Saltwater Wetlands Rehabilitation Manual

Department of **Environment & Climate Change** NSW

Cover photos (main image, clockwise):
Black-winged stilt (Tony Karacsonyi, DECC);
Bruguiera gymnorhiza, River mangrove, Sarcocornia (Adam Gosling, WetlandCare Australia)

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Preface

Saltwater wetlands are important features of the NSW coastal zone. They provide an array of social, economic and environmental services. Although the degradation and loss of coastal wetlands has occurred in the past, awareness of their ecological significance has created greater interest in the preservation of existing wetlands, rehabilitation of degraded wetlands and construction of new wetlands.

This manual aims to increase knowledge and understanding of saltwater wetlands and to be a key resource in the field of rehabilitation and management. This manual focuses on the rehabilitation of wetlands influenced by brackish or saline waters. These wetland types are home to swamp forests, saltmarshes, mangrove forests and seagrass beds.

A general overview of saltwater wetland environments, their rehabilitation and the use of this manual is provided in Part 1. Part 2 provides specific advice for planning and implementing saltwater wetland rehabilitation projects. Part 3 of the manual is on the accompanying CD and provides information about saltwater wetland characteristics and processes.

Contributors

The production of this manual was a collaborative effort between the Department of Environment and Climate Change and the Department of Commerce (Manly Hydraulics Laboratory). Contributors included Kerryn Stephens, Dayle Green, Dr David Rissik, Phil Anderson, Dr Pia Laegdsgaard, Dr Brian Wallace, Dr Ian Turner, Peter Nelson, Dr Julie Phillips and Ann Finnigan.

The symbols in chapter 11 are used courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Centre for Environmental Science.


(Adam Gosling, WetlandCare Australia)

Part 1
Overview

1 Introduction

1.1 Background

Wetland habitats of NSW have been severely degraded and depleted since the arrival of Europeans in Australia over 200 years ago, helped by the fact that in excess of 80% of the population of NSW live near coastal waterways and their accompanying wetlands. It is estimated that over 60% of the State's coastal wetlands have been lost or severely degraded (Bowen *et al.* 1995). In some areas up to 70% of wetlands have been destroyed (Merrin and Chafer 2000). In addition, the distribution of specific wetland types such as saltmarsh has been severely reduced (for example, by 80% in the Sydney region, Stricker 1995).

Wetlands have not had such a good image in the past. For centuries they were mistakenly seen as wastelands, places of little value that were better exploited for urban or rural expansion.

As the understanding of how wetlands operate has improved, the perceptions about wetlands have changed and today they are recognised as valuable natural and community assets.

Across Australia it is estimated that around 50% of the wetlands have been destroyed since European settlement. This has served to deprive many individual landholders, and the broader community, of the many services and benefits that wetlands provide.

Source: Bennett *et al.* (2001)

Physical changes to coastal wetlands have resulted from poor catchment management practices, land reclamation, agricultural drainage works, urbanisation, and construction of navigation channels, ports and canals. Recent awareness of the ecological significance of wetlands has created greater interest in the preservation of existing wetlands, rehabilitation of degraded wetlands and construction of new wetlands. The destruction or degradation of coastal wetlands is a common issue that has been raised in many of the estuary management plans that have been developed in NSW over the last 15 years or so.

Clyde River estuary and wetlands (DECC)

Hunter River estuary and wetlands (DECC)

1.2 Aim of this document

In recent years there has been a significant increase in the amount of information available in Australia regarding the design, implementation, use and management of constructed and rehabilitated wetlands. For inland and freshwater environments, this has been addressed by *The Constructed Wetlands Manual* (DLWC 1998). The aim of that manual is to provide readers with sufficient information to plan, design, construct and operate a freshwater wetland. It provides comprehensive information on many aspects of constructed freshwater wetlands, with an emphasis on the use of natural wetland processes to treat and manage urban runoff or polluted discharges.

While *The Constructed Wetlands Manual* (DLWC 1998) is useful in providing guidelines and general information on wetland rehabilitation, it does not specifically address saltwater wetlands, which lie within or adjacent to estuarine or coastal environments and are either permanently or occasionally inundated by brackish or saline waters.

The aim of this *Saltwater Wetlands Rehabilitation Manual* is to provide technical information and guidance to assist with the rehabilitation of degraded saltwater wetlands, that is, restoration to a functional condition. Saltwater wetlands have complex hydraulic, physical, chemical, biological and ecological interactions which are quite different from those of freshwater wetlands and which need to be understood and addressed before rehabilitation is undertaken. Furthermore, there are significantly different issues for excavation and construction works in saltwater wetlands, due to the physical (low strength, saturated conditions) and chemical (potentially low pH, highly saline and high organic content) nature of soils in these areas.

The construction of new or compensatory wetlands is not specifically addressed here, though many of the principles and techniques discussed in this manual are applicable. The advice in this manual regarding construction techniques generally relates to construction within existing saltwater wetlands for purposes such as water treatment or habitat enhancement.

1.3 Objectives

The objectives of the manual are:

- to provide land managers and community groups with sufficiently detailed information to design, implement, manage and monitor a saltwater wetland rehabilitation project
- to provide a logical and robust process for wetland rehabilitation, capable of accommodating developing technologies, information, concepts and ideas
- to provide sufficiently detailed information to convey the complexity of saltwater wetlands ecosystems to assist with planning and management of rehabilitation projects.

1.4 Document style and scope

The manual has been prepared for a target audience including:

- technical staff in local government (engineers, planners and landscape architects)
- technical staff in government agencies
- consultancy firms and construction companies
- potential operators, managers and owners of rehabilitated saltwater wetlands (private landholders, agencies, local councils, community groups and schools)
- community groups.

Particular features of the manual include:

- a scientific approach to projects with an emphasis on planning and setting objectives
- encouragement of optimal design through community involvement, multidisciplinary project teams and other techniques
- an outline of an optimal sequence and relationship of tasks during the various project phases from planning through to implementation, operation, maintenance and monitoring
- information on the best available techniques, methodologies and tools for achieving the objectives of the rehabilitation process
- the inclusion of detailed background information on saltwater wetland flora, fauna and physical processes to assist with planning and decision making.

The issues relating to saltwater wetlands are often complex. Where possible, the manual includes simple guidelines to address some of the tasks involved in wetland rehabilitation. As far as possible, the manual has been written in plain English with technical jargon **bolded** and described in a glossary of terms.

A comprehensive literature review has been undertaken during preparation of this manual. A bibliography is included to ensure an authoritative document, and to allow the reader to follow up more detailed information if required.

Information relating to general principles and processes of rehabilitation is applicable to all readers interested in saltwater wetland environments. Information relating to soils, tidal processes, flora and fauna is relevant to NSW and adjacent areas with similar climates, coastal processes and vegetation characteristics. Information relating to legal and policy issues is confined to the Commonwealth and NSW legislative processes and, while correct at the time of publication, may change.

1.5 Restoration or rehabilitation?

The terms 'restoration' and 'rehabilitation' appear to have similar meanings and are often used interchangeably. But within the field of ecology there are subtle differences dependent on the expectations or outcomes that are desired.

The goal of restoration is typically to return a degraded ecosystem to its natural or original state by removing the cause of degradation. Rehabilitation, on the other hand, seeks to improve or recover natural functions and processes without necessarily achieving the pre-disturbance condition. Rehabilitation therefore aims to improve wetland health and function to whatever degree is considered feasible.

The term 'restoration' is widely used in overseas literature in relation to wetland recovery projects. However, in Australia, 'rehabilitation' appears to be more commonly used, perhaps because it is considered a more practical and achievable endpoint. This manual uses the term 'rehabilitation', in acknowledgment of the fact that full restoration to natural conditions is often not possible, given the many stresses that may be acting upon a wetland.

1.6 Description of saltwater wetland types

Estuaries are semi-enclosed bodies of water with a permanent or intermittent connection to the ocean that are characterised by brackish or saline water derived from the mixing of marine and fresh waters. In NSW, estuaries may comprise a number of interrelated wetland habitats, including swamp forest, saltmarshes, mangroves, seagrass beds, reedbeds, shallow sand and mud flats, rocky shores and reefs, and deeper waters.

This manual focuses on the rehabilitation of wetlands whose inundation regime and vegetation characteristics are influenced by brackish or saline waters. These wetland types are home to swamp forests, saltmarshes, mangrove forests and seagrass beds.

Swamp forests

Swamp forests occur around the margins of many estuaries, forming a buffer between dryland communities and the estuaries. The structure and species composition can vary considerably with physical factors, but many consist principally of swamp oak (*Casuarina glauca*), paperbark (*Melaleuca* spp.) or swamp mahogany (*Eucalyptus robusta*), with an understorey characterised by vines, shrubs and a groundcover of forbs, sedges, grasses and leaf litter.

Saltmarshes

Saltmarshes occur at the upper levels of the **intertidal** zone. They are not subject to daily tidal inundation but may be flooded by larger tides. In NSW, saltmarshes are characterised by herbaceous species such as samphire (*Sarcocornia quinqueflora*), saltwater couch (*Sporobolus virginicus*) and rushes (for example, *Juncus kraussii*).

Mangrove forests

Mangroves grow along the shorelines of many NSW estuaries in areas subject to regular tidal inundation. The two most common species are grey mangrove (*Avicennia marina*) and river mangrove (*Aegiceras corniculatum*).

Mangroves (Adam Gosling, WetlandCare Australia)

Seagrass beds

Seagrasses grow in the **subtidal** zones of estuaries. The most common species are eelgrass (*Zostera* spp.), paddleweed (*Halophila* spp.), strapweed (*Posidonia australis*) and sea tassel (*Ruppia* spp.). Seagrass meadows may be **monospecific** or consist of a number of species.

1.7 The importance of saltwater wetlands

Saltwater wetlands are significant features of the coastal zone with many different social, economic and environmental values. A range of services derived from saltwater wetlands are shown in Table 1.1 (overleaf).

Swamp forest communities are found on the coastal floodplains of NSW. Swamp forests are generally associated with clay-loams and sandy loam soils, where the groundwater is saline or sub-saline, on waterlogged or periodically inundated flats, drainage lines, lake margins and estuarine fringes associated with coastal floodplains. The community is important in terms of habitat value, **riparian** protection, flood control and water quality improvement.

Both mangroves and saltmarsh occupy a unique transitional position between purely aquatic and purely terrestrial environments. They have a number of important structural functions, including flood and erosion control, buffering storm surges, and improving water quality by filtering pollutants and excess **nutrients**. In addition, mangrove forests are important habitats for fish, molluscs, crabs, bats and birds, and the trees provide large amounts of organic matter as a food source for the estuary. Saltmarshes support a rich and diverse community of **invertebrates**, provide roosting sites for many species of birds, and provide habitat for juvenile fish when inundated (Morrisey 1995, NSW Fisheries 1999).

Seagrass meadows are important for sustaining recreational and commercial fisheries, by maintaining sediment stability and water quality in estuaries and providing food and shelter for fish, particularly during their juvenile life stages (Bell and Pollard 1989).

Rehabilitation projects usually aim to protect or restore some of these values. A key goal of wetland rehabilitation is to maintain an ecologically healthy, functioning system that maintains its structure over time and is able to recover from stress.

The key threats to the biological health and integrity of saltwater wetlands relate mainly to various human activities that occur in the coastal zone or within coastal river catchments, including:

- drainage
- dredging and stream channelisation
- human-induced climate change and sea level rise
- deposition of landfill
- structural works (levees, floodgates, dams, weirs and road culverts)
- urban development, including stormwater runoff
- air and water pollutants
- introduction of non-native and invasive species
- agricultural activities, including grazing by livestock and runoff
- river regulation and water extraction
- recreation, including boating and four-wheel driving.

Saltmarshes are particularly susceptible to disturbances from both natural and anthropogenic sources. Four-wheel drive vehicles, grazing and trampling by livestock, flooding, fires, drainage works and floodgates can all easily destroy saltmarshes.

Seagrass beds may be directly affected by dredging and reclamation; artificial opening of coastal lagoons; structures such as breakwaters, jetties, ramps and pontoons; boating; oyster leases; and diffuse and point-source pollution (Smith *et al.* 1997).

As a result of the large losses of saltwater wetlands in NSW, remaining wetlands have been protected through a variety of legislation and policy (see Chapter 12). For example, a number of saltwater wetland communities have been listed under the *Threatened Species Conservation Act 1995* (TSC Act) as endangered ecological communities. These include coastal saltmarsh and swamp oak floodplain forest in the NSW North Coast, Sydney Basin and South-East Corner bioregions.

Table 1.1 Services provided by saltwater wetlands

(Relative magnitude (per unit area) of ecosystem services derived from different types of wetland ecosystems: Millennium Ecosystem Assessment 2005).

Services	Comments and examples
PROVISIONING	
Food	Production of fish, algae and invertebrates
Fresh water	Storage and retention of water; provision of water for irrigation and drinking
Fibre, timber, fuel	Production of timber, fuelwood, peat, fodder, aggregates
Biochemical products	Extraction of materials from **biota**
Genetic materials	Medicine; genes for resistance to plant pathogens; ornamental species
REGULATION	
Climate regulation	Regulation of greenhouse gases, temperature, precipitation and other climatic processes; chemical composition of the atmosphere
Biological regulation	Resistance of species invasions; regulating interactions between different trophic levels; preserving functional diversity and interactions
Hydrological regimes	Groundwater recharge and discharge; storage of water for agriculture or industry
Pollution control and detoxification	Retention, recovery and removal of excess nutrients and pollutants
Erosion protection	Retention of soils
Natural hazards	Flood control; storm protection
CULTURAL	
Spiritual and inspirational	Personal feelings and wellbeing
Recreational	Opportunities for tourism and recreational activities
Aesthetic	Appreciation of natural features
Educational	Opportunities for formal and informal education and training
SUPPORT	
Biodiversity	Habitats for resident or transient species
Soil formation	Sediment retention and accumulation of organic matter
Nutrient cycling	Storage, recycling, processing and acquisition of nutrients

Scale is low ●, medium ●, to high ●; blank cells indicate that the service is not considered applicable to the wetland type. The information in the table represents expert opinion for a global average pattern for wetlands; there will be local and regional differences in relative magnitudes.

	Estuaries and marshes	Mangroves	Lagoons, including salt ponds	Intertidal flats, beaches and dunes	Rock and shell reefs	Seagrass beds
	⬤	⬤	•	●	●	•
	•		•			
	⬤	⬤	●			
	•	•				
	•	•	•			
	●	●	●	•	•	•
	●	⬤	●	•	•	
	•		•			
	⬤	⬤	●		•	•
	●	⬤	•			•
	⬤	⬤	•	•	●	●
	⬤	•	●	⬤	•	•
	⬤	•	•	⬤		
	●	•	●	●		
	•	•	•	•	•	
	●	●	•	⬤	⬤	•
	●	●	•	•		
	●	●	●	•	•	

1.8 How should I undertake the rehabilitation process?

This manual provides a process for the effective rehabilitation of saltwater wetlands which encourages rehabilitation based on accurate assessments of the problems, in a manner which is adaptive and therefore able to be changed in response to changing conditions or additional information. The science of rehabilitating saltwater wetlands is still in its infancy in Australia. While some wetland rehabilitation projects have been successful, several have been unsuccessful, and many have been poorly assessed or not assessed at all.

The scale and location of the project being undertaken will determine the effort required in the various stages of the process, but all stages are important to consider and will assist with effective outcomes. Many saltwater wetland species require specific environmental elements for successful establishment and growth. Tidal influence, elevation and topography are essential components to get right in the overall plan and design. The selection of a suitable site for rehabilitation will depend on local conditions, works required and the species to be encouraged or planted. Some aspects of rehabilitation will be more important in some locations than in others; for example, designing saltmarsh rehabilitation so as to minimise mosquito numbers will be more important in wetlands adjacent to urban areas. Greater success will be achieved if adjacent sites are fully functioning ecosystems rather than highly degraded areas.

A flow chart of the suggested process for undertaking rehabilitation projects in saltwater wetlands is presented in Figure 1.1. The major tasks are outlined below and discussed in greater detail in Chapters 2 to 6.

Project management

Overall management of the project should be thought out and clearly articulated. Project management will include the setting up and support of a working group, steering committee or other project 'driver'. Roles, responsibilities and time frames should always be clearly defined.

Selection of wetland and identification of issues and values

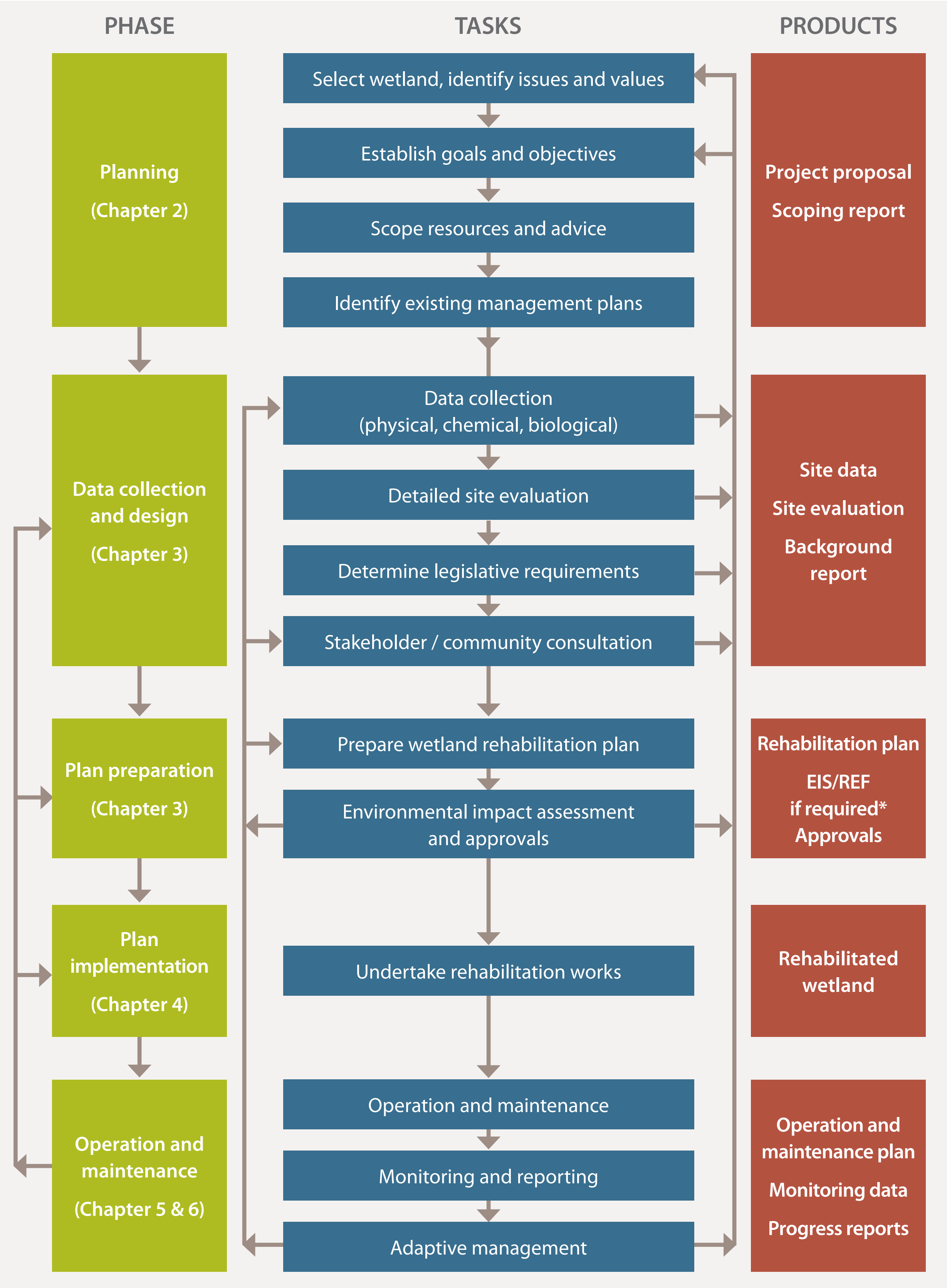
The decision to rehabilitate a wetland is usually made to fulfil a specific objective, which in turn reflects the values that are attributed to wetlands. Values can be diverse and may include scenic quality, recreational opportunities or presence of waterbirds.

Identifying the issues of concern is an important step in the planning process, and can help to focus wetland rehabilitation activities. Issues that are of common concern in NSW saltwater wetlands include water quality, loss or degradation of habitat, weed encroachment, bank erosion, **sedimentation** and changes to fauna populations. It is important to remember that wetlands are generally the receiving waters for the surrounding catchment and thus can be significantly affected by activities within the catchment, as well as those acting directly on the site.

Establishing goals and setting objectives

Regardless of the size of the rehabilitation or constructed wetland project being considered, it is essential that clear, measurable goals and objectives be established. Establishing clear objectives enables you to assess the problem and determine what needs to be done to improve the wetland or to achieve your objectives. Good and focused planning enables identification of materials, labour activities and time frames that will be needed to achieve project goals.

Figure 1.1 Flow chart indicating the management process to achieve effective rehabilitation of saltwater wetlands



*EIS Environmental Impact Statement
REF Review of Environmental Factors

Scoping resources and advice

It is often necessary to solicit advice and help for the planning, undertaking and funding of wetland rehabilitation projects. Advice can generally be sought from a range of specialists, including State agencies, Catchment Management Authorities (CMAs), local councils, non-government organisations and consultants. The amount of advice required depends on the goals and objectives, extent and degradation of the site, and type of wetland.

Integrating with existing management plans

Rehabilitation projects must be fully integrated with other rehabilitation plans in the area and be consistent with the objectives and processes outlined in other management plans relevant to the area such as catchment action plans and estuary management plans. These plans will generally be available through local councils or State agencies.

Data collection

The amount of data collection required will depend on the scale and nature of the project and the amount of information that is already available. The information collected should aim to support a good understanding of the major issues, the natural processes occurring in the wetland and the general biological and hydrological characteristics of the wetland. It will be necessary to identify and understand both the processes currently occurring and those that would be occurring if the wetland were in pristine condition. Where little information is available about a wetland, it may be necessary to begin a data collection program a year or more before preparing a rehabilitation plan.

Detailed site evaluation

A detailed site evaluation is necessary to establish the causes of degradation of the wetland, and the limitations and potential for a range of rehabilitation activities. The site evaluation usually involves several visits to the wetland and analysis of all the available information. The results of the site evaluation should assist in determining the appropriate rehabilitation activities, future data needs and possible monitoring requirements.

Consideration of legislative and legal requirements

After the basic outline of the rehabilitation plan has been prepared, any requirements of legislation or regulatory agencies should be considered, including what level and form of environmental assessment and approval is required.

