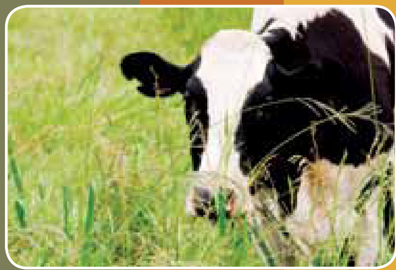
Wetland Management Handbook

Farm Management Systems (FMS) guidelines for managing wetlands in intensive agriculture



This technical report has been previously published by the Queensland Government. The technical information in this publication is still current, however it may contain references to former departmental names. Please refer to the Department of Agriculture, Fisheries and Forestry's website at www.daff.qld.gov.au for up-to-date contact details.

Australian Government

Queensland Wetlands Program

Queensland Government

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Farm Management Systems (FMS) guidelines for managing wetlands in intensive agriculture

Foreword

Whether it is an internationally recognised lake or a farm dam, most of Queensland's wetlands are on private property. This means farmers are among the most important managers of wetlands in the state. In the past it has been difficult to get good advice about what actually constitutes a wetland and how to best manage them within a farming context.

This handbook, developed as part of the Queensland Wetlands Program Improving Land Management in Agricultural Systems (Farm Management Systems) project, is a very useful resource for wetlands managers and extension officers. It offers comprehensive advice on how to identify wetlands, how to manage them and how to construct artificial wetlands. The handbook is designed to complement the Farm Management Systems developed by industry organisations within the Queensland Farmers' Federation.

The Queensland Farmers' Federation is proud to have been involved in the development of the handbook and would like to recognise the significant effort from Ian Layden in putting the handbook together.

Good farming practice and good wetlands management go hand-in-hand, and this handbook will greatly contribute to the better management of wetlands on private land.

Gary Sansom
President, Queensland Farmers' Federation

This is the final report for the Improving Land Management in Agricultural Systems (Farm Management Systems) (WL DPI 01) of the Queensland Wetlands Program, a joint initiative between the Australian and Queensland governments. The Queensland Wetlands Program was established in 2003 to protect and conserve Queensland's wetlands.

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Acknowledgments
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The Improving Land Management in Agricultural Systems (Farm Management Systems) Technical Review Panel consisted of John Bagshaw and Denis Hamilton (DEEDI), Peter Negus of the Queensland Government Department of Environment and Resource Management (DERM), Mike Ronan (DERM), Mark Bayley of WetlandCare Australia, Phil Trendell of BSES Limited and John Reghenzani of Terrain Natural Resource Management.

Contents

The Queensland Government is developing the *Reef Protection Package* to improve the quality of the waters entering the Great Barrier Reef Lagoon. The focus of the *Reef Protection Package* is to provide information and support to farmers on how to best manage their farming operations for improved water quality benefit, as well as regulating use of fertilisers and herbicides in the Wet Tropics, Burdekin Dry Tropics and Mackay Whitsunday catchment areas. While the information in this Handbook is provided according to current known best farm management practices, the Handbook will be updated to complement the *Reef Protection Package* when the package and its support tools are finalised.

List of tables

Purpose

This handbook contains information and guidelines to help producers protect the functions of Queensland's wetlands in intensive agricultural production systems. The handbook follows the Farm Management System (FMS) approach to managing agricultural businesses.

This handbook comprises four parts:

Part 1: Farm Management Systems (FMS)

- The FMS framework
- Using a risk assessment process to manage natural resources
- Wetland management and the FMS framework.

Part 2: Getting to know wetlands

- Defining wetlands and wetland values
- Wetland types and classifications
- Identifying wetlands using maps and field indicators
- Wetland functions and processes and their role in the landscape.

Part 3: Managing wetlands

- Why managing wetlands is important
- Catchment and farm services provided by wetlands
- Managing wetlands using FMS
- Best-practice options to managing agricultural impacts on wetlands.

Part 4: Wetland treatment systems and reinstatement

- Introduction to constructed wetland treatment systems
- Planning wetland construction
- Key treatment processes
- Constructed wetland components
- Calculating wetland sizes
- Vegetating a constructed wetland.

This handbook also identifies further information and resources to manage natural and constructed wetlands.

Queensland Wetlands Program

In 2003 the Australian and Queensland governments established the Queensland Wetlands Program. Its objective is to support projects that will result in long-term benefits to the sustainable use, management, conservation and protection of wetlands. With this objective in mind, the Program has funded projects such as the Improving Land Management in Agriculture (FMS) to improve wetland management in Queensland's wetlands. The full range of Queensland Wetlands Program resources and information is available online at Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

The Queensland Wetlands Program Improving Land Management in Agricultural (FMS) project has sought to improve wetland management throughout Queensland's intensive industries. The project was undertaken by the Queensland Government Department of Employment, Economic Development and Innovation (DEEDI) with Queensland Farmers' Federation (QFF) member organisations.

The project has also produced a series of five case studies highlighting successful wetland management integration into farm practices. These case studies are available online at Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

Queensland
Wetlands Program

Part 1: Farm Management Systems

What is a Farm Management System

The Queensland Farmers' Federation (QFF) describes Farm Management System (FMS) as various on-farm programs that help farmers better manage their business, natural resources and staff.

A FMS is a voluntary, structured, step-by-step approach to managing an agricultural business and brings together a range of programs, tools and resources to help producers manage the various components of running a profitable and sustainable primary production enterprise (QFF, 2005).

The primary aim of a FMS is to achieve continuous improvement by focussing attention on implementing **best** or **recommended** management practices and reviewing the progress made against identified risks (QFF, 2005).

Many producers and extension staff may already be familiar with the principles used in FMS as they are the same as those used in other management systems such as Environmental Management Systems (EMS), Hazard Analysis and Critical Control Point (HACCP), food safety systems, ISO 9001 and ISO 14001.

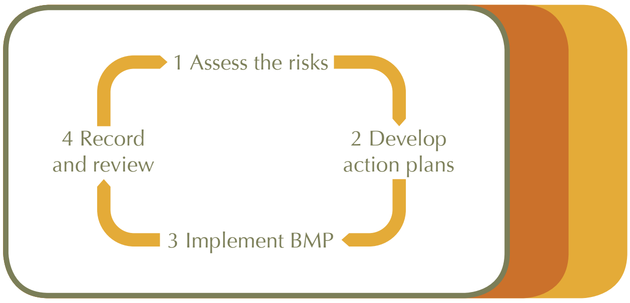
The following QFF industry groups have established industry-specific FMS programs:

- Sugar FMS—Smartcane (Canegrowers)
- Cotton BMP (Cotton Australia)
- GROWCOM FMS (Growcom)
- Dairying Better-n-Better (Queensland Dairyfarmers' Organisation)
- NIASA & ECOHORT (Nursery & Garden Industry)
- Meat Chicken National Environmental Management System (Queensland Chicken Growers Association).

The key strength of a FMS is that it allows producers to demonstrate to others how their business is being managed.

FMS and risk management

The cornerstone of FMS is **risk management**. Risk management is a process primary producers can use to identify and manage business risks (including environmental risks) which may result from their farming operations (QFF, 2005).



The continual improvement cycle using 4 steps to risk management

What is a risk?
A risk is any event or factor that may impact on an enterprise or its objectives.

What is risk management?
Risk management is the process of identifying, responding to and monitoring risks.

Why manage risks?
Risk management enables the producer to anticipate and reduce (or eliminate) the impact of any potential issue (i.e. anticipate what could go wrong and plan for it).

A risk management approach encourages 'continual improvement' through the **plan**, **do**, **check** and **review** cycle, this cycle allows producers to:

- assess the risks and opportunities to the business
- develop an action plan
- implement the plan or best practice
- record, review and improve.

Managing natural resources with FMS

The long-term sustainable management of the environment is a key to a profitable and sustainable farm business. Many producers are already aware that improving the management of natural resources like soil, water and biodiversity can add value to their farm and its products.

Increasingly, producers are also being asked to demonstrate to government regulators, legal systems, and the community that their business is managing natural resources sustainably.

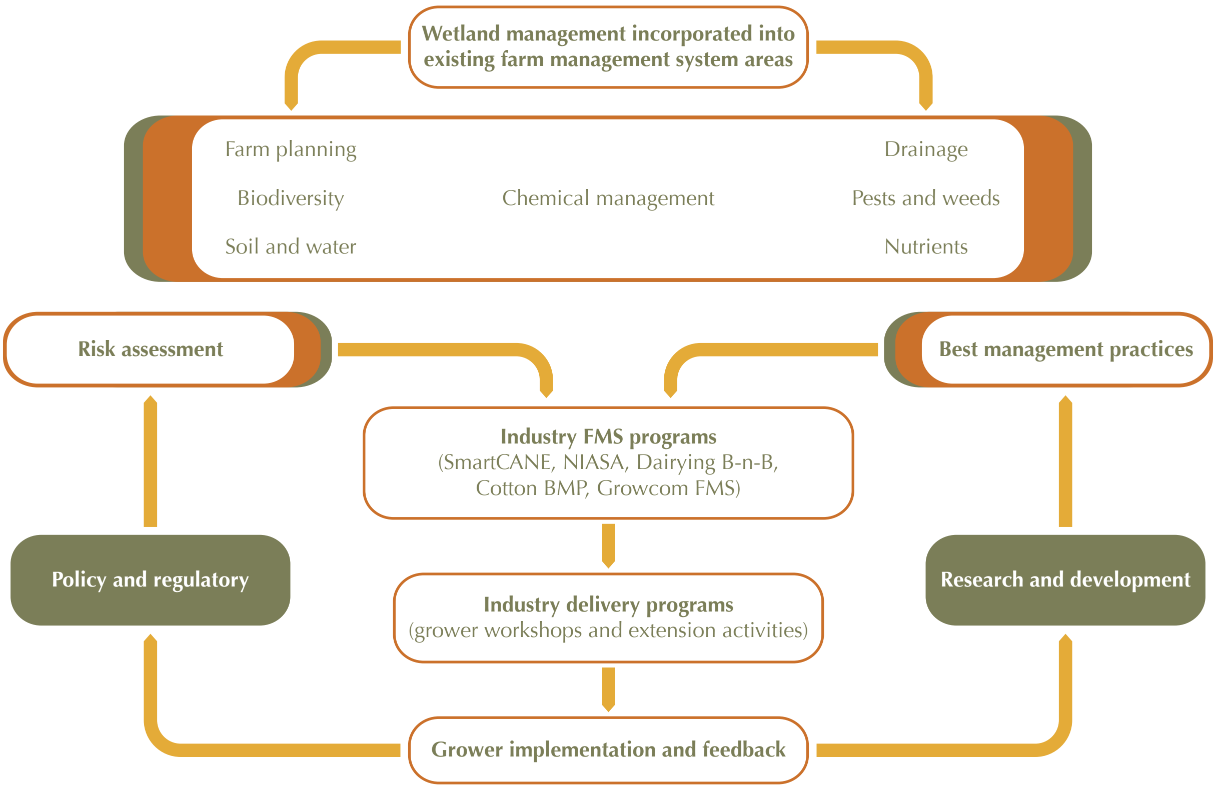
Some international markets require suppliers to implement programs such as EurepGap® (now known as GlobalGap®). This and other national and international supplier programs require producers to demonstrate the steps they have taken to minimise potential environmental impacts of the operation and/or that the product has been grown in a sustainable manner.

Where do wetlands fit into the FMS framework?

Natural and artificial wetlands provide a range of services to the landscape and to the farm. However, due to their position in the landscape and their sensitivity to disturbance, they have the potential to be threatened by a range of different farm activities and practices.

To help producers manage their business risks (including risks to the environment) Queensland's intensive industries have developed FMS programs. These FMS programs have incorporated wetland specific material (e.g. risk assessment questions and best practice options) with guidelines for other farm management activities such as farm planning, biodiversity, native vegetation management, soil and water management and drainage management.

The diagram below shows how wetland management has been incorporated into the overall FMS framework.



Wetlands and the Farm Management System framework

Part 2: Getting to know wetlands

What are wetlands?

Wetlands cover about 71,000 km² of the mainland area of Queensland; most (69 per cent) are seasonally inundated wetlands (EPA, 2006b).

Wetlands cover a wide variety of habitat types including flowing waterways (river and creeks), shallow coastal waters (e.g. mangroves, saltmarshes, tidal flats, and coral reefs), permanent and seasonally ponded waterbodies (lakes), swamps, marshes, peatlands, mangroves, and constructed dams and reservoirs.

The term 'wetland' can therefore be used to describe a diverse mix of landscape features.

Wetland systems share one fundamental feature: the complex interaction of their basic components—soil, water, animals and plants.

Wetland definitions

There are a broad range of wetland definitions in use in Australia and Queensland. However, the definition used in this handbook is based on the definition in the *Queensland Wetland Strategy,* which has been modified for adoption into the Queensland Wetlands Program.

Wetlands are defined as:

> *"Areas of permanent or periodic/intermittent inundation, with water that is* ***static or flowing****, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."*

To be classified as a wetland the area must have one or more of the following attributes:

- At least periodically the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle.
- The substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers.
- The substratum is not soil and is saturated with water, or covered by water at some time.

Wetlands **excluded** under this definition:

- areas that may be covered by water but are not wetlands according to the definition
- floodplains that are intermittently covered by flowing water but do not meet the vegetation and soil criteria
- the riparian zone above the saturation level (EPA, 2006).

The combination of **waterlogged soil**, **hydrophytic vegetation** (hydrophytic vegetation includes Melaleuca species, mangroves and other water plants) and **hydrology** are used as diagnostic indicators of wetlands in Queensland.

The association or connection between all three indicators needs to be recognised for any application of the definition (Dear and Svensson, 2007).

Wetlands occur in many different forms. Coastal wetlands can be:

- coral reefs
- mangroves
- seagrass meadows
- mud flats
- shorelines
- sedge lands
- estuaries
- salt marshes
- saltpans
- melaleuca swamps.

Inland wetlands can include:

- flowing streams
- billabongs
- springs
- dams
- constructed or artificial wetlands
- ephemeral (seasonal) lakes.

Can wetlands be dry?

Yes. The variable nature of Queensland's climate means that many wetlands are ephemeral and can remain dry for lengthy periods. Wetlands on a floodplain are a good example of wetlands that only receive water during flood events.

For some wetlands to be healthy, there needs to be a cycle of wetting and drying. In fact, wetlands that dry out periodically can be the most biologically diverse wetlands (Oates, 1994).

This natural wetting and drying cycle changes pH levels of soils and increases the availability of nutrients to plants (Mitsch and Gosselink, 2000). Re-flooding of a dry wetland helps produce plant material on which insects and animals feed (DNRE, 1997).

Farm operations such as irrigation, farm drainage networks and construction of levee banks can affect the natural drainage patterns and have the potential to seriously alter the wetting and drying regime of a wetland.

Melaleuca swamp (palustrine) wetland in a dry period. (Photo by Harry Bishop).

What is a wetland value?

A wetland value is the important aspect (e.g. ecological health) of a wetland. A wetland value includes any aspect of wetland ecology, health and economics, and can also encompass public amenity and safety.

In natural wetland systems, wetland processes (see below) are considered the **default wetland values** that should be managed or protected, as they are necessary for the other values of the wetland to be maintained.

For example, a wetlands hydrological value can be compromised by draining or water diversion. This will impact on other wetland values such as the capacity for the wetland to carry out nutrient cycling and/or the provision of habitat.

The wetland processes that should be managed or protected include:

- hydrology
- food webs
- habitats
- nutrient cycling
- sediment trapping and stabilisation.

A full suite of wetland values has been developed and can be used as the starting point for identifying the environmental values of a specific wetland.

The full list of wetland values is available on Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

Are farm dams wetlands?

Yes. Water storages such as farm dams are included under the current wetland definition because they can also have wetland values.

Dams can mimic natural wetland processes such as trapping sediment, nutrient processing and attenuation (slowing) of overland flows. Farm dams can also provide habitat for plants, birds and fish.

There can be many variations in the values offered by either natural or artificial wetlands; in some cases farm dams can provide higher quality habitat than some natural wetlands.

Some examples of artificial structures that can provide wetland values include:

- irrigation tail-water recycling systems
- large water-storage areas (ring tanks)
- ponds, farm dams, stock ponds
- aquaculture ponds
- irrigated land and channels
- seasonally flooded farm land
- canals and drains.

Like natural wetlands, farm dams can provide wetland values such as habitat and hydrological values. (Photo by Ian Layden).

Classes of wetlands in Queensland

Queensland's wetland systems have been divided into different groups based on general hydrology characteristics. They are categorised by the following criteria:

- quantity of water
- quality of water (in particular, salinity)
- frequency (how often water inundates the wetland)
- duration (how long the wetland remains inundated).

The main classifications of wetland groups are:

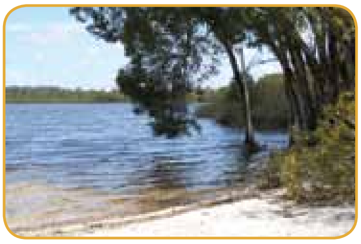
- palustrine
- lacustrine
- riverine
- estuarine
- groundwater and marine wetlands.

Following are the various categories of wetland systems used throughout Queensland:

Palustrine

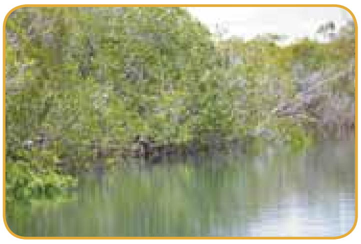
Palustrine wetlands are primarily vegetated non-channel environments of **less than 8 ha**. They include billabongs, swamps, bogs, springs and soaks, among others, and have **more than 30 per cent** emergent vegetation. (Photo by Chris Sanderson).

The palustrine system was developed to group the vegetated wetlands traditionally called by such names as marsh, soaks, swamps, bogs, fens, and prairies.



Lacustrine
Lacustrine wetlands are large, open, water-dominated systems **larger than 8 ha** (e.g. lakes). This definition also applies to modified systems (e.g. dams) that possess characteristics similar to lacustrine systems (i.e. deep, standing or slow-moving waters). (Photo by Andrea Ferris).

Riverine
Riverine wetlands describe all wetlands and deepwater habitats within a channel. The channels are naturally or artificially created; they periodically or continuously contain moving water, or form a connecting link between two bodies of standing water. (Photo by Angela Reed).



Estuarine
Estuarine wetlands are those with ocean water that is sometimes diluted with freshwater runoff from the land.

Other wetland classes include **marine** and **spring**. Marine includes the area of ocean from the coastline or estuary to the jurisdictional limits of Queensland waters (3 nm). Spring wetlands occur where groundwater flows out of the ground forming pools or streams.

Further classification of wetlands
Wetlands are further classified to distinguish modified (e.g. farm dams) and artificial (e.g. ring tanks, canals) from natural wetlands.

Further refinement of the wetlands types in Queensland is underway through the Queensland Wetlands Program, and detailed conceptual models that summarise current scientific knowledge of these wetland types are available through Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

Example of marine wetlands. (Photo by DERM).

Identifying wetlands

Wetland mapping
The Queensland Wetlands Program has mapped wetland types, locations and associated regional ecosystems (REs) across Queensland to help wetland managers identify and manage wetlands. This mapping is being delivered through an interactive map server as GIS layer or as PDF maps. They are available in the Maps and Data on Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

The mapping has classified wetlands according to a range of criteria, including the type of ecological system (riverine, estuarine etc), its degree of water permanency, and salinity and whether it is natural, modified or artificial. Most mapping is already available and the remainder of the state will be available by the end of 2008.

Wetland maps are available at a scale of 1:100,000, with finer detail (1:50,000) in the coastal regions where appropriate mapping data exists.

Important note on mapping accuracy

Areas along the east coast that are mapped at 1:50,000 have a positional accuracy of +/–50 m, with a minimum polygon size of 1 ha or 35 m wide for linear features.

The positional accuracy of wetland data mapped at 1:100,000 is +/–100 m with a minimum polygon size of 5 ha or 75 m wide for linear features.

The current mapping data does not allow for sufficient positional accuracy of wetlands smaller than 1 ha.

It is important to remember that the resolution of current imagery does not identify wetlands below 1 ha. This does not mean that wetlands below this size are unimportant; it is that the resolution of the mapping is inadequate to identify them. Other sources of information which may be used to more clearly refine the boundaries of a wetland include aerial photography and satellite (Spot 5) imagery.

Wetland hydrology

The term **wetland hydrology** generally refers to the inflow and outflow of water through a wetland and its interaction with other wetland factors.

Hydrology affects many wetland processes, such as sediment and soil processes and nutrient treatment. In coastal wetlands, hydrology affects salinity levels. In turn, these processes come together to determine the type of flora and fauna that develop in the wetland.

Hydrologic conditions are extremely important for the maintenance of a wetland's structure and the way it functions. A wetland's hydrologic signature (sometimes referred to as 'hydroperiod') is one of the most important determinants of the establishment and maintenance of specific types of wetlands and wetland processes (Mitsch and Gosselink, 1993).

The hydrological features that affect the wetland do not only involve the amount of water entering the wetland but also the time when it arrives, and the retention period. For example too much water entering a wetland (farm runoff or irrigation tail-water) may be detrimental to that wetland type and change the values of the wetland; similarly, restricting water from entering a wetland (irrigation drawdown or diversion) may also be detrimental to values of the wetland.

Hydrological conditions also affect nutrient cycling, with wetlands that have water flowing through them or in pulses having the highest rate of nutrient cycling (Mitsch and Gosselink, 2000).

The main types of inflows to a wetland are:

- rainfall
- flooding rivers
- surface flows (e.g. farm runoff and irrigation tail-water)
- groundwater
- tidal influences.

The main types of outflows from a wetland are:

- seepage to groundwater (aquifer recharge)
- evaporation from standing or running water
- water released to the atmosphere by plants (called evapotranspiration)
- water held in soils and sediments
- overland or channel flows.

Small changes in the amount of water flowing in or out of a wetland can result in significant changes to the type of vegetation.

Wetland vegetation

Wetland plant species often exhibit distinct adaptations that allow a greater tolerance and survival in wetland areas. The adaptations enable wetland plants to live in low oxygen (anaerobic) soils, and various species (such as some seagrasses) are capable of living permanently submerged in water.

Functions of wetland vegetation

Wetland plants play a vital role in wetland ecology and perform a number of significant functions including:

- maintaining water quality by filtering out nutrients and sediments
- providing food, shelter and breeding habitat for fauna
- preventing erosion
- competing for nutrients that can reduce the frequency and severity of algal blooms
- shading riparian zones (Allen, 2000).

Plant species that are common to the wettest environments often exhibit the greatest degree and most effective adaptations to wetland conditions. Plant species with these adaptations are often called **hydrophytes**.

Hydrophytes grow in water or very moist ground. They are used as wetland indicators because of the strong relationship between soil saturation and the development of communities dominated by plants specifically adapted to, and requiring, wetland conditions (EPA, 2006).

There are four broad categories of wetland vegetation.

Floating

Floating wetland plants include both free-floating plants that are unattached (floating on the water surface) and plants that are attached to the wetland substrate (known as floating attached plants).

Free-floating plants include native species such as *Azolla filiculoides* (Pacific azolla) and Lemna sp. and a number of wetland weeds such as *Eichhornia crassipes* (water hyacinth), *Pistia stratiotes* (water lettuce) and *Salvinia molesta* (salvinia).

Floating attached plants include species such as *Nymphoides indica* (water snowflake), *Monochoria cyanea* (monochoria) and *Ludwigia peploides* (water primrose).

Submerged

This category includes plants that are rooted in the wetland substrate or are free-floating. In both cases the leaves and stems remain submerged.

Submerged plants can produce flowers that float on the water surface or are held above it. In some cases the leaves may be temporarily exposed due to falling water levels, fast-flowing water or crowded growing conditions.

Examples of submerged plants include native species such as elodea, milfoil and pondweeds. A number of wetland weeds are also in submerged category such as cabomba or fanwort (*Cabomba caroliniana*) and parrots feather (*Myriophyllum aquaticum*).

Emergent

These plants are rooted in the wetland substrate and have stems, flowers, and most of the mature leaves protruding above the water surface. Because some juvenile plants may have stems/leaves that are still submerged it can be difficult to distinguish some emergent plants before maturity.

Examples of emergent plant species include sedges, rushes, phragmites, cumbungi (*Typha sp.*) and smartweeds. Many emergent wetland species are also weeds for example para grass and hymenachne.

Trees & shrubs
These include emergent species that have woody stems. Plants in this group can sometimes grow in seasonally wet habitats such as floodplains and estuary environments.

Species in this category include *Melaleuca quinquenervia* (paperbark), *Casuarina glauca* (she-oak), *Casuarina equisetifolia* (coastal she-oak), *Melaleuca leucadendra* (weeping paperbark) and mangrove species.

Wetland plant terminology

Floating—plants whose leaves float mainly on the water surface. Much of the plant body is under water and may be rooted in the substrate. Only flowers rise above water level.

Emergent—plants that are rooted in soil that is under water most of the time. These plants grow up through the water so that stems, leaves and flowers emerge above water surface (e.g. sedges, reeds).

Submerged—plants that are largely under water with few floating or emergent leaves. Flowers may emerge (briefly) for pollination in some cases.

Want to know more?

Here is a list of additional resources to help identify wetland vegetation.

- **Sainty GR, Jacobs SWL (1988) *Waterplants in Australia*. (Sainty and Associates: Darlinghurst, Australia).**
- **Stephens KM, Dowling RM (2002) Wetland Plants of Queensland: a field guide (Queensland Herbarium) CSIRO Publishing, Melbourne.**
- **Wetland*Info* (www.derm.qld.gov.au/wetlandinfo) summary information (Maps and Data segment).**

Wetland soils
Soils can be powerful indicators of wetland dynamics because of the specific soil features that can develop in wet, oxygen-poor environments (Dear and Svensson, 2007).

