A guide to managing and restoring wetlands in Western Australia

Managing hydrology

In Chapter3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Managing hydrology' topic

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Contents

Case studies

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

Introduction

Managing wetland hydrology is the most important consideration when managing a wetland. A wetland's physical, chemical and biological processes are so closely tied to the natural patterns and fluxes of water that changes to these influence the nature and ecological character of a wetland. Managing a wetland's hydrology is often likely to take the highest priority amongst all of the possible actions needed at a wetland, because it can trigger cascades of ecological impacts; causing, contributing to or amplifying the effects of many common wetland management challenges, such as loss of native plants and animals, poor water quality, weed invasion, acidification, inappropriate fire regimes, algal blooms and nuisance midge. Dealing with these problems without addressing the root cause may achieve little. For some wetland managers, all that will be required is a watching brief to make sure changes aren't likely, while for others managing hydrology will consume most of their time.

This topic outlines the causes of altered wetland hydrology in Western Australia (WA), the effects of altered hydrology, and potential management responses. The topic, 'Wetland hydrology' in Chapter 2 is recommended background reading because it describes the natural hydrology of wetlands, how it influences the plants, animals and water chemistry of wetlands and lists resources that can be used to characterise the natural hydrology of a wetland in WA.

Altered hydrology affects most of the state's land area and is one of the most prevalent and serious threats to WA's wetlands. The hydrology of most wetlands and waterways in WA have been significantly modified since European settlement, particularly in the south-west.[1] Some of the best-known examples of wetland decline in WA are caused by altered hydrology, including the secondary salinisation of Wheatbelt wetlands and the drying of wetlands on the Gnangara groundwater mound in the Perth region. Lesser-known examples include the acidification of wetlands in the South Coast, south-west and in Perth and the coastal plain stretching north and south of it due to drying; and the permanent inundation of previously intermittently inundated wetlands in inland mining regions due to the disposal of water from mine dewatering. An assessment rated the west and the north to be worst affected areas of the state, with the central and eastern regions suffering minor hydrological change with localised instances of major hydrological change[1,2] (Figure 1).

Altered hydrology is a significant challenge for land management in WA. In 2007 the Environmental Protection Authority compared WA's environmental threats and rated altered hydrology as being the second highest priority, on a scale of five, for policy development, management action and investment.[1]

> *"Alteration of natural water regimes is now recognised as a major contributor to loss of biodiversity and functionality of aquatic and terrestrial ecosystems. It can modify the values of inland waters and lead to other land and water problems including floods and drought-like conditions, waterlogging, salinisation, eutrophication, acidification and erosion. The maintenance of biodiversity and productive land and water systems depends on ecosystem services that in turn rely on maintenance of natural water balances and flow regimes. In severe cases, excessive alteration of natural water regimes leads to widespread loss of whole ecosystems and water supplies."*
>
> - Environmental Protection Authority, *State of the Environment Report: Western Australia 2007.*[1]

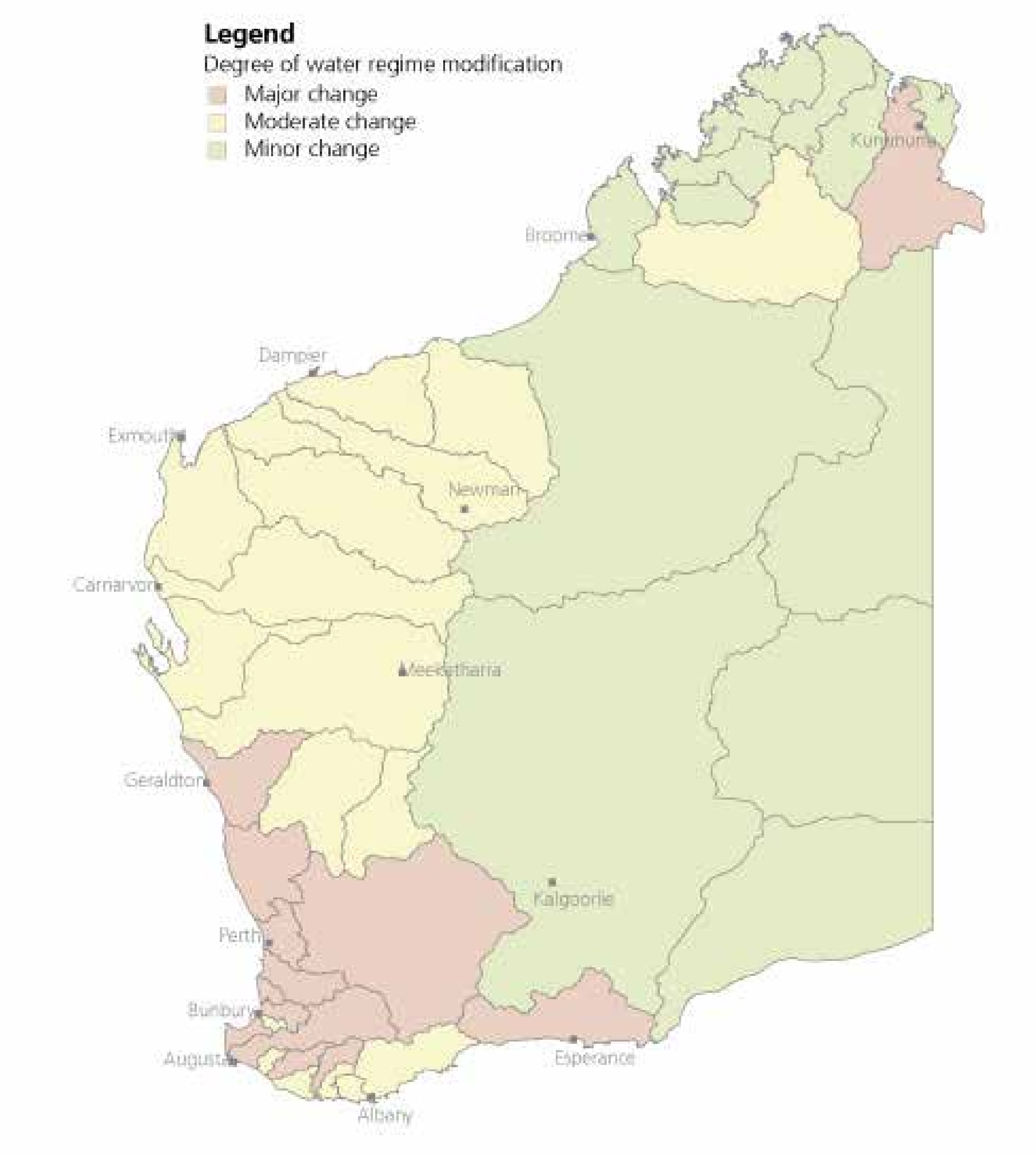


Figure 1. Extent of altered water regimes in WA, by river basins. Image - Environmental Protection Authority.[1]

Despite its high priority for management, altered hydrology and its impacts on WA's wetlands continue to be difficult to address for a number of reasons:

- Australia is one of the highest users of water on a per capita basis in the world.
- Human demand for water is increasing. Water use in WA has tripled in the last twenty-five years[3], increasing the competition between water for human needs and water for the environment.
- Altered wetland hydrology can reflect the wider broadscale change in a catchment. Very large falls or rises in regional groundwater tables are two of the most difficult problems for wetland managers in WA.
- Climate change is causing and will continue to cause severe changes to water availability and patterns in most parts of the state. Wetlands in the south-west of WA in particular are likely to be adversely affected.
- There exists the universal challenge of balancing land development against ecosystem conservation. For example, wetland flats on the coastal plain east and south of Perth have been extensively drained to make them more suitable for pasture and other agricultural uses.
- Water flows through landscapes, so hydrological modifications in one part of the landscape can affect wetlands located a considerable distance away. For example, groundwater dewatering to access minerals can create drawdown in aquifers far beyond the mine site, which can cause groundwater dwependent wetlands to dry beyond natural variability.
- Hydrological change can be intractable (that is, complex and enduring) because it may be ecologically, politically and/or socially difficult to restore the original wetland hydrology. For example, many urban wetlands around the state contain water year-round even though they originally dried out over the dry season, because the people living around them prefer them that way, despite this altering their ecological functions and values.
- Because of economic and social factors, protecting and managing some wetlands often comes at the cost of sacrificing other wetlands. This is the case in many secondary salinised catchments of the Wheatbelt, where the alternative to turning some wetlands into sacrificial drainage basins is to return almost all of the land back to deep-rooted trees, which could only be done at the cost of agricultural production.
- Wetland hydrology is influenced by complex interactions between many factors, including geology, soils, landscape shape, vegetation and climate. Information gaps can result in misunderstanding of the hydrological system, which undermines management decisions. For example, attempts to artificially maintain water levels of some wetlands in WA have had unexpected adverse impacts.
- Historical perceptions about the availability of water and the priorities for water allocation—"the pathological perception of plenty"[4]—are built into our cultural norms, legislation and infrastructure, so while there has been changes in community perceptions there are significant social, technical, commercial and regulatory hurdles to overcome in order to make changes to our water use in the future.
- There has been significant water reform in WA. However, a number of water management Acts are quite old, limiting some potential reforms. For example, the ninety-eight year old Act, *Rights in Water and Irrigation Act 1914*, was written to establish landholders' rights to water in a very early phase of the state's development.[5] It has been recognised as simplistic and out of date with modern requirements, including failing to deal adequately with environmental and social impacts of water use.[6,4] Similarly, legislation for coastal drainage is in need of review.[7]

These complexities mean that managing hydrology in wetlands typically requires much more than good local wetland management. It requires understanding, consideration and management of the effects of cumulative changes in a catchment, each of which viewed on its own may seem insignificant.

One of the biggest challenges facing wetland managers is that on-ground works at the wetland will often yield little improvement in wetland water regime in the long term, especially for those low in the catchment. The landscape-scale hydrological alterations driving altered hydrology of most wetlands means that the vast majority of wetland managers need to embrace the role of advocate, and work with and influence water users, land managers and decision-making authorities across broad landscapes.

Awareness, incentives and regulation are all important and complementary vehicles for change. Encouragingly, there has never been more recognition of the problems nor momentum across so many sectors to address the issues of water management in WA. Wetland managers can capitalise upon and strengthen this momentum by drawing attention to local wetlands of conservation significance, and engaging others to better understand the cumulative effects of their communities upon these wetlands, what values are at threat, and what can be achieved with collective action. The combined voice of wetland managers and other stakeholders can and has produced local, regional and institutional-scale reforms and initiatives in WA, and it is important that wetland managers participate in water planning and water resource management reform processes.

To address the big picture, an integrated approach to land and water management, often referred to as 'catchment management', has been applied to various degrees in WA (linked initiatives include total water cycle management and water sensitive cities). Key elements include cooperation among state and local governments, natural resource management organisations and landholders; involvement of landholders and local communities in identification of issues and solutions; and agreement on common objectives. A more integrated approach to catchment management requires a long-term perspective, and an appreciation that it requires many people and agencies to move beyond their traditional roles.[8] It is increasingly becoming a feature of natural resource management in WA.

However, sometimes a long-term, holistic approach to addressing hydrological issues cannot achieve change quickly enough to protect important wetlands that are under immediate hydrological threat. For wetlands of high conservation priority, a quicker-fix might be necessary, and this usually involves engineering. Engineering solutions have been implemented in several WA catchments, where catchment and landscape management cannot solve hydrological problems within the necessary timeframe. Some examples include artificial supplementation of wetlands with water in response to drying outside of known ranges (for example, at Thomsons Lake in the Perth suburb of Beeliar), and surface water diversions and groundwater dewatering to protect wetlands that are becoming too wet (such as at Toolibin Lake, east of Narrogin in the Wheatbelt and Lake Warden system north of Esperance in the south coast region). Unfortunately, this type of engineering can have downstream impacts and can be expensive. One study estimated that if groundwater dewatering was used to protect just 10 per cent of the Wheatbelt ecosystems threatened by rising saline groundwater tables, it would cost $63–78 million per year.[9]

extra information

Important concepts in wetland hydrology – a primer from the 'wetland hydrology' topic

Some important concepts in wetland hydrology are summarised here. These concepts are described in more detail in the topic 'Wetland hydrology' in Chapter 2.

- **Hydrology** refers to the properties of the Earth's water, particularly the distribution and movement of water between the land surface, groundwater and atmosphere, and its study. Hydrology can be studied at a range of scales (such as hillslope, catchment, regional or global) and from different perspectives (for example, focusing on a particular wetland, a river catchment or a groundwater aquifer) depending on the questions being asked.

- The term **wetland hydrology** is generally used to refer to the movement of water in and out of, and within a wetland.

- The term **hydroperiod** refers to the periodicity (permanent, seasonal or intermittent) of waterlogging or inundation of a wetland. It refers to the potential for water to either inundate a wetland or saturate it without supporting a free standing water column, and the duration of these states. Table 1 shows the wetland hydroperiods recorded in Western Australia.

Table 1. Wetland hydroperiods recorded in Western Australia. Adapted from Semeniuk and Semeniuk (2011)[10]

Periodicity	Hydrotype	
	Waterlogged	**Inundated**
Intermittent	Not applicable	Intermittently inundated
Seasonal	Seasonally waterlogged	Seasonally inundated
Permanent	Permanently waterlogged	Permanently inundated

- Wetlands with altered hydrology are often described in broad terms such as being 'wetter' or 'drier' than they should be. These descriptions convey the problem in broad terms, which is often all that is needed to initiate some form of management action. However, to fully understand and manage altered wetland hydrology what is needed is an understanding of changes relative to the wetland's natural water regime. The **water regime** of a wetland is the specific pattern of when, where and to what extent water is present in a wetland.[11] The components of water regime are the timing, frequency, duration, extent and depth and variability of water presence (Table 2).[12] This is also referred to as 'hydropattern' in many texts.

Table 2. Features of the water regime of wetlands. Adapted from Bunn et al., (1997).[17]

Feature	Definition
Timing	The timing of a wetland being waterlogged or inundated. Within-year patterns are most important in seasonally waterlogged or inundated wetlands (that is, what time of year) whereas between-year patterns and the variability in timing may be more important to intermittently inundated wetlands.
Frequency	How often wetting and drying occur. Ranging from not at all in wetlands that are permanently inundated (lakes) to wetting and drying many times a year. The rate at which wetting and drying occur can also be important.
Duration	The length of time of waterlogging and/or inundation. Duration in days, weeks or even years, varying within and between wetlands.
Extent and depth	The area of waterlogging or inundation and the depth of the water.
Variability	The degree to which the features mentioned above change at a range of time scales (variability in timing mentioned above). Variability is recognised as a significant part of wetland water regime.

- The wetting-drying cycle encompasses a wetland's natural, cyclic transition between wet and dry conditions. The duration of a single wetting-drying cycle varies between wetlands (with permanently inundated wetlands never, or extremely rarely, drying).

- Surface water reaches wetlands from the **catchment,** an area of land bounded by natural features such as hills or mountains from which surface water flows downslope to a particular low point or sink, where water

extra information

Important concepts in wetland hydrology – a primer from the 'wetland hydrology' topic (cont'd)

collects. Rain and surface water from overland flows and waterways are important natural sources of water for wetlands, particularly **perched** wetlands, which are not connected to groundwater.

- **Groundwater** is water occurring beneath the ground surface in spaces between soil grains and pebbles and in fractures or crevices in rocks. The **groundwater table** (or water table) is the upper surface of groundwater in an unconfined aquifer (top of the saturated zone). In technical terms, it is the surface where the water pressure head is equal to the atmospheric pressure. **Groundwater capture zones** are the area within which any recharge (infiltrating water) eventually flows into the wetland.
- **Groundwater dependent ecosystems** are those parts of the environment, the species composition and the natural ecological processes of which are dependent on the permanent or temporary presence or influence of groundwater. Not all wetlands are groundwater dependent ecosystems (such as perched wetlands and gnammas) and not all groundwater dependent ecosystems are wetlands (such as terrestrial vegetation communities that use groundwater).
- A **water budget** is the balance of all of the inflows and outflows of water over a set period of time. Inflows (inputs) include rainfall, surface water inflows and groundwater inflows. Outflows (outputs) include evaporation, transpiration, surface water outflows and groundwater outflows.
- Wetland water regime is the most important driver of wetland processes, and plays a key role in determining wetland characteristics such as the composition of plant and animal communities.
- The water regime directly affects wetland species. It also affects species indirectly by influencing the characteristics of a wetland including its physical (for example, turbidity), chemical (for example, acidity) and biological (for example, algal blooms) characteristics.
- Wetland water regime is influenced by many factors including climate, landscape shape, geology, soils and vegetation. That is, wetland hydrology is complex and driven at a number of spatial scales.
- Wetland water regime is also dynamic at longer timeframes. Wetlands have responded to changing climate over millennia. For example, Semeniuk and Semeniuk[13] and McHugh[14] have studied changes to Swan Coastal Plain wetlands occurring over thousands of years in response to climate changes.

What causes altered wetland hydrology in Western Australia?

The water regime of a wetland can be altered by anything that affects the movement of water into, out of or within the wetland. Change within a wetland's catchment or groundwater capture zone has the potential to alter wetland hydrology, with the main causes in WA being:

- climate change
- vegetation change
  - large scale clearing and planting of vegetation, vegetation decline
- removing water from wetlands and associated landscapes
  - groundwater bores, surface water pumps, dewatering, subsoil drainage and wetland drainage for land reclamation
- disposing of water (applying, disposing and moving) in wetlands and associated landscapes
  - stormwater disposal, dewatering discharge, deep drainage, irrigating, discharging effluent, discharging tailings
- changing wetlands
  - creating islands, deepening wetlands, puncturing confining layers, obstructing flows with causeways, burning of soils causing the loss of organic matter and subsidence of wetland sediments
- creating water loss
  - creating mining voids, artificial lakes

These drivers of altered hydrology are covered in more detail below.

Both the causes and the impacts of altered hydrology can vary in scale. Localised causes of altered hydrology include a groundwater bore near a wetland or a stormwater pipe discharging directly into a wetland; regional causes include broad-scale vegetation clearing or abstraction of significant volumes of water leading to aquifer-wide decline in water levels; and global causes include climate change. It is important to consider scale in identifying altered wetland hydrology and deciding how to manage it.

The causes of altered hydrology at a wetland can be multiple, complex and may originate far away from the wetland. For example, on the **Swan Coastal Plain**, hydrological change at wetlands is caused by a number of factors, including widespread clearing and urbanisation, climate change and groundwater **abstraction**. These factors are in turn driven by social drivers including economic trends, water pricing, politics and population growth scenarios.[15]

When considering what the causes of altered wetland hydrology might be, it is important to consider the potential linkages between water sources. Water resources in Australia are often classified as either surface water or groundwater, because in some cases the sources are separate. However in WA the connection between surface water and groundwater can be significant, and in many cases, abstraction of groundwater may cause a decline in the surface water resource, and vice versa.[16]

The cumulative effect of changes is critical. For example, modelling demonstrates that the decline in groundwater table in the superficial aquifer of the **Gnangara groundwater system** varies in location but is primarily due overall to declining rainfall, abstraction and pine plantations. This is despite the effect of clearing, which reduces the evapotranspiration of water.

Swan Coastal Plain: a coastal plain in the south west of Western Australia, extending from Jurien south to Dunsborough, and the Indian Ocean east to the Gingin, Darling and Whicher Scarps

Abstract: to take, remove, extract

Gnangara groundwater system: the groundwater system formed by the superficial, Leederville and Yarragadee aquifers located in northern Perth, east to Ellen Brook, south to the Swan River, west to the Indian Ocean and north to Gingin Brook

Lastly, a wetland's hydrology may alter naturally, but this usually occurs over longer timeframes than human-induced changes. For example, the build-up of sediments can change the shape of the wetland or modify the conductivity of wetland sediments, and these changes can modify the water regime.[17] Similarly wetland vegetation can influence hydrologic conditions and the physical and chemical environment by slowing water flows, creating new flow paths through the wetland, trapping soil particles and producing peat and other organic sediments.[17]

The following is a summary of the main driving forces of altered regime of wetlands in WA.

Climate change

Climate change is a major threat to wetland values worldwide. Western Australia, and in particular the south-western region of the state, is recognised as one of the regions most vulnerable to the effects of climate change worldwide.

Climate change is widely used to refer to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.[18]

extra information

Climate change defined

Climate change is defined as a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.[18]

The water regime of wetlands can be affected by climate change because it may affect natural patterns of:

- temperature
- evaporative demand
- rainfall.

In most areas of the Kimberley, temperature has increased by up to 0.6 degrees Celsius over the last forty years, but in some areas it has actually dropped by 0.2 degrees Celsius (Figure 2).[19] The temperature in the Pilbara has increased by 0.2–0.8 degrees Celsius. Although predictions vary between climate change models, northern WA is expected to become warmer, with more hot days and less cold nights.[19] Increased average and maximum water temperatures may trigger changes in the sex ratio of species in which temperature influences sex determination, such as turtles and crocodiles.[19]

In some parts of northern WA, including the Canning Basin and West Kimberley[19], increased rainfall has occurred over the period 1950–2000.[20,21] This may possibly be due to raised levels of aerosols from particulate pollution over Asia.[19] In general, this promotes wetter water regimes in the region's wetlands. The rise in sea level that is predicted to occur may also cause seawater intrusion into freshwater wetlands. Modelling predicts that rainfall will reduce slightly in the Kimberley by 2030 compared to the 1930–2007 baseline.[19] Refining climate modelling is an important step towards better managing wetlands in northern WA into the future.

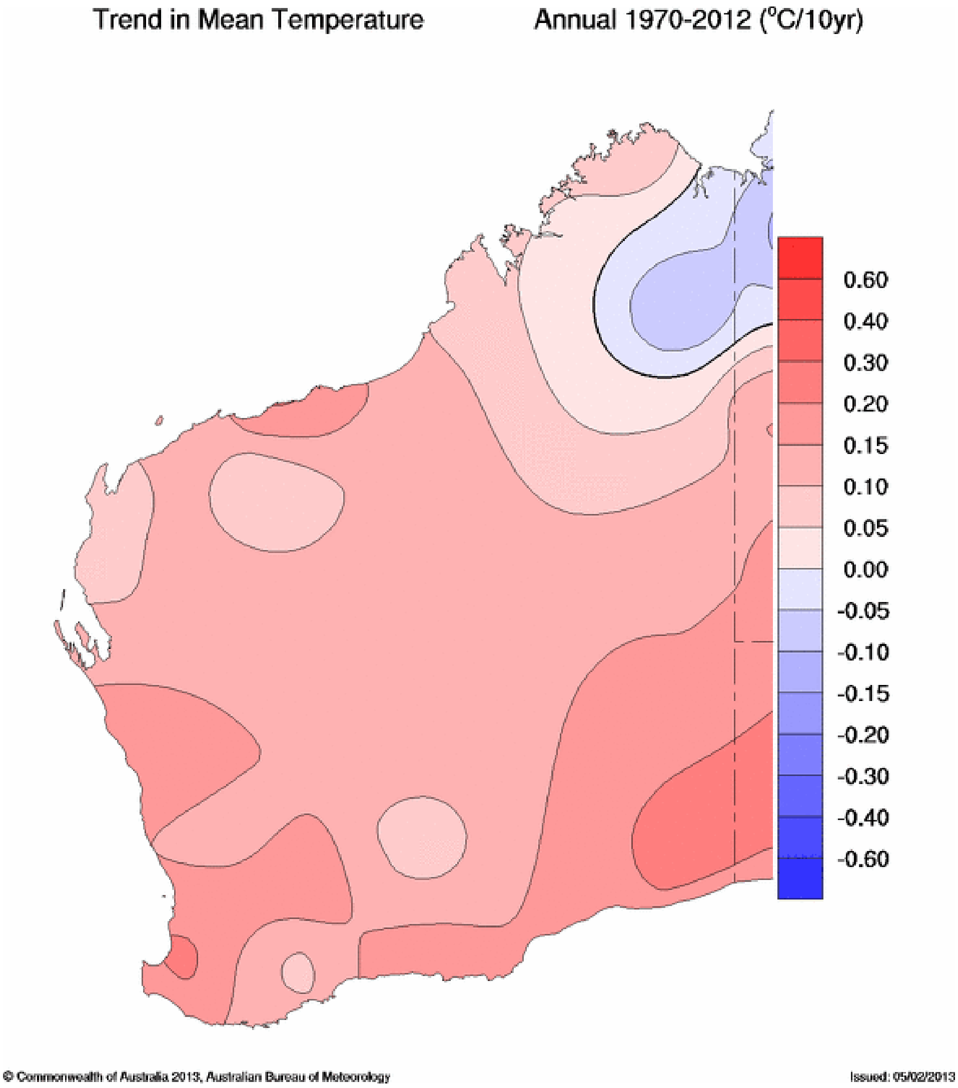


Figure 2. Trends in mean temperature 1970-2012. Image - Bureau of Meteorology.

In contrast, in the south-west of WA, both the annual and seasonal (autumn-winter) rainfall has already decreased significantly since the mid 1970s (Figure 3) and is projected to continue decreasing throughout this century. In fact, the largest reduction in rainfall in Australia has occurred in the northern part of the south-west.[19] The coastal and near coastal region between Geraldton and Albany (which is the study area of the CSIRO south-west WA sustainable yields [SWSY] project) has experienced a 10 to 15 per cent decrease in annual rainfall since about 1975[22], with the decline in autumn and early winter rainfall being the most marked.[22] Already, medium-intensity winter storms (in the range of 10–40 millimetres) which generate much run-off have become less frequent.[23] Runoff has decreased by over half since about 1975.[22] Extreme summer rainfall events have been more frequent since 1970, although there isn't conclusive evidence of the cause.[23]

The south-west is predicted to experience some of the largest reductions in rainfall in all of Australia[19]; projections to 2030 predict a 2–14 per cent reduction (median 8 per cent), over and above the 10–15 reduction that has occurred.[22] Slightly more rain in summer is also likely[19], with the potential for more unseasonal rainfall due to cyclonic activity.[19] Although there is a prediction that extreme rainfall events will become more common on a global scale, modelling with respect to south-west WA is less clear cut[23], with potential implications for the maintenance of processes such as the recruitment of trees.

