Collins 2006).

[54] Slavich & Johnston (2003). See e.g. Johnston *et al*. (2003d).

[55] Site data may include GPS location, groundwater physico-chemical characteristics, soil profile description, and elevation.

[56] Melville, M., pers. comm.

[57] At Yarrahapinni, the Stuarts Point aquifer is a source of groundwater for irrigation. Detailed investigations were carried out, involving the installation of monitoring bores and geophysical investigations to assess groundwater levels and salinity levels (Rumpf 2002).

[58] Bush *et al.* (2002); Sullivan & Bush (2002), p. 15.

[59] See e.g. Smith (2002), p. 190.

[60] Slavich (2001).

[61] Sullivan & Bush (2000).

[62] M. Wood, RRCC, pers. comm.

[63] R. Quirk, pers. comm.

[64] Juveniles of commercially and recreationally significant species move into drainage systems with frequent and regular opening of floodgates, although habitat quality is often poor, due to issues such as excess nutrients, grasses and rushes, and lack of mangroves and seagrass: Kroon *et al*. (2004), p. 132.

[65] See e.g. Kroon *et al*. (2004), p. 134, who noted that where fish are trapped and killed due to a sudden decrease in water quality, 'the cure may be worse than the disease, as valuable recruits will be lost to the fisheries'.

[66] Kroon *et al*. (2004), p. 133.

[67] Ahern *et al.* (1998b), p. 9.

[68] Ahern *et al.* (1998b), p. 9. In: Stone *et al.* (1998).

[69] See also Kroon *et al*. (2004), pp. 132, 134.

[70] This section deals with inundation with brackish to saline estuarine water. Inundation with fresh water is addressed in the section Containment, see Wet Acid Containment.

[71] This is a major component of the remediation strategy at Yarrahapinni: Shortland Wetland Centre (1997).

[72] Tidal predictions for open ocean coasts are presented in NSW Tide Charts: Department of Commerce (2006). Tidal ranges for estuarine conditions are more difficult to model, although generally, there is a reduction in tidal amplitude upstream, and an increase in mean tide level, although this is not always the case: Manly Hydraulics Laboratory (2006), section 7.2.

[73] See e.g. Shortland Wetland Centre (1997), pp. 3.3.5, 3.3.6.

[74] Information on the responses of various species to brackish tidal inundation in both grazed and ungrazed conditions has been compiled from the Little Broadwater project: Graham *et al.* (2004).

[75] Original survey plans are available from the Department of Lands. For most coastal floodplains, data will be available from the late 19th century.

[76] DLWC (1996), p. 5.

[77] *TSC Act 1995*, Schedules 1, 2 and 3.

[78] See the Saltwater Wetlands Rehabilitation Manual (Draft). Manly Hydraulics Laboratory (2006) for a comprehensive treatment of issues relevant to estuarine wetland restoration projects.

[79] See e.g. Portnoy (1999), who measured subsidence when wetlands were flooded with brackish water.

[80] White, I. *et al*. (2006). At Little Broadwater, stewardship payments were provided for the (potential) loss of grazing land, and linked to the reintroduction of estuarine water. The management plan was later revised to admit fresher water only due to impacts on the existing land use.

[81] Johnston *et al*. (2004a).

[82] Johnston *et al.* (2003a), p. 29. See also Glamore (2004) and Glamore & Indraratna (2006), p. 4.

[83] Johnston *et al*. (2004a).

[84] Cibilic & Henderson (2004).

[85] On the Shoalhaven River, Manildra Starches Pty Ltd employs a variation on the containment theme whereby irrigation of waste water is balanced with crop use, so that groundwater gradients remained unchanged: Australian Society of Soil Science Incorporated (2006). Drains have also been relocated drains away from high risk areas and drains have been redesigned to make them wider and shallower: EPA (1997).

[86] Wilson *et al*. (1999).

[87] Johnston *et al*. (2004b).

[88] Wilson *et al.* (1999).

[89] White *et al.* (1997).

[90] White *et al.* (1993), p. 140.

[91] Land grading and the infilling of many field drains has been completed over much of the Tweed floodplain. However, statistics on activities related to ASS management are not compiled., although some information is available from sugar industry audit reports. See e.g. Beattie (2005).

[92] It has been stated that practices such as these have reduced the discharge of acidity by 80% (see e.g. ASSAY No. 39, June 2006, p. 5) or 90% during 1 in 2 year floods (White, I. *et al*. 2006, p. 16) at one site. It is reported that after significant rain, pH still falls to around 3.5 for 3 - 4 days, although previously, acidic discharges would have continued for some weeks: Quirk, R., pers. comm.

[93] White *et al.* (1997), p. 61, Figure 4.

[94] e.g., sugar cane requires ~500 mm of freely drained soil.

[95] George (1999). See also George & Heagney (2002).

[96] Johnston *et al*. (2003c). However, without very detailed investigations it is not easy to assess the vegetation communities that might have existed on the floodplain in the past. Longer scale weather patterns, vegetation communities and therefore hydrological regimes would have been different from those experienced since European settlement.

[97] Johnston's (2005b) review of the data available suggests that K_{sat} varies by up to 3 orders of magnitude; it is stressed that it is difficult to make broad generalisations from the data: p. 43.

[98] Smith *et al.* (2003) found that existing acidity averaged 50 t/ha on one farm. However, the figures reveal large ranges, with palaeo-geomorphic factors the key to understanding the pattern of variation. See also White *et al.* (1997).

[99] See e.g. Macdonald *et al.* (2002), pp. 314-315; Donner & Melville (2002), p. 2; Smith *et al.* (2003), p. 76.

[100] Andersson (1995), p. 57; Kinsela & Melville (2004), p. 574 Fig. 7. Smith *et al*. (2003), pp. 64, 65, Fig. 3, p. 68. The production of further acid has been estimated as being at least 300 kg/ha/yr at one site: van Oploo (2000), p. 273. Cook *et al*. (2002) found that oxidation exceeded discharge at Pimpama, Qld (p. 37), and Cook *et al*. (2004) estimated acid formation at ~10 t H_2SO_4/ha.yr, which they described as an "*ongoing environmental hazard*" (p. 506).

[101] DLWC (1998a). See also NSESD 1992; the Framework for Marine and Estuarine Water Quality Protection; NSW Policy for Sustainable Agriculture 1998.

[102] Blunden *et al.* (1999), Johnston (2004b), Aaso (2004).

[103] Smith (2004), p. 128.

[104] Johnston *et al*. (2004b), p. 63.

[105] Early discussions should be held with the DPI (Fisheries) and DWE regarding the feasibility of this strategy.

[106] Williams & Copeland (1996), p. 167.

[107] White *et al.* (1997), p. 58.

[108] Ward *et al.* (2004).

[109] Rose *et al.* (2002); See also Rose & Henderson (2003). For data on carbon in and around scalds, see Rosicky *et al.* (2004b), Table 2, p. 598.

[110] Blunden *et al*. (1999), p. 67.

[111] Haskins, P. (in press).

[112] Johnston *et al*. (2004b). Similarly, at Partridge Creek, a WACS has been used to reduce acid discharge by 86%, preventing over 2 900 t of acid from entering the estuary in the period March 2004 to October 2006: unpublished data, Port Macquarie-Hastings Council.

[113] Bush *et al.* (2006), pp. 5, 41; White, N. *et al.* (2006). See also: Wilkinson (2004), p. iii.

[114] Johnston *et al*. (2003b), p.793.