Soils can be a reflection of the physical processes occurring in the wetland (for example, water inflow, water chemistry, filtering of pollutants). Wetland soils impact directly on other wetland characteristics (e.g. water quality, fauna, vegetation) (EPA, 2006a).

Soils found in wetland areas (or areas that were once wetlands) typically have distinct properties that allow some form of identification and understanding of current or previous inundation regimes (Dear and Svensson, 2007).

General soil indicators that are used to identify a wetland soil are:

- the accumulation of organic matter (e.g. peat)
- gleyed (greenish-blue-grey) soil colours
- soil mottling (the presence of more than one soil colour in the same soil horizon)
- iron or manganese segregations
- oxidising root channels and soil pore linings
- reduction of sulfur and carbon (e.g. acid sulfate soil) (EPA, 2006a).

Above is an accumulation of organic matter. Wet soil conditions favour the accumulation of thick organic horizons, which is often only partially decomposed. Soil consists predominantly of decomposed plant material (e.g. fibric, hemic or sapric peat), has a thick layer of decomposing plant material on the surface or has a dark surface. (Photo by DERM, 2007).

Above is a a gleyed matrix (bluish-grey or grey colour below the surface) that occupies 60 percent or more of a layer starting within 30 cm of the soil surface. (Photo by DERM, 2007).

Oxidised rhizospheres (root channels), above, are thin iron deposits present in an otherwise grey matrix along small roots. (Photo by DERM, 2007).

Soil mottling, above, is usually an indicator of poor drainage or water fluctuation throughout a soil profile. The dominant soil colour for this particular soil is grey. (Photo by DERM, 2007).

Above is an example of streaked organic matter. Soil is sandy and has dark stains or dark streaks of organic material (decomposed plant material attached to the soil particles) in the upper layers. This soil leaves a dark stain when it is rubbed between the fingers. (Photo by DERM, 2007).

Part 3: Managing wetlands

Why managing wetlands is important

Wetlands are important for maintaining ecosystem health. They help filter water and are important for a wide range of social and recreational activities.

They provide nurseries for fish and other freshwater and marine life, making them critical to Australia's commercial and recreational fishing industries.

Wetlands also protect our shores from wave action, reduce the impacts of floods, absorb pollutants and provide habitat for plants and animals.

Wetlands are a vital part of our waterways and contribute to the health of our coastal resources (such as sea grass beds, fisheries production) and the Great Barrier Reef. Wetlands do this by improving the quality of water flowing from the catchments to the sea. For this reason they are often referred to as 'nature's kidneys'. However, like any kidney, if they are expected to filter excessive contaminants they will cease to function.

Wetlands slow the passage of water and encourage the deposition of nutrients and sediments thereby improving water quality downstream.

The landscape services provided by wetlands

Wetlands can perform the following landscape or catchment services:

- nutrient removal and treatment
- sediment and pollutant detention
- shoreline stabilisation
- flood mitigation/alteration
- groundwater recharge
- groundwater discharge
- habitat for flora
- habitat for birds, fish and beneficial insects.

Wetlands and climate change

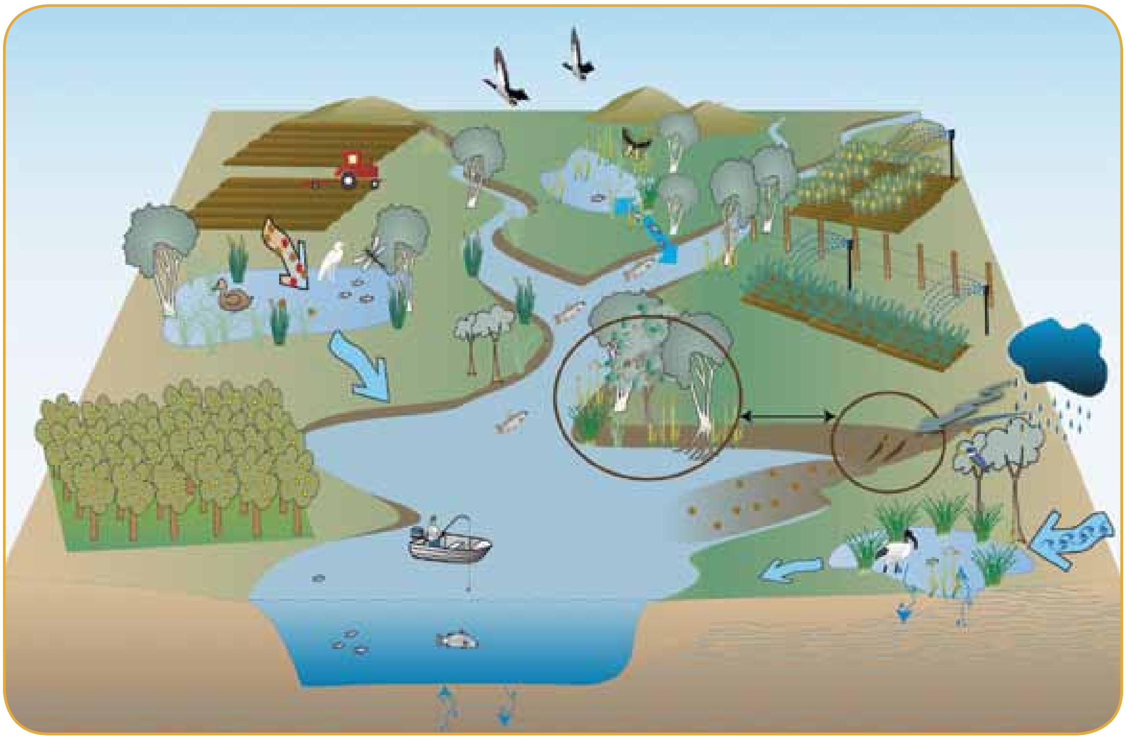
Wetlands play at least two critical roles in mitigating the effects of climate change:

- management of greenhouse gases (especially carbon dioxide)
- physically buffering climate-change impacts such as flooding from increased storm activity and predicted sea-level rises (Ramsar, 2006).

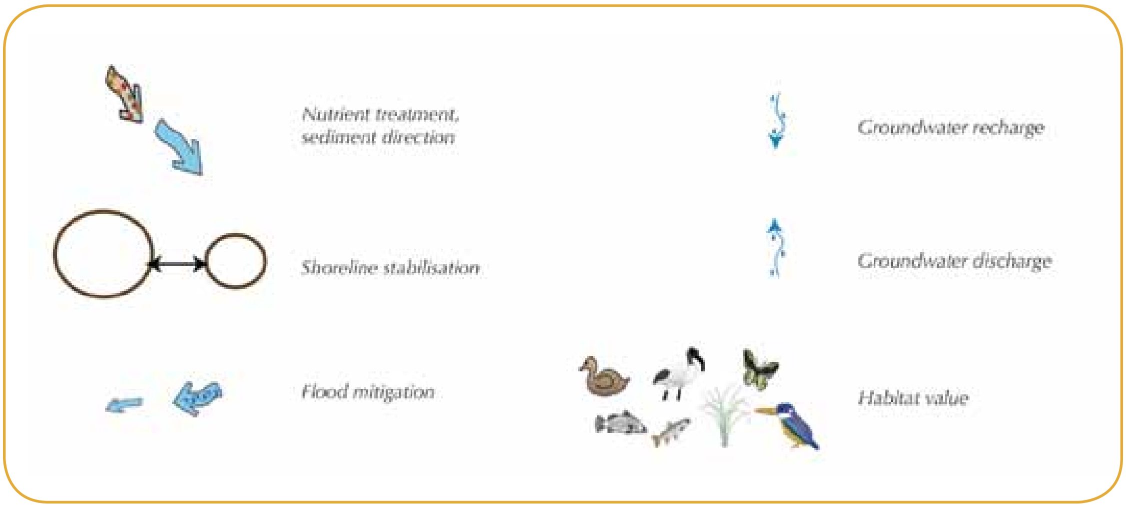
Did you know?

Wetlands have been identified as significant storehouses (sinks) of carbon, which can help to reduce carbon in the atmosphere.

Wetlands in the landscape



Legend—wetlands in the landscape



The benefits of wetlands to the producer

Depending on the wetland type and location, there are a number of benefits wetlands can provide to the farm.

1. **Erosion management:** wetlands have the ability to slow the movement of water through the landscape. This reduces the risk of erosion and can be a valuable part of any erosion management program.
2. **Flood management:** wetlands act as sponges that can soak up and slowly release storm and flood waters, lessening flooding and resulting in less pressure on downstream waterways.
3. **Improved irrigation and stock water:** biological activity in wetland systems can transform and retain nutrients and pollutants in the soils and vegetation, resulting in cleaner water for stock and crops.
4. **Increased groundwater recharge:** wetlands provide a site for surface waters to percolate through to the groundwater, particularly in landscapes where the wetland is able to retain surface waters.
5. **Pest management:** wetland vegetation can provide habitat for beneficial/predatory insects and birds, which can be valuable in an integrated pest management program.
6. **Shelter belts:** fringing wetland vegetation can provide crops with protection from wind damage and provide cattle with shade.
7. **Seasonal foraging:** wetlands are highly productive areas of the landscape and if grazed wisely can provide good seasonal foraging opportunities.
8. **Recreational activities:** wetlands can provide recreational opportunities such as fishing and canoeing for farm staff and may also offer an opportunity for farm-based tourism.
9. **Land values:** as coastal land values in Queensland continue to rise, there is growing recognition that farmlands that maintain a range of natural features and biodiversity can attract higher sale prices.
10. **Increased farm biodiversity:** due to their high productivity wetlands can be biodiversity ‘hotspots’ supporting a wide range of plants, insects, fish and birdlife.

Wetlands in floodplain landscapes

One of the main differences between a floodplain wetland and other wetlands, is that floodplain wetlands are only covered with water during times of floods or high flow events.

Floodplain wetlands play an important hydrological, geomorphic and ecological role in the landscape; they receive water during periods of high flows and can recharge main channels during periods of low-flow (Frazier and Page, 2006).

Floodplain wetlands have the ability to attenuate flood flows by storing and slowing the release of flood water; ecologically floodplain wetlands can act as:

- a source and sink for organic matter and/or nutrients
- breeding grounds for aquatic organisms
- habitat for a range of aquatic and terrestrial animals and flora (Kingsford, 2000).

During flood events floodplains:

- allow passage for fish during high flow and at times provide a link between waterbodies
- interact with rivers to supply nutrients, debris and organic material back into the main channels
- provide extensive areas for invertebrate populations to develop, providing food supply for young fish
- provide spawning sites for native fish species such as perch, mangrove jack and barramundi.

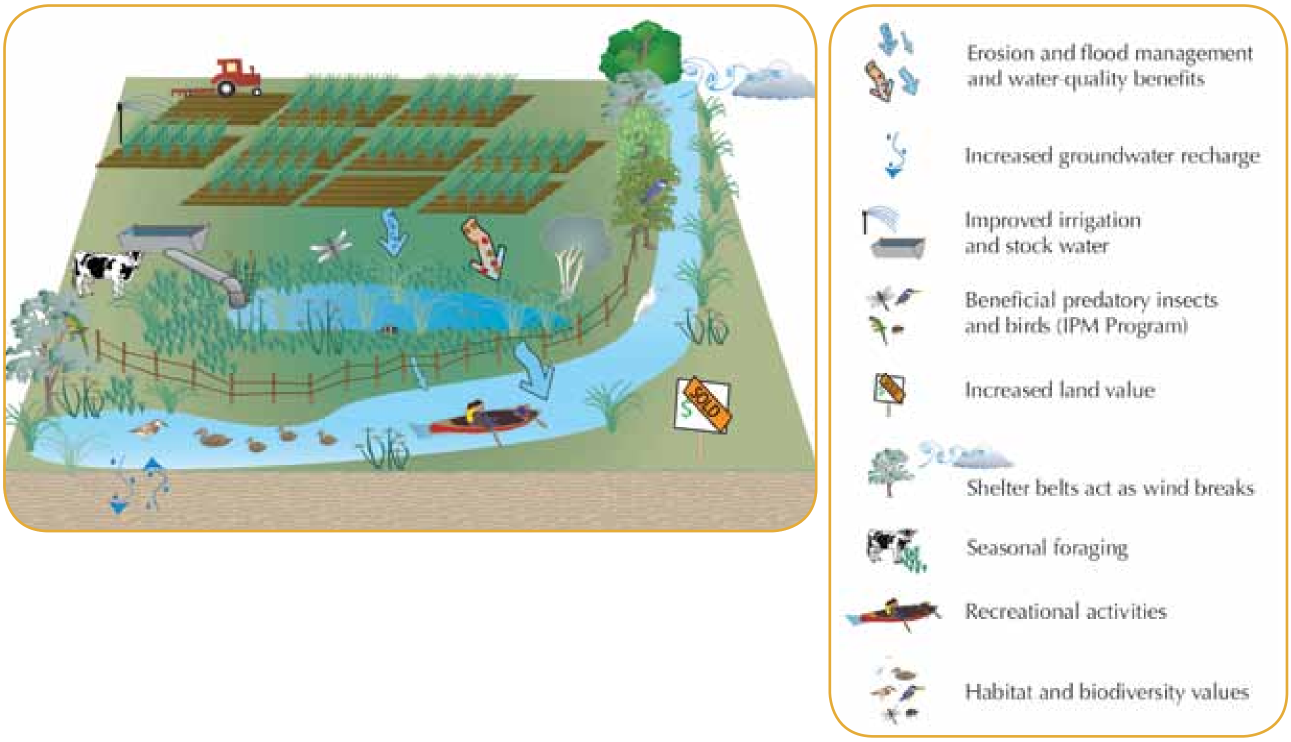
In floodplain landscapes that have coarse sands and gravels or soil types that are highly transmissive (free draining) water moves laterally or outwards from the wetland or riverine system (Young *et al.*, 2002).

This lateral movement of water increases the wetted extent of the soil, promoting sub-surface irrigation, which can have the following soil benefits:

- improved development of the soil profile
- reduced soil compaction
- increased retention of nutrients in the soil profile
- better retention of soil organic matter (Young *et al.*, 2002).

The Queensland Wetlands Program has developed a series of wetland case studies illustrating how managing wetlands through industry FMS can provide benefits to the landholder as well as the community. The case studies feature producers from cotton, sugar cane, horticultural, dairy and nursery production industries. These case studies are available online in the Managing Wetlands section of Wetland*Info* (www.derm.qld.gov.au/wetlandinfo) or by contacting Queensland Employment, Economic Development and Innovation on 13 25 23.

Wetlands and production



The risks to wetlands from intensive agriculture

Wetland health is also affected by landscape modifications such as land clearing, drainage work, bunding (for irrigation or ponded pasture), diversion of water and groundwater extraction. Inappropriate grazing regimes and stocking rates can degrade wetland health by damaging wetland soils and vegetation. Stock that have unrestricted access to wetlands (and riparian zones) increase the risk of spreading or introducing weeds and contribute to poor water quality by degrading bank stability and by defecation.

Sediment and nitrogen contained in runoff is estimated to have increased three-fold in the last 150 years. Phosphorus runoff is estimated to have increased more than 10-fold (Reef CRC, 2001).

Research in Queensland's coastal catchments indicates large quantities of sediment and associated nutrients and pesticides are washed or leached from cropping areas into rivers, streams and groundwater during rain, irrigation and farm management events. Excess sediments, nutrients and agro-chemicals impact on wetland health.

Farm activities have the potential to cause a number of negative changes to wetland environments such as:

- changes in water regime
  —reduced flood frequency, duration and volume
  —increased permanent inundation
  —changes to water quality
  —changed groundwater conditions
- the loss and decline of riparian and wetland vegetation
- the loss of habitat and other biodiversity values
- the introduction of exotic animal and plant species.

The FMS approach is the ideal system to demonstrate to others that there is a plan in place to manage on-farm natural resources.

Agricultural practices that can constitute a risk to wetlands include:

- draining or filling wetlands or low-lying areas that may have been old wetlands
- hydrological modifications that alter flows and the wetting/drying cycle of the wetland
- placement of bunds or barriers that prevent fish passage and provide favourable conditions for weed growth
- nutrient runoff or leaching from the production area, which encourages excessive weed and algal growth
- excessive withdrawal of water for irrigation, which reduces the ability for wetlands to treat nutrients and other pollutants
- inadequate vegetative buffer type and width between the production area and wetland
- unmanaged headlands that supply sediments and nutrients from the production area to waterways
- herbicide and pesticide drift or runoff
- overgrazing or unmanaged stock access to wetland or waterways
- fire regimes that are too hot and too often
- poor weed management causing invasive species to degrade wetland values.

Table 1: Agricultural activities and the risks to wetland health

Agricultural activity	Risk to wetland health
Draining or filling wetlands or low-lying areas that may have been old wetlands	• Change in landscape hydrology reducing the landscape's ability to attenuate flood flows and treat pollutants • Loss of habitat • Potential exposure of acid sulfate soil
Hydrological modifications that alter flows (e.g. drainage modifications, placement of bunds or barriers)	• Affects the wetting/drying cycle of the wetland, which can change wetland vegetation and encourage weeds. • Prevents fish passage and breeding
Nutrient runoff or leaching from the production area	• Reduces wetland water quality • Encourages excessive algal and weed growth • Increases the risk of nitrates reaching groundwater
Inadequate vegetative buffer type and width between the production area and wetland	• Increased nutrient, sedimentation, chemical runoff or drift • Impact on wetland biodiversity
Excessive withdrawal of water (pumping)	• Reduces the ability for wetlands to treat nutrients and other pollutants • Changes to wetland vegetation • Reduced groundwater recharge
Poorly managed headlands or farm roads	• Increases the supply of sediments and nutrients from the production area to wetlands
Herbicide and pesticide drift or runoff	• Damage to sensitive vegetation • Reduces water quality • Harmful to fish and birds
Overgrazing or unmanaged stock access to wetland or waterways	• Reduces bank stability • Reduces water quality • Damages vegetation
Fire regimes that are too hot and too often	• Damages wetland/riparian vegetation • Reduces regeneration of native plants • Damages wetland soils such as peat

Experience is now showing that poorly managed wetlands (including farm dams) can reduce farm productivity by increasing the risk of:

- inundation of the production area with associated risk of siltation of crops
- increased spread of weeds from the wetland to the production area.

Some of the practices listed in Table 1 may also put the producer at risk of breaching a range of Commonwealth, State and local government regulations.

Find out which legislation impacts on your project.

The Queensland Wetlands Program has developed a tool to help wetland managers find relevant wetlands-related legislation, policy and planning instruments.

The online tool is interactive, with searches conducted by basin, Natural Resource Management region or local government area.

The Wetlands Planning and Legislation Support Tool is available online on Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

Managing wetlands with FMS and best practice

Industry recommended best practice is the key to a profitable and sustainable farm!

Best practice (also called 'recommended practice') refers to agricultural practices that reflect the current level of knowledge about farm management that sustains land, water and biodiversity resources without sacrificing productivity. This section outlines a range of farm management options that also represent best practice for wetland health.

Industry groups and producers are increasingly being asked to demonstrate to the community, markets and regulators that best management practice (BMP) is being undertaken to reduce or minimise the movement of sediment and other pollutants off-farm and that natural resources are not adversely impacted by farm activities.

To achieve an effective balance between natural resource management and productivity, it is recognised that production capacity and/or methods may need to be re-evaluated. Achieving a workable balance is a challenge for extension officers, industry groups, natural resource management bodies and producers.

There are a range of best practice programs recommended by Queensland's peak industry and grower groups. These are intended to maximise both the profitability and sustainability of the farm.

Implementing new practices or altering farm work plans requires careful consideration. Investing in additional resources and equipment depends on the level of risk that is posed by the current farm practice.

Four steps to managing wetlands with FMS

Step 1
Assess the risks to wetlands and waterways from current farm practices via the risk assessment process (e.g. an on-line questionnaire, on-farm assessment or industry/grower workshop).

Step 2
Plan actions based on the results of a risk assessment and prioritise them. Actions could include installing sediment control devices, soil and sediment management programs, maintaining grassed headlands or revegetating riparian areas.

Plan actions that will minimise the risk to the enterprise and wetlands.

Step 3
Implementing best management practices like nutrient, soil and drainage management and farm design options (e.g. contour banks and filter strips) that reduce the risk to wetlands.

Step 4
Recording the steps taken and **reviewing** whether practices and farm designs have reduced the risk to wetlands.

Recording the steps taken and reviewing actions are the key methods to demonstrating that a business is farming sustainably!

Step 1—Assessing the risks

Using the cycle of continual improvement requires undertaking a risk assessment of farm activities. This is the first step in planning and prioritising actions.

Not all wetlands are the same, and the same wetland type can have different values (Wetland values page 4) and conservation significance.

It is recommended that before undertaking an industry risk assessment the wetland mapping (www.derm.qld.gov.au/wetlandinfo) is consulted to determine whether wetlands on a property have been recognised as being of high conservation value or if any other assessment has been undertaken to determine the values of a particular wetland.

Where do I get an industry risk assessment from?
Industry FMS programs include risk assessments that producers and extension staff can use to identify productivity and environmental risks. They are available in a variety of platforms such as on-line, through industry grower workshops or self-assessment checklists.

Risk assessment questions targeting agricultural activities that can pose a threat to wetlands and riparian areas have been included in industry FMS risk assessments (Table 2, page 16). A generic risk assessment table (Table 3, page 16) has also been included.

Industry groups offer a farm inspection and/or audit service to help growers benchmark or score their current business practices.

Once a risk assessment has been completed, typically there will be a number of issues that require attention; the next step is to develop a plan of action to minimise or address the risks that have been identified throughout the risk assessment process.

Table 2: Industry FMS programs and risk assessments.

Industry	FMS program	Relevant wetland risk assessment	Industry facilitated or grower self-assess	Available from
Cane	Sugar FMS (SmartCANE)	COMPASS BSES Farm Productivity Assessment (FPA)	Both	Canegrowers www.canegrowers.com.au BSES www.bses.com.au
Cotton	Cotton BMP	Land & Water module	Self-assess with follow-up Industry audit	Cotton Australia www.cottonaustralia.com.au
Dairy	Dairying Better N Better for Tomorrow	DairySAT	Industry	Queensland Dairyfarmers' Organisation www.dairyinfo.biz
Horticulture	Growcom FMS	Wetland FMS module	Industry	Growcom www.growcom.com.au
Production Nursery	Nursery Industry Accreditation Scheme (NIASA)—BMP	EcoHort (Guidelines for Managing the Environment)	Both	Nursery & Garden Industry Queensland www.ngiq.asn.au

Table 3: Example farm risk assessment

Risk assessment location: Paddock A, Smith farm			**Date:** 30 August 2008	
Assessment carried out by: B. Smith (owner/manager)				
Identified hazard or risk	**Risk assessment (what might happen)**	**Likelihood of impact**	**Action required to reduce risk**	**Actions implemented and when**
Chemical storage area—lack of adequate bunding	Unmanaged spills Leakage of chemicals into soil or waterways	Moderate	• Build concrete bund around chemical store • Advise staff of potential risks	
Bank slumping near creek	Loss of production land Impacts on downstream water quality	High	• Improve ground cover • Construct sediment trap	

Assessing risks to wetlands using property mapping

Farm maps help to assess risks and plan actions.

The first step in establishing if farm practices are presenting environmental risks is to map the farm. By mapping the farm a producer can determine where it is positioned in the overall landscape and if there are external factors that pose a risk to the farm. Farm maps also allow a producer to locate sensitive areas (e.g. wetlands) and assess if these areas may be at risk from farm practices (e.g. farm runoff or spray-drift).

Maps that display a range of features such as contours, drainage lines, wetlands, soils and vegetation types can help producers fine-tune farm practices, plan farm activities and develop funding applications.

Wetland maps are available from Wetland*Info* (www.derm.qld.gov.au/wetlandinfo); however, landholders may require maps with a higher resolution of 1:25,000 and 1:50,000 for risk assessment and farm planning. High resolution aerial photographs and/or satellite mapping are readily available from a range of agencies, consultants, industry and natural resource management groups. Most regional natural resource management groups provide a mapping and property planning service for producers.

Identifying risks using condition assessment tools

Condition assessment tools are employed widely in landscape management. In the management of production systems they are typically used to assess grazing land health, soil health and river and waterway condition.

Condition assessment tools enable producers and/or extension staff to assess farm wetlands according to a defined process which then ranks or scores the current condition.

Assessing the condition of the farm's natural resources also highlights areas that are at risk of further degradation and may require attention.

Results from the condition assessment can then be used to:

- highlight areas requiring attention
- plan actions across the farm
- establish a benchmark for future condition assessments.

It should be noted that it is important to identify the values of any existing wetlands on the property and the processes required to support them before moving to condition assessment.

Step 2—Planning farm actions

2 Develop action plans

The key to effective action planning is to set realistic and achievable targets or goals.

Actions need to be prioritised according to the level of risk they present to the business; however, keep in mind that priorities are also likely to change. For example, planning to restore riparian vegetation as well as implementing best practice nutrient management in the same year may be unrealistic.

Similarly, in the action planning process you may have identified that you need to better manage farm runoff as well as implement soil moisture monitoring. To remain profitable and sustainable both these issues require addressing; however, you need to decide if the unmanaged farm runoff that is causing environmental harm is a higher priority than measuring soil moisture.

The action plan should record the following information:

- the risk assessment date, identified hazards, assessed risks and chosen actions
- how the actions were implemented, monitored and reviewed
- relevant related farm records (e.g. soil tests)
- any consultation undertaken and who was involved (e.g. agronomist).