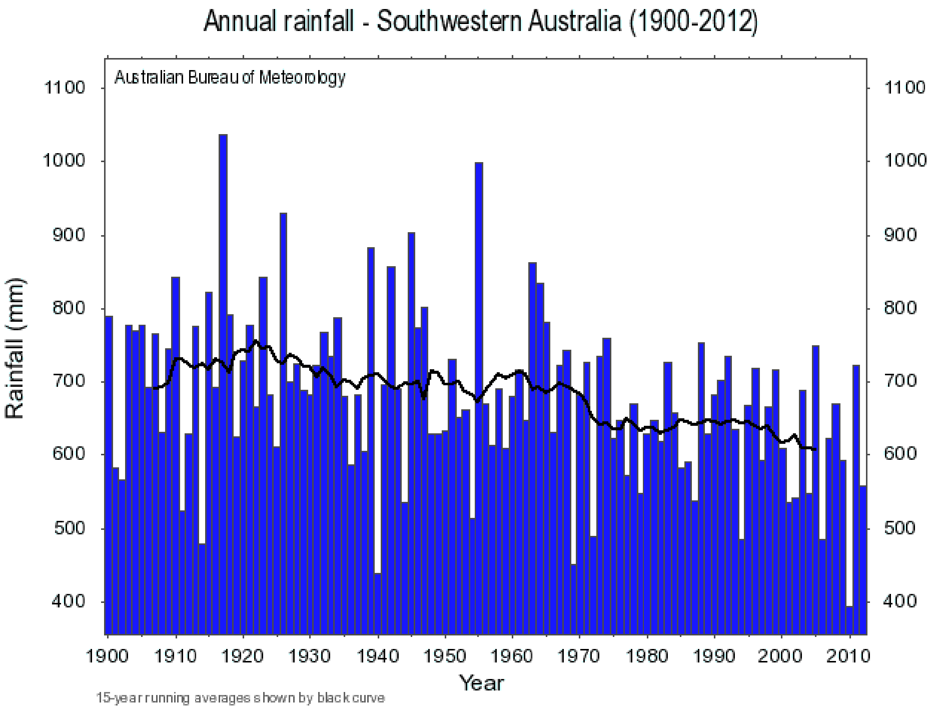


Figure 3. Average rainfall in south-western Australia, with the black line showing the 15 year average. It shows the continuing pattern of declining rainfall in the region. Image – Australian Bureau of Meteorology.

Temperatures have increased 0.4–0.8 degrees Celsius over the last forty years in the SWSY region.[19] Further increases in temperature are predicted: 0.5–2.0 degrees by 2030, compared to the 1960-1990 baseline.[19]

These factors contribute to drier wetland water regimes. All aspects of wetland water regime are likely to be affected (that is, the timing, frequency, duration, extent and depth and variability of water presence). CSIRO has concluded that, in the SWSY study area, 'Wetlands and perennial streams that were relatively abundant in the mid-twentieth century have either decreased or dried out as a result of this change'.[22] It has also predicted that falling groundwater levels are 'likely to result in groundwater dependent ecosystems such as wetlands being impacted'[22], with the potential for about 20 per cent of the area where groundwater dependent ecosystems may occur to experience high or severe stress under the dry extreme future climate modelling scenario in the southern half of the Perth Basin. Modelling indicates that by 2030, groundwater levels are expected to drop by an average of 3 metres within the western Swan Coastal Plain and by at least 3 metres within the Blackwood Plateau.[24]

Vegetation in and around wetlands, waterways and rainforests is likely to be most adversely impacted if drying leads to increased frequency of bushfires.

For information on climate change see:

➤ the DEC website www.dec.wa.gov.au/our-environment/climate-change/index.html

- the Australian Bureau of Meteorology website www.bom.gov.au/climate/change
- the south-west sustainable yields project on the CSIRO website www.csiro.au/en/Outcomes/Climate/Understanding.aspx
- the Indian Ocean Climate Initiative website www.ioci.org.au
- the Intergovernmental Panel on Climate Change (IPCC) website www.ipcc.ch

Changing vegetation

Clearing vegetation

Intact native vegetation in catchments and wetlands uses a significant amount of water and for this reason is important for maintaining the natural wetland hydrological regime. Vegetation clearing has been extensive in WA's urban centres and in areas used for cropping and grazing in the south-west and northern parts of the state.

The Avon Wheatbelt bioregion is one of the most highly cleared catchments in the world, with approximately 93 per cent of original vegetation cleared for cropping.[1] Although much of the cleared area has been planted with crops, compared with **perennial** native vegetation, these **annual** crops tend to use less water, have a shallower root profile, and only be present for part of the year. These features mean less water uptake and transpiration compared with native vegetation, resulting in greater rates of infiltration and aquifer recharge.

In the northern parts of the state, extensive areas of native vegetation have been modified through grazing by livestock and feral animals including camels, goats and horses, which has led to changes to the hydrology of some wetlands.

The presence and condition of dryland vegetation across a wetland's catchment can influence its hydrology by regulating the rates, pathways and amount of water that reaches the wetland. As water flows through bushland, the stems, trunks and plant litter slow its flow and promote its infiltration into soils that are held together by a network of shallow and deep roots. A significant amount of the water percolating through the soil may be taken up by plant roots and **transpired** to the atmosphere. Some water drains through, reaching the water table and recharging the groundwater aquifer. Some is intercepted by plant parts and litter before it reaches the soil, and evaporates. The clearing of native vegetation can impact on wetland hydrology in the following ways:

- Increased runoff on sloped landscapes: removing the stems, trunks and plant litter that slow flows on sloped land means that water has less chance to infiltrate into the soil and reach the wetland slowly through the sub-surface soil.[25] Wetlands downslope of cleared areas tend to receive more water, more quickly, via surface sheet flows. This can result in wetter water regimes as well as more sediment being transported into wetlands.
- Increased infiltration and aquifer recharge on flat landscapes: removing vegetation that intercepts and transpires infiltrating water can allow larger volumes of water to reach the water table. This can result in a rise in the water table and wetter conditions at some wetlands, as well as secondary salinity and acidity.

Changes in vegetation have been widespread in the south-west, and while there are likely to be some further changes in this region, these are likely to be localised. Regulations under the *Environmental Protection Act 1986* introduced in 2004 regulate the clearing of native vegetation, to protect native vegetation while allowing for permitted clearing activities.

One of the emerging considerations in the south-west is the effect of reduced rainfall associated with climate change. Current modelling suggests that the reduced

Perennial: a plant that normally completes its life cycle in two or more growing seasons (from germination to flowering, seed production and death of vegetative parts)

Annual: a plant that completes its life cycle within a single growing season (from germination to flowering, seed production and death of vegetative parts)

Transpiration: the process in which water is absorbed by the root systems of plants, moves up through the plant, passes through pores (stomata) in the leaves, and other plant parts, and then evaporates into the atmosphere as water vapour groundwater recharge associated with reduced rainfall may slow, but not offset, the additional recharge still occurring in many inland catchments of the south-west.[26] Furthermore, the reduction in rainfall can deprive wetlands of the freshwater inputs needed to maintain freshwater communities in the many wetlands undergoing secondary salinity.

In the north of the state, clearing by grazing, and in some areas mining, has been significant in some areas. The reduction in groundcover has significantly altered water infiltration and runoff patterns in affected areas. Currently, clearing of thousands of hectares of native vegetation is underway within the expanded Ord River Scheme near Kununurra, with further clearing proposed in association with the ongoing expansion of irrigation areas and the development of new agricultural zones. The Ord East Kimberley Expansion Project is a state government initiative that will increase the size of the Ord irrigation area to approximately 28,000 hectares of agricultural land. Approximately 14,000 hectares of irrigated farmland has already been developed.

➤ More information on the expansion of agriculture in northern WA is available from the Department of State Development website: www.dsd.wa.gov.au/8161.aspx.

Less well understood is the relationship between vegetation and rainfall. Reduced rainfall has been linked with clearing of native vegetation in areas of WA as well as other parts of Australia and the globe. For example, studies along the "clearing lines" in the eastern Wheatbelt indicate that the removal of vegetation influences rainfall patterns over wide areas. The link between vegetation and rainfall is thought to be related to the micro-relief of the vegetation surface and the air turbulence it causes, producing greater rainfall in vegetated areas.

Researchers from the Centre for Water Research at the University of Western Australia have found evidence that extensive clearing in the south west of WA has caused a 16 per cent reduction in rainfall. Researchers say that clearing of the forested coastal strip region south of Perth, which removed 50 per cent of the native forests between 1960 and 1980, coincided with a 16 per cent reduction in rainfall relative to stationary coastal rainfall. This highlights that not all rainfall decline is attributable to climate change, and land use decisions relating to clearing, revegetation and particularly reforestation will have a bearing on future rainfall patterns. Researcher Dr Mark Andrich cited growing tall native trees including jarrah and karri on vacant coastal land, as well as strategically growing native trees in and around farms, as possible ways to mitigate changes in climate.

Changing fire regimes

European land management practices have led to altered fire regimes across most of Australia. Fire removes above-ground plant parts, and therefore can have a similar effect on hydrology as vegetation clearing. It can promote run-off from sloped landscapes, and increase groundwater recharge on flat areas. As such, changed fire regimes in catchments have the potential to impact on wetland hydrology. Fire within wetland can also have significant effects on hydrology, particularly where sediments with organic matter such as **peat** are burnt, and the **hydraulic conductivity** of the wetland changes.

Tree plantations

Tree plantations (also known as **plantation forestry**) are common across the south-west (notably pines, *Pinus pinaster*, and Tasmanian blue gum, *Eucalyptus globulus*). In most cases, planting trees that consume large volumes of water can lower the water table in two ways: by reducing recharge (the roots take up water before it can percolate to the aquifer) and by using groundwater directly. For example, research by the Department of Agriculture and Food has shown that in an 800 millimetre rainfall zone, blue gum plantations did not allow any part of the annual rainfall to penetrate below 2 metres

Peat: partially decayed organic matter, mainly of plant origin

Hydraulic conductivity: a measure of the ease of flow through a pore space or fractures. Hydraulic conductivity has units with dimensions of length per time (for example, metres per second, metres per minute or metres per day).

Plantation forest: non-irrigated crop of trees grown or maintained so that the wood, bark, leaves or essential oils can be harvested or used for commercial purposes, including through commercial exploitation of the carbon absorption capacity of the forest vegetation depth of the soil profile, leading them to conclude that no recharge occurs in blue gum plantations in these areas.[27]

Gigalitres (GL): one thousand million litres (L); that is, one billion litres

In catchments where clearing has resulted in excess surface and groundwater, plantations may help to return the natural water balance of the catchment. However plantations can also lead to the drying of wetlands which source some or all of their water from the water table. For example, since the 1970s, the Gnangara pine plantations have been responsible in part for groundwater decline in the Gnangara groundwater system, which has resulted in severe drying of some wetlands.[1] The impact of pine plantations on the superficial groundwater aquifer varies, depending upon both the density of the plantation and its location on the mound. In areas where pine plantations were particularly dense they have caused groundwater declines in the order of 3.5 metres in the period 1979–2004.[28]

Factors that can increase the uptake of water in plantation forests include:

- large plantation area
- plantations in valleys and close to wetlands and other aquatic ecosystems
- high tree density
- high leaf cover or density
- no thinning or harvesting of trees
- mature trees with large canopies
- light or medium textured soils
- fresh groundwater
- shallow groundwater.[29]

Infrequently, tree plantations require the application of abstracted groundwater, rather than interception and shallow groundwater use by the trees. For example, proponents of a 900 hectare tropical timber (teak, Indian rosewood and Indian sandalwood) plantation in Beagle Bay, Dampier Peninsula (120 kilometres north of Broome) proposed to abstract 4.5 **gigalitres (GL)** a year from the Broome aquifer for application on the trees.[30]

Finally, water table changes triggered by the harvesting of plantations may cause acidification at nearby wetlands under certain conditions (M Smith, pers. comm.).

Removing water

Water is usually taken for one of three reasons:

- for use
- its presence is preventing the installation of infrastructure in the short-term (such as below-ground pipelines)
- its presence is preventing the land being used for another purpose in the medium to long term (such as mines, agriculture or houses)

Taking water for use

Water is consumed as domestic drinking water, in producing and processing food and other primary produce, extracting minerals, manufacturing, generating energy, watering parks and gardens and in other urban, industrial and agricultural uses. It was estimated that 2,340,000,000,000 litres, or 2,340 gigalitres (GL), of water was consumed in WA in 20053, harvested from a wide range of surface and groundwater sources. Irrigated agriculture (including pasture, horticulture and turf) accounts for 35 per cent of all licensed use in WA. With a growing population and economy, there is increasing pressure on WA's water resources for consumptive uses.1 This growing demand is an increasing threat to wetlands, because any water consumed from or delivered to a wetland's catchment can affect its hydrology. Taking water for use involves either groundwater abstraction or surface water harvesting.

➤ For an overview of WA's water use by sector, see the *State Water Plan.*[3]

Drawdown: the lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure

Cone of drawdown: the depression of the potentiometric surface. Also known as a cone of depression.

Unconfined aquifer: an aquifer close to the land surface which receives direct recharge from rainfall. Its upper surface is the water table. Also known as a superficial, or surficial, aquifer.

Abstracting groundwater for use

Compared with other Australian states and territories, WA relies heavily on groundwater for consumption. It is the only readily available source of water over about 60 per cent of the state. Groundwater is a source of water in all regions of WA. In fact, until the Perth and Southern Seawater desalination plants began supplying water, groundwater provided about two-thirds of the state's water.[31]

At the local scale, abstraction can cause localised cones of depression. The cumulative effect of large amounts of abstraction can be a significant lowering of the groundwater table. These two forms of impact are outlined below.

Drawdown causing localised cones of depression

At the local scale, abstraction can reduce the water in a wetland if it occurs in proximity to it, because it creates **drawdown** in the form of a **cone of drawdown**. In an **unconfined aquifer**, groundwater pumping causes a cone-shaped depression in the water level that expands outwards from the pumping bore until reaching a stable shape (Figure 4). If the cone of depression reaches a wetland, water can be drawn out of the wetland, leading to a direct reduction in water in the wetland (Figure 5). As a guide, the depth of the cone is dictated by the pumping rate, the slope of the cone is dictated by the characteristics of the aquifer medium (storativity and hydraulic conductivity), while the radius is dictated by the duration of pumping. Both small and large abstraction volumes can affect nearby wetlands if not managed appropriately, with the potential to generate adverse effects from abstraction for a small-scale market garden through to a public water supply scheme bore.

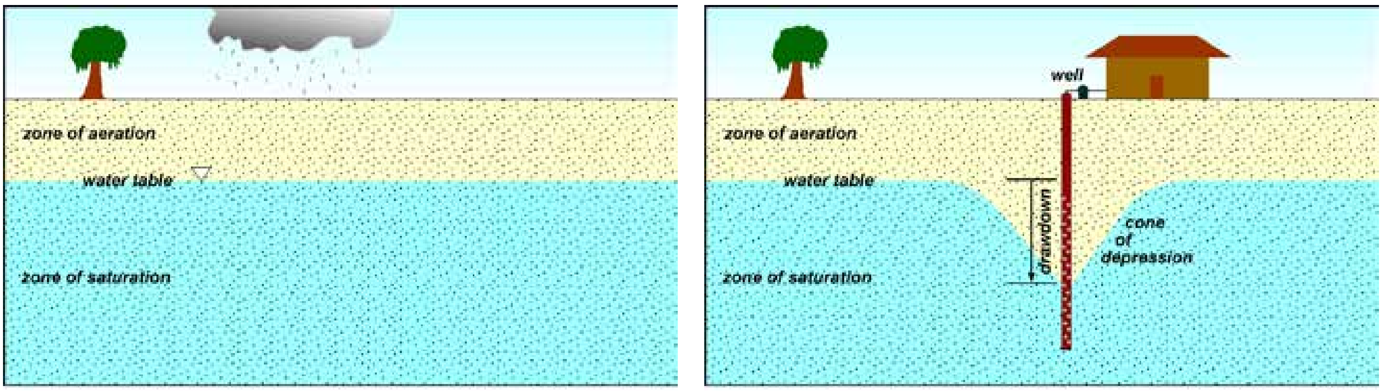


Figure 4. A stylised cone of depression caused by groundwater abstraction in a superficial groundwater aquifer. Image source - http://myweb.cwpost.liu.edu/vdivener/notes/groundwater.htm

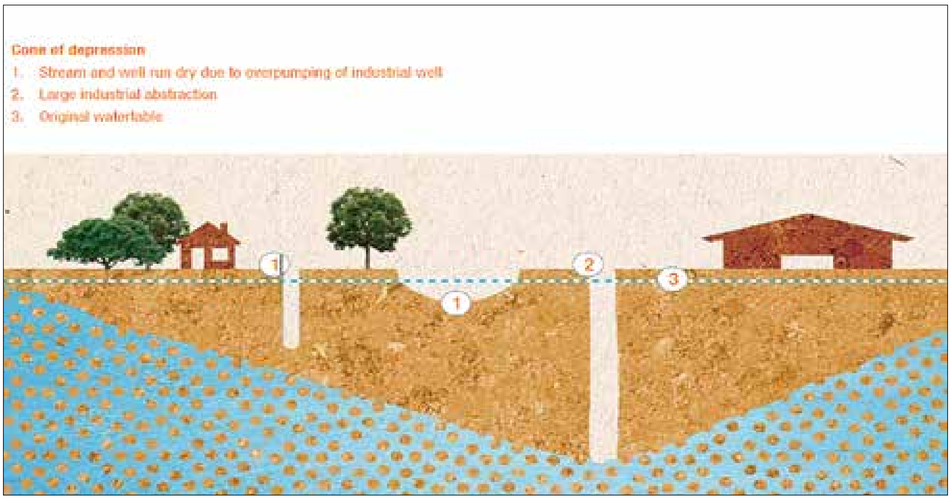


Figure 5. A cone of depression that has lowered the superficial aquifer beyond the base of a stream. Image – National Water Commission.

Confined aquifer: an aquifer deep under the ground that is overlain and underlain by relatively impermeable materials, such as rock or clay, that limit groundwater movement into and out of the aquifer

Regional drawdown of groundwater aquifers

Sustained abstraction of large volumes of groundwater can significantly reduce the amount of water in affected aquifers. Where those aquifers provide water to wetlands, or are connected to those aquifers, wetlands can become drier. The risk of wetland drying caused by groundwater abstraction is particularly prevalent on the Swan Coastal Plain, the south-west, Carnarvon and Pilbara. Groundwater dependent wetlands may be maintained by either superficial or confined aquifers. For example, the significant 'Reedia wetlands' are maintained by groundwater discharge from the Leederville aquifer's Vasse Member.[32]

➤ To find out what aquifers occur below/in proximity to a wetland, refer to the Department of Water's *Hydrogeological Atlas*, available at www.water.wa.gov.au/idelve/hydroatlas/.

➤ To find out more about the state of a particular aquifer, the groundwater webpages of the Department of Water are a good place to start: www.water.wa.gov.au/Understanding+water/Groundwater/default.aspx

➤ For mapping of groundwater dependent ecosystems, see the Bureau of Meteorology's *National Atlas of Groundwater Dependent Ecosystems*: www.bom.gov.au/water/groundwater/gde/.

The most studied example is the Gnangara groundwater system, which is located north of the Swan River in metropolitan Perth. Prior to the operation of the two desalination plants supplying Perth, around 60 per cent of Perth's public water supply was sourced from groundwater, via production bores[33] (Figure 6), with the Gnangara Mound being the main groundwater resource (with the level of abstraction varying in recent years) (Table 3). As well as supplying the people of Perth with a very significant proportion of their 'scheme' water needs (via water service providers such as the Water Corporation), very significant volumes of water from the Gnangara groundwater system are also used for commercial agriculture, forestry and market gardens, and by local government authorities and domestic bore users. The Department of Water estimates that up to a quarter of water abstracted from the Gnangara Mound is done so for domestic use (domestic garden bores are not licensed or metered).[34] The cumulative effects of abstraction, climate change and pine plantations have significantly reduced groundwater in the aquifers that make up the Gnangara groundwater system. Here the deep, **confined** (northern) Yarragadee aquifer, has declined by approximately 50 metres, with most decline centring around Gwelup and Wanneroo.[35] The confined aquifer that overlies it, the Leederville, shows declines of 10 metres, with the largest decline evident around Wanneroo-Pinjar. Above this is unconfined, superficial aquifer. The water table of the superficial aquifer, which most of the 200 wetlands in the area are directly dependent upon for some proportion of their water, has fallen by up to 6.5 metres in areas since the 1970s.[36] Impacts from water abstraction are centred on the Pinjar, Wanneroo, Gwelup and Mirrabooka borefields, with declines of a maximum of 2.4 metres, 2.0 metres, 3.0 metres and 1.5 metres respectively within a six kilometre radius of the borefields.[28] Wetlands that are dependent upon this groundwater have been affected, with the severity of drying differing between wetlands. Water storage in the aquifer has declined by about 500 gigalitres over the last 20 years.[37]

Although the deeper unconfined aquifers are not directly connected to wetlands on the Gnangara Mound, the volume of water stored in them does affect wetlands, as a deficit in the volume of water in a confined aquifer can be transferred to the superficial aquifer because of the hydraulic connection between aquifers. There is downward leakage from the superficial aquifer in locations where the major confining materials are absent from the confining aquifers. The Kardinya Shale separates the superficial aquifer from the Leederville, while the South Perth Shale separates the Leederville from the Yarragadee.[38] When abstraction in the confined aquifers occurs, the decline in the potentiometric heads can cause increased leakage from the superficial aquifer. The increase in leakage can cause water table decline in the superficial aquifer. Groundwater modelling suggests that while the confined aquifer responds to confined abstraction rapidly, the superficial aquifer responds to it slowly.[38] In this way, abstraction of an aquifer can have either a direct or indirect effect on wetlands.

➤ The state of the Gnangara Mound is subject to ongoing monitoring and management. Two key webpages are the Gnangara Sustainability Strategy webpages, www.water.wa.gov.au/gss, and the Department of Water's Gnangara Mound webpage: www.water.wa.gov.au/Understanding+water/Groundwater/Gnangara+Mound/default.aspx#1.

Table 3. 10 year integrated water supply service abstraction history for Gnangara and Jandakot mounds. Source – Department of Water[39]

Year	Jandakot Mound (gigalitres)	Gnangara Mound (gigalitres)	Combined (gigalitres)
2001-02 (dry year)	11.92	153.21	165.13
2002-03	7.8	159.2	167
2003-04	7	151	158
2004-05	5.7	150.3	156
2005-06	5	136	141
2006-07 (dry year)	8.36	160.84	169.2
2007-08	8.5	135	143.5
2008-09	10.8	136.2	147
2009-10	10.8	110.2	121
2010-11 (dry year)	13.3	151.71	165.01

Figure 6. (a) Groundwater, surface and desalinated water sources in the Perth area; and (b) a production bore on the Gnangara Mound, one of many used to source water for the public water supply. Image (a) Water Corporation; (b) Department of Water.

Harvesting surface water

Harvesting water directly from wetlands

The taking of water directly from a wetland can reduce water levels, particularly in wetlands that are not connected to groundwater (in general or at the time of the harvesting). Under the *Rights in Water and Irrigation Act 1914*, areas of the state are either proclaimed water resource areas or not. In those areas that are not proclaimed, the owner or occupier of any land in direct contact with a watercourse or wetland can take water for domestic or non-intensive stock water without a licence under certain conditions; these are known as 'riparian rights'. Permits are required in proclaimed water resource areas, regardless of whether a riparian right to take water exists. Landholders can take water from springs rising to the surface on their land and wetlands wholly on their land, provided the resource is not noticeably or sensibly diminished. The Act does not specify the amount that can be taken under the auspices of riparian rights in unproclaimed areas.

➤ A map of proclaimed surface waters of WA is available from www.water.wa.gov.au/PublicationStore/first/86306.pdf

Compared with groundwater abstraction, the practice and impact of surface water harvesting on WA's wetlands is thought to be less widespread. While not uncommon in Perth's peri-urban areas, most surface water harvesting is in the high-rainfall south-west, and mostly from waterways and dams rather than from wetlands directly. An exception is springs, which are often harvested, usually by excavation to allow greater access to water for on-farm use. Many of the **mound springs** of WA have been excavated to form dams or filled with limestone to create pasture.[40] Intact mound springs are very important **ecological communities**, and across the state, many have been recognised

Mound spring: an upwelling of groundwater emerging from a surface organic mound

Ecological community: naturally occurring biological assemblages that occur in a particular type of habitat by the state and Australian governments as threatened ecological communities. As well as being threatened by surface water harvesting, many mound springs are threatened by groundwater decline, and in the Pilbara, from direct impacts of trampling by managed and unmanaged livestock and feral camels.

extra information

Springs under threat

In the south of the state springs under threat include the following ecological communities:

- Communities of tumulus springs (Organic mound springs, Swan Coastal Plain)
- Assemblages of the organic mound springs of the Three Springs area.

In the north these include the:

- Assemblages of Dragon Tree Soak organic mound spring
- Assemblages of Bunda Bunda organic mound spring
- Assemblages of Big Springs
- Organic mound spring sedgeland community of the North Kimberley bioregion
- Black Spring organic mound spring community
- Assemblages of the organic springs and mound springs of the Mandora Marsh area.

For more information on these threatened ecological communities (TECs), refer to DEC's TEC webpage: www.dec.wa.gov.au/management-and-protection/threatened-species/wa-s-threatened-ecological-communities.html.


(a)


(b)

Figure 7. (a) This dam has been constructed to reduce the impact of livestock on (b) Saunders Spring, Mandora Marsh, Shire of Broome. Water is gravity-fed, while the wetland is protected by fencing. Photos – G Daniel/DEC.

Harvesting surface water flows

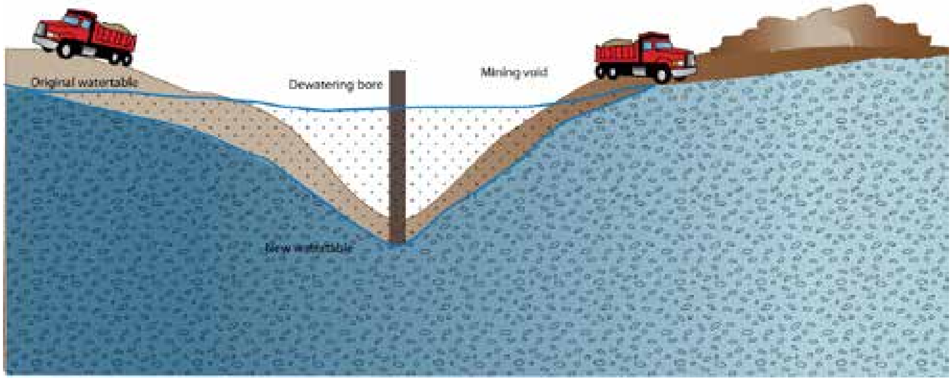
In agricultural catchments, the natural volume of overland flows into wetlands can be reduced if seepage or run-off is harvested by altering flows using **roaded catchments** and other earthworks[41] and directing water into farm water storages such as dams. Historically, much of this water harvesting actually helped to combat the effect of widespread clearing, which makes wetlands wetter than they are naturally. However, with the intensification and diversification of agricultural land uses and the effect of climate change in the south-west, harvesting surface run-off is now potentially depriving many wetlands of their natural inflows. The construction of dams has been linked with a number of environmental changes including major impacts on wetland ecosystem hydrology by altering the timing, magnitude and frequency of water movement.[42] The changes in water movement that a dam creates may threaten the ecological values of wetlands.[42] Similarly, structures to harvest rainwater falling on natural granite outcrops[43] can deprive wetlands on granite outcrops and in the surrounding areas of an important source of water.