Liaison and consultation with community and stakeholders

Effective consultation with the various interested parties is essential for the perceived success of the project. This process must begin as early as possible and ensure full involvement of all stakeholders.

Preparation of a wetland rehabilitation plan

Some form of rehabilitation plan should be prepared for each project. While the amount of detail in the plan will vary with the size and complexity of the project, the plan should include broad and specific rehabilitation objectives and specific actions. Actions should be prioritised as far as possible, and time frames, performance indicators, costs, funding sources and other resource requirements should be specified.

Environmental impact assessment and approvals

Obtaining approval to make environmental changes can be a complex and time-consuming process. In NSW the requirement for environmental impact assessment is determined by the *Environmental Planning and Assessment Act 1979* (commonly referred to as the EP&A Act). Wetland rehabilitation activities may require consent from your local council or various State Government departments (and sometimes both). In addition, Commonwealth legislation may sometimes apply.

Undertaking rehabilitation works in accordance with the rehabilitation plan

Implementation of a rehabilitation plan involves the on-site actions required to set up the rehabilitation processes, such as the construction of works and the establishment of plantings.

Operation and routine maintenance of the rehabilitation plan

Plan operation involves all the actions required to ensure continued management of the rehabilitation plan, and normally involves the preparation and implementation of an operation and maintenance plan. While rehabilitated ecosystem functions should be designed to be as self-sustaining as possible, it is likely that at least in the short to medium term, regular operational activities such as inspections, weeding, and maintenance of structures will be required.

Regular monitoring and reporting of agreed success measures

Effective monitoring is critical to the success of a wetland rehabilitation plan. Without proper monitoring the degree of success or failure of a rehabilitation plan cannot be properly judged. The progress and outcomes should be monitored and reported, even if the plan is not being implemented successfully. A well-designed monitoring program with clear objectives and measurable performance criteria will ensure that important information is available at key stages of the plan, and will facilitate informed wetland management decisions in the future.

Adaptive management and fine-tuning of the rehabilitation plan

Owing to the complexity of estuarine systems and the current state of knowledge, management of a saltwater wetland rehabilitation project must be adaptive. That is, management must change if monitoring results indicate that certain objectives have not been achieved. The addition of new knowledge or data or changes in rehabilitation techniques may also necessitate changes to the rehabilitation plan over time (Dialogue Box 1.1).

Dialogue Box 1.1 Adaptive management of Millennium Wetlands

An example of adaptive management can be seen from the Millennium Wetlands at Homebush Bay (near the Sydney 2000 Olympics site). A large area of saltmarsh and mangroves was earmarked for rehabilitation a few years before the Olympics were due to begin. The main objectives at that time were to:

- reduce mosquito breeding
- improve habitat for wading birds
- increase the extent of saltmarsh
- increase the diversity of **benthic** macroinvertebrates.

The main management tool was the use of improved flushing; a number of culverts were built, and two main drainage channels were deepened. The result was vastly improved flushing, draining all water out of the wetland in each tidal cycle. The rapid influx and efflux of the large volume of water reduced mosquito breeding, but eventually resulted in erosion and reduction of use of the area by native birds.

Following this, a decision was made to monitor the movement of water into, out of and within the wetland to determine the effects of changing the flushing regime. The results showed that appropriate changes could be made to the flushing capacity of the system to reduce erosion and increase mudflats and habitat for migratory birds.

1.9 Principles to incorporate in wetland rehabilitation

The following principles offer a useful starting point for wetland rehabilitation. Incorporating these principles into your project design will help provide the foundations of a successful wetland rehabilitation project. (The principles have been adapted from US EPA 2000 and the Ramsar Convention on Wetlands 2002.)

Conserve and protect aquatic resources

The maintenance and conservation of existing wetlands is always preferable and more economical than their subsequent rehabilitation. Existing, relatively intact ecosystems are critical for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of degraded systems. Even in wetlands for which rehabilitation is planned, the first objective should be to prevent further degradation.

Aim for ecological integrity

Rehabilitation should re-establish as far as possible the ecological integrity of degraded habitats, that is, the structure, composition, and natural processes of the biological communities and physical environment. An ecosystem that retains integrity is a resilient and self-sustaining natural system able to withstand or recover from a certain level of stress and change.

Restore natural structure and function

Many wetlands in need of rehabilitation have problems that originate from alteration of their natural form or other physical characteristics. Structure and function are closely linked in wetlands and estuaries. Re-establishing the appropriate natural structure can bring back beneficial functions and is essential to the success of other objectives, such as improving water quality or restoring native biota.

Work within the catchment and broader landscape context

Whenever possible, plan for wetland rehabilitation at the catchment level. Activities throughout the catchment can have adverse effects on the subject wetland. A localised project may not be able to change what goes on in the whole catchment, but it can be designed to better accommodate catchment effects.

Understand the natural potential of the catchment and anticipate future changes

The environment and our communities are both dynamic. Establishing rehabilitation goals for a wetland requires knowledge of the historical range of conditions that existed at the site before degradation and what the future conditions might be. Although it is impossible to precisely plan for the future, many foreseeable physical, ecological and social changes can be factored into rehabilitation design.

Address ongoing causes of degradation

Rehabilitation efforts are likely to fail if the sources of degradation persist. It is essential to identify the causes of the degradation and eliminate or remediate stresses wherever possible. While degradation can be caused by one direct impact, much degradation is caused by the cumulative effect of numerous, indirect impacts.

Develop clear, achievable, measurable goals

Clear goals provide direction for a rehabilitation project and provide the standards for measuring success. Goals should be achievable ecologically, given the natural potential of the area, and socioeconomically, given the available resources and the extent of community support for the project.

Involve the skills and experience of a multidisciplinary team

Rehabilitation can be a complex task that integrates a wide range of disciplines, including ecology, **hydrology**, **geomorphology**, engineering, planning and social science. To the extent that resources allow, the planning and implementation of a rehabilitation project should involve people with experience in the disciplines needed for the particular project.

Involve all relevant stakeholders

Wetland rehabilitation should be an open process that involves the local community and other stakeholders who may be affected by or have an interest in the project. It will be essential to secure the support of any potentially affected neighbours. All stakeholders should be fully involved in wetland rehabilitation from the earliest stage of the project through its implementation to its ongoing management.

Design for self-sustainability

Successful rehabilitation should, as far as possible, be designed for self-maintenance. High-maintenance activities not only add costs to the project, but also make its long-term success dependent on human and financial resources that may not always be available. Where self-sustainability is unlikely, it is important to recognise the need for long-term stewardship and the resources and commitment needed to sustain this stewardship.

Use passive rehabilitation when appropriate

'Time heals all wounds' may apply to some rehabilitation sites. Before actively altering a wetland site, determine whether passive rehabilitation (that is, simply reducing or eliminating the sources of degradation and allowing recovery time) will be enough to allow the site to naturally rehabilitate.

Restore native species and avoid non-native species

Many **introduced species** out-compete natives because they are expert colonisers of disturbed areas and lack natural controls. Invasive, non-native species should not be used in a rehabilitation project, and special attention should be given during the project to avoiding the unintentional introduction of such species at the site.

Use natural fixes and ecological engineering techniques where possible

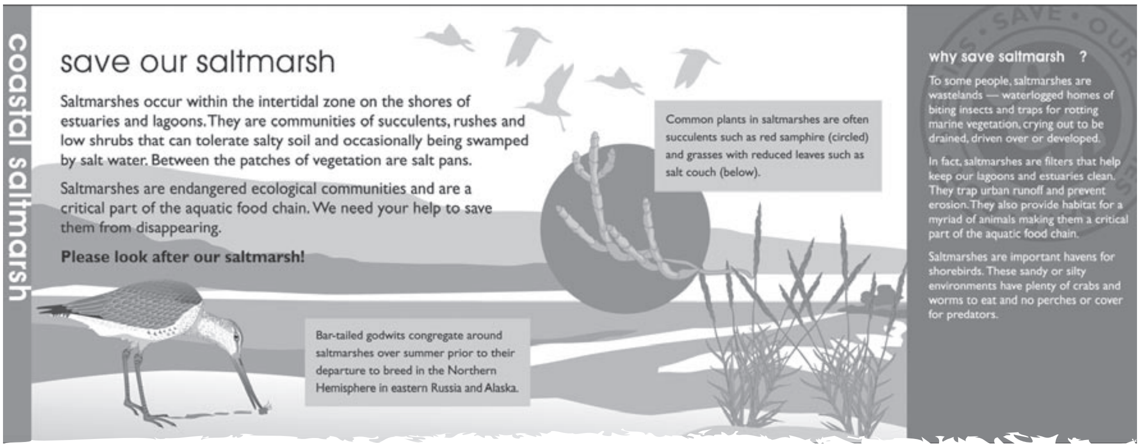
Whenever possible, apply ecological engineering principles and methods in preference to methods requiring hard structures or extensive construction works. Ecological engineering uses living, functioning systems to prevent erosion, control sediment and pollutants, and provide habitat. Examples include the use of constructed wetlands for the treatment of stormwater and the rehabilitation of vegetation on river banks to enhance natural filtering of runoff.

Monitor and adapt where changes are necessary

Monitoring before and during a rehabilitation project is crucial for determining whether goals are being achieved. If they are not, adjustments to the project should be made. It may also be necessary to make changes to the project to accommodate unforeseen circumstances or to take advantage of newly acquired knowledge and resources. This process is known as adaptive management.

Share the results of rehabilitation projects

Successful rehabilitation projects can provide inspiration for continuing stakeholder involvement and for the development of further projects. Information on the results of a rehabilitation project should be widely disseminated in both scientific forums and more accessible sources available to the community and stakeholders. Where possible, wetland rehabilitation should be coupled with measures to raise awareness and influence the behaviours and practices that led to the degradation of the wetland in the first place. Methods to raise awareness of the importance of the rehabilitation site may include information days, media coverage and the use of interpretive signage on site.



Interpretive signage, Koona Bay, Lake Illawarra (DECC; Site Specific Pty Ltd)


(Conservation Volunteers Australia)

Part 2
Project planning and implementation

2 Planning for wetland rehabilitation

The first stage of any wetland rehabilitation project is the planning and design phase. The concepts must be clearly thought out at this stage if the project is to be a success. Good planning, including setting time frames and staging goals, can avoid misunderstandings and the decreasing motivation that may occur if expectations of the working group are not fulfilled within a reasonable time frame. Planning also allows identification of appropriate resources and the timing of activities to achieve objectives. For example, if migratory birds use the wetland as a feeding ground during the Australian summer, it is necessary to recognise this during the planning phase and to conduct any potentially disrupting activities during winter.

2.1 Why rehabilitation?

Reasons for selecting a wetland or part of one for rehabilitation are generally related to the values that stakeholders assign to that wetland. The values that are assigned will in themselves have implications for the management of the wetland (Table 2.1).

Social reasons

When human development occurs near wetlands, there is often a desire to improve the aesthetics of the wetland. Aesthetics can be taken to include scenic quality, amenity related to odours and mosquitoes, and opportunities for recreation, tourism, education, scientific study and social activities.

The protection of **cultural values**, especially those associated with indigenous and European cultural heritage sites and areas, can be a reason for rehabilitation of a saltwater wetland.

Table 2.1 Values and management implications for saltwater wetlands

Value	Management implications
Social	Maintain aesthetics through overall wetland structure Provide appropriate access for recreation and tourism Maintain and commemorate significant sites as far as possible and link them with other management strategies Identify and provide infrastructure and resourcing for development of educational and scientific opportunities with linkages to recreation and commercial opportunities Limit encroachment of rural and residential development (includes managing flood risks) and ensure community activities are compatible with maintaining ecological health Manage odours and mosquitoes
Environmental	Maintain water quality, flora and fauna distributions (including protection of threatened species), hydrological regimes and soil integrity Maintain overall integrity of saltwater wetlands (the importance of this will increase with climate-induced sea level rise and storms)
Economic	Ensure commercial activities are sustainable and compatible with maintaining other wetland values

Mangrove forest, Tweed River estuary (Adam Gosling, WetlandCare Australia)

Environmental reasons

Habitat creation, expansion, enhancement and maintenance within saltwater wetlands can be important for birds, fish, invertebrates, mammals, reptiles and amphibians, including native and migratory species, as well as for overall biodiversity.

Improvement or maintenance of natural resources within a wetland such as water quality, soils and hydrological regimes will in turn benefit surrounding areas.

A plan of management such as an estuary management plan may include as an action the rehabilitation of a saltwater wetland. Such an action would therefore contribute to the overall health and protection of the estuary.

Owing to the combination of values attached to a wetland, the wetland may be considered regionally significant or rare and hence require rehabilitation to maintain those values. Rehabilitation of such wetlands may in turn contribute to regional biodiversity.

Economic reasons

Commercial and economic activities such as extractive industries can result in the need to rehabilitate saltwater wetlands. Alternatively, activities such as ecotourism require degraded wetlands to be rehabilitated for the activity to be viable.

If human activity results in the destruction of a saltwater wetland – for example, through construction of public infrastructure – it may then be appropriate to rehabilitate another wetland or to create new habitat to compensate for the loss of the existing values.

2.2 Identification of issues

The identification of issues will provide direction to rehabilitation activities and assist in prioritising work programs. Issues should be identified in consultation with the full range of stakeholders who have an interest in the site. Some of the issues that may be important for a wetland are described below.

Uncontrolled vehicle access through a wetland (DECC)

Catchment status and activities

As most saltwater wetlands receive runoff from the surrounding catchment, it is important to review the health, processes and activities of the catchment to identify their potential impacts on the wetland. This may include surrounding industry and considering any past and present pollution discharges to the wetland. Encroachment into the wetland by surrounding uses or terrestrial species may also be an issue. Unless catchment effects are addressed, wetland rehabilitation activities could be unsuccessful.

Integration with surrounding management

Management of saltwater wetlands cannot be considered in isolation, but must be integrated with planning policies and management objectives and plans in the surrounding area.

Estuarine and coastal processes

As saltwater wetlands are part of the estuarine or coastal zone, they are affected by estuarine and coastal processes. These processes can include tidal flows and inundation, wave activity and sediment transport by water and wind action. Climate-induced changes will also affect these processes. The effects of these processes need to be considered in the planning of rehabilitation activities.

Climate change processes

Although many aspects of climate change are not easily predicted, it is likely that wetlands will be affected through a number of processes, including sea level rise (see Chapter 7), increased sea temperatures, changes in hydrology, and increases in the frequency and intensity of extreme events such as storms, droughts and floods.

Adaptation strategies need to be considered in the planning of rehabilitation activities. The prevention of additional stress may improve the ability of wetlands to respond to climate change (Bergkamp and Orlando 1999). Reducing pollution, avoiding vegetation removal and protecting wetland biological diversity and integrity will be viable activities to maintain and improve the resiliency of wetland ecosystems so that they continue to provide important services under changed climatic conditions (Kusler and Burkett 1999). Another important adaptation strategy is preventing the fragmentation of existing wetland systems and buffer zones that allow for landward vertical migration of wetlands if sea level rise exceeds the rate of vertical sediment accretion.

Available methods of rehabilitation

Rehabilitation strategies must be compatible with the methods available, otherwise the strategy will not be successful. Review of other rehabilitation projects and scientific literature may be required to determine the most appropriate method to achieve rehabilitation goals.

Beneficiaries

The non-human and human beneficiaries of the rehabilitation activities need to be identified to ensure the activities are appropriate. Conversely, if there are likely to be those who may not benefit from the activities, their concerns should be addressed as early in the process as possible.

Water quality

Identification of the current status of and processes affecting water quality in the wetland will normally be critical to planning and design of a rehabilitation project. Poor water quality can influence the quality of wetland habitat and the chemical processes that occur within wetlands. These in turn may affect the diversity of flora and fauna that can be supported.

Foreshore erosion

Foreshore erosion is a common process in saltwater wetlands. The extent to which this erosion should be managed and the means of doing so must be considered in conjunction with the causes of the erosion. Causes of erosion may include wind-waves, boat wash, removal of riparian vegetation or alterations to natural flow patterns.

Sedimentation

Sedimentation resulting from catchment runoff, input from estuary and coastal sources and reworking processes within the estuary can affect the water flow and volumes within the estuary as well as the distribution of mangroves, saltmarsh and seagrass.

Degradation of habitat, including loss of vegetation and weed encroachment

Swamp forest, mangroves, saltmarsh and seagrass are important habitat types, and their degradation significantly reduces the value of saltwater wetlands. Saltmarshes and swamp forest in particular are vulnerable to weed invasion, which can reduce the habitat value of the wetland for fauna species. The major weed species in saltmarsh include *Juncus acutus*, groundsel bush (*Baccharis halimifolia*), pampas grass (*Cortaderia selloana*) and American pennywort (*Hydrocotyle bonariensis*). The weed species found in swamp forest are numerous and include whiskey grass (*Andropogon virginicus*), madeira vine (*Anredera cordifolia*), crofton weed (*Ageratina adenophora*), camphor laurel (*Cinnamomum camphora*), lantana (*Lantana camara*), small-leaved privet (*Ligustrum sinense*), Japanese honeysuckle (*Lonicera japonica*) and wandering jew (*Tradescantia fluminensis*).

Lantana removal, Tom Thumb Lagoon (Conservation Volunteers Australia)

Changes to faunal diversity

The preservation of faunal diversity has local, regional, national and international implications. Predation by pest fauna such as foxes and cats can reduce the viability of wetlands as faunal refuges.

2.3 Setting goals and objectives

Many wetland rehabilitation projects suffer from poorly stated goals and objectives. Establishment of goals and objectives helps to provide direction to a project and facilitates a clear vision of the desired outcome. The overall success of the project will generally be measured against its goals and objectives by the measurement of performance criteria. It is essential to set clear goals and objectives to ensure that methodologies chosen for the rehabilitation project are not in conflict.

Setting clear goals and objectives help in integrating your project with other plans. How do your goals and objectives fit in with other management actions that are occurring in the area?

Goals are general statements about the desired outcomes of the project. Stating goals allows all people involved to understand in general terms the desired results. In general, goals focus on the values to be restored, enhanced or protected. Goals should be achievable in realistic time frames, or should be staged for longer, more complex projects.

Objectives are specific statements about the desired outcomes of the project. Projects typically have more than one objective, reflecting the multiple functions that individual wetlands perform. Objectives must be unambiguous and measurable and should preferably include time frames. In this way it is possible to test them effectively and make necessary adjustments to management plans. Adjustments may be required if improved knowledge becomes available or because the management actions prove to be ineffective.

Performance criteria are observable or measurable attributes that can be used to determine whether a project meets its intended objectives. Each objective will have at least one performance criterion. It is essential that any measurements be conducted using appropriate methodologies and at appropriate scales that account for natural variability. Information on monitoring is provided in Chapter 6.

Dialogue Box 2.1 Examples of goals, objectives and performance criteria

Project 1

Goal: Increase the quality of wildlife habitat at wetland X.

Objective: To improve habitat value for migratory waterfowl by 2010.

Performance criterion: The abundance of key migratory species using wetland X.

Project 2

Goal: Restore the extent of tidal wetlands of River Y to pre-1970 conditions.

Objective: To increase the area of saltmarsh communities by 50% by 2015.

Performance criterion: Area in hectares of saltmarsh.

Project 3

Goal: To protect and manage the remnant native vegetation of Lake Z.

Objective: To protect riparian vegetation communities by the exclusion of stock within 3 years.

Performance criterion: Area in hectares of vegetation fenced from stock.

The objectives for rehabilitating saltwater wetlands vary, but are often focused on enhancing conditions for native fauna, enhancing visual amenity or expanding the occurrence of rare species. Some of these goals may be mutually exclusive, so it is essential to consider the goals for rehabilitation before initiating works. For example, creating habitat for waders may not necessarily enhance visual amenity or expand the occurrence of a rare plant. Optimising habitat for one faunal group may be detrimental for another, or may create conditions for undesirable species such as mosquitoes.

You may need to ask whether your project aims to provide habitat for a range of species to conserve biodiversity, or to a particular species such as an endangered shorebird. Where the latter applies, the ecology of the target species will be essential knowledge for input to the project design. Typically, the aim of rehabilitation projects should be to provide habitat for a diversity of saltwater wetland plants and animals.

The design of wetland rehabilitation projects must therefore be planned carefully to ensure the right balance between wetland values and to ensure that appropriate measures are implemented for the proposed goal.

2.4 Scoping resources and advice

Once goals and objectives have been set, it is then possible to understand and begin planning the full scope of the project. At this stage the need for specialist advice, funding and other resources can be considered.

Gathering information

Undertaking a review of similar projects either from the literature or from site inspections is an essential task in order to obtain ideas on preferred rehabilitation strategies, technical and practical problems that may be encountered, and time frames over which similar rehabilitation projects have been achieved. The review may also lead to the identification of important contacts, consultants or suppliers that will be useful to the project. The information obtained from this process should be documented in a background or scoping report, along with information obtained during the data collection phase (Chapter 3).

Expert advice is not always free of charge, but the ramifications of not having good advice are large and can be costly. The need for specialist advice should be factored in when scoping the project budget.

Advice can be obtained from a range of sources, including:

- local, State and Commonwealth Government agencies
- special-interest groups including community-based environmental centres
- academic institutions
- libraries and online resources
- specialist consultants in fields such as construction and wetland rehabilitation, hydraulics, hydrology, water quality, and flora and fauna.

Increasingly, information from Commonwealth, State and local authorities is being made available via the Internet. For example, a number of natural resource datasets can be accessed through the *NSW Natural Resource Atlas* (www.nratlas.nsw.gov.au).

The NSW Comprehensive Coastal Assessment toolkit (Department of Planning 2007) provides comprehensive data and information on coastal values and attributes to enable better decision making. The toolkit contains information on environmental, economic, social and cultural heritage issues along the coast. Datasets available include aquatic habitat maps, showing the location and extent of mangroves, saltmarsh and seagrasses; contextual information such as potential aquaculture areas; fish species distribution and biodiversity; and soil and land feasibility maps.

Obtaining funding

Possible sources of funding need to be considered. Rehabilitation projects are eligible for funding under various Commonwealth, State and local programs. In particular, CMAs can often provide advice on available grant programs.

Funding for community-driven projects may be available through the Caring for our Country program. Caring for our Country incorporates the former Natural Heritage Trust and a number of other natural resource management funding programs. Local government, community groups and individuals can apply for grants to carry out actions to target local problems. Your local CMA can provide further information about gaining funding, or you can visit the natural resource management funding website (www.nrm.gov.au).

Funding for works by local councils and other public land managers may be available through the NSW Estuary Management Program, administered by the Department of Environment and Climate Change (DECC; www.environment.nsw.gov.au). The program was established to restore and protect estuaries along the NSW coast. Works funded through the program need to be consistent with a relevant estuary management plan, coastal zone management plan or other strategic plan.