[115] Slavich (2001). See also Johnston *et al.* (2003b).

[116] Johnston *et al.* (2003b), p. 783.

[117] Isaacson *et al*. (2006), p. 170.

[118] Beavis *et al*. (2005), pp. 22-26.

[119] Rosicky *et al.* (2002). See also Beavis *et al*. (2005) and Isaacson *et al*. (2005) at Mayes Swamp on the Macleay, and Bolton *et al.* (2002), p. 20, Bolton (2001), Bolton & Warner (2002) and Bolton (2003) at West Byron.

[120] See e.g. Kempsey Shire Council (2004a). Note however that Johnston *et al*. (2004a) found that surface discharge was only a small proportion of the total acid discharge from ASS backswamps, the largest proportion being from groundwater seepage.

[121] Rosicky *et al.* (2004a), p. 593.

[122] Rosicky *et al.* (2004a), pp. 593, 601.

[123] e.g. composted green waste, tea-tree mulch, hay, sugar cane waste, treated sewage sludge.

[124] per WAC remediation projects at Clybucca, Rawdon Island and Rossglen: Aaso, T. pers. comm., Port Macquarie-Hastings Council.

[125] See e.g. Rosicky *et al.* (2004a), p. 593.

[126] Burton *et al*. (in press).

[127] See e.g. NSW Agriculture & Fisheries (1989), Havilah & Launders (1996), Smith (1999), Rose *et al*. (2002), and Rose & Henderson (2003). Species present may include spiny mudgrass (*Pseudorhaphis spinescens*), and saltwater couch (*Paspalum vaginatum*), the distribution controlled by wetness (including microelevation) and salinity gradients.

[128] Rose *et al.* (2002); see also Rose & Henderson (2003), working at Seven Oaks, where more than 150 ha of acid scalds have been rehabilitated with up to 95% water couch.

[129] Up to 22% in leaf: Rose & Rose (2006).

[130] Rose *et al*. (2002).

[131] Rosicky *et al.* (2004a), p. 593.

[132] Rosicky *et al.* (2004b), p. 593.

[133] On the Macleay, ~8 000 ha (23%) is managed with generally higher water tables: Henderson *et al.* (2002); on the Hastings, ~5 000 ha: Port Macquarie- Hastings Council (2006).

[134] See e.g. Stevenson (2003).

[135] Rosicky *et al.* (2004b), p. 593.

[136] Johnston *et al.* (2003c). Shallow water depths in backswamps might favour the expansion of *Melaleuca*.

[137] See e.g. NRCMA (2006), pp. 146-147.

[138] See e.g. Yarrahapinni Wetlands Reserve Trust (1999), p. 2.1.6; DIPNR (2001).

[139] See also Tulau (1999g).

[140] Glamore & Indraratna (2006), p. 1.

[141] Haskins (2004), pp. 182, 184.

[142] See e.g. Johnston *et al.* (2002), p. 150.

[143] Emery (1985). The land capability approach finds support within the policy framework: see e.g. the *Policy for Sustainable Agriculture* (NSW Agriculture 1998, p. 15); NRC (2005), pp. 87-89; NRCMA (2006), p. 146.

[144] Includes groundwater gradient modification to influent by crop use.

[145] Measured as a 1:5 soil:deionised water suspension: Ahern et al. (1998a), p. 56.

[146] <18 mol H^+/ tonne: Ahern *et al*. (1998a), p. 27.

[147] <18 mol H^+/ tonne: Ahern *et al*. (1998a), p. 27.

[148] >18 mol H^+/ tonne: Ahern *et al*. (1998a), p. 27.

[149] >18 mol H^+/ tonne: Ahern *et al*. (1998a), p. 27.

[150] In this Guideline, references to 'ASS' are taken to include both actual ASS (AASS), or sulfuric material, and potential ASS (PASS), or sulfidic material.

[151] Wilson (2005).

[152] See e.g. Haworth *et al*. (2002).

[153] At East Trinity (Hicks *et al*. 1999, p. 15), the surface elevation is now 1.3 m lower at -0.4 m AHD, mainly due to peat loss. Van Breemen (1973); Dent (1986), p. 83; White & Melville (1993), p. 37); White *et al*. (1993), p. 136 discussed soil 'ripening', involving irreversible shrinkage due to removal of water and flocculation of clays. Consequently, some areas are wetter than prior to drainage; other areas that were previously above the tidal range are impacted by tidal salt water. See also Rosicky *et al*. (2004b), p. 597. See also Portnoy (1999), who suggested that subsidence can be further exacerbated if the landscape is then reflooded with brackish water.

[154] e.g. ASS has been found at 0.7 m AHD at Partridge Ck and Rawdon Is in the Hastings (T. Aaso, Port Macquarie – Hastings Council, pers. comm.).

[155] e.g. mangrove incursion into saltmarsh: See e.g. Endangered Ecological Community Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner Bioregions – profile, available at: http://www.threatenedspecies.environment.nsw.gov.au/tsprofile/profile.aspx?id=10866.

[156] Rawson & McInnes-Clarke (2002).

[157] Rawson & McInnes-Clarke (2002).

[158] Denmead *et al*. (2006), p. 99.

[159] Denmead *et al*. (2006), p. 103.

[160] Denmead *et al*. (2006), p. 102.

[161] Denmead *et al*. (2006), p. 103.

[162] Denmead *et al*. (2006), p. 98.