Roaded catchment: a catchment where a series of adjacent v-shaped (in cross section) channels are created in the landscape to channel water to a downslope water storage

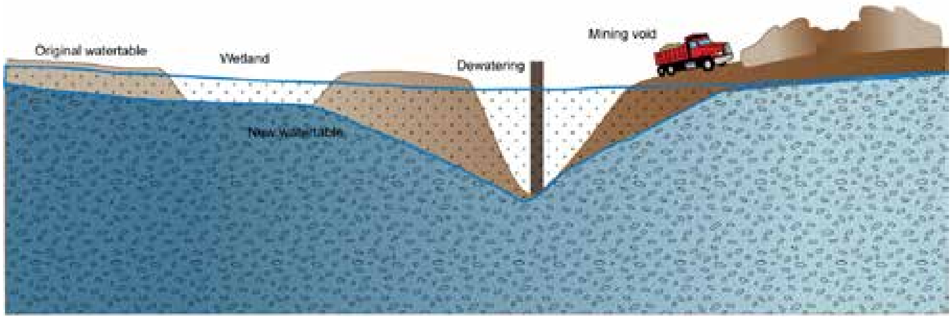
Dewatering: the process of removing underground water to facilitate construction or other activity. It is often used as a safety measure in mining below the watertable or as a preliminary step to development in an area.

Dewatering groundwater

Dewatering involves the removal of groundwater to provide access below the water table. It is a common practice across WA. Dewatering is often a component of mining, as well as when installing underground infrastructure such as pipelines. Dewatering may be achieved by pumping water from groundwater bores in order to draw down the groundwater table (Figure 8a). Alternatively, groundwater that flows into an excavation may be pumped out. Both methods usually result in drawdown of the groundwater table beyond the excavation area. In the case of mining, the groundwater table may need to be lowered by hundreds of metres, and over timeframes of decades. This is the case in a number of operations in the Pilbara.[44] In fractured rock aquifers of the Pilbara, the amount of water abstracted may range from less than 1 gigalitre to 10–40 gigalitres per year.[45] Mine dewatering discharge accounts for an estimated 52 per cent of total water use in the Pilbara, which in 2008 was estimated at 127 gigalitres per year.[45] It is predicted that over the next 20 years, mine dewatering volumes in the Pilbara are likely to increase threefold.[46] Altered wetland hydrology due to dewatering can be caused by either the drawdown itself, or by disposal of unwanted groundwater to wetlands, discussed later. Groundwater drawdown can cause wetlands near the dewatering site to experience drying, if their natural water source includes the superficial aquifer and the cone of depression reaches the wetland (Figure 8b). This has been identified as a risk for wetlands near mines in the south-west, Pilbara[47] and the Mid-West.[48]



(a)



(b)

Figure 8. (a) a groundwater drawdown cone of depression produced by a pump in a mining void; and (b) a groundwater drawdown cone of depression affecting the water regime of a wetland.

Transferring water to aquifers

Aquifer storage and recovery is a process in which water is harvested when it is readily available and pumped into an aquifer for storage, for use in drier times. Distinction is made here between aquifer storage and recovery using water harvested from natural water sources, and managed aquifer recharge using sources such as wastewater, stormwater and dewatering excess, as discussed later in this topic. Aquifer storage and recovery is not widespread in WA, but it has been suggested as a method to replenish hypersaline aquifers (that is, aquifers containing water saltier than seawater) in the eastern Goldfields depleted by abstraction for minerals processing.[49] Water from a large network of salt lakes has been proposed as a potential source of water for replenishment in the eastern Goldfields.[49] The use of water from wetlands to 'replenish' these aquifers would result in sudden and possibly extreme drying of wetlands from which water is sourced.

Draining wetlands

Traditional drainage: open and piped drains

Much of the urban, agricultural and industrial landscapes present today across the south-western coastal areas of WA were made possible through extensive draining, clearing and infilling of wetlands.[50] Much of Perth was built on drained wetlands (for example, the northern Perth area, known as the 'Great Lakes District', shown in Figure 9.

Figure 9. Map of the former Perth wetlands or 'Great Lakes District', constructed from a map by M. Pitt (1979), which itself was reconstructed from a map by John Septimus Roe (1834). Source – Wikipedia (http://en.wikipedia.org/wiki/Perth_Wetlands).

Check: a concrete frame with boards slotting into it, creating a barrier across the drain. The checks are opened or closed by addition or removal of the boards.

Open or piped drains may carry away up to 80 per cent of the rainfall volume in clay catchments and up to 25 per cent in sandy catchments in south-western WA. By rapidly transporting water away, there is less recharge of rainfall to shallow, unconfined aquifers and greater volumes of water are transported and discharged into downstream receiving surface water bodies. Many drains also intersect the groundwater table. Today, much of the south-west coastal zone has networks of drains that intersect the groundwater table to prevent natural winter waterlogging and inundation.[50,51] Broadscale draining of wetlands has particularly targeted the once extensive areas of flat, winter-waterlogged wetlands common to areas of WA's south-west, particularly eastern Swan Coastal Plain and the Scott Coastal Plain, as well as Albany. Water levels in some drains are manually controlled using **checks** and boards, weirs or other devices.

Rural surface drainage of the Swan and Scott coastal plains

Swan Coastal Plain

Most areas of pasture on the eastern side of the Swan Coastal Plain either are or were wetlands[52] that, when intact, had exceptional ecological significance. The remaining intact areas are representative of what was naturally a mosaic of an extensive area of flat, seasonally waterlogged wetlands that were interspersed with shallow, seasonally inundated basins and channels and dryland prior to European settlement. They are described as a "broad, interconnected chain of swamps many kilometres wide". There are a number of accounts of wetland loss and devastation of such areas (including Riggert[53], Seddon[54] and Bekle[55]), and all indicate the significant extent of impact. For example, Seddon reported that between 1955 and 1966, the area of wetland identified as 'shallow freshwater marshland' on the Pinjarra Plain declined in extent from around 8,000 hectares to less than 3,000 hectares, whilst 'deep freshwater marshland' declined from more than 6,000 hectares to less than 1,500 hectares.[54] Rural drainage on the Swan Coastal Plain was reported as extending over 200 kilometres south of Perth, covering an area of 321,000 hectares, and encompassing five gazetted drainage districts: Mundijong, Waroona, Harvey, Roelands and Busselton.

Seasonally waterlogged flats (called **palusplains**) on the Pinjarra Plain occur because of the presence of clay soils interspersed with sandy soils in a very flat landscape bound by scarps.[57] The clay impedes the movement of groundwater both horizontally and vertically, and so rain and runoff collects on the Pinjarra Plain, creating waterlogged conditions until drying occurs in late spring/summer[57], when evaporation exceeds rainfall. In many cases, these wetlands were targeted for use because they offered good prospects for pasture or horticulture due to the water held in their sediment.

extra information

Who is responsible for rural drainage?

Rural drains were created by the Public Works Department and managed by drainage boards from 1900 under the *Land Drainage Act 1900* and subsequently the *Land Drainage Act 1925*. An example of a drainage board was the Benger Drainage Board, which regulated water levels in Benger Swamp between 1918 and 1985.[56] Drainage districts, including those of Albany, Mundijong, Waroona, Harvey, Roelands and Busselton, were gazetted under these Acts. The Public Works Department also developed and managed irrigation channels in irrigation districts proclaimed under the *Rights in Water and Irrigation Act 1914*. Responsibilities associated with drainage were assigned to the Water Authority upon its creation in 1985. The Water Corporation, created in 1996, now has responsibility for the provision of services to the drainage districts as a community service obligation under the service standards imposed by the operating licence issued and regulated by the Economic Regulatory Authority under the *Water Services Licensing Act 1995*. The Water Services Operation Licence No 32 outlines the Water Corporation's sole operational requirement in this regard: "to operate and maintain its rural drainage infrastructure so that the period of inundation to land abutting a drain that forms part of the system shall be a maximum of 72 hours". The Water Corporation has the authority to control connections into their drainage systems. The Water and Rivers Commission, also created in 1996, was given the power in 2000 to provide local bylaws to regulate and control drainage and dewatering that was likely to affect the water in a wetland under the *Rights in Water and Irrigation Act 1914*, but this has not often been exercised. The Department of Water, created in 2006, is now responsible for administering this Act, including drainage governance and reform. More information of the history of drainage governance is available in the *Coastal drainage discussion paper.*[7]

DEC's *Geomorphic Wetlands Swan Coastal Plain* dataset[52] shows that 97 per cent of palusplain on the Swan Coastal Plain has been cleared. Widespread clearing had the effect of increasing the water in the landscape, prompting the installation of rural drains and, over time, extensive and effective rural drainage networks. This is described by Safstrom and Short: "Eventually, after landholders lodged numerous complaints relating to lost crops and property damage, the government addressed the problem of inundation by implementing a network of drains. In 1900, the first Drainage Bill was passed by state parliament. Over the next 70 years, trees on the banks of waterways were removed, lower river reaches were de-snagged, the rivers were straightened and deepened, and systems of interconnecting drains were dug across pastoral lands. Swamps were drained and the flow rate of the river courses increased".[58] The effect of these drains on the hydrology of the wetlands has been variable, but with time a common trend has been the compounding effect of climate change, because of the rainfall-dependent nature of these wetlands. In Pinjarra, for example, there has been 14 per cent less rainfall on average between 1975 and 2008 than in the period 1877–1975. As a result, there is more drying of palusplains than previously.

Scott Coastal Plain

The Scott Coastal Plain occurs on the south coast. It covers a total area of about 105,000 hectares and stretches about 70 kilometres along the coast and 20 kilometres inland, covering Brockman Highway, Stewart Road, Barlee Brook, Donnelly River, the Southern Ocean coastline and the Blackwood River. Private freehold land covers about 42,900 hectares, with the remainder being state forest, national parks/nature reserves, other

Crown land and other minor uses. It consists of predominantly undulating to near flat land. It is an area of deep sediments, with varied soils including coloured deep sands, some deep sandy duplex soils, sandy loams and loams. A significant proportion of the plain has been classified as being wetland, containing a large diversity of wetland types ranging in both size and condition. Wetland types include extensive seasonally waterlogged or inundated areas (palusplain, damplands, sumplands, creeks) and areas of permanent water (lakes, rivers).

Most agricultural or land planning reports tend to refer to 'poorly draining' land that is 'subject to high watertables and waterlogging in winter'. Particularly in the eastern Scott Coastal Plain, this has been attributed to the presence of a coffee rock (iron-oxide cemented layers) or impermeable peaty layer, which serves to slow vertical leakage of groundwater from the superficial aquifer into the Yarragadee aquifer. The water held in these wetlands also provides significant flows to the Scott River and the Hardy Inlet.

Drainage in the Scott River catchment is notable in that it has been designed and installed in an ad-hoc way with little coordination or integrated planning. As it is not a gazetted drainage district, there is no governance structure, meaning that no single organisation is responsible for the management and operation of these networks. It was not until 1984 that the Water Authority was given the power to prohibit drainage works, by amending the *Rights in Water and Irrigation Act 1914*. It is also notable in that it is one of the largest areas where drainage development is still underway. The effect of drainage on the area's wetlands is likely to be variable; for example, large areas of wetland are likely to be drained of water while others are likely to be receiving excess discharge.

Urban subsoil drainage

Subsoil drainage is used to control the maximum height of the groundwater table. It is usually used in urban areas with high groundwater tables, such as areas supporting wetlands, to achieve a vertical separation distance between the groundwater table and infrastructure such as houses. It is used instead of, or in combination with, the use of fill (that is, soil sourced from somewhere other than the location being developed) to ensure that infrastructure and health are not adversely affected by water being present at or close to the soil surface in inhabited areas. It is likely to become used more often, due to urban development in urban centres including Perth and Peel increasingly occurring over more marginal land - areas of wetland and areas where shallow, unconfined groundwater is in proximity to the natural ground surface. It is also likely to become more popular with the land development industry because sourcing and transporting fill to new developments is an increasingly expensive and unsustainable proposition, with the availability of fill becoming more limited, and mining/quarrying for this fill having significant ecological impacts.

Subsoil drainage in urban areas is typically achieved by draining away groundwater using 100 millilitre pipes with slotted holes (perforations). Coarse gravel is laid around the perforated pipes to enable groundwater intake. When groundwater rises to the level of the pipes, they take in water, minimising the vertical distance that the groundwater reaches above the pipes. The pipes are usually laid in road reserves to enable access for maintenance, although in industrial developments they may be installed down the back or sides of lots. The spacing of the pipes influences the degree of drainage achieved. The groundwater is drained to an outlet location. Following installation, subsoil drain infrastructure typically becomes the management responsibility of local government authorities.

Drainage planners design subsoil drainage to specific **controlled groundwater levels** (CGLs). A controlled groundwater level is the **invert** level of a groundwater management conduit such as a drain or channel in metres Australian Height Datum. The CGL is a

Controlled groundwater level: the invert level of a groundwater management conduit such as a drain or channel in metres Australian Height Datum (AHD)

Invert: the level of the lowest portion at any given section of a liquid-carrying conduit, such as a drain or a sewer, and which determines the hydraulic gradient available for moving the contained liquid different depth to the separation distance, which is the actual maximum groundwater level achieved, taking into account the mounding in between pipes. This is an important distinction for infrastructure managers.

Where heavily degraded wetlands and non-wetland areas with a high water table are developed over, there is a need to ensure that urban developments are not affected by high water levels. But this approach can have significant environmental impacts when the drainage is indiscriminate, as the maximum water level of any remaining high conservation value wetlands in the area are also capped, while downstream wetlands (and other ecosystems) may be receiving environments for this drainage discharge.

Stormwater: water flowing over ground surfaces and in natural streams and drains as a direct result of rainfall over a catchment[60]

Recharge: water infiltrating to replenish an aquifer

Impermeable surface: the part of the catchment surfaced with materials, either natural or constructed, which prevent or limit the rate of infiltration of stormwater into the underlying soil and groundwater and subsequently increases stormwater runoff flows. Also referred to as impervious surfaces.

Disposing water: applying and discharging it

Disposing of stormwater in urban wetlands

Stormwater consists of rainfall runoff and any material it picks up in its path of flow. Stormwater is an important source of water for wetlands, and either too much, too little or poor quality stormwater can affect wetlands. In undeveloped catchments, up to 90 per cent of rainfall is absorbed and infiltrated into the earth's topsoil, and there is relatively little stormwater. Particularly when the rainfall event is small, most of the rainfall is infiltrated into the topsoil. Some of it may then slowly reach a wetland by subsurface flows. Some of it is lost to the atmosphere by evaporation from the soil and other surfaces; some is lost to the atmosphere by transpiration by vegetation in the catchment. Some of it reaches the water table, thereby **recharging** groundwater, and slowly reaching downgradient groundwater dependent wetlands in this way. In moderate to large rainfall events, a greater proportion of the water is likely to be stormwater, following natural overland flow paths to receiving wetlands and waterways.

In contrast, in built environments including urban, commercial and industrial areas, as little as 10 per cent of rainfall may infiltrate into the earth because of the extent of paved, **impermeable surfaces** that limit the rate of infiltration of stormwater into the ground.[59] The risk of flooding is significantly increased by the reduction in the vegetated area, and the reduction in permeable surfaces where water can infiltrate, meaning that a lot of water needs to be 'caught' and conveyed to reduce this risk to humans and property. Conveyance to wetlands, waterways and oceans using infrastructure such as pipes and open channels has traditionally been the approach used, and much of the stormwater infrastructure in urban areas around WA is designed to do this (Figure 10). This causes one of two problems for a wetland: either it receives more water than it should, or the stormwater infrastructure bypasses it or provides it with a limited amount and it receives less water than it should. Both pose serious threats to wetlands.

Figure 10. Pipes discharge stormwater directly into Lake Monger, Perth. Photo – L Mazzella/ Department of Water.

Although wetlands receiving stormwater would have naturally received stormwater, they would not have received so much, so quickly. This is because water captured and conveyed from largely developed catchments delivers water to wetlands in greater volumes by bypassing the natural evaporation, transpiration and infiltration pathways in the catchment. Following a large rainfall event, water is captured and conveyed to wetlands and other receiving environments in greater amounts over shorter periods, without the passive water quality treatment that the earth and native vegetation provides. Under these circumstances wetlands can experience:

- increased volume
- increased rate of water rise
- longer duration of the high water level
- potentially less groundwater input
- erosion and sedimentation caused by the entry of water from pipes and open drains
- potentially more water in the dry season.

In Perth and surrounding urbanised parts of the Swan Coastal Plain, and in some other urban centres in WA, stormwater often flows into networks of drains that are also designed to lower the groundwater level, often called main (arterial) drains and branch drains (Figure 11). The intercepted groundwater flows into the drain along with stormwater. In this way, stormwater and groundwater management in the Perth metropolitan area are integrally linked.[59]

Figure 11. A main drain in Baldivis, south of Perth. Photo – J Higbid/DEC.

In some areas, drainage schemes have formally designated the use of wetlands as receiving bodies for stormwater. For example, Yangebup Lake is designated as a ‘compensating basin’ for the South Jandakot Drainage Scheme, which drains a number of southern Perth suburbs, with an area of 200 square kilometres. The aim of the system is to provide drainage for the urbanised areas and to maintain the water levels in Thomsons Lake, recognised as internationally significant via the Ramsar Convention. The drainage scheme was approved by the Environmental Protection Authority. The scheme was designed so that stormwater could flow directly into Yangebup Lake, North and South Kogolup lakes and Thomsons Lake from residential areas, and through a series of pumps and drains the maximum water levels in each can be controlled. When the water reaches a maximum designated height in Yangebup Lake it is pumped out to Cockburn Sound. It is reported that prior to the 1960s Yangebup Lake was a seasonally inundated wetland, naturally drying out each year.[61] With the water received from the urbanised catchment, it is now permanently inundated. Many wetlands are affected by such drainage schemes in urban areas in the south-west.

In south-western WA, the excess water being delivered by traditional stormwater systems to many wetlands is to some extent being counteracted by the drying effects of climate change and the abstraction of groundwater. This needs to be taken into account when managing stormwater. Stormwater is a precious resource that, with good management, can be an important water management tool. Especially in a drying climate, stormwater can be an important source of water within a wetland catchment that may ultimately reach a wetland, and if it is instead discharged to the ocean or another catchment, affected wetlands may experience a drier water regime.

Secondary salinisation: a human-induced process in which the salt load of soils, waters or sediments increases at a faster rate than naturally occurs

➤ Documents describing drainage schemes in the Perth and Peel area include:

- *Byford townsite drainage and water management plan*[62]
- *Forrestdale main drain arterial drainage strategy*[63]
- *Jandakot drainage and water management plan: Peel main drain catchment*[64]
- *Murray drainage and water management plan*[65]
- *Swan urban growth corridor drainage and water management plan*[66]

Disposing of drainage water in Wheatbelt wetlands

In the Wheatbelt, large areas of agricultural land are degraded, or at risk of degradation, by **secondary salinisation**. One response is the removal of saline waters using a network of deep drains, mole drains, bore siphons and groundwater pumps, directed to valley floors, wetlands and waterways. Affected wetlands are subjected to wetter water regimes (Figure 12), and a new water source which often carries higher salt loads, acid and heavy metals.[67,68] These wetlands are often called 'sacrificial wetlands' as, in effect, they are sacrificed to reduce the impacts upon the surrounding agricultural land. Wetlands that are hydrologically downstream of the receiving wetland can also be affected.

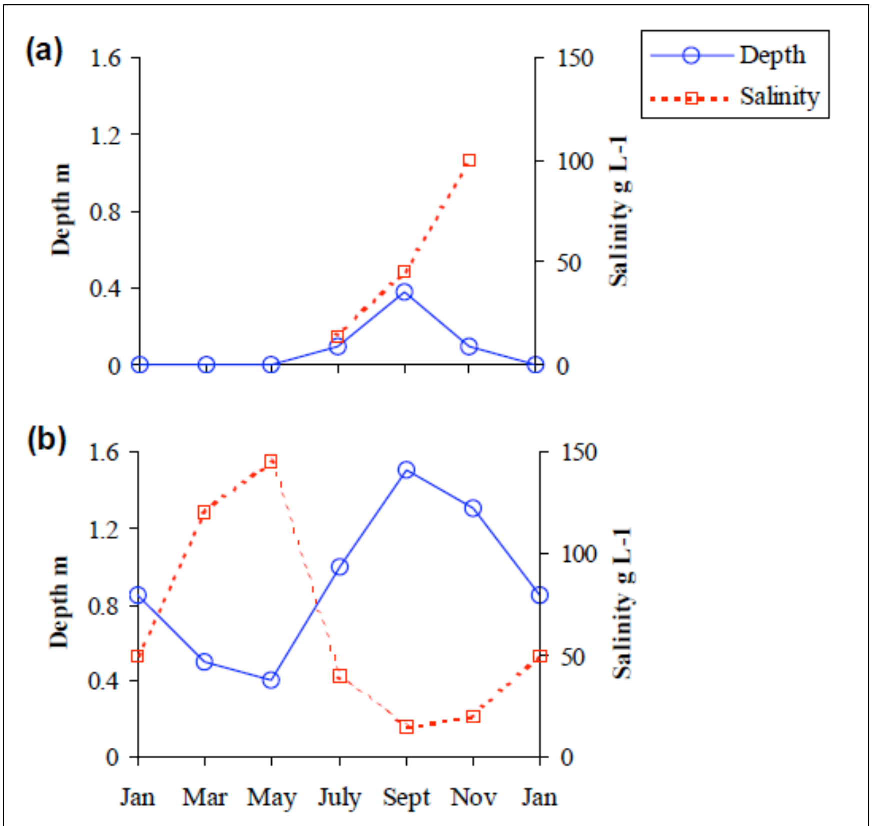


Figure 12. Hydroperiod and salinity patterns in a naturally saline Wheatbelt wetland (a) hydrologically undisturbed, and (b) receiving drainage. Image – Halse (2004).[68]

It is estimated that more than 5,000 kilometres of deep open drains that intercept groundwater have been constructed in the Wheatbelt.[69] Jones et al (2009) describe how 'Some of the saline water removed from these areas is re-used, but the vast majority is discharged into a receiving water body. Often, natural waterbodies, such as basin wetlands, are seen as ideal disposal bodies for this water since they function as natural evaporation basins and are agriculturally unproductive'.[70] Jones et al found that the effect of the disposal of groundwater into wetlands depends on the quality, volume and timing of discharge, and the physical, chemical and biological characteristics of the receiving basin. Drains in the Wheatbelt have been reported to carry from around 8,600–2,592,000 litres per day in spring.[71] When this large quantity of water is discharged into a basin, it is likely to change the timing, frequency, extent and inundation period of the wetland.

The hydrology of many Wheatbelt wetlands have been altered, or are at risk of alteration due to the rising groundwater. The effect of deep drainage upon the hydrology of receiving wetlands compounds these hydrological effects. Adding to this complexity is the potential for less rainfall and different rainfall patterns due to climate change.

➤ Reports describing the effect of deep drainage on wetlands include:

- the topic 'Water quality' in Chapter 3 of the guide, which covers wetland acidification;
- the topic 'Secondary salinity' in Chapter 3 of the guide
- the report, *The potential effects of groundwater disposal on the biota of wetlands in the Wheatbelt, Western Australia.*[70]

Discharging of dewater

Direct discharge to wetlands

Dewatering is the process of removing groundwater to facilitate construction or other activity. It is often used as a safety measure in mining below the watertable or as a preliminary step to development in an area. The water, sometimes referred to as dewater, is sometimes directly discharged into a wetland. This imposes wetter water regimes and introduces a new water source that may be of a different chemical composition, and therefore water quality, to a wetland's natural water sources. Dewatering discharge to wetlands has occurred in the Goldfields and the Pilbara. In the Pilbara, mine dewatering discharge accounts for an estimated 52 per cent of total water use in the Pilbara, which in 2008 was estimated at 127 gigalitres per year.[45] Discharge to salt lakes is commonplace in a number of mining operations in the Goldfields. These salt lakes are typically intermittently inundated, receiving water episodically from rainfall and catchment runoff in times of heavy rainfall, some remaining dry for years and often holding surface water for as little as a few months. A report published by the Department of Water provides some background to their use as dewatering discharge sites: 'The salt lakes of the Goldfields have been the preferred option for the disposal of surplus groundwater (dewatering discharge) produced during mining operations. The lakes are large and flat, providing an expansive surface area for evaporation. Because of the lack of knowledge and understanding of salt lake ecosystems, there was a perception that they were 'barren' and that disposal to these lakes was the most 'environmentally friendly' option for dewatering discharge'.[72] Table 4 is reproduced from this report.

Table 4. Dewatering discharge wetlands in the Goldfields, as listed in Outback Ecology Services (2009).[72]

Discharge lakes in 2009	Discharge lakes, prior to 2009
Lake Carey	Kurrawang White Lake
Lake Way	Lake Fore
Lake Raeside	Lake Tee
White Flag Lake	Banker Lake
Lake Lefroy	Southern Star Lake
Lake Cowan	Lake Miranda
Lake Hope	North Lake Austin
Lake Wownaminya	Lake Koorkoordine
Yarra Yarra Lakes	

Dewatering discharge has been found to generally result in a prolonged wet cycle, with the input of discharge water resulting in permanent localised inundation.[72] Factors that affected the water regime include:

- the rate and volume of water discharged
- bathymetry of the wetland
- the permeability of wetland sediments
- the natural cycles of wetting and drying of the wetland
- the prevailing wind direction, as this can influence movement of the discharge
- the capacity of the wetland and the changes in water levels that occur upon filling.

In addition the discharge has the potential to cause significant water quality impacts. For example, in the Goldfields, hypersaline groundwater is continuously added to many salt lakes, such as Lake Austin, which is naturally intermittently inundated from rainfall.[73] In the Pilbara, the opposite has historically occurred, with fresh groundwater being continuously disposed of into wetlands such as the naturally intermittent, brackish to saline Fortescue Marshes. Both situations can be damaging to the ecology of the receiving wetland. Other contaminant may also be discharged, including metals.

➤ The report, *Development of framework for assessing the cumulative impacts of dewatering discharge to salt lakes in the Goldfields of Western Australia*[72] is a useful summary of the state of discharge in the Goldfields.

➤ *The classification of inland salt lakes in Western Australia*[74] also provides information on discharge characteristics.

Discharge to the superficial aquifer causing mounding

Dewatered groundwater and treated wastewater is sometimes re-injected or allowed to re-infiltrate into a superficial aquifer. This can cause groundwater mounding, that is, a localised dome in the water table, which has the potential to cause wetter conditions in nearby groundwater dependent wetlands. This has occurred at The Spectacles wetlands in the Town of Kwinana. Water quality changes may also occur, due to the addition of a new source.