The NSW Department of Primary Industries (DPI) administers the Saltwater Fish Habitat Grant Program to encourage the community to rehabilitate fish habitats so as to achieve long-term improvements to fish numbers and recreational fishing opportunities. Details can be found at www.dpi.nsw.gov.au/fisheries.

The NSW Environmental Trust is an independent statutory body established by the NSW Government to support exceptional environmental projects that do not receive funds from the usual Government sources. One of the objectives of the Trust is to encourage and support restoration and rehabilitation projects. The Trust is administered by DECC (www.environment.nsw.gov.au).

Some stakeholders may be willing to provide 'in-kind' assistance. For instance, an oyster farming association may be willing to provide access to water quality monitoring data that it collects. This can be a good way of encouraging long-term support for the project. Ongoing assistance and financial or technical contributions are more easily achieved if desired outcomes are clearly stated, the nature of the contributions are clearly defined, and all assistance is appropriately acknowledged.

A rehabilitation project will be carried out in various stages from plan preparation to implementation through to operation and monitoring. The latter stages of the project are just as important as the earlier stages. If funding is being sought on a stage by stage basis, it should be remembered that not carrying out subsequent stages of the project may jeopardise the success of the whole project.

2.5 Integrating with existing management plans

Integration with planning policies, management objectives and natural resource management plans applicable to the surrounding area is an important consideration. During the information-gathering process discussed in Section 2.4.1, a search for applicable policies and plans should be made, noting main points from these.

Integrating with broader plans can ensure that activities that will add value to the success of your project will be undertaken simultaneously; for example, if the local council were undertaking a catchment-wide education plan to reduce sediment runoff. This ensures that maximum benefit can be obtained through the rehabilitation process (positive cumulative impact). It also prevents duplication of effort, which saves money and makes the rehabilitation process more efficient.

Local goals should be complementary to or consistent with regional goals. Alignment of objectives with other plans can also be useful when you are attempting to obtain funds. Funding bodies are more likely to invest in well-thought-out, structured, focused actions which provide outcomes of relevance to them.

Consult the Local Environment Plan (LEP) for your local council area, as well as relevant Regional Environment Plans (REP) and other planning policies. Further information on these and other legislation is provided in Chapter 12.

Catchment action plans are natural resource management plans that aim to make improvements to a wide range of natural resource conditions, including coastal and marine waters, rivers and wetlands, soils, coastal lakes and estuaries, threatened species, and native vegetation. The plans are prepared by CMAs and aim to coordinate all environmental work in a region through community partnerships and collaborations. The plans list the most important environmental issues in the catchment and can therefore guide investment and rehabilitation works to where they are most needed.

Dialogue Box 2.2 An example of integrated management

A local community group wanted to rehabilitate a small area of saltmarsh (25 m^2) near their homes. The area consisted of some sparse *Juncus kraussii*, some *Sporobolus virginicus* and a variety of weed species. Because no historical information about the area had been sought and no information about the substrate in which the saltmarsh had established had been gathered, the group was unaware that it was above a large area of reclaimed land.

They were also unaware that an estuary management plan had been prepared for the area, and that a high priority of that plan was the removal of the filled area and re-grading of the edges of the wetland. The plan also included a massive replanting program for that particular area as well as for other small wetlands around the estuary.

When the group became aware of the management plan, they were able to integrate their objectives with those of the plan and work together with local council staff during the replanting and management phases.

3 Data collection and plan preparation

3.1 Data collection

Gathering information about your wetland and the type of management activities you are planning will assist you in reviewing your objectives, assessing how achievable they are, identifying data gaps and planning a future monitoring program.

The amount of detail required will depend on the size and scale of the proposed project, the amount of information that is available about the site, and the complexity of the site. For example, water movement within and about wetlands can be highly complex, and understanding it may require elaborate equipment and sophisticated analyses. While data collection and analysis may be expensive, understanding water movements is often essential to determining appropriate management actions. Ecological and **biogeochemical** interactions are even more complex and time consuming to monitor. It is therefore essential to consult experts and, if necessary, hire consultants to fill in appropriate gaps in information.

Some essential information can be obtained without expert advice and may provide a basis for certain rehabilitation activities. If available, historical records are often very useful in developing an understanding of changes that have occurred to the wetland and its catchment. This can help with the setting or revision of objectives, may provide a pictorial or descriptive vision of what you are trying to achieve, and may help with more specific habitat information such as determining the correct vegetation taxa to be planted.

Early surveys can be invaluable in determining what previously grew on a site. They can be very instructive as to the attributes of the site, such as elevation in relation to **tidal planes**. In the case of extremely modified sites, they may even help determine the type of wetland that grew there originally. Maps or aerial photographs can provide information on the primary sources of water in the catchment, the sources of disturbance and other stresses acting on the wetland, and how these influencing factors have changed over time.

Identify human influences and constructed features such as roads, weirs, drains and impervious areas, such as parking lots. Identify the presence of levee banks and floodgates, and investigate the reason for their construction (for example, for flood mitigation or land reclamation).

Gather all available information on your wetland site or similar wetlands to help develop a hypothetical or conceptual model of the processes taking place within the wetland. Document any sources of uncertainty or any assumptions, and identify the **risk** associated with these assumptions. Some of the specific information requirements that should be considered include:

- current and historical tidal and survey information
- surface and groundwater flows and their possible interactions
- vegetation communities native to the site
- use of the wetland by fauna (which fauna use which habitats)
- soil types and changes in sediment processes
- water quality (within the wetland and entering it from its catchment)
- Aboriginal and European heritage and cultural values.

Further information about some of these wetland characteristics and processes is provided in Part 3.

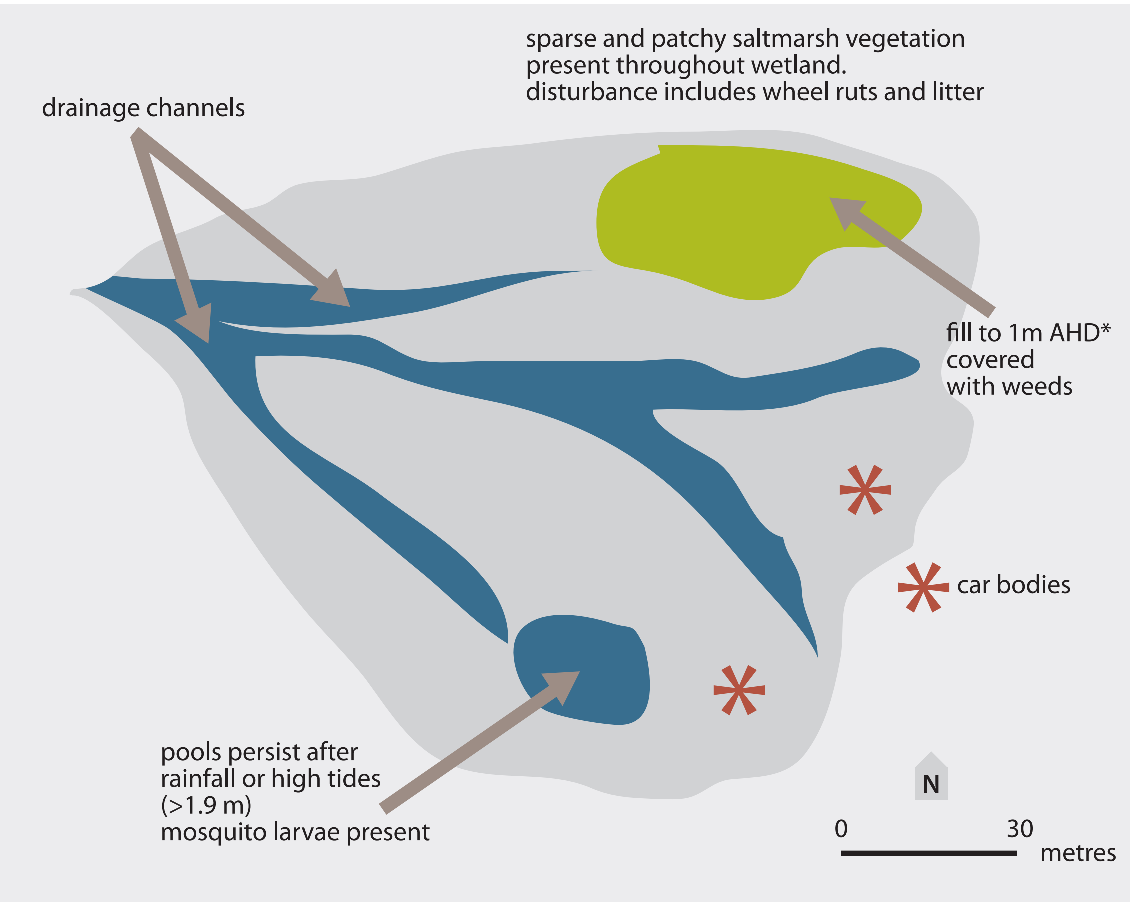
3.2 Detailed site evaluation

The amount of detail in the site evaluation will depend on the scale of the project. Generally, the bigger the project is, the more detail will be required. Small-scale projects may require only the drawing of 'mud-maps' (Figure 3.1), while large-scale projects are likely to benefit from the use of spatial information stored in a **geographic information system** (GIS) (Figure 3.2, overleaf).

Visit the proposed project wetland and other similar wetlands in the vicinity and pay careful attention to what vegetation species are present, where weeds grow, and any areas with erosion problems or exposed **acid sulfate soils** (**ASS**). Make notes on maps or aerial photographs of the site. You may want to use a **Global Positioning System** (**GPS**) receiver to record the location of any significant natural or cultural features. You can then load the GPS data into a GIS if you are using one, or use it to accurately plot the locations of the features on a topographic map.

Depending on the size of the project and the money available, it may be necessary or possible to undertake several data collection activities. In large projects where it may be necessary to model possible changes to tidal inundation, detailed high-quality data may be needed. This may include data on water levels at a few sites, water movement within the wetland, and levels of the wetland bottom and banks. Details on undertaking topographic and bathymetric surveys and on tidal gauging are given in Appendix 1.

Figure 3.1 Sample annotated wetland map



*Australian Height Datum

In other situations it is possible to collect information about the wetland during a few visits to the site and with some careful thought. Components which are often necessary include:

- connectivity to other wetlands
- exact elevations and topography
- water flow rates and timing
- location of different sediment and soil types and wetland plants
- diversity and cover of native and exotic or invasive plants
- diversity of fauna species.

Avocets (Kooragang Wetland Rehabilitation Project)

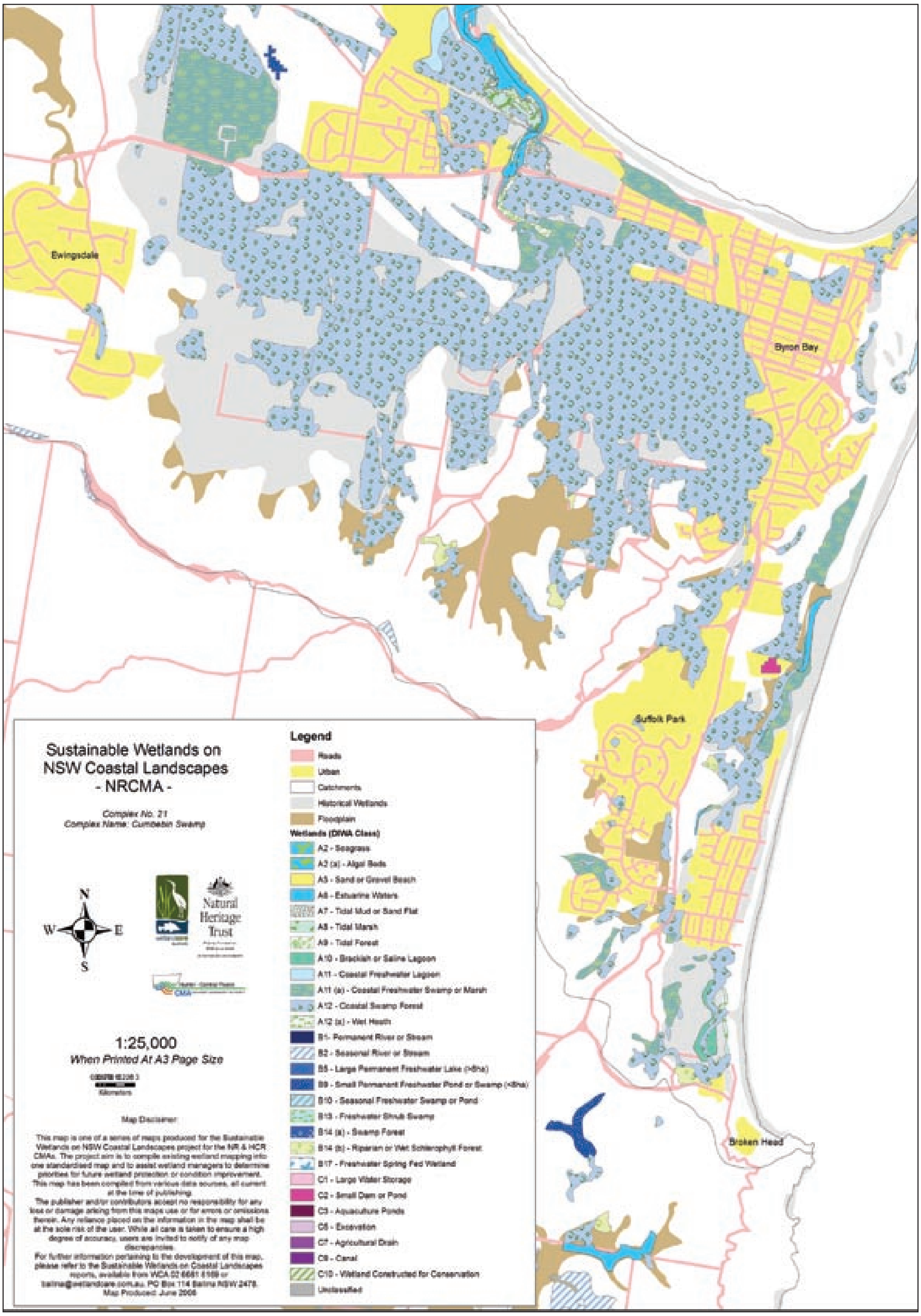
Obtain information on soils at the site either from available information or by site investigation. Information that may be useful includes soil profile descriptions, soil limitations, testing of soil chemistry and soil quality (further information on soils is presented in Chapter 9 and Appendix 5).

While you are on site it is important to draw a rough map of your wetland and to annotate it. An example is presented in Figure 3.1. Also write down the time and dates of ambient weather conditions, flora and fauna observations, and any other relevant observations.

Remember: To monitor the success of your rehabilitation project it is necessary to collect information before you begin. The information you collect in the early stages of your project will be the **baseline** against which you measure future changes at the site.

As part of the site evaluation it is essential to establish the causes of degradation, as this can enable you to design an effective rehabilitation process. If a wetland is degraded because of events occurring in the catchment, it may be better to concentrate your efforts in the catchment before beginning rehabilitation of the wetland itself. Alternatively, you will need to plan your rehabilitation with the knowledge that these influences will continue.

Figure 3.2 Sample GIS wetland map



Source: WetlandCare Australia, 2006

Dialogue Box 3.1 Tools for carrying out a site evaluation

Essential tools

- notebook
- pencil or waterproof pen
- tide tables
- plant and weed identification books
- bird identification books
- camera
- plastic bags
- topographic maps

Desirable tools

- aerial photographs
- GPS receiver

3.3 Determination of legislative requirements

At all levels of government a large amount of diverse planning instruments and policy may be relevant to wetland rehabilitation or protection (see Tables 3.1 to 3.4, overleaf).

Determining the legislative requirements during the early stages of a rehabilitation project will ensure that the relevant authorities have been contacted and the possible time frames for approvals can be built into the rehabilitation plan. Delaying consultation with local councils and government agencies until you are ready to start work may result in significant delays to the project. You may also have to rethink your goals and objectives if you find out that a proposed action is not possible or has to be modified owing to legal requirements.

Further information on the legislation, planning instruments and policy outlined in Tables 3.2 to 3.4 can be found in Chapter 12.

Environmental impact assessment processes

All proposed rehabilitation activities should have an appropriate level of environmental impact assessment. For minor matters this may involve consideration of environmental impacts as part of the issue of a licence or Development Application (DA). For larger projects it may require a detailed **Environmental Impact Statement** (**EIS**) or Review of Environmental Factors (REF). In addition, you may be required to prepare an ASS management plan if there is the potential for ASS to be disturbed, which is often the case along the NSW coast.

Local government has a significant role in determining legislative requirements, as the local council will often be the authority that grants consent for an activity or development under the *Environmental Planning and Assessment Act 1979* (EP&A Act).

Table 3.1 Wetland rehabilitation issues and relevant agencies

Agency	Issue
Local council or DECC	water pollution
Local council or NSW Heritage Office	European heritage
CMA or local council	clearing of native vegetation
DECC	Aboriginal heritage native flora and fauna threatened species and endangered ecological communities activities in coastal areas soils (including ASS)
DPI	aquatic vegetation aquatic threatened species fisheries dredging and reclamation fish passage
Local council or DPI	noxious weeds
Local council or Department of Lands	public land management
Department of Water and Energy	activities in or near rivers and foreshores

Development Application

A Development Application (DA) is required for any development identified in a local government planning instrument as requiring consent. This can vary from council to council, so you will therefore need to read the relevant Local Environmental Plan for your council area.

If the proposed activity does not require consent from a local council, it may still require consent from other government authorities. The relevant authorities are required to assess the impacts of the activity and determine whether there will be any potential problems.

If the works are to be carried out on land owned by the Crown, the local council or someone other than the group undertaking the work, the landowner's consent will be required before a DA can be lodged. In the case of Crown Land, contact the Department of Lands.

Environmental Impact Statement

An EIS or other supporting document may be required as part of the approval process if the impacts are likely to be significant. Certain activities classified as designated development automatically trigger the preparation of an EIS.

Review of Environmental Factors and Statement of Environmental Effects

Where an activity is not a designated development, the local council or the determining government authority may still request a supporting document – usually referred to as a Review of Environmental Factors (REF) or Statement of Environmental Effects – to assist them in assessing the likely environmental impact.

Permits and approvals required

A range of permits or approvals may be required from a range of agencies. Agencies that may need to be consulted are listed in Table 3.1. Legislation, planning instruments and policy that may indirectly affect wetland protection and rehabilitation are listed in Tables 3.2 to 3.4.

General legal issues

A number of other general legal issues need to be considered during the rehabilitation process, particularly if the project is located on public land or if contractors will be employed to carry out works on the site. *The Constructed Wetlands Manual* (DLWC 1998) provides further details of these issues, as outlined below.

Due diligence

At least one of the parties involved in planning, establishing, operating and decommissioning a wetland rehabilitation project must take reasonable care to ensure the safety of people who come in contact with the project.

Nuisance

The operator can be held liable for nuisance if the project substantially and unreasonably interferes with the beneficial use and enjoyment of nearby land.

Damage to adjoining property

The operator can be held liable for all damage caused by the escape of any inherently dangerous thing brought to the wetland by the operator. This can include pollution, flora and fauna, and water (for example, saltwater intrusion onto neighbouring properties).

Contractual obligations

The operator can be held liable for damage suffered by other parties to any agreement expressed or implied in relation to the various phases of the project.

Occupational health and safety

Occupational health and safety obligations are imposed on employers, employees and certain manufacturers and suppliers involved with the project by the *Occupational Health and Safety Act 2000*.