[163] Hicks (2001); Macdonald *et al*. (2004); Denmead *et al*. (2005). The Australian Greenhouse Office has initiated a program to quantify greenhouse gas emissions from a range of different agricultural land uses In time greenhouse gas emission data are likely to become important factors influencing integrated floodplain management.
[164] Haskins (2004), p. 185.
[165] Established under the *Local Government Act 1993* (*LG Act 1993*).
[166] Established under s.355 of the *LG Act 1993*.
[167] Established or saved under the *Drainage Act 1939*.
[168] Established under Part 5, Division 4 of the *Crown Lands Act 1989*.
[169] Haskins (2004), p. 185.
[170] As at 2007, there were almost 100 such delegations on the major North Coast floodplains.
[171] Delegations may also benefit from conditional defences, available to public authorities, from certain forms of liability: ss. 731 and 733 of the *LG Act 1993*.
[172] The *Drainage Act 1939*, under which drainage unions were continued (Part 2) or formed (Part 3), was repealed by the *Water Management Act 2000*, which saved these bodies as Private Drainage Boards (Chapter 4 Part 3).
[173] *Drainage Act 1939* Long Title.
[174] *Drainage Act 1939* s. 8.
[175] *Drainage Act 1939* s. 32(1) (a); *Water Management Act 2000* s. 202(1)(b).
[176] As at 2007, there were ~50 functional drainage boards in NSW. Note however, that the level of activity varies, and many tend to become activated in response to particular issues or events only. Drainage board administration is overseen by DWE.
[177] Department of Lands (2006). Available at: http://www.lands.nsw.gov.au/land_management/trusts
[178] An example is the former Yarrahapinni Wetlands Reserve Trust: Yarrahapinni Wetlands Reserve Trust (1999), p. 3.5.1, 3.5.2.
[179] See http://www.aph.gov.au/library/intguide/sp/spgrants.htm. See also the Community grants and funding centre http://www.ourcommunity.com.au/funding/funding_main.jsp. A Green Grants Guide is also available annually: see http://www.molinostewart.com.au/Green_Grants_Guide.htm.
[180] This represents a total area of 153 000 ha on NSW coastal floodplains. There is 30 000 ha (20%) in the highest risk < 1 m elevation class and 123 000 (80%) in the 1-2 m class. Of this, 94 000 ha is on the North Coast, 44 000 ha in the Hunter – Manning and 14 000 ha on the South Coast: ASS Risk Maps (Naylor *et al.* 1997).
[181] Tulau (1999a, b, c, d, e, f), Tulau & Naylor (1999).
[182] Wood *et al.* (2002), p. 203. Where Crown land is involved, the local Aboriginal land council may also need to be consulted.
[183] For further information on community consultation strategies, see e.g. Carson (2001) and Aslin & Brown (2004).
[184] Roles and responsibilities will need to be formalised in the case of contractual arrangements, or as conditions of an appropriate approval.
[185] e.g., when ASS issues were largely seen as an agronomic problem, the solution focused on pasture productivity and scald rehabilitation.
[186] Slavich (2001).
[187] Ahern *et al*. (1998a), p. 12, Table 2.3.
[188] DECC holds water quality data generated from the 7 ASS Hot Spot Program sites; councils, county councils, universities and other agencies have generated data from research projects in other locations.
[189] DECC has soil landscape data for the entire NSW coast, and soils point data on the Soil and Land Information System (SALIS) site: www.naturalresources.nsw.gov.au/soils/data.shtml; universities and other agencies have generated data from research projects in other locations.
[190] e.g. survey plans, available from the Department of Lands, aerial photos, and satellite images.
[191] For preliminary information and references in relation to each of these matters, see the discussion of each ASS Priority Area (‘hot spot’) in Tulau (1999a,b,c,d,e,f,), Tulau & Naylor (1999), or Davies & Mumby (1999), as the case may be. More detailed and up-to-date information has been generated from projects carried out in ASS areas subsequently.
[192] Geomorphic characteristics can be determined from the relevant ASS Risk Map, or from Quaternary geomorphic mapping (Hashimoto & Troedson (2005)).
[193] Ahern *et al.* (1998a).
[194] McDonald & Isbell (1990).
[195] Milford *et al.* (2001). Available at: http://www.naturalresources.nsw.gov.au/soils/data.shtml.
[196] Ahern *et al.* (2004). This document supersedes the chapter ASS Laboratory Methods Guidelines (Ahern *et al*. 1998c) in the *ASS Manual* 1998 (Stone *et al*. 1998).
[197] Johnston *et al* .(2004a).
[198] Tulau (1999a, b, c, d, e, f,) Tulau & Naylor (1999).
[199] Naylor *et al*. (1997).
[200] Atkinson (1999); Chapman & Murphy (1989); Eddie (2000); Eddie (n.d); Hazelton (1992); Hazelton & Tille (1990); Matthei (1995); Milford (1996); Morand (1994); Morand (1996); Morand (2001); Murphy (1993); Murphy (1995); Murphy (n.d.); Tulau (1997); Tulau (2002b); Tulau (2005).
[201] Available at: http://www.naturalresources.nsw.gov.au/soils/data.shtml. Data may also be available for selected sites from a wide range of other publications and sources including PWD reports, DMR reports, university theses, sugar industry soil profile data, or consultant reports.
[202] ALS is a survey technology with vegetation- and water-penetrating capabilities with a vertical accuracy of 0.1 – 0.15 m, with horizontal accuracy up to 0.2 m and typical point spacing of 1.5 m. Survey using ALS has been carried out for much of the NSW coast. In addition, land-based elevation survey giving an elevation accuracy of +/- 10 mm have been carried out in a number of areas on the North Coast: Atkinson *et al.* (2002b). See also Evans (1999) for Hexham Swamp. See also Flood Management Plans.
[203] Yarrahapinni Wetlands Reserve Trust (1999), p. 2.1.8.
[204] See e.g. the field calibration methods of Davies (2004) and Smith (1998). See also MHL (2006), section 7.2.).
[205] ‘Real estate’ (or ‘immovable property’) is a legal term used in some jurisdictions that encompasses land along with anything permanently affixed to the land, such as buildings, fences, etc, and is often considered synonymous with real property (realty), in contrast with personal (moveable) property. Right of access to drains may be provided under an easement; in other cases access is by informal agreement.
[206] *WM Act 2000* Chapter 4 Part 3. Note however, that many former union drains have been expanded and transferred to councils.

[207] Atkinson *et al*. (2002a).
[208] Williams *et al*. (1996); Williams & Watford (1997).
[209] e.g., Clarence River County Council (CRCC) conducted an environmental audit of that Council's floodgates. An inventory of floodgates in the Hastings catchment has also been carried out by Smith (1998).
[210] Case law developed under this section, as well as the old s. 90(1)(d) is outlined in Farrier *et al*. (1999), pp. 205-207. DUAP produced a *Guide to Section 79C(1)* to assist councils in the application of this section of the Act. Plans prepared under Part 3 of the *WM Act 2000*, including Drainage Management Plans, must also have due regard to the socio-economic impacts of the proposals: s. 18(1). Guidelines for socio-economic assessment for committees under the water management planning process were compiled by IACSEA (1998). See also IACSEA)(2000). For more general information on social impact assessment see Becker & Vanclay (2003), and in the Australian context, Coakes (1999) and Aslin & Brown (2004).
[211] See e.g. Aaso (2004).
[212] These may include vacant Crown land, leased Crown land, dedicated Crown land, Crown land subject to enclosure permits or a grazing licence.
[213] Targets may be expressed e.g. as % reduction in the discharge of certain oxidation products within a certain time. See e.g. Glamore & Indraratna (2006), p. 2, who determined specific objectives for a project on the Shoalhaven River floodplain.
[214] Ahern *et al*. (1998a), pp. 17, 19, 52.
[215] Ahern *et al*. (1998a), pp. 24-25.
[216] e.g. Groundwater should be managed so that climatically-induced groundwater fluctuations can occur without causing oxidation of sulfidic materials.
[217] e.g. ASS remediation + agricultural production, wetland rehabilitation and/or fish habitat. In some cases, objectives may conflict, in which case the NSW Government policy framework and any related information, such as Johnston *et al*. (2003a) and Part 1 of these Guidelines should be consulted.
[218] e.g. ; 'fix-and-forget' designs are preferred to high-tech, high maintenance and/or labour-intensive designs.
[219] e g. ANZECC Guidelines (2000).
[220] The map should be based on DoL 1:25 000 topographic maps and, where available, DECC drain maps Note only available for the North Coast (Manning – Tweed).
[221] Smith & CRCC (1999).
[222] MHL & DNR (2006).
[223] DLWC (1998b).
[224] Patterson & Smith (2000), Walsh & Copeland (2004), p. 119.
[225] Glamore & Indraratna (2006), p. 5.
[226] Smith (2004), p. 128.
[227] Robertson *et al*. (1998), p. 5.
[228] Robertson *et al*. (1998).
[229] Ahern *et al*. (1998a).
[230] Robertson *et al*. (1998), p. 5.
[231] Robertson *et al*. (1998), pp. 5, 14.
[232] The upper level of the ASS layer in backswamps is commonly at ~0.2 – 0.4 m AHD (DECC unpubl. Data; see also Wilson (2005). To this should be added the freeboard required for effective drainage, where this may be required. Also, soil depth-elevation calculations should allow for the importance of evapotranspiration in determining groundwater levels in some areas. The effects of capillary action in causing accumulation of surficial salts were discussed by Rosicky *et al.* (2006), who suggested that a saline watertable within 1 m of the soil surface would allow salt to concentrate in the surface soil, although the depth of the capillary fringe will vary with sediment texture. The emphasis in the Drainage Guidelines on 'sulfidic layers' should also be read in the context of Johnston *et al.*'s. (2004a) research, which has drawn attention to the importance of groundwater movement through sulfuric layers, and its emphasis on the 'acid export window' as the dominant mode of export. Robertson *et al*. (1998) hinted at this, noting that *"the drainage design should avoid drainage of soil layers that contain deposits of jarosite. Jarosite is a store of acid. Any drainage of jarositic soil will result in acid drainage waters.".*
[233] Robertson *et al*. (1998), p. 6.
[234] Robertson *et al*. (1998), p. 13.
[235] Robertson *et al*. (1998), p. 16.
[236] A range of in-drain WCSs has been assessed by Smith (2004), p. 131.
[237] After Glamore & Indraratna (2006), p. 5.
[238] Blunden & Indraratna (2001).
[239] Walsh & Copeland (2004), p. 8.
[240] Lloyd (2004), p. 134.
[241] Kroon *et al*. (2004), p. 134.
[242] See e.g. CVC (2006), p. 4 for an example from the Coldstream River on the Clarence River floodplain.
[243] These are variously known as overshot-undershot gates or head and discharge doors.
[244] Kroon *et al*. (2004), p. 134.
[245] An example is at Swan Creek on the Clarence River floodplain.
[246] A hinged weir gate is the main remediation structure at Partridge Creek hot spot on the Hastings: Aaso (2004). Other structures so far less commonly used on coastal floodplains are discussed in Paterson & Smith (2000).
[247] Stone *et al*. (1998). See also the Queensland ASS Technical Manual Soil Management Guidelines: Dear *et al*. (2002).
[248] e.g. with projects including floodgate management, the proponent should be prepared to close the gate(s) if required should the effect be unreasonably adverse: see e.g. Yarrahapinni Wetlands Reserve Trust (1999), p. 2.1.13.
[249] Johnston *et al*. (2003a), pp. 29-31.
[250] Johnston *et al*. (2003a), pp. 29.
[251] It should be noted however that these are estimates only, and other factors including high river levels, storm surges, and low atmospheric pressure can cause these estimates to be out by up to 0.5 m.
[252] e.g. Glamore (pers. comm.) reported that flows through a headwork at East Trinity exceeded 20 cusecs. Glamore & Indraratna (2006) proposed a methodology for introducing tidal flushing to drains, which incorporates flood design criteria.
[253] Glamore & Indraratna (2006). See e.g. Yarrahapinni Wetlands Reserve Trust (1999), p.3.3.5, where data from a Stage I trial opening of one gate was analysed and assessed to identify potential impacts, prior to proceeding to further stages.
[254] See e.g. Yarrahapinni Wetlands Reserve Trust (1999). Yarrahapinni Wetlands Rehabilitation Project Stage One – The Trial Opening of a Single Flood Gate With Monitoring, EIS, August 22, 1999, p. 2.1.9.
[255] For further information see Farrier *et al*. (1999) and EDO (2006) and, specifically in relation to ASS, Tulau (1999g).