Irrigating

Irrigation is most widespread in WA's south-west and in specific irrigation areas in the north and mid-west, including the Ord and Carnarvon irrigation areas.[75] The production of fruit and vegetables is the largest component of the irrigated agricultural sector, with dairy and beef pasture, nurseries and turf farms the other major irrigation groups. Irrigation, and low-efficiency irrigation in particular, has the potential to cause wetter water regimes in nearby low-lying wetlands, because water drains beyond the root zone of crops, and flows downgradient through sub-surface soil. Agricultural chemicals can also be transported to wetlands along with this water.[76] Furthermore irrigation salinisation, which currently occurs in the Ord irrigation area and in some of the irrigation areas of the south-west, poses an additional threat to wetlands in these areas.[77] Some, but not all, irrigation is regulated; irrigators generally use groundwater and surface water under licence, though there are some groups in unproclaimed water resource areas that operate without licences. Changes to the regulation of irrigation instigated in the mid-2000s[75] has seen an increase in the efficiency of irrigation.

➤ For more information, see the *Irrigation review final report.*[75]

Discharging effluent

Sewage pumping stations and on-site sewage systems can have localised effects on wetland hydrology. On average, domestic on-site sewage systems dispose of a minimum of 150–200 litres of wastewater per person per day.[78] Septic tanks (underground tanks where sewage is treated to a degree before leaching into the soil) are prevalent in WA. They generally pose a more serious threat to a wetland's water quality than to its hydrology.

Tailings dams

Water used in the mining process is often disposed of in tailings dams, mined-out voids, valleys created by overburden stripping or underground mined areas. Tailings water typically contains toxic substances such as arsenic and heavy metals, and may also be a high temperature. If tailings storage areas are not properly sealed, contaminants may leach into the groundwater and affect wetlands.[79] As with sewage from septic tanks, the input of contaminants to groundwater from tailings dams is generally a greater risk than the change in hydrology associated with the input of water.

Changing wetlands

Mining/deepening/lining/sealing wetlands, creating islands

Since European settlement, physically altering wetlands has been a common wetland 'enhancement' practice in WA. Whether for aesthetic purposes, mining (peat, gypsum, bentonite, marl, salt and algae are just some of the products mined), recreational purposes (such as waterskiing, swimming and fishing) or water-holding purposes (for livestock watering and fire-fighting), these practices result in altered water depth and duration. For example:

- in the case of basin wetlands, deepening may result in a seasonally inundated wetland becoming permanently inundated, by intercepting the groundwater table, or holding a greater volume of water for longer. Excess sediment 'spoil' is often used to create islands in wetlands, which compounds the altered hydrology.
- in the case of flats, deepening tends to involve creating a basin and results in a seasonally waterlogged flat becoming a seasonally or permanently inundated basin
- deepening alters the composition of the sediment and its spatial arrangement and distribution, which affects the water holding capacity of the wetland

Lining wetlands using impervious or low-permeability materials has the effect of artificially retaining surface water in wetlands. Materials that have been employed or proposed to be employed include a polymer proposed to be used at Lake Jualbup in the Perth suburb of Shenton Park (formerly known as Shenton Park Lake, and originally known as Dyson's Swamp). In considering the proposal, the Environmental Protection Authority has concluded that in addition to altering the wetland water regime, and limiting the ability of the oblong turtle population to burrow into the sediment, the installation of a polymer in Lake Jualbup would in effect create a closed system that would result in the concentration of contaminants and nutrients and could lead to odour problems.[80]

Culvert: a conduit used to enable water flow beneath a structure such as a road, causeway, railway or track

Turbid: the cloudy appearance of water due to suspended material

Obstructing flows via roads, causeways and tracks

WA's roads, causeways and tracks act as hydrological barriers in the landscape, changing the route and characteristics of surface and shallow sub-surface flows. As barriers to surface flows, roads can alter the water regimes of surface water fed wetlands. By diverting sub-surface flows to the surface, they can create wetlands where they did not naturally occur. Causeways have been constructed across the beds of a number of large, intermittently inundated wetlands in WA, and can obstruct natural flow paths within wetlands, leading to a change in inundation extent (Figure 13). **Culverts** enable greater hydrological connectivity (Figure 14), but can produce increased flow rates as water is forced through them, causing erosion and sedimentation on the downgradient side, creating **turbid** conditions.

Figure 13. The causeway across Lake McLeod in the Gascoyne region prevents the spread of surface water across the bed of the wetland. Photo - A Lam.

Figure 14. Culverts can enable some degree of water flow beneath barriers such as roads, but they need to be well designed in order to avoid problems such as erosion and sedimentation. Image – Department of Water.

Earthworks and control structures to confine water to wetlands

Some wetlands in regional WA are used for recreational activities such as waterskiing. Many of these wetlands have been altered to improve conditions needed for these activities. In particular, artificially blocking a wetland's natural drainage outlets using earthworks or control structures, so that high water levels are maintained for longer following rain, has made a number of wetlands more suitable for waterskiing. This results in wetter water regimes. This has occurred at Yenyening Lakes, where a gate at Qualandary Crossing was constructed in the early 1900s and has served to dam waters in the lakes for a variety of purposes over time, including waterskiing.[81]

This practice is also carried out for agricultural purposes. Levee banks (human-made ridges or embankments) are often constructed around wetlands to confine water to reduce the size of the wetland and reduce the amount of water that spreads across the land around the wetland. Levee banks sever the natural hydrological connectivity between a wetland and its surrounding landscape - a process which is important for the exchange of material and nutrients. Levee banks are also used to direct flows downstream. This increases the rate of downstream outflow, as water is prevented from spreading out across the land. This delivers more water to downstream wetlands, causing wetter water regimes in them.

Puncturing retarding layers

Excavation near or in wetlands, for purposes such as pipelines, bores and cores, can puncture natural layers in the sediment or soil that retard water leakage and so retain water in wetlands. Many wetlands in WA are perched (not connected to groundwater**)**. In these wetlands, water from rainfall and often from surface flows waterlogs and/or collects as a lens on top an impermeable surface layer (such as heavy clays). Perched wetlands are fairly common in the Wheatbelt, along the eastern side of the Swan Coastal Plain (Pinjarra Plain wetlands), and some of the salt lakes of the Goldfields. If the impermeable layer that contains the water is punctured by excavation, it may, in effect, 'leak', leading to drier water regimes. Some of the activities that require excavation include drilling bores and cores, installing underground pipes, mining and laying building foundations.

Creating water loss

Mining voids

The holes created by excavating mineral ores are called mining voids. In 2003 it was estimated that there were approximately 1800 existing mine voids and more than 150 mines operating below the watertable in WA.[82] Some of these holes dwarf the natural wetlands of WA in dimension, particularly in depth, such as the Muja coal pit in Collie, that is predicted to be 200 metres deep and 400 hectares in area. The extent of impact of these mine voids on the surrounding groundwater environment is largely dependent on the local hydrogeology, as to whether the mine void will act as a groundwater sink or groundwater throughflow cell. In the groundwater sink regime, evaporation exceeds the rate of groundwater inflow into the void and is typical of most hard-rock mines throughout Western Australia.[82] Wetlands down-gradient of mine voids that function as groundwater sinks can experience altered hydrology. Hydrogeological connection of mine voids with important wetlands or groundwater resources is a major consideration in the Pilbara.[82]

Constructing (artificial) lakes

Many water features in urban developments, including those marketed as stormwater treatment constructed lakes, are permanently inundated constructed water bodies with very little native vegetation. These constructed features can be subject to high evaporation rates due to their depth to surface area ratio and where they intercept groundwater, or are topped up with groundwater, they can result in substantial water loss. They often have serious water quality problems, weeds, algal blooms and nuisance insect populations, and if poorly planned, have the potential to generate acid sulfate soils, on-going maintenance and life-cycle costs and flood risks.

➤ For more information see the Department of Water's *Interim Position Statement: Constructed Wetlands.*[83]

Threatened ecological community: naturally occurring biological assemblages that occur in a particular type of habitat that has been endorsed by the WA Minister for Environment as being subject to processes that threaten to destroy or significantly modify it across much of its range

Altering hydrology to manage other wetland problems

Sometimes, hydrology is altered in order to manage other problems, such as poor water quality and nuisance populations of midge and mosquito in wetlands. The decision to manage water quality by altering a wetland's hydrology should be taken with extreme care, within the context of all the management issues at the wetland, by developing a wetland management plan, and ensuring that all legal requirements are met.

One method involves reducing the volume of inflowing water of poor quality. For example, Toolibin Lake, 40 kilometres east of Narrogin, is recognised as an internationally significant wetland, but its condition is threatened by rising groundwater of very high salinity. To mitigate this risk, the natural flow pathways into the wetland have been deliberately modified. This involves diversion of the 'first flush' of water that would normally flow into the wetland with each rainfall event (which carries high salt loads from the catchment) to Lake Taarblin, a downstream wetland. Toolibin Lake receives less salt but also less water, and the downstream wetland receives more water and salt.[84] Later flows that are lower in salt are allowed to flow into Lake Toolibin to help maintain the hydrological balance of the lake.

Another method involves diluting or flushing polluted water with a new, clean water source. For example, freshwater creeks which previously bypassed Lake Towerrinning in the Shire of West Arthur are now diverted into the wetland to dilute nutrients and prevent algal blooms. This approach has implications for the ecology of the freshwater creeks as well as environments downstream of Lake Towerrinning. From a wetland conservation perspective, it is much more sustainable to manage the nutrients entering the wetland.

What effect does altered hydrology have on wetlands?

Altered hydrology can affect wetland water quality, the species and communities present in individual wetlands, the physical and chemical processes in wetlands, regional populations of wetland species, and in the case of drying, it may ultimately result in the loss of wetlands. In practice, it can be difficult to separate out the effects of altered hydrology, because water has such a fundamental effect on wetland species, and physical and chemical conditions in wetlands.

In 2004, a summary of the likely impacts of various threatening processes in the south-west was estimated based on the then current literature and expert assessment by scientists of the (then) Department of Conservation and Land Management. This assessment focused on the number of likely species extinctions that would arise if threatening processes were not managed. Altered biochemical processes associated with altered hydrology were found to be the most significant potential driver of species extinction in the south-west (750 species extinctions).[85]

At the community scale, thirty-seven of the sixty-nine **threatened ecological communities** currently listed by the WA Minister for Environment are wetland communities. Hydrological alteration and climate change are major threats to these communities. It also threatens many wetland communities listed as priority ecological communities.

Table 5 summarises the effects of altered hydrology.

Table 5. A summary of the effects of altered hydrology on wetlands

Change	Increased risks associated with increased drying	Increased risks associated with increased wetting
Changes in water quality	• Altered water chemistry • Acidification • Eutrophication • Altered salinity	• Altered water chemistry • Altered salinity • Eutrophication
Changes in species and communities, in some cases leading to changes in regional populations of species	• Altered species composition • Altered species distribution • Species mortality • Altered species richness • Altered species abundance • Altered community structure	• Altered species composition • Altered species distribution • Species mortality • Altered species richness • Altered species abundance • Altered community structure
Changes in physical and chemical wetland functions	• Altered nutrient cycling • Increased risk of frequent fire, and associated risk of acidification • Altered sediment including desiccation, smaller organic fraction, cracking, oxidation, consolidation	• Altered nutrient cycling • Altered sediment including swelling, flocculation, increased suspension, increased organic fraction, less oxygen leading to reducing conditions
Loss of wetland types and wetlands	• Conversion of wetland types (e.g. permanently inundated wetlands to seasonally inundated) • Loss of wetlands, particularly seasonally waterlogged wetlands	• Conversion of wetland types (e.g. seasonally inundated wetlands to permanently inundated)

Effects on water chemistry and quality

For an organism to inhabit a wetland, the wetland's water regime and water chemistry must suit its needs. Because altered hydrology can alter water regime and chemistry, it can cause changes in the mix of species able to survive at a wetland. What is more, organisms can modify their environment. So to complete the cycle, a change in the mix of wetland species can have impacts on the water regime and water quality. In this way, altered hydrology can cause a series of impacts in wetlands that involve the water regime, water quality and the ecological community (Figure 15).

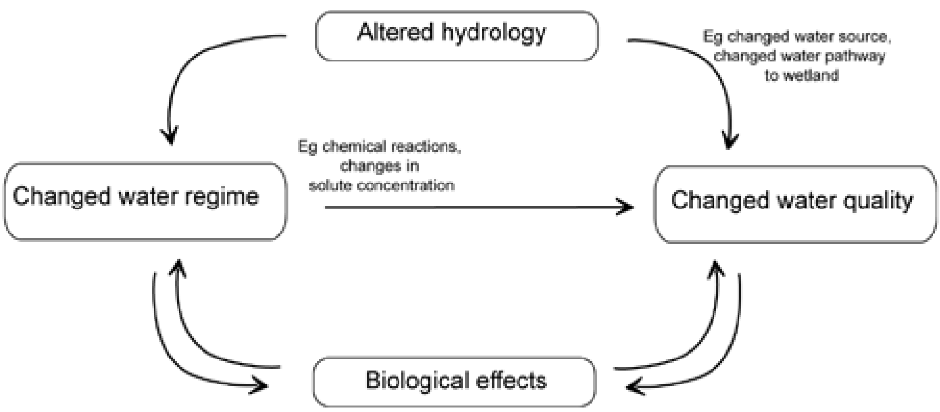


Figure 15. Altered hydrology can produce a range of far-reaching effects because of the interactions between the hydrology, water regime, water quality and biological impacts of wetlands.

If the wetland begins to receive water from a different source, or the proportion of water it receives from each source changes, this can lead to changes in water chemistry. Water sources vary naturally in their composition. For example, groundwater is often rich in minerals, and can vary in salinity from fresh to hypersaline, while rainwater is typically fresh and slightly acidic. Surface water may be derived from rainwater or groundwater, and can pick up both soluble substances (such as salt) and insoluble substances (such as sediment) on its way to a wetland. These differences in composition give rise to variations in characteristics of water such as temperature, salinity, hardness, acidity, nutrients, turbidity, light and dissolved oxygen. A wetland's unique mix of water sources influences its water quality, so any change in sources caused by altered hydrology can cause changes in water quality.

Salty, turbid or acidic water sources are commonly recognised as having potential to degrade the water quality in a wetland that is not naturally salty, turbid or acidic, but fresh, clear, and neutral water can cause problems too. The dilution of natural substances within a natural water source lowers their concentration, and changes the water chemistry in a way that might not suit the resident wetland species (as is occurring at the Fortescue Marshes, Figure 16). Wetland ecosystems are adapted to their own unique mix of water sources, which might naturally include salty, turbid or acidic waters, for example.

The way water leaves a wetland has an influence on the concentration of dissolved substances in the water. Water can leave a wetland through the processes of evaporation and transpiration; processes which leave behind and concentrate compounds such as salt. On the other hand water that flows out of a wetland removes the dissolved substances with the water, and their concentration does not change. Wetlands that are connected to waterways may experience large pulses that flush them, scouring them of sediments or salt, for example. In areas of WA this process isn't as common as in the eastern states of Australia, where it is one of the tools used in wetland management. In this way alterations to hydrology that influence how water leaves a wetland also have the potential to cause changes in water quality that degrade wetlands.

Figure 16. Fortescue Marshes, Pilbara. When fresh groundwater dewatered from a nearby mine was being disposed of in this wetland, the combination of the wetter water regime and continuous fresh water affected the native salt marsh vegetation. Photo – S Halse/DEC.

Acidification of wetlands due to altered hydrology is a major management issue in the south-west of WA. Acidification is a serious threat to wetlands and the primary management aim should be to avoid triggering it, with altered hydrology a key trigger.

Acid sulfate soils: includes all soils in which sulfuric acid is produced, may be produced or has been produced in quantities that can affect the soil properties. Also referred to as acid sulphate soils.

In the case of wetlands containing **acid sulfate soils**, the sulfidic material-containing soils are benign when they remain waterlogged or inundated, but when they are exposed to air, they generate acid which can be released into the wetland. Changes to water regime that involve surface or groundwater drawdown can trigger this process. The acid itself can cause ecological damage. In addition, toxins such as metals and other poisons such as arsenic remain bound in wetland soils under neutral conditions, but they become soluble and toxic when conditions become acidic. Below are some examples of alterations to hydrology leading to acidification:

- excavation of peat-based wetlands in the City of Stirling in Perth for urban development generated acidic groundwater, which became contaminated with arsenic as a result[86]
- inland peat wetlands in the south-west have become acidic because of dewatering and peat mining (for example, Lake Cowerup in the Lake Muir-Byenup Lagoon Ramsar site[87])
- wetlands receiving drainage constructed to combat rising groundwater in the Wheatbelt are suffering the effects of acidity and salinity.

Nutrients may also increase with drying. For example, drying of peat releases nutrients, particularly organic nitrogen.[88]

Not only can changed water regimes generate contaminants, they can also move existing contaminants into wetlands. Secondary salinity in the Wheatbelt is also caused by altered water regimes moving existing salt into new places. Rising water tables wet previously dry parts of the soil profile, mobilising salt and bringing it to the surface. The combination of saltier and wetter (waterlogged) conditions affects wetlands.

➤ The management of altered hydrology in the Wheatbelt is also addressed in the topic 'Secondary salinity', in Chapter 3.

Groundwater drawdown in near-coastal superficial aquifers may allow seawater intrusion into the aquifer.[89] This may result in seawater entering wetlands that previously received groundwater.

When vegetation is cleared and land is developed over or put into agricultural production, shallow sub-surface flows are often re-routed to the surface, increasing the proportion, amount and flow speed of water delivered to wetlands as surface water. This water may gather contaminants as it flows overland to the wetland, without the filtration provided by flowing slowly through the soil. In addition, its increased flow speed may allow it to collect and deliver extra sediments and organic material to wetlands. In this way, the load of manufactured chemicals, the turbidity and nutrient content of a wetland's waters can be increased. If large amounts of extra sediment are delivered, sedimentation can cause changes to wetland shape, which may bury wetland organisms and/or result in further changes to the water regime.

Changes to water regime and/or water quality may leave dead vegetation or animals in the water column. Decomposition of this organic material by bacteria and other organisms consumes oxygen, resulting in low levels of dissolved oxygen in the water column. This can affect the health of aquatic plants and animals, including fish, and can cause further deaths of wetland organisms.

➤ The effects of altered hydrology on water quality is discussed in the topic 'Water quality', also in Chapter 3.

Effects on populations, communities and species

Thresholds: points at which a marked effect or change occurs

As established in the topics 'Wetland ecology' and 'Wetland hydrology' in Chapter 2, when seeking to determine how species may be affected by altered water regimes, an understanding of their water requirements is critical.

Some of the key points about water requirements include:

- Species have **water requirements**: the water required by a species, in terms of when, where and how much water it needs, including timing, duration, frequency, extent, depth and variability of water presence.
- Water requirements are driven not only by the water needed by a species, but also the chemical environment of water, such as the levels of oxygen, carbon dioxide, light, salt and acidity in water.
- Water absence and presence also drives physical processes in sediments. For example, the cracking and swelling of clays in response to drying and wetting that is important for some wetland plants and animals (such as planigales, which are very small carnivorous marsupials); the consolidation of sediments on drying that provides habitat for rushes and sedges; and the development of peat, and impairing peat fires, that provides a refuge for desiccation and fire-sensitive species.
- Species employ a range of adaptations that enable them to cope with particular water regimes. These include physiological, behavioural and reproductive adaptations or traits. For example, in wetlands that dry, smaller animals develop desiccation resistant/tolerant resting eggs before dying (such as many microcrustaceans); plants develop seeds, algae and bacteria develop spores and cysts; larger animals go into aestivation or dormancy in the wetland sediment (including some fish, crayfish, molluscs and turtles) or migrate to another site (including crocodiles and other reptiles, frogs, birds, mammals, many insects); and plants use groundwater where it is within reach.
- Boom and bust cycles are a natural part of the population dynamics of many wetland species in WA. Many of the species that inhabit WA's wetlands are quite resilient to year-to-year hydrological change over their normal wetting-drying cycles (for example, seasonal or intermittent waterlogging/inundation).
- In highly altered landscapes, the ability of individuals and populations of plants and animals to cope with natural amounts of variability in water regime can be compromised by the additional stressors (such as salinity, fragmentation, excess nutrients, weeds, fire and so on). Human-induced change is escalating population and ecosystem level stress, threatening wetland biodiversity in the south-west[15] and other areas of WA.
- The study of water requirements goes under many names including environmental water requirements, ecohydrology and hydroecology.

For an organism to live at a wetland, the wetland's water regime and water quality must suit its requirements. Altered hydrology can impact on both of these factors, and can result in organisms' requirements not being met.

An aspect of the water regime (frequency, duration, depth, extent, seasonality, rate, variability) may be particularly important for an individual's survival or reproductive success. So may an aspect of water quality (such as salinity, acidity, nutrients, oxygen, turbidity, light or temperature). Since altered hydrology can impact on any combination of these, there is a large chance that altered hydrology will affect a wetland's suitability for a range of organisms. Conditions beyond an organism's tolerance, or **threshold**, can cause declining health, dispersal to more suitable habitat, or death.

Drought and flood can naturally cause such conditions to occur. However, human changes to the environment have greatly impaired the natural capacity of many species and communities to recover from drought[90] and flood, particularly in areas impacted by intensive land and water use. For example, at Lake Gregory, prolonged inundation triggered by a cyclone resulted in drowning and death of the wetland's trees. Seedlings sprouted but regeneration was limited by cattle grazing of the seedlings. Lake Gregory's trees are vital to maintaining waterbird breeding levels at the wetland.[91] Animals may also be directly affected: land uses can create barriers and hazards to migration to remaining suitable habitats during drought, particularly for animals such as frogs, tortoises, quendas, rakali, fish, snakes and lizards; and when they coincide with bust cycles of a population, they can have catastrophic consequences for the population. The loss of the mosaic of wetland and dryland in natural landscapes means that those species with poor dispersal abilities will be disadvantaged.

Decline in condition of vegetation

A decline in condition of plants often occurs with altered water regime. Wetland plants establish under the conditions that suit their anatomy and physiology, and when the conditions change, their condition can decline, in very rapid (days) to very long-term (decades) timeframes, depending on the change and their ability to adapt to it. Decline in the vigour of a plant is usually evident as yellowing, browning, wilting or dead foliage. In the case of drying, dropping leaves or branches can help plants to survive by reducing

extra information

Studies of the water requirements of WA's wetland species

Knowledge of water requirements is based upon deduction, observation, and studies. Some of the local studies are listed below. There are also a large number of studies of the water requirements of WA's waterways, available from the Department of Water website www.water.wa.gov.au.

Wetland vegetation has been much more intensively studied than fauna. However, even with this level of study, scientists generally cannot make absolute or definitive statements about the response of a particular species in different wetlands. As described by Horwitz, Sommer and Hewitt[92], the degree of response depends on the magnitude, rate and duration of water level increase or decrease, the historic changes in water levels, the specific site conditions (soil stratigraphy, etc.), habitat type and species in question, the influence of disturbance impacts (fire, etc.), and finally the condition of the vegetation. Resilience of a community may be site-specific, rather than species-specific, stemming from historical adaptations.[93]

Generalised understandings of a species response can be refined at a particular wetland using a range of investigations, including measurements of water potential and sapflow sensors to quantify a plant's water use.

Methodologies

- *Approach to determination of ecological water requirements of groundwater dependent ecosystems in Western Australia*[94]

Kimberley

Riparian studies that include wetland species in the Kimberley include:

Water regime for wetland and floodplain plants. A source book for the Murray-Darling Basin[95] (includes some species found in WA wetlands including *Eucalyptus camaldulensis*)

Pilbara

Riparian studies that include wetland species in the Pilbara include:

- *Environmental water report series, report no. 17: Determining water level ranges of Pilbara riparian species*[96]
- *Environmental water report series, report no. 20: Determining water level ranges of the lower De Grey River*[97]
- *Environmental water report series, report no. 22: Determining water level ranges of Lower Robe River*[98]
- *Climate, management and ecosystem interactions in the Pilbara: tree water use at Millstream National Park, WA*[99]
- *Waterlogging and salinity tolerance in riparian and floodplain trees and shrubs in the Pilbara region* (in preparation)
- *Water requirements of the riparian tree Melaleuca argentea in the Pilbara* (in preparation)

extra information

Studies of the water requirements of WA's wetland species (cont'd)

Swan Coastal Plain

- *Draft Ecological character description of the Becher Point Wetland Ramsar Site*[100]
- *Gnangara mound ecohydrological study. Final report to the Western Australian Government, Department of Water. Report No. CEM2010-20*[101]
- *Study of the ecological water requirements of the Gnangara and Jandakot Mounds under section 46 of the Environmental Protection Act*[102]
- *Ecological water requirements for selected wetlands in the Murray drainage and water management plan area*[103]
- *A guide to emergent plants of south-western Australia*[104]
- *Identification of the wetland plant hydrotypes on the Swan Coastal Plain, Western Australia*[105]
- *Wetlands of the Swan Coastal Plain: The effect of altered water regimes on wetland plants*[106]
- *Ecological character description of the Forrestdale and Thomsons Lakes Ramsar Site, A report to the Department of Environment and Conservation*[107]

Unpublished

- *Turquoise Coast Development Jurien Bay: Assessment of likely impacts of drawdown on groundwater dependent ecosystems*[108]

South-west WA

- *Determination of ecological water requirements for wetland and terrestrial vegetation – southern Blackwood and eastern Scott Coastal Plain*[109]
- *A summary of investigations into ecological water requirements of groundwater-dependent ecosystems in the South West groundwater areas*[110]
- *South West Yarragadee – assessment of vegetation susceptibility and possible response to drawdown*[111]
- *Relationship between water level, salinity and emergent and fringing vegetation of the Muir-Byenup wetlands*[112]
- *Ecological character description of the Muir-Byenup System Ramsar Site, South-west Western Australia: report prepared for the Department of Environment and Conservation*[113]
- *Ecological character description of the Lake Warden System Ramsar Site, Esperance Western Australia: a report by the Department of Environment and Conservation*[114]
- *Environmental water requirements of wetlands in the Torbay Catchment, South Coast Region.*

Unpublished

- *The south-west Yarragadee Blackwood groundwater area project: Assessment of fauna in relation to groundwater dependent ecosystems and ecological water requirements*[115]
- *South West Yarragadee proposal: Assessment of drawdown impacts upon fauna*[116]

their water needs. Some species may show signs of stress sooner than others, or plants in one area or zone of the wetland may show signs of distress first. While it is possible to make generalisations about the response of a species to wetland water regime changes, there is variability amongst individual plants and sites.