Table 3.2 Commonwealth and New South Wales legislation

Legislation	Principal agency	Purpose	Implications for wetlands
COMMONWEALTH LEGISLATION			
Environment Protection and Biodiversity Conservation Act 1999	Department of Environment and Heritage	Protects the environment, particularly matters of national environmental significance, and provides mechanisms for protection of biodiversity	Activities within Ramsar wetlands or wetlands which provide habitat for migratory waders under international agreements require environmental assessment under the Act. Also applies to Commonwealth marine areas
Australian Heritage Council Act 2003	Australian Heritage Council	Provides for the constitution of the Australian Heritage Council and its responsibilities in providing heritage advice	Allows for listing of wetland sites on the Register of the National Estate
NEW SOUTH WALES LEGISLATION			
Environmental Planning and Assessment Act 1979	Department of Planning	Establishes the process and requirements for assessment of development and activity applications	Requires environmental impact assessment before a development or activity can proceed Allows for creation of policies, including SEPP 14 and the Coastal Policy, that protect coastal wetlands
Local Government Act 1993	Local councils Department of Local Government	Allows local government to undertake a range of functions and responsibilities	Sets requirements for drainage, removal of obstructions Outlines requirements for State of the Environment reporting
Coastal Protection Act 1979	Department of Environment and Climate Change (DECC)	Provides a framework for coastal management and defines the coastal zone	Development activities within the coastal zone that are below the mean high-water mark, excluding any estuary, lake or artificial harbour, require concurrence from the Minister for the Environment and Climate Change

Legislation	Principal agency	Purpose	Implications for wetlands
Contaminated Land Management Act 1997	DECC	Provides a process for investigating and remediating land where contamination presents a significant risk of harm to human health or the environment	Where site contamination is considered to pose a significant risk, DECC has powers to direct the investigation or remediation of polluted land and water
Crown Lands Act 1989	Department of Lands	Provides a regime for the ownership and management of Crown Land	Conservation or restoration works in wetlands and foreshore areas on Crown Land require land assessment and approval
Fisheries Management Act 1994	Department of Primary Industries (DPI)	Establishes responsibility for management and protection of marine, estuarine and freshwater fish and aquatic habitats	Protects threatened aquatic species and habitats Requires permits for fish habitat destruction and any works involving disturbance of wetland sediment Provides for development of habitat protection plans, creation of aquatic reserves and habitat rehabilitation (for example, fishways)
Heritage Act 1977	NSW Heritage Office	Provides for the constitution of the Heritage Council of NSW and the establishment of the State Heritage Register and heritage agreements	Permit is required for damage to or removal of heritage items
Marine Parks Act 1997	DECC	Provides for the declaration of marine parks for the conservation of marine biology and marine habitats. It also regulates the activities that may be undertaken within a marine park	Where a wetland forms part of a Marine Park, any Development Application is subject to the EP&A Act, and consultation with the Marine Parks Authority is required

(continued overleaf)

Legislation	Principal agency	Purpose	Implications for wetlands
National Parks and Wildlife Act 1974	DECC	Provides a framework for managing National Parks and reserves and provides mechanisms to conserve and manage cultural and natural heritage across NSW	Permits are required for the taking of native fauna and flora and for disturbance of Aboriginal objects Allows for off-reserve conservation of wetland areas through wildlife refuges and voluntary conservation agreements
Native Vegetation Act 2003	Catchment management authorities (CMAs)	Controls the management of native vegetation in rural areas Protects sensitive areas from tree removal and provides for penalties for illegal clearing	May apply to clearing and rehabilitation projects on private land, depending on circumstances Permit is required to remove trees within 20 m of a prescribed stream or other protected lands
Noxious Weeds Act 1993	DPI Local councils	Provides for the management and monitoring of noxious weeds on public and private lands	Specifies landholder responsibilities to control noxious weeds. Outlines requirements for herbicides and their use
Protection of the Environment Operations Act 1997	Local councils DECC	Protects the quality of the environment through controls on air, water and noise pollution	Restoration activities such as dredging, landfill and aquaculture may require a licence
Threatened Species Conservation Act 1995	DECC	Establishes a process for classifying and protecting endangered species and critical habitats Allows for development of species recovery plans	A licence is required if an activity is likely to significantly affect threatened species, populations or ecological communities, or their habitats Endangered ecological communities include coastal saltmarsh and swamp oak forest
Water Management Act 2000	Department of Water and Energy	Provides for the integrated and sustainable management of the State's waters Provides for the carrying out of works along rivers and foreshores	Allows for preparation of water management plans that may affect wetlands and estuaries Requires approval for works within 40 m of a river, lake or foreshore

Bollards used to protect swamp oak forest at Coila Lake (DECC)

Table 3.3 NSW planning instruments

Planning instrument	Principal agency	Purpose	Implications for wetlands
Local Environment Plans	Local councils	Controls land use by identifying permissible and prohibited activities	Maps identify zoning of wetland areas and land use tables determine permissible uses in wetland areas
Regional Environment Plans (REPs)	Department of Planning	Applies land use controls across regional areas to issues of regional significance	Some REPs relate specifically to coastal and wetland issues
STATE ENVIRONMENTAL PLANNING POLICIES (SEPPS)			
SEPP 14 Coastal Wetlands	Department of Planning	Provides for the protection of coastal wetlands in NSW	EIS is required for works within an SEPP 14 wetland A rehabilitation plan is required for any restoration works

(continued overleaf)

Planning instrument	Principal agency	Purpose	Implications for wetlands
SEPP 19 Bushland in Urban Areas	Department of Planning	Provides protection of natural bushland in listed local government areas	Development consent must be obtained before bushland is disturbed
SEPP 26 Littoral Rainforest	Department of Planning	Controls development activities within or adjacent to littoral rainforest communities	EIS is required for works within wetlands affected by SEPP 26
SEPP 44 Koala Habitat	Department of Planning	Provides for the protection of koala habitat in listed local government areas	Swamp mahogany, a koala habitat species, is commonly associated with wetlands. Councils must investigate core koala habitat before granting development consent
SEPP 71 Coastal Protection	Department of Planning	Ensures that development within the coastal zone is appropriate and consistent with the principles of ecologically sustainable development	Guides development assessment in sensitive coastal areas, including SEPP 14 wetlands, coastal lakes, Ramsar wetlands, marine parks and aquatic reserves

Table 3.4 Commonwealth and New South Wales policies

Policy	Principal agency	Purpose	Implications for wetlands
COMMONWEALTH GOVERNMENT POLICIES			
Commonwealth Coastal Policy	Department of Environment and Heritage	To promote ecologically sustainable use of Australia's coastal zone	Guides government decision making in coastal areas managed by the Commonwealth. Provides guiding principles for all levels of government to encourage sustainable use of coastal resources
Wetlands Policy of the Commonwealth	Department of Environment and Heritage	To ensure that the activities of the Commonwealth Government promote the conservation, ecologically sustainable use and enhancement of wetland functions	Guides government decision making in relation to wetlands on Commonwealth land. Provides guiding principles for all levels of government to encourage sustainable use and management of wetlands

Policy	Principal agency	Purpose	Implications for wetlands
NEW SOUTH WALES GOVERNMENT POLICIES			
NSW Coastal Policy	NSW Government	Provides a framework to balance and coordinate management of the physical, ecological, cultural and economic attributes of the NSW coastal zone	Applies to lands within the coastal zone
NSW Estuary Management Policy	DECC	To achieve integrated, balanced, responsible and ecologically sustainable use of the State's estuaries	Estuaries and wetlands can be protected through the preparation of estuary or coastal zone management plans with funding available through the Estuary Management Program
NSW Fisheries Policy and Guidelines	DPI	To achieve consistent management of aquatic resources in NSW	Guides conservation and management actions in all marine and estuarine environments
NSW Weirs Policy	DECC	To halt and, where possible, reduce and remediate the environmental impact of weirs	Discourages construction of new weirs or structures in wetland areas. Impacts of existing structures will be reviewed
NSW Wetlands Management Policy	NSW Government	To halt and, where possible, reverse the loss of wetlands in NSW, and to encourage activities that will restore the natural functions and values of wetlands	Guides government decision making in relation to the management of all types of wetlands in NSW

3.4 Stakeholder and community consultation

Strategies for consultation

Many people may have an interest in the management of a particular wetland area, including the local council, Landcare groups, adjacent landowners, recreational users and the residents who live near the wetland. Taking into account many different values and opinions can be a challenge when you are designing a rehabilitation project. However, an effective program of consultation can help to ensure that the community takes an active role in the conservation of its local area and can therefore contribute to the continued success of the project.

Community and stakeholder input is likely to be required during both the plan establishment and plan operation phases. Any required ongoing activities such as maintenance, monitoring and adaptive management are more likely to succeed if stakeholders have been involved in the plan and support its outcomes.

Community involvement is particularly relevant to cultural heritage. Aboriginal community participation can be initiated by contact with the relevant local Aboriginal Land Council at the early stages of the project. Many local councils will have an Aboriginal liaison officer, who may be able to assist in identifying additional Aboriginal community contacts. If archaeological surveys, excavations and assessments are required, a heritage officer will usually represent the Aboriginal Land Council. Relevant information is available from the DECC Aboriginal Heritage Information Management System and the NSW Aboriginal Land Council.

Local historical societies and similar groups can provide information on the European cultural and heritage values of the project site. Some local councils have a heritage officer. Museums and the Heritage Office of NSW may also be able to provide information.

The methods that you can use to engage with the community will vary with the size of the project and its aims. Some of the more common methods include:

- steering committees
- use of a project facilitator
- using local champions (community leaders)
- questionnaires and surveys
- printed brochures and newsletters
- media releases to local newspapers and to radio and TV stations
- public meetings and workshops that identify issues and objectives
- community monitoring programs
- project launch and field days
- involvement in hands-on activities such as site clean up, planting and weeding, landscaping and fencing, monitoring, operation and maintenance activities.

The Constructed Wetlands Manual (DLWC 1998) outlines seven key steps to achieving community involvement in wetland projects, as shown in Dialogue Box 3.2.

Dialogue Box 3.2 Steps to achieving community consultation and involvement

1. Identify your project objectives and determine the best level of community involvement.
2. Canvass the community to determine the interest level of groups and individuals, and identify their potential roles.
3. Discuss the community's values, expectations and required resources with key decision makers of the project.
4. Define community involvement objectives.
5. Determine the best mix of community involvement techniques to achieve your community involvement objectives.
6. Prepare a community involvement plan.
7. Implement the plan and form an agreement with community groups and individuals outlining their roles and responsibilities.

Source: DLWC 1998 (adapted from America's Clean Water Foundation 1991).

Principles for effective consultation

For consultation to be effective it must be undertaken as soon as possible to allow full participation of all interested parties in the planning process. A common complaint about community consultation is that community members feel that their opinion is not valued or that it is sought when it is too late or too difficult to make changes.

For consultation to be meaningful, useful and effective, Carson and Gelber (2001) provide the following principles. Each consultative situation should be:

Timely: Consultation must occur early in the project, when participants have the best chance of influencing outcomes. Give people enough time to consider implications and express their views.

Inclusive: Select participants in a way that is not open to manipulation and that includes a cross-section of the population. Random selection offers the best chance of achieving this.

Community focused: Ask participants what they consider is appropriate in their role as citizens, not what they want personally or what is in their self-interest.

Interactive and deliberate: Encourage debate and allow consideration of the big picture so people can become engaged. Avoid reducing questions to simplistic responses.

Effective: Although decision making can strive for consensus, complete agreement does not necessarily need to be the outcome. Be clear on how decisions will be made so that participants know and understand the impact of their involvement. Make sure all participants have time to understand material they are unlikely to be familiar with.

Meaningful: The potential for any recommendations that emerge from the consultative process to be adopted is important. If they are not, provide a public explanation. Faith in the consultative process by both the organisers and the participants is important.

Well-facilitated: An independent, skilled and flexible facilitator with no vested interest in the project will give the process credibility and allow participants some control of the agenda.

Open, fair and subject to evaluation: The consultation method should be appropriate to the target group. Formulate evaluation questions in advance. Decide how the success of the consultation will be measured and provide feedback to the community afterwards.

Cost effective: Consider how many and which types of community members should be consulted on a given issue. Some questions will require broader consultation, others more targeted consultation. Costs will vary, but the process must be properly resourced.

Flexible: A variety of consultation mechanisms exist. Consider which one best suits the circumstances. Try a variety of mechanisms over time. Think about how to reach all your users, including those with special needs (for example, language, disability, age). Different communities and different questions will produce better responses with different forms of consultation. Mix qualitative and quantitative research methods.

3.5 Preparing a wetland rehabilitation plan

A wetland rehabilitation plan will normally be required. The level of detail in the plan will depend on the size and nature of the activities being undertaken and the relevant approval processes. Some plans will need to be detailed; for example, rehabilitation work within an *SEPP 14* wetland will require a formal wetland rehabilitation plan to be prepared and lodged as part of the approval process. Having a documented plan including a project timeline and budget will assist with obtaining funding and stakeholder support, and ensure that all participants have consistent and realistic expectations. It also assists in monitoring the progress of your project.

The minimum components of a rehabilitation plan should include:

- goals and objectives
- an outline of the issues and the proposed management actions
- a timeline for various phases of the project
- identification of the project team (how and when each person will contribute)
- the project budget, including funding sources and major expenditure associated with each phase of the project.

The plan does not have to provide fine details about specific implementation activities such as seed harvesting and weed removal techniques, but if it does not, it should provide a reference to a document with that information.

A monitoring program should be designed to determine the success of the plan over a long period of time. This could form a part of the rehabilitation plan, or it can be developed as a separate document for projects where a detailed level of monitoring is being proposed.

3.6 Methods and techniques available

A wetland rehabilitation plan can involve both structural and non-structural measures. New techniques are being developed and tried constantly, and a number of successful methods have been documented.

Examples of structural measures:

- restoration of previously blocked meanders and natural flow paths to allow for natural regeneration of affected areas
- modification of artificial barriers such as floodgates and road crossings to enable the return of natural flows
- alteration of contours and bank batters to enhance natural colonisation
- construction or improvement of ditches, runnels or channels to improve water flow
- construction of bunds to prevent or alter water flow
- filling of areas to above the tidal limit to create an estuarine–terrestrial transition zone
- removal of degrading processes or materials such as solid waste, sediment from landfill, liquid effluent or toxic waste
- diversion of stormwater away from saltwater wetlands
- fencing to control movement of animals and visitors away from sensitive areas
- construction of boardwalks, bird hides and other interpretation facilities.

Boardwalk on foreshores of Merimbula Lake (DECC)

Examples of non-structural measures:

- control and removal of competitive introduced species to allow for regeneration of native species
- revegetation where natural regeneration processes are interrupted
- education programs
- rubbish and litter removal.

Litter removal Hunter River estuary (Kooragang Wetlands Rehabilitation Project)

The design and implementation of rehabilitation strategies are intimately linked, and feedback from implementation to subsequent design or redesign is often necessary. Accordingly, some details relevant to design of strategies are presented in Chapter 4.

4 Plan implementation

4.1 Introduction

As discussed in Chapter 3, implementation of a wetland rehabilitation plan may involve both structural and non-structural works. This chapter addresses various types of works and issues related to their implementation.

Many aspects of construction in wetland environments are already covered in *The Constructed Wetlands Manual* (DLWC 1998). For example, the introduction and sections on contract administration and construction management in Chapter 22 apply equally to saltwater wetlands. This section avoids repeating topics covered in *The Constructed Wetlands Manual* and focuses on areas more specific to saltwater wetlands.

Saltwater wetlands are rarely constructed from scratch. Projects generally comprise the rehabilitation of existing wetlands which have suffered a degree of degradation. Degradation may range from draining of part of a saltmarsh or moderate siltation of a mangrove area to extensive bunding and filling of an entire wetland with waste.

Most construction activities in a saltwater wetland will have to be carried out within or just outside the intertidal zone and will often have to fit in with the tidal cycle. This creates special problems for working in and around wetlands on account of the soft sediments, the potential for disturbance of ASS and the constant inundation that may occur in some habitats. Saltwater wetlands usually contain fine-grained sediments which, once disturbed, can be very difficult to handle and require long timescales to stabilise their sediment structure and pore water pressure.

It is usually important to preserve most vegetation in the wetland, so construction activities must avoid damaging vegetation. These habitats are particularly susceptible to indirect impacts such as the generation of **turbidity** or bed compaction. Trampling by people through saltwater wetlands can also have a deleterious effect on plants and animals. If the area is to be used recreationally or educationally, then the installation of boardwalks may need to be planned into the design.

When you are considering restoration in estuarine areas, it is important to assess the use of boats in the area. Damage by boat anchor chains, propellers and boat wash can have a deleterious effect on the success of a rehabilitation effort. Likewise the use of areas for moorings and informal boat storage may also affect habitats. Make efforts wherever possible to minimise damage from these sources.

Mooring within mangrove pneumatophores, Minnamurra River (DECC)

4.2 Major construction considerations in saltwater wetlands

Access

Consider access to the site to minimise the potential for disturbance during both the construction and maintenance phases.

Environmental loadings

Most artificial estuarine constructions, such as weirs, spillways, culverts and floodgates, may be subjected to both environmental forces, such as waves, currents and fluctuating water levels, and specific forces, such as vessel impacts.

Construction of saltmarsh at Scott Park, Rockdale (DECC)

Saltmarsh created at Scott Park, Rockdale (DECC)

Site layout

Saltwater wetlands create a difficult environment for survey work, as they invariably have unstable soil, which poses problems for establishing survey marks, and restricted line of sight due to vegetation. Carry out survey work as early as possible, preferably before or during the design phase, to allow design decisions to be based on hard numbers rather than guesswork. Engage a registered surveyor to set up a survey control system. Where property boundaries are involved, a registered surveyor is essential.

Information on survey control is presented in Appendix 1.

Foundation design

Foundation design for estuarine and coastal structures requires reasonable estimates of the expected loading conditions in order to determine the foundation soil engineering properties and to understand the interaction between structure and soil. Geotechnical investigations are conducted to gather information about the soil layers beneath the construction.

Environmental impacts of construction

Environmental issues have to be considered for all construction in coastal wetlands. Threatened and endangered species of fish, birds, mammals and reptiles merit special consideration and accommodation during the reconnaissance, planning, implementation and monitoring phases of projects. Construction activities that involve dredging are most detrimental. Many crustaceans (such as shrimp and blue crabs) burrow and overwinter in channels and are likely to be encountered during maintenance dredging. **Sessile** invertebrates (such as oysters, mussels and clams) can be buried and killed by dredging. When dredging is planned, estimate the dredging volumes and determine how the dredged material will be transported and disposed of. Consider beneficial uses of the material.

Estuarine and coastal projects generally require regulatory approval from local, State and sometimes Commonwealth agencies. Fulfilling the regulatory requirements may affect the construction design, the method of construction, the transportation of materials to the site and even the choice of construction materials. Therefore, you must clearly understand the provisions likely to appear in various permits and approvals so that the design will meet all approval criteria. Failure to consider these important aspects will result in delays, added expenses or even an unviable project.

Maintenance of completed construction

Maintenance requirements for each construction element have to be taken into account, especially for elements that are expected to suffer some damage over their **design life**.

Land-based constructions may have adequate access for maintenance with land-based equipment. Monitoring and periodic inspections of intertidal or submerged constructions may be required to determine when maintenance should be performed.

At some project sites it may be necessary to consider the potential consequences of vandalism and theft of materials. If vandalism and theft are potential threats, materials must be chosen that cannot be easily cut, carried away, dismantled or damaged. For example, sand-filled geotextile bags can be cut and small concrete blocks can be stolen.

Construction of saltmarsh as part of the Kooragang Wetland Rehabilitation Project (Kooragang Wetland Rehabilitation Project)

Saltmarsh created as part of the Kooragang Wetland Rehabilitation Project (Kooragang Wetland Rehabilitation Project)

Construction in a saline environment

Construction in saline environments is often exposed to continual cyclic wave loading, impact loading from waves or vessels, and occasionally accelerations due to seismic activity. Construction also needs to resist abrasion, chemical attack and corrosion, marine **biodegradation**, wet–dry cycles, freeze–thaw cycles and temperature extremes.

The construction materials used may vary depending on adaptability, cost and availability. Material strength, flexibility, durability and resistance to cyclic, impact and seismic loads are important to resisting tension, compression and flexure stresses. Information on construction materials in saline environments is presented in Appendix 3.

Depending on the type of project, construction may require land-based plant, floating plant or a combination of both.

4.3 Implementing structural works

Earthwork may be required to increase the size of channels, to lower or raise bottom levels, to remove unsuitable material or to construct bunds to prevent water flow (Table 4.1, overleaf). Before any earthworks are carried out, engage a specialist to determine the most effective construction methods and materials in terms of both production and minimisation of environmental impact. Production efficiency will depend on selecting machinery that can handle the sediment after it has been disturbed and that suits the weight-bearing capacity of the site. The soil properties critical to soil handling and trafficability of equipment can be estimated by field or laboratory tests (Appendix 5).

Both hydraulic and mechanical methods can be used. Hydraulic methods pump the soil as a slurry. Mechanical methods involve excavating and moving discreet blocks of soil.

Channel construction

Drainage systems in estuarine wetlands are typically constructed to a **dendritic** or branching pattern comprising, in descending order of size, channels, ditches and runnels. Ditches are constructed as lateral drains to channels, and runnels as lateral drains to ditches or channels.

Channels

Channels should have a depth sufficient to ensure that they remain inundated throughout the tidal cycle. As a general rule they should be at least twice as wide as they are deep, and battered sufficiently to prevent slumping of their banks, which causes sediments to build up in the channels. The actual slope will depend on the properties of the sediment, but as a general rule the slope should be no steeper than 1 in 3 (vertical to horizontal). Channel excavation is well suited to being performed by a small barge floated into position. Don't place excavated sediments along the side of the channel as this may lead to the formation of stagnant pools.

Ditches

Ditches are smaller in section than channels, and their bed level may be above low tide level. Excavation methods are similar to those for channels, but if bed levels are above low tide, only small barges can be used, and barges will be left stranded on the bottom at low tide. Alternatively, the ditch can be over-dredged and allowed to fill in somewhat during construction.

Table 4.1 Mechanisms in earthwork construction phases

Methods for . . . excavation	removal and transport	deposition
Cutting or ripping with knife, blade or plough	Mechanical: by loader scraper, truck or conveyor belt	Simple dumping from transporter or discharge of slurry from pipeline into disposal area
Scooping or digging with a bucket, shovel or clamshell	Water-based: by barge	Partial compaction by wheels or tracks
Scouring (erosion) with a moving water or air stream	Hydraulic: pumping a slurry of soil particles or clumps of material in a pipeline	Full specification compaction by mechanical rolling in layers or by vibration
Equipment for . . . excavation	**removal and transport**	**deposition**
Dozers, loader-scrapers	Loader-scrapers, wheeled trucks	Mechanical or hydraulic
Backhoes, shovels, bucket ladders, draglines, clamshells	Conveyor belts	
Dredges: direct suction, cutter suction, bucket wheel suction	Barges, slurry pipelines	
Factors affecting suitability of . . . excavation	**removal and transport**	**deposition**
Soil trafficability	Bulking, pumpability, abrasiveness	Sticking of clayey soils
Soil characteristics (presence of ASS, hydraulic conductivity, etc.)		Turbidity for underwater disposal
Availability of water for pumping		Degree of compaction required

Runnels

Runnels are very shallow spoon-shaped channels that connect pools in saltmarsh to open waters of the estuary. Their width is generally three times the depth, and they follow natural drainage lines along a low gradient. The aim of creating runnels is to increase the tidal flushing into areas where water tends to pond and stagnate. Runnels are generally constructed by hand-trenching to minimise disturbance to vegetation and during a period of **neap tides** to maximise the time available for construction. Runnels are generally 600 to 900 mm wide and 150 to 300 mm deep. The depth of the runnels is adjusted so that water is drained from the lowest pool on the ebb tide (Dale *et al.* 1996, Hulsman *et al.* 1989).

Take care to ensure that no large isolated pools occur within the runnels at low tide. Don't place excavated material along the side of the runnel as it may lead to the formation of stagnant pools. Once the runnel system is constructed, sediment transport induced by the tidal flow should result in the formation of a natural channel system. Incorporation of runnels into a saltwater wetland can assist in alleviating mosquito problems by allowing improved drainage and greater fish passage; this is further discussed in Section 4.8.

Pay particular attention to ensuring that the drainage system remains free of sedimentation and blockages, which can reduce tidal flushing. To ensure that channels remain free-flowing, it is important to consider the layout of the system that is to be constructed. Pay detailed attention to sharp bends, stream intersections or other places where low velocities can cause sedimentation. Mimicking the dendritic drainage patterns that occur in natural systems will minimise the likelihood of blockages.

Runnells are best suited to sites with simple, clear water movement patterns and where the length of runnels is relatively short, so that flushing reaches well into the wetland (Dale 2005). Pay attention to soil type before you construct runnels so as not to disturb shallow ASS and not to facilitate erosion of susceptible soil types.

Hydraulic structures

Locate hydraulic structures with care so as not to concentrate flows and thus cause localised erosion and consequent sediment deposition further downstream.

If hydraulic structures are to be used to control the tidal flushing of saltmarsh rehabilitation areas, it may be necessary to install screens to prevent mangrove seeds entering and establishing within the area.

Culverts

Culverts, which carry a stream under or through an embankment or fill, can be used to reconnect side channels, ponds, billabongs or cut-off channel meanders within wetlands that have become isolated from the main channel or water body. Take into account the movement or migration of fish species when planning culverts.

Floodgates

Floodgates are one-way hinged flap gates that are a common feature of coastal floodplain drainage systems, particularly on the North Coast of NSW. Floodgates prevent saline tidal water and river floodwaters from inundating low-lying land. They also allow ebb tide drainage to the local low tide level. Unfortunately, floodgates have many unintended side effects, such as reducing water quality, blocking fish and prawn movement, and accumulating substances that can reduce downstream water quality.