Table 4: Sample of a farm action plan

Date of risk assessment	Issue or activity	Action or materials required	Resources required	Who's responsible	Due for completion
5/2/2008	Repair erosion on bank of creek	Replant bank with native tree species	Ring local landcare group for species to use	Farm manager	Before next planting season
5/2/2008	Improve field/ paddock drainage	Reshape headlands	Laser level	Farm manager	Do fallow areas first. Complete the rest by next season
5/2/2008	Undertake soil mapping across farm	Call agronomist to arrange farm visit	Nil	Owner	After harvest
5/2/2008	Manage stock access to wetland area	Submit grant application	Fencing /pump and water trough	Manager	Before wet season begins
5/2/2008	Increase buffer width & ground cover near bottom creek	Calibrate seed spreader	Grass seed	All staff	Before harvesting

Plan actions identified during the risk assessment process that will have the most effect in managing risks.

Prioritise and tackle the most important things first. As each action is completed, tick it off on the action plan. Farm action plans should be kept current and actions reprioritised once other actions have been completed.

Step 3—Implement best management practices

3 Implement BMP

This section outlines best management practices (BMPs) that can deliver positive outcomes for the producer while contributing to wetland health.

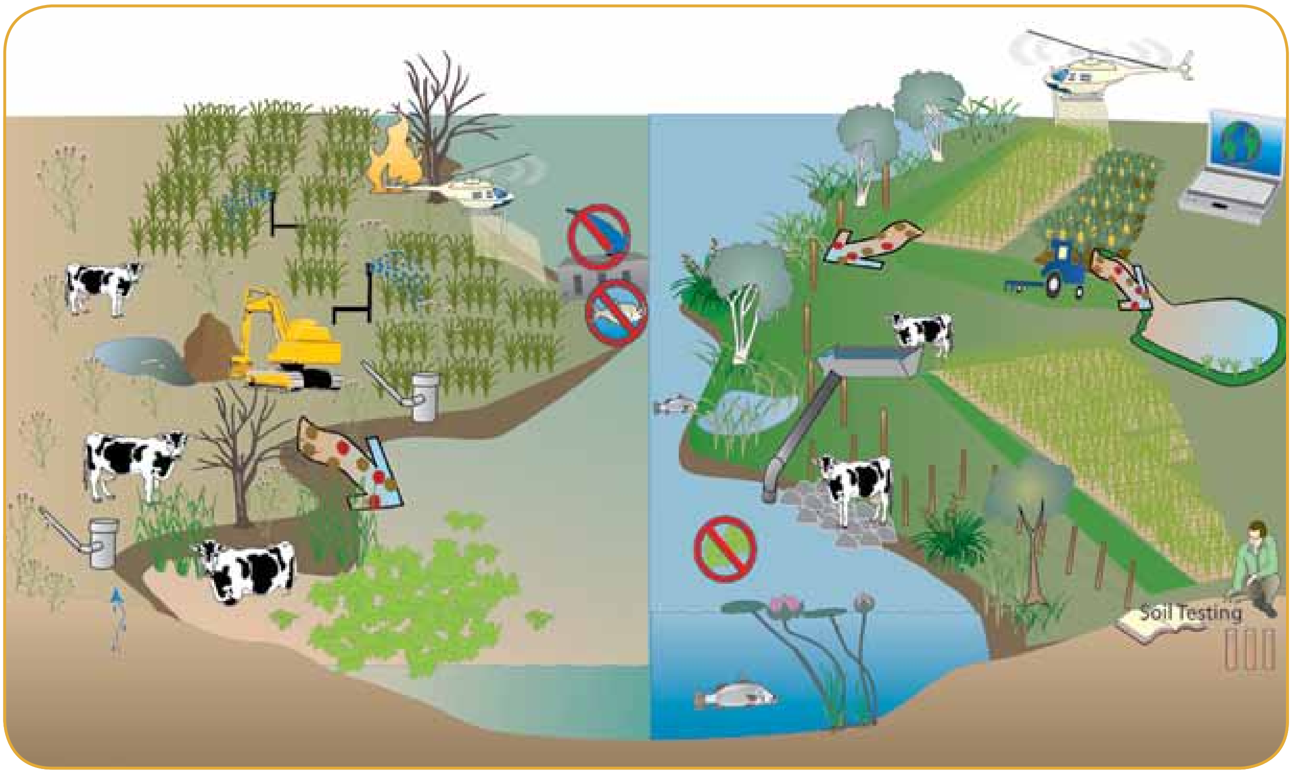
BMPs are farm management practices that have been through a process of research and development, grower testing and adaptation and are widely recognised as being both practical and technically sound.

Best practices for managing wetlands are:

- nutrient management
- erosion and sediment management
- buffering wetlands from farm runoff
- spray-drift management
- managing acid sulfate soil (ASS)
- managing floodgates, crossings and drains for fisheries values
- wetland and riparian weed management
- exotic animals and wetlands
- wetland treatment systems.

BMPs are recommended by industry for industry.

High-risk practices *Best practice*



Legend—high-risk practices

- Draining and filling
- Hydrological modifications that alter flow and inhibit fish passage
- Nutrient runoff from production areas encouraging excessive weed and algal growth
- Excessive withdrawal of water for irrigation reduces the ability of wetlands to treat nutrients
- Inadequate vegetative buffer type and width between the production area and the waterway
- Poorly managed headlands that supply sediments and nutrients from the production area to waterways
- Herbicide and pesticide drift or runoff
- Overgrazing or unmanaged stock access to wetlands or waterways
- Fire regimes that are too hot and too often
- Poor weed management causing invasive species to degrade wetland values

Legend—best practice

- Recording and managing nutrient applications through the use of soil testing and record keeping
- Sediment management—filter strips and riparian buffer zones
- Fish passage
- Wetland weed management
- Constructed wetlands and sediment traps
- Management of spray-drift
- Accessing and utilising wetland mapping and management tools from Wetland*Info*

Best practice: nutrient management

On farm risks managed
- **yield decline**
- **soil health decline**
- **surface and groundwater contamination.**

Wetland risks managed
- **excessive weed and algae growth**
- **surface and groundwater contamination**
- **adverse biodiversity impacts.**

Managing fertiliser inputs with the traditional one-size-fits-all approach is imprecise and can be expensive over the long term. Nutrient inputs should always be aimed at profitable production and achieved in combination with minimal on- and off-site effects (Schroeder, 2007).

Nutrient management aims to optimise crop yield and quality, minimise fertiliser input costs while protecting soil and water resources.

The basic principles are to apply fertiliser only to make up the difference between what is in the soil and what is required to achieve a yield target and ensuring that applied nutrients are available to the crop (Schroeder, 2007).

Matching fertilisers to soil types is the key to cost-effective nutrient management.

The first step in achieving these basic principles is to obtain information about soil types across the farm. Soils can differ markedly across a farm and identifying different soil types with adequate precision to determine nutrient applications can be difficult without assistance.

Most growers use agronomic consultants to undertake fine-resolution soil mapping across the farm. This information is then used to develop prescribed fertiliser blends that match soil type and crop requirements.

Nutrient management = the right product, the right amount, in the right place, at the right time.

Employing the nutrient balance equation below is a good way to start developing better nutrient management.

Nutrient balance equation

Soil nutrients + Crop requirement = Added nutrients + Excess nutrient (should equal zero)

Table 5: Five universal principles of best practice nutrient management

Step	Goal	Action to achieve goal
1	Match nutrient inputs to crop requirements	Farm & soil mapping /development of prescribed fertiliser blends
2	Tailor timing and application methods	Nutrients applied when needed with correct equipment
3	Maximise crop uptake	Fertiliser application and/or irrigation scheduled to ensure maximum uptake by the crop Consider use of soil moisture monitoring devices
4	Monitor nutrient status and crop performance regularly (adjust as required)	Soil, leaf and sap analysis and /or monitor nutrient leaching
5	Manage & monitor nutrient management systems	Document nutrient applications and crop response

Table 6: Industry-specific nutrient management program and tools

Industry	Nutrient management courses, program and information	Tools available
Cane	Combining Profitability and Sustainability (COMPASS)—Nutrition & fertiliser use BSES Six Easy Steps to nutrient management BSES Soil constraints and management package (SCAMP) Fertcare (fertiliser industry program)	Safeguage for nutrients (risk-assessment decision tool available from the Department of Environment and Resource Management) www.canegrowers.com.au www.bses.org.au
Cotton	Cotton BMP—Land & Water Management module (soil nutrition) NUTRIpak SOILpak WATERpak	NutriLOGIC (Cotton CRC) HydroLOGIC (Cotton CRC—Irrigation management software) www.cottoncrc.org.au
Dairy	DairySAT—Nutrient module	Dairying Better-n-Better CD: Use of animal manures as fertiliser Pootential: Utilising animal waste products as fertiliser Feedlot Services Australia (www.fsaconsulting.net) Dairy Australia Nutrient Budget Calculator www.dairyaustralia.com.au Queensland Department of Employment, Economic Development and Innovation dairy calculators www.deedi.qld.gov.au
Horticulture	Growcom FMS—Nutrient module Guidelines for Environmental Assurance in Australian Horticulture Freshcare—Environmental Code of Practice Fertcare Ute Guide: Healthy soils for sustainable vegetable farms (AusVeg)	Safeguage for nutrients (risk-assessment decision tool available from the Department of Environment and Resource Management)
Production nurseries	Nursery Industry Accreditation Scheme Australia (NIASA)—BMP Guidelines EcoHort—Guidelines for managing the environment.	Nursery Papers Collection www.ngiq.asn.au

Best practice: erosion and sediment management

On-farm risks managed

- **soil degradation and loss**
- **poor quality of re-use water**
- **inundation of production area**
- **nutrient & chemical loss**
- **spread of weeds.**

Wetland risks managed

- **sedimentation of wetlands**
- **water quality decline**
- **increased water weeds.**

Although natural and artificial wetlands have the ability to cope with some sediment and nutrient inputs, the amount of sediment and other potential pollutants from an intensive agricultural operation can reduce a wetland's capacity to process or absorb nutrients and other pollutants.

Wetland soils (like most soils) have a limited capacity to absorb (or adsorb) nutrients and excessive sediment loads before they cause the natural filtering ability of wetlands to break down.

Sediment infilling of wetlands decreases the wetland depth. This can change the composition of wetland vegetation as nutrient rich sediments can be quickly colonised by invasive weeds and grasses (e.g. hymenachne and para grass).

Allowing unmanaged farm runoff (which can contain high sediment and nutrient loads) to enter wetlands has the potential to severely damage wetland values, reduce productivity and expose the business to risk of causing environmental harm.

Protecting wetlands by managing farm runoff

There are typically periods between planting and harvesting when the soil surface is exposed to potential erosion and sediment transport.

In annual cropping systems the fallow period needs to be managed to maintain high levels of surface cover, especially during the autumn, spring and summer months, which is the period of highest erosion risk in Queensland (Carey, 2007).

In tree-cropping systems, soil compaction and sub-standard management of the inter-row (e.g. inadequate grass or mulch cover) can reduce infiltration and increase runoff.

The keys to controlling erosion are:

- use climate forecasting to aid management of soil erosion at times of high probability of above average rainfall (www.bom.gov.au/climate)
- use land in accordance with its capability
- protect the soil surface with some form of cover
- control runoff before it develops into an erosive force.

What can be done to manage farm runoff?

There are numerous sediment and erosion control structures that can be used to reduce the incidence of agricultural runoff. The simplest measures involve using standard industry best practices. These include:

- effective farm design
- the adoption of minimum tillage systems
- maintaining ground cover in high rainfall periods
- appropriate fallow management (e.g. cover crops, stubble detention and trash blanketing)
- installing and maintaining effective wetland buffers or filter strips
- the use of sediment management devices (e.g. sediment traps).

These standard approaches to soil and erosion management are included in various modules of industry FMS programs (see Table 9, page 25).

However, some farming systems and landscape types require additional runoff control measures (e.g. strip cropping, contour banks or drains) that can be over and above standard industry practice and are generally determined by farm location, slope, row lengths and soil type (see the highlighted box).

The efficiency of erosion control structures such as contour banks depends on the original design and level of maintenance. To help producers and extension personnel, the Department of Environment and Resource Management has produced a *soil conservation design manual* for a range of intensive and extensive agricultural applications. The manual details effective farm design and how to design and construct soil conservation devices.

To access the manual, visit <www.derm.qld.gov.au/land/management/erosion/index.html>.

Using the sediment budget approach

One approach to managing and reducing erosion from the production landscape is to identify sediment **sources** and sediment **sinks**. This is also known as developing a sediment budget (Reghenzani and Roth, 2006).

A sediment budget resembles a bank account in that:

- sediments that are moved from their original position equal **cash flow within the account**
- sediments moved but deposited on the farm equal **cash being stored in the account**
- sediments leaving the farm landscape equal **cash leaving the account**.

The sediment budget approach can guide the landholder to consider where on the farm the sediment is coming from (sediment sources), where on the farm the sediment is being deposited; or where it is exiting the farm (sediment sink). This helps focus efforts on areas that may require greater attention in order to reduce soil losses (Reghenzani and Roth, 2006).

In using the sediment budget approach the key issue is not the total amount of sediment loss but recognising that principal sources of sediment may originate from multiple parts of the farm system. Each sediment source may require a different control strategy.

Using oats as a green mulch in the inter-rows of this pineapple crop reduced soil loss by 53 tonnes per hectare over the 18-month cropping cycle compared to the conventional system. (Photo by Ian Layden).

Table 7: Erosion-control practices and devices and their suitability to industry

Erosion control measure	Industry Type					
	Cane	Cotton	Dairy	Horticulture (annuals)	Horticulture (tree crops)	Production nursery
Grassed drains/swales	●	●	●	●	●	●
Filter strips (grassed)	●	●	●	●	●	●
Sediment (silt) basins/traps	●	●	●	●	●	●
Contour mounds/planting	●	●	●	●	●	●
Constructed treatment wetlands	●	●	●	●	●	●
Tail-water detention basins	●	●		●	●	●
Cover crops (inc. stubble, mulches, and inter-row covers)	●	●	●	●	●	
Living mulches				●	●	
Green trash blanketing	●					
Controlled traffic farming (CTF)	●	●	●	●	●	
Minimum tillage	●	●	●	●		
Effluent pond or solids trap			●			

Table 8: Advantages and limitations of erosion-control measures

Erosion-control measure	Erosion-control value	Advantages	Limitations
Contour mounds	High—depends on type of grass used and if vegetation is maintained	• Low cost • Average lifespan before maintenance 5–10 years	• Effectiveness highly dependent on design and construction • Capacity declines over time • Prone to failure if earth becomes cracked in dry periods
Grassed drains/swales	High	• Low cost • Able to convey high flows • Can be used as traffic area	• Requires design • Suitable for gentle slopes • May become sediment source if grass cover not maintained
Filter strips	High—dependent on: • width of strip • type of vegetation used • maintenance • adjacent slope	• Simple to install and maintain • Effective on coarse sediment types • Can also be used as headland or traffic area	• Ground cover needs to be maintained • Can require weed control to ensure grasses remain dominant • Land area required to achieve effective filtering of fine particles/soluble nutrients
Sediment basins/traps	Medium/high—depending on design and site variables (e.g. soil types)	• Good when used in conjunction with other soil management practices • Good for trapping coarse soil particles • Can provide water reuse option	• Requires other land management practices to be implemented • Provides final trapping of sediment only • Not effective in trapping fine particles/ mobile nutrients • Requires regular emptying • Pollutants may break down in collected sediment and be re-suspended during high flows
Constructed wetlands (see Part 4 of this handbook)	Low—unless used in conjunction with other measures	• Able to provide nutrient treatment • Can provide habitat value • Can provide water reuse option	• Can be expensive to construct • Requires sound understanding of site hydrology • In-flows need pre-treatment • Prone to failure if poorly designed
Ground covers (stubbles, mulches & cover crops)	Medium/high	• Reduces runoff velocities at the source • Improved soil health • Irrigation and nutrient efficiency • Potential for yield improvement • Green manure/fertiliser source • Can aid nematode control • Potential to double crop	• Potential for root diseases & crop health issues through increased water retention (crop dependent) • Needs soil moisture for germination • Minimal erosion control until germination
Controlled traffic farming (CTF)/minimum tillage	Medium/high	• Improved soil structure/health • Increased water filtration • Reduced fuel/labour costs • Better management of soil types across the farm through the development of zones	• High start-up costs • Requires change in farm operations/ implements • Can require increased weed control compared to conventional • Compacted areas may become sediment source in sloping areas

Table 9: FMS toolbox for sediment and erosion management

Industry type	Industry-specific erosion and sediment management information
Cane	• Canegrowers COMPASS (SmartCANE) –Section 2: Soil health & conservation –Section 4: Drainage –Section 6: Management of vegetation www.canegrowers.com.au • BSES –*Riparian and Wetland Areas on Sugar cane Farms:* Volume 6 Canegrowers Best Management Practice series –Farm Productivity Assessment (FPA) –Cane-Check—BMP Manual –Best practice surface drainage for low-lying sugar cane lands (Herbert District): a manual for extensionists and practitioners. www.bses.org.au
Cotton	• Cotton BMP Manual (FMS) Land & Water Management module: –Objective 2: Good soil management –Objective 8: Good riparian management • Cotton Australia—SOILpak • Cotton CRC: Managing riparian lands in the cotton industry –Design principles for healthy waterways on cotton farms www.cottoncrc.org.au
Dairy	• DairySAT (FMS) chapters –Irrigation –Effluent management –Soils –Pests & weeds –Biodiversity www.dairyinfo.biz
Horticulture	• Freshcare—Environmental Code of Practice (Element E3—Land & Soil) www.freshcare.com.au • Ute Guide: Healthy soils for sustainable vegetable farms (AusVeg) www.ausveg.com.au • Guidelines for Environmental Assurance in Australian Horticulture—Section 5 Land & Soil Management • QPIF Agrilink Series (telephone 13 25 23) • Pineapple Grower's Handbook for Management of Erosion and Sedimentation • Golden Circle Pineapple BMP Manual www.goldencircle.com.au • Queensland Strawberry Growers Assoc. BMP Manual www.healthycountry.org/HealthyCountry/Resources/SustainableLandManagementResources.aspx • QPIF *Managing Soil Erosion in Vegetables—How well am I doing?* fact sheet
Production nurseries	• Nursery Industry Accreditation Scheme Australia (NIASA)—Best Management Practice Guidelines • EcoHort—Guidelines for managing the environment (www.ngiq.asn.au)

Best practice: spray-drift management

On-farm risks managed
- **chemical loss**
- **off-target effects**
- **surface & groundwater contamination.**

Wetland risks managed
- **damage to sensitive vegetation**
- **surface & groundwater contamination**
- **adverse biodiversity impacts.**

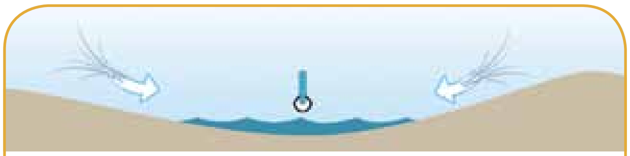
Contamination of wetland areas with agricultural chemicals poses a significant threat to aquatic ecosystems and drinking water resources. Wetland biodiversity (plants and animals) are sensitive to chemicals and spray-drift can degrade the values of a wetland by:

- reducing water quality
- causing dieback of wetland and fringing vegetation, which reduces shading and increases risk of erosion
- direct poisoning of fish and other wetland animals such as frogs.

As wetlands typically occupy low parts of the landscape they are susceptible to spray-drift caused by katabatic (also known as cold-air drainage, see diagram below) wind flows. This means that overnight, when air over a slope is cooled by cold ground it becomes dense and heavy and drains to lower levels.

What is spray-drift?

Spray-drift consists of any non-target pesticide (including herbicides) lost as a result of either aerial or ground application. It occurs when chemical droplets/particles or vapour remain in the air after application and move to non-target areas.



Cold air drains down slopes, particularly overnight, when the air over a slope is cooled by cold ground, becoming dense and heavy. It drains to the lower parts of the landscape, where wetlands are most commonly found

Cold air flowing down slope

Cold air pooling in a low part of the landscape, over a wetland

Agricultural chemicals (sometimes called agrochemicals, agchems, pesticides or farm chemicals) are substances used for controlling or managing pests or weeds in specific crop or non-crop situations. They are generally classified according to their use and the intended target, for example insecticides, herbicides, fungicides, nematicides and rodenticides (QDPI&F, 2005).

Sprayed chemicals can drift as **droplets**, **vapours** or **particles**.

Droplet drift is the easiest to control because under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant surfaces. Droplet drift is the most common cause of off-target damage caused by herbicide application. For example, spraying fallows with glyphosate under the wrong conditions can lead to severe damage to nearby established crops or natural areas.

Particle drift occurs when water and other chemical carriers evaporate quickly from the droplet leaving tiny **particles** of concentrated chemical. This can occur with herbicide formulations other than esters. Instances of this form of drift have damaged susceptible crops up to 30 km from the source.

Vapour drift is confined to volatile pesticides such as short-chain 2,4-D esters. Vapours may arise directly from the spray or evaporation of herbicide from sprayed surfaces. Use of 2,4-D esters in summer can lead to vapour drift damage of highly susceptible crops such as tomatoes, sunflowers, soybeans, cotton and grapes. This may occur hours after the herbicide has been applied (Storrie, 2007).

The Australian Pesticides and Veterinary Medicines Authority (APVMA)—the agency that registers agricultural chemicals in Australia—has placed restrictions on the application of some 2,4-D ester products. Products containing 2,4-D as either the ethyl, butyl or isobutyl ester have been classified as high volatile esters and their use is confined to between 1 May and 21 August.

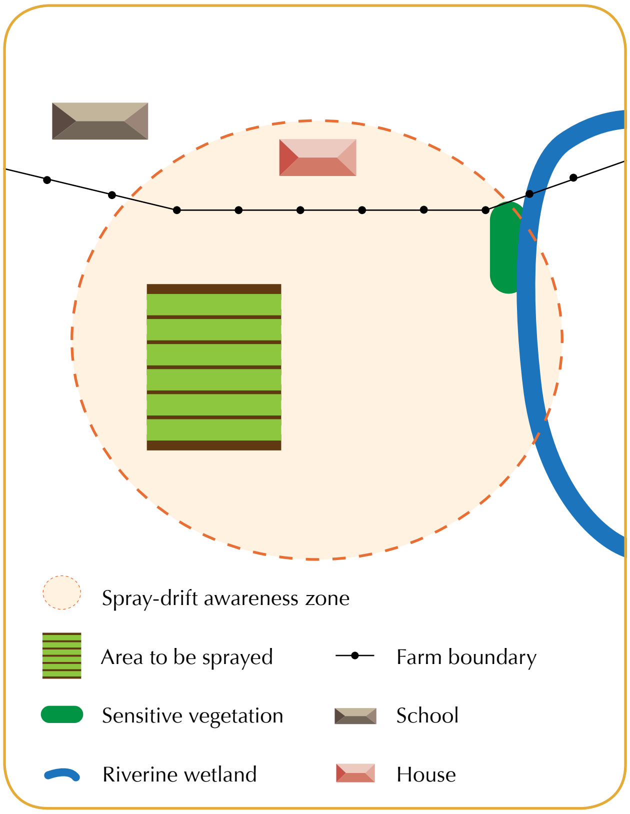
More information on the restrictions imposed on 2,4-D ester products can be found at the APVMA website (www.apvma.gov.au).

The causes of spray-drift are one, or a combination of, the following:

- spraying in unsuitable weather conditions
- incorrect type of equipment or using spray equipment outside manufacturer's recommendations
- using an unsuitable chemical formulation for a particular use or area (e.g. one that is registered or approved for a use other than the intended use)
- using a droplet size that is too small (QDPI&F, 2005).

All agricultural chemicals are capable of drift and there is a moral and legal responsibility to prevent pesticides from drifting and contaminating or damaging neighbours' crops and sensitive areas such as wetlands (Ensbey and Johnson, 2007).

However, the risks posed by the application of agricultural chemicals can be substantially reduced by employing appropriate management actions. When applying pesticides the aim is to maximise the amount reaching the target and to minimise the amount reaching off-target areas. This results in maximum chemical effectiveness and reduced damage and/or contamination of off-target crops and environmental areas.



Spray-drift awareness zone

Key principles for managing spray-drift

Good spray-drift management employs a number of techniques to minimise off-target contamination while achieving maximum pesticide effectiveness.

1. **Establishing spray-drift awareness zones:** Establishing awareness zones and identifying sensitive areas (see schematic below) is the first step in managing spray-drift and is best undertaken using a property planning approach. In most circumstances the awareness zone for ground-based spraying could range from 100 m to 1 km from the paddock to be sprayed, and up to 5 km for aerial applications (PISC, 2002).

   The width of the awareness zone depends on the presence of sensitive areas such as wetlands and the presence of local meteorological/wind patterns. Identifying an awareness zone doesn't imply spray-drift will not be transported beyond that zone or excuse poor chemical management (PISC, 2002).

   It is important not to confuse awareness zones with buffer zones.

2. **Avoiding undesirable weather conditions:** Weather plays an important part in the final destination of applied agricultural chemicals. There are three main weather or climatic variables that need to be considered before chemicals are applied:

   - ***Wind speed and direction***—apply when the wind speed is steady and between 3–15 km/hr and blowing away from wetland or other sensitive areas. Avoid calm conditions where small droplets may remain suspended for long periods.