Some wetland trees, such as the moonah *Melaleuca preissiana* (a paperbark that occurs in the south-west of WA), may alter their root system distribution and attempt to elongate their roots to follow water down the soil profile when the groundwater table declines. Certain conditions are needed, with a slow rate of change one of the most important factors in addition to the magnitude of change. A range of studies by Professor Ray Froend and others (including Froend et al[106], Groom et al[117], Froend and Loomes[94], and Sommer, Froend and Paton[118]), have demonstrated the importance of rate of change for trees and other Swan Coastal Plain wetland plant species. For example, it has been found that at slow rates of change, moonah can be fairly resilient to altered groundwater regimes, responding over many decades. Figure 17 shows the risk of impact for wetland vegetation, based upon research done in WA. Trees are often long-lived (for example, moonah can be hundreds of years old), and can provide a long-term indication of conditions. When mature trees die due to altered conditions, they are sometimes replaced with new recruits that are better able to cope with the conditions if they develop root morphologies suitable to the new water regime.

Precautionary principle: where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation[123]

Banksia tree species have a dimorphic rooting system consisting of a central thick sinker (tap) root and subsurface lateral roots from which smaller sinker roots may arise.[119] *Banksia littoralis* is a wetland tree in coastal and near-coastal south-west WA that has been declining in abundance, with poor seedling recruitment.[117,120] It was one of two *Banksia* species looked at in a recent study into response to water decline. The study found that the maximum rate of root elongation was 18.2 mm day^{-1} but that this rate was not achievable when plants were unable to meet their water requirements once the groundwater table fell below the rooting depth of the plants. It confirmed that the response of phreatophytic *Banksia* to rapid water table decline depends on the availability of other water sources, and the rate of groundwater table decline.[121]

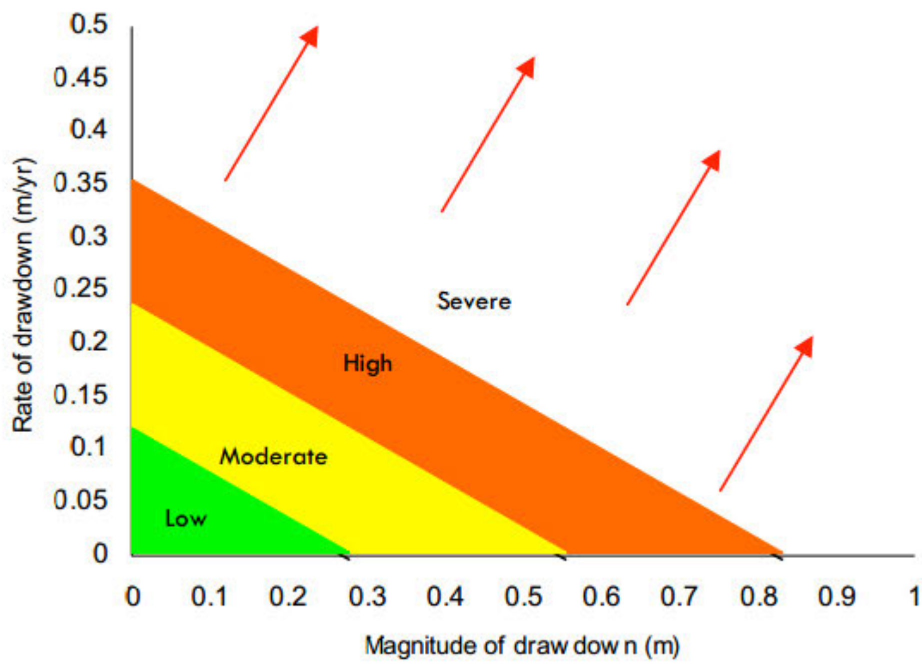


Figure 17. Risk of impact categories for wetland vegetation (trees, shrubs, sedges) based on cumulative rate and magnitude of groundwater level change (drawdown). Source - image in Sommer and Froend[101], citing Loomes and Froend (2004).

It is important to note that the risk categorisation in Figure 17 is a guide to the risk of impact. There are a number of sites where decline has occurred even though the drawdown was within the low risk of impact category (for example, at Lake Yonderup[122]). This highlights the importance of understanding individual wetlands and applying the **precautionary principle** in decision-making. Extrapolating known responses to new sites involves risks, and expertise and site-specific knowledge is generally advisable. As researchers (Horwitz, Sommer and Hewitt[92]) describe, the degree of response depends on the magnitude, rate and duration of water level increase or decrease, the historic changes in water levels, the specific site conditions (stratigraphy, etc.), habitat type and species in question, the influence of disturbance impacts (fire, etc.), and finally the condition of the vegetation. Resilience of a community may be site-specific, rather than species-specific, stemming from historical adaptations.[93] Generalised understandings of a species response can be refined at a particular wetland using a range of investigations, including measurements of water potential and sapflow sensors to quantify a plant's water use. Sophisticated methods of studying tree water use, such as Zim probes, are now being employed in some areas (for more information, see www.foresthealth.com.au).

Plants also respond to too wet conditions in a variety of ways, depending upon their anatomy and physiology. Generally speaking, where the duration or depth of inundation is beyond the tolerance of plants, there are a minimum of two key problems: the plant cannot get enough oxygen, and secondly the lack of oxygen in the soil creates reduced soil conditions that lead to the development of toxic compounds that can affect plants. When the oxygen supply to roots is reduced, respiration and photosynthesis rates are reduced. Plants may wilt, drop leaves and branches, and ultimately die if the duration of inundation is sustained. Plant species respond differently to sustained inundation, and indeed, individual plant responses can vary depending on site-specific factors and degree of adaptations such as shallow root systems, aerenchyma, pressurised gas flow, adventitious roots, loss of stomata and floating leaves (described in the topic 'Wetland ecology' in Chapter 2).

Vegetative reproduction: a type of asexual reproduction found in plants. Also called vegetative propagation or vegetative multiplication.

Suckering: growing roots laterally under the soil, which project shoots to emerge in a new location away from the base of the parent plant

Changes in species distribution and abundance within a wetland

Changes in water regime can change species distribution within a wetland. Where changes are beyond the capacity of individual plants to adapt, vegetation sometimes responds to wetter conditions by shifting to drier areas of the wetland, or to drier conditions by shifting to wetter areas of the wetland. This is because under the new hydrological conditions, the new location meets their water requirements better than their original location (Figure 18). As well as colonising new locations by growing from seed, sedges and rushes can expand **vegetatively i**n the preferred direction by growing extra rhizomes, roots and shoots. Some wetland trees, such as sheoaks (*Casuarina* species), can also expand vegetatively, by growing roots horizontally under the ground, or **suckering.** However, many wetland shrubs and trees can only shift locations through the germination and establishment of seedlings in the new location.

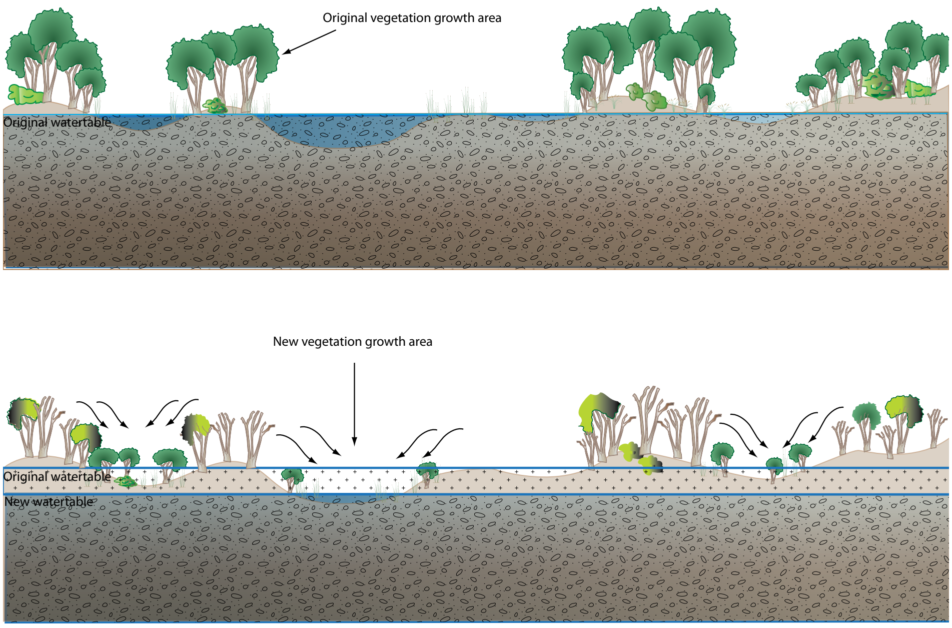


Figure 18. Within a wetland, plants sometimes germinate or otherwise colonise drier locations (often upslope) in response to wetter water regimes, or wetter locations (downslope) in response to drier water regimes, in areas that best suits its water requirements. In basin wetlands, this may involve colonising a different part of the bank. In wetland flats, this may involve movement to localised mounds or depressions.

Of course, vegetation may only shift within a wetland if there is:

- another location that meets its water requirements and other conditions such as suitable soil type)
- an area available for colonisation
- seeds or vegetative parts that are able to reach that location.

If these conditions aren't met, species may become locally extinct at the wetland.[106] In a number of wetlands on the Swan Coastal Plain, for example, swamp paperbarks (*Melaleuca rhaphiophylla*) are being replaced with flooded gums (*Eucalyptus rudis*) trees. Forests and woodlands dominated by the swamp banksia (*Banksia littoralis*) are becoming rare, due to the combined effect of wetland drying, Phytophthora dieback and more frequent fires.[120] If fauna rely on the species for habitat, they may also be lost. The process in which wetland plants are replaced by dryland plants is known as 'terrestrialisation'.

At some wetlands, flood events are required for the establishment of stands of trees, including some species of wetland paperbarks and eucalypts. Changes to the frequency of flood events can therefore influence the success of recruitment. This may lead to long-term changes in the structure and composition of wetland ecosystems.

Species composition: the species that occur in a community

Benthic microbial communities: bottom-dwelling communities of microbes (living on the wetland sediments)

Loss of species from a wetland, changes in species composition

Altered hydrology can change the mix of species (**species composition**) present at a wetland. Species differ in their capacity to tolerate changes in wetland water regime, with some species more sensitive to changes in water regime and water quality than others. More sensitive species may decline, while more tolerant species may increase in abundance. This may be short, medium or long term, depending upon the changes that have occurred and the resilience of the species to variability.

Species of mammals, birds, reptiles, frogs, fish, invertebrates, fungi, plants and bacteria may all be affected. Altered hydrology can lead to invasion by new species (both native and introduced), as the new water regime provides suitable conditions where they did not exist before. For example, simpler, less diverse aquatic invertebrate communities may be present in drier years, with richer and more diverse assemblies returning under more normal conditions if they are able to reach the wetland. Or, as has happened in many Wheatbelt wetlands, much more pervasive change has occurred, where seasonally drying, freshwater wetlands dominated by rushes, sedges, submerged plants and charophytes have become permanently inundated, saline wetlands that are dominated by **benthic microbial communities.**[124,125] The seed banks of the plants may have disappeared from many of these wetlands.[125]

Some species have times in their lifecycle at which they are most sensitive to alterations. For example, adult frogs may be able migrate to more suitable wetlands but if, when they spawn, the water levels dry rapidly, tadpoles will not be able to mature past their aquatic phase (Figure 19). In these ways, altered water regime can have significant impacts on a wetland's species composition.

Figure 19. The water in this wetland near Mandurah, in the Peel region, receded before these tadpoles could mature into adult frogs. Photo – J Lawn/DEC.

The ways in which altered wetland water regime may affect an individual include:

- by altering cues for hatching/germination of eggs, seeds, spores and cysts. These include the depletion of eggs and seed banks due to too frequent flooding and drying, or the loss of their viability due to age given unsuitable conditions to hatch or germinate
- by reducing the ability of animals to develop into adults, reproduce and maintain resilience to disease
- by reducing the ability of plants to grow, maintain new growth, periodically flower and set seed, and maintain resilience to disease and other factors

To complicate matters further, altered hydrology can also have a range of indirect effects, because it can disrupt normal biological interactions such as pollination, predation, herbivory and symbiosis. Even if a species is itself able to tolerate the new hydrological conditions, it may be impacted indirectly through the decline of another species on which it depends. Altered hydrology may also bias the outcome of competition between two species, particularly if the new conditions favour one species more than another. Cascading effects on habitats and food webs may be triggered.

The compounding effect of drought in combination with ongoing climate change is of particular concern. An example comes from a study of **invertebrates** in **gnammas** (granite rock outcrops) of the Wheatbelt by researcher Dr Brian Timms.[126] Granite rock outcrops are important habitats for small aquatic fauna, including many **endemic** species. They support a rich and diverse range of species and have particular conservation value for rotifers, microcrustaceans, oligochaetes and midges.[127] They are important because they are seasonally inundated, 'freshwater islands' in areas where wetland plants and animals are seriously threatened by sustained waterlogging or inundation and secondary salinisation. These wetlands fill by rainfall, typically in winter, and persist for several weeks or sometimes months, depending on their size, shape and when the rainfall occurs. Their inhabitants are well adapted to this seasonality by being able to disperse (insects), having a drought-resistant stage such as a resting egg (such as rotifers and copepods) or silk-encased larvae (some midge).[127] The water regime is of paramount importance to the invertebrate community structure of gnammas. Of concern is the decrease in rainfall of between 2 and 10 per cent in much of the Wheatbelt over the last forty years. Generally being active dispersers, the insects inhabiting these gnammas are relatively buffered in drier times. However, the very small crustaceans such as cladocerans and ostracods need water for periods of time in order to complete their life cycles. In considering whether the changing climate has affected this, Dr Timms concluded that, given that all crustaceans and almost all insects completed their life cycles in the drought year of 2010 at most study sites, there isn't conclusive evidence yet of invertebrate communities in the study area being affected. However, in considering the predictions of a further decrease of 2–5 per cent in rainfall, Dr Timms predicts that life cycles may be disrupted and diversity affected. In considering the most affected northern gnammas, where many species did not complete their life cycles in the drought year of 2010, Dr Timms notes that it is not known how often the failure of many species to complete their life cycles can occur before local extinction takes place, and indeed whether it has already taken place in some areas.

Some **obligate wetland species** have a low tolerance for altered hydrology and are more likely to show a decline in condition if a wetland begins to dry, and are therefore useful as 'indicator species' of altered hydrology (Figure 20). Dryland obligate species can be used in a similar way to indicate wetter water regimes. Many **facultative wetland plants**, which can also occur in drylands, are likely to tolerate a wide range of water regimes. They are less likely to be affected by altered hydrology, and therefore more expertise and more supporting evidence is generally required when using them to infer that a wetland's hydrology has been altered.

Invertebrate: an animal without a backbone

Gnamma: a hole (commonly granite) that collects rainwater, forming a wetland. This word is of Nyungar origin.

Endemic: naturally occurring only in a restricted geographic area

Obligate wetland species: species that are generally restricted to wetlands under natural conditions in a given setting

Facultative wetland plants: plants that can occur in both wetlands and dryland under natural conditions in a given setting

Figure 20. The endangered Dunsborough burrowing crayfish, *Engaewa reducta*, is one of the endangered species of burrowing crayfish that inhabit WA's south west and south coast. They burrow into damp soils each year once surface water dries out and resurface with the onset of rains. With a drying climate the soils of many of their wetland habitats are drier for longer. Photo – K Rogerson/DEC.

➤ For additional detail on wetland species' water regime tolerance, see the topic 'Wetland ecology' in Chapter 2.

Changes in population distributions

Species with the ability to disperse may show significant population-scale changes in distribution in response to large-scale altered hydrology and climate changes. Waterbirds may breed less frequently in wetlands subject to reduced water. Migratory birds may also be affected by disruptions to the synchronicity of migration and prey flushes[131], that is, changes in the timing of environmental cues to migrate and during migration that may have effects on migratory birds.

The Swan Coastal Plain has been recognised as playing a significant part in the life cycle of many WA birds, playing a part in life-supporting systems that is out of all proportion to its size.[54] Researcher Dr Stuart Halse has considered the effect of climate change on waterbirds, and predicts that the proportion of the State's waterbirds using northern Australia will increase and the Swan Coastal Plain will probably become less important as a summer drought refuge, as well as a breeding area. Southern specialists such as chestnut teal are most likely to be affected by climate change. Dr Halse also considers it possible that some species of waterbird characteristic of the north are likely to extend their ranges southwards with increased summer rain.[26]

Extinction of species

Large-scale changes to hydrology in a region can endanger species. In particular, warmer, drier conditions predicted under many climate change scenarios will pose a significant threat to a number of WA's wetland species, particularly flora of shallow freshwater claypans, salt-intolerant species, cool-adapted species, species with poor or flood-dependent dispersal mechanisms, and groundwater dependent species, such as aestivating fish, some frogs, burrowing crayfish.[132]

Many species of frogs in the south-west are potentially at risk. For example, the climatic habitats of the white-bellied frog (*Geocrinia alba*), yellow-bellied frog (*Geocrinia vitellina*) and sunset frog (*Spicospina flammocaerulea*) are predicted to disappear completely with an increase of annual temperatures of 0.5 degrees Celsius.[133]

Initiatives such as ClimateWatch are collecting information on the population of particular species to understand how changes in temperature and rainfall are affecting their behaviour. WA animals studied in the initiative include the oblong turtle and a number of frogs. It uses citizen science, enabling every Australian to be involved in

case study

When peat wetlands dry out: a case study of Lake Wilgarup

As peat forms in places that rarely dry out, drier water regimes at peat wetlands can cause great damage:

Firstly, the plants and animals are exposed to drier conditions.

Secondly, the drying of the peat can trigger acidification, affecting sensitive species.

Thirdly, the wetlands may become more susceptible to fire. Peat does not occur in places that normally become dry enough to burn, yet dried peat, being dry organic matter, is flammable. In general, the species at peat wetlands are not adapted to fire and are more likely to be killed by it. Peat fires at wetlands are difficult to extinguish, and can burn underground for weeks, or even months. For wetlands undergoing drying and acidification, resilience in the event of fire can be low, with the potential for the loss of the original ecological community.

Lastly, burning or overheating of sediment due to fire can result in the loss (volatilisation) of organic material, cracking and/or erosion, further exposing the remaining sediment to air and potentially triggering the release of significant amounts of stored acidity. Cracks as deep as 1 metre have been recorded in organic sediments.[128]

In addition to these impacts, peat smoke contains compounds which are toxic to humans, so the burning of peat wetlands can be a serious human health issue.[129]

Drying, acidification and fire has occurred at Lake Wilgarup, a peat wetland on the Gnangara Mound in the City of Wanneroo. A progressively drier water regime was causing declines in the condition of dense stands of paperbarks (*Melaleuca rhaphiophylla*) within the wetland. A fire in January 2005[130] killed much of these stands, and the population has not regenerated because of a combination of drier water regimes and changed soil conditions after the fire, including the drying of organic sediments and severe acidification due to oxidation of acid sulfate soils. Dense recruitment by flooded gums (*Eucalyptus rudis*), which tolerate drier water regimes, is now replacing the paperbarks (Figure 21).

Figure 21. A dense stand of flooded gums (*Eucalyptus rudis*) are recruiting under the dead stags of paperbarks (*Melaleuca rhaphiophylla*) at Lake Wilgarup on the Gnangara Mound. The paperbarks were killed by fire, and were unable to regenerate because of drier water regimes. Photo - R Susac/DEC.

collecting and recording data that will help shape the country's scientific response to climate change. ClimateWatch was developed by Earthwatch with the Bureau of Meteorology and The University of Melbourne. The website is www.climatewatch.org.au.

extra information

Species vulnerable to climate change in the south-west of WA

A collaborative project coordinated by Murdoch University concluded that the species most vulnerable to climate change in the south west are anticipated to be:

- Species of seasonally inundated or waterlogged wetlands whose life cycles, survivorship and reproduction may be adversely affected by premature wetland drying and change in seasonality.
- Freshwater turtles which depend on permanent moisture, regular winter rainfall and temperatures to determine sex of offspring e.g. western swamp tortoise *Pseudemydura umbrina* and side-necked tortoises (family Chelidae).
- Species that breed in autumn because the change in timing of seasonal rainfall and temperature triggers may not allow them to complete life cycles (e.g. tadpoles may not have time to develop into adult frogs).
- Species of cold climates, mostly with south coast distributions, which will lose suitable habitat due to increasing temperatures e.g. the rare sedge *Reedia spathacea* and disjunct south-eastern Australian wetland sundew species *Drosera binata.*
- Species which are endemic, have restricted range, are already endangered or threatened, for example, Albany pitcher plant *Cephalotus follicularis*, sunset frog *Spicospina flammocaerulea*, white-bellied frog *Geocrinia alba*, hairy marron *Cherax teniumanus*.

For more information, see the report *Climate change and Western Australian aquatic ecosystems: impacts and adaptation responses.*[132]

Effects on wetland soils

The types of sediments that develop, and their rates of accumulation can be determined, in part, by a wetland's water regime. For example, in wetlands with permanent inundation or waterlogging, it is not uncommon for peat to develop, over long periods of time. Peat is the product of wetland plants that have only partially decayed/ decomposed. In wetlands with inundation and other conditions suitable for diatoms (a type of algae), the sediment may be dominated by their remains: tiny glass-like cell walls of silica; this sediment is known as diatomaceous earth, which slowly builds up over time. In inundated wetlands, abundant populations of charophytes, molluscs and other invertebrate fauna can leave behind shells and deposits, which over time, can form carbonate sediment. Drier water regimes may reduce the extent to which these types of sediments accumulate, and with increased potential for fire, they are at greater risk of losing peat and other organic sediments through combustion (as discussed in the earlier case study 'When peat wetlands dry out: a case study of Lake Wilgarup').

Drying of wetlands that contain acid sulfate soils can generate acids and trigger serious changes to wetland soils. These are described earlier and also in the topic 'Water quality' in Chapter 3.

➤ Detailed case studies of changes to wetlands and wetland soils arising from climate changes are provided in the article, *The response of basin wetlands to climate changes: a review of case studies from the Swan Coastal Plain, south-western Australia.*[13]

Hysteresis: the condition that caused a shift from one state to another does not necessarily result in a shift back to the first state when the condition is simply reversed

Limits of acceptable change: variation that is considered acceptable in a particular component or process of the ecological character of the wetland, without indicating change in ecological character that may lead to a reduction or loss of the criteria for which the site was Ramsar listed

Effects on wetland ecosystems

The changes to water quality, soils, species and communities can have cumulative effects on wetland ecosystems. Changes may be evident as a gradual change; this is known as 'proportional response' and describes a progressive decline in ecosystem processes with changes in water regime.[94] An abrupt change or regime shift can signal the occurrence of a 'step change' or 'threshold change', this is when little change is evident until a particular threshold is reached and rapid and extensive changes follow. It describes a non-linear response to a relatively small change in the external stressor.

The response of the wetland to altered regime can inform the potential management response. For example, for those wetlands where the **hysteresis** model of non-linear change applies, reversing the external stressor does not result in the original wetland ecology being restored.

The concept of defining '**limits of acceptable change**' can be useful for wetland managers seeking to identify the water requirements needed to maintain a wetland's ecological character (Figure 22A). In addition to defining absolute minimums and maximums, it is important to consider other aspects, such as baseline shifts, number of peak events and seasonal shifts (Figure 22 B–D).

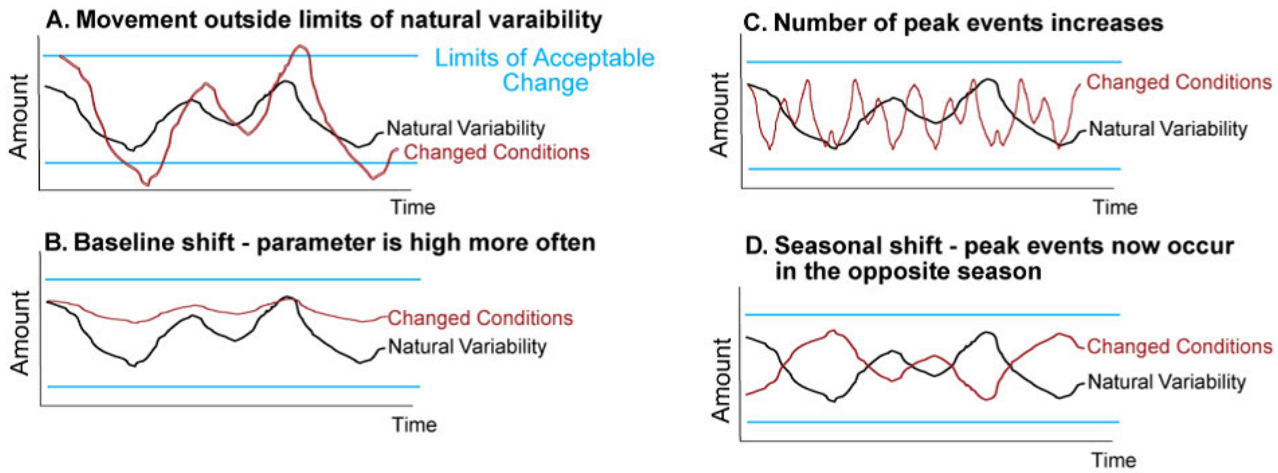


Figure 22. Limits of acceptable change. Source – Hale and Butcher (2007).[134]

Limits of acceptable change have been defined for a number of Western Australia's internationally significant wetlands recognised via listing under the Ramsar Convention. Table 6 is an excerpt of the limits of acceptable change defined for Thomsons and Forrestdale Lakes in southern metropolitan Perth.

➤ A factsheet on limits of acceptable change is available from the Australian Government website: www.environment.gov.au/resource/limits-acceptable-change-fact-sheet

Table 6. An excerpt of some of the limits of acceptable change defined for Forrestdale and Thomsons Lakes, internationally significant wetlands located in Perth's southern suburbs. Source – Maher and Davis, 2009.[107]

Components and processes	Baseline condition and range of natural variation where known (range with average in brackets)	Limits of acceptable change
Annual minimum water depth	Typically falls to around 0.5 m below the lake bed level. **Permanent water** (in most years): • Thomsons: 1972–1977 and 1989–1995 • Forrestdale: 1972–1982 and 1989–1993 **Annual drying** (in most years): • Thomsons: 1978–1988 and 1996–present • Forrestdale: 1983–1988 and 1994–present	• At the sediment surface (wet years), or up to 0.5 m below the lake bed levels (medium years), or 0.5–1.0 m below the lake bed surface (dry years) (DoE 2004) for 3–4 consecutive months annually. • Always <1.0 m below the sediment surface (DoE 2004). • Not 0.5–1.0 m below the sediment surface for longer than 4 consecutive months more than once every ten years or for 2 consecutive years (Froend et al 1993).
Annual maximum water depth	**1952–2005**: Thomsons Lake 38–371 cm (139 cm) Forrestdale Lake 45–266 cm (129 cm) **1980–1999** (decades before and after Ramsar listing): Thomsons 38–206 cm (105 cm) Forrestdale 47–187 cm (103 cm)	• >0.9 m (DoE 2004) for 2 months during spring. • > 1.6 m at least once every 10 years (for invertebrates) • No less than 0.5 m more than once every 10 years (Froend et al 1993). • No greater than 2.5 m for 2 consecutive years (Froend et al 1993).
Period of inundation/ drying	**1972–2005**: Thomsons 5–12 months (9.6 months) Forrestdale 5–12 months (9.9 months) **Drying phase 1 (1980s)**: Thomsons 7–10 months (8.6 months) Forrestdale 9–12 months (10.2 months) **Drying phase 2 (mid-1990s to 2005):** Thomsons 5–9 months (7.3 months) Forrestdale 5–9 months (6.8 months)	• > 6 consecutive months annually (Balla and Davis 1993; Briggs and Thornton 1999). • Preferred earliest drying by April (wet year), Feb–Mar (medium year) or January (dry year) (DoE 2004). • Permanent water present for not more than 2 consecutive years in every ten years (Crome 1988; Halse et al. 1993; Davis et al. 2001).