256 Sunshine Sugar (2000).
257 Ahern *et al*. (1998a), p. 40.
258 Ahern *et al*. (1998a), p. 39.
259 For an example of a comprehensive monitoring program for soil, surface water, groundwater, pore water, sediment, suspended solids, colloids, gases and biota in relation to East Trinity, see Hicks (2001). Monitoring and evaluation strategy for CASSP East Trinity Demonstration. CSIRO.
260 See e.g. the Everlasting Swamp ASS Hot Spot Remediation Project: Wilkinson (2004), p. iii.
261 Bush *et al*. (2006), p. 45
262 For further detailed information in relation to soil monitoring, see McKenzie *et al*. (2002).
263 Ahern *et al*. (1998a), pp. 20-21.
264 Speight (1990), pp. 24-34.
265 McDonald & Isbell (1990).
266 Milford *et al.* (2001).
267 The mineralogical composition of sediments, including the occurrence of key minerals, may be determined using a combination of techniques such as thermal analysis, x-ray diffraction and electron microscopy with microprobe analysis: Hicks (2001), p. 3.
268 Rawson & McInnes-Clarke (2002).
269 Hicks (2001); Macdonald *et al*. (2004); Denmead *et al*. (2005); Denmead *et al*. (2006).
270 Cook *et al*. (2000); Johnston *et al*. (2004a).
271 Bush *et al*. (2006), p. 44.
272 Hicks (2001), p. 2.
273 For more detailed information on installation of piezometers and groundwater monitoring, see Schmidt *et al*. (1998).
274 Schmidt *et al*. (1998).
275 Schmidt *et al*. (1998), p. 4. e.g., see Johnston *et al*. (2004a) for an example of groundwater monitoring design.
276 Hicks (2001), p. 3.
277 See e.g. Green *et al*. (2006), p. 359.
278 See e.g. van Oploo (2000).
279 e.g., relocation of water quality data loggers during the program can compromise analysis of long-term data: Bush *et al*. (2006), p. 44.
280 Ahern *et al*. (1998a), p. 33.
281 Bush *et al*. (2006), p. 44.
282 As an example, see White, N. *et al*. (2006) at Little Broadwater.
283 Bush *et al*. (2006), pp. 10, 45. For further information on monitoring of pH, see ANZECC/ARMCANZ (2000). See also Coastal CRC at: http://www.coastal.crc.org.au/ozcoast/issues/indicators/ph.html
284 Bush *et al*. (2006), p. 43.
285 Bush *et al*. (2006), p. 44.
286 e.g. Green *et al*. (2006), p. 359.
287 See e.g. Johnston *et al*. (2004a), p 625; Ahern *et al*. (1998a), p. 33.
288 See e.g. Sammut *et al*. (1994).
289 Ahern *et al*. (1998a), p. 33. See e.g. Johnston *et al*. (2004a), p. 625.
290 Ahern *et al*. (2004).
291 Bush *et al*. (2006), p. 43.
292 For further information, see ANZECC/ARMCANZ (2000). See also Coastal CRC at: http://www.coastal.crc.org.au/ozcoast/issues/indicators/dissolved_oxygen.html
293 Bush *et al*. (2006), p. 44. This is largely because pH is a measure of H^+ activity, and does not measure other forms of acidity such as acidic metals (Al^{3+}, Fe^{3+}).
294 Hicks *et al.* (2002) studied acidic discharge at East Trinity, Herbert and Pimpama in Qld, and Partridge Creek on the Hastings in NSW.
295 Sullivan & Bush (2000).
296 This can indicate whether sulfidic material in the vicinity of the site is being, or has been, oxidised: Mulvey (1993).
297 Key minerals may include schwertmannite and jarosite.
298 Data such as water colour and turbidity may also be important, because the colloids (suspended iron flocs and clay particles) may have elevated heavy metals such as zinc and arsenic and metalloids adsorbed and could play a major role in the export of contaminants: Hicks *et al*. (1999).
299 This section is based on Slavich *et al*. (2006).
300 *In situ* apparent soil EC measurements made with the EM-38 have been found to be well correlated with groundwater acidity (and salinity) at Shark Creek and could assist groundwater sampling strategies.
301 Bush *et al*. (2006), pp. 10, 43 considered that the long-term measurement of DO and redox is impractical in ASS environments due to the immense requirements for ongoing maintenance.
302 Benkendorff (n.d.).
303 See e.g. Murray *et al*. (2002), DLWC (1999).
304 Haskins (2006).
305 See e.g. Kroon *et al*. (2004).
306 See e.g. Deeley & Paling (1999).
307 See e.g. Turak *et al.* (2004).
308 See e.g. Yarrahapinni Wetlands Reserve Trust (1999), p. 3.3.5. The primary aim of Stage I of the Yarrahapinni Wetland Rehabilitation Project was to determine the extent of tidal inundation from opening one floodgate, and to calibrate and confirm draft flood inundation predictions for complete opening. See also Aaso (2004).
309 Ahern *et al*. (1998a), p. 41.
310 The information in this section is based on: Ahern *et al*. (1998a), pp. 41-42.
311 See also Gunningham (2007), p. 310.
312 See e.g. Young *et al*. (1996). More recently, the Department of Agriculture, Fisheries and Forestry has initiated a National Market-based Instrument Pilot Program: http://www.daff.gov.au/natural-resources/vegetation/market-based.
313 See e.g. Tulau (2002a).
314 See e.g.: Young *et al*. (1996); Farrier (1995a,b,c); WetlandCare Aust. (2005); Environmental Defender's Office (2006). Most recently, see Proctor *et al.* (2007).
315 Aretino *et al.* (2001), p. vii.
316 Mobbs (1996); Young *et al*. (1996); ASSMAC (1999); WetlandCare Australia (2005).
317 e.g. stewardship payment have been used at Little Broadwater. Similarly, DLWC's Environmental Services Scheme (ESS) was a trial scheme, which paid participating landholders for delivering environmental services over the 5-year contract period. Three of the pilot farms were on coastal floodplains.
318 For that reason, the ESS scheme was intended as a pilot venture prior to setting up a self-perpetuating trading market in environmental credits. The main problem with payment schemes appears to be defining the environmental 'products' (such as a reduction in tonnes of acid discharged) and setting up processes to value these products. See also WCA (2001), which proposed a formula for incentive payments based stocking rates.