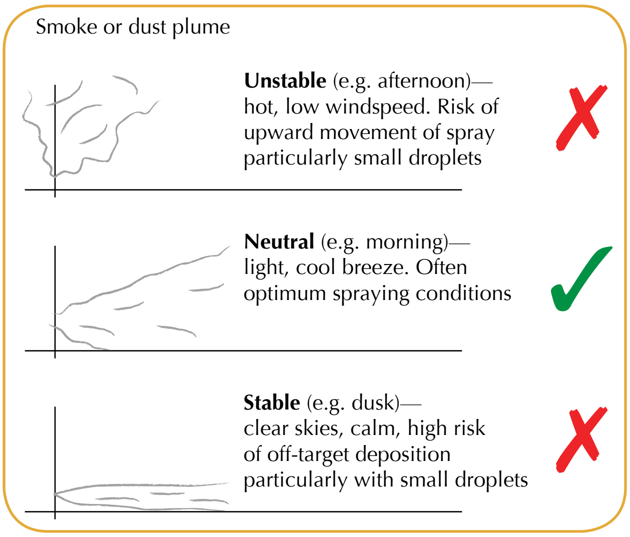
     Wind at ground level tends to flow in much the same way as water flows in a stream and maximum wind variation occurs during late morning and mid afternoon. Wind may also be deflected or blocked by obstacles (BOM, 2004).

   - ***Temperature and humidity***—ground temperature may be up to 20 °C higher on a hot day. Volatile pesticides exposed to high temperatures are inclined to vapourise, releasing damaging vapour.

     Humidity affects evaporation rate. Humidity levels of greater than 45 per cent are often recommended for spraying, but very high humidity can suppress droplet evaporation, leading to extended life and unacceptable spray-drift. On the other hand, if humidity is too low, water-based droplets—especially small ones—quickly evaporate leading to a high risk of spray-drift occurring.

   - Atmospheric stability—atmospheric stability refers to the vertical movement of air in the atmosphere. A stable atmosphere will resist upward motion of air, an unstable atmosphere will assist it, while a neutral atmosphere will neither assist nor resist it.

A neutral atmosphere is therefore best for spraying since droplets will fall solely under gravitational force—rather than being swept up by air currents in unstable conditions. Atmospheric stability can be assessed by using smoke or driving a vehicle along a dusty track (PISC, 2002).



A guide to the behaviour of smoke or dust under various atmospheric conditions

Adapted from *Spray-drift Management: Principles, Strategies and Supporting Information*. Primary Industries Report Series 82. © Commonwealth of Australia and each of its states and territories 2002. www.publish.csiro.au/pid/3452.htm.

Seven-day computer-generated forecasts of temperature, humidity, precipitation and wind are available for any location around Australia through the Bureau of Meteorology's SILO website for a small annual fee. For details, visit <www.bom.gov.au/silo/products/meteograms>.

3. **Selection of the appropriate droplet size**: the required droplet sizes used to deliver agricultural chemicals are small and are measured in microns (µm).

   The selection and calibration of spray equipment that is suited to the chemical type and the target is a key method to improve both spray efficiency and minimising any off-target effects.

   Spray equipment can be selected to produce droplets within a desired size range that is best suited to the crop or target. Following the formation of the droplet it must be transferred to the target. Size, speed, evaporation rates and weather conditions influences how it moves through the air (PISC, 2002).

   The examples below demonstrate how droplet size influences the distance of drift.

   - A 250µm (micrometre) droplet has a sedimentation rate (the rate at which it falls to the ground) of 1 metre per second. This means it will fall to the ground a few seconds after release from most spray equipment.
   - A 100µm droplet has a sedimentation velocity of 0.25 metres per second and can impact on surfaces several hundred metres downwind of the release point.

Controlling droplet size is essential to managing spray-drift. The larger the droplet size, the less a spray is susceptible to drift.

Table 10 (below) shows a range of droplet sizes and their predicted transport distance in a 1 metre/second crosswind.

Table 10: Theoretical downwind distance droplets would be transported if released 3 m above a crop

Droplet diameter(µm)	Sedimentation rate (m/sec)	Time taken for droplet to fall 3 m.	Downwind displacement in a 1m/sec crosswind.
1	0.00003	28.1 hours	10,000.0
10	0.003	16.9 minutes	1000.0
20	0.012	4.2 minutes	250.0
50	0.075	40.5 seconds	40.0
100	0.28	10.9 seconds	10.7
200	0.72	4.2 seconds	4.2
500	2.14	1.7 seconds	1.4
1000	5.0	0.8 seconds	0.6

Notes: assumes a steady crosswind of 1 metre per sec. Table should not be used to predict the transport of very small droplets as their motion is determined by turbulence rather than gravity. (PISC, 2002).

4. **Design and placement of vegetative barriers to buffer spray-drift:** Vegetative barriers are useful for reducing (or buffering) the downwind impact of spray-drift. The aim of a vegetative barrier to reduce spray-drift is to use natural surfaces (leaves, stems, flowers) of the vegetation to collect chemical droplets as air flows through or over the buffer area (PISC, 2002).

   Some pesticide labels specify downwind buffer distances that are required to prevent damage to sensitive areas (e.g. endosulfan requires a 200 m buffer distance when spraying at ground level). Buffer width, however, is determined by factors such as:

   - buffer type (e.g. vegetation, fallow area, hard structures)
   - weather conditions
   - toxicity of the chemical being applied
   - sensitivity of the areas that may be affected (e.g. wetlands, native vegetation, residential areas)
   - method of chemical application used
   - chemical release height (lower the release height the less potential for drift).

   Trees, shrubs, crops and fallow areas planted downwind of a production area can be used to recover or trap spray droplets, therefore mitigating the effects of spray-drift. Importantly, there is some vegetation that is more effective at intercepting spray-drift. The following are key points to consider when designing vegetative barriers:

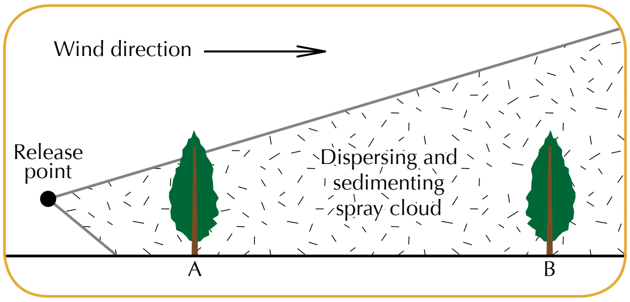
   - plant surfaces that have a small frontal area are more effective in trapping droplets. Trees such as she-oaks (*Casuarina* spp.) with needle-like leaves and numerous branches are particularly suitable
   - plants that have large leaves covered with small hairs are also effective
   - a semi-permeable barrier (i.e. you should just be able to see through it) allows air to pass through foliage and filters out spray particles and dust
   - to be effective, vegetation should be at least 50 percent taller than the target (crop) plant
   - vegetation should be located in consideration of sunlight and prevailing wind direction
   - vegetation should be made up of multiple rows if possible (DPI Victoria, 2002).

Droplet release height versus distance to buffer

The release height of the chemical is an important factor that influences the amount of spray-drift. The higher the droplets are released the greater the risk of drift (PISC, 2002).

The figure right shows the relationship between release height and distance to a vegetative buffer.

The buffer at position A is able to intercept a greater proportion of the spray. Although the buffer at position B will intercept droplets at ground level it has minimal effect on droplets above the buffer.



Effect of buffer distance on the point of release of the chemical

Source: *Spray-drift Management: Principles, Strategies and Supporting Information*. Primary Industries Report Series 82. © Commonwealth of Australia and each of its states and territories 2002. www.publish.csiro.au/pid/3452.htm.

Additional resources for managing spray-drift

- **QDPI&F (2005) Agricultural Chemical Users Manual: guidelines and principles for responsible agricultural chemical use. (Queensland Department of Primary Industries & Fisheries: Brisbane). www.deedi.qld.gov.au**
- **PISC (2002) Spray-drift management: principles, strategies and supporting information. Primary Industries Standing Committee, Report No. 82. (CSIRO Publishing: Collingwood, Victoria). www.publish.csiro.au/pid/3452.htm**
- **Ensbey R, Johnson A (2007) Noxious and Environmental Weed Control Handbook: a guide to weed control in non-crop, aquatic and bushland situations, 3rd edition. (NSW Department of Primary Industries). www.dpi.nsw.gov.au/agriculture/pests-weeds/weeds/**

Best practice: wetland buffers

On-farm risks managed

- **soil degradation and loss**
- **nutrient and chemical loss**
- **crop damage.**

Wetland risks managed

- **sedimentation of wetlands**
- **adverse biodiversity impacts**
- **adverse impacts on wetland health**
- **increased water weeds.**

The use of vegetative buffers has long been recognised as an effective long-term method to reduce the export of sediment and nutrients from the landscape.

Vegetation buffers can also perform many other functions such as providing bank stability, flood management, crop protection and spray-drift management. They also provide habitat and promote biodiversity.

What is a wetland buffer?

Buffers are the transition zone between the wetland or riverine ecosystems and the surrounding land use. They help protect and support the functions and values of wetlands (EPA, 2006b).

They are the area surrounding wetlands from which normal farm activities can be excluded or more actively controlled.

Types of buffers

Vegetation buffers generally consist of grass filter strips, native shrub and tree species or a combination of both. However, buffering ability can be enhanced by structures and filters such as:

- fences that help to manage vehicles and stock that are damaging sensitive vegetation
- grassed farm drains/headlands
- straw (hay) bales or sediment fences that help trap runoff
- hard engineering devices (such as sediment traps and constructed wetlands).

Wetland buffers can perform many functions:

- reducing surface water runoff from farmland into the wetland
- maintaining good water quality in a wetland by reducing sediment, nutrient and pollutant loads contained in farm runoff
- reducing flood damage by slowing overland flows
- minimising spray-drift entering the wetland area
- minimising invasion by weed species
- providing habitat and shelter for a range of plants and animals
- provision of habitat for desirable species in integrated pest management programs
- contribute to wildlife corridors between the wetland and adjacent wetlands or bushland
- provide a buffer area between residential areas and nuisance insects such as mosquitoes and midges
- provide an area for passive recreational activities such as bird watching, photography and bush walking.

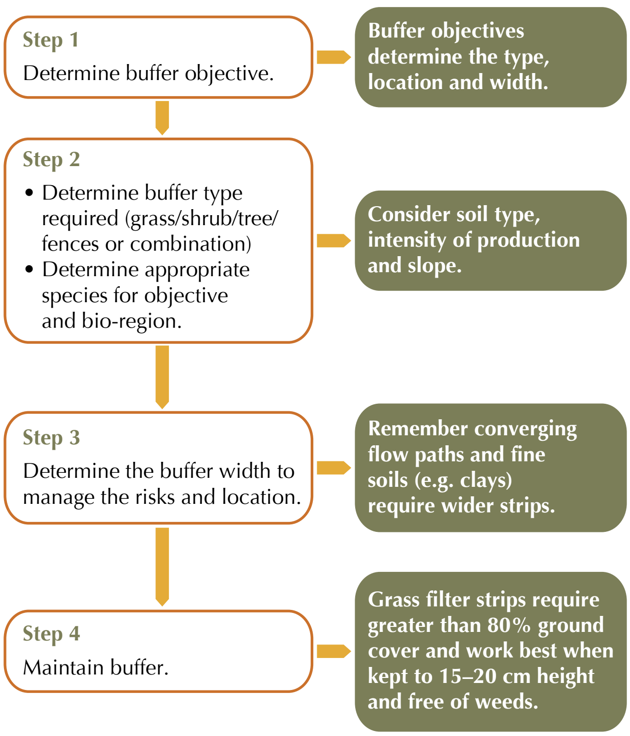
Designing vegetation buffers

In intensive agriculture, buffers are typically used to reduce soil (and associated nutrient loss) moving from the production area while also providing trafficable areas.

There is no one-size-fits-all approach to determining buffer width and, in most cases, buffer width and the type of vegetation used depends on:

- objective of the buffer (e.g. to improve water quality, provide habitat, reduce spray-drift, provide bank stability)
- the intensity or risk presented by production activities
- rainfall intensity
- location in the landscape (e.g. are you buffering a 1st, 2nd, or 3rd-order stream, floodplain or uplands?)
- slope
- soil type (sands or clays)
- the type of buffer material used (e.g. grass, shrubs, trees)
- additional complementary engineering works (e.g. contour banks, straw bale barriers, and sediment control fences)
- overall farm management (e.g. the use of farm BMPs such as stubble cover, trash blanketing, cover cropping).

Four steps to designing wetland buffers



Step 1—Determine the objectives

The location, type and width of a wetland (or waterway) buffer depend on the intended buffer objective.

Objectives might include the management and/or protection of:

- water quality
- streambank stabilisation
- soil conservation
- flood management
- wildlife habitat or biodiversity corridors.

Step 2—Identify the best vegetation types or buffer material to meet the objectives

Grasses versus trees and shrubs
If using a grass filter strip to reduce sediment and nutrient loss the most important characteristics are its structure, density and condition.

The density of the vegetation at ground level is the most important. Sediment deposition is achieved by reducing flow velocities. Stems that are close together increase surface roughness and therefore improve sediment trapping ability (Karssies and Prosser, 1999). For this reason, it is better to establish grass with a spreading habit (e.g. kikuyu, couch or signal grass) rather than grasses that tussock or have a bunching habit (Prosser *et al.*, 2001).

In general, dense grass will provide a more effective filter on steeper riparian land than trees or shrubs. However, retaining only grass on stream banks will do very little to minimise erosion during flow events. If stream bank stabilisation is the objective then a mix of tree, shrub and groundcovers is required.

Trees provide ecological benefit in all situations and a combination of both trees and grasses should be considered (Prosser *et al.*, 2001). Table 11 (right) indicates the relative effectiveness of different vegetation types for a range of objectives.

Table 11: Relative effectiveness of different vegetation types

Buffer objective	Effectiveness of vegetation type		
	Grass	Shrub	Tree
Stabilise bank erosion	Low	High	High
Filter sediment	High	Low	Low to medium
Filter nutrients and pesticides:			
• sediment bound	High	Low	Low
• soluble	Medium	Low	Medium
Aquatic habitat	Low	Medium	High
Bank failure prevention	Low	Medium	High
Flood mitigation	Low	Medium	High
Spray-drift management	Low	Medium to high	Medium to high

Based on: Karssies and Prosser (1999); Fischer and Fischenich (2000).

Step 3—Determining buffer widths and location
The objective will determine the buffer width. For example if the goal is biodiversity protection then the range of specific plant species and buffer widths will be important. Table 12 (below) shows a range of buffer objectives and the widths required to achieve the intended objectives.

For the purposes of filtering out sediment and nutrients, aim for a buffer width of at least 10 m for a **forest (or tree) buffer.** On low gradient land a minimum width of 5 m is recommended for a grass filter strip to be effective over more than one rainfall runoff event. (Karssies and Prosser, 1999; Prosser *et al.*, 2001).

Table 12: General buffer strip guidelines

Buffer objective	Description	Recommended buffer width
Water quality	Buffers, especially dense grassy or herbaceous buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants, and promote groundwater recharge. For low to moderate slopes most filtering occurs within the first 10 m; greater widths are necessary for steeper slopes, soils that have fine particles and regions that receive high-intensity rainfall.	10–30 m
Stream/bank stabilisation	Riparian vegetation moderates soil moisture conditions in stream banks, and roots provide tensile strength to the soil matrix, enhancing bank stability. Good erosion control may require the protection of only a width of riparian vegetation back from the top of the bank that is equal to the height of the bank. Where there is active bank erosion a wider buffer will be required. Major bank erosion may require additional hard or soft engineering techniques.	10–50 m
Spray-drift	Medium to tall tree buffers are better at reducing spray-drift. Species with fine or hairy leaves (*Casuarina* spp.) are recommended.	40–300 m
Flood attenuation	Riparian buffers promote floodplain storage due to backwater effects. They intercept overland flow and increase travel time, resulting in reduced flood peaks.	20–150 m
Habitat	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife.	30–500 m+

Based on Rutherfurd and Abernathy (1999); Fischer and Fischenich (2000); Prosser and Karssies (2001).

Examples of buffer management

Example of a narrow buffer which lacks sufficient grass cover to prevent soil and/or nutrient runoff into the adjacent wetland. Inadequate buffer management may result in environmental harm. (Photo by Ian Layden).

Maintained grassed headlands in conjunction with riparian vegetation represents best practice runoff management. (Photo by Zane Nicholls).

Areas that require extra buffer width
Although a general rule should be to provide the widest buffer possible, some parts of the landscape, particularly where overland flows come together (or converge), require wider buffers to manage increased water velocity and the associated sediment loads.

Buffer strips (grass filters and trees) should be located in areas to intercept runoff from the production area. This includes farm drains and levees that channel water.

Soils that have predominantly fine particles (such as clays) will generally require a wider filter strip.

Buffer distances for regions such as the Wet Tropics where surface erosion rates are high or where flow paths converge can require grass filter strips to be more than 30 m wide to achieve sufficient sediment trapping (Karssies and Prosser, 1999).

However, where possible it is generally more efficient to reduce the intensity of the runoff/sediment source rather than continuing to extend the buffer distance (Prosser *et al.*, 2001).

Levee banks
Many streams have naturally developed levee banks that act to channel flow in flood times and prevent overtopping of banks and inundation of floodplains. These levees are a natural feature of many streams, resulting from past overtopping and stabilisation of those sediments (Lovett and Price, 2001).

Use of grassed filter strips in conjunction with replanting of natural riparian vegetation, is likely to help re-establish such levees. It is important that in developing production land for farming these natural levees are identified and retained, otherwise the risk of periodic flooding will be substantially increased (Lovett and Price, 2001).

However, constructing or increasing the height of natural levee banks runs counter to the basic principle of spreading flood flows as they tend to concentrate flows, which can lead to higher water velocities and increased potential for erosion (Carey, 2004).

Levees along a watercourse can increase the discharge downstream and thus increase flooding problems. Further, serious scouring and gully erosion can also result if a constructed levee bank is breached and water rushes through in a confined flow (Carey, 2004).

The areas where runoff converges will require additional buffer management.

Table 13 (overleaf) shows the relationship between soil and rain erosivity, ground cover, slope and soil loss when considering widths for grass filter strips.

Table 13: Indicative soil losses and design-grass filter-strip widths for Queensland regions

Region (annual rainfall—mm)	Rainfall erosivity*	Soil erodibility*	Slope*	Soil loss if poor cover* (t/ha/yr)	Filter width required (m)	Soil loss if good cover (t/ha/yr)	Filter width required (m)
Wet Tropics (800–5000)	High	Medium	Low	17	7	1	2
			Medium	41	26	2	2
			High	74	>30	4	2
	Very high	High	Low	25	15	1	5
			Medium	61	>30	3	5
			High	112	>30	6	7
		Medium	Low	29	15	1	2
			Medium	71	>30	4	2
			High	130	>30	7	2
		High	Low	44	27	2	5
			Medium	107	>30	5	7
			High	195	>30	10	10
Wet Tropics (800–5000)	Extreme	Medium	Low	38	20	2	2
			Medium	92	>30	5	2
			High	167	>30	8	2
		High	Low	57	>30	3	5
			Medium	138	>30	7	7
			High	251	>30	13	12
Dry Tropics (500–1200) (also use for Brigalow bioregion)	High	Low	Low	8	2	0	2
			Medium	20	13	1	2
			High	37	24	2	2
		Medium	Low	17	7	1	2
			Medium	41	26	2	2
			High	74	>30	4	2
Dry Tropics (500–1200) (also use for Brigalow bioregion)	High	High	Low	25	15	1	5
			Medium	61	>30	3	5
			High	112	>30	6	7
	Very high	Low	Low	15	5	1	2
			Medium	36	23	2	2
			High	65	>30	3	2
		Medium	Low	29	15	1	2
			Medium	71	>30	4	2
			High	130	>30	7	2
		High	Low	44	27	2	5
			Medium	107	>30	5	6
			High	195	>30	10	10
South-east (800–2000)	Medium	Medium	Low	8	2	1	2
			Medium	20	13	1	2
			High	37	24	2	2
South-east (800–2000)	High	Low	Low	8	2	1	2
			Medium	20	13	1	2
			High	37	24	2	2
		Medium	Low	17	7	1	2
			Medium	41	26	2	2
			High	74	>30	4	2
		High	Low	25	15	1	5
			Medium	61	>30	3	5
			High	112	>30	6	5

*Based on Karssies and Prosser (1999), www.clw.csiro.au/publications/technical99/tr32-99.pdf

Remember that buffer distances and types should be based on the key *threatening processes* and can include both vegetation and other buffer elements like sediment traps, hay bales and check dams.

Buffering nitrates in groundwater with riparian vegetation
Riparian zones can provide a protective buffer between streams and adjacent land-based activities by removing nitrate from the shallow groundwater flowing through the riparian zone (Rassam *et al.*, 2005).

Denitrification in the riparian zones of perennial streams primarily occurs via two mechanisms: firstly, as base flow passes though the riparian zone; and secondly, as stream water is stored in banks when a flood wave passes (Rassam *et al.*, 2005).

Denitrification is assumed to occur only in the saturated part of the root zone across the width of vegetated riparian buffers.

For maximal nitrate removal in riparian buffers, the following features are important:

- Buffer zones are most effective along the middle-order reaches of a river network and along low-order tributaries that have floodplains.
- The very existence of the floodplain is crucial. It is recommended that its width should be in the order of tens of metres such that it can provide a low hydraulic gradient.
- A well vegetated buffer provides a good carbon source, with deep and densely rooted vegetation an advantage.
- The nitrate-removal capacity of most soils is expected to be highest at the surface, where root density, organic matter, and microbial activity are highest; it declines rapidly with depth.
- The floodplain should have a suitable hydrology that favours denitrification. That is:
  –a shallow water table that intercepts the carbon-rich root zone, thus providing anoxic conditions
  –relatively slow flow rates that allow sufficient residence time for nitrate to be denitrified.

Step 4—Maintaining wetland buffers
Once vegetation type, width and placement have been determined and planting has been completed, a maintenance plan is necessary to obtain successful buffer establishment and long-term benefits.

Height of the vegetation is very important as this affects surface roughness (remember that increased surface roughness reduces water velocity) and occasional slashing or spot-spraying with herbicides may be required to maintain both the dominance of the desired species and a dense groundcover (Fischer and Fischenich, 2000; Karssies and Prosser, 1999).

A dense swathe of grass up to 15–20 cm high is recommended. For areas of most intense runoff, hedges of upright grasses or other dense species (e.g. *Lomandra* spp.) can be used in the waterway to trap additional sediment.

Most practitioners recommend that buffers (including headland areas) are maintained so there is **no less than 80 per cent ground cover** (headlands or buffer with cover levels less than 65 per cent begin to actively erode). This prevents the buffer from becoming a source of sediment (Karssies and Prosser, 1999; Reghenzani and Roth, 2006).

The maintenance of vegetated buffers is very important to ensure that wetlands and downstream water quality are maintained.

It is advisable to mow/slash grass filter strips before they set seed, keeping in mind that low-cut lawns have little sediment trapping capacity.

To find out more about grass or tree species to use in your buffer zones, contact your local industry representative, local government office, regional natural resource management group, or Landcare.

The use of inter-row cover crops, well maintained grassed headlands and retaining native riparian vegetation on this south-east Queensland pineapple farm is a good example of best practice wetland management. (Photo by Zane Nicholls).

Best practice: managing acid sulfate soil (ASS)

On farm risks managed
- **soil pH levels**
- **surface scalding**
- **irrigation water**
- **crop damage**
- **yield decline**
- **low pH water in drains.**

Wetland risks managed
- **contamination of surface water with acidic runoff**
- **vegetation dieback**
- **low oxygen levels in waterways**
- **fish kills.**

ASS occur naturally over extensive low-lying coastal areas, predominantly below 5 metres Australian Height Datum (AHD). In Queensland an estimated **2.3 million ha** of coastal lands contain potential or actual ASS (Brodie, 2002).

Deposits of ASS are commonly found in range of wetland environments such as:

- mangroves
- salt marshes
- floodplains
- swamps
- estuaries
- brackish or tidal lakes.

Inland wetlands along the Murray Darling which overlay old marine sediments have also been found to contain ASS.

Wetland types that correspond with ASS:

- coastal melaleuca swamp wetlands
- mangrove wetlands
- saltmarsh wetlands (saltmarshes)
- coastal grass-sedge wetlands
- inland wetlands overlaying old marine sediments.

ASS may be found close to the natural ground level but may also be found at depth in the soil profile (Dear *et al.* 2002). The presence of ASS may not be obvious on the soil surface as they are often buried beneath layers of more recently deposited soils and sediments of alluvial or aeolian (wind derived) origin (Dear *et al.* 2002).

ASS are highly variable in form, ranging from mud to sand and peat; however, they all contain iron sulfides, most commonly in the form of pyrite (FeS_2). In their normal waterlogged state, ASS are harmless to the environment; however, when disturbed by drainage, excavation or other activities, the sulfides in the soil are exposed and react with oxygen in air to produce sulfuric acid (Jaensch and Joyce 2005).

Sulfuric acid mobilises toxins such as aluminium, iron, arsenic and other metals. These toxins leach into waterways and can cause serious consequences such as poisoning of fish, oysters, crabs and other aquatic life. ASS can also promote diseases such as fish red-spot, and corrode and destroy concrete and steel structures (Jaensch and Joyce 2005).

Draining of wetlands can lower water tables, causing oxidation of naturally occurring but potentially destructive ASS. If exposed to air through cultivation or drain construction these soils can release metals that are harmful to fish and other aquatic life.

Identifying actual acid sulfate

Soil mapping
Mapping at 1:100,000 scale has been completed in south-east Queensland from the New South Wales border to Noosa.

More detailed maps (1:25,000 and 1:50,000 scale) have been prepared for selected sugar cane areas (including Rocky Point, Moreton, Maryborough and Bundaberg), the Gold Coast hinterland, and the Maroochy River catchment.

Mapping has also been conducted around Mackay, in areas from Gladstone to Yeppoon, Cairns and the coastal areas near Ingham.