Guidelines are available from the DPI outlining principles and strategies which can be used to improve the environmental performance of coastal floodplain drainage systems while retaining their benefits for agriculture (Johnston *et al.* 2003 available at www.dpi.nsw.gov.au/agriculture/resources/soils/ass/general/balance).

Spillways

Spillways used as overflow or emergency channels provide a safe discharge from the wetland during storms that exceed the design specifications. A common design condition of an emergency spillway is the 50- to 100-year storm event. In wetland design, the emergency spillway should be placed to limit the extended detention of stormwater to a maximum of 1 m or the level calculated as a result of a 50- to 100-year **design storm**, whichever is less.

Riser and barrel

Riser and barrel structures are often used to control flow from a wetland. The riser is a vertical pipe or inlet structure joined to a horizontal pipe (or barrel) that conveys flow under an embankment to an outlet point.

Floodgate at Macleay River (DECC)

Pipe being floated over a wetland during the 1966 construction of the Taloumbi Radial drains, that now drain into Lake Wooloweyah (Clarence Valley Council)

Weirs

Weirs are used to control and regulate wetland inflow, outflow and water level. The permanent pool in a wetland system is defined by the water level determined by the lowest outlet point of the weir. In the case of a wetland controlled by a weir, the permanent pool can make up a large proportion of the total detention storage of a wetland compared to one controlled by a riser.

Drop board weirs and culverts

Drop board weirs and culverts can be used to control tidal flushing of a wetland. Water enters the wetland, then boards are placed in the weir or culvert to keep the water in. Structures such as this have been used to improve wader bird habitat and for the management of ASS.

Level spreaders

Level spreaders are structures that are designed to distribute concentrated flow uniformly over a large area. Level spreaders come in many forms, depending on the peak rate of inflow, the duration of use, and the site conditions. Level spreader inflow pipes are commonly used in constructed wetlands.

Excavation equipment and techniques for soft ground

When disturbed, the bed materials of saltwater wetlands readily turn to mud. The ability of a machine to stay on top of soft ground is affected by its ground pressure (weight per unit area of ground contact), shear (the load on the edge of the track or tire) and total weight. Shear is most important when a soft soil is protected by a harder crust. Total weight affects deep mud, which may creep or flow from beneath a machine. Problems working in mud can be reduced by proper selection of equipment. Crawlers are better than wheels; tracks should be the longest and widest available; tires should be big, soft and cleated; mechanical equipment should be the smallest that will do the job. Some wheel tractors can be fitted with temporary metal and rubber tracks which enable them to work in soft soils.

Temporary roads

Temporary roads can be constructed to provide access to soft areas. Geotextile fabric may be spread over soft surfaces to increase their load bearing capacity. A corduroy road comprising logs or half logs laid across the route touching each other can be built to support heavy equipment on very soft ground. Plank roads comprising planks on sleepers are more expensive but are easier to lay and provide a smoother surface.

Platforms, pontoons or mats

Platforms, pontoons or mats are timber supports used by machinery such as draglines or revolving shovels working on soft ground. They spread the weight of machines over a large area and act as temporary bridges over ditches and holes. They are usually trucked as near to the job as possible and then dragged or carried by a loader or shovel. Platforms can be used to move a shovel across soft ground: the shovel transfers them from behind it to in front of it as it moves from platform to platform.

The space between platforms will vary with the nature of the ground. In very soft conditions they should be placed in contact and chained together or even laid in two layers. On ordinary soft or suspicious ground, the widest spacing should be that which will allow the shovel to reach the next platform before its centre of gravity reaches the edge of the current one so that the shovel will not tip forward so much that the track will push the next platform instead of climbing it.

Draglines

Draglines are often the most efficient machines in soft conditions. Their long reach allows them to keep well back from the holes they are digging and to pile spoil far enough away to reduce slumping back into the pit or against the shovel. The sliding action of the bucket during digging and hoisting reduces problems with suction.

Hydraulic full-revolving backhoes

Hydraulic full-revolving backhoes are comparable to draglines but can dig much harder material and to greater depths, and have more precise control in both digging and dumping. They are better at getting themselves out of trouble and working without a platform. However, their reach is much shorter in proportion to weight and bucket size: in wetland work, long reach is highly desirable and weight increases problems, costs and risks.

Clam shells

Clam shells have almost as much reach as a dragline and can work without dragging debris such as roots, stumps and boulders up against themselves or platforms. However, they have the disadvantage of pulling the bucket straight up, which in sticky mud requires overcoming suction greater than the weight of the bucket and load.

Bulldozers

Bulldozers are not suited to wet excavations since they cannot work on artificial supports. However, they can skim shallow layers of mud off hard surfaces and dig cautiously in muds compact enough to give them some traction. In skimming work it is usually best to start at one side of the mud area and make a pass removing the mud cleanly.

During wet digging, large quantities of water will be retrieved along with the solid material. In some situations the water running back into the excavation may be minimised by compartment digging. In this case a ridge is left between the hole and the water until excavation is finished, and the ridge is then dug out to allow the water to flow in. Compartments may be large or small. This technique permits water-free digging for the bulk of the excavation but can't be used if the whole excavation area is under water.

If groundwater flows into the excavation rapidly enough to be a nuisance, digging can be carried out in two or more compartments. The whole area is first dug in layers until it gets wet. Digging is then concentrated in one area until most of the water flows into the hole. An adjoining area, separated by a ridge, is then dug deeper, and the ridge is cut. The water will now flow into the deeper hole, leaving the first one nearly dry and ready to be deepened in its turn. This alternation of digging locations can be continued to the bottom of the cut.

Permanent access roads should not be built over unstable mud unless absolutely necessary. Mud (particularly if rich in organic matter) will be gradually compressed and displaced by the weight of the road, causing it to sink unevenly. Mud must therefore be removed down to a firm bottom and replaced with clean fill if possible. If it is too deep or otherwise too difficult to remove, measures such as the use of geotextile fabric must be taken to stabilise it.

Prepare a plan for the event that bogged machinery must be rescued. Time to rescue machinery may be limited by an approaching high tide. The strongest measures should be applied early, as every failed attempt is likely to make the job more difficult. A minor rescue job can become a major job by continuing to spin wheels too long. Generally, the most effective device for extricating bogged machinery is a winch. A power winch with a long cable can reach a long way from firm ground or can multiply its power by using pulleys and ground anchors. Loaders and shovels have a greater chance of self rescue. Crawler machines do not bog down as easily as wheeled vehicles, but when they do are more difficult to rescue.

Dredging

Dredging is a form of channel modification, used to deepen, widen or lengthen as well as to clean. Dredging involves the scooping or suction of underwater materials including, but not limited to, rocks, bottom sediments, debris, sand, refuse, and plant or animal matter from the bottom of a water body. Dredging systems are available as land-based and water-based plants and are divided into hydraulic and mechanical systems. Dredging plants comes in all sizes, but the operation depth depends mainly on pumping power to bring up the slurry.

Dredging is often too expensive to be practical because the dredged material must be disposed of somewhere and the stream will usually fill up again with sediment in a few years.

Mechanical dredging

Mechanical dredging is generally done with a barge-mounted crane using a clam bucket or dragline bucket. The material is excavated and placed in a barge. A towboat or tugboat moves the barge to the disposal area. In estuaries, the barge is generally moved to the shore and the mud is unloaded with a crane using a clam bucket. The mud is placed in trucks and hauled to a disposal site. For coastal dredge disposal the barge is towed to an approved area that is generally far out in the ocean and the mud is bottom-dumped from the barge. The barge can also be unloaded by pumping to a spoil area.

Hydraulic dredging

Hydraulic dredging systems are usually mounted on a floating barge. A boom, called a ladder, is lowered into the mud. On the end of the is a cutter head, which rotates and excavates the material. A large pump in the hull of the dredge sucks the excavated material from inside the cutter head through a pipe. The slurry in the pipeline contains about 20% mud and 80% water. Excavated material is placed in a barge or pumped through pipes to other destinations.

Bunding

A bund is a raised earthen barrier used to separate an area and control the water level within a wetland or protect the inflow or outflow of adjacent areas. During construction within wetlands, dispersal of silt can be prevented by bunding to protect the water quality. Temporary bunds may be required to protect an area of germinating vegetation, at least until the plants can withstand currents and waves.

Bunding is also used to improve the efficiency of wetland stormwater drainage. Installation of a permanent bund must be approved in advance and monitored after setting up, because of its ecological impacts on high-value protected marine wetland areas such as loss of tidal habitats, reduced tidal prism, altered water quality and salinity, reduced fish passage and altered weed management within the wetland.

4.4 Implementing non-structural works

Natural regeneration

Rehabilitation efforts will have the most success in areas that require little effort to promote natural recovery. This reduces the effort and costs associated with long-term maintenance, which can be intensive and expensive.

Examples include saltmarsh areas adjacent to urbanised areas, which can be damaged by cars and trail bikes. Natural regeneration of such areas will be assisted by the blocking of access using fences or bollards.

Cows in particular will seek out mangrove seeds and seedlings. Their consumption of seeds and leaves and their trampling of the root systems can undo rehabilitation work. If cattle are present, fencing is imperative to prevent damage. Sheep and goats may also be a problem.

Although in some areas wetland can appear to regenerate rapidly, at Kooragang Wetlands on the Hunter River the regeneration of saltmarsh areas following the exclusion of stock took approximately 5 years to return to natural condition. Other areas may take even longer (Section 6.1.4).

Establishment of *Wilsonia* sp. in wheel ruts after vehicle exclusion, Coila Lake (Eurobodalla Shire Council)

Replanting

Natural recovery of saltwater wetlands may not always be possible, particularly where the site is separated from natural wetlands: species may not be able to cross over to recolonise it. In such cases, it may be necessary to lend a helping hand in the form of replanting.

It is essential to ensure that the area to be replanted is compatible with the requirements of the species to be planted, or it may not be successful. For this reason it is necessary to understand as much as possible about the local topographical range of the species being planted if a specific area of each community is to be rehabilitated.

Each form of flora to be established has its specific planting strategies. It is important to consider the habitat suitable for each of these. Normally, a permit is required to collect plants or seed. Information on replanting swamp forest, mangrove, saltmarsh and seagrass habitats is presented in Appendix 2.

Volunteers assisting with replanting (Kooragang Island Rehabilitation Project)

4.5 Reinstating tidal inundation

Most areas suitable for establishment of mangrove and saltmarsh wetlands were formerly tidal areas which have had tidal inundation eliminated or reduced by reduction of the tidal range or alteration of the topography. Tidal flooding in NSW estuaries has typically been reduced by construction of weirs and floodgates, levees, culverts, bunds and roads. On the NSW coast over 4000 of these structures have been identified (Williams and Watford 1997).

Often where the tide has been excluded from areas, the ecology has been completely altered, changing to either freshwater or terrestrial communities. Where these areas are to be reconnected, the existing vegetation must be dealt with. For example, a sheltered tidal embayment is to be reconnected to a large estuary after being cut off for some decades. Freshwater species with low salt tolerance have taken over. Should the vegetation be removed before the salt water is reintroduced, or can the expected die-off and redistribution of the plant material and organic substrate be tolerated? Biomass largely made up of pasture can be reduced by mowing, but removal of freshwater reeds could require extensive excavation at considerable cost.

Where saltmarsh rehabilitation is to be achieved through the removal of restriction to tidal flows, upland grasses will usually be present. If so, these should be left in place, as after they quickly succumb to the salt water, the dead root systems will hold the soil together until the saltmarsh becomes established, and the leaves will help to trap and hold saltmarsh plant seeds floating on the tide.

Where land needs reshaping to restore tidal inundation, it is important to understand that changes of only a few centimetres in elevation can strongly influence the type of wetland that will establish. Zonation of plants requires a specific combination of land gradients (to ensure inundation) and soil salinity. This may be particularly difficult to achieve. Tidal inundation is particularly important. Mangroves will establish where tidal inundation is regular. However, if saltmarsh is to be encouraged, elevation and maintaining soil salinity are crucial in excluding mangroves from the saltmarsh flats.

In addition, soil salinity and hydraulic conductivity are major factors determining seed germination and the ability of plants to mature, so the right balance of tide and fresh water is essential (discussed further in Chapters 8 and 9).

4.6 Timing rehabilitation activities

It is important to consider timing of works if the goal of the project is to attract birds. This is particularly true if adjacent habitats are functioning as bird roosts and the aim is to expand habitat availability. Continual disturbance of waders feeding on intertidal flats may severely limit their food intake, particularly smaller waders and especially during February to April, when the birds are rapidly building up fat reserves before their return migration: heavy losses may occur during migration if the birds have insufficient fat reserves. The birds also have high energy requirements from October to February, when they are moulting their flight feathers and replacing them, so a reduced food intake during this period may also have serious effects on their preparation for migration (Smith 1991).

Timing of structural works may also be important, particularly where the undertaking of tasks at low water levels requires planning ahead to ensure that low tide coincides with suitable working times. In some areas it may also be best to work outside local wet seasons.

It is also advantageous to time works even if visual amenity is the only goal for the site. Vegetation will appear sooner and grow better if works are timed to be completed when nearby areas are flowering or setting seed.

4.7 Minimising disturbance during construction

All construction work should be planned and implemented to minimise effects on both the short-term and long-term health of the wetland and to improve its amenity, including water quality. To achieve this, a number of factors must be considered:

- Construction work can readily result in the blanketing of adjacent areas with sediment. In some cases the sediment can be toxic. In others, it can stifle flora and fauna growth.
- Mangroves can die if sediment covers pneumatophores.
- Disturbance of ASS should be minimised or avoided.
- It is important to monitor the rate of sedimentation to ensure that it is not excessive.
- A number of erosion and sediment control measures can be used to reduce sedimentation of adjacent areas, such as silt curtains and sedimentation basins.

Erosion and sediment control measures are discussed in Chapter 24 of *The Constructed Wetlands Manual*. Another document that presents a thorough treatment of this topic is *Managing Urban Stormwater – Soils and Construction* (Landcom 2004), also known as the *Blue Book*.

Wetland plants play an important role in reducing erosion within a wetland, including protecting newly constructed banks and channels. Root growth can bind the soil, vegetation can reduce water flow velocity, and **evapotranspiration** by plants can reduces soil saturation, which in turn helps to prevent bank collapse. In addition, the stems of plants can armour the soil surface to reduce soil erosion.

Disposal of excavated sediment from mangrove areas may be difficult. Don't place it where it may trap water and lead to the formation of stagnant pools. If it is not feasible to remove sediment from the area, place it carefully at the base of nearby mangrove plants without damaging the pneumatophores or scatter it widely so as to avoid pooling. Acidic sediments would require neutralisation before placing near vegetation.

Vegetation may be disposed of by burial and long-term decay, shredding or chipping and removal from the site, or a combination of these methods.

4.8 Rehabilitation and construction to control mosquitoes

When planning wetland creation or rehabilitation, avoid areas that may enhance breeding of mosquitoes. In estuarine habitats, *Ochlerotatus vigilax* (previously known as *Aedes vigilax*) and *Ochlerotatus camptorhynchus* (previously *Aedes camptorhynchus*) are the major pest mosquitoes, and both are vectors of viruses affecting humans (Russell 1994). In southern coastal areas of NSW, *O. camptorhynchus* is the major pest (Webb and Russell 2006). *Ochlerotatus vigilax* may disperse far from its larval habitat, and its connections with Ross River virus and dog heartworm have made it a focus for control efforts in coastal urban areas (Turner and Streever 1997). Other species of mosquito associated with estuarine areas include *Ochlerotatus alternans* (previously *Aedes alternans*), *Culex sitiens* and *Anopheles annulipes*.

Knowledge of egg laying sites favoured by mosquitoes may help improve mosquito control and guide wetland rehabilitation practices to avoid creating or exacerbating a mosquito problem. Mosquitoes are typically found in the ephemeral pools of saltmarshes and at the back of mangroves, rather than within the mangroves, where there is regular tidal exchange. In disturbed areas, stagnant pools create ideal mosquito breeding habitat. Poor drainage will promote mosquitoes, so there should be no restriction to tidal flushing. This will not only reduce the risk of mosquito infestation, but also assist in establishing saltmarsh plants.

As discussed in Section 4.3.1, runnels can assist with drainage of low-lying areas and prevent mosquito breeding by flushing larvae out into the more hazardous open water. Runnels also allow greater fish passage into the area, increasing predation of mosquito larvae.

Information on other methods for mosquito control is found in Section 5.5.6.

Dialogue Box 4.1 A case study of runnelling for mosquito control

Runnelling was carried out at Coomera Island on the Gold Coast in 1985. A half-hectare portion of saltmarsh was experimentally runnelled after more than 3 years of field and aerial survey research, to see whether a small alteration to the saltmarsh would be enough to reduce the larval population of the mosquito *Ochlerotatus vigilax*.

The runnels were manually dug with smooth sides to no more than 300 mm deep and 900 mm wide. This design mimicked the existing natural saltmarsh channels.

The project has been monitored for nearly 20 years. After 3 months there were very few mosquito larvae in the runnelled site (an average of 0.6 larvae per 240 mL dip compared with the surrounding saltmarsh (16 larvae per 240 mL dip).

Minor environmental changes related to runnelling have been identified at Coomera Island:

- increased wetness near runnels (because tides flood the area more often)
- slightly lowered salinity near runnels (because of flushing)
- increased numbers of some crabs (mainly in the upper saltmarsh).

However, runnelling was not found to affect:

- the acidity of soils or groundwater
- **water table** depth or groundwater salinity
- the size or density of the dominant grass, succulents or mangrove pneumatophores.

Compared with other methods of modifying saltmarshes for mosquito control (for example, open marsh water management and drain ditching), runnelling has been shown to have the least impact on saltmarshes. Runnels significantly reduce the numbers of mosquito larvae but do not significantly affect the saltmarsh or its processes (Dale *et al.* 1996, Dale *et al.* 2002, Dale 2005).

A note of caution: Consider runnelling only where drainage systems are likely to remain free of blockages, shallow ASS will not be disturbed and the soil type will not result in erosion.

4.9 Hazardous materials considerations

A hazardous substance can be defined as any substance that, because of its quantity, concentration, acute or chronic toxic effects, carcinogenicity, teratogenicity, mutagenicity, corrosiveness, flammability, explosiveness, radioactivity, or physical, chemical or infectious characteristics, may pose a hazard to human health or the environment when improperly treated, stored, disposed of or otherwise managed.

Laws apply to the use, storage and transport of certain hazardous materials (for example, dangerous goods and pesticides). Managing the generation, treatment, storage and disposal of hazardous materials, including household and industrial hazardous waste, is essential for wetland protection. Hazardous materials cannot be dumped in wetlands. Make sure you are aware of any requirements before using hazardous materials.

Hazardous materials can occur in wetland sediments and vegetation as a result of the long-term accumulation of heavy metals or toxic compounds. Thus, dredged materials which contain hazardous levels of toxic materials must be disposed of in accordance with the Waste *Avoidance and Resource Recovery Strategy* (Resource NSW 2003), and never in wetlands.

The DECC's Hazmat register (www.environment.nsw.gov.au/hazmat/index.htm) list providers that offer resources, equipment, products and advice on how to minimise the environmental effects of hazardous materials incidents.

For further relevant information about chemicals, visit the National Chemical Information Gateway (www.environment.gov.au/erin/index.html).

The soil within a wetland will act as a sink for many heavy metals, which can be released back into the water if pH is reduced or salinity is increased (Hart 1982). Heavy metal concentrations above **background levels** can cause adverse impacts on aquatic flora and fauna and, by association, people.

4.10 Acid sulfate soil management

Potential ASS contain iron sulfides (mainly pyrite), which can generate large amounts of sulfuric acid when exposed to air. NSW has about 600 000 hectares of ASS along its coastline (Naylor *et al.* 1998). The occurrence of ASS is related to low elevation and so is common in estuarine wetlands, estuary foreshores and the beds of estuaries. These soils formed naturally over the last 10 000 years, and are safe unless dug up or drained. Large-scale drainage of coastal flood plains for flood mitigation, urban expansion and agriculture has exposed large areas of ASS. Acid **leachate**, plus the aluminium, iron and heavy metals it releases from soils, can cause significant environmental and economic problems. Further information on the extent, formation and physical properties of ASS is given in Section 9.9.

ASS risk maps covering the entire NSW coastline are available from DECC. The Department of Planning has encouraged coastal local councils to develop local environmental plans for developments in ASS areas.

It is likely that an ASS management plan will be required for saltwater wetland projects.

Information resources on acid sulfate soils

The ASS risk maps are a series of 1:25 000 maps which identify the potential distribution of ASS along the NSW coastline. These maps also indicate the likely depth of ASS, the probability of ASS occurrence and the types of work that might disturb them. Guidelines to assist with the interpretation of the maps (Naylor *et al.* 1998) can be downloaded from the DECC website.

The *Acid Sulfate Soils Manual* (Stone *et al.* 1998) is a detailed reference manual on ASS assessment and management. The manual includes sections on planning, assessment and management, laboratory methods, drainage, groundwater, drain clearing and industry guidelines. The manual is currently under revision. The *Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales* (Tulau, 2008) provides a framework for designing ASS remediation projects. The guidelines provide information on the design, implementation, management and monitoring of ASS remediation projects.

Principles for managing acid sulfate soils

In managing ASS the primary objective is to prevent or minimise the potential impacts, both on-site and off-site. The NSW *Acid Sulfate Soils Manual* (Stone *et al.* 1998) provides general management strategies for dealing with ASS including:

- prevent oxidation of iron sulfides:
  - avoid ASS
  - place iron sulphide sediments under water
  - collect and treat acid leachate (where the iron sulphide content of soil is very low)
- neutralising acid soil and leachate, generally through the addition of large quantities of lime
- separation of acid sulphate material (applicable to wet dredging operations where the acid sulphate fines can be separated by sluicing or hydrocycloning techniques).

With the exception of avoiding ASS disturbance, each strategy has its strengths and drawbacks. The limitations of ASS remediation strategies are discussed in the *Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales* (Tulau, 2008).

Regeneration of swamp oak forest at Coila Lake after vehicle exclusion (Eurobodalla Shire Council)

Wader roost constructed at Stockton Sandspit (Kooragang Wetland Rehabilitation Project)

Floodgate Yarrahapinni, Macleay River (DECC)

5 Operation and maintenance

5.1 The need for management

Saltwater wetlands that have been constructed or rehabilitated are susceptible to a number of external and internal pressures and require medium- to long-term management to ensure that project objectives are achieved. Ongoing management is necessary to deal with damage due to physical, chemical and biological processes and the ongoing effects of human activities such as agricultural and industrial pursuits adjacent to or within wetlands systems.

A prime objective of the management of saltwater wetland rehabilitation is the protection or enhancement of ecosystem health. Accordingly, operational procedures will normally focus on this objective.