[319] Land under a Conservation Agreement under the *National Parks and Wildlife Act 1974* (*NPW Act 1974*) is normally eligible for tax deductions for any reduction in market value of the land because of the conservation agreement, and is exempt from council rates: *LG Act 1993*, s. 555 (1) (b1). Rate relief is also available from time to time as a drought measure.
[320] NSW DPI (2007). Carbon trading. Available at: http://www.forest.nsw.gov.au/env_services/carbon/trading/Default.asp. Also note the *Carbon Rights Legislation Amendment Act 1998* which amended the *Conveyancing Act 1919* by effectively separates ownership of stored carbon from ownership of land or vegetation such as forest trees.
[321] Australian Greenhouse Office (2007). Emissions trading analysis. Available at: http://www.greenhouse.gov.au/emissionstrading/ Department of the Environment and Water Resources.
[322] e.g. DECC under the *NPW Act 1974*, local councils under the *LG Act 1993.*
[323] The DoL acquired land at Yarrahapinni on the Macleay floodplain: Shortland Wetland Centre (1997). Additional land has now been acquired by DECC. Land was also purchased at Hexham Swamp on the Hunter (Evans 1999), Great Lakes Council acquired Darawakh wetlands; Hastings Council purchased the Partridge Creek backswamp (Aaso *et al*. 2002a), and DECC purchased a key property in Everlasting Swamp on the Clarence. The Qld Government also purchased the site at East Trinity for remediation: Smith & Martens (2002), p. 58. In some cases an easement only may be created in order to provide access to drainage infrastructure, although this would not necessarily grant the right to more widespread land management and/or hydrologic changes. An easement binds successors in title to the land: Gardner & Setter (1998).
[324] This was a major issue at Yarrahapinni.
[325] See also *EP&A Act 1979* s. 94.
[326] e.g. the purchase by GTCC of a 500 ha property in the Cattai Creek area of the Manning, management under a s. 355 committee, preparation of a management plan, and subdivision and sale of 4 elevated lots of <10 ha while retaining the lower wetlands (Atkinson & Gardner 2003).
[327] A Manual for establishing landholder/sponsor management agreements for coastal backswamps has been prepared by Smith (2001).
[328] Acts may include the *EP&A Act 1979*, the *FM Act 1994*, and the *WM Act 2000*.
[329] *LG Act 1993* s. 355(b).
[330] Common purposes include maintaining fresh water levels for irrigation and stock, flood irrigation of paddocks, and reducing acidic discharges.
[331] See e.g. Clarence Floodplain Services (2006a).
[332] *Conveyancing Act 1919* s. 88E.
[333] *Conveyancing Act 1919* s. 88D.
[334] Bates (1992).
[335] See http://www.nationalparks.nsw.gov.au/npws.nsf/Content/conservation_agreements.
[336] *NPW Act 1974* s. 69C (2). Land under a Conservation Agreement is normally exempt from council rates. Income tax concessions are also available for any reduction in market value of the land because of the conservation agreement.
[337] Issues with the design and implementation of this type of environmental market have been discussed by Curnow & Fitz-Gerald (2006).
[338] The arrangement is made binding by the addition of a clause that removal or operation of the structure contrary to the plan may lead to pollution, and that Council may use a notice under the *POEO Act 1997* to ensure compliance with the remediation management plan.
[339] Bouwer & Rice (1983), Boast & Langebartel (1984).
[340] Johnston *et al*. (2003d).
[341] Millham & Howes (1995).
[342] Bouma (1991).
[343] Use in this fashion is user dependant.
[344] Based on Bouwer & Rice (1983) or Boast & Langebartel (1984).
[345] According to MacDonald *et al*. (1998).
[346] K_{sat} pit test data analysis.xls, available at http://www.ricecrc.org/reader/hydraulic-conductivity.
[347] Note: this is an approximation only. Quantitative assessment of K_{sat} from the data collected in this method will require the user to apply the calculation method(s) outlined in Bouwer & Rice (1983) or Boast & Langebartel (1984).
[348] ESDSC (1992). Available at: http://www.deh.gov.au/esd/national/nsesd/strategy/intro.html
[349] Available at: http://www.deh.gov.au/esd/national/igae/index.html
[350] ESDSC (1992).
[351] NSW Government (1992a).
[352] NSW Government (1992b).
[353] Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment (JAMBA) (1974); Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment (CAMBA) (1986); Republic of Korea-Australia Migratory Bird Agreement (RoKAMBA) (2006); Convention on Wetlands of International Importance Especially as Waterfowl Habitat (1971) (Ramsar Convention).
[354] Environment Australia (2001). These include a number of ASS areas, such as the Clarence River estuary, Everlasting Swamp (Clarence), the Clybucca Creek estuary, Swan Pool and Belmore Swamp (Macleay).
[355] DLWC (1996).
[356] DLWC (1996), p. 5. Note that this requires a demonstrated understanding of the geomorphic context of wetlands, their hydrology and natural salinity regimes.
[357] Goodrick (1970).
[358] Available at: http://www.fisheries.nsw.gov.au/aquatic_habitats/aquatic_habitats/policy__and__guidelines
[359] Dwyer (2004), p. 123.
[360] DLWC (1997).
[361] The Weirs Policy states that a weir is "a structure (including a dam, lock, regulator, barrage or causeway) across a defined watercourse that will pond water, restrict flow or hinder the movement of fish along natural flow paths, in normal flow conditions".
[362] Johnston *et al.* (2004b); Johnston *et al.* (2005b).
[363] See Johnston *et al.* (2003a).
[364] Kroon *et al.* (2004), pp. 133, 135.
[365] NSW Government (1986).
[366] NSW Agriculture (1998). Policy for Sustainable Agriculture, p. 1.
[367] DLWC (1998a).
[368] In this regard see also e.g. the Framework for Marine and Estuarine Water Quality Protection: Department of Environment and Heritage (n.d.).