Potential acid sulfate soil
Potential acid sulfate soil (PASS) are soils containing iron sulfides (commonly pyrite) that have the potential to produce sulfuric acid if they are drained or excavated. Preliminary identification can be carried out using the field test for peroxide oxidised pH (pH_{FOX}), and confirmed by laboratory analyses.

Actual acid sulfate soil
Actual acid sulfate soil (AASS) have already undergone oxidation to produce acid, resulting in a soil pH of **less than 4**. They also often exhibit a yellow and/or red mottling in the soil profile. If these soils still contain sulfides, they have the potential to produce more acid if allowed to oxidise further. This would be identified by a further decrease in pH reflected in the pH_{FOX}. AASS should also be confirmed by laboratory analysis.

Jarosite (yellow) mottling is an indicator of ASS. (Photo courtesy of the Department of Environment and Resource Management).

Collective evidence

Generally, the more indicators there are at a site, the more confidence there can be in a positive identification of ASS. Some indicators are more conclusive than others, with jarosite being one of the most conclusive.

Although indicators and environmental effects typical of ASS may be due to factors other than ASS, ASS should always be considered in coastal areas below five metres (AHD), and each site should be assessed on an individual basis.

Laboratory analysis is the most accurate indicator of ASS, and results can be used to determine the level of acidity, from which liming rates can be calculated.

Managing actual acid sulfate in the production system

While minimising the disturbance should be the primary goal, there are a variety of management options available to treat ASS. The selection of an appropriate management option will depend on the:

- physical and chemical characteristics of the ASS
- the hydrological circumstances
- the environmental sensitivity of the site (Watling and Dear, 2006).

All disturbances to subsoil, sediments, groundwater hydrology or surface drainage patterns in coastal areas below 5 m AHD, should be investigated, designed and managed to avoid potential adverse effects on the natural and built environment from ASS (Dear *et al.*, 2002).

Current best practice is to avoid inappropriate drainage of these soils and to manage existing drained lands and drains to minimise movement of acid off-site into wetlands and waterways.

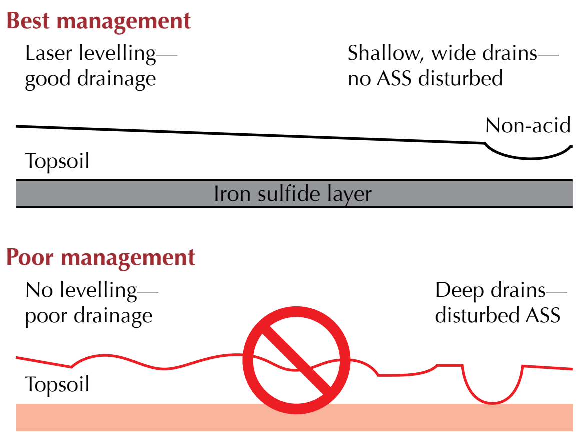
Best management practice options

The best management practice options include:

Minimisation of disturbance: If ASS cannot be avoided, their disturbance should be minimised. Strategies that aim to minimise the disturbance of ASS include:

1. redesign of earthworks for sites with a variable distribution of ASS so that areas with high levels of sulfides are avoided
2. limiting disturbances on site so that only shallow disturbances are undertaken
3. redesign of existing drains so they are shallower and wider and do not penetrate sulfidic layers
4. minimising groundwater fluctuations by avoiding activities such as dewatering, the construction of deep drains and the installation of new groundwater extraction bores.

Managing ASS with laser levelling is the best approach to managing drainage in ASS environments.



Laser-levelled paddocks with shallow darins are the preferred management method for drainage in acid sulfate soils.

Source: Eldridge (2004)

Neutralisation: neutralisation of ASS involves the physical incorporation of neutralising/alkaline materials into the soil or waterway.

Agricultural lime is the best choice for ASS application. Thoroughly mixing the appropriate amount and type of lime into disturbed ASS will neutralise any acid produced. Lime has an alkaline pH and buffers any acid produced while raising the soil pH to acceptable levels. Table 14 (page 37) shows the amounts of limestone required to treat ASS spoil according to pH_{FOX} levels.

Note: the rates specified in Table 14 refer to agricultural lime that has been finely ground and applied to soil. Different products (such as dolomite) can have differing neutralising values. To achieve adequate neutralisation of ASS using other lime products, application rates may need to adjusted.

Hydrated lime is often more appropriate for treating acid waters due to its higher solubility. After acid water has been treated to pH 6.5–8.5, it can usually be safely released from the site at a controlled rate to prevent significant changes to the quality of offsite waters.

The amount of neutralising agent required depends on soil and water test results and the neutralising capacity of the lime source. Other materials that can be used include:

- quicklime
- sodium bicarbonate
- dolomite (Watling and Dear, 2006).

It is important to consider the possible downstream effects that may result from the release of neutralised water and soil.

If managed correctly farm drains can provide valuable fish habitat. (Photo by Mathew Johnston).

Table 14: Limestone requirements of drain spoil associated with ASS, based of relationships using pH_{FOX} for soil samples from coastal northern New South Wales and coastal Queensland

pH_{FOX}	Limestone rate (kg/m³)	
	Coarse textured soils	Fine and medium textured soils
0.25	85	374
0.30	66	289
0.35	54	232
0.50	33	140
0.75	19	79
1.00	13	53
1.25	9	38
1.50	7	30
2.00	5	20
2.50	4	14
3.00	3	11
4.00	2	7
5.50	1	5

Source: Raymond and Rayment (2004)

Best practice: floodgates, crossings and drain management for fisheries values

Risks managed
- **disturbance to wetland hydrology**
- **poor water quality in drains**
- **adverse biodiversity impacts.**

Wetland risk managed
- **biodiversity loss**
- **fish passage.**

On-farm wetlands and waterways, whether they be marine, freshwater, brackish water, artificial or natural are important fish habitats that can contribute significantly to the fisheries productivity of the region.

On-farm management practices to reduce sediment and nutrient runoff can help keep wetland habitats viable; however, there are a number of other best management strategies that will help maintain wetland processes, including fish habitat values.

These management practices include:

1. Keeping woody debris and other structures in farm wetlands
2. Retaining or growing riparian vegetation adjacent to wetlands
3. Floodgate management
4. Fish-friendly stream crossings
5. Providing off-stream water for stock.

Keeping woody debris (snags) and other structures in farm wetlands

Large woody debris provides one of the most important habitats for fish in a wetland. Large woody debris provides:

- protection from predators
- shelter from direct sunlight
- resting areas out of the main channel flow
- territorial markers
- breeding sites and foraging sites.

Large wood in wetlands can also reduce bank erosion and increase bank stability.

Incorporating woody debris into wetlands provides a multitude of benefits for fish. (Photo by Ian Layden).

Management actions

- Leave woody debris (logs) and other structures in place wherever possible.
- Modify woody structures by lopping, realigning or moving in preference to removal.
- Re-establish native riparian vegetation to ensure a future source of large woody debris.
- Consider 're-snagging' if your wetland is free of woody debris and other structures, because in-wetland structures can provide immediate benefits to fish.
- Before removing problem logs or re-snagging a wetland, contact the local Department of Environment and Resource Management office for advice.

Retaining or growing riparian vegetation adjacent to wetlands

Exotic vegetation such as camphor laurel, Chinese celtis, hymenachne and para grass can invade wetlands and streambanks and exclude native vegetation, changing the structure and function of the riparian zone and creating a poor habitat for native fish.

Some exotic vegetation like Chinese celtis are deciduous, and can drop their leaves all in one go. This alters the timing and quality of organic inputs in the waterbody, causing wide temperature variations and reducing the amount of oxygen, shade and protection.

Fish and other aquatic species prefer waterways with good riparian vegetation because the plants:

- provide food in the form of fruits and terrestrial insects, shelter, shade and fine organic material
- help to regulate water temperature
- are sources of large woody debris and can help filter sediment, phosphorus and organic nitrogen from runoff.

Management actions

- Revegetate riparian areas in layers with a mix of species native to your area.
- Control weeds during regeneration.
- Maintain a well-vegetated buffered area between the production area and the riparian area.
- Reduce the dominance of exotic plant species.
- Work with neighbouring landholders to prevent re-infestation of the area.

Grassed headlands and riparian vegetation adjacent to this ginger farm protect the crop, improve water quality and fish habitat. (Photo by DERM).

Floodgate management

Floodgates are widely used on farms on low-lying coastal floodplains to manage floodwater or tidal water ingress into farm drains.

Many floodgated farm drains were once natural drainage channels or tidal inlets that have been modified to suit farm drainage needs. Blockage of these habitats removes a useable and valuable resource for fish.

Although these structures are an effective means of maintaining drain function without compromising valuable farming land they can, if improperly managed, have a number of significant environmental consequences detrimental to wetland processes, such as:

- prevention of fish passage
- reduction of water quality, particularly on farms on acidic soils (such as ASS)
- growth of exotic aquatic weeds.

Prevention of fish passage

Floodgates (and other structures such as bunds) physically impede fish passage or movement into or through wetlands. Unimpeded fish movement is necessary for numerous reasons including predator evasion, food sourcing, colonisation of new habitats and breeding.

This tide activated mini-floodgate allows fish passage. (Photo by Mathew Johnston).

This floodgate on the upper end of a tidal system prevents the inflow of tidal water and fish. Note the fish blocked at the floodgate. (Photo by Matt Gordos).

Water quality

Floodgates are designed to prevent water moving into farm drainage systems. Consequently water in drains and wetlands can become very stagnant, particularly during periods of low rainfall.

Lack of flushing can lead to water quality issues including low oxygen levels and high temperatures, further reducing the value of the wetland (or drain) to fish. If the farm is in ASS areas, very low water pH levels may develop.

Increasing the level of tidal exchange raises salinity levels in the drain, which can help reduce the dominance of invasive grasses.

Although these poor-quality waters remain in the farm drain, they have no impact on downstream environments. However, when a rain event occurs the poor-quality waters are discharged into the natural environment and can cause chronic (red spot disease in fish) and acute effects (fish kills, vegetation death).

Exotic Weeds

Lack of flushing in drainage systems can also lead to the proliferation of exotic aquatic weeds such as water hyacinth. An infestation of aquatic weeds can choke the drain, reducing its ability to function effectively.

In addition to reducing drain function, aquatic weed proliferation lowers water oxygen levels, reduces the habitat values of the ecosystem for aquatic life and increases drain maintenance work (chemical or mechanical) for the producer.

Management actions

- Increasing the level of tidal exchange raises salinity levels in the drain which can help reduce the dominance of invasive grasses. Modify floodgates to allow exchange with estuarine and river water during non-flood periods. Designs include sluice gates, side-hinged floodgates, tidally activated (automatic) floodgates and winch gates. Consult Queensland Employment, Economic Development and Innovation for advice and approvals.
- Make the opening as large as possible to maximise fish passage and reduce the force of the current flowing through the opening.
- Make your drains shallower. Shallow dish drains (0.3 m depth) minimise the potential of disturbing ASS and because of the larger surface area of water, can help to oxygenate drains with low oxygen levels.

Table 15: Floodgate operation and 'fish-friendliness'

Floodgate operation	Fish-friendly rating			
	Very friendly	Friendly	Fond	Unfriendly
Manually operated	No floodgate	Winch gates Large vertical-lift sluice gates (fish friendly if predominantly left open)	Small vertical-lift sluice gates (high water velocity through gate not conducive to fish passage)	Any type of floodgate that is never or rarely opened to allow water entry
Automatic	No floodgate	Tidally activated mini-gate Electrically activated large vertical sluice gates (the above gates only close fully when tide reaches a predetermined height). Side-hinged floodgates	Holes cut in floodgate Other designs to allow water (but not fish) through floodgate structure.	Any type of floodgate that is never or rarely opened to allow water entry

Side-hinged floodgate. (Photo by Mathew Johnston).

Sluice gates at Dungarubba, Richmond. (Photo by Pat Dwyer).

Top hinged floodgate. (Photo by Mathew Johnston).

Tide activated mini-gate on the Maroochy River. (Photo by Mathew Johnston).

Fish-friendly stream crossings

Many freshwater fish species are migratory and must move between a variety of habitats to complete essential life history stages. Even a small structure such as a concrete causeway or a pipe culvert can create a barrier such as a small waterfall or shallow flows that restrict fish movement.

Pipe culvert in the Mary River catchment, the height and water velocity during flows prevent fish passage. (Photo Mary River Catchment Coordination Committee).

Vehicles and stock crossing waterways on ford-type wet crossings can stir up sediments, cause erosion and increase turbidity. Manure increases organic nitrogen, suspended solids and pathogens, and reduces water quality.

Cows are 50 times more likely to defecate when crossing a stream in-stream compared to using a raised crossing (Davies-Colley *et al.*, 2004).

Management actions

- Always seek advice from Queensland Employment, Economic Development and Innovation on fish-friendly designs and approvals.
- Modify or remove structures that are barriers to fish.
- Include a fish ladder or suitable passage for fish (bridges and arch structures have the least impact) in new crossing designs.
- Minimise the use of causeways.
- Set culverts at bed level and include a low-flow channel. Cells should have a minimum water depth of 0.2–0.5 metres.
- Avoid locating bridge foundations and piers in the main waterway channel.
- Remove debris from around the crossing.

Design criteria for fishways in Queensland

The criteria for fishway designs in Queensland have been developed, tested and improved upon over the last two decades. Currently the basic design premise for fishways in Queensland is:

- that the fishway(s) should cater for the whole fish community (species, size classes and swimming abilities)
- that the fishway(s) capacity should reflect the biomass of fish likely to use it, to minimise any delays in fish passage
- that the fishway(s) should be capable of operating whenever there is flow in the river, until flows are such that they preclude fish movement
- that safe upstream and downstream passage should be provided, if necessary with separate upstream and downstream fishways
- that fishways are properly screened and maintained to ensure that gross pollutants (e.g. rubbish or branches) do not compromise their operation and that moving parts and computerised components do not fail, causing the fishway to be inoperative (Marsden and Peterken, 2007).

For further information on fish-friendly stream crossings and outlets consult Queensland Department of Employment, Economic Development and Innovation' *Waterway Barrier Works and Fishways—Decision Support Guidelines* available at <www.deedi.qld.gov.au>.

Provide water for stock off-stream

When stock have direst access to streams they cause bank and stream bed erosion, destroy riparian vegetation, stir up sediments, reduce water quality and cause the loss of habitat for fish and other wildlife.

Management actions

- Provide a number of off-stream watering points.
- Pipe from an existing supply or pump water from a bore or waterway to troughs in the paddock.
- If complete restriction is not viable, manage stock access with limited, carefully considered drinking points, provide armouring (rock pad) to protect bank stability.

Best practice: wetland and riparian weed management

Weed infestation in wetlands can be the result of a variety of causes, including poor water quality (nutrient enrichment), too much or too little water, water at the wrong time, excess sedimentation and invasion from neighbouring paddocks and watercourses (DLWC, 2003).

Although often blamed for the degradation of wetlands, weeds are often symptoms of degradation, not the disease. This is especially true of waterplants where many species are highly mobile and efficiently transported by waterbirds (Westlake, 2004).

Both agricultural runoff and floating weed mats have the potential to reduce oxygen levels in wetlands. Weed mats can dramatically increase diurnal (daily) fluctuations of oxygen levels, leading to fish kills and conditions that favour the release of nitrogen and phosphorus; which can support further weed growth and further degrade water quality.

Common wetland weeds and Weeds of National Significance (WONS)

Riparian zone weeds:

- Chinese (or Chinee) apple (*Ziziphus mauritiana*)
- Chinese celtis (*Celtis sinensis*)
- lantana (*Lantana camara)* (WONS)
- mimosa or giant sensitive weed (*Mimosa pigra*) (WONS)
- parkinsonia (*Parkinsonia aculeata*) (WONS)
- pond apple (*Annona glabra)* (WONS)
- prickly acacia (*Acacia nilotica*) (WONS)
- rubber vine (*Cryptostegia grandiflora*) (WONS and toxic to livestock)
- Singapore daisy (*Sphagneticola trilobata*).

Aquatic weeds:

- alligator weed (*Alternanthera philoxeroides*) (WONS)
- cabomba (*Cabomba caroliniana*) (WONS)
- salvinia (*Salvinia molesta*) (WONS)
- water hyacinth (*Eichhornia crassipes*)
- water lettuce (*Pistia stratiotes*).

Invasive grasses and ponded pastures:

- aleman grass (*Echinochloa polystachya*)
- hymenachne (*Hymenachne ampexicaulis*) (WONS)
- para grass (*Brachiaria mutica* or *Urochloa mutica).*

For weed identification and further information on wetland weeds, declared weeds, Weeds of National Significance and weed control options, visit the Queensland Department of Employment, Economic Development and Innovation's Biosecurity website (www.deedi.qld.gov.au) or contact your nearest local government weed management officer.

Other on-line weed management resources:

- **Australian Government (www.weeds.gov.au)**
- **Weeds Australia (www.weeds.gov.au)**
- **Weed CRC (www.weedscrc.org.au)**

Ponded pastures

It is recognised that ponded pastures have been developed and are managed for economic production and have contributed to the beef industry.

However, the impact of these developments on tidal areas and natural wetlands through the spread of introduced pasture species and interference with water flow has been substantial (Queensland Government, 2001).

The Queensland Government *Ponded Pastures Policy (2001)* considers that the development of ponded pastures should occur only in areas that are **not**:

- tidal areas
- in or adjacent to natural wetlands
- of high conservation value fish habitat value.

The Queensland Government *Ponded Pasture Policy* is available on the Department of Environment and Resource Management website (www.derm.qld.gov.au).

What species are used in ponded pastures?

The species used for ponded pastures include both native and introduced plants. The introduced species used in Queensland are:

- hymenachne (*Hymenachne amplexicaulis cv. Olive*)
- para grass (*Brachiaria mutica*)
- aleman grass (*Echinochloa polystachya cv. Amity)*.

These three introduced grasses used in Queensland ponded pastures are now regarded as invasive weeds in natural freshwater wetland systems and other waterways.

Hymenachne and aleman grass, which can grow in deeper water, are spreading and invading natural ecosystems both by natural means and by humans. Para grass is a widespread serious weed of shallow wetlands.

Hymenachne

Legal status of hymenachne in Queensland

Hymenachne (*Hymenachne amplexicaulis cv. Olive*) is declared as a **Class 2** pest under the *Land Protection (Pest and Stock Route Management) Act 2002*, which means it potentially has serious economic, environmental and social impacts. Under this legislation, landholders must take reasonable steps to keep their land free of hymenachne by controlling and, if possible, eradicating any outbreaks on their property.

Table 16: Weed management approaches for controlling hymenachne

Physical	Not suited to hand removal since it re-shoots from any remaining small segments.
Mechanical	Mechanical harvesting gives some control. Similar to mowing a lawn, as weed grows back every month and therefore requires ongoing commitment. Note: purchase cost of mechanical harvester is substantial.
Chemical	Three herbicides are registered for off-label minor use, using hand, boom or aerial spraying. Will require multiple treatments in the first year, then consistent follow-up in the following years. Mass die-off of weed can degrade water quality. Check with your local council or DEEDI Biosecurity officer.
Biological	No biological control agents. This control option is not thought likely given the existence of the closely related native hymenachne and the economic importance of the sugar cane industry.

Source: Weed CRC (2003)

Para grass

Para grass (*Brachiaria mutica*) is a common weed in many cane-growing areas of Queensland. This plant can be a very aggressive invader, particularly in low-lying areas and in sugar cane crops and drains.

It is often found in shallow wetlands and drains, but will also grow in deep soils in non-swampy areas.

The ability of para grass to thrive in wet areas highlights this species as a potential threat to natural wetland ecosystems. Native plants are significantly displaced by its vigorous growth. It also invades areas of disturbed remnant vegetation on suitable soils.

Legal status of para grass in Queensland

Para grass is **not** a declared plant under the *Land Protection (Pest and Stock Route Management) Act 2002*. However, plants that are not declared under State legislation may have control requirements imposed by local government.

Aleman grass

Aleman grass (*Echinochloa polystachia*) is a semi-aquatic grass that can invade wetlands in the wet-dry and wet tropics regions. It can grow in water up to 2 m deep. This grass was released recently and is therefore not widely spread, however, it has greater weed potential than para grass.

Legal status of aleman grass in Queensland

Aleman grass is **not** a declared plant under the *Land Protection (Pest and Stock Route Management) Act 2002*. However, plants that are not declared under State legislation may have control requirements imposed by local government.

Managing wetland weeds

Simple removal of weeds by manual or chemical methods may not solve the problem, especially if the problem originates outside the property boundary (e.g. when the seeds of weed species are transported from a nearby area). In most cases a combination of control methods will be required. This is known as 'integrated weed management'.

To help manage weeds, consider the following:

- Use integrated weed management techniques to increase the chance of success and reduce the risk of herbicide resistance and other problems associated with single strategy approaches.
- Thoroughly clean down machinery, vehicles, tools and clothing that have been in weed-infested areas.
- Provide a properly constructed wash down area as near as possible to your farm gate. Insist that any contract equipment or service vehicles be cleaned before coming onto and when leaving your property.
- Get a vendor declaration of the weed status of fodder, hay, road base and seed before purchase. Similarly, insist upon inspecting the log book of farm contractors entering your land.
- Keep access roads, easements and yards weed free.
- Move livestock to frequently used holding areas after they've been grazing on weedy paddocks. This will limit the spread of weeds and allow easy control of new seedlings which may emerge from animal waste.
- Hold livestock that may be infested with seed in a single location until they are shorn or until weed seeds have had the chance to pass through their digestive system.
- Develop a pest management plan for the property.
- Factor weed control into drought planning—talk to local agronomist.
- Factor weed control issues into prescribed fire plans.
- Keep an eye out for some of the more serious exotic weeds, and any new weed infestations on your land.

In a riverine wetland, a permit under the *Water Act 2000* is required if the weed removal involves disturbing the bed or banks or destroying any native vegetation in the stream. Check with the Department of Environment and Resource Management before starting any weed removal, especially mechanical, fire or herbicide methods.

Managing weeds with controlled grazing and fire in the Burdekin, Mackay and Fitzroy regions

Exotic pasture grasses such as para grass (*Brachiaria mutica)* and hymenachne (*Hymenachne ampexicaulis*) are major environmental weeds of Queensland's floodplain, wetland and riparian ecosystems (Tait, 2004).

These species cause a range of impacts that result in the loss of biodiversity including direct competitive exclusion of native plants, reduced tree recruitment, massive fuel loads and associated hot-fire-regime impacts, smothering and organic loading of water bodies that generates low dissolved oxygen levels and reduced water quality (Tait, 2004).

One management approach is to reduce the dominance of these weed species by using controlled grazing pressure and a carefully managed fire regime.

The information in Tables 17 and 18 (page 44) is based on results obtained from Burdekin and Fitzroy areas during pilot scale trials carried out under the Queensland Wetlands Program's Great Barrier Reef Coastal Wetlands Protection Program pilot Program.

Table 17: Potential merits of different stock for grazing-based weed management in riparian and wetland habitats

Stock type	Potential habitat benefits	Potential habitat negatives	Grazing/production issues
Cattle	Less selective grazers consume many weed species in addition to pasture grasses	Consume native vegetation including recruiting tree saplings in addition to exotic pasture grasses	Good market for stock Require sturdy fencing—prone to breaking out and causing conflict in cane-growing areas
Horses	More selective grazers, avoid more native species including emergent riparian vegetation and recruiting tree saplings	More selective grazers prone to promote proliferation of less palatable weed species	More easily managed stock—fencing requirements not as major as cattle (single strand electric fence will often suffice) Stock not as marketable though potential for agistment returns
Goats	Grazers and browsers with broad diet consume many weed species in addition to pasture grasses—suitable for bare-earth weed control and site preparation for revegetation Tread more lightly on the ground; potentially less compaction/ erosion concerns More agile on sloping banks potentially suited to smaller and steeper sites	Grazers and browsers with broad diet; consume native vegetation including recruiting tree saplings in addition to pasture grasses—may require protective fencing for individual native specimens	Limited market Manageable with multi-strand electric fence Smaller and or steeper areas viable for grazing Individuals can be tethered in intensively managed areas

Source: Tait (2004)

Table 18: Example of grazing calendar for weed control in Burdekin Dry Tropics region

Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wet	Spell area											
Post-wet				Solid grazing								
Early dry							Short period of grazing with possible cool burn					
Late dry									Short period of grazing with possible cool burn			

Source: Tait (2004)

Wet season (Jan–March)—spell to avoid trampling, flood risks to stock and to allow seedling germination/ establishment.

Post-wet growing season (April–Jun)—this is the main period for grazing, subject to how many stock you apply. Consider a six-week grazing period and monitor ground cover/pasture response/trampling/browsing impacts.

Early dry (July–early Sep)—this is a period in which cool burns might be considered subject to fuel conditions.

Late dry (Late Sep–Dec)—consider another short graze in this period if rainfall has promoted new growth to keep pasture dominance and rank growth down before going into the hot-fire risk period and the wet season overstorey germination period.

This period can still be suitable for burning (many plants expect fire to occur at this time of the year and have germination/life histories geared accordingly) if grazing has reduced fuel-load conditions sufficiently to prevent hot-fire damage to fire-sensitive overstorey species (Tait, 2004).

Grazing of wetlands and riparian areas must be *well managed* as overgrazing of these areas can damage soils and vegetation which increases the risk of erosion and reduces water quality.

Best practice: managing wetland animal pests

Although wetlands can provide a range of habitats for native animals, they are also ideal habitats for many introduced pest species.

Two of the most prevalent exotic pest animals in Queensland's wetlands are feral pigs and exotic fish species.

Although cane toads are also an introduced exotic pest there are limited methods to successfully control this species. As toads prefer open terrain, planting dense vegetation along wetland edges can reduce their access to wetlands.