The type and intensity of management should depend on the scale of the activity, and should be considered before the initial rehabilitation or construction process begins.

As indicated in *The Constructed Wetlands Manual* (DLWC 1998), it is sometimes necessary to prioritise management activities and then to allocate resources accordingly for their implementation. The priority list for constructed freshwater wetlands is also suitable for saltwater wetlands:

1. Safety – Give the highest priority to public safety.
2. Stability – Maintain and repair structures to prevent their failure.
3. Plants – Maintain plants to prevent their loss and consequent reduction in the ecological health of the wetland.
4. All other management activities – essential for the health and performance of the wetland.

5.2 Elements of management

The main elements of management can be categorised as:

- operation
- maintenance
- monitoring and inspection
- emergency management.

The successful operation of a saltwater wetland rehabilitation plan will require the effective implementation of each one of these elements. Implementation is not a linear process, but rather a circular process with continual feedback from one element to another.

The operation, maintenance and monitoring of constructed wetlands is comprehensively covered in *The Constructed Wetlands Manual* (DLWC 1998). Much of that material is directly applicable to saltwater wetlands, and should be consulted in conjunction with this manual.

Examples of each of the elements of management:

- Operation – controlling flows into and out of the saltwater wetland.
- Maintenance – repairing damage to structures built as part of the rehabilitation plan; controlling weeds and pests.
- Monitoring – data collection in relation to water levels, water quality and habitat.
- Inspection – inspecting structures for damage and to assess whether they are working as planned.
- Emergency management – repair to controlling structures, general geomorphology and plantings following coastal storms or floods.

The information in this chapter is provided as a guide or a possible approach to maintenance. The amount of detail required in individual projects will depend on their nature and size, and can be adjusted to suit your purposes. A small-scale project may require only a single-page operational plan, while a larger-scale project may require more detail. It is essential that plans be tailored to the people undertaking the work.

5.3 Operation and maintenance plan

An operation and maintenance plan provides an adaptive management framework and should be tailored to suit the main objectives of the rehabilitation project.

Management activities should seek to maintain sustainable coverage of native vegetation. The operation and maintenance plan should allow for gradual changes in the relative coverage of these species, rather than seek to prevent such changes.

Elements of the operation and maintenance plan include:

- a description of the saltwater wetland, its values and the management strategies or structures that have been established
- a list of specific management objectives related to the values
- a list of management activities or tasks
- a timetable for activities and resource availability
- a description of monitoring activities
- an inspection checklist
- a list of contacts for approvals and advice
- an emergency management plan.

Details of each of these elements are presented in Appendix 4.

5.4 Implementing the operation and maintenance plan

The implementation of the operation and maintenance plan can be considered in terms of the phases presented in *The Constructed Wetlands Manual* (DLWC 1998) with some adaptation; that is, commissioning, operation, decommissioning and refitting.

Commissioning phase

The commissioning phase is generally taken as the time from the end of the construction or installation phase to when plantings and surface and groundwater flow regimes have become established.

Access requirements should be reviewed in the commissioning phase to ensure that access is adequate for maintenance activities.

Careful monitoring and inspection are necessary during the commissioning phase to ensure that any control structures are operating appropriately, any erosion or sedimentation is acceptable or can be rectified, and water levels are maintained within an acceptable range to prevent the new plantings from drying out or becoming drowned.

At this time the newly rehabilitated saltwater wetland can be particularly vulnerable to outside influences such as catchment runoff, flooding, storm and wave attack, and disturbance by humans and other animals. It is therefore important that regular (possibly weekly) inspections be undertaken. If necessary, public access may need to be restricted until plantings are successfully established.

Operation phase

The operation phase covers the design life of the rehabilitated saltwater wetland, which could be up to 50 years. During this phase, all management activities applicable to operation, maintenance, monitoring, inspection and emergency management would be implemented. These management activities seek to ensure that the saltwater wetland is performing adequately to attain the management objectives. Ongoing monitoring and inspections are necessary to ensure that performance is acceptable and to identify where changes to the operation and maintenance activities may be necessary.

Several years after the start of the operational phase it will be appropriate to review the original management objectives. As estuarine and coastal systems are dynamic environments, it is possible that the values of the saltwater wetland will change or the initial management activities will no longer be entirely appropriate to protect and enhance those values. As a result of this review, some change to the operation and maintenance plan may be necessary.

Decommissioning and refitting phase

The decommissioning and refitting phase comes after the end of the design life of the rehabilitated saltwater wetland. While in most cases we should hope that the wetland would last indefinitely, some situations, such as growth in adjacent residential and commercial areas, can make a saltwater wetland unviable or at least affect the operation of wetland processes.

Common reasons that may result in the need to refit a saltwater wetland, particularly within a very urbanised environment, are the accumulation of sediment from the catchment and reworked sediment within the wetland and the alteration to stormwater runoff due to changes in the catchment. Changes in runoff can bring additional loads of pollutants to the wetland and change the flow regime.

Major refits to the wetland could include the removal of accumulated sediment, alteration to flow control structures and the re-establishment of plantings. Sediment must be removed in such a way as to minimise damage to existing vegetation communities, and be disposed of appropriately. Flow control structures should be altered only after an assessment of the likely changes to the flow regime. This would normally require seeking specialist advice and reviewing the results of any monitoring of water levels and flows.

In the refit of the wetland it may be appropriate to set new management objectives.

A possible cause for the decommissioning of a saltwater wetland could be the growth in adjacent urban development, which may increase catchment pollutant loads to such an extent that the wetland cannot operate satisfactorily. To avoid this situation, take all opportunities during the planning process to minimise encroachments on the wetlands.

Information on a range of general operation and maintenance considerations is included in Appendix 4.

5.5 Maintenance considerations

Storms and floods

High flows and wave activity can result in erosion and sedimentation. In addition, litter and other debris can be deposited in the wetland. Inspect your wetland as soon as possible after storm and flood events to note any damage or deposition of sediment and litter and rectify it.

Storms and floods may damage saltwater wetland vegetation through sedimentation or erosion. Small events are unlikely to cause significant damage. However, if larger events do cause damage, seek specialist advice to determine the most suitable form of remediation.

Invasive plant species

Several invasive species have the potential to completely overrun saltwater wetlands. Of particular note are common cordgrass (*Spartina anglica*) and spiny rush (*Juncus acutus*). The invasive common cordgrass was introduced into Tasmania and Victoria specifically for reclamation of land and stabilisation of mudflats. In Tasmania, it has completely taken over the Tamar Estuary (Adam 1981). Yet despite attempts to establish it in NSW it has not become a problem here (Adam and Hutchings 1987). It can have several detrimental effects on natural environments in Australia, including invading mudflats that are rich in invertebrates and producing dense monospecific stands that replace more diverse plant communities. Birds have been observed to avoid it (Simpson 1995, Hedge and Kriwoken 2000), and species richness and total abundance of fauna are greater in areas dominated by native plants than in those dominated by *S. anglica* (Hedge and Kriwoken 2000).

Juncus acutus removal (Kooragang Wetland Rehabilitation Project)

Spiny rush was introduced from the Mediterranean, and has become widespread throughout estuaries and on saline pasturelands in south-eastern Australia (Milford and Simons 2002). It has been so successful that it has been listed as a noxious weed in Australia (NAWC 2003). It occupies the same niche as the native rush, *Juncus kraussii*, but is tougher and more resilient and easily out-competes the native species.

The introduction of *J. acutus* into saltmarshes has altered their structure and complexity. Once *J. acutus* becomes established, its sharp, tough, cylindrical leaves form dense, impenetrable thickets, displacing the native rush. Many gastropods and other invertebrates are believed to depend on *J. kraussii* for completion of their life cycle, which the harsher habit of *J. acutus* precludes. Therefore, the ecosystem may be severely affected by the invasion of *J. acutus*. Removal of this species has become a focus for management in some areas, but it is proving particularly difficult to eradicate. Paul and Young (2006) have trialled a number of methods for its control, including physical removal, application of glyphosate and application of salt. More information is required on the general biology and physiology of this species in order to formulate effective methods for its permanent eradication.

Weeds

Although seagrasses and mangroves in NSW have remained substantially uncontaminated by weeds, a number of weed species have become established in saltmarsh and swamp forest.

Annual beardgrass (*Polypogon monspeliensis*) favours damp, disturbed sites often close to water, and coast barbgrasses (*Parapholis incurva* and *Monerma cylindrica*) are found in saline soils subject to flooding. Other common introduced species include buck's horn plantain (*Plantago coronopus*), rock sea lavender (*Limonium binervosum*), annual beardgrass and salt daisy (*Aster squamatus*). All these species have been introduced from the Northern Hemisphere, and most can out-compete native species. Generally, however, invasive annual species are not as detrimental as invasive perennials that may invade during periods of low salinity and become a permanent feature of the wetland (for example, *Typha orientalis*).

Groundsel bush (*Baccharis halimifolia*) is an increasing problem in North Coast marshes owing to its masses of windborne seeds. Alligator weed (*Alternanthera philoxeroides*) and bitou bush (*Chrysanthemoides monilifera*), though generally more a problem in other habitat types, show a level of salt tolerance and are found on brackish saltmarsh margins. Other exotic species found in the saltmarsh margins and swamp forest are pennywort (*Hydrocotyle bonariensis*) and coastal morning glory (*Ipomoea cairica*). Salt daisy is found throughout the upper marsh. Common weed species in swamp forest also include lantana (*Lantana camara*) and wandering jew (*Tradescantia fluminensis*).

Macroalgal mats

In shallow estuaries and coastal lagoons, species of the opportunistic green algal genera *Cladophora*, *Enteromorpha*, *Ulva* and *Chaetomorpha* and of the red algal genus *Gracilaria* grow luxuriantly and form extensive mats which, under certain conditions, can detach and float in the water column. For example, *Enteromorpha intestinalis* formed mats along the shoreline of shallow semi-enclosed bays in Lake Macquarie, first appearing in the late winter and early spring and later developing into dense mats which detached and floated in the lake (Wood 1959). In the same lake, *Enteromorpha prolifera* and an unidentified *Enteromorpha* sp., at first **epiphytic** on seagrasses, formed free-floating mats in the shallows.

Floating mats of these nuisance species are becoming more common in estuarine systems around the world, a phenomenon due largely to **eutrophication**. In eutrophic estuaries, large free-floating banks of opportunistic green algae, sometimes exceeding 0.5 m in thickness, grow in response to the increased nutrient loading. Following the opening of coastal lakes, the sudden drop in water level can strand the macroalgae in dense mats that eventually dry out and decompose.

Dense mats of macroalgae exposed as water levels drop in Lake Wollumboola after the lake's opening to the sea (DECC)

Litter and debris

If gross pollutant traps have been installed to trap litter and other debris, they will require regular inspection and cleaning, especially after storms. If traps are not installed or prove to be ineffective, litter and other debris can accumulate in the saltwater wetland. Some of the accumulated litter and debris may leave the wetland on the ebb tide, while additional material can enter on the flood tide.

Litter and accumulated debris within a wetland (DECC)

Certain facilities such as walkways may result in increased litter in their vicinity due to the number of people visiting them. It is important to determine the sources of litter and then implement a reduction plan, which could involve structural measures such as installation of gross pollutant traps or non-structural means such as an education program.

Control of cattle, pests and mosquitoes

Cattle can trample and graze plants in saltwater wetlands. They can be excluded by appropriate fencing and off-stream watering points.

Damage caused by uncontrolled cattle access to an estuary bank (Adam Gosling, WetlandCare Australia)

Pests

Pests may include rats, birds, flies and mosquitoes. Birds and rats can damage saltwater wetland vegetation, especially new plantings. Regular inspections are necessary after new plantings. In extreme situations culling may be necessary.

The larvae of a moth (*Enoplidia* sp., Oecophoridae) periodically cause widespread damage to mangroves in the Hunter estuary and possibly elsewhere. The species is undescribed, and control measures have not been investigated. Although damage is substantial, the larvae do not appear to cause permanent damage to mature stands. However, the degree of damage evident in mature stands would cause severe setbacks to seedling establishment projects, and control methods such as spraying would have to be carried out to prevent substantial loss of the new plants.

More recently, the Sydney Olympic Park Authority has commissioned a study by the University of Western Sydney of a severe attack by a moth. The attack started in late 2003 and has been repeated over the last 3 years. As a consequence or as a coincidence, a significantly low number of **propagules** have been produced by the mangroves in the greater Sydney area. The moth was identified as a species of *Ptyomaxia* (Phycitinae). The species is believed to be close to *Ptyomaxia metasarca*, which has been described from Brisbane (S. Paul, Sydney Olympic Park Authority, personal communication, 11 January 2006).


Mangrove dieback as a result of insect grazing (DECC)

Insects such as Cecidomyiidae flies can cause galls or lumps on mangrove leaves. Ten different types of cecidomyiid-caused galls have been recorded from *A. marina* in Queensland (Burrows 2003).

Insects can be a symptom of stress, and may not actually be the cause. Where insect damage is of concern, look more broadly for causes of mangrove stress.

Mosquitoes

Mosquitoes are common in saltwater wetlands and can cause health problems. Stagnant areas tend to become mosquito breeding zones. The objective of mosquito control is to maintain the population below threshold levels for disease transmission and nuisance.

Mosquito control is achieved by physical, biological or chemical means. Physical control by habitat modification can be achieved by preventing ponding, as the larvae are generally easily washed out with flowing water. Information on the use of runnels is provided in Sections 4.3.1 and 4.8. Biological control is achieved by predators, including larvae and adult insects, bacterial and fungal **pathogens**, and growth regulators. Chemical control is achieved by spraying with larvicides and insecticides. This can have immediate results, but is often indiscriminate and can lead to the development of resistance. Chemical spraying is not appropriate where the site has conservation or habitat value.

Educating the local community on the ecology and the risk levels allows a more informed and environmentally sustainable approach. There is a need to balance the perceived threat with the actual public health risk and the needs of the environment. Effective mosquito control requires liaison between land use planners, mosquito managers and the local community. An example of a coordinated regional response to mosquito populations and arbovirus activity in NSW is the *Living with Mosquitoes* program developed by five local councils and stakeholders in the Lower Hunter and Mid North Coast regions.

Mosquito populations in wetlands can be managed by integrated control measures such as:

- the reduction or minimisation of areas suitable for mosquito breeding
- the maintenance of vegetation communities in a form which does not provide extensive mosquito breeding habitat
- the development of a diverse and balanced aquatic community
- the encouragement or implementation of biological control (such as the presence of native insectivorous fish species)
- the use of pesticides in a judicious manner and only when necessary.

Within tidal wetlands the scope for introducing fish as a mosquito control mechanism is obviously limited, but if the wetland area is effectively flushed, then predators such as native fish should be able to enter the area freely. However, if self-contained pools of water are a part of the wetland rehabilitation design (for example, to provide a range of diverse habitat types for birds), it may be possible to stock native fish to control mosquitoes.

Many small native fish are widely distributed in natural waters and are considered effective for the control of insect pests. If investigating fish stocking as a control mechanism, use only local native fish, as the introduction of non-locals may have detrimental effects if they expand their distribution. Native fish are easy to locate, are suited to local conditions, and are unlikely to cause ecological disturbance. Most small native fish are hardy and will reproduce quickly in most permanent water bodies such as ponds in created wetland habitats. They can be obtained from some aquarium shops or from registered fish hatcheries. It is important to select species that occur within similar habitats and locations to those that are being recreated. Fish stocking may require a permit from the DPI.

The use of pesticides for mosquito control is limited by the availability of appropriate products and concern for effects on non-target species and environmental contamination. The number of chemicals considered environmentally acceptable for use in diverse ecosystems is diminishing. The organophosphate pesticide temephos is widely used in freshwater wetlands, where it kills mosquito larvae on contact, but it is not suitable for saline wetlands because it has detrimental effects on the development of some crustaceans.

Two agents are available for the control of mosquito larvae (University of Sydney and Westmead Hospital, Department of Medical Entomology 1998):

- *Bacillus thuringiensis israelensis* is considered to be a temporary control measure owing to the relatively narrow window of opportunity for it to be effectively applied. This commercially produced bacterium kills larvae when ingested. It must be applied within the first few days of the mosquito's aquatic life cycle as it does not affect mature larvae.
- Methoprene is an insect hormone analogue and a growth retardant relatively specific to mosquitoes which prevents the larvae from developing to adulthood. The product must be applied to larval populations as it does not affect pupae. Larvae will continue to develop after the application but will eventually die in the pupal stage, and no adults will be produced. However, because it does not directly kill the larvae, its effectiveness is often difficult to evaluate in the field.

These products are believed to target aspects of mosquito biology without having undue effects on non-target species and the environment in general.

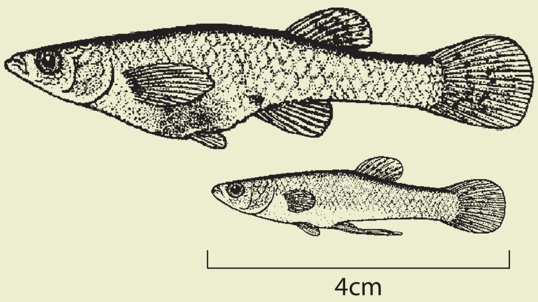
Dialogue Box 5.1 A note on the use of mosquito fish

The mosquito fish *Gambusia holbrooki* is a small, live-bearing fish native to Central America and has been used widely in mosquito control. First introduced to eastern Australian waters in 1929, by 1945 it was widespread. The introduction of exotic fishes adversely affects native systems and fauna through competition for food and space and the introduction of exotic disease and parasites.

Mosquito fish not only cause reductions in native fish populations, but may also reduce populations of invertebrates such as aquatic insects, crustaceans and molluscs. There is also evidence that mosquito fish prey upon eggs and tadpoles of the green and golden bell frog (*Litoria aurea*) (Morgan and Buttermer 1996).

The actual impact that these fish have on mosquitoes is minimal, as mosquito larvae form only a small portion of their diet. Consider native alternatives if fish are to be a means of biological control of mosquito larvae in any constructed ponds or areas of standing water.

Predation by *Gambusia holbrooki* has been listed as a key threatening process under the TSC Act.



Mosquito fish (*Gambusia holbrooki*): Top, female; bottom, male (adapted from Department of Primary Industries (Victoria), 2003)

Sediment and toxic materials

You may need to monitor sediment accumulation in the saltwater wetland if sedimentation from the surrounding catchment is accelerated by anthropogenic influences. Sedimentation may be a particular problem after storms and floods. Accumulated sediment may need to be removed to maintain water depths and flow conditions.

Accumulation of heavy metals and other toxic compounds in saltwater wetland sediments and vegetation can lead to **bioaccumulation** in the ecosystem and redistribution by wetland food chains, with implications for faunal and human health.

Sediments must be disposed of in accordance with current legislation. This will usually require contaminant testing of the sediment, and disposal may require consent from DECC.

Vandalism

Vandalism can reduce the environmental and aesthetic qualities of the rehabilitated wetland. Activities can include damage to control structures, other facilities, plantings and established vegetation; dumping of litter, sediment, chemicals and other material into the wetland; and disturbance of wetland fauna.

Education programs are recommended to advise of the values and sensitivities of saltwater wetlands. If the vandalism is recurrent or extreme, monitoring or the involvement of local council rangers or the police may be required.

Neighbouring activities and usage

Operation and maintenance activities need to allow for neighbouring activities and usage. Monitor any odours and mosquito problems generated by the wetland, and put appropriate measures in place.

Consider also the potential effects of the neighbouring areas on the saltwater wetland in ongoing management. The effects can range from minor short-term impacts such as the isolated deposition of litter to major long-term impacts such as the loss of sustainability of the wetland due to the growth of urban development. The wetland operator must always be aware of neighbouring activities and usage and be prepared to respond to changes in them.

It is important to anticipate and then prevent damaging impacts on the wetland. Activities to particularly watch out for include any that will generate sediment or hydrocarbons. These include construction work, commercial and residential developments, and activities that redirect stormwater, as well as waves generated by boats, and oil or toxic spills.

6 Monitoring and reporting

6.1 Monitoring

Introduction to monitoring

The current management of Australia's estuarine areas is often confounded by an absence of adequate scientific information. Environmental monitoring within estuaries is poor, so the consequences of pressures on the environment are not well understood or documented.

> *Monitoring is defined as the intermittent recording of the condition of a feature of interest to detect or measure compliance with a predetermined standard.*
>
> *Source:* Hellawell (1991)

Monitoring is a very important component of successful management and rehabilitation of wetland environments. Monitoring may be used to determine when a wetland is moving away from its desired state, to measure the success of management actions, and to detect the effects of disturbances to the wetland (Legg and Nagy 2006).

Since monitoring addresses the extent of change within the environment, which is naturally variable, monitoring studies require a degree of scientific rigour. This does not mean that an effective monitoring program is necessarily complex or expensive, just thorough and well designed with clear objectives. Inadequate or inappropriate sampling design and lack of clear objectives in past monitoring programs has led to a failure to deliver useful information when required (Finlayson and Mitchell 1999, Grayson *et al.* 1999, Chapman and Underwood 2000). If rehabilitation, restoration and creation of saltwater wetlands are to succeed, then monitoring is key.

This manual provides only a brief summary of the parameters and techniques that can be used in monitoring a saltwater wetland. A number of useful guidelines provide more specific information on sample design, methods of measurement and statistical analysis for rivers and wetlands (Dialogue Box 6.1). While not all relate specifically to saltwater wetlands, many of the methods and principles are transferable.

We strongly recommend that you seek professional assistance in the design of monitoring programs and in the collection and analysis of monitoring data.

Dialogue Box 6.1 Useful references for wetland monitoring

ANZECC, ARMCANZ (2000) *Australian Guidelines for Water Quality Monitoring and Reporting*. Available from www.mincos.gov.au

McGloin E, Botting S. (2005) *Establishment of a monitoring and evaluation framework for the Hunter–Central Rivers Catchment Management Authority.* NSW Department of Natural Resources, Hunter Region.

Rutherford I D, Jerie K, Marsh N. (2000) *A Rehabilitation Manual for Australian Streams, Volume 1*. Cooperative Research Centre for Catchment Hydrology, Monash University, Victoria. Available from www.rivers.gov.au

Tucker P. (2004). *Your Wetland: Monitoring Manual – Data Collection*. River Murray Catchment Water Management Board, Berri, and Australian Landscape Trust, Renmark. Available from www.rivermurray.sa.gov.au

Ward T, Butler E, Hill B. (1998) *Environmental Indicators for National State of the Environment Reporting – Estuaries and the Sea. Australia: State of the Environment (Environmental Indicator Reports)*, Department of the Environment, Canberra.