[369] The IPCC estimated that over the past 100 years, global sea level has risen by an average of 1-2 mm yr^{-1}, and projected that the rate of rise will accelerate (IPCC 2001b), with mean sea level to rise between 0.11 and 0.77 m by 2100 (IPCC (2001a). IPCC (2007) cited core projections of sea level rises ranging from 28 to 43 cms by 2100. The NSW Greenhouse Office accepts an increase between 9 and 88 cm by 2100, with a 'best estimate' of 50 cm (NSWGO 2006). See also MHL (2006).
[370] NSW Government (1997), Objective 2.2 requires recognition and consideration of "the potential effects of climate change in the planning and management of coastal development."
[371] DIPNR (2005a).
[372] NSW Government (2006), Appendix D10.
[373] DoP (2006), pp. 5, 31-32. Available at: http://www.planning.nsw.gov.au/farnorthcoast/index.asp
[374] Available at: http://www.planning.nsw.gov.au/midnorthcoast/index.asp
[375] Available at: http://www.planning.nsw.gov.au/southcoast/index.asp
[376] Available at: http://www.planning.nsw.gov.au/plansforaction/illawarra.asp
[377] See e.g. State Environmental Planning Policy No. 71 cl. 8(j), and the Standard Local Environmental Plan cll. 30(1)(iv), 30(2) (f).
[378] *Walker v Minister for Planning* (2007). NSWLEC 741, 27 November 2007.
[379] COAG Meeting - 10 February 2006 Attachment C. Council of Australian Governments' Plan for Collaborative Action on Climate Change. February 2006 Communique. Available at: http://www.coag.gov.au/meetings/100206/attachment_c_climate_change.pdf
[380] The most likely forms of claims only are discussed here. For more discussion of the application of common law to ASS, see Jones (2000).
[381] For further discussion on private and public nuisance, see Bates (1992), p. 30; Farrier *et al.* (1999), pp. 33-35
[382] Bates (1992), p. 37.
[383] *Gartner v Kidman* (1962).
[384] *Cambridge Water Co v Eastern Counties Leather* (1991).
[385] *Van Son v Forestry Commission of New South Wales* (1995). The law of nuisance has lost much of its relevance following the codification of water pollution law under the *Clean Waters Act 1970* (repealed), although it remains potentially relevant in other actions.
[386] These can be substantial: in *Kempsey Shire Council v Lawrence* (1995). Note that liability is limited to the foreseeable consequences of an action.
[387] Farrier *et al*. (1999), p. 33; *Kempsey Shire Council v Lawrence* (1995), at 6; *Van Son v Forestry Commission of New South Wales* (1995).
[388] *POEO Act 1997*, s. 6.
[389] The Act distinguishes between scheduled and non-scheduled premises. The 'Appropriate Regulatory Authority' (ARA) for carrying out of most functions in relation to scheduled premises is the Environment Protection Authority (EPA).
[390] *POEO Act 1997*, s. 92(1).
[391] *POEO Act 1997*, Part 4.2.
[392] *POEO Act 1997*, Part 4.3.
[393] However, the EPA can issue a licence to regulate water pollution from a non-scheduled activity, in which case it becomes the regulator for all environmental impacts from the activity instead of local council. Licences have been issued in relation to forestry, but not in agricultural situations.
[394] *POEO Act 1997*, s. 96(1).
[395] *POEO Act 1997*, s. 96(3).
[396] It is a defence to an alleged offence under the Act if the occupier of premises is in receipt of a licence, although in few cases will ASS remediation projects of the kind discussed in these Guidelines require licencing: *POEO Act 1997,* Schedule 1.
[397] Bates (1992), p. 44; Lipton (1995).
[398] Fleming (1987); Jones (2000).
[399] Dear *et al.* (2004), p. 3.
[400] ASS affected surface waters may be highly acid and favourable to mosquitoes. Information on mosquito risk assessment and management is available in DLWC (1998b) and MHL (2006).
[401] *OH&S Act 2000*, s. 5. The Act applies to all 'places of work'.
[402] Note that criminal penalties arise from breach of the duties under the Act, but not under the common law of negligence.
[403] *OH&S Act 2000*, s. 8(1).
[404] *OH&S Act 2000*, s. 8(2).
[405] See e.g. Clarence Floodplain Services (2006a).
[406] Walsh & Copeland (2004), p. 8.
[407] See e.g. Clarence Floodplain Services (2006a).
[408] This would normally include a medical evaluation: Clarence Floodplain Services (2006a).
[409] See e.g. Clarence Floodplain Services (2006a). The insurance may also cover volunteers on direct route to and from the council work site.
[410] *LG Act 1993*, s. 731.
[411] *LG Act 1993*, s. 733.
[412] Marsden (2005).
[413] *Bankstown City Council v Alamdo Holdings Pty Ltd* (2005).
[414] Marsden (2005).
[415] *Kempsey Shire Council v Lawrence* (1995), at 7.
[416] *Garrett v Freeman* (No. 2) (2006).
[417] For further information see Farrier *et al*. (1999) and EDO (2006) and, specifically in relation to ASS, Tulau (1999g).
[418] Part 3A, Major infrastructure and other projects, inserted in 2005, is less relevant to ASS remediation projects, and will not be covered here.
[419] Farrier *et al*. (1999), p 30. The zoning tables, which spell out permissible development, are generally in Part 2 of an LEP. However, clauses dealing with 'Special Provisions' may override the basic position spelt out in the tables, an example being Acid Sulfate Soils clauses (see below).
[420] The *Environmental Planning & Assessment Model Provisions 1980* were prepared in order to impart a degree of consistency to planning schemes. Councils were directed to adopt the *Model Provisions 1980* (NSW Government Gazette, 26 September 1980) insofar as they are relevant to the aims and objectives of the LEP: Direction G1 Model Provisions.
[421] These have generally been adopted from the *Model Provisions 1980*, Schedule 1. See below.
[422] Unlike LEPs however, DCPs are not legally binding, although they are one of the factors that must be *"taken into consideration"*: *EP&A Act 1979* s. 79C (1) (a) (iii).
[423] Other SEPPs tend to focus on more significant developments. Most day-to-day development continues to be regulated by local councils through LEPs.
[424] Farrier *et al.* (1999), p. 98. The *North Coast REP 1988* spells out regional policies to guide the preparation of LEPs and to be considered when development control decisions are made.