Feral pigs

The damage caused to crops and wetland areas from feral pigs presents a significant cost to the landholder and natural resource management organisations.

Feral pigs are habitat generalists and have colonised sub-alpine grasslands and forests, dry woodlands, tropical rainforests, semi-arid and monsoonal floodplains, swamps and other wetlands in many parts of Queensland and other states throughout Australia. The prime requirements for pigs are a reliable and adequate supply of water, food and cover.

The feral pig is a declared animal under the Regulations of *Land Protection (Pest and Stock Route Management) Act 2002*. It is categorised as a Class 2 pest.

Section 77 of the *Land Protection Act (2002)* places the responsibility on the owner of land (this includes the State) to take reasonable steps to keep the land free from feral pigs.

Local governments are empowered under Section 78 to issue a non-complying landholder with a notice to control feral pigs, and a maximum penalty of $60,000 is applicable if they do not comply.

Feral pigs are subject to many infectious diseases and parasites, including some economically important exotic diseases, such as foot-and-mouth disease, and endemic diseases and parasites, such as leptospirosis, brucellosis, and melioidosis that can affect the health of domestic livestock or people (Choquenot *et al.*, 1996).

Why pigs like wetlands

The high productivity and seasonality of wetland systems ensures a dependable (though seasonally variable) food source for pig populations. In north Queensland, pigs tend to target wetlands during the early dry season. At the height of the dry season they move into forested areas for shade cover preferring to descend onto floodplain lagoons and wetland systems during the night.

The impact of feral pigs on the environment takes one of two forms:

- damage to habitats
- direct damage to animal species.

Pigs cause most of their environmental damage by rooting up soils, grasslands or forest litter, particularly along drainage lines, moist gullies and around wetland systems such as swamps and lagoons. (Choquenot *et al.*, 1996).

Their diet preferences include many wetland plants such as grasses, sedges and rush species in addition to animals that are typically found in wetland habitats such as earthworms, snails, arthropods (especially beetles), crustaceans, shellfish, frogs, fish, reptiles (including turtle eggs), eggs of ground-nesting birds, birds, mice, and other small mammals (Choquenot *et al.*, 1996).

Although feral pigs eat animal material, they are probably not significant predators of most fauna. Their impact on different plants is largely unknown, as is the extent of their role as seed eaters or dispersers, and in spreading root rot fungus (*Phytophthora cinnamomi*). Root rot fungus is responsible for dieback disease in native vegetation and horticultural crops (Choquenot *et al.*, 1996).

Feral pig damage near the boundary of a wetland. (Photo by Ian Layden).

Techniques to control feral pigs

The most effective and cost-efficient method of controlling pig populations is to develop a coordinated control program that enlists the support of landholders, local government and State agencies.

The successful control of feral pigs generally relies on employing a range of control methods, with the most successful approach a combination of those listed in Table 19 (page 109).

Table 19: Control options for feral pigs in Queensland

Control option	Advantages	Disadvantages
Trapping	Can be made target specific Allows capture for commercial purposes Can be incorporated into existing management practices Pig numbers can be monitored Traps can be re-used Landholders can offset trap costs by selling trapped pigs Does not affect normal pig behaviour More humane than other methods	Labour intensive Requires access to traps and suitable baits
Shooting	Target specific Suitable for commercial purposes	Requires adherence to firearms legislation Costly for large numbers Not suitable for thick vegetation Labour- and skill-intensive
Fencing	Low impact on non-target species Suitable for small wetland areas	Requires constant maintenance Can be expensive to construct Costly and largely ineffective Tendency to shift the problem elsewhere May impede movement of non-target species
Dogging	Involves animal welfare concerns Suitable for commercial purposes	May displace pigs rather than capture Controls only part of population
Baiting	Can control large numbers over large areas economically Proven method Widely accepted in rural communities Fast and effective initial knockdown Relatively cheap method Can be tailored to be target specific	May require pre-feeding before bait setting Involves possible non-target issues if not conducted correctly Some baits are unsuitable for Wet Tropics region Raises public concern over humaneness and safety Can encourage the occasional use of non-registered chemicals (legal issue)

Source: NRME (2004)

Depending on the severity of the problem, controlling feral pigs generally requires professional assistance and guidance on employing the control measures listed in Table 19.

For further information on controlling pigs including shooting, trap design, baiting procedures and other issues related to feral pig management, consider the following:

- Contact the local Queensland Department of Employment, Economic Development and Innovation Land Protection Officers or Local Government pest management personnel.
- View the Biosecurity fact sheets on trap design on the Queensland Department of Employment, Economic Development and Innovation website (www.deedi.qld.gov.au).
- Consult the Queensland Wetlands Program *Rehabilitation Guidelines for Wetlands in the Great Barrier Reef Catchment* at Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

Noxious fish

Noxious fish are fish species that have been deemed harmful or produce conditions that are harmful to fisheries resources or habitat. There are 18 species, genera or families of fish that are declared noxious in Queensland.

The three species or species groups that are of most concern in Queensland are tilapia, gambusia and carp. Each of these species has established significant self-maintaining populations in the state and is believed to have had detrimental impacts on native fishes and their habitats.

What's the difference between noxious and exotic fish?

A *noxious* fish is one that has been declared harmful by Australian statute law because they are, or may become, a pest to native aquatic communities. Noxious fish have characteristics that are detrimental to other fish, aquatic habitats or humans.

Exotic pest fish are fish species that are not native (not indigenous) to an area.

Exotic or noxious fish must not be used to stock dams.

Tilapia

Description

Tilapia are part of the Cichlidae family. Two species have established in Queensland—the Mozambique mouthbrooder (*Oreochromis mossambicus*) and the black mangrove cichlid (*Tilapia mariae*).

O.mossambicus can grow to more than 36 cm and can live up to 13 years. They have pale olive to silver-grey bodies with two to five indistinct dark blotches on the side. *T.mariae* have vertical stripes on the head and body and vary in colour from dark olive-green to light yellowish green. They can grow to 30 cm.

Distribution

Tilapia originate from the warm, fresh and salty waters of Africa, South and Central America, southern India and Sri Lanka.

*Mozambique mouthbrooder (*O.mossambicus*): (top) stunted male and (bottom) female. (Photo by DEEDI).*

Several breeding populations of *O.mossambicus* have established in north Queensland (Cairns to Mackay) and in the Greater Brisbane and Gold Coast areas of south-east Queensland.

T.mariae has established populations from the north of Cairns and possibly as far south as Mackay.

Habitat
O. mossambicus are hardy fish and can survive temperatures between 8 ˚C and 42 ˚C, although they require temperatures of approximately 16 ˚C to remain active and feed.

They can also withstand high salinities and low dissolved oxygen (DO). *T.mariae* is less tolerant of cooler temperatures and therefore has a lower latitudinal range.

Diet
Tilapia are omnivorous. *O. mossambicus* feed mainly on plankton, insects and weed but will take a wide variety of other foods. *T.mariae* eats mainly plants.

Reproduction
Tilapia are sexually mature at three years or less in favourable conditions. They are able to reach sexual maturity at small sizes in poor conditions or when they are overcrowded. This is known as 'stunting' and results in large populations of mature fish with small body sizes.

O.mossambicus are mouth brooders, protecting the eggs and larvae from predators. They can produce 1200 eggs per year with up to four broods per year. The breeding season in Queensland is September–October and April–May.

T.mariae spawn from September to March and lay their eggs on substrate.

Juvenile Tilapia mariae. *(Photo by Wade Micke).*

Environmental impacts
Tilapia have successfully invaded and dominated many aquatic habitats with their highly efficient reproductive strategy, simple food requirements and ability to live in a variety of conditions. Tilapia can release eggs even when they are dead.

Unlike many native freshwater fishes, Tilapia are able to retreat downstream into highly saline waters during drought and move back upstream when conditions improve. They affect native species when competing for habitat and food, behaving aggressively and disturbing plant beds when building nests.

It is illegal in Queensland to possess Tilapia (alive or dead) for any purpose. *Fines of up to $150,000 may apply.*

Report any sightings or catches of Tilapia to the Queensland Department of Employment, Economic Development and Innovation on 13 25 23 or visit <www.deedi.qld.gov.au/fishweb>.

Gambusia (mosquito fish)

Description
Gambusia (*Gambusia holbrooki*) are live-bearing fish. They are small fish, growing to less than 7 cm and most only reaching 3–4 cm. They are large-scaled and stocky-bodied.

They have adapted to living and feeding at or near the surface of the water. Their colour varies with habitat but usually they are dark grey or olive on the head and back, becoming lighter on the belly. They have faint pigment spots on the fins and under the eyes.

Distribution
Gambusia are widely distributed, occurring throughout almost all freshwater environments in Queensland.

Habitat
Gambusia inhabit warm, fresh and brackish waters at low elevations. They can withstand environmental conditions that native fish cannot, such as high temperatures and low oxygen, but they are sensitive to high salinity.

Diet
Gambusia have a varied diet, feeding on insect larvae, insects, plants, worms, crustaceans, snails, frog eggs and small fishes.

Reproduction
Gambusia give birth to live young. Females mature at about 18–20 mm, which is 4–6 weeks old. They can produce up to 315 young per season.

They produce small broods at frequent intervals, thereby increasing reproductive output and survival of the young. The breeding season varies between 2–9 months.

Day length is believed to determine the timing of the reproductive cycle.

Environmental impacts
Gambusia were introduced to eastern Australia in 1929 as a mosquito control agent because they thrive in calm, shallow, vegetated waters where mosquitoes lay their eggs. They dominate habitats where they are introduced, demonstrating aggressive behaviour such as nipping the fins of other fish species and eating their eggs.

Gambusia mature early, their fry have a high survival rate and produce a large number of broods annually. They are also able to gulp air from the surface when there is low oxygen in the water. Their presence results in the reduction and possible disappearance of native fish species.

Carp

Description
There are three varieties of carp in Australian waters. The common or European carp, koi carp and mirror carp. Carp have large scales, a deeply forked tail, single dorsal fin and two pairs of fleshy whiskers (or barbells) in the corners of their upper lip. These barbells are a useful way of distinguishing them from goldfish which have none.

Carp colouration is highly variable—they may be bronze or olive-gold, becoming pale yellow or whitish on the sides and belly or have a bright gold colouration. Koi carp are often brightly coloured with dark blotches over their back.

Carp can live up to 17 years.

Carp. (Photo by Wade Micke).

Distribution
Carp are native to central Asia and were introduced to Australia as a sportfish in the late 1800s. In Queensland, carp are established in the Murray–Darling River in the Condamine–Balonne catchment as well as the Paroo, Warrego, Culgoa, Barwon, Logan and Albert rivers. It is also found in Nebine Creek.

Habitat
Carp prefer warm, still waters with silt bottoms and abundant aquatic vegetation. They are rarely found in clear, cool, swiftly flowing streams. They can survive at high and low temperatures (4–35 ˚C), high salinity and turbidity and low dissolved oxygen levels.

Diet
Carp feed by sucking up mud and plants from the bottom and blowing out what they don't want. This feeding behaviour is known as roiling. Adults feed on crustaceans, insects and plant material. Larval stages of carp feed on plankton.

Reproduction
Male carp are sexually mature between 1–3 years and females between 2–4 years. Carp spawn from September to December and can produce up to 1.5 million eggs.

Environmental impacts
Carp can survive a range of environmental conditions. Their feeding habits result in muddied water and uprooted aquatic plants, which reduces the amount of light penetrating the water. This results in degraded water quality through less plant matter and reduced oxygen levels. The poor water quality impacts on the survival of other species of fish.

Strategies are being developed to control and reduce the number of carp in Australia. Fish poisons have been used to eradicate carp in ponds and small dams, but are not practical for rivers and streams as these poisons also kill native fish. Biological control methods, such as manipulating the genetic structure of carp to disrupt their breeding or bring an early death, are being investigated.

Intensive fishing may have the potential to reduce carp numbers in small enclosed waterbodies, but it is very unlikely that fishing alone is an effective long-term control measure.

Carp are declared noxious in Queensland under the *Fisheries Act (1994)* Qld. It is unlawful to possess them alive or dead or use them as bait. It is illegal to place or release carp into Queensland waterways.

What do I do if I see exotic fish in a wetland?

Queensland Department of Employment, Economic Development and Innovation has a register for people to report information on exotic fish. This information helps the department determine how widely spread the fish are and aids in planning control measures.

To report sightings of noxious or introduced fish in Queensland's waterways, please call the Queensland Department of Employment, Economic Development and Innovation on 13 25 23.

You will then be asked a series of questions about the sighting including:

- **the type of fish and how it was identified (e.g. particular markings, museum identification etc)**
- **the number of fish (e.g. one, a few or many)**
- **how long these fish have been there (if known)**
- **the location of the fish.**

For more information about exotic and noxious fish visit the department's Fishweb at <www.deedi.qld.gov.au/fishweb>.

Step 4—Record and review

4 Record and review

The final step in the risk-management process is to monitor and review the effectiveness of the activities that have been undertaken to address the risks identified during the assessment phase.

Record keeping is a key component of managing an efficient farm business. Records are needed not only for legal, financial and taxation purposes but also for maintaining a permanent record of the farm business, analysing the business, monitoring day-to-day activities, and future planning.

Without good record keeping you have no proof that you are making an improvement in production or managing the environment.

Why records are important

Some of the reasons for keeping records about the risk management process and actions undertaken across the farm are to:

- demonstrate that a risk assessment process was conducted (e.g. to provide evidence)
- provide a record of identified risks
- provide a responsible and accountable mechanism and tool
- measure progress and change through continuous monitoring and reviewing
- if necessary provide third parties with a risk-management plan for approval and subsequent implementation
- provide an audit trail.

What type of records should be kept?

The type of records kept will depend on the type of farm and level of risk presented by farm activities. The number of records maintained and the detail recorded will vary according to individual needs and how the information is to be used.

Examples of the types of records that should be kept include:

- weather conditions and rainfall
- soil testing results
- chemical usage
- farm risk assessments
- action plans (see Step 2—planning farm actions)
- erosion management actions
- water and irrigation records
- fertiliser applications
- yield and crop performance.

When writing down your results keep them simple. They do not have to be perfect—just suitable and sufficient.

Depending on the area of risk, a producer may need to show records that illustrate:

- a proper check or assessment was undertaken
- people who might be affected have been asked
- all the obvious significant risks have been taken into account
- the actions undertaken are reasonable and have minimised the risk.

Reviewing—why is it necessary?

An essential component of any risk management system is the evaluation and review process. Few workplaces remain the same from year to year as new farm practices and different machinery and staff can be introduced to the business.

Reviews are necessary to assess whether the level of risk has changed from the introduction of new practices. In reviewing whether the actions taken to address the risks have been effective, ask questions such as:

Have the actions been carried out as planned?

- Are the actions or measures being used correctly?
- Are they working?
- Have the changes made or actions implemented to manage the risks resulted in what was intended?
- Have the risks been eliminated or adequately reduced?
- Have implemented actions resulted in the introduction of any new problems?
- Do the actions comply with legislative requirements?
- Have implemented actions resulted in the worsening of any existing problems?

Table 20: Example of a review checklist

Actions identified	Not yet started	Begun	Completed	Problems or comments
Repair erosion on bank of creek		●		Need tree guards to prevent wildlife damaging plantings
Undertake soil mapping across farm	●			Agronomist booked to start before next planting season
Increase buffer width and ground cover near bottom creek			●	Need to maintain adequate ground cover—assess following harvest

Part 4: Wetland treatment systems

Constructed (or artificial) wetlands have the potential to provide substantial economic, social and ecological benefits for both the producer and the community.

Because wetlands have a higher rate of biological activity than most other ecosystems they have the ability to transform many types of pollutants into harmless by-products. The use of natural environmental energy means that wetlands are one of the least expensive systems to operate and maintain when compared to other water treatment technologies (Kadlec and Knight, 1996).

What are treatment wetlands?

Constructed wetlands mimic the conditions found in natural wetlands but have the flexibility to be built in a range of locations for a variety of purposes. Constructed wetlands have been used to treat a wide range of polluted waters, including primary and secondary municipal sewage, landfill leachate, industrial wastewaters and agricultural runoff or irrigation tail-water.

The plant communities in constructed wetlands create the biological environment necessary for the treatment of polluted water. These plant communities typically consist of a range of wetland plants, including emergent, submerged, and free-floating water tolerant species (Kadlec and Knight, 1996).

Constructed wetlands that remove nutrients and other contaminants from polluted water subsequently release them to the atmosphere (converted to gaseous forms), store them in the wetland substrate or consume them in plant biomass.

So why treat agricultural wastewater?

Agricultural wastewater typically contains high biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nutrients and in some cases plant and animal pathogens (Kadlec and Knight, 1996).

Improving water use efficiency by treating and reusing farm and/or irrigation runoff is also possible via a treatment wetland system.

Constructed wetlands can be effective in treating:

- biochemical oxygen demand (BOD)
- suspended solids
- nutrients (nitrogen and phosphorous)
- metals and pathogens.

Types of constructed wetlands

There are three basic types of wetland treatment systems for agricultural waste or runoff water:

- constructed surface-flow or free-water wetlands (SF wetlands)
- constructed subsurface-flow wetlands (SSF wetlands or reed beds)
- facultative ponds (mainly used for treatment of animal effluents).

Dairy effluent and treatment wetlands

Dairy and other intensive animal operations can deliver very high hydraulic, nutrient and organic loads which can compromise the treatment capacity of a wetland treatment system.

Although wetland treatment systems have been used in the treatment of dairy wastewater (effluent), the preferred approach to managing dairy effluent in the Queensland dairy industry is to recover the nutrient value by using a solids separator (also known as 'weeping wall' or 'solids trap').

Where effluent is ponded, anaerobic or facultative ponds are typically used. Anaerobic ponds lack dissolved or free oxygen in the water column. Facultative ponds are aerobic near the surface and anaerobic at greater depths.

Several electronic calculators are available free to dairy farmers to help with the design of effluent management systems. To access these calculators visit <www.publications.qld.gov.au>.

For more information on designing solids separators or effluent ponds visit the Queensland Department of Employment, Economic Development and Innovation website (www.deedi.qld.gov.au).

What are surface-flow wetlands?

Surface-flow (SF) wetlands (sometimes known as free-water surface wetlands) are wetlands where water flow is predominantly across the surface in a pond or retaining structure (DLWC, 1998a).

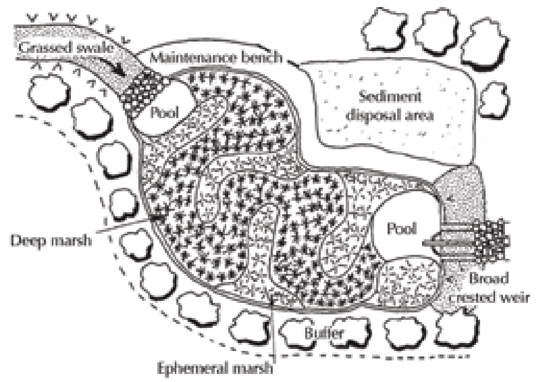
Constructed surface-flow treatment wetlands are generally about 0.3–1 m deep, with >80 per cent extensive vegetation cover. Such systems use enhanced sedimentation, fine filtration and biological uptake processes to remove fine to colloidal particulates and dissolved contaminants from runoff or wastewater.

Water levels rise during rainfall or irrigation events and outlets are configured to slowly release flows, typically over two or three days. The length of time water spends in the treatment wetlands dictates the level of treatment it will receive, and thus the quality of water flow from the treatment wetland.

Constructed surface-flow wetland with emergent macrophytes around the edge

Surface-flow treatment wetlands generally consist of four zones (see figure below):

1. *Inlet zone*: gross pollutant trap and/or sediment basin to remove coarse sediments.
2. *Macrophyte zone*: shallow heavily vegetated area to remove fine particulates and uptake soluble pollutants.
3. *High-flow bypass channel*: to protect the macrophyte zone from scour and prevent damage to vegetation during periods of high rainfall or inflows.
4. *Outlet zone:* open-water zone that encourages the oxygenation of water, and limits blockages in the outlet area from vegetation matter.



Schematic layout of a surface-flow wetland

Agricultural applications of constructed surface-flow wetlands

SF wetlands are a suitable water management and treatment option for the following agricultural situations:

- sugar cane
- intensive horticulture (including bananas)
- horticultural tree crops (e.g. macadamias, avocados, mangoes)
- irrigated cotton and grain
- production nurseries
- dairy (though solids separators are the preferred method of treating and reusing dairy effluent).

Benefits of surface-flow wetlands

- low energy wastewater treatment option
- facilitates water recycling
- can provide multiple habitat opportunities (including fish recruitment)
- improves flood management
- requires only periodic maintenance once established
- improves visual amenity and public acceptance
- can benefit production due to improved water management in low-lying farm areas.

Limitations of surface-flow wetlands

- area of land required can be prohibitive
- wetland treatment efficiency may vary seasonally in response to environmental conditions, including rainfall and drought
- maintaining the hydrological regime (a minimum amount of water is required to enable survival of plants and treatment ability)
- requires careful design—lack of a one-size-fits-all design
- potential to attract exotic pests and weeds
- potential for odours.

What are subsurface-flow wetlands?

Subsurface-flow (SSF) wetlands (or reed beds) share many similarities with surface-flow wetlands however, SSF wetlands use a bed of gravel or rock screenings as a substrate in which microbial organisms and wetland plants grow. Water travels hydroponically through the gravel substrate, as opposed to above the substrate in SF wetlands.

SSF wetlands are generally sealed with a dam or pond liner (or sometimes clay) to prevent leakage of the wastewater into the groundwater and intrusion of groundwater into the wetland system (Dirou *et al.*, 2003).

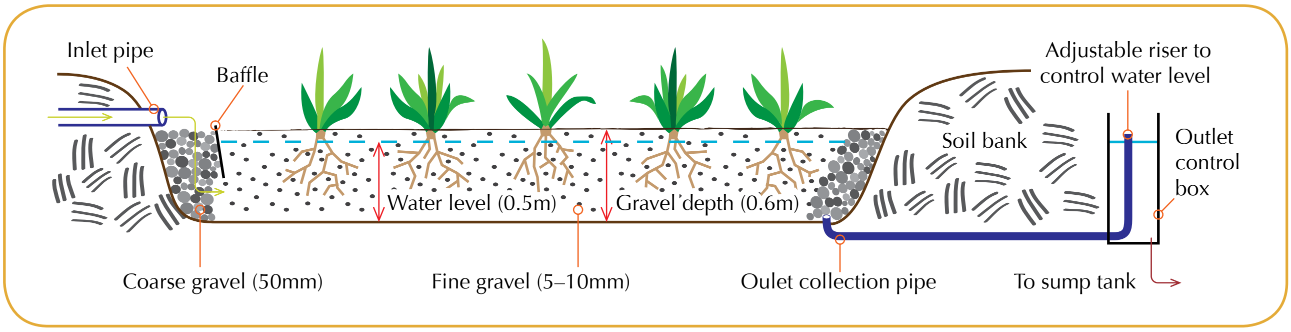
Gravity causes the wastewater inflows (or influent) to flow horizontally through a gravel (media) substrate, where it comes into contact with microbes that colonise the substrate and the plant roots.

As with surface-flow wetlands, nutrients are either converted to gas by microbial activity or stored in the wetland media. The treated water exiting the SSF wetland can then be captured and stored for reuse or released safely to the environment.

SSF wetlands are a suitable water recycling and treatment option for intensive horticulture, hydroponic and greenhouse-based production systems.

Benefits of subsurface-flow wetlands:

- passive water-treatment system
- ability to treat high nutrient wastewater to a high quality
- improved public or workplace safety due to no ‘free’ surface water
- reduced incidence of insect pests such as mosquitoes
- minimal maintenance requirements
- reduced risk of treated water becoming reinfected with wind borne pathogens.



Schematic of a subsurface-flow wetland. (Original diagram courtesy of Dirou et. al*, 2003).*

Limitations of subsurface-flow wetlands:

- expense of liners
- reduced treatment efficiency as pore space in the gravel (media) becomes clogged with sediment over time
- liner (if required) can be punctured by roots
- excessive influent loads causing hydraulic overloading, reducing treatment efficiency
- need for some level of pre-treatment if water contains high sediment loads (for example a sedimentation pond).

A reed bed wetland treatment system at a production nursery in New South Wales. This system, which captures and treats site runoff and irrigation water, has saved the nursery 124,000 litres/day. (Photo by Ian Layden).

The New South Wales Department of Primary Industries has produced several publications on the design and use of wetlands in intensive horticulture and production nurseries.

Badgery-Parker, J. (2002) *Managing waste water from intensive horticulture: a wetland system.* Agnote DPI-381, 2nd ed.

Dirou J, Headley T, Huett D, Stovold G, Davison L (2003), *Constructing a reed bed to treat runoff water: a guide for nurseries.* (NSW Agriculture).

Badgery-Parker, J. (2003) *Managing waste water with a wetland.* (NSW Agriculture)

For more information, visit <www.dpi.nsw.gov.au/agriculture/horticulture/greenhouse/water>.

What are rehabilitated wetlands?

Wetland rehabilitation refers to a process of reconstruction or rehabilitation of degraded wetlands (or areas in the landscape where wetlands may have previously existed) to **reinstate** their function as wetlands.

In a production system, rehabilitating wetland function in the landscape is undertaken to achieve the following:

- obtain multiple benefits from a wetland system (for example water reuse, improved water quality, flood management and provision of habitat)
- improve production outcomes by raising low-lying areas of the farm that are prone to water-logging, have poor productivity and are difficult to manage.

Care must be taken to ensure that while reinstating wetland function, natural wetland values are not degraded or destroyed. For example changing an existing natural wetland to treat wastewater is inappropriate.