Available from www.deh.gov.au/soe

Sampling design

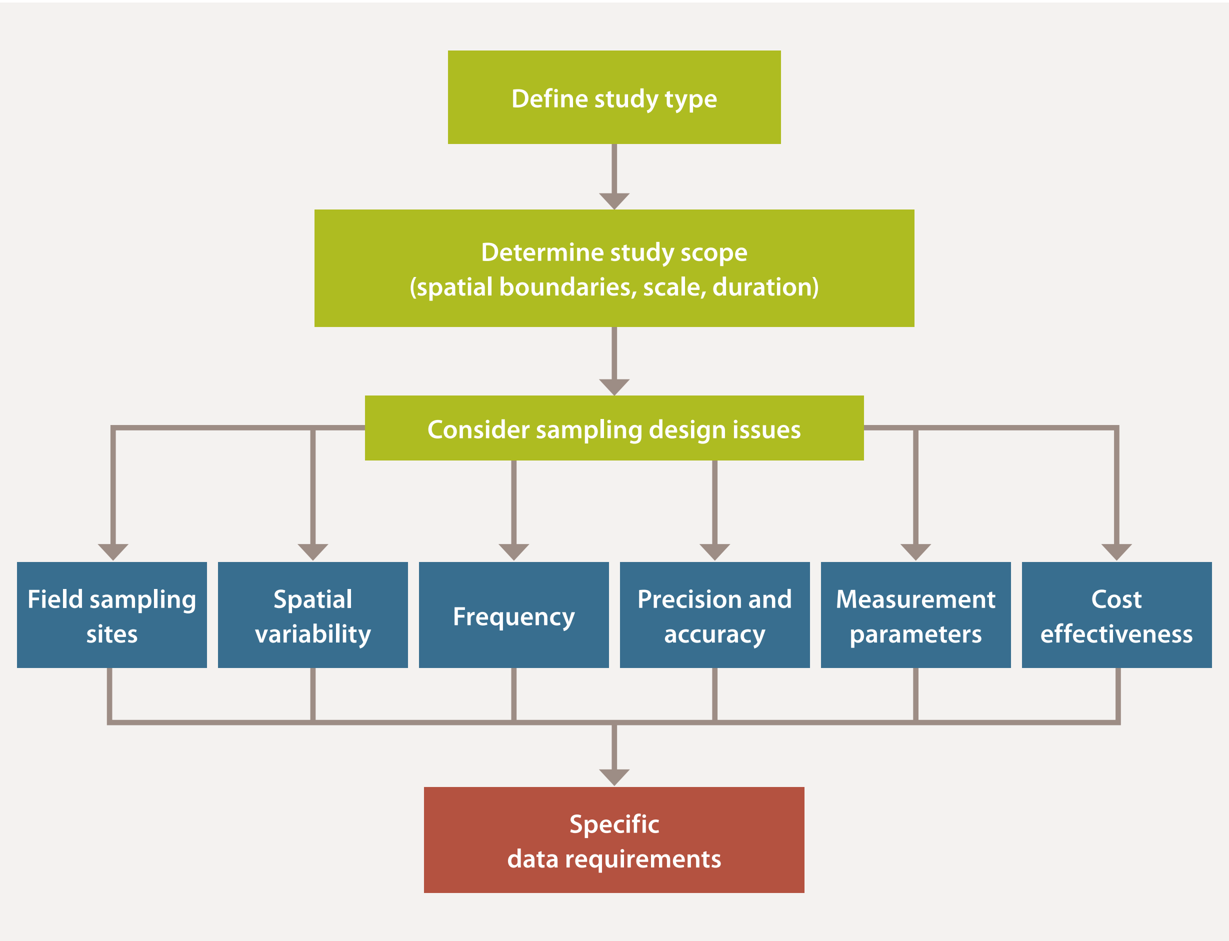
The design of the monitoring program should be based on the stated goals and objectives of the rehabilitation project (Section 2.3). The identification of clear objectives and measurable performance criteria will form the starting point for your monitoring program.

The ultimate design of your monitoring program will depend on many factors, including:

- time and budget available
- whether specialist consultants will be required
- how large and complex your wetland is
- how extensive the proposed changes or rehabilitation actions will be.

Figure 6.1 presents a framework to consider when you are designing a monitoring program. It highlights some of the decisions that you need to make when determining what, where and how you will collect data. Dialogue Box 6.2 provides a more comprehensive checklist of things to consider before you embark on a program of data collection.

Figure 6.1 Framework for designing a monitoring study



Source: ANZECC and ARMCANZ (2000)

Baseline and operational monitoring

Some degree of monitoring is necessary before any rehabilitation or disturbance of the project site occurs. Begin this during the data collection phase of your project (Chapter 3). Baseline monitoring is necessary to provide a basic understanding of how your wetland is functioning and what its current condition is. Baseline data provides information against which future changes can be detected and quantified.

Baseline monitoring should cover as long a period as possible, but as a minimum, you will need at least two sampling events before the proposed rehabilitation begins (ANZECC and ARMCANZ 2000). It is preferable for baseline sampling to cover at least two different seasons (summer vs. winter, or autumn vs. spring) to take into account seasonal differences in, for example, water temperatures, aquatic organisms, vegetative conditions and waterbird activity.

Operational monitoring is used to assess the effectiveness of operation and maintenance activities. Operational monitoring may include regular checking and clearing of any litter and debris traps or checking for soil erosion. Many aspects of operational monitoring can be carried out through inspections of the wetland (Section 6.1.7).

Dialogue Box 6.2 Checklist for designing a monitoring study

1. Has the study type been made explicit and been agreed on?
2. Have the spatial boundaries of the study been defined?
3. Has the scale of the study been agreed on?
4. Has the duration of the study been defined?
5. Have the potential sources of variability been identified?
6. Are there sufficient sampling sites to accommodate variability?
7. Are the sites accessible and safe?
8. Can sites be accurately identified?
9. Has spatial variation in sites been considered, and have options to minimise it been considered?
10. What is the proposed frequency of sampling?
11. Have decisions been made about the smallest differences or changes that need to be detected?
12. Is replication adequate to obtain the desired level of precision in the data?
13. Have the measurement parameters been chosen?
    (a) Are they relevant?
    (b) Do they have explanatory power?
    (c) Can they be used to detect changes and trends?
    (d) Can they be measured in a reliable, reproducible and cost-effective way?
    (e) Are the parameters appropriate for the time and spatial scales of the study?
14. Has the cost-effectiveness of the study design been examined?
15. Have the data requirements been summarised?

Source: ANZECC and ARMCANZ (2000)

Reference and control sites

The design of the monitoring program should include sampling at reference and control sites. These sites are used to characterise the before and after condition of the wetland.

Reference sites are places that have not been subject to degradation. They approximate the condition that is being aimed for at the restored wetland.

Control sites are places that are in similar condition to the unrestored wetland and where no rehabilitation work will take place.

For a wetland to be considered rehabilitated it should change to become similar to the reference sites and different from the control sites.

It is preferable to have at least two reference and two control sites so that any differences can confidently be attributed to the rehabilitation actions rather than to natural variability. Control and reference sites should be located so that they will experience the same natural processes (tides, wind, floods etc.) or stresses as the wetland to be restored, and should be free of any human impacts that are not present at the rehabilitation site.

Depending on the size of the project site it may be possible to find suitable reference or control sites within the same wetland. For example, one side of a tidal channel may be in good condition (and can therefore represent the reference condition), while the opposite side of the channel is the site to be restored. Alternatively, there may be a section of the wetland that may not be able to be rehabilitated (for example, owing to the continuing presence of a structure), and this may then act as a control site against which to compare the rehabilitated part of the wetland.

Parameters to measure

Parameters measured as part of a monitoring program can be physical, chemical, biological or social. There are two main types of data that can be collected by monitoring programs: quantitative and qualitative.

Quantitative data

Quantitative data refers to data collected in an exacting and measurable manner. As the name implies, the emphasis of this method is to rigorously quantify the data so that an exact measure of change can be estimated. The assumption is that anybody repeating the study or using the same instruments and methods would get comparable results. Monitoring of parameters such as water or soil chemistry usually involves quantitative methods.

Qualitative data

Qualitative data refers to data that is collected in a less exacting, more subjective manner. The data collected by these methods is indicative, meaning it will indicate a change but not by a precise degree. The use of photo monitoring points or survey results from recreational users would be considered a qualitative method of data collection.

The parameters that need to be measured must relate to the objectives and performance criteria selected for the project. It is important to ensure that information collected on wetland performance can be and is related to wetland operation. This will then enable subsequent review of operational procedures. Once you have defined a possible list of parameters to monitor, ask these simple questions as you consider each one:

- *What am I monitoring?* Be specific, for example, percentage vegetation cover, not just vegetation.
- *Why am I monitoring this?* How does it relate to the project objectives?

- *How am I going to monitor this?* Is the method qualitative or quantitative? Is there a better method?
- *What will this tell me?* Is the data going to provide a clear indication of change?

Some of the common parameters that may be included in wetland monitoring programs are listed in Table 6.1 (overleaf; adapted from Laegdsgaard 2003). Again, the parameters you choose will depend on the specific objectives to be achieved at your site. For example, monitoring changes in elevation through surveying is unnecessary if your project is weeding and revegetation, but it will be critical where channel works or tidal alterations are proposed.

Photo monitoring

One of the easiest ways to document changes in a wetland is to establish permanent photo points that can be revisited on a regular basis. The following guidelines will ensure that you get the best results from a photo monitoring program (modified from Tucker 2004):

- Try to use a relatively high vantage point (for example, fallen log or step ladder) so you can continue the photograph series if vegetation begins to grow.
- To provide perspective, include the sky line in each photograph, and make use of features such as fallen logs, dead trees or rocks.
- Consider using a range pole at a set distance from where you are standing to provide your photograph with a measure of relative height.
- Ensure that you are able to locate the photo point at a later date by accurately recording the site location (using GPS, a sketch map or other detailed description).
- Consider using permanent posts (star pickets or wooden survey pegs) to mark the location if there are no other significant features to use for reference.
- Use a compass to record the bearing (direction) of each photograph to ensure that the same frame is taken repeatedly each time you return.
- Take a copy of the previous series of photographs into the field with you to assist with reproducing the exact view (amount of sky, location of prominent features and amount of zoom used).

Inspections

Inspections are required to check that all components within the wetland are operating appropriately, to check for any damage, and to check for any unanticipated changes. Make inspections on a predetermined regular basis and following specific events, such as storms and floods, large spring tides or large community functions on adjacent land.

An inspection checklist should list the inspections required, listing:

- the component to be inspected
- the required frequency of inspection
- the date of inspection
- the result of the inspection
- the action taken
- additional follow-up required.

The checklist can be kept as a record of operation and maintenance activities and used as a basis for quality assurance to verify that activities are being undertaken in accordance with the operation and maintenance plan.

Table 6.1 Parameters that could be included in wetland monitoring programs

Information sought	Measurements	Methods
Changes in elevation of the study site	Land levels	Surveying of transects
Changes to water level	Water levels	Water level recorder
Changes to area of inundation	Area inundated	Land survey
Concentrations of nutrients available for plant growth	Total nitrogen and phosphorus in water and sediments	Laboratory analysis
Changes in organic content of sediments	Percentage total organic content of sediments	Laboratory analysis
Salinity of the environment with respect to plant zonation	Soil salinity	Field measurements of soil pore water
Temperature range of the water	Water temperature	Field measurements with a water quality instrument
Salinity range of the water	Water salinity	As above
Dissolved oxygen range of the water	Dissolved oxygen	As above
Amount of waterborne sediment arriving at the site	Turbidity	As above
Change in vegetation cover over time	Percentage cover of vegetation	Field measurements using quadrats or transects
Change in vegetation composition over time	Species composition of vegetation	As above
Mangrove incursion	Recording mangrove seeds and seedlings	Field measurements of number and height of seedlings Air photo monitoring
Changes in the diversity and abundance of molluscs	Density and species composition of molluscs	Field measurements in 1 m^2 quadrats
Changes in the diversity and abundance of crabs	Abundance of crab holes	Field measurements in 1 m^2 quadrats
Changes in the diversity and abundance of insects and spiders	Density and species composition of insects and spiders	Sweep netting Laboratory sorting and identification of insects and spiders

Information sought	Measurements	Methods
Changes in the benthic invertebrate fauna over time	Composition of benthic invertebrate fauna	Core samples (in conjunction with total organic carbon samples) Laboratory sorting and identification
Use of the wetland by fish	Composition of fish fauna	Fish traps, dip-netting or seine netting Field or laboratory sorting and identification
Use of the wetland by waterbirds	Composition of waterbirds and waders	Observations of numbers and composition of waterbirds (early morning or dusk)
Use of the wetland by surrounding residents	Visitation	Survey of local residents Visitor counts

Field measurements of plant distribution using small quadrats (Koorangang Wetland Rehabilitation Project)

Collection of fish from a seine net (Koorangang Wetland Rehabilitation Project)

How long and how often should we monitor?

Monitoring can be a very intensive task that is often underestimated in preliminary project plans and budgets. Insufficient monitoring and poorly designed monitoring programs make it impossible to gauge the true impact of management actions. Ideally, the more information that can be gathered over a given time frame, the better the data set will be and the easier it will be to establish clear patterns in the data. Monitoring needs to occur more frequently in the early stages of a rehabilitation project while rapid changes are occurring (perhaps monthly or bi-monthly), while seasonal or biannual sampling will usually be sufficient after a few years.

Since it is easier to measure structure than function, it is necessary to have clear links between the two. In this way, measurements of structure can be used to provide useful information on function. Monitoring must continue even after the wetland structure looks right to ensure that proper functioning of the wetland has also been restored. Examples from rehabilitation projects at Homebush Bay show that this is not always the case (discussed in greater detail in Section 6.4).

Full wetland functionality may not return for many years, or may never return. Long-term documentation of saltmarsh recovery in North Carolina (USA) showed that although vegetation may quickly compare to reference sites, it can take 15–25 years for benthic fauna to become similar in composition and abundance to that at reference sites. Soil attributes were the slowest to match reference sites and were still dissimilar after 26 years (Craft *et al.* 1999). Other studies have confirmed that soil attributes are the slowest to recover after rehabilitation works (Table 6.2).

There is general consensus within the literature that saltmarsh vegetation often recolonises within 4 to 6 years (Table 6.2), but it may not fully resemble the natural reference sites for at least 20 years (Williams and Orr 2002, Warren *et al.* 2002, Morgan and Short 2002).

If left to recover under natural conditions, local saltmarsh species can vary in recovery from a few years up to 10 years depending on the type of impact. *Sarcocornia* sp. saltmarsh at Kooragang Island, near Newcastle, took at least 5 years to recover naturally following cattle exclusion, while experiments by Laegdsgaard (2002) have shown that recovery of this species may be as quick as 2 years on the lowest parts of the shoreline.

Studies of natural saltmarsh recovery in Connecticut (USA) have shown that certain types of benthic fauna such as snails may return relatively early (within 5 years), yet full recovery of other species may take up to 20 years (Warren *et al.* 2002). Similarly, while a typical fish species assemblage may return within 5 years, it can take much longer for the population size to be similar to that at reference sites.

In the context of the above examples, an initial monitoring plan should aim to collect data for at least 5 years after the rehabilitation works have been implemented. At this time the monitoring program can be reviewed, and a less intensive, longer-term sampling program can be designed. Although water quality and vegetation objectives may be achieved within a 5-year time frame, it is likely that faunal populations and soil properties will still be evolving in response to the management actions. A continuing program of monitoring is therefore required if the objectives are to continue to be assessed.

Table 6.2 Observed wetland recovery times

Wetland component	Recovery time	References
Saltmarsh vegetation	4–6 years for initial recovery	Broome *et al.* 1988
(general)	Up to 20 years for full recovery	Frenkel and Morlan 1990 Simenstad and Thom 1996 Boumans *et al.* 2002 Eertman *et al.* 2002 Thom *et al.* 2002 Williams and Orr 2002 Craft and Sacco 2003
Salt couch (*Sporobolus virginicus*)	5–6 years	Laegdsgaard 2002
Samphire (*Sarcocornia quinqueflora*)	4–5 years on upper shore 2 years on lower shore	Laegdsgaard 2002
Benthic fauna	15–25 years (re-creation sites) 9–21 years (natural recovery sites)	Craft *et al.* 1999
	5–15 years	Warren *et al.* 2002 Craft and Sacco 2003
Waterbirds	15 years for saltmarsh specialists	Warren *et al.* 2002
Fish	5–15 years	Warren *et al.* 2002
Soils	> 25 years	Seneca *et al.* 1976 Havens *et al.* 1995 Craft *et al.* 1999 Havens *et al.* 2002 Craft and Sacco 2003

6.2 Data storage, analysis and reporting

The storage, analysis and reporting of monitoring data are all important if meaningful information is to be obtained.

Data storage

Data may be stored in a variety of forms, including hard copies of field and laboratory notes and computer spreadsheets and databases. Organise field sheets and laboratory records in a folder or filing system. Retain the data sheets even when the data has been transferred to computer in the event of computer failures or errors in data entry.

Spreadsheets are an appropriate form of data storage for the manipulation of small data sets, calculation of simple summary statistics, and presentation of data in basic graphical formats.

Data should be stored in databases, which can sort and present data according to specific criteria. This can be useful for generating reports on various parameters and sites over time. Data sets can be exported into statistical packages for detailed analysis and presentation of data. Spatial data, such as that collected using GPS (Section 3.2) should be stored in databases compatible with the GIS to be used.

Data analysis

Data analysis can range from simple observations of trends to very complicated statistical and mapping techniques. Graphical analysis of data can reveal a wealth of information and should always be the first step in any analysis. Graphs are a simple and important way to check by simple observation that the statistical analyses undertaken match what the data is telling you. In many cases it is sufficient to draw conclusions from graphs that depict clear trends, unless a measure of statistical significance is being sought.

There are many statistical methods available to analyse data. Simple statistics are often the best and can be most easily interpreted by a range of people. Often the significance of data can be tested. There are many statistical software programs available to assist with data analysis, so that intimate knowledge of the maths behind the analyses is not required. However, it is important to understand the analyses you are doing and what information they provide about the data to ensure that you are interpreting the results correctly.

Table 6.3 (overleaf) summarises statistical analyses that could be useful in a wetland monitoring program (Laegdsgaard 2003).

Reporting

It is important to include in the design of the rehabilitation plan measures for reporting progress and outcomes, so that others can learn from the experience. This applies even if the project is unsuccessful.

Compile all data gathered and analysed as part of a monitoring program into regular progress reports. These should detail the results of the sampling and the interpretation of the results in relation to each monitoring event and any previous monitoring events. Progress reports would typically be produced each year, with a major report prepared after 3 to 5 years of data collection. By this time it should be possible to draw some conclusions about the recovery of the site with respect to natural variation and seasonality. The major report should include full analyses of the data and interpretation of the results. At this time it should then be possible to evaluate future data collection and any adjustments that may be required to sampling methods or frequency.

People interested in the results of your project may include:

- community and conservation groups
- the scientific community
- the local council
- local businesses
- regional, State and Commonwealth natural resource management agencies.

Table 6.3 Statistical analyses that could be applied in wetland monitoring

Parameter	Appropriate analyses relating to each monitoring event	Appropriate analyses relating to whole data set over time
Changes in any of the individual parameters among sites	Analysis of variance (ANOVA)	Repeated-measures ANOVA
Relationship between water quality parameters or sediment parameters to biotic factors	Correlations and regressions	Correlations and regressions
Differences in faunal or vegetation communities among sites	Numerical classifications Ordination Multivariate analysis of variance (MANOVA)	Numerical classifications Ordination Repeated-measures MANOVA

Consider which format is most appropriate for delivering the project results. Newsletters and brochures are easily digested and understood by the local community and school children, but detailed reports may be of more interest to local council and government agencies. Websites and CDs are increasingly popular and cost-effective methods of providing access to information for a wide range of people.

6.3 Adaptive management

Often when you are implementing a management plan and assessing the performance of outcomes, it becomes clear that certain actions did not achieve their objectives. To accomplish these objectives it may be necessary to review the actions being implemented and to change them somewhat. This process is known as adaptive management. Adaptive management can be achieved by assessing and reviewing the performance of a management plan at a site and its control locations and then altering the plan. It can also be achieved by reviewing a management plan based on experience gained at other sites.

A key part of adaptive management is the monitoring of performance indicators, including regular inspection of how specific wetland components and regulating works are operating or performing, so that any necessary maintenance action or changes to operating strategies can be made.

6.4 Monitoring and reporting as a contribution to research

With the current state of saltwater wetland knowledge, rehabilitation projects should be considered as experiments. Whether the project is ultimately successful in its aims or not, the knowledge gained through a well-thought-out monitoring program will help in improving future rehabilitation projects.

Examples can be seen at the restoration works undertaken by the Sydney Olympic Park Authority at Homebush Bay in Sydney (Barnes and Chapman 2001, Lindegarth *et al.* 1999, Lindegarth and Chapman 2001).

Example 1: Restoring tidal flushing to mangroves

Large areas of mangroves at Newington, on the southern shore of the Parramatta River, have been destroyed or seriously degraded. To increase the ecological health of the remaining mangrove wetlands, the Sydney Olympic Park Authority constructed a channel from the Parramatta River into the wetlands. The aim of the channel was to restore tidal flushing and natural drainage. Previous studies showed that the numbers and types of benthic invertebrates found in naturally flushed and drained mangrove forests in Sydney Harbour were very different from those in forests with reduced tidal flushing such as that at Newington.

To assess changes in the benthic fauna in response to the improved tidal flushing, replicate sites were sampled twice before and four times after the construction of the channel. Samples were also taken from two nearby reference sites. The sampling showed no evidence that the new tidal conditions had restored benthic fauna to what might be expected under more natural conditions. Possible reasons for this may be that:

- there may not have been enough time for change to occur
- the muddy floor of the mangroves (which varies from that at the reference sites) may not be suitable habitat
- the artificial channel may be preventing or restricting the arrival of **planktonic** larvae into the mangroves
- the new regime of tidal flushing may still be different from that at the reference sites and may not be suitable for animals to recolonise or survive in.

The moral of the story

The results illustrate the importance of testing the success or otherwise of management strategies with well-designed biological monitoring. This example highlights the fact that while a wetland may look to be rehabilitated (because tidal flushing is restored), its biological functioning may not have been restored. This may be because wetlands evolve slowly over time and more time is needed, or because some other limiting factor prevents full function from being restored. Without such monitoring it would be difficult to know whether the rehabilitation had truly been successful, and the value of spending large amounts of money on constructing future channels would be unknown. Continuing monitoring and research into reasons for the lack of success will allow the Sydney Olympic Park Authority to make more informed decisions regarding the conservation and maintenance of the Newington mangroves.