Loss of wetlands

Complete, sustained drying beyond natural variability can lead to the loss of areas of wetlands and entire wetlands. The terrestrialisation of wetlands into dryland is a natural phenomenon that can occur due to natural processes and conditions, but the potential scale and rate of human-induced terrestrialisation, in already very altered landscapes, may have much larger ramifications for biodiversity and groundwater quality.

Wetlands are the ecosystems most vulnerable to climate change in the south-west of WA

A collaborative project coordinated by Murdoch University concluded that the ecosystems most vulnerable to climate change in the south west are anticipated to be:

- shallow, seasonally wet (waterlogged or inundated) surface water dependent wetlands
- groundwater dependent wetlands, especially where water abstraction is also occurring, such as the Swan Coastal Plain.

For more information, see the report *Climate change and Western Australian aquatic ecosystems: impacts and adaptation responses.*[132]

Recognising the signs of altered hydrology

There are observable changes in wetland ecosystems that can indicate a change in wetland hydrology and water regime. The observations take various forms, but do not have to involve direct numeric measurement. Given that most WA wetlands naturally go through cycles of wetting and drying, detecting a relatively slow or subtle change in water regime is likely to require observations over several years (or even decades). Wetland ecosystems with greater natural variability in their hydrology or longer wetting-drying cycles will require observations over longer time periods. The ecological and hydrological time lags between disturbance to the groundwater regime and an ecological response vary.

General observations

A person familiar with a wetland will often notice hydrological changes, or their biological symptoms, without measuring their observations. Regular visitors to a wetland might notice such signs as:

- in wetlands with surface water, sustained trends in patterns of movement of the waterline (which signifies extent and depth of water) (such as over a number of years)
- a decline in the condition of wetland vegetation evident as yellowing, browning, wilting or dead foliage in vegetation
- population declines or explosions of particular plants or animals, including weeds and feral animals
- new types of plants or animals appearing, or familiar plant species appearing in new parts of the wetland
- changes in the sediments, such as deep cracking in clays, beyond what normally happens in drought.

Care should be taken when attributing any observed ecological effects to altered hydrology or any other cause, because altered hydrology is only one of many environmental factors that might affect wetland organisms. Some other factors include diseases, fire, predators, herbivores, competition, nutrients, weed invasion, salinity or other pollutants. If altered hydrology is suspected to be the cause of decline in ecosystem condition, then further information should be sought to confirm it, and to investigate its potential links with other potential degrading processes.

Aside from general observations, information can be gained in several ways, including:

- talking with people who are familiar with a wetland over a number of years
- viewing sequences of aerial photographs, which can show changes in the distribution of perennial wetland vegetation, sediments or the water line over a number of years. Internet sources of aerial photography include Google EarthTM and Landgate's map viewer (www.landgate.wa.gov.au/bmvf/app/mapviewer).
- viewing old photographs of the site
- reading oral histories and history books, which can be an important source of information on past vegetation structure, land use, fauna populations and water regime of the wetland (see below)
- looking at long-term data on water levels from a variety of sources (see below)
- examining rainfall records, which can be used to understand general trends in an area. Rainfall records are available for most locations in the state from the Bureau of Meteorology website through tools such as 'Climate data online': www.bom.gov.au/climate/data/index.shtml.

extra information

Historical information on wetland water levels

Sources of information on wetland water levels include:

- The Department of Water's water information network. Its records are available online at the water information resources catalogue: http://kumina.water.wa.gov.au/waterinformation/wric/wric.asp
- Hydrographs are available for many sites, available at http://kumina.water.wa.gov.au/waterinformation.wrdata/wrdata.cfm
- Reports from the South West Wetlands Monitoring Program, available via the DEC library: http://science.dpaw.wa.gov.au/conslib.php (authors 'Lane' and 'Halse').
- Reports online, and in public libraries, state government libraries, and the repositories of regional natural resource management (NRM) organisations.

extra information

Oral histories

Oral histories can provide a wealth of information on conditions in wetlands following European settlement, but prior to monitoring.

For example, Clohessy describes how: "Oral histories compiled by the Gwelup Progress Association provide an interesting account of the historical horticultural activities that dominated the Gwelup area for about 90 years until the commencement of urbanisation in the 1970s. The City of Stirling was identified as 'swamp land that people could crop three times a year' and was generally thought to be a productive horticultural precinct. The presence of peat in the City of Stirling was identified long before the onset of urbanisation and was crucial to the horticultural productivity of the area. Sand-dominated landscapes were considered 'worthless' as there was no irrigation in the area prior to the late 1930s and 1940s, making it difficult to produce a consistent crop on these nutrient poor sands. Upon the construction of irrigation bores, horticultural activities expanded to the 'sanded land', which was also much cheaper and easier to work than the 'swamp land' as horses and machinery could be used (Moore 2001).

Farming practices associated with horticultural activities in the Gwelup area comprised the burning of peat (Moore 2001) and the use of fertilisers. The burning of peat may have released significant amounts of stored acidity, perhaps adversely affecting the quality of groundwater prior to the onset of urbanisation. Fertiliser use during this horticultural era contributed to the presence of elevated nutrient concentrations in groundwater in combination with the commencement of unsewered urban development (Barber et al. 1993). Nitrate concentrations in the lower half of the Superficial aquifer, where production bores are screened, have declined since".[135]

Relevant oral histories include:

- *Forrestdale: people and place*[136]
- *Oral histories documenting changes in Wheatbelt wetlands*[137]
- *Oral histories of Wanneroo wetlands: recollections of Wanneroo pioneers, changes that occurred between European settlement and the 1950s*[138]
- *Recollections of the Beeliar wetlands*[139]

For more sources, see the WA Branch of the Oral History Association of Australia website: www.ohaa-wa.com.au/ and the Royal Western Australian Historical Society Inc: http://histwest.org.au/?page=links.

Monitoring water levels

Monitoring the levels of surface water and groundwater provides data on some of the most important aspects of the water regime that affect wetland ecology. Monitoring water depth through time at various points within a wetland provides information on the depth, extent, duration and timing of inundation or waterlogging.

Monitoring the surface water depth of wetlands that are inundated can be carried out by installing a depth (or staff) gauge and measuring the depth of water in relation to the depth gauge. A gauge should be positioned so that wetland water levels can be measured when they are at their lowest and highest; in drying wetlands, some gauges have been left stranded by water level declines. In some cases, it may be appropriate to carry out a lakebed sediment bathymetric survey to determine the lowest lakebed level, so that surface water staff gauges can be installed in the most appropriate locations, as occurs in monitoring of some wetlands on the Gnangara and Jandakot mounds.[140] In wetlands that are seasonally waterlogged, neutron probes may be useful for monitoring moisture content.

Groundwater can be monitored using monitoring bores, also known as piezometers, to measure the depth of water in the bore. The installation of the bores needs to be carefully considered in order to get the information required, particularly the location, screens and configuration of the bore network. The bores should be positioned up-gradient and down-gradient of the wetland so that both horizontal and vertical groundwater flow can be measured. For wetlands fed by the superficial aquifer, it may be useful to install the groundwater monitoring bores in clusters of three: shallow (screened at the water table), intermediate (screened approximately half way through the superficial aquifer) and deep (screened at the base of the superficial aquifer). It is also important that the flow components of the regional groundwater system in the vicinity of the wetlands are known. Neutron probe access tubes, for monitoring unsaturated zone moisture content, may also be installed adjacent to monitoring bores.

Changes may influence the timing (season or month) of the driest or wettest conditions, or the rate of change in water depth or extent. Water regimes can be characterised using a range of parameters that define features of the water regime (timing, frequency, duration, extent, depth and the variability in these). The water regime parameters used might vary between wetlands, because a parameter that is meaningful to describe one water regime may be irrelevant in another. For example, 'season of maximum inundation' might be a meaningful parameter to define a seasonally inundated wetland, but is irrelevant for a wetland that could contain surface water in any season, or for a wetland that naturally experiences waterlogging but not inundation.

Some of the parameters used to characterise water regimes at wetlands are:

- timing (season or month) of driest/wettest conditions
- frequency of driest/wettest conditions
- duration of driest/wettest conditions
- maximum and minimum depth of inundation or waterlogging
- extent (area and location) of inundation or waterlogging
- rate of change in water depth or extent

In all wetlands there is natural variation in water regime. This means that water regime parameters are best described by a range of values rather than a definitive value. For example, the recorded maximum water depth of a seasonally inundated wetland might vary 'between *X* and *Y* metres' in a ten year period. When characterising the water regime, the extremes should be recognised as natural to the wetland, unless there is evidence to suggest that the extremes have been caused by altered hydrology. The natural variability should therefore be taken into account when deciding whether a wetland's water regime (and therefore its hydrology) has been altered.

Quadrat: a plot (often square) that is marked, either temporarily or permanently, to facilitate counts of plants in a given area

> *'When Europeans arrived in Australia… they called the dry times 'drought' and the wet times 'flood' and the times of perfect pasture growth 'normal'. The extremes were regarded as aberrations of the 'normal' conditions. However, as records show, extremes of wet and dry are not abnormal – they are part of the natural pattern.'*
>
> -Brock et al. (2000)[141], p. 2.

➤ For additional detail on monitoring, see the topic 'Monitoring wetlands' in Chapter 4.

Monitoring vegetation or other biological indicators

Photo monitoring can provide a good visual record, where a rigorous record of change is not required. If time or money is not available for the quantitative monitoring of vegetation and other wetland parameters, photo points may be useful in determining if changes are occurring. Photo points are simple, fast and relatively cheap to establish. The drawback of photos is that they only provide an indication that a change is occurring or has occurred and may not enable that change to be quantified. Small, incremental changes may be difficult to detect in photos, and it may take a number of years before change is noticeable, by which time remedy or reversal may be difficult to achieve.

Similarly, examination of aerial maps and photographs from monitoring points over time are simple methods of identifying change.

➤ For a guide to photo points for monitoring purposes, see the *Land for Wildlife* program's Wildlife Note No. 9 *Photographic monitoring of vegetation*.[142]

➤ Google Earth www.google.com/earth supplies a free software program that provides online access to aerial photography covering WA. Some areas have many years of aerial photography (time series), which can assist with identifying vegetation change.

➤ Aerial photography can be viewed and purchased from Landgate's Map Viewer www.landgate.wa.gov.au/bmvf/app/mapviewer/ and NearMap www.nearmap.com.

To detect the degree and rate of the change associated with water regime, vegetation monitoring may consider characteristics such as:

- extent
- species composition
- structure (height class and dominance); and
- vegetation density (percentage cover)

Common measures include stem diameter at breast height (DBH); species richness; crown health; species cover and abundance; weediness index; regeneration index; stem condition; presence/absence of seedlings; and presence/absence, density and foliage cover of understorey species. Monitoring programs need to be designed carefully to detect and record change accurately and to establish any correlations with water regime changes. **Quadrats** are a standard monitoring tool.

➤ For additional detail on monitoring, see the topic 'Monitoring wetlands' in Chapter 4.

➤ More guidance on composition, structure and density changes are provided in 'Managing wetland vegetation' in Chapter 3.

Technology now offers opportunities to monitor vegetation in new ways, making use of aerial photography and high-resolution digital airborne imagery to detect indications of canopy change, water use and plant health. These techniques may be suitable for large, complex wetlands or those in remote or inaccessible areas.

➤ For more information, see CSIRO www.csiro.au/Organisation-Structure/Divisions/Land-and-Water/Environmental-Earth-Observation.aspx.

Understanding the potential for, and the impact of, altered hydrology

Models are often used to simulate hydrological systems, and predict the effect of changes. A **groundwater model** is a simplified representation of a groundwater system and it captures and synthesises all of the known information, and where information is not known, identifies any assumptions being made about how the system is thought to work. Groundwater models may be conceptual, analytical or numeric. Conceptual models are used as visual tools to display the relationships between parts of the groundwater system. They may be simple or more complex, such as shown in Figure 23. Numeric models assign actual quantities to each part of the system. Perth regional aquifer modelling system, or PRAMS, is a regional model of Perth's groundwater (Moora–Mandurah). It is used by the Department of Water to manage groundwater in the region and to help predict cause and effect under different scenarios (for example, more or less groundwater abstraction). The Peel-Harvey and south west models are referred to as PHRAMS and SWAMS respectively.

While regional groundwater models tend to be useful in understanding regional trends, they are often unsuitable for use at the scale of individual wetlands. In the case of PRAMS, its calibration and resolution are based on a 500 by 500 metre grid size and therefore cannot provide detailed information for local scale management objectives, such as managing individual wetlands, which require smaller grid sizes, higher resolution conceptual models and higher quality calibration. To gain a better understanding of the role of the Gnangara groundwater system's effect on wetlands, the Department of Water have developed local area models (LAMs) at a refined level of detail (50 to 100 metre grid) for five wetlands/wetland sites (Lake Mariginiup, Lake Nowergup, Melaleuca Park, Lake Bindiar and Lexia). These local area models provide quantitative tools to assess land and water use impacts on the environment and groundwater systems. These local area models will be used to refine and improve PRAMS so that the impact on wetlands due to changes in the superficial aquifer can be determined.

Modelling of surface water-groundwater interaction sometimes involves the coupling of surface hydrological models with groundwater models.

Models are often used to help determine the potential environmental impacts of proposals assessed by the Environmental Protection Authority under the *Environmental Protection Act 1986*. It is important to be aware that models reflect the information they are based on, and it is possible for them to be wrong. For example, if a model is based upon one year's monitoring data, its predictive capability about how a system works over the long term and how it may respond to events is likely to be extremely limited. Important factors include the type of model used and its suitability for the task at hand, the assumptions built into the model, the integrity of the data, calibration and the stated uncertainty of its outputs.

➤ For more information on groundwater modelling, see the *Australian groundwater modelling guidelines.*[144]

➤ The eWater toolkit www.toolkit.net.au/Default.aspx is a source of software tools and information related to the modelling and management of water resources provided by the eWater Cooperative Research Centre.

➤ For more information on local area models, see the reports listed under 'Local area modelling' at: www.water.wa.gov.au/sites/gss/reports.html.

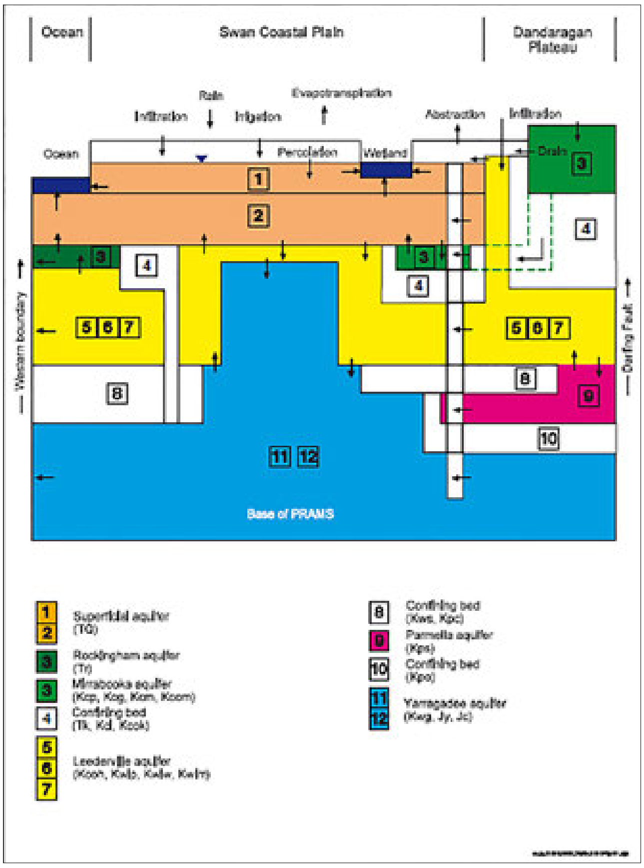


Figure 23. A conceptual hydrogeological model of the Perth groundwater system. Image – Department of Water.[143]

At the wetland scale, the complexity of groundwater flows can be compounded by the complexity of wetland sediments. For example, Figure 24 shows the wetland sediment profile of Lake Mariginiup on the Gnangara Mound, in the suburb of Mariginiup north of Perth. In winter/ spring, groundwater flows into the wetland on its eastern side, then up to 92 per cent is removed by evapotranspiration; a small amount is recharged to groundwater from the western side of the wetland.[145]

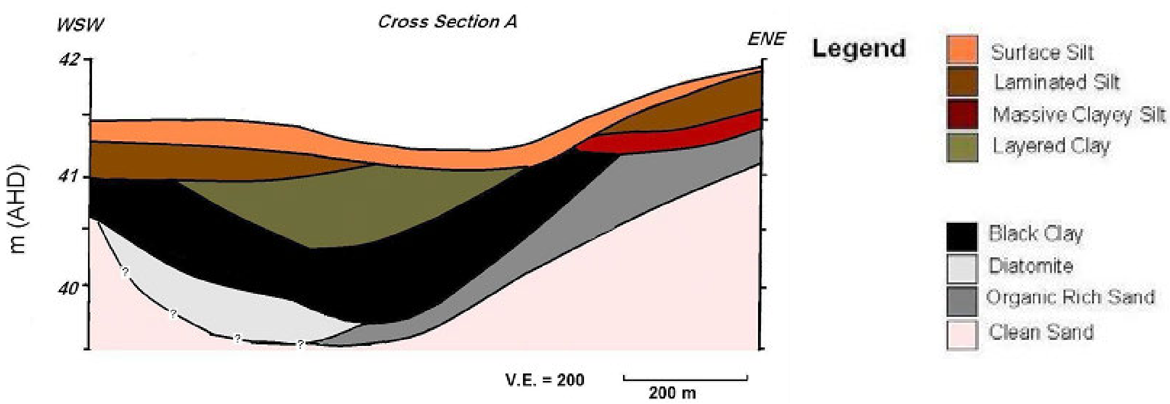


Figure 24. In many wetlands, the sediment is not uniform across the wetland, such as those of Lake Mariginiup, represented here in cross-section. Image – Department of Water.[63]

Notwithstanding this, models can help us to analyse a lot of complex information and to draw conclusions about broad trends. Examples are the:

- South West Sustainable Yields Project, which models the potential effects of climate change on wetlands between Geraldton and Albany (Figure 25). Predictions have been developed of the potential effects of drying upon wetlands under a number of different potential future climate scenarios. These predictions are an important tool for people involved in natural resource management at subregional to regional scales. At the scale of individual wetlands, however, predictions should be used with care. For more information, see www.csiro.au/partnerships/SWSY.

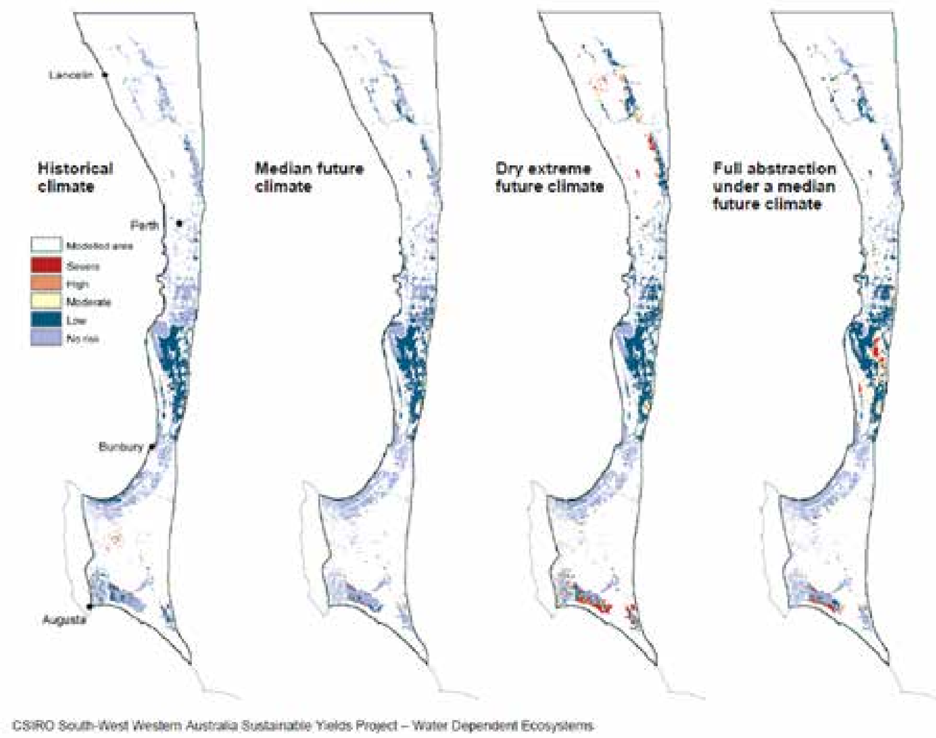


Figure 25. Modelled predicted impacts of climate change on wetlands of south-west WA, based on different climate and abstraction scenarios. Image – CSIRO.

Managing hydrology in wetlands

First and foremost, deciding how best to manage altered hydrology at a particular wetland requires an understanding of the wetland's hydrology (including catchment and aquifer, where relevant).

Once this is established, an important decision is the level or levels at which to take action. The various levels at which to operate range from on-ground works or local scale works through to involvement in sub-regional or regional initiatives, plans and policies. The appropriate level of action will depend on the circumstances. In most cases, the actions that yield the biggest effect on managing a wetland's hydrology do not involve on-ground work. The existing approved land and water uses, competing demands for land and water use, legislative controls, available funding, conservation priorities, likelihood of success of on-ground works and so on all need to be weighed up when deciding how best to act.

It might be within the power of one person or an organisation to effectively tackle altered wetland hydrology, if the cause is localised. However, managing a wetland's hydrology usually requires a catchment- and aquifer-scale approach. As well as improving outcomes for wetland ecosystems, such an approach may also improve outcomes for natural dryland ecosystems, as well as farming systems and infrastructure, because hydrology can affect all of these things, not just wetlands. These gains, however, do not come easily and quickly. It can be challenging to align the priorities of all of the relevant people and organisations to develop a suitable approach to manage a landscape and its hydrology. Managing at this scale requires a big-picture approach and a long-term vision to achieve ecosystem health and productive landscapes that meet human needs. Determining and agreeing on an appropriate approach may take years, implementing

Ensuring you have sound expert input

Before embarking on on-ground activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate.

On-ground actions to manage wetland hydrology should generally only be taken after a management planning process has been completed and a management plan prepared, however basic it may be. This process should determine what actions are legal, feasible, cost-effective and without adverse side effects. For guidance on wetland management planning, see the topic 'Wetland management planning' in Chapter 1.

Where on-ground action involves hydrological interventions, it is likely that the input of a qualified hydrologist or hydrogeologist, and in some cases, an engineer, will be needed.

It is also essential to make sure you have all the necessary legal approvals. Guidance is provided in the following sections and in the topic 'Legislation and policy' in Chapter 5.

the approach will take more years, and waiting for the hydrological outcomes can take decades. These improvements might be too late to save wetlands of high conservation priority which are at immediate risk of degradation due to altered hydrology.

To deal with wetlands of high conservation priority that are under immediate hydrological threat, a quicker solution than catchment and aquifer-scale management is required. In these cases, engineering solutions are often considered, as a way to take immediate pressure off a high-value ecosystem. Some approaches include earthworks to modify surface flows, groundwater pumping to lower water tables, and artificial supplementation of water levels. These options require large investments of time, commitment and money, and require expertise from a number of fields. They are usually only used where a wetland's conservation values are well-documented, and its conservation priority is well-justified and accepted. Due to the investment levels required, government is normally involved.

For social, economic or ecological reasons, it may not be possible or appropriate to restore every wetland to its original hydrology. In these cases, it might be better to accept the altered hydrology and where appropriate, shift focus from restoring hydrology to maintaining a functioning, if changed, ecosystem.

Lastly, it is important to acknowledge that it is possible that reinstating the natural water regime might not restore the wetland ecosystem present before the change to the water regime, or might have unintended outcomes. This is potentially the case at Lake Warden, where lowering the water level in the wetland to natural levels appears to have dramatically increased the wetland salinity.

Table 7 provides a summary of the major causes of altered hydrology in Western Australia, and how their impacts may be mitigated. In some cases, the only mitigation measure is to avoid the activity that causes hydrological change.

Table 7. Potential responses to altered hydrology.

Cause	Potential management responses		
Aim: to maintain hydrological processes in healthy wetlands			
	• maintain wetland vegetation and surrounding dryland vegetation	• avoid any earthworks, drainage, pumping, clearing or plantations that might alter flows into or out of the wetland	Page 57
	• avoid placing abstraction bores near the wetland, or borefields upgradient of wetlands that rely on groundwater.	• monitor wetland condition	
	• influence proposals in planning phase	• influence legislation, policy or plan	Pages 57 - 63
Aim: to avoid water rise in wetlands			
New proposal to dewater or clear	• influence proposal in planning phase	• influence legislation, policy or plan	Pages 57 -63
Dewatering	• aquifer reinjection of dewater (managed aquifer recharge)	• alternative uses of excess dewater	Pages 65 - 66
Aim: to manage water rise in wetlands			
Clearing	• maintain native vegetation	• large scale revegetation	Pages 66 - 72
	• large scale deep-rooted perennial cropping/plantations	• landscape drainage modifications	
	• surface water inflow diversions	• wetland dewatering	
	• groundwater pumping		
Aim: to manage water decline in wetlands			
New proposal to take water	• influence proposal in planning phase	• influence legislation, policy or plan	Pages 57 - 63
Existing use of water	• ensure water is allocated to wetlands at a sub-regional scale	• employ water use efficiencies	Pages 72 - 87, 89 - 91, 93 - 94
	• deter illegal/unapproved use of water	• recycle water	
	• use alternative water sources - desalination - alternative groundwater aquifers - stormwater and rainwater	• recharge groundwater	
	• avoid abstracting near wetlands	• minimise drawdown of wetlands via best practice abstraction	
	• artificial supplementation		
Dewatering	• use alternative to dewatering	• design and operate dewatering to minimise impacts	Pages 88
Plantation, vegetation	• design, operate and modify tree plantations	• modify natural vegetation	Pages 92 - 93
Aim: to manage water balance			
General development	• use well-designed culverts in existing wetland causeways	• do not install new causeways	

Cause	Potential management responses		
New proposal for urban development	• influence proposal in planning phase	• influence legislation, policy or plan	Pages 57 - 63
	• infiltrate water into the soil throughout the catchment in small rainfall events, rather than directing it into pipes or open drains	• use well-designed public open space, road reserves and wetlands to receive stormwater in moderate to large rainfall events by overland flow paths across vegetated surfaces	Pages 85 - 87, 95 - 97
	• adequately separate sub-soil drainage systems from wetlands		
Urban development	• Retrofit urban environment		Pages 85 - 87

Maintaining hydrological processes in healthy wetlands

Prevention is better than cure. It is easier to maintain hydrological processes than to reverse altered hydrology. If a wetland's hydrology is still largely intact, then the following actions will help achieve good hydrological management:

- maintain wetland vegetation and surrounding dryland vegetation
- avoid any earthworks, drainage, pumping, clearing or plantations that might alter flows into or out of the wetland
- avoid placing abstraction bores near the wetland, or borefields upgradient of wetlands that rely on groundwater
- monitor wetland condition.