This rehabilitated floodplain lagoon on a North Queensland cane farm provides improved water quality, habitat and flood control. (Photo by Ian Layden).

To date, the majority of wetland rehabilitation work has occurred in the cane industry in Queensland's Mackay region and the Wet Tropics. In most cases there has been a demonstrated improvement in farm productivity, landscape function (e.g. flood water management) and habitat opportunities.

For detailed information on rehabilitating wetlands see the Queensland Wetlands Program's *Rehabilitation Guidelines for Wetlands in the Great Barrier Reef Catchment*. This is available on Wetland*Info* (www.derm.qld.gov.au/wetlandinfo).

Designing a wetland system for agricultural runoff or wastewater

Constructed wetlands are not new. However, understandings about the design, size, depth, batter slopes, hydraulic capacity and landscape position have changed significantly as new information becomes available.

Designing wetland treatment systems in the range of climates and cropping systems across Queensland prohibits the use of generic wetland design criteria.

The difficulty and expense in accessing expert advice can also make constructing a wetland system a challenging task for the landholder and/or extension officer.

Creating and operating an effective wetland requires a balanced approach between engineering, ecology, landscape design and natural resource management (DLWC, 1998a).

Designing effective treatment wetlands can be a complex task. Additional references are provided at the end of this section for those seeking more detailed design advice and calculations.

The objectives of this section are to provide information and advice on designing and constructing treatment and multi-purpose wetlands for agriculture.

This section will focus on:

Setting objectives and planning considerations

- designing a farm wetland
- construction of farm wetlands
- management & maintenance
- where to go for further information.

The wetland construction process

1. Setting wetland objectives. What do I want to improve?

To achieve the desired outcomes it is important to consider the main objective, or purpose, of the wetland. This objective determines both the project feasibility and the overall design parameters of the wetland.

In most cases the primary objective of a constructed wetland is to improve water quality discharges (e.g. management of effluents, sediments, nutrients or diffuse urban runoff). Increasingly, constructed wetland design is focussing on how to obtain a range of additional benefits. These benefits could include:

- habitat for a diverse range of plants and animals
- flood detention (peak flow reductions)
- groundwater interactions (discharge and recharge)
- recreational pursuits
- visual amenity
- Economic resources (such as water reuse) (DLWC, 1998a).

Examples of objective setting

1. If the primary objective is the treatment of nutrients, then the hydraulic detention time, plant types and planting design will need to be considered primarily in the design.
2. If the primary objective is provision of habitat, then consideration of water depths, habitat islands, fish passage and fringing vegetation takes precedence.

Can constructed wetlands deliver multiple objectives?

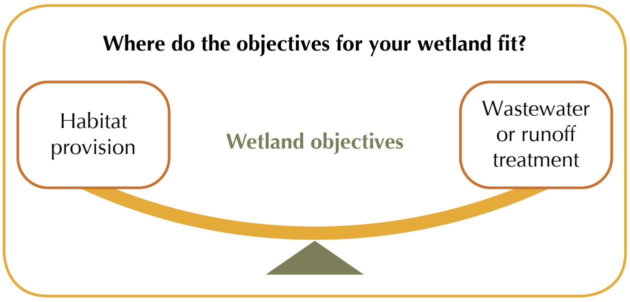
Yes. However, these need to be designed for; as they won't just happen. The preferred approach is to set clear objectives for the wetland and if multiple outcomes are sought then to rank the objectives according to their level of importance, then design the wetland to achieve the highest ranked objective.

Ranking the objectives will aid the design process and improve the final product.

Setting objectives

In deciding to invest time and money in a water management project it is important to understand that the management device (e.g. a sediment trap or wetland) needs to be fit for purpose or able to fulfil its design purpose.

For example, a sediment trap is unlikely to be an efficient sediment trapping device as well as provide a full range of habitat values. Similarly, a wetland system designed purely for nutrient reduction may not provide adequate pesticide treatment or be able to provide a wide range of habitat types.



2. *Planning considerations for constructed wetland systems*

Developing an on-farm wetland system requires significant consultation and planning if the objectives for the wetland are to be realised. There are several planning and legislative areas that require attention before proceeding to the design stage.

Planning and legislation

Before undertaking any site-based inspections, an analysis of the planning and legislative requirements is necessary. Investigations should focus on the following areas:

Legislative checklist

- ☐ Is there a Water Resource Plan (*Water Act 2000*) currently in place (or being developed) in the region and/or is there a moratorium on the capture and storage of overland flows?
- ☐ If the construction process or the wetland requires disturbing marine plants (e.g. mangroves) will an assessment under the *Sustainable Planning Act 2009* be necessary?
- ☐ Is a development permit (self- or code-assessable) issued under the *Sustainable Planning Act 2009*, required before construction?
- ☐ Will the proposed works require certified engineering drawings to be submitted to State or local authorities?
- ☐ Is a Land and Water Management Plan under the *Water Act 2000* required?
- ☐ Are permits on the clearing of native vegetation under the *Vegetation Management Act 1999* or *Environmental Protection Act 1994* required before clearing a site for construction?
- ☐ Does the proposed construction interfere with riparian vegetation on a watercourse, lake or spring and require an assessment to be made under the *Sustainable Planning Act 2009*?
- ☐ Will the proposed works require a permit to destroy vegetation, excavate or place fill in a watercourse, lake or spring as defined by the *Water Act 2000*?
- ☐ Are there any local government requirements?
- ☐ Will the development impact on existing wetlands or riparian areas?

The Queensland Wetlands Program has developed a wetlands planning and legislation support tool to help extension staff and landholders identify State and Commonwealth legislation that applies to wetlands and waterways.

This interactive, web-based information tool provides a comprehensive catalogue of information on wetlands-related policies, legislation and planning as well as links to relevant legislation.

The tool is available at Wetland*Info* at www.derm.qld.gov.au/wetlandinfo

Regional and catchment planning

The range of ecosystem services offered by both constructed and natural wetlands mean that they can be an important asset in natural resource management. For example, wetlands can improve water quality, increase biodiversity, mitigate flooding, reduce erosion, and recharge groundwater.

Constructed wetlands (or rehabilitation of degraded natural wetlands) can provide natural resource management benefits at a catchment and/or regional scale. It is worth investigating if the proposal aligns with, or can add to, local government and regional natural resource management activities such as Water Quality Improvement Plans (WQIPs) and sustainable agriculture investments.

Catchment data can also be used to determine the following:

- wetland size
- potential water flows (or hydraulic loading) through the wetland
- hydraulic detention times (HRT) (how long the water stays in the wetland)
- sediment settling times.

Catchment and landscape checklist

- ☐ Does the regional Natural Resource Management group have a Water Quality Improvement Plan (WQIP) that the wetland project might support?
- ☐ Is the catchment a Nutrient Management Zone (NMZ) in the Great Barrier Reef?
- ☐ Are there other wetland projects (natural or constructed) underway in the catchment/region?

☐ Does the wetland mapping, topographical maps, aerial photographs or other GIS layers showing contours and drainage lines support the proposed location of the wetland?
☐ Will the wetland impact on neighbouring properties by decreasing or increasing flows?
☐ Will the wetland impact on natural wetlands by reducing flow or changing flow patterns?
☐ Have discussions been held with neighbours to help coordinate drainage design?
☐ What is the annual rainfall and evaporation for the catchment/region?

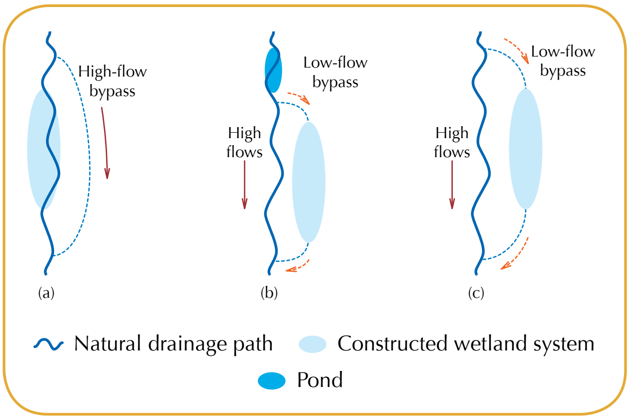
Locating the wetland on farm

The location of the wetland in the farm area is important. It is better to choose a relatively flat site as this reduces the amount of cutting, filling and levelling required. The correct site should also provide sufficient passive (gravitational) energy for water to move through the wetland, avoiding stagnation and the need for pumping equipment.

In an agricultural setting the wetland could be located in the following areas:

- farm drainage lines
- existing water courses (subject to legislation)
- close to farm infrastructure (electricity and irrigation equipment)
- areas in the landscape where wetland indicators are already visible (e.g. wetland soil types and vegetation indicators, though care must be taken to ensure that any existing natural wetlands are not damaged)
- in locations where the constructed wetland will protect high value areas (e.g. natural wetlands)
- low-lying areas of the property where farm runoff exits the property.

High flows can re-suspend sediments as well as destroy wetland vegetation and the biofilms that enable pollutants to be processed. Incorporating a flow bypass can protect the wetland vegetation and sediments from damaging flows.



Options for locating a wetland

Source: CSIRO (1999)

Option (a) provides a high-flow bypass around a wetland system located on the natural drainage path.

Option (b) locates the pond only on the natural drainage path. Downstream of the pond, all but flood flows are directed into a wetland via a low-flow bypass. Flood flows are directed away from the wetland, along the natural drainage path.

The final example (c) diverts all except the flood flows into a wetland system, located on a low-flow bypass away from the natural channel. Once again, flood flows are directed away from the wetland system along the natural drainage path.

Reminder about wetland design and location

Poorly designed and located wetlands can:

- **reduce natural stream connectivity**
- **impact on fish passage**
- **increase downstream flooding**
- **concentrate flows, increasing erosion potential**
- **capture overland flows (which could upset downstream water users and breach legislation)**
- **increase the spread of wetland weeds.**

Geology and soils

To receive and treat overland flows or irrigation runoff, farm wetlands are generally constructed at or below ground level. This requires excavation of soil material. This spoil can then be used to create berms and levees and to raise low-lying areas on the farm (Kadlec and Knight, 1996).

Ring-tank sumps and tail-water detention basins can be designed to have wetland values such as sediment trapping, and nutrient and chemical treatment, as well as habitat potential. To achieve this, follow the same design considerations for wetlands.

The most cost-effective design will attempt to balance the cutting and filling needs of the project.

Following filling of the wetland, most soil types (with the exception of freely drained sands and gravels) will develop a saturated soil which can then support emergent wetland vegetation (Kadlec and Knight, 1996).

In the case of free-draining soils, lining the wetland with clay, clay-bentonite mixtures, synthetic polyvinylchloride (PVC) or high-density polyethylene (HDPE) liners may be necessary. It is important to identify the need and cost of lining a wetland as it can be significant.

As catchment runoff also includes sediments, it is important to understand what contribution soils from the surrounding catchment will have to water flowing into the wetland. This information will aid in the design of sediment traps and identify whether additional runoff management devices (e.g. grass filters strips and contour banks) are required.

The presence of acid sulfate soil (ASS) requires examination before entering the more detailed design phase of a constructed wetland project. Confirmation of ASS in the proposed construction area may prohibit the excavation of soil and a re-evaluation of the projects objectives may be required.

A range of soil tests will be required to identify any site and/or catchment constraints. This information may already be available from local sources and the producer may have some information from previous soil testing.

Soils, geology and BMP checklist

☐ Undertake the following soil tests:
- soil profile description
- particle size analysis
- hydraulic conductivity
- shrink/swell tests
- dispersion tests
- phosphorous sorption capacity
- pH and ASS tests
- cation exchange capacity (CEC).

☐ Do geological maps/surveys indicate the presence of shallow bedrock, landslip potential or sand lenses?

☐ Does the site requiring lining with clay or artificial liners?

☐ What effect will the soils of the catchment area have on sediment and pollutant inputs into the wetland?

☐ What farm BMPs will be required to support the objectives of the wetland?

A good understanding of the landscape, geology and soils is vital to planning and achieving a successful constructed wetland. (Photo by Mario Porta Jnr.).

3. Key wetland processes for treatment systems

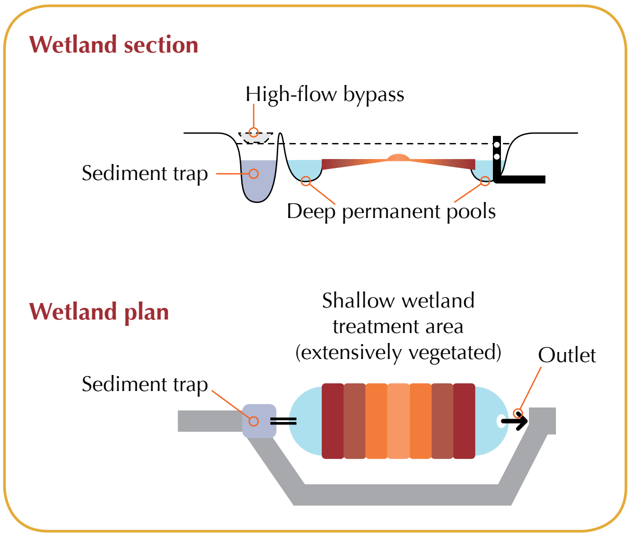
Designing wetlands for the capture and treatment of wastewater requires:

- sizing the wetland for a particular wastewater flow rate, catchment area and/or the removal of a particular pollutant
- configuring a water-flow path by using a series of wetland cells, levees and/or berms
- consideration of a variety of depths for habitat, pollutant removal, re-oxygenation and flow distribution (Mitchell *et al.*, 1998).

Wetland design requires an understanding of hydraulics. Hydraulics are crucial to the treatment performance of constructed wetlands as it:

- determines the effective detention time of water in the wetland
- the extent of water contact with wetland components such as plants and biofilms
- influences the time wetland treatment processes have to act on the inflowing water (Breen, 2007).

Poor hydraulic efficiency is one of the primary reasons for the poor performance of many constructed wetlands and can mean the difference between a functional and visually appealing wetland and a stagnant pond that offers little functional wetland values.



Conceptual layout of a treatment wetland showing sediment trap, high-flow bypass and deeper pools in the main wetland treatment area (Figure based on Healthy Waterways, 2006).

What is detention period?

Detention period (sometimes known as Hydraulic Residence Time (HRT) or detention time) is the period of time a 'parcel' of wastewater is retained within the wetland system.

The hydraulic effectiveness of a wetland reflects the interaction of four factors:

- detention period
- inflow characteristics
- wetland design
- storage volume.

Treatment efficiency is greatly improved the longer water spends in contact with the biofilms that grow on the plants and substrate in the wetlands.

Detention period—The time it takes for a 'parcel' of water to flow from the inlet of a wetland system to the outlet. Depending on the flow path taken by individual parcels of water, the time may vary significantly in the one system.

Ideal flow conditions occur when a parcel of water takes the same time to pass through the wetland (this is known as *plug flow*), and when the entire volume of the wetland is being utilised (Wong *et al.*, 1999).

The detention period can vary depending on the pollutant and the desired level of treatment, with typical detention times ranging from 0.5 to 5 days for sediment removal and up to 14 days for nutrient removal depending on catchment soil type, loads entering the wetland and the desired treatment objectives.

Detention periods can also be manipulated by increasing the distance the water has to travel before exiting the wetland. This can be done by incorporating a number of wetland cells, baffles, berms or levee banks into the wetland design.

Table 21 (below) shows some of the key design aspects that help to achieve hydraulic efficiency in a treatment wetland.

Determining detention periods and volumes

Before deciding on the size of the wetland, the amount of wastewater or runoff generated (also known as the hydraulic loading) by the site needs to be calculated.

Detention periods can be determined using several methods. A conservative approach to selecting a detention period for wetlands is to match the settling time of soil particle sizes for the pollutant or nutrient to be removed (Wong *et al.* 1999). Using sediment settling rates is also handy for determining sediment trap sizes (see Example E, page 64).

Hint: if soil particles obtained from the site takes three hours to settle out of suspension, then a sediment trap before the wetland that could hold a parcel of wastewater/runoff generated from three hours of runoff would enable sediment settling to occur.

Detention periods can also be calculated by determining the daily volume of wastewater to be treated multiplied by the time required for treatment objectives to be met. This requires pollutant concentration data of the wastewater influent and the desired level of pollutant reduction required.

Calculating detention volumes involves establishing the site runoff in cubic metres (m^3 or megalitres) that will enter the wetland system (this is known as the hydraulic loading rate or HLR) and determining the contribution of other catchment or site variables to the site runoff such as rainfall or extra irrigation events.

Table 21: Some key design aspects to achieve good hydraulic efficiency

Open water areas	
Maximise length-to-width ratio (*L:W*)	Include meanders or berms if needed to ensure *L:W* ratio >3.1 Avoid having excessively high *L:W* ratios as this increases flow velocities and leads to re-suspension of settled particulates
Spread flow at inlet	• weirs • multiple inlets • submerged berms • islands in front of inlet
Macrophyte areas	
Vegetate across the flow path	Either fully vegetate basin, or arrange bands of vegetation across flow path
Uniform cross-section	Ensure depth across flow path

Source: Wong *et al.* (1999)

A method to calculate detention volume is shown in Example A below.

Example A: Calculating detention volume

Required detention period = 3 days for nitrogen reduction

Daily wastewater or site runoff = 5800 litres/day

Detention volume = detention period × daily runoff

= 3 days × 5800 litres/day

= 17,400 litres or 17.4 cubic metres (m^3)

The time a parcel of water spends in the wetland can be lengthened by increasing the volume of the wetland or decreasing the hydraulic load.

Structures such as bund walls, baffles and habitat islands made of earth and/or rock can be included in the design to increase the time it takes for water to travel through the wetland system.

Determining wetland sizes
For agricultural applications there are generally two methods for determining wetland size, the choice of which depends on the purpose of the wetland and water quality treatment objectives. These methods are:

1. percentage of catchment area method
2. capture of single storm event or first-flush runoff.

Percentage catchment area method
As a general rule of thumb the area of a constructed wetland should be 2–5 per cent of the total catchment, otherwise excessive hydraulic loading and short-circuiting can occur (short-circuiting is when water flows directly through the wetland before being treated).

The percentage catchment area method provides a simple back-of-envelope calculation to determine if there is enough land available and is used for preliminary wetland sizing and determining the feasibility of the project.

Rainfall also needs to be taken into account as this can add to the detention volume and has the potential to displace untreated water from the wetland. If practical, this can be overcome by increasing the volume of the wetland to accommodate the average yearly rainfall for your area. In areas of north Queensland that receive high annual rainfall, increasing the size of the wetland to accommodate rainfall volumes may be impractical.

Example B: Determining wetland size using percentage catchment area method.

Area available on farm for wetland = **1.5 ha**

Size of farm catchment = **40 ha**

(Available wetland area/catchment area) × 100 = ?%

(1.5 ha /40 ha) × 100 = 3.75%

Therefore the size of the wetland is feasible as it is between 2%–5% of the catchment area.

Wetland area can be reduced by treating only those areas of the site that are the highest risk to water quality or farm production. This will reduce the amount of treatment area and the amount of wetland area required.

Capture of storm event (first-flush) runoff
Many treatment wetlands are designed to capture the first 25 mm of rainfall events to mitigate the effects of the first-flush transfer of pollutants.

The amount of runoff generated in a rain event depends on a range of catchment variables such as interception, infiltration, evaporation, existing soil moisture and groundwater flow characteristics of the catchment area.

To calculate catchment runoff, hydrologists and engineers use runoff coefficients that take into account catchment variables. Runoff coefficients are generally expressed in equations as '*C*'.

In some cases it will be necessary to determine an average annual volumetric runoff coefficient (C_V). However, for the design of stormwater management systems for agricultural purposes (e.g. sediment basins and treatment wetlands) determining the volumetric runoff coefficient for a single storm event is an acceptable method.

Volumetric runoff coefficient (C_V) is defined as the ratio of the volume of stormwater runoff to the volume of rainfall that produced the runoff.

The volumetric runoff coefficient for a single storm event can be used to estimate the catchment runoff volume for the design storm event.

The runoff coefficient is greatly influenced by soil type and vegetation density. In a high intensity storm a hard surface that does not allow any rainfall to soak in will have a very high runoff coefficient, around 0.9 or 0.95. Sandy soil that allows a lot of water to soak in would have a very low runoff coefficient, around 0.2.

Forested areas have a low runoff coefficient because some rainfall is intercepted by branches and leaves and leaf litter and infiltration is generally higher.

Coefficient values for agricultural areas vary according to soil types, slope and the capacity of the farm drainage network to accelerate or retard surface runoff. For example, high flow concrete V drains would be expected to increase runoff volumes and wide grassed trapezoidal-shaped drains would have the potential to limit the runoff generated during a storm event.

The use of BMPs such as cover cropping, stubble management and filter strips will also affect runoff and therefore the volumetric runoff coefficient.

Table 22 displays volumetric runoff coefficients for different soil types derived from the United States of America Soil Conservation Service and United States of America Department of Agriculture. These coefficients are used extensively throughout the United States of America and Australia in the design of both urban and rural runoff control structures.

Table 22: Typical single storm event volumetric runoff coefficients (C_v) for different soil types

Rainfall (mm)	Soil Hydrologic Group			
	Group A Sand	Group B Sandy loam	Group C Loamy clay	Group D Clay
10	0.02	0.10	0.09	0.20
20	0.02	0.14	0.27	0.43
30	0.08	0.24	0.42	0.56
40	0.16	0.34	0.52	0.63
50	0.22	0.42	0.58	0.69
60	0.28	0.48	0.63	0.74
70	0.33	0.53	0.67	0.77
80	0.36	0.57	0.70	0.79
90	0.41	0.60	0.73	0.81
100	0.45	0.63	0.75	0.83

Source: NRW (2008)

Group A soils: soil with very high infiltration capacity. Usually consist of deep (>1 m), well-drained sandy loams, sands or gravels.

Group B soils: soil with moderate to high infiltration capacity. Usually consist of moderately deep (>0.5 m), well-drained medium loamy texture sandy loams, loams or clay loam soils.

Group C soils: soil with a low to moderate infiltration capacity. Usually consist of moderately fine clay loams, or loamy clays, or more porous soils that are impeded by poor surface conditions, shallow depth or a low porosity subsoil horizon.

Group D soils: soil with a low porosity. Usually consists of fine-texture clays, soils with poor structure, surface-sealing (dispersive/sodic) soils, or expansive clays. Included in this group would be soils with a permanent high watertable.

Source: USSCS (1986)

Hint: if the soil texture is not known use a C_v value of 0.5.

Example C: Determining catchment runoff for capturing first-flush runoff.

Farm catchment area = 40 ha or 400,000 m^2

Size of rainfall event to capture = 30 mm

Soil type: clay—Group D (see Table 19)

Volumetric runoff coefficient = 0.56 (see Table 22, left)

catchment area (m^2) × rainfall event (mm) × volumetric runoff coefficient (C_v) = net runoff (litres)

400,000 m^2 × 30 mm × 0.56 = **6,720,000 litres or 6,720 m^3 or 6.72 megalitres (ML)**

Therefore, to trap a 30 mm rain event generated by a 40 ha farm a wetland or detention basin that can hold **6.72 ML** of runoff is required.

Remember: the wetland size needs to be increased if frequent storm events were to be captured and if detention times are long.

Example D: Surface area of the wetland required to cater for 6.72 ML of runoff.

Assumed average depth of wetland required = 1.8 m

Surface area (m^2) = runoff volume (m^3)/average depth (m)

= 6720 m^3/1.8 m = **3733 m^2 or 0.37 ha**

Sizing agricultural treatment wetlands

Sizing wetlands using the above methods provides an estimate of the wastewater or runoff generated by a catchment or production area and the wetland area required to manage and/or treat the runoff volume.

Use of these sizing methods are generally the first part in the decision-making process. Establishing a wetland on a working farm requires achieving a balance between the wetland objectives and the on-farm situation.

In most cases the size of a farm wetland will be determined by:

- **the primary objective of the wetland**
- **the amount of land the producer is willing to set aside to achieve his/her objectives**
- **the ability of the project budget to support the calculated wetland size (taking into account other site and planning constraints).**

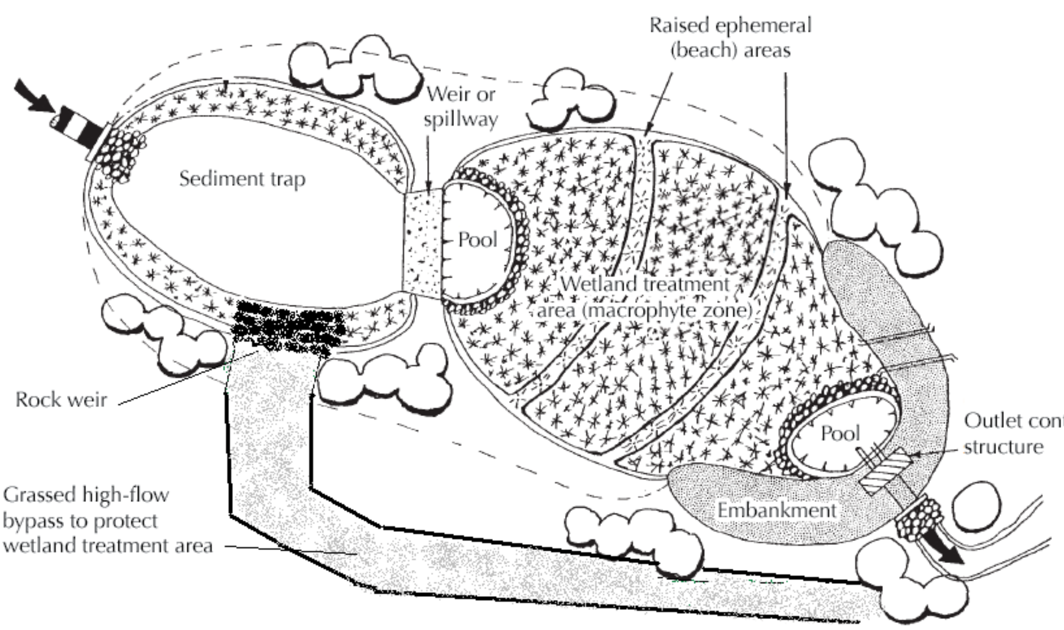
4. Key components of a constructed farm wetland

Once location, catchment variables and wetland sizes/volumes have been investigated, more detailed design issues may be considered.