[425] An exception is the category of exempt development.
[426] Farrier *et al*. (1999), p. 490.
[427] *EP&A Act 1979*, s. 111.
[428] *EP&A Act 1979*, ss. 4, 116B, EP&A Regulation 2000, cl. 226.
[429] Ahern *et al*. (1998a).
[430] Ahern *et al*. (1998b).
[431] *SEPP 71* cl. 8 (j).
[432] cl. 30 (1) (iv).
[433] cl. 30 (2) (f).
[434] *Walker v Minister for Planning* (2007).
[435] *Environmental Planning & Assessment Model Provisions 1980* Schedule 1, cl. 2.
[436] Except: (i) the erection of buildings, the installation or erection of plant or other structures or erections and the reconstruction or alteration of buildings so as materially to affect the design or external appearance thereof, or (ii) the formation or alteration of any means of access to a road: *Environmental Planning & Assessment Model Provisions 1980* Schedule 1, cl. 11.
[437] Note that the policy does not affect assessment and consent requirements under *SEPP 14* (except in relation to emergency and maintenance works), or other approvals, permits etc that may be required under other Acts.
[438] An "existing use" is defined as "the use of a building, work or land for a lawful purpose immediately before the coming into force of an EPI which would .. have the effect of prohibiting that use.": *EP&A Act 1979* s. 106.
[439] Provisions relating to 'existing uses' are in *EP&A Act 1979* Part 4, Division 10, ss. 106-109B, and *EP&A Regulation 2000* cll. 39-46.
[440] *EP&A Act 1979*, ss. 106 (a), 107, 108. *EPAA*, s. 109 (1).
[441] Farrier *et al*. (1999), pp. 43. The use is abandoned if it ceases to be actually so used for a continuous period of 12 months: *EPAA*, s. 107 (2).
[442] Farrier *et.al*. (1999), pp. 13-14, 43. Central to the operation of the provisions is the characterisation of the existing land use, and issues such as the extent of right and abandonment. The extent of the protection in terms of change of land use from grazing to cropping was examined in *Tagget v Tweed Shire Council*, NSW Court of Appeal, unreported, 3 November 1993, No.40520/92. The applicant's existing-use rights were confined to grazing and did not extend to the adoption of other agriculture, "which differed in kind from the activities being undertaken at the relevant date." Whether there had been a change of use should be seen from the perspective of the impact of the use on the neighbourhood. See also: *Dorrestijin v South Australian Planning Commission* (1984) 59 ALJR 105 at 108; 54 LGRA 99 at 105.
[443] *EP&A Act 1979* s. 109 (2), (3); Lee *et al*. (1998), p. 132. see *Tagget v Tweed Shire Council*, NSW Court of Appeal, unreported, 3 November 1993, No.40520/92.
[444] *EP&A Act* s. 107 (2) (b). See also *Vaughan-Taylor v David Mitchell-Melcann Pty Limited & Minister for Minerals and Energy* (1991) 73 LGRA 366.
[445] *EP&A Act 1979* ss. 107 & 109.
[446] Jones (1998).
[447] Sunshine Sugar (2000), p. 1.
[448] Beattie *et al*. (2001).
[449] Later State Environmental Planning Policy No 4 – Development Without Consent and Miscellaneous Complying Development.
[450] Note that this clause was later amended so that it did not apply to land to which *State Environmental Planning Policy No 14 – Coastal Wetlands* applies (*SEPP 4* cl. 10 (3) (f), and later still, to land that is a sensitive coastal location within the meaning of *State Environmental Planning Policy No 71 – Coastal Protection* (cl. 10 (3) (f1)). 'Sensitive coastal location' includes: land within 100 m above mean high water mark of the sea, a bay or an estuary; in or within 100 m of a coastal lake, a Ramsar wetland, an aquatic reserve, or a marine park; or land within 100 m of a *SEPP 14* wetland or a national park or nature reserve: *SEPP 71* cl. 3.
[451] Stone & Hopkins (1998).
[452] Note that there may be some variation between council LEPs. See also *Works that do not Require Consent or Approval*, below. The sugar industry exemption is of particular relevance to much ASS land.
[453] e.g., a remediation project that involves large-scale redesign or realignment of a drainage system may be considered an artificial waterbody >0.5 ha, and therefore may be designated development (there are no limitations as to the shape of the artificial waterbody). Under normal circumstances, agricultural drains would be considered ancillary and subsumed in the dominant purpose of agriculture. However, substantial drainage works could be considered to be independent of the dominant purpose because of their scale and nature, and may be categorised as artificial waterbodies.
[454] *SEPP No. 14 Coastal Wetlands*, cl. 2.
[455] Maps of SEPP 14 areas at the time of gazettal are included in Adam *et al.* (1985). Note however, there have been numerous amendments to the gazetted maps since that time. Maps of current *SEPP 14* areas may be sourced from the relevant council or the Department of Planning.
[456] SEPP 14 wetland maps are based on interpretation of aerial photography run in 1982-3, with the instrument gazetted in 1985, and there may have been subsequent changes in the boundaries and characteristics of those wetlands.
[457] e.g., half of the proposed remediation works in many of the management areas in the Everlasting Swamp could not proceed due to the expense associated with the need to prepare an EIS: Wilkinson (2004), p. 9. Planning law does not distinguish between activities that, it may be claimed, are beneficial to the environment, against those that may be detrimental to the environment. Rather, the law looks to the nature of the works themselves, and leaves it to the assessment process to determine their merit or otherwise.
[458] *SEPP No. 14 Coastal Wetlands*, cl. 2.
[459] Note that 'filling' does not include filling with water.
[460] The case of the Yarrahapinni Broadwater is illustrative: tide exclusion works carried by the former Macleay River County Council as part of the flood mitigation program in 1971 changed a tidal estuarine wetland into a partially drained acidic freshwater wetland. The gazettal of the fresh water wetland 14 years later then created a requirement for an EIS to justify and assess the impact of a proposed remediation project to restore estuarine conditions to the Broadwater: Yarrahapinni Wetlands Reserve Trust (1999). Note that no EIS was required for the construction of the tide exclusion and drainage works in 1971, as Environmental Impact Assessment requirements were first instituted in 1974.

[461] See e.g. Graham *et al.* (2004), p. 65 in relation to the Little Broadwater restoration.

[462] *SEPP No. 14 Coastal Wetlands*, cl. 7A.

[463] DUAP (1999).

[464] See e.g. Kempsey Shire Council (2004b), a plan submitted under cl. 7A for the restoration of Berne's drain, constructed through part of SEPP 14 Coastal Wetland No. 484 on the lower Maria River: *Kempsey Shire Council v Berne* (1996).

[465] *SEPP 71* cl. 8.

[466] *SEPP 71* cl. 11.

[467] *SEPP 71* cl. 3.

[468] 'Approval' is defined in s.110 of the *EP&A Act 1979* to include a consent, licence or permission or any form of authorisation.

[469] DUAP (1995).

[470] LEP sugar industry exemption clauses for Tweed, Byron, Ballina, Lismore, Richmond Valley, Clarence Valley Councils.

[471] *Crown Lands Act 1989*, s. 155 (1)(b), (e) and (h).

[472] See e.g. *Fishwatch v Sawtell, Sawtell, Gray, Stark, Lismore City Council, Richmond River City Council, the Minister Administering the Crown Lands Act and the Minister for Planning* (1994), in which failure to obtain a permit in relation to a road reserve was an issue.

[473] Sections 199, 200 and 201 deal with dredging or reclamation by a public authority (other than local authority), a local government authority, or a person respectively.

[474] Water land is land submerged by water whether permanently or intermittently, or whether forming an artificial or natural body of water, and includes 'wetlands'. Wetlands includes marshes, mangroves, swamps, or other areas that form a shallow body of water when inundated intermittently or permanently with fresh, brackish or salt water, and where the inundation determines the type and productivity of the soils and the plant and animal communities. That is, wetlands do not include deep water: *FM Act 1994* s. 198A.

[475] Note however that DPI Fisheries are preparing maps of 'key fish habitat', which will remove the need to obtain a permit for dredging and reclamation in artificial drains, except where threatened species are known or expected to occur: M. Riches, pers. comm. It is advisable to contact DPI Fisheries for details.

[476] *FM Act 1994* s. 198A.