Example 2: Providing habitat for Japanese snipe

Another project at Homebush Bay aims to create new habitat for the the Japanese snipe (or Latham's snipe, *Gallinago hardwickii*), a wading bird. The project involves large-scale modification of freshwater levels to create areas along the edge of a marsh where the birds will be able to feed. Benthic fauna in the sediments fringing the marsh are thought to be a food source for the birds. For modifications to be successful it is therefore necessary that the areas drained during the experiment provide sufficient prey for the birds. Monitoring the abundance of animals is required in order to test whether modifications are successful.

Monitoring involved measurement of changes at two sites within the manipulated pond and at one site in a nearby control pond (where water level was not manipulated).

The results of the experiment were contrary to the initial predictions, that is, draining of the wetland area reduced the abundance and diversity of benthic fauna. At the conclusion of the sampling program, very few benthic animals were left that were suitable as food for Japanese snipe. The abundance and diversity of animals at reference sites, however, had increased or remained similar.

The moral of the story

Testing hypotheses about the effects of rehabilitation actions is important and should be planned before the initiation of large-scale projects. Pilot studies may need to be undertaken to assess whether success is likely before large amounts of time and money are invested. When biological monitoring is undertaken, appropriate spatial replication is required in order to take into account natural variability in animal abundances. Otherwise differences between control sites and the project site may be difficult to interpret. As with the mangrove example, monitoring must focus on function as well as structure. In this case, monitoring was able to clearly show that the predicted results did not occur. These results contribute to the current state of knowledge about wetland rehabilitation and will allow future projects to learn from the experience.

References for Parts 1 and 2

Chapter 1

Bell JD, Pollard DA. 1989. Ecology of fish assemblages and fisheries associated with seagrasses. In: Larkum AWD, McComb AJ, Shepherd SA, eds. *Biology of Seagrasses*, 565–597. Elsevier, Amsterdam.

Bennett J, Whitten S, Handley M, Moss W, Phillips B. 2001. *Wetland Management Assistance for Private Landholders*. Environment Australia, Canberra.

Bowen R, Stephens N, Donnelly P. 1995. SEPP 14 — wetland protection and the role of mitigation. *Wetlands (Australia)* 14: 6–12.

DLWC. 1998. *The Constructed Wetlands Manual*, vols 1 and 2. NSW Department of Land and Water Conservation, Sydney.

Environment Australia. 2001. *A Directory of Important Wetlands in Australia*, 3rd edn. Environment Australia, Canberra.

Merrin J, Chafer C. 2000. *Illawarra Wetlands Action Plan*. Illawarra Catchment Management Committee, Wollongong.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Wetland and Water Synthesis*. World Resources Institute, Washington DC.

Morrisey D. 1995. Saltmarshes. In: Underwood AJ, Chapman MG, eds. *Coastal and Marine Ecology of Temperate Australia*, 205–220. UNSW Press, Sydney.

NSW Fisheries. 1999. *Policy and Guidelines Aquatic Habitat Management and Fish Conservation* (Smith AK, Pollard DA, eds). NSW Fisheries, Port Stephens.

Ramsar Convention on Wetlands. 2002. *Principles and Guidelines for Wetland Restoration* (resolution VIII.16). http://www.ramsar.org/key_guide_restoration_e.htm. Accessed 9 July, 2007.

Smith AK, Holliday JE, Pollard DA. 1997. Management of seagrass habitats in NSW estuaries. *Wetlands (Australia)* 16(2): 48–55.

Stricker J. 1995. Reviving wetlands. *Wetlands (Australia)* 14: 20–25.

US EPA. 2000. *Principles for the Ecological Restoration of Aquatic Resources*. EPA841-F-00-003. Office of Water (4501F), United States Environmental Protection Agency, Washington DC.

Chapter 2

Bergkamp G, Orlando B. 1999. *Wetlands and Climate Change — Exploring collaboration between the Convention on Wetlands (Ramsar, Iran, 1971) and the UN Framework Convention on Climate Change*. IUCN Background Paper for Ramsar Convention on Wetlands. IUCN, Gland, Switzerland.

Kusler J, Burkett V. 1999. Climate change in wetland areas. Part I: Potential wetland impacts and interactions. *Acclimations* May–June 1999. Newsletter of the US National Assessment of the Potential Consequences of Climate Variability and Change.

Department of Planning 2007 *Protecting our Coast: The Comprehensive Coastal Assessment Toolkit*. State of NSW through the Department of Planning, Sydney.

Chapter 3

Carson L, Gelber K. 2001. *Ideas for Community Consultation. A Discussion on Principles and Procedures for Making Consultation Work.* Prepared for NSW Department of Urban Affairs and Planning, February 2001. DUAP, Sydney.

DLWC. 1998. *The Constructed Wetlands Manual*, vols 1 and 2. NSW Department of Land and Water Conservation, Sydney.

Wetland Care Australia. 2006. *Sustainable Wetlands on NSW Coastal Landscapes*. Report prepared for Northern Rivers and Hunter Central Rivers Catchment Management Authorities, Wetland Care Australia, Ballina.

Chapter 4

Dale P. 2005. Longterm impacts of runnelling on an intertidal saltmarsh. *Arbovirus Res in Aust* 9: 80–85.

Dale PER, Chandica AL, Evans M. 1996. Using image subtraction and classification to evaluate change in subtropical intertidal wetlands. *International Journal of Remote Sensing* 17: 703–719.

Dale MB, Dale PER, Li C, Biswas G. 2002. Assessing impacts of small perturbations using a model-based approach. *Ecological Modelling* 156: 185–199.

DLWC. 1998. *The Constructed Wetlands Manual*, vols 1 and 2. NSW Department of Land and Water Conservation, Sydney.

Johnston S, Kroon F, Slavich P, Cibilic A, Bruce A. 2003. *Restoring the Balance: Guidelines for Managing Floodgates and Drainage Systems on Coastal Floodplains.* NSW Agriculture, Wollongbar, NSW. Available at www.dpi.nsw.gov.au/reader/floodgate-guidelines.

Hart BT. 1982. *Australian Water Quality Criteria for Heavy Metals Water.* Technical Paper, Studies Centre, Chisholm Institute of Technology, Australian Water Resources Council. Australian Government Publishing Service, Canberra.

Hulsman K, Dale P, Kay B. 1989. The runnelling method of habitat modification: an environment focussed tool for saltmarsh management. *Journal of the American Mosquito Control Association* 5: 226–234.

Landcom. 2004. *Managing Urban Stormwater — Soils and Construction*, 4th edn. Landcom, Parramatta.

Naylor SD, Chapman GA, Atkinson G, Murphy CL, Tulau MJ, Flewin TC, Milford HB, Morand DT. 1998. *Guidelines for the Use of Acid Sulfate Soil Risk Maps*, 2nd edn. Department of Land and Water Conservation, Sydney.

Resource NSW. 2003. *NSW Waste Avoidance and Resource Recovery Strategy*. Resource NSW, Parramatta.

Russell RC. 1994. Mosquito-borne arboviruses in Australia: the current scene and implications of climate change for human health. *International Journal for Parasitology* 28: 955–969.

Smith P. 1991. *The Biology and Management of Waders (suborder Charadrii) in NSW*. NSW National Parks and Wildlife Service, Sydney.

Stone Y, Ahern CR, Blunden B. 1998. *Acid Sulfate Soils Manual*. ASSMAC, NSW Agriculture, Wollongbar, NSW.

Tulau MJ. 2008. *Acid Sulfate Soils Remediation Guidelines for Coastal Floodplains in New South Wales*. NSW Department of Environment and Climate Change, Sydney.

Turner PA, Streever WJ. 1997. The relationship between the density of *Aedes vigilax* (Diptera, Culicidae) eggshells and environmental factors on Kooragang Island, New South Wales, Australia. *Journal of the American Mosquito Control Association* 13(4): 361–367.

Webb CE, Russell RC. 2006. Mosquito management and legislation in NSW. In: *Wetland Legislations: Where and How to Apply Them*. Wetland Education and Training Program, 21–22 September 2006, Sydney Olympic Park.

Williams R, Watford FA. 1997. Identification of structures restricting tidal flow in New South Wales. *Wetlands Ecology and Management* 5: 87–97.

Chapter 5

Adam P. 1981. Australian saltmarshes. *Wetlands (Australia)* 1: 8–10.

Adam P, Hutchings P. 1987. The saltmarshes and mangroves of Jervis Bay. *Wetlands (Australia)* 6(2): 58–64.

Burrows DW. 2003. The role of insect leaf herbivory on the mangroves *Avicennia marina* and *Rhizophora stylosa*. PhD dissertation, School of Tropical Biology, James Cook University, Townsville, Queensland.

DLWC. 1998. *The Constructed Wetlands Manual*, vols 1 and 2. NSW Department of Land and Water Conservation, Sydney.

DPI (Victoria). 2003. *An Illustrated Checklist of Freshwater Fishes of Victoria*. Fisheries Note FN0019. Department of Primary Industries, Melbourne.

Hedge P, Kriwoken LK. 2000. Evidence for effects of *Spartina anglica* invasion on benthic macrofauna in Little Swanport estuary, Tasmania. *Austral Ecology* 25: 150–159.

Milford HB, Simons N. 2002. *The Salinity Soil Data Card. Supplement 1 to the 3rd edition of the Soil Data Entry Handbook*. NSW Department of Land and Water Conservation, Sydney.

Morgan LA, Buttermer WA. 1996. Predation by the non-native fish *Gambusia holbrooki* on small *Litoria aurea* and *L. dentata* tadpoles. *Australian Journal of Zoology* 30: 143–149.

NAWC. 2003. *Noxious weeds list for Australian States and Territories*. National Australian Weeds Committee, Canberra.

Paul S, Young R. 2006. Experimental control of exotic spiny rush, *Juncus acutus*, from Sydney Olympic Park: I. *Juncus* mortality and re-growth. *Wetlands (Australia)* 23(2): 1–12.

Simpson J. 1995. Wading birds of Anderson Inlet and the work of the Victorian Wader Study Group. In: Rash JE, Williamson JS, Taylor JS, eds. *Proceedings of the Australas Conference on Spartina control.* Victorian Government, Melbourne.

University of Sydney and Westmead Hospital, Department of Medical Entomology. 1998. *Mosquito Management for Wetlands – Saline*. http://medent.usyd.edu.au/fact/saltwet.htm. Accessed 9 July 2007.

Wood EJF. 1959. Some aspects of the ecology of Lake Macquarie NSW with regard to an alleged depletion of fish. *Australian Journal of Marine and Freshwater Research* 10: 322–340.

Chapter 6

ANZECC, ARMCANZ. 2000. *Australian Guidelines for Water Quality Monitoring and Reporting*. Australian and New Zealand Environment Conservation Council, Canberra.

Barnes PB, Chapman MG. 2001. *Changes to Benthic Fauna in the Newington Mangroves in Response to Restoration of Tidal Flushing.* Final Report to the Olympic Co-ordination Authority. University of Sydney, Centre for Ecological Impacts of Coastal Cities.

Boumans RMJ, Burdick DM, Dionne M. 2002. Modeling habitat change in saltmarshes after tidal restoration. *Restoration Ecology* 10(3): 543–555.

Broome SW, Seneca ED, Woodhouse WW Jr. 1988. Tidal saltmarsh restoration. *Aquatic Botany* 32: 1–22.

Chapman MG, Underwood AJ. 2000. The need for a practical scientific protocol to measure successful restoration. *Wetlands (Australia)* 19(1): 28–59.

Craft C, Reader J, Sacco JN, Broome SW. 1999. Twenty-five years of ecosystem development of constructed *Spartina alterniflora* (Loisel) marshes. *Ecological Applications* 9(4): 1405–1419.

Craft C, Sacco JN. 2003. Long-term succession of benthic infauna communities on constructed *Spartina alterniflora* marshes. *Marine Ecology Progress Series* 257: 45–58.

Eertman RHM, Kornman BA, Stikvoort E, Verbeek H. 2002. Restoration of the Sieperda tidal marsh in the Scheldt Estuary, The Netherlands. *Restoration Ecology* 10(3): 438–449.

Finlayson CM, Mitchell DS. 1999. Australian wetlands: the monitoring challenge. *Wetlands Ecology and Management* 7: 105–112.

Frenkel RE, Morlan JC. 1990. *Restoration of the Salmon River Saltmarshes: Retrospect and Prospect*. Final Report to the US EPA (Region 10), 143 pp. US EPA, Washington DC.

Grayson JE, Chapman MG, Underwood AJ. 1999. The assessment of restoration of habitat in urban wetlands. *Landscape and Urban Planning* 43: 227–236.

Havens KJ, Varnell LM, Bradshaw JG. 1995. An assessment of ecological conditions in a constructed tidal marsh and two natural reference tidal marshes in coastal Virginia. *Ecological Engineering* 4: 117–141.

Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. *Ecological Engineering* 18: 305–315.

Hellawell JM. 1991. Development of a rational for monitoring. In: Goldsmith FB, ed. *Monitoring for Conservation and Ecology*. Chapman and Hall, London.

Laegdsgaard P. 2002. Recovery of small denuded patches of the dominant NSW coastal saltmarsh species (*Sporobolus virginicus* and *Sarcocornia quinqueflora*) and implications for restoration using donor sites. *Ecological Management and Restoration* 3(3): 200–204.

Laegdsgaard P. 2003. *A Guide to Monitoring a Created Wetland at Kooragang Island*. NSW Department of Land and Water Conservation, Sydney.

Legg CL, Nagy L. 2006. Why most conservation monitoring is, but need not be, a waste of time. *Journal of Environmental Management* 78: 194–199.

Lindegarth M, Chapman MG. 2001. Testing hypotheses about management to enhance habitat for feeding birds in a freshwater wetland. *Journal of Environmental Management* 62: 375–388.

Lindegarth M, Barnes PB, Chapman MG. 1999. *Changes to benthic fauna in Wharf Marsh in response to water drainage to provide habitat for the Japanese Snipe* (Gallinago hardwickii). Final report to Olympic Co-ordination Authority. University of Sydney, Centre for Research on Ecological Impacts of Coastal Cities.

McGloin E, Botting S. 2005. *Establishment of a Monitoring and Evaluation Framework for the Hunter–Central Rivers Catchment Management Authority*. NSW Department of Natural Resources, Hunter Region, Newcastle.

Morgan PA, Short FT. 2002. Using functional trajectories to track constructed saltmarsh development in the Great Bay estuary, Maine/New Hampshire, USA. *Restoration Ecology* 10: 461–473.

Rutherford ID, Jerie K, Marsh N. 2000. *A Rehabilitation Manual for Australian Streams*, vol. 1. CRC for Catchment Hydrology, Monash University, Melbourne.

Seneca EDSW, Broome WW, Woodhouse LM, Cammen, Lyon JT. 1976. Establishing *Spartina alterniflora* marsh in North Carolina. *Environmental Conservation* 3: 185–188.

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. *Ecology Applications* 6: 38–56.

Thom RM, Ziegler R, Borde AM. 2002. Floristic development patterns in a restored Elk River estuarine marsh, Grays Harbour, Washington. *Restoration Ecology* 10: 487–496.

Tucker P. 2004. *Your Wetland: Monitoring Manual — Data Collection*. River Murray Catchment Water Management Board, Berri, and Australian Landscape Trust, Renmark, SA.

Ward T, Butler E, Hill B. 1998. *Environmental Indicators for National State of the Environment reporting — Estuaries and the Sea*. Australia: State of the Environment (Environmental Indicator Reports). Department of the Environment, Canberra.

Warren RS, Fell PE, Rozsa R, Brawley AH, Orsted AC, Olsen ET, Swamy V, Niering WA. 2002. Saltmarsh restoration in Connecticut: 20 Years of science and management. *Restoration Ecology* 10(3): 497–513.

Williams PB, Orr MK. 2002. Physical evolution of restored breached levee saltmarshes in the San Francisco Bay estuary. *Restoration Ecology* 10(3): 527–542.

Glossary

advective: The horizontal movement of water, as in an ocean current.

aeolian: A geomorphic process whereby soil-forming material is transported and deposited by wind.

aerobic: A state where free oxygen (O_2) is available.

anaerobic: A state where no oxygen is available.

AHD: Australian Height Datum; the single reference point to relate all vertical measurements throughout Australia. AHD is based on the Mean Sea Level.

anoxic: A metabolic state where there is no free oxygen, but molecularly bound oxygen is still available.

ANZECC and ARMCANZ: Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

ASS: acid sulfate soil.

***Australian Soil Classification* (Isbell 1996):** This classification scheme operates using a hierarchical system and is based on Australian soils data that is significant with regard to land management. The general form of the nomenclature is: Subgroup, Great Group, Suborder, Order; family (for example, Bleached, Eutrophic, Red Chromosol; thick, sandy).

background level: Level of substance commonly found in the local environment.

bathymetry: the measurement of water depth at various places in a body of water.

baseline: A datum used as the basis for calculation or comparison.

benthic: Bottom-dwelling, that is, on a wetland substrate.

bioaccumulation: Process in which substances are accumulated by organisms, for example through consumption of food containing the substance.

biodegradation: Decomposition of biological substances into more elementary compounds by the action of microorganisms.

biofilm: Organic matrix supported by substrates which contains an often diverse and abundant microfauna and microflora.

biogeochemical: The chemical, physical, geological and biological processes and reactions that govern the composition of the natural environment.

biological oxygen demand: The demand for oxygen, measured as the concentration of biodegradable organic matter present in a sample.

biota: The sum total of the living organisms of any designated area.

CAMBA: China–Australia Migratory Birds Agreement (1986).

cation exchange capacity (CEC): A general indicator of soil storage capacity for available, positively charged plant nutrients such as Ca, Mg, K and NH_4. Generally determined by the amount and type of clay and the amount of organic matter.

cultural value: Value determined by sites, places, artefacts or memories that are meaningful to contemporary society or parts of society; for example, sites showing material evidence of past Aboriginal occupation.

DECC: NSW Department of Environment and Climate Change.

dendritic: With the branching shape characteristic of a tree.

design life: The period of time during which an item is expected by its designers to work within its specified parameters.

design storm: A storm with a given amount of rainfall and distribution over a particular drainage area.

detritus: All non-living organic material, including animal waste products and the remains of animals, plants and microorganisms, together with the associated microbial community (bacteria and fungi).

dispersive: Tending to separate and move apart.

dissolved oxygen: The gaseous oxygen (O_2) that is dissolved in water and available for organisms to use.

DPI: NSW Department of Primary Industries.

DWE: NSW Department of Water and Energy.

EIS: Environmental Impact Statement.

emergent: Form of an aquatic plant that is rooted in the sediment and extends its leaves into the air.

epiphytic: Form of a plant that grows on another plant upon which it depends for mechanical support but not for nutrients.

euryhaline: Able to live within of a wide range of salinity.

eutrophication: Enrichment of a water body by nutrients which can lead to excessive algal growth or other water quality problems.

evapotranspiration: The process of transferring moisture from the earth to the atmosphere by the evaporation of water and transpiration from plants.

fluvial: Of, relating to, or inhabiting a river or stream or produced by the action of a river or stream.

geographic information system (GIS): A computer system used for capturing, storing, checking, integrating, manipulating, analysing and displaying data related to positions on the Earth's surface.

geomorphology: The study of landforms and the processes that shape them.

global Positioning System (GPS): A navigation system for determining position on the Earth's surface by comparing radio signals from several satellites.

great Soil Group: A soil classification system developed by Stace *et al.* (1968). It is based on the description of soil properties such as colour, texture, structure, drainage, lime, iron, organic matter and salt accumulation, as well as on theories of soil formation.

hydrogeologist: A geologist who deals with the occurrence, distribution and effects of groundwater.

hydrological cycle: The continuous circulation of water within the Earth's hydrosphere driven by solar radiation. This includes the atmosphere, land, surface water and groundwater. As water moves through the cycle, it changes state between liquid, solid and gas phases.

hydrology: Study of the movement, distribution and quality of water throughout the earth.

intertidal: Those areas of land covered by water at high tide but exposed at low tide. This is the interface between the aquatic and terrestrial environments.

introduced species: Plant or animal species that has been introduced by humans, deliberately or accidentally, to a place where the organism is not native to.

invertebrate: Animal without a backbone.

JAMBA: Japan–Australia Migratory Birds Agreement (1974).

jarosite: A hydrous sulfate of potassium and iron. Jarosite mottles (yellow streaks and mottles around old root channels) are a positive indicator of acid sulfate soils. Jarosite can form as an intermediate mineral during the chemical reaction, which results in sulfuric acid.

king tide: Highest of the spring tides.

leachate: A liquid produced when water percolates or drains through material. It may contain dissolved or particulate material.

microphytobenthos: Community of bottom-dwelling microscopic diatoms and cyanobacteria.

monospecific: Relating to or made up of the one species.

neap tide: Tide with the smallest range in a monthly cycle.

nutrient: Substance that provides nourishment to biota.

oxidation: The combination of oxygen with a substance.

pathogen: Organism capable of causing disease in another organism.

pedologic: Relating to soil formation, soil morphology and soil classification.

permeability: Measure of the degree to which water or air can enter a soil.

photosynthesis: The conversion of carbon dioxide and water to carbohydrates in the presence of chlorophyll by light energy, undertaken by most plants.

piezometer: A small-diameter water well used to the measure the top of groundwater in aquifers.

plankton: Plants (phytoplankton) and animals (zooplankton), usually microscopic, suspended in water systems.

propagule: Seed, bulb or other organ by which a plant propagates itself.

riparian: Pertaining to rivers and streams.

ripening: Whereby a freshly deposited mud is transformed to a dryland soil. Physical ripening essentially involves an irreversible loss of water (drying out).

risk: A statistical concept defined as the expected frequency or probability of undesirable effects resulting from a specified exposure to known or potential hazards.

RoKAMBA: Republic of Korea–Australia Migratory Birds Agreement (2006).

saturated hydraulic conductivity: A measure of how quickly water can move through soil when it is saturated.

sedimentation: The process in which settleable solids are removed from the water column by gravity.

semi-diurnal: Occurring approximately once every 12 h, as the tides.

sessile: Of organisms that are not able to move about. They are usually permanently attached to a solid substrate of some kind, such as a rock.

shrink–swell: A characteristic of soils that tends to make the clays within them expand on contact with water and shrink (and crack) when they dry.

sodicity: A measure of exchangeable sodium in the soil. High levels adversely affect soil stability, plant growth and land use.

spring tides: Tides with the largest range in a monthly cycle.

subtidal: Below the level of low tide.

submergent: An aquatic plant that is rooted in the sediment and grows entirely under the water.

tidal plane: Height of standard tide above a datum, usually Indian Spring Low Water.

total actual acidity: A simple measure of acidity within the soil. Includes free acid and acidity absorbed on the clay and organic matter, and in acid salts.

turbidity: Measure of the clarity of water on a colorimetric scale, generally relating to suspended material in water.

water table: The surface of a body of groundwater at which the pressure is atmospheric.