Incorporating multiple cells or chambers

To improve treatment efficiency and lifespan, many surface-flow wetland designs incorporate more than one cell or chamber. Incorporating cells adds to the 'treatment train' effect by providing a secondary treatment process before final polishing and can improve treatment efficiency by:

- increasing sediment settling
- spreading and controlling water flow into the next cell
- protecting wetland vegetation and the biofilms from damaging flood flows.



Schematic layout of a sediment trap combined with a wetland system consisting of two separate cells, where a deep trap flows into a shallow wetland. The sediment trap removes coarse sediments, protecting the wetland vegetation from smothering, and the high-flow bypass protects the wetland vegetation by allowing storm flows to pass around the wetland.

Runoff pre-treatment using sediment (silt) traps
Construction of runoff control or water treatment structures requires consideration of inputs from higher in the catchment such as sediment and organic matter.

Excessive inputs of sediments and/or organic matter can quickly change the depth of natural and/or artificial wetlands and creates the potential for:

- weed dominance
- smothering of habitat
- reduced oxygen levels
- reduction in treatment efficiency
- reduced wetland lifespan.

Wetlands will perform poorly if gross pollutants and coarse sediments are not removed before the wetland treatment area.

Most coarse sediments and organic matter can be removed by incorporating a sediment or silt trap before the wetland. Like managing natural wetlands, consideration should also be given to land management practices in the catchment area. To minimise sediment input into farm-constructed wetlands, the adoption of BMPs such as grassed filter strips and headlands, minimum tillage, and the use of ground covers are recommended.

Sediment traps differ from wetlands because they primarily rely on physical settling rather than biological means of pollutant removal. They are often at the upstream end of wetlands to provide coarse sediment removal (CSIRO, 1999).

Incorporating a sediment trap before the wetland encourages sedimentation by enlarging the channel so water velocities are reduced to a point where sedimentation can occur.

The size of the sediment trap will vary according to catchment characteristics, in particular soil type (e.g. sediment settling rates) and slope. The *NSW DLWC Constructed Wetlands Manual Vol. 2* (1998) suggests that the recommended depth be between 1.5–2.5 m. This will provide the following benefits:

- limit the stratification of the water column
- limit the potential for emergent waterplant or weed growth
- maximise sediment accumulation
- reduce the frequency of maintenance.

Advantages of a sediment trap
- simple design, ease of construction
- reduces stormwater coarse sediment loads
- slow runoff velocities reducing erosion further downstream.

Limitations of a sediment trap
- breakdown of collected pollutants in the wet sump
- limited removal of fine sediments or soluble pollutants
- potentially large structure requiring substantial area
- possible source of sediments due to scouring during large floods
- maintenance requirements.

The sides (or batters) of the sediment trap should be relatively steep to aid in sediment removal and to discourage the establishment of excessive vegetation. Steeper batters also reduce the amount of land required.

When constructing sediment-trap batters the slope should be between:

- 2H:1V (2 horizontal: 1 vertical) for erosion resistant clays and up
- 4H: 1V (4 horizontal: 1 vertical) for sandy soils

Example of detention basin/sediment trap. Note the steep batters, which required less production land. (Photo by Joe Rhodes).

Calculating sediment trap size
The effective capture of sediment requires the trap to be designed according to site characteristics such as sediment type and flow rates generated by the farm catchment or drainage network.

Sediment trap surface areas are commonly determined on the basis of sediment settling velocities. The settling velocity of sediment particles under ideal settling conditions is presented in Table 23.

Hint: placing sand or rocks on the bottom of the sediment trap allows the excavator operator to know when the right depth has been reached during emptying.

Using the appropriate sediment settling rate for the soil types of the site, the overall size (m²) of the sediment trap can be determined by using the following equation.

$$A = \frac{Q}{V_S}$$

where: A = surface area of the sediment basin (m²)

Q = flow rate (m^3/sec)

V_S = sediment settling velocity (metres/sec)

An example calculation is shown below in Example E.

Table 23: Sediment settling rates based on particle size

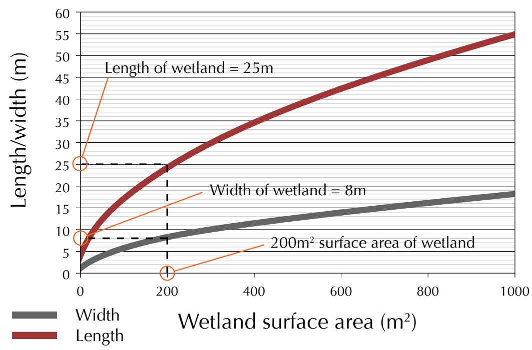
Classification of particle size range	Particle diameter (μm) (microns)	Settling velocity (m/s) V_s
Very coarse sand	2000	0.2
Coarse sand	1000	0.1
Medium sand	500	0.053
Fine sand	250	0.026
Very fine sand	125	0.011
Coarse silt	62	0.0026
Medium silt	31	0.0066
Fine silt	16	0.0018
Very fine silt	8	0.0004
Clay	4	0.00011

Source: Pilgrim (2001)

An alternative method to determine the length and width of a sediment trap or constructed wetland is to use the graph below, which allows the user to quickly determine dimensions using a 3:1 *L:W* ratio.

Simply find the nearest surface area (m²) of the sediment trap that has been calculated using the formula outlined in Example E (below), draw a vertical line that intercepts both the width and length lines. From the intercept points draw two horizontal lines across to the y axis

Calculation of wetland length and width based on 3:1 ratio



Graph supplied courtesy of Mark Bayley—Australian Wetlands.

Example E: Calculating sediment trap dimensions using particle-settling velocity.

Assumed flow rate into sediment trap = 2 m³/sec

Assumed sediment type = coarse silt

Particle settling velocity (coarse silt) = 0.0026 metres/sec (based on Table 23 above)

Depth = 2.0 m

Therefore:

A = 2/0.0026

Sediment trap area (SA) = **769.23 m²**

Example E continued: determining sediment trap length and width.

To avoid short-circuiting and improve sediment trapping efficiency (particularly during high flows) the recommended length:width (*L:W*) ratio for sediment traps is **not less** than 3:1 or **greater than** 10:1 (DLWC 1998b).

The following equations can now be used to determine the length and width of the sediment trap, given a known surface area:

$$Width = \frac{\sqrt{SA}}{L:W} \times 1.754386 \qquad Length = \frac{L:W \times \sqrt{SA}}{1.754386}$$

For example, to obtain the dimensions using a 3:1 *L:W* ratio, 769.23 m² sedimentation basin, you would substitute 769.23 for SA and 3 for *L:W* in the above equations to read:

$$Width = \frac{\sqrt{769.23}}{3} \times 1.754386$$

$$Length = \frac{3 \times \sqrt{769.23}}{1.754386}$$

Width = 16.2 m

Length = 47.4 m

Therefore the sediment trap size required to trap coarse silt in a drainage system that generates an inflow of **2 m³/sec** is approximately **16.21 m wide** and **47.4 m long.**

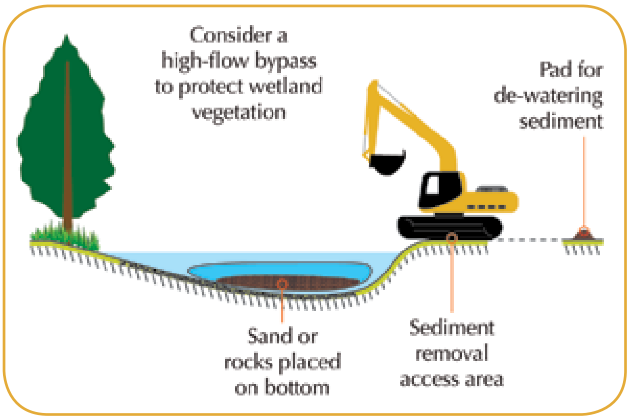
Reminder: 1 cubic metre (m³) = 1000 litres

Maintaining a sediment trap
The following issues can be considered for sediment trap maintenance:

- vehicular and excavator access to sediment trap to allow for periodic sediment removal
- sand or rock base to allow ease of removal of debris and sediment
- dewatering (silt drying) area may be required to drain removed material—sediment trap leachate has the potential to degrade water quality in receiving waterways. Bunding and collection of the leachate for further treatment or evaporation may be required.

Sediment accumulated in the trap requires removal to prevent sediment being re-suspended during storm events with emptying a necessity when storage volume has been reduced by half.

A rule of thumb is to ensure the sediment trap is emptied when 50 per cent capacity has been reached or before the onset of the wet season.



Conceptual layout of a sediment trap. (Original model courtesy Melbourne Water).

Sediment trap/sump under construction—bank in the background will be fenced and vegetated. Front batter has been made relatively flat to allow for grazing. (Photo by Joe Rhodes).

Sediment traps or basins

Sediment traps are an accepted option to reduce the offsite movement of sediment and allow the producer to recover the soil for further use.

Sediment traps are effective in trapping coarse sediment particles but are limited in dealing with fine clays and are generally used in catchments greater than 1 ha .

They require a design based on catchment hydrology, sediment type and the trapping efficiency required.

Importantly, the use of sediment traps does not excuse poor soil and erosion management in other areas of the farm.

Sediment traps are generally unsuitable for use in areas with dispersive soils unless lining with geo-textile fabric is undertaken. For information on designing sediment or gross pollutant traps consult the technical references listed at this end of this section.

Incorporating a high-flow bypass
If the sediment trap forms part of a wetland treatment system, a high-flow bypass is generally necessary to protect wetland vegetation from high-velocity flows and from the sediments that can be re-suspended from the sediment trap during periods of intense runoff.

High-flow bypasses normally consist of the following:

- a spillway from the sediment trap that allows flood flows to escape
- a grassed channel that carries the flood flow to the drainage network (DLWC, 1998b).

Scour protection may be required where the bypass channel re-enters the drainage network.

Wetland shape and orientation
The shape of the wetland will depend on the objectives and site constraints. Wetland shape and how it is orientated in the landscape can affect the following aspects:

- how water moves through the wetland
- creation of dead spots where water can stagnate
- dissolved oxygen levels, water temperatures
- pesticide reduction rates
- use of the wetland by water birds.

As circular shaped wetlands commonly create dead spots, more rectangular designs are favoured when the main objective of the wetland is water quality. A constructed wetland with a length to width (*L:W*) ratio of 3:1 or greater is the most hydraulically efficient, maximising the water contact with vegetation for treatment.

If multiple objectives are sought, use a shape that combines hydraulic efficiency with habitat provision.

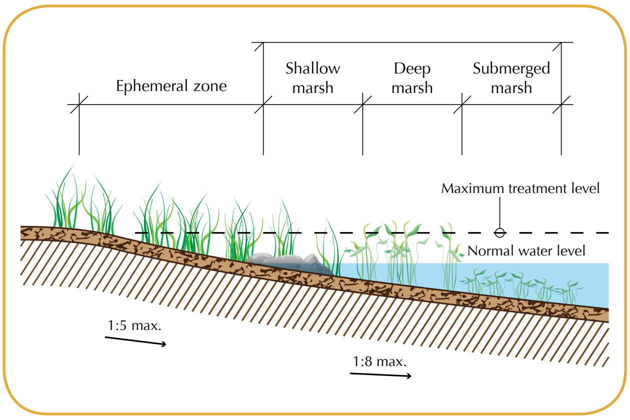
When orientating the wetland on the farm consider the following:

- length to width (*L:W*) ratios of 3:1 or greater are preferable for hydraulic efficiency
- position the wetland so some wind mixing and oxygenation of the water column can be achieved, while noting that excessive wind 'fetch' may cause bank erosion or scouring
- the risk of mosquito and feral pests (pigs)
- providing a hardened pad for machinery access to allow maintenance,
- provision of open water areas (or UV disinfection areas) >2 m deep to reduce pesticide levels.

Banks and edges
Although the edge zones of treatment wetlands may have little impact on the overall treatment performance they play a role in maintaining the integrity of the wetland by filtering sediments, preventing bank erosion.

Including vegetation on the wetland edge also promotes colonisation by macro-invertebrates and fish.

The final shape and steepness of the bank determines the vegetation types that will establish. Steep-sided banks reduce the opportunities for weed species to colonise wetland margins but also increase the risk of bank erosion.



Example of bank slope and vegetation zones. (Original figure courtesy Melbourne Water).

The irregular shape and gentle batter and habitat island of this newly constructed farm wetland reflect the desire to achieve multiple objectives of habitat provision and water reuse. (Photo by Ian Layden).

Steep edges may be unacceptable for safety or habitat reasons and a slope of 1:5 (vertical:horizontal) is often used.

Wetland outlets
The water level in a treatment wetland is controlled by the outlet structure. Wetland outlets can consist of the following engineering measures:

- weirs
- spillways
- adjustable riser pipes
- excavated earthen drains
- natural depression or waterway
- rock chute
- flumes or drop structures.

Creating a small deeper pool (1–1.5 m) before the outlet, reduces the risk of the outlet clogging with debris during periods of high flow, while providing some scope for aerating the water column.

Water exiting from the constructed wetland can be:

- stored in holding tanks or open-water areas for reuse
- re-introduced to the farm drainage network and/or directed to a natural waterway.

The potential impacts of drainage outlets are summarised below and need to be considered before deciding on the type of outlet.

- Increased flows in the stream
- Erosion of bed and banks at the outlet
- Sediment, nutrient and salt inputs
- Entry of untreated farm effluent through the high-flow bypass
- Litter and pollutants entering waterways
- Potential headward erosion in the bed of the outfall
- Native vegetation disturbance.

The choice of outlet type depends on the position of the wetland in the landscape, the receiving environment (e.g. whether the wetland is discharging to natural wetlands or waterways) and if downstream properties are likely to be affected by the discharge from the wetland.

Regardless of the type of outlet chosen, outlets control water levels in the wetland; therefore the position and design of the outlet are important for maintaining enough water in the wetland for the vegetation to survive dry periods.

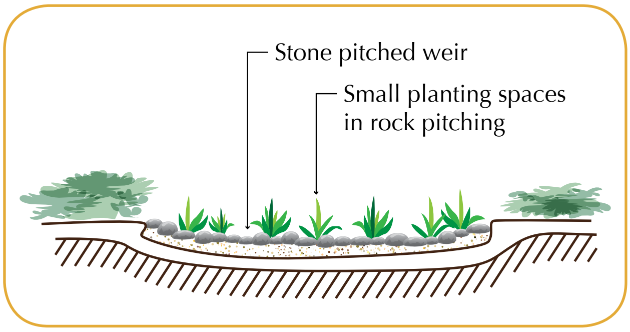
It is also important that the outlet not result in excessive and prolonged ponding of water in the wetland. This may cause vegetation dieback and a reduction in the treatment capacity of the wetland.

Experience has shown that outlets with height adjustment are more beneficial for wetland establishment, maintenance and normal wetland operation.

Choice of outlet will also depend on whether the wetland requires connectivity to a nearby waterway to enable fish migration.

For further information on how to design fish-friendly stream and drainage crossings consult the Queensland Department of Employment, Economic Development and Innovation's *Waterway Barrier Works and Fishways—Decision Support Guidelines* available at www.deedi.qld.gov.au

Erosion control in the form of rockwork and/or vegetation is generally required at the outlets. In Queensland, experience in treatment wetlands have shown that a well planted shallow outlet zone acts as a final filter for solids and floatable matter before discharge (NRW, 2000).



Schematic of a stone-pitched weir outlet that enables vegetation to be incorporated in the design. (Figure courtesy Melbourne Water).

Example of a rock gabion 'leakage' weir outlet from a sediment trap that discharges flows direct to a creek. Note the rock ramp (chute) that prevents bank erosion and the formation of gully heads when the trap is overflowing. (Photo by Joe Rhodes).

The incorrect design of this drainage outlet for the soil type and amount of runoff generated has resulted in bank collapse and the formation of a gully head which is retreating and contributing further sediment to the drainage network. (Photo by Ian Layden).

Incorporating habitat and biodiversity
Constructed wetlands provide habitat for some native plant and animal species, regardless of whether this is a design objective.

Incorporating biodiversity features into a wetland requires a diverse range of habitats and is generally achieved by variations in wetland shape, depth and plant species and should be designed into the wetland at the beginning of the process (DLWC, 1998).

Wetland design features for wildlife habitats include:

- an irregular shoreline to maximise the length and variety of edge habitat
- variations in edge slope and substrates (e.g. sand, pebbles, clay) to provide different habitats. Wading birds forage in shallow water less than 200 mm deep
- areas of deeper open water to attract ducks, geese and fish
- tall trees, e.g. *Melaleuca* spp. provide roosting sites for waders and shade for fish
- dense tall thickets of sedges and reeds allow small birds to nest and forage
- islands in open water provide roosting and nesting sites for water birds. In small wetlands, artificial floats moored to the wetland bed can be installed
- debris such as rocks, tree limbs and hollow logs placed in the wetland provide shelter for fish, aquatic invertebrates and frogs
- shade provided by plants helps to maintain lower water temperatures, while reducing the potential for algal blooms. High water temperature can lead to fish kills
- areas of permanent deep water for fish refuge throughout dry or periods of high temperatures.

A well vegetated habitat island. (Photo by Ian Layden).

Logs cleared from the construction site have been retained and placed in the wetland bank for habitat and stabilisation. (Photo by Ian Layden).

Habitat islands

- **modify wetland flows**
- **can provide good habitat for fish if constructed from rock**
- **place rocks to the normal water level then cap with soil. Provide logs and other habitat items**
- **establishing vegetation after the island is completed reduces erosion from wave action**
- **consider a gentle batter beach area for wading birds on the leeward side out of predominant wind**
- **consider the potential water quality impacts that large numbers of birds (e.g. ibis) may cause.**

Vegetating a constructed wetland
Like natural wetlands, the vegetation in constructed wetlands are a dominant feature and play an important part in wetland treatment processes and the provision of habitat (Jenkins and Greenway, 2005).

Wetland vegetation communities are determined by the inundation (hydrological) regime, which reinforces the importance of achieving a design that caters for catchment variables such as runoff generated.

Invasive grasses and wetland depth

The depth of the wetland determines the type of vegetation that will establish.

In north and central Queensland where invasive grasses (e.g. for example hymenachne and para grass) can quickly colonise shallow wetland areas, increasing the depth of the wetland to around 2 m has been shown to reduce the ability of these species to dominate the wetland.

The factors that determine wetland vegetation communities are a complex interaction of the following characteristics of the hydrological regime:

- depth of inundation
- frequency of inundation
- duration of inundation
- timing of inundation.

Remember to stockpile existing topsoil for reuse as a wetland substrate and, if it is suitable, for planting on the embankments.

Successful planting of wetland habitat is critical to wetland treatment performance and depends on six main factors:

1. planting design
2. site preparation
3. supply of planting stock
4. planting
5. water-level control
6. establishment period and maintenance.

Emergent species are normally more suited to planting by digging a hole, placing the entire root or rhizome and backfilling with substrate. Ensure that at least one third of the stem is above water level. Further guidance on planting can also be sought from the supplier (NRW, 2000).

Planting of wetlands in Queensland has shown that the shallower edge margins are more responsive zones for planting. Experience in the non-tropical regions in Queensland has shown that planting should be avoided between May and August, inclusive (NRW, 2000).

Plant the right species in the right zones at high densities, depending on the particular species, optimum planting densities can vary between five and twenty-five plants per square metre (50 to 25 cm plant centres) (NRW, 2008).

Hint: Planting density is a major factor in determining wetland planting success. The greater the planting density, the less competition from weeds and the faster the system becomes fully operational.

Planting of *different* macrophyte species across a flow path should be avoided. This will minimise the development of preferential flow paths, caused by flow resistance variations between different macrophyte species.

Planting layout patterns for emergent species include:

- band planting, e.g. a band of *Eleocharis* spp. then a band of *Baumea* spp. across the direction of flow
- planting parallel to the wetland edge, in depth zones typically 0–150 mm, 150–300 mm, 300–500 mm.

Banded planting of wetland plants is preferable if water quality is the objective. (Photo by Mark Bayley).

A note on establishing wetland vegetation: during the early stages of wetland establishment, water birds can be a major nuisance due to their habit of pulling out recently planted species.

Interlocking planting systems (i.e. where several plants are grown together in a single container such as floral edges) can be used, as water birds find it difficult to lift the interlocking plants out of the substrate unlike single plants grown in tubes.

Maintenance requirement during construction:

- **water level control during plant establishment**
- **regular watering of edge vegetation during plant establishment.**

Table 24: Types and functions of wetland plants in different areas of constructed wetlands

Wetland zone	Primary role of plants	Plant examples	
		Common name	Scientific name
Inlet	Distribution of flows, binding and protecting sediments	River club-rush Common reed Rush	*Schoenoplectus validus* *Phragmites australis* *Juncus procerus*
Shallow marsh: *Shallow inundated area that regularly dries out*	To provide a substratum for algal epiphytes and biofilms to enhance soluble pollutant uptake	Common spike-rush Pale twig-rush Soft twig-rush Swamp club-rush River club-rush	*Eleocharis acuta* *Baumea acuta* *Baumea rubiginosa* *Isolepsis inundata* *Schoenoplectus validus*
Marsh: *Medium-depth inundated area that occasionally dries out*	To maximise surface area in the flow path for the adhesion of particles	Marsh club-rush Rush spp.	*Bolboschoenus medianus* *Baumea arthrophylla* *Schoenoplectus pungens*
Deep marsh: *Permanently inundated area*	To enhance sedimentation of particles	River club-rush Jointed twig-rush Tall spike-rush	*Schoenoplectus validus* *Baumea articulata* *Eleocharis sphacelata*
Littoral: *Transitional area between wet and dry zones, subject to regular water level fluctuations*	To provide an edge buffer zone to protect banks from erosion	Tall sedge Tassel sedge Square twig-rush Rushes Tassel cord-rush Paperbarks	*Carex appressa* *Carex fascicularis* *Baumea tetragonia* *Juncus* spp. *Restio tetraphyllus* *Melaleuca* spp.
Ephemeral: *A dry to waterlogged area subject to regular inundation*	To maximise surface area in the flow path for the adhesion of particles under event flows	Tall sedge Common sedge Knobby Club-rush Rushes Paperbarks	*Carex appressa* *Carex tereticaulis* *Isolepis nodosa* *Juncus* spp. *Melaleuca* spp.

Source: Wong *et al.* (1999)

Key steps in planting a wetland

Determine wetland size and bathymetry (shape of the bottom surface)

↓

Identify different water depths or zones in the wetland

↓

Divide the wetland into water depth zones, and allocate suitable wetland plants and planting densities to each zone

↓

Plant wetland plants, ensuring effective maintenance while they establish (protection from birds, stock and flood events)

Maintaining a constructed wetland
Wetlands treat runoff or wastewater by filtering it through vegetation and providing extended detention time to allow sedimentation to occur.

In addition, wetlands have a flow-management role that needs to be maintained to ensure adequate flood protection of the wetland ecosystem and local properties (Healthy Waterways, 2006).

Maintaining healthy vegetation and adequate flow conditions are the key maintenance considerations.

Experience in Queensland has shown that wetlands require varying degrees of maintenance. The maintenance demand can depend on the climatic characteristics. In north Queensland a lack of maintenance can lead to the wetland being overgrown and infested with nuisance weeds.

Wetland vegetation maintenance involves mainly the removal of noxious or nuisance species, control of rank or dense growth and harvesting of certain species.

Constructed wetland maintenance tasks
Typical maintenance tasks for constructed wetlands involve:

- desilting the sediment trap (inlet zone) when 50 per cent capacity has been reached
- routine inspection of the wetland to identify any damage to vegetation, scouring, formation of isolated pools, litter and debris build up
- routine inspection of inlet and outlet points to identify any areas of scour, litter build up and blockages
- removal of litter and debris
- removal and management of invasive weeds
- repair to wetland bottom profile to prevent the formation of isolated pools
- replacement of plants that have died (from any cause) with plants of equivalent size and species
- pest monitoring and control.

Inspections of the wetland are also recommended following large storm events to check for scour and damage.

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Summary

As most of Queensland's wetlands are on private property producers play an important role in the management of these natural resources. Through their ability to provide a range of services (such as flood management, sediment and nutrient processing, habitat provision, soil development and pest management) natural wetland systems are an important resource not only to the producer but also to the landscape.

Because of the range of properties that exist in different wetland systems, managing wetlands requires an understanding of:

- where they are in the landscape
- what they look like
- the values that need to be looked after
- areas or risks in the production system that have the potential to affect wetlands
- the actions that can improve the outcomes for producers and wetlands.

As well as providing a mechanism that allows producers to demonstrate good work, using a risk-based approach via an industry-specific FMS program allows both the producer and extension staff to systematically carry out:

- an assessment of risk
- the planning of actions
- the implementing of best practice options
- a review the progress.

In intensive production systems producers are continually looking for ways to balance profitability with sustainability. The increasing use of artificial wetlands and sediment management devices across a range of crops in Queensland is testament to this.

Structures that have the capacity to provide water treatment and reuse along with habitat opportunities are one way of achieving this balance, though reaching the goal is not always assured. By using the information contained in this handbook producers and NRM groups can look to developing a shared understanding and common language regarding the pros and cons involved with artificial wetland systems.

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