[477] This section has effect irrespective of any other Act to the contrary: *FM Act 1994* s. 200.

[478] NSW DPI, M. Riches, pers. comm.. Substantial changes to flow velocity and turbulence can also impede fish movement. As such, in-stream rehabilitation works that do not extend across the full width of a watercourse (such as pin ramps, groynes and revetments) should still be referred to DPI for assessment prior to their construction.

[479] See Dwyer (2004), p. 123.

[480] Dwyer (2004), p. 123; NSW DPI, M. Riches, pers. comm..

[481] e.g. Best Management Practice Agreement for Richmond River County Council: Dwyer (2004), p. 12.

[482] The agreement can include assessment procedures, approvals for 12-24 month work programs, protocols for opening and closing the gates and review mechanisms, or other details as required.

[483] NSW DPI, M. Riches, pers. comm..

[484] For port areas, including that of Sydney, Newcastle, Botany Bay, Port Kembla, Richmond River, Clarence River, Coffs Harbour and Twofold Bay, see the *Maritime Services Act 1935*, *Management of Waters and Waterside Lands Regulation*, cl. 66(2).

[485] Note however that DPI Fisheries are preparing maps of 'key fish habitat', which will remove the need to obtain a permit for harm to marine vegetation in artificial drains, except where threatened species are known or expected to occur: M Riches, pers. comm. It is advisable to contact DPI Fisheries for details.

[486] *Marine Parks Act 1997*, s. 19.

[487] *Marine Parks Act 1997*, s. 20.

[488] *Water Management Act 2000* s. 91.

[489] Clause 39A of the *Water Management (General) Regulation 2004* details the exemptions that apply.

[490] Other than Landcom.

[491] Non-protected regrowth younger than 1 January 1990 can take place without approval: (s. 9 (2) (a)), except if that regrowth is protected regrowth, which includes riparian regrowth: s. 11, *Native Vegetation Regulation 2003* cl. 31, Native vegetation management in NSW, Info Sheet 15, available at: http://www.nativevegetation.nsw.gov.au/p/clearing_on_state_protected_land_15.pdf

[492] Where <50% of the groundcover comprises live indigenous species: Native vegetation management in NSW, Info Sheet 6, available at: http://www.nativevegetation.nsw.gov.au/fs/fs_06.shtml

[493] s. 11 (1).

[494] Endangered species are defined in *TSC Act 1995*, s.4 (1), and listed in Schedule 1, Part 1 by s. 6 (1).

[495] Vulnerable species are defined in *TSCAct1995* s.4 (1), and listed in Schedule 2, by ss. 7 (1), 14.

[496] Endangered populations are defined in *TSC Act 1995*, s.4, and listed in Schedule 1, Part 2 by s.6 (2).

[497] Endangered ecological communities are defined in *TSC Act 1995* s.4, and listed in Schedule 1, Part 3, by s. 6 (3). Saltmarsh and Swamp Oak Forest are both Endangered Ecological Communities.

[498] Amendments to the *TSC Act 1995* and in turn the *EP&A Act 1979* and *NPW Act 1974* by the *Threatened Species Conservation Amendment Act 2002* have altered the definitions of threatened species by adding a category of 'vulnerable ecological community'.

[499] 'Harm' is defined so as to include direct injury or killing, but does not include harm by changing the habitat.

[500] *National Parks and Wildlife Act 1974*, s. 118A.

[501] 'Pick' is defined as gathering, plucking, cutting, pulling up, destroying, poisoning, taking, digging up, removing or injuring: *National Parks and Wildlife Act 1974*, s. 5.

[502] *NPW Act 1974* s. 118A.

[503] *NPW Act 1974* s. 118D.

[504] *NPW Act 1974* s. 118C.

[505] It is a defence to prosecution for offences under the *NPW Act* if the offending actions (damage to habitat of threatened species in this case) taken was *"essential for the carrying out of development in accordance with a development consent"* under Part 4 of the *EP&A Act 1979*: see *NPW Act* s.118A (3) (b)(i). The same formula is applied in ss. 118C and 118D. The equivalent applies to an activity under Part 5 of the *EP&A Act* if the activity was done pursuant to a Part 5 approval: *NPW Act 1974*, s.118A (3)(b)(ii). The same formula is applied in ss.118C and 118D. Endangered species are defined in *TSC Act 1995* s.4(1), and listed in Schedule 1, Part 1 by s.6(1).

[506] *NPW Act 1974* s. 118A (3).

[507] *NPW Act 1974* s. 118A (3A); see also Farrier *et al*. (1999), p. 373. Other actions that do not require a 'harm to threatened species' licence include those carried out in accordance with a permit issued under s. 37 of the *FM Act 1994*, or a Ministerial order or interim order made under Subdivision 1A of Division 6 of the *FM Act 1994*.
[508] Part 4 developments: *EP&A Act 1979* ss. 78A (8) (b), 79C (1); Part 5 activities: s. 111 (4) (b). The process of threatened species assessment is described in detail in DUAP (1995); NPWS (1996a, b); *EP&A Act 1979*, s. 5A; ss.78A, 79B, 79C, 80A (Part 4).
[509] s. 5A *EP&A Act 1979*.
[510] *EP&A Act 1979*, s. 5A (1).
[511] *TSC Act 1995*, s.109, 110.
[512] A SIS must contain the information required by Division 2, Part 6, *TSC Act 1995*, ss. 109-112.
[513] Part 4 applications: *EP&A Act 1979*, s. 78A(8)(b), Part 5 activities: *EP&A Act 1979*, s. 112 (1B).
[514] *TSC Act 1995*, s.110. See also NPWS (1996), p.15. In addition, if there is likely to be a significant effect on threatened species, the consent authority must take a further step, of either Ministerial-level consultation or agency-level concurrence, depending on which party is the consent authority.
[515] *TSC Act 1995* s. 91(1).
[516] *TSC Act 1995* s. 94(1).
[517] *TSC Act 1995* s. 95(1).
[518] *EPBC Act 1997* Chapter 2 Part 3 Division 1.
[519] *EPBC Act 1997* s. 178.
[520] *EPBC Act 1997* s. 18A.
[521] Convention on Wetlands of International Importance Especially as Waterfowl Habitat (1971) (Ramsar Convention). Ramsar wetlands on the NSW coast are: Myall Lakes, Hunter estuary wetlands and Towra Point Nature Reserve: Australia's Ramsar sites, available at: http://www.deh.gov.au/water/wetlands/publications/ramsar/pubs/ramsar.pdf.
[522] Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment (JAMBA) (1974); Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment (CAMBA) (1986); Republic of Korea – Australia Migratory Bird Agreement (RoKAMBA) (2006).
[523] *EPBC Act 1997* ss. 16, 20.
[524] *Water Act 1912* s. 112, unless the work is carried out by the Crown.
[525] *Water Act 1912* s. 116AA.
[526] Note that when the relevant provisions of the *WM Act 2000* come into force, the corresponding provisions of the *Water Act 1912* will be repealed.
[527] *POEO Act 1997* Schedule 1.
[528] *NPW Act 1974* ss. 86, 87, 90. Touching or interfering with relics without authorisation is an offence under the *National Parks and Wildlife (Land Management) Regulation 1995* cl. 13.
[529] Relics may be protected through Interim Heritage Orders, listing on the State Heritage Register, EPIs, or by s. 128 orders.
[530] The full text of legislation and regulations, including SEPPs and REPs, can be obtained through the Australian Legal Information Institute at www.austlii.edu.au.