Influencing legislation, policies and plans to protect wetland hydrology

Government policies, plans and legislation form the basis for permitting or prohibiting activities that can alter hydrology, and therefore they can strongly influence wetland hydrology. They can determine the nature of land use or water use, so influencing their formulation or their revision can be more effective than on-ground works to maintain or restore natural wetland hydrology.

The community has an important role in setting political agendas and raising government awareness of wetland conservation issues. While specific government agencies are assigned responsibilities for wetland conservation by the state government, government agendas and programs are frequently influenced by community concerns and opinions. Some government committees include community representatives to facilitate greater consideration of community opinions when developing policy and making decisions. For example, the Wetlands Coordinating Committee (described later) and a number of its sub-committees include representatives of the voluntary conservation movement and wetland scientists from universities and the private sector.

Agencies of both the Western Australian and Australian governments publish documents that guide water management in the spheres of land use planning, environmental protection and water resources. Influencing the positions established by government, and ensuring that these positions are mirrored in decision-making processes, can be effective. Most policies, strategies, and position statements developed by government agencies or committees are released in draft form for public comment. Submissions made during this time are usually considered through a formal process and a response is made to each substantive point raised. Submissions with well defined and explained points make it easier for the agency or committee to respond. Most agencies publish guidelines for preparing submissions. The response to submissions is sometimes published. Some agencies or committees will invite community input before a draft is prepared, in the form of a workshop or survey. Invitations may be extended on a random basis or to known representative community members.

extra information

Gnangara sustainability strategy: an example of public participation

The Gnangara sustainability strategy (GSS) is a cross-government initiative working on an action plan to ensure the sustainable use of water for drinking and commercial purposes and to protect the environment. The consultative approach taken seeks to address land, water and biodiversity issues on the Gnangara system through a transparent, cooperative framework for the benefit of all groundwater users.

The draft GSS was released for public comment on 6 July 2009 for an eight week period concluding on 31 August 2009. Sixty-two submissions were received, consisting of 1179 comments. A further 136 comments were made on Appendix 1 - Gnangara groundwater system zone plans. All comments received during the public submission period for the draft GSS have been collated and analysed. The analysis of public submissions is available from the GSS website, and together with a final strategy has been delivered to the Western Australian State Government for consideration in December 2009. Further consultation is taking place on some elements of the strategy.

For more information see www.water.wa.gov.au/sites/gss/index.html.

Broad policy development can also be initiated by government in response to an issue raised by the community through individual or group lobbying to the responsible Cabinet Minister. The community response to a specific plan or proposal can also contribute to broader policy development on an issue.

Changing the way water is managed, referred to as *water reform*, has been high on the state and Australian Government agenda. In particular, the National Water Initiative (NWI), of the National Water Commission, is guiding nation-wide reforms. The NWI represents a shared commitment by governments to increase the efficiency of Australia's water use, leading to greater certainty for investment and productivity, for rural and urban communities, and for the environment. The WA Government signed the NWI in April 2006. WA's water reform agenda is aimed an ensuring there is enough water for long term economic and social needs in a changing climate as well as ensuring the environment is protected. Improved water planning and water allocation processes and outcomes are key tenets of water reform.

Table 8, Table 9 and Table 10 outline some of the key studies, state plans and legislation that determine how wetland hydrology is influenced by water and land use in WA. More information on water allocation process is provided in the below section entitled 'Ensuring water allocated to the environment in water allocation plans provides for wetland water requirements'.

➤ More details on water reform progress are available from www.water.wa.gov.au/Future+water/Water+reform/default.aspx#1.

➤ More information on policies and legislation relevant to the protection of wetland water regimes is available in the topic 'Legislation and policy' in Chapter 5.

➤ Information on the roles of state and Australian government agencies is provided in the topic 'Roles and responsibilities' in Chapter 5.

Table 8. Regional water studies

Study	Geographic scale	What it establishes	More information
Northern Australia Water Futures Assessment	Kimberley, north and east from Broome across northern Australia	The information needed to inform the development and protection of northern Australia's water resources, so that development is ecologically, culturally and economically sustainable	www.environment.gov.au/topics/water/water-information/northern-australia-water-futures-assessment

Table 9. Some of the plans, licenses and approvals that have an influence on wetland hydrology (see also Table 11, page 97)

Type of plan	Geographic scale	What it establishes	Lead organisation	More information
Regional water plans	Regional	The region's water allocation; water use efficiency; water service provision; waterways, drainage and floodplain management.	Department of Water	www.water.wa.gov.au/Future+water/Resource+management/Regional+water+planning/Overview/default.aspx Currently, there are four regional plans covering the Kimberley, Pilbara, Perth-Peel and South-west regions.
Water allocation plans	Regional	How much water is allocated to wetlands	Department of Water	www.water.wa.gov.au/Managing+water/Allocation+planning/default.aspx See also the below section 'Ensuring water allocated to the environment in water allocation plans provides for wetland water requirements'.
District water management strategies	District	Whether the area is capable of supporting urban development, and if so, how water in the landscape will be managed	Department of Water	www.water.wa.gov.au/Managing+water/Water+and+land+use+planning/default.aspx www.water.wa.gov.au/Managing+water/Urban+water/Strategies+and+management+plans/default.aspx#1
Strategic water issue plans	Variable	Variable	Variable	For example, the ***Gnangara Sustainability Strategy*** is a cross-government initiative: www.water.wa.gov.au/sites/gss/gss.html
Development proposals	Local	How a development is designed, constructed and operated	Department of Planning, Environmental Protection Authority	

Type of plan	Geographic scale	What it establishes	Lead organisation	More information
Licenses to take water	Local	How much water can be taken and under what conditions	Department of Water	www.water.wa.gov.au/Business+with+water/Water+licensing/default.aspx
Wetland management plans	Local	How a wetland is managed	Land manager; third party on behalf of/with consent of land manager	Seek from the land manager.
Strategic regional plans (various names)	Regional	What vision and priority is given to wetlands in a region by the group/community	Natural resource management organisations	Northern Agricultural Catchments Council www.nacc.com.au *Regional Natural Resource Management Strategy, Northern Agricultural Region of Western Australia* Perth Region NRM www.perthregionnrm.com *The Swan Region Strategy for Natural Resource Management* Rangelands NRM WA www.rangelandswa.com.au *Rangeland NRM Strategic Plan 2012-2015* South Coast Natural Resource Management Inc. www.southcoastnrm.com.au *Southern Prospects 2011-2016* South West Catchments Council www.swccnrm.org.au *Draft South West Regional Natural Resource Management Strategy 2012-2020* Wheatbelt NRM www.wheatbeltnrm.org.au *Wheatbelt Strategic Plan 2010-2012*

Table 10. WA Acts covering water resources management

Act	Purpose
Country Areas Water Supply Act 1947	Provides for the protection of public drinking water source areas in rural areas and the regulation of clearing control areas.
Environmental Protection Act 1976	Provides for the prevention, control and abatement of pollution and for the conservation, preservation, protection, enhancement and management of the environment.
Land Drainage Act 1925	Provides for the constitution and abolition of drainage districts.
Metropolitan Water Authority Act 1982	Authorises the provision of certain drainage works and coordinates drainage services.
Metropolitan Water Supply, Sewerage and Drainage Act 1909	Provides for the protection of public drinking water source areas in the metropolitan area.
Rights in Water and Irrigation Act 1914	The principal legislation for the allocation and management of use of water resources.
Water Agencies (Powers) Act 1984	Provides many of the works and other powers of the Minister for Water and the Department of Water.
Waterways Conservation Act 1976	Provides for the conservation and management of certain waters and associated land and environment.

Influencing proposals and decisions in the planning phase - avoiding or mitigating impacts

Decision-making processes often have a public consultation phase built-in. Community input during these phases can be a very effective way to influence a decision-making authority's determination of a proposal (a decision-making authority, or DMA, is a public authority empowered by legislation to make a decision in respect of a proposal). Raising issues early in the planning process is most effective, as it provides the proponent with more opportunity to address an issue or modify a proposal during the earlier stages of planning.

Planning development and new infrastructure can require considerable investment and the later in the process an issue is raised, the less likely it will be that the proponent will want to, or be able to afford to change the proposal.

A decision-making process that can involve considerations of wetland hydrology is the environmental impact assessment process. Where proposals that are likely to result in a significant effect on the environment, these need to be referred to the Environmental Protection Authority (EPA) under Part IV of the *Environmental Protection Act 1986*. For example, where an application for a water licence being sought under the *Rights in Water and Irrigation Act 1914* would have a significant effect on the environment the Department of Water must inform the EPA, and the impact of the licence would be considered by the EPA during its environmental impact assessment process.

As shown in Figure 26, the EPA requires proponents of land and water use proposals to seek to avoid impacts to the environment.

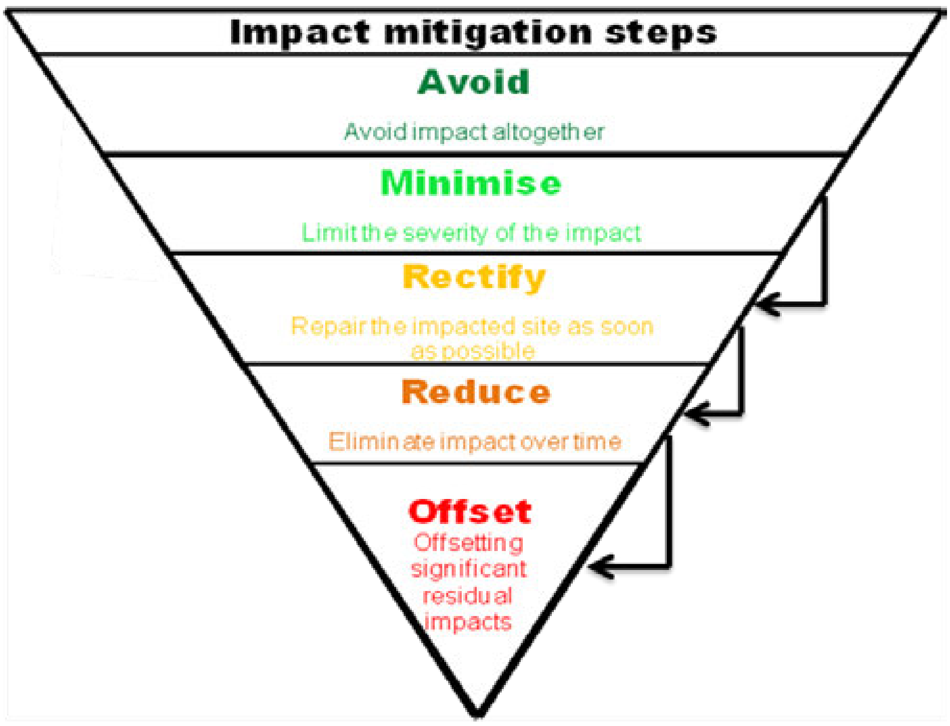


Figure 26. The EPA's decision framework. Avoiding environmental impact is the primary objective of environmental impact assessment. Image – R Pybus/DEC, adapted from EPA (2006).[146]

Via the environmental impact assessment process, the Government of Western Australia has established the water to be allocated to wetlands and other groundwater dependent ecosystems on Perth's Gnangara and Jandakot mounds.

In 1986 the EPA assessed the Water Corporation's proposal to abstract groundwater from the Gnangara Mound for public water supply and provided advice to the Minister for the Environment. In 1988, the Minister for the Environment approved the proposal, subject to conditions, to ensure that the wetlands (and other groundwater dependent environments) would be protected. These conditions were applied under the provisions of the *Environmental Protection Act 1986* and published in Ministerial Statement No. 021. These conditions established water level criteria for a number of wetlands. These wetlands are commonly referred to as 'Ministerial criteria sites' and they were chosen to represent the range of wetlands across the mound. The water level criteria were established through the determination of ecological water requirements. Typically, the way water was 'allocated' to wetlands was to identify a minimum water level permissible at each wetland below which the water should not fall (either surface or groundwater). The Ministerial conditions for the Jandakot Mound were first established in 1992 in Statement No. 253.

The impacts of abstraction are chiefly measured through compliance with environmental conditions that are monitored at Ministerial criteria sites. Compliance reporting is published by the Department of Water. The Ministerial conditions have been revised a number of time since 1986, in part because of the compounding effect of climate change and pine plantations on groundwater levels (the amendment of conditions is provided for under section 46 of the Act). Since 1997, the then Water and Rivers Commission (now Department of Water) has been subject to the Ministerial conditions. A review of the Ministerial conditions was completed in 2008 and most recently the requirements have been established in Ministerial Statement No. 819[147] for the Gnangara Mound, and Ministerial Statement No. 688[148] for the Jandakot Mound.

➤ For water level data for selected wetlands on the Gnangara and Jandakot mounds, see http://kumina.water.wa.gov.au/waterinformation/ewp/ewp.cfm.

Other water supply projects approved with Ministerial conditions under the *Environmental Protection Act 1986* include the Exmouth and Kemerton water supply.

The environmental impact assessment process grants members of the community specific rights to have concerns and views regarding proposals taken into consideration. These rights are generally applicable where a proposal is formally assessed, however, the EPA may request targeted public input into proposals that are assessed informally and that do not have to undergo a full assessment.

The types of submissions and appeals an individual may make include:

(i) a submission to the EPA during the public submission period of a project proposal undergoing environmental impact assessment

(ii) an appeal against decisions, recommendations and orders issued in respect to the environmental impact assessment process and applications to clear native vegetation to the Minister for Environment.

Appeal rights include the right to appeal:

- the decision of the EPA not to assess a proposal
- the content or recommendations of an EPA report.

The following appeals are only available to the proponent of the proposal:

- conditions imposed on a proposal by the Minister
- an order imposed on a proponent by the Minister following a breach of conditions.

➤ More information on public participation in decision making processes is available in the topic 'Legislation and policy' in Chapter 5.

➤ Information on the roles of decision making authorities is provided in the topic 'Roles and responsibilities' in Chapter 5.

Accepting hydrological change and managing the new conditions

It will not always be possible, practical or appropriate to reinstate the wetland's hydrology, or even to know what it was. Some of the reasons for this include:

- The remediation tools and techniques available are not effective enough to reinstate the original hydrology and vegetation.
- Wetland conservation may be a lower priority than the management goal for which the hydrology was altered (for example, water supply, urban development).
- The influence of a changing climate on wetlands cannot be mitigated directly through on-ground management.
- New ecological or social values have developed at the wetland as a result of the altered hydrological conditions. For example, at Lake Yangebup drainage inputs have caused increased water levels, and the lake now supports a significant population of diving birds.
- Irreversible change has occurred. For example, Lake Gnangara, which has undergone drying over more than twenty years, severe and sustained acidification, and a complete change in the ecological community; and some wetlands in the WA Wheatbelt.[125]

In such cases, management might involve accepting the wetland's new state, making modifications to reduce (rather than cease) the impacts of the land use, or a combination of the two.

More broadly, there are some basic principles that can be applied to assist wetland ecosystems to adjust to new hydrological conditions. These include:

- Preventing excessive or sudden hydrological changes, to allow plants and animals to 'migrate' if possible.
- Increasing the resilience of wetlands by reducing other stressors, and managing other threats to the integrity of wetland ecosystems. Under changed hydrological conditions, wetlands are likely to be less resilient to other threats, for example, the effect of too frequent fire if a wetland is drying, particularly if there is a risk of acidification. Similarly, other threats could reduce the capacity of wetland ecosystems to cope with altered hydrology.
- Improving the biological connectivity between wetlands in the landscape, through a planning process that supports ecological corridors and land uses that are sympathetic to nature conservation.

What not to do: make wetlands deeper if they dry out

Landowners can understandably become upset when wetlands dry out beyond their natural water regime. There are many instances of landowners excavating wetland soil to make a deeper wetland that intercepts groundwater. There are many potentially significant impacts in doing this including:

- a high potential to cause the acidification of soils and water due to disturbance of acid sulfate soils
- direct harm to species inhabiting the soils including aestivating turtles, fish, frogs, plants, macroinvertebrate egg banks and wetland plant seed banks
- changes in habitat due to changes in the topography of the site
- loss of wetland sediment, which is habitat for species
- alteration of the ecological character of the wetland, due to the loss of sediment biogeochemical processes
- alteration of wetland sediment, potentially increasing the loss of water from the wetland due to loss of retarding layers such as clay and important soil stratigraphy such as layers of sand and clay
- exposure of groundwater, increasing transpiration of the superficial aquifer and potentially affecting other nearby wetlands and waterways

Digging out wetlands may constitute environmental harm under the *Environmental Protection Act 1986*. Authorisation is typically required to carry out such actions, as outlined in the topic 'Legislation and policy' in Chapter 5.

Prioritisation processes

Often the regional scale of altered hydrology means that it is likely that it will not be possible to tackle altered hydrology at every wetland. Prioritisation is typically required to decide which wetlands should receive intervention measures and which will miss out. In areas where the risks of altered wetland hydrology are high, prioritisation processes can help to focus management efforts where they will have most effect. Prioritisation processes usually entail an identification of:

- wetland values
- threatening processes
- potential to address threats.

An example of sub-regional wetland prioritisation process is the *Buntine-Marchagee Natural Diversity Catchment Recovery Plan: 2007–2027.*[149]

A drying climate in the south-west and further pressures on water resources are realities that must be taken into consideration in wetland management. The draft *Gnangara Sustainability Strategy*[150] recognises that some of the legally required water levels for wetlands on the Gnangara Mound (via ministerial conditions) are no longer achievable. It is generally agreed that new standards need to be set, against which to monitor management of the groundwater resource.[150] This will require accepting that many Gnangara Mound wetlands will inevitably become drier and some will transition to dryland environments. Minimising further exacerbations to wetlands adjusting to new, drier conditions will involve designing ways to abstract groundwater that protect the most sensitive locations.

extra information

Climate change adaptation: what the buzz words mean for wetlands

There are two main categories of human responses to climate change: mitigation and adaptation. Both types of response help to reduce the risks of climate change.

Mitigation involves actions that are intended to reduce the magnitude of our contribution to climate change. It includes strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks.

Adaptation consists of actions undertaken to reduce the adverse consequences of climate change, as well as to harness any beneficial opportunities. Adaptation actions aim to reduce the impacts of climate stresses on human and natural systems.

At the scale of a region's wetlands, adaptation strategies include:

- identifying, protecting, managing and planning for climate change refuges
- maintaining and creating connectivity of habitats and landscapes
- using technological and engineering solutions to sustain important threatened ecosystems
- translocating fauna to other habitat, where assessments indicate this is appropriate
- increasing resilience by reducing other stressors
- effective monitoring of change and timely and appropriate responses
- establishing incentives to promote improved conservation management on private lands.[151]

For more information, see the *Climate change and Western Australian aquatic ecosystems, impacts and adaptation responses, 2011 report card*[19]

Avoiding water rise in wetlands

Wetlands and interconnected drainage network systems are not appropriate discharge outlets for dewatering. Methods used to avoid water rise in wetlands include:

- aquifer reinjection of dewater
- alternative uses of excess dewater

Reinjecting aquifers with dewater (managed aquifer recharge)

Where conditions are suitable, aquifer reinjection of dewater offers an alternative to direct discharge into wetlands. It has been employed in the Pilbara, where it was pioneered at the Yandicoogina mining operation by Rio Tinto Iron Ore. Via five re-injection bores,16,500,000 litres (0.0165 gigalitres) a day of excess water has been reinjected into the Yandicoogina aquifer since 2006, avoiding what had been the standard regional practice of discharging surplus water into surface ecosystems such as waterways.[152] The project was recognised as leading practice, winning the 'Management of water resources – commercial project' category at the 2007 Western Australian Water Awards. This aquifer reinjection is considered to be a form of **managed aquifer recharge.**

Managed aquifer recharge: recharging an aquifer under controlled conditions to store the water for later abstraction, to achieve environmental benefits or to mitigate the impacts of abstraction

Using surplus dewater rather than discharging it to wetlands

Mining proponents are required to use dewatering volumes to mitigate any environmental impacts in the first instance. That is, where dewatering is creating a deficiency for a wetland or other ecosystem, the priority is for the dewatering to be used to mitigate this. Water needs of the mine and mining camp are the second and third priorities. Where surplus water still exists following these needs being met, it is now required of proponents of mining operations to consider alternatives to discharge to the environment.[153] There is now a mandate for the analysis of the potential for appropriate alternative uses of dewatering surplus in sectors such as irrigated agriculture, industry or recreational or social needs in the community.

Managing water rise in wetlands

Methods used to manage water rise in wetlands include:

- large-scale native revegetation of dryland and wetland
- planting of deep-rooted perennial crops
- modifying landscape drainage patterns
- controlling surface water inflows
- wetland dewatering
- groundwater pumping
- draining into low value ecosystems to protect high value ecosystems

Managing water in agricultural catchments can entail retaining and replanting native vegetation and modifying landscape drainage patterns. In productive agricultural catchments, it is not always viable to revegetate catchments to the extent needed to improve wetland hydrology. The significant resources need to alter catchment flows by means other than revegetation means that a limited number of priority wetlands and priority catchments are the focus of recovery actions by state government.

The 'Natural Diversity Recovery Catchments' program developed under the State Salinity Strategy is a landscape-scale program aimed at protecting areas with high natural diversity that are threatened by rising water tables and salinisation, and focusing especially on wetlands. So far, six Natural Diversity Recovery Catchments exist:

- Buntine-Marchagee
- Drummond
- Lake Bryde complex
- Lake Muir-Unicup
- Lake Warden
- Toolibin Lake.

A central aim of salinity and landscape-scale water management in these catchments is to achieve integration between nature conservation and sustainable agricultural practices[149] (Figure 27).

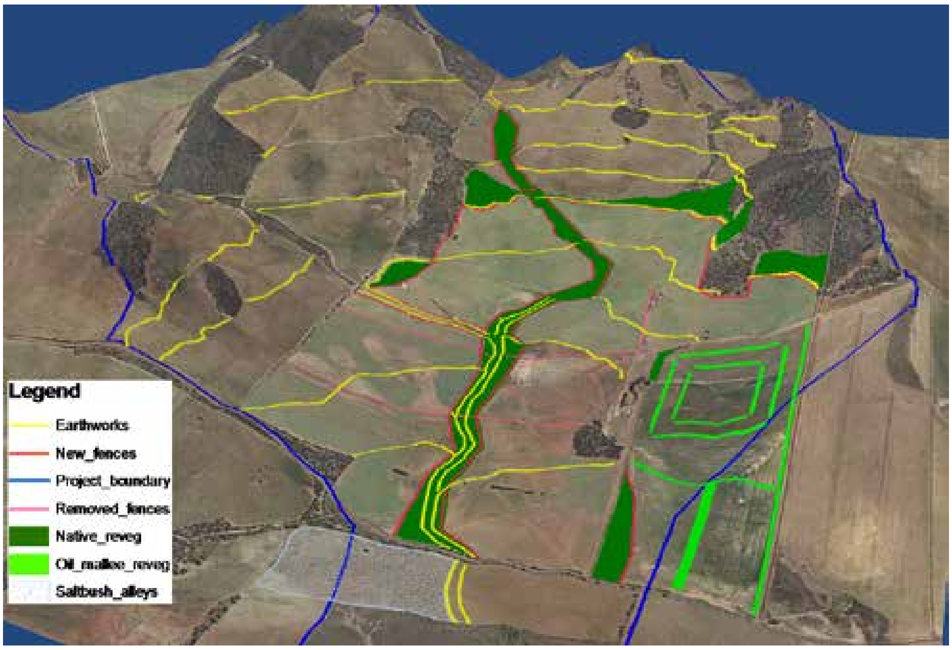


Figure 27. Integrated water management at the landscape scale in agricultural catchments has a positive effect on reducing salt, nutrient and sediment export to downstream wetlands. Engineering and biological options are integrated to optimise gains in water management (surface and groundwater) and agricultural productivity in this 800-hectare demonstration area in the Buntine-Marchagee. Note the elevations are exaggerated. Image – R Dawson/DEC.

Oil mallee: multi-stemmed eucalypt planted on agricultural land, with the stems arising from an underground root mass known as a lignotuber. Stems can be harvested for products such as eucalyptus oil.

➤ Information on DEC's Natural Diversity Recovery Catchments can be found at DEC's website.[154]

Another major state government program, which focuses on landscape-scale salinity management more broadly, is the Engineering Evaluation Initiative led by the Department of Water. It examines a range of potential mitigation options including deep drains, groundwater pumping and surface water management, safe saline water disposal and regional drainage planning.

➤ More information on the Engineering Evaluation Initiative is available from the Department of Water website.[155]

Retaining and replanting native vegetation

Native vegetation uses water, and retaining vegetation is a cost-effective way of maintaining existing water use. It also slows surface flows in the catchment, and understorey vegetation can be just as important as trees in regulating flows. Native vegetation also helps to maintain biodiversity. It can be achieved by fencing off remnant vegetation from livestock (Figure 28).

While not offering a magic bullet to landscape-scale watertable rise in agricultural settings[156], replanting native vegetation can also be beneficial (Figure 29). For maximum effectiveness the extent needed and location is best determined in consultation with hydrologists, based on an analysis of recharge characteristics in a catchment. As a rule, trees are best planted in recharge areas; discharge plantings rarely reclaim saline areas; responses are generally confined beneath the planting; and plantings of extensive areas of a landscape are required to significantly reduce watertables.[157] Perennial crop plantations such as **oil mallees**[158] can achieve nature conservation and sustainable agricultural objectives under the right conditions.[159] A number of government and non-government programs provide funding and labour for fencing of native vegetation and covenanting of protected remnants.

In some circumstances, the government offers farmers cost-sharing arrangements to revegetate areas to improve water use and contribute to recharge control. This is the case in the 140,000 hectare Lake Bryde Natural Diversity Recovery Catchment, where more than 400,000 native species plants have been planted on private property and reserves, and more than 500 hectares of remnant vegetation have been fenced off. These actions are complemented by a large scale surface water management project.

➤ For more information on funding, labour and other assistance see the topic 'Funding, training and resources' in Chapter 1.

➤ Analysis of the uptake of water by trees is outlined in reports such as *Hydrological impacts of integrated oil mallee farming systems*.[159]

➤ Revegetation case studies, such as those provided at www.dec.wa.gov.au/management-and-protection/land/salinity/revegetation.html?showall=&start=1 highlight useful information.

Figure 28. Fencing off native vegetation can be a cost-effective measure for hydrological management. Photo – G Mullan/DEC.

(a)

(b)

Figure 29. (a) oil mallee eucalypts, on right of photo, a prospective commercial crop, growing alongside traditional crops in the Buntine-Marchagee catchment; and (b) mixed shrubs and trees have been chosen in this location within the Buntine-Marchagee catchment for their resilience, structural diversity and genetic integrity. Photos – G Mullan/DEC.

Contour banks: mounds of earth which follow hillslope contours to arrest flowing water and allow infiltration

Grassed waterway: a vegetated channel which directs water flow paths. The vegetation slows surface flows.

Retaining and replanting trees

Deep-rooted trees are proving useful in lowering high groundwater in some areas of the south-west. For example, blue gum (*Eucalyptus globulus*) plantations are attributed with reducing the unnaturally high water levels in some wetlands in the south coast of WA associated with widespread clearing of native vegetation for cropping and grazing. In the West Poorrarecup area, for example, it was found that some wetlands were showing improvements in condition as a result of nearby plantations[27], while other wetlands had dried up[160], although it is not clear whether these had formed due to the high groundwater following clearing.

Modifying landscape drainage patterns

Simple modifications can often be made to water flow paths to lessen the impacts of altered hydrology on wetlands. Increasingly, farmers are using mulching and earthworks to increase water uptake, slow the flow of water through the landscape, promote infiltration and reduce erosion and sedimentation. This might simply involve the reinstatement of the original lie of the land by removing artificial structures such as drains or levee banks. Other measures include **contour banks**[161], **grassed waterways** (G Mullan 2009, pers. comm.)(Figure 30), and cropping practices that leave stubble and mulch in place such as conservation tillage. These works can also improve farming outcomes, as healthy catchments are more productive. Any works should be undertaken with caution, because manipulating hydrology can often have unexpected impacts. Changes to landscape drainage patterns may be subject to regulation under the *Soil and Land Conservation Act 1945* and the *Environmental Protection Act 1986*. For more information, see the 'Legislation and policy' topic.

Figure 30. A landholder inspects a constructed grassed waterway in full flow in the Buntine-Marchagee catchment. The grassed waterway is part of the landscape-scale integrated water management approach. Photo – K Stone.

Controlling surface water inflows

Structures that bypass or divert some of the surface water flows are used in some high value wetlands, such as Toolibin Lake. A surface water diversion channel is used at Toolibin Lake to regulate the amount and quality (specifically, salinity) of the surface water that enters the wetland. The diverted flows are sent to the sacrificial wetland, Lake Taarblin. However, in the last decade, the management criterion for salinity levels at the wetland inlet has rarely been met, and as a result, the wetland bed has been largely free of surface water for an extended period[162] which creates another suite of problems for the wetland. Large rainfall events can play an important role at such sites, for example, an intense rainfall event on 12 December 2012 resulted in 0.013 gigalitres (13,000,000 litres) entering via the diversion weir, with the majority slowly evaporating over six weeks.[163]

Changes to surface water inflows may be subject to regulation under the *Soil and Land Conservation Act 1945* and the *Environmental Protection Act 1986*. For more information, see the 'Legislation and policy' topic.

Dewatering wetlands

Lowering wetland water levels by directly removing surface water is a management response that, due to its expense, is an intervention measure for wetlands of high conservation significance. Because of the need to dispose of the water, significant downstream impacts are possible. It can necessitate the construction of an evaporation basin or the sacrifice of other wetlands to receive the discharge. This is particularly harmful when the water is of a different salinity (or similarly different in its water chemistry).

Lake Wheatfield in the Lake Warden Ramsar system in Esperance is dewatered and the discharge is released into Bandy Creek. Dewatering removes excess water from the wetland generated from increased catchment runoff caused by clearing 85 per cent of the catchment's native vegetation to allow for agricultural land uses. Lake Wheatfield is hydrologically connected to Lake Warden. Prior to dewatering, "beach" areas needed by migratory and resident waders had been significantly reduced and bird numbers recorded in biannual monitoring showed steep declines. The dewatering successfully controls water levels (Figure 31) and available wader habitat. However, the alteration of water levels has contributed to increased salinity levels, a serious management issue.

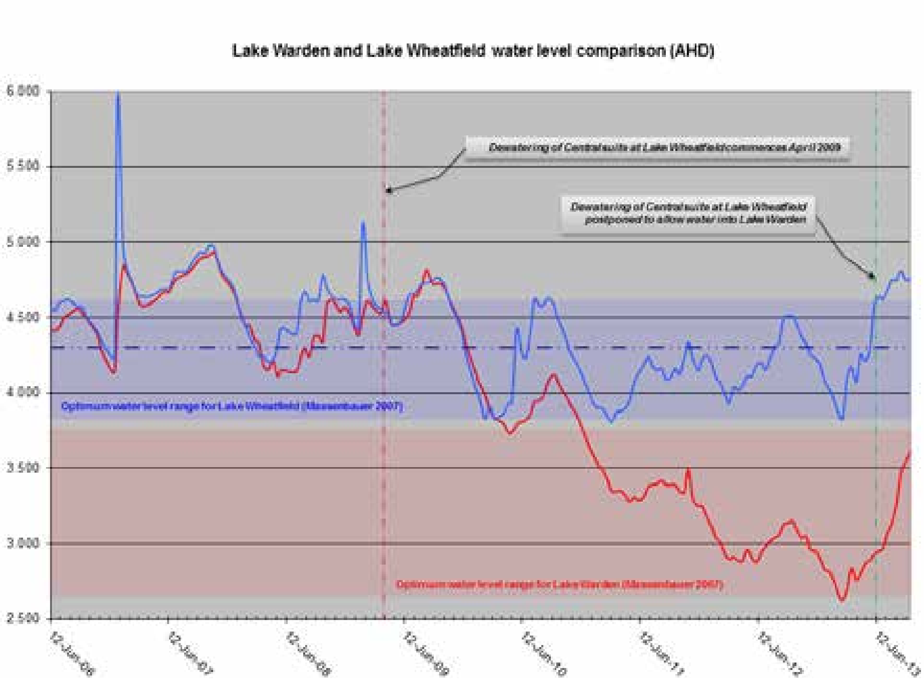


Figure 31. Hydrological response to management interventions for Lake Wheatfield (blue) and Lake Warden (red). Measurements are in metres AHD. Image: J Lizamore/DEC.

➤ Dewatering of wetlands may be subject to regulation under the *Soil and Land Conservation Act 1945* and the *Environmental Protection Act 1986.* For more information, see the 'Legislation and policy' topic.

Pumping groundwater

Groundwater pumping to lower the groundwater discharging into wetlands is a management response that, due to its expense to establish and operate, and potential complexities, is an intervention measure for wetlands of high conservation significance. It is a measure that 'buys time' to allow longer-term measures to be put in place. It isn't always an option, particularly when the hydrogeological setting is not suitable. Groundwater pumping is being used to help manage groundwater levels at Toolibin Lake, although in the past technical problems have resulted in two periods where many groundwater pumps have been out of commission.[85] Groundwater pumping may be subject to regulation under the *Environmental Protection Act 1986.* For more information, see the 'Legislation and policy' topic.

➤ For a general review of the considerations involved in groundwater pumping, see the report, *A review of groundwater pumping to manage dryland salinity in Western Australia.*[164]

Draining into low value ecosystems to protect high value ecosystems

Inland drainage should result in an overall environmental benefit.[165] Any proposal to install inland drainage should avoid wetlands and other ecosystems of high conservation value. Wetland mapping and a number of studies and policies have been developed to aid land managers and decision making authorities to identify wetlands of high conservation value in the Wheatbelt and other areas where deep saline drainage is being used to manage waterlogging and salinity. These resources include:

- *Wheatbelt basin and granite outcrop wetland evaluations* dataset
- *Evaluating the conservation significance of basin and granite outcrop wetlands in the Avon natural resource management region: Stage One Assessment Method*[166]
- *Evaluating the conservation significance of basin wetlands within the Avon Natural Resource Management region: Stage Three Assessment Method*[167]
- *Policy framework for inland drainage*[165]

Minimising water decline in wetlands

Minimising water decline in wetlands can be achieved by selecting a suite of strategies, such as:

- ensuring water allocated to the environment in water allocation plans provides for wetland water requirements
- using desalinated water
- using less water
- preventing illegal water use/ loss of unused water
- prioritising water for the environment over aesthetic uses such as artificial lakes
- reusing (recycling) more water
- harvesting alternative water sources (desalination, deep aquifers and coastal superficial aquifers)
- recharge aquifers through managed aquifer recharge
- developing alternative water sources
- choosing abstraction locations to avoid wetlands
- minimising drawdown near wetlands via abstraction depth, rate and timing
- minimise subsoil drainage effects on wetlands
- avoiding or minimising dewatering impacts near wetlands
- artificially recharging wetland with dewater
- maintaining wetland water levels artificially
- reducing drawdown caused by plantation trees
- modifying current vegetation

These are outlined below.

Ensuring water allocated to the environment in water allocation plans provides for wetland water requirements

The *Rights in Water and Irrigation Act 1914* provides the legislative basis for the planning, regulation, management, protection and allocation of water resources in WA, including the identification and management of water for ecosystems.[168]

Under the RIWI Act, the right to the use and control of all groundwater (artesian and non-artesian) is vested in the 'Crown', that is, the state of WA. No person can access or use groundwater except in accordance with the rights and obligations conferred under the RIWI Act (or another law).[34] The Minister for Water has delegated responsibility to the Department of Water for administering the Act through the preparation of **water allocation plans** and the administration of water entitlements and water rights. Unlike many other jurisdictions in Australia, there are no **held environmental water** entitlements in WA.[168]

The decisions made by the Department of Water when a **water licence** is applied for under sections 5C and 26D of the Act are guided by water allocation plans. Water allocation plans are non-statutory, but provide important guidance on the water **allocation limits** within a particular geographic area, how much water is assigned for the environment–the **environmental water provision**–and the **sustainable yield** that

Water allocation plan: a plan that determines and licenses how much groundwater or surface water can be taken from a region for domestic or commercial purposes without adversely affecting ecological, recreational and cultural values

Held environmental water: water available under a water access right, a water delivery right or an irrigation right for the purposes of achieving environmental outcomes

Water licence: a formal permit which entitles the licence holder to 'take' water from a watercourse, wetland or underground source under the *Rights in Water and Irrigation Act 1914*

Allocation limit: annual volume of water set aside for consumptive use from a water resource

Environmental water provision: the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements.

Sustainable yield: the amount of water that can be taken from a water resource system (expressed as an extraction regime) without causing unacceptable impacts on the environment can be taken. There are currently twenty water allocation plans in place, covering 80 per cent of WA's water use (Figure 32). This includes four groundwater water allocation plans under development.[168]

Environmental water requirement: the water regime needed to maintain the ecological values (including, assets, functions and processes) of water-dependent ecosystems at a low level of risk

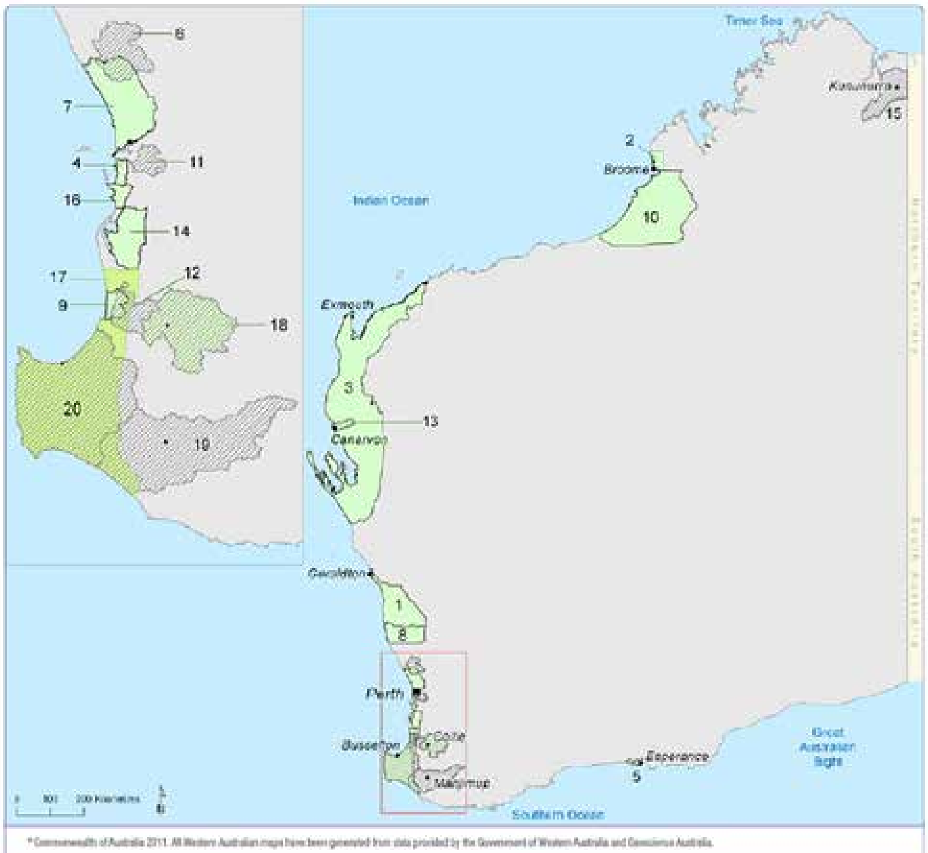


Figure 32. Water management plan areas in WA. Image – National Water Commission 2011.[170]

The Department of Water is required to consider environmental needs for water in accordance with *Statewide policy no. 5 – Environmental Water Provisions Policy for Western Australia.*[171] Plans are required to state the regimes, levels, volume or thresholds required for environmental water, that is, their **environmental water requirement,** and how this has been determined, to what extent it will be achieved through the environmental water provision and how it will be monitored. In developing water allocation plans, the Department of Water carries out pre-planning assessments to determine what water the environment requires.

Environmental water provisions are then established for each resource and implemented through the setting of allocation limits and through system specific management rules and trigger levels. These may relate to attributes of the groundwater regime such as flux or flow, level (in unconfined aquifers), pressure (in confined aquifers) and water quality. An objective of the Gnangara allocation plan, for example, is to 'Protect groundwater-dependent ecosystems from direct impacts associated with abstraction'[36] and a maximum allowable depth to groundwater (summer and/or spring maximum) below valuable groundwater dependent ecosystems is applied. High value groundwater-dependent ecosystems that may be affected by abstraction may have local area policies applied to them. The department develops these additional requirements to protect high value areas or areas at high risk of impact. Trigger and response criteria may also apply to some sites.[36]

Draft water allocation plans are released for pubic comment, and this is the best time for stakeholders to examine how the plan ensures a wetland's water requirements are met. Plans are approved by the Minister for Water and apply for a seven-year period, with ongoing interim evaluation. Taking the opportunity to comment on these plans through the public consultation process, or becoming involved with a stakeholder committee on water planning, are two ways to advocate for the maintenance of wetland hydrology at a big-picture level.

➤ The process for stakeholder participation, are explained in the report *Water allocation planning in Western Australia: a guide to our process.*[172]

➤ A review of environmental water management in WA has been produced by the National Water Commission in 2012, entitled *Australian environmental water management: 2012 review.*[168]

➤ A report card on how well WA carries out water planning was produced by the National Water Commission in 2011[170]: www.nwc.gov.au/?a=19805.

➤ The current allocation plans for various areas of WA are available on the Department of Water website at: water.wa.gov.au/Managing+water/Allocation+planning/default.aspx.

➤ Potential reforms of WA's water allocation process are outlined in the report *Proposed Water Resources Management Act background discussion paper*.[6]

The importance of participating in the water allocation planning process

A water allocation plan includes:

- objectives for the plan
- water allocation limits (as volumes)
- water for the environment (as volumes or regimes)
- water licensing policies
- arrangements for implementing and evaluating the plan.[173]

Ensuring the full range of stakeholders participate in the water management planning process is important in ensuring that the public participation process represents the views of all Western Australians. To this end, the Department of Water has published a short guide entitled *How to make a submission on a water allocation plan during the public comment period*[174] available from www.water.wa.gov.au/PublicationsStore/first/99163.

Using less water

Across Australia and globally, individuals, groups and governments are acknowledging the precious nature of our freshwater resources, and changing behaviour to reduce water use.

Using less water is important across all sectors including mining, industry, agriculture and domestic. Even in those areas where there is too much water in the landscape, freshwater is still a scarce resource and needs to be used efficiently.

Perth is now saving more than 100 gigalitres (that is, 100 billion litres) of scheme water each year[175] (that is, water from the integrated water supply scheme, which does not account for water harvested from rainwater tanks, groundwater bores and so on). Over the past five years, savings work out to about 8 per cent per person.[175] 'Waterwise' campaigns and water pricing that better reflects the true cost of water use have contributed to changing behaviour. However, the Water Corporation reports that the average water use per person was 132,000 litres in the 2012–13 financial year, making Perth one of the highest water using cities in not only Australia, but the world. Regulation of water use is still critical, for example, the two-day-a-week sprinkler roster in Perth, which accounts for slightly more than half of the 100 billion litre saving in scheme water; and which tackles one of the key issues for water use in residential areas, "Western Australia's most extensive and expensive irrigated crop, the suburban lawn".[54] In addition to more efficient use of scheme water, another important initiative is reducing the volume of groundwater abstracted via garden groundwater bores; there are an estimated 169,200 domestic garden bores taking groundwater from the superficial aquifer in Perth, and the Department of Water estimates that up to a quarter of water abstracted from the Gnangara Mound is done so for domestic use.[176] The Department estimates that approximately 73 gigalitres of groundwater was abstracted using domestic garden bores in the Perth metropolitan area in 2010.[177] Although unlicensed and not metered, they are subject to some control via the sprinkling restrictions and controls on their use near high value wetlands.

In WA, the Department of Water and the Water Corporation have sought to reduce water use via 'Waterwise' campaigns. The Water Corporation has published a target to reduce water use by 15 per cent/125 kilolitres of scheme water used per person per year in Perth by 2030.[175]

Similarly, in the Kimberley, Pilbara, Great Southern and Goldfields regions, water efficiencies achieved through the 'Regional Integrated Water Efficiency Program' are estimated to have saved 4.5 gigalitres of water in its first full year.[175]

In 2007 the Minister for Water Resources established the requirement for all local governments to prepare and implement water conservation plans that conserve groundwater and improve water use efficiency.

Through the massive cultural shifts in water use taking place, there is evidence that Western Australians do value wetlands and other water-dependent ecosystems, and embrace the sense of place that makes Western Australia unique. George Seddon, author of *Sense of Place, a response to an environment: The Swan Coastal Plain, Western Australia* wrote that, on arriving from Victoria, "I was ill-prepared for Western Australia, and I think this must be a common experience. Even the West Australians whose families have been here for three and four generations are ill-prepared in some basic ways, because our primarily British background is still apparent in our attitudes towards the way we use the environment; and in nothing so much as our attitude to water. Centuries of water-riches makes it hard to grasp our water-poverty and its implications, although these are better-understood in Western Australia that they are in the coastal cities of eastern Australia. In Perth (and Adelaide) the aridity of this most arid of continents is a part of one's consciousness".[54]

Ongoing reductions in water use will continue to be needed, in order to help offset increasing population and, in larger areas of WA, the increasing drying associated with climate change. Climate models indicate a possible further 8 per cent reduction in surface water yields (for example, from dams) by 2030 in a median scenario.[175]

➤ Significant potential still exists to reduce water use in WA. Support and incentives for individuals, businesses and local government abounds. The role of individuals and groups in bringing about improved water use of individuals, businesses and local governments through corporate citizenship should not be underestimated.

➤ For more information, see the:

WA Water Awards: www.awa.asn.au/awards/wa/

Department of Water's website: www.water.wa.gov.au/Managing+water/Water+efficiency/default.aspx

Water Corporation's website: www.watercorporation.com.au/about-us/the-way-we-work/our-strategies

Preventing illegal water use and loss of water

Prevent illegal water use

The right to take groundwater or surface water is primarily granted by way of a licence by the Department of Water under sections 5C and 26D of the *Rights in Water and Irrigation Act 1914*. Allocation limits define how much water can be taken by those with a licence, and how much water is reserved for the environment. When people take water without a licence, or take more water than is allowed for in their licence, this reduces the water left for the environment. Details about licences are publicly available via a spatially-based dataset called *The Water Register*, available from www.water.wa.gov.au/ags/WaterRegister. Details about the operating strategies that form part of the terms and conditions of a licence to take water (for example, the abstraction regime and methods used to minimise impacts on wetlands) may be available to the public, subject to Freedom of Information applications.

The Department of Water has increased the metering of water use. As outlined in Strategic Policy 5.03 *Metering the taking of water*[178], this increased regulation is required because unmetered use of water resources may lead to overuse, which could have unacceptable impacts on the local ecological, economic and social values of an area. In recent years the Department has increased its compliance and enforcement activities. This includes an increased on-ground presence of compliance officers visiting properties to speak with licensees, survey water use, check meter readings, monitor daytime sprinkler bans and ensure that operations are in accordance with conditions on licences. The Department's compliance enforcement unit monitors metering readings submitted to it and audits selected licensees to assess compliance with all aspects of their licences.

The Department of Water has signalled that illegal water use is not tolerated. It issues directions, infringement notices and takes action to prosecute those in breach of the law. In recent years it has successfully prosecuted a number of illegal water users. These include a grower in the suburb of Gnangara who took more than 79 million litres (0.079 gigalitres) more water than he was entitled to, and a vegetable grower in the suburb of Wanneroo who illegally took water and tampered with a state-owned water meter to prevent the meter flow wheel from accurately measuring how much water was taken from the ground.

➤ For more information on metering on the Gnangara Mound, see the Department of Water's website: www.water.wa.gov.au/Understanding+water/Groundwater/Gnangara+Mound/Gnangara+Mound+metering+project/Project+background/default.aspx

➤ Compliance and enforcement information is available at: www.water.wa.gov.au/Business+with+water/Water+licensing/Compliance+and+enforcement/default.aspx#1

Prevent the unnecessary loss of water from wetlands and aquifers

Uncapped artesian bores are a source of water loss in areas of WA, particularly the Pilbara. Decommissioning or recommissioning these bores is effective at preventing unnecessary water loss. For example, during phase 2 of the Carnarvon artesian basin rehabilitation project, finished in September 2010, fourteen controlled bores were drilled and twenty-eight free-flowing bores were decommissioned. This saved 8 gigalitres of water from being lost across the plan area. Pressure heads increased in most areas as a result. In 2011, the Department of Water identified eight free-flowing bores that require capping as part of finalising the Carnarvon Artesian Basin rehabilitation project. The aim is to cap these bores and/or license any use from them.[179]

Feral animals including camels, horses and goats can consume significant volumes of water from natural and artificial water sources, and controlling their numbers can be important in significant and sensitive wetlands. For example, in droughts, large herds of over one hundred camels may congregate on available water, and in addition to depleting the surface water, they can cause overgrazing, trampling, pugging and fouling of wetlands.

➤ For more information on feral animal control, see the topic 'Introduced and nuisance animals' in Chapter 3.

Converting open irrigation channels to piped channels reduces seepage and evaporative losses. Harvey Water has been carrying out this conversion in the Harvey Water Irrigation Area (made up of the Harvey, Waroona and Collie irrigation zones). Harvey Water gets water from seven Darling Scarp dams controlled and maintained by the Water Corporation. It uses delivery infrastructure made up of a network of channels and pipes: 83 kilometres of lined channels, 172 kilometres of unlined channels and 430 kilometres of pipeline with a total of 1 536 supply points. Harvey Water states that the conversion of open channels to pipelines is leading to water efficiency savings of approximately 17 gigalitres (that is, 17 billion litres) per year due to water not being lost through seepage and evaporation. Harvey Water has stated its aim is to convert the remainder of the system, which is a mix of soil and concrete lined channels to pipes. The initial conversion of channels to pipelines, known as the Harvey Pipe Project, was the inaugural winner of the WA Water Awards and the WA Engineering Excellence Award in 2006.

➤ For more information see the Harvey Water website: www.harveywater.com.au.

Prioritising water for the environment over aesthetic uses such as artificial lakes

The creation of permanently inundated water bodies in urban settings is generally not supported by state government. This is particularly the case when they require the exposure of groundwater through excavation, which exposes the groundwater to evaporation and can change local hydrological patterns, affecting nearby natural wetlands and ecosystems (as well as posing a risk of acid sulfate soils). The same principle applies to artificial water bodies that are created by preventing water from infiltrating through the use of a lining or layer that slows or prevents infiltration of stormwater into groundwater. Similarly, the modification of wetland type, such as converting a seasonally waterlogged basin into a seasonally inundated basin, is not supported.

➤ This position is outlined in the *Decision process for stormwater in WA*[180] and the *Interim position statement: Constructed lakes*.[83]

Reusing (recycling) more water

Currently the vast majority of water used in WA is discharged to the ocean or other receiving environments, or lost to evapotranspiration (for example, in the case of water put on gardens). Recycling reduces the need to take more water from the environment. WA now recycles around 21 gigalitres (21 billion litres) of water a year.

Wastewater recycling

Recycled water is usually treated wastewater which is further treated to varying qualities that is 'fit for purpose' for its intended use. Wastewater is the spent or used water from a community. It comes from domestic, commercial and industrial sources, and it is 99.97 per cent water because the greatest volume comes from showers, baths and washing machines. The rest is dissolved and suspended matter. Once treated, it can then be used for:

- irrigation of sports grounds, golf courses and public open spaces
- industrial processing
- groundwater replenishment
- toilet flushing/clothes washing/garden watering
- environmental benefits (for example, maintaining wetlands)
- irrigation of food crops
- irrigation of non-food crops (for example, trees, woodlots, turf, flowers)
- construction/dust suppression

In 2012 13.6 per cent of wastewater was recycled. Generally, there is a much higher percentage of recycling in regional areas, with some towns recycling 100 per cent of their wastewater.[175] The Water Corporation is involved in approximately 50 water recycling schemes in WA to irrigate parks, gardens, golf courses, sports grounds and other open spaces. The Water Corporation has published a target to recycle 30 per cent of all wastewater in WA by 2030.[175] As well as expanding water recycling in current types of uses, such as in new industrial areas including Neerabup and East Rockingham, the Water Corporation is looking at the potential irrigation of vineyards and other horticulture, and at the potential use of dual reticulation. Dual reticulation, or 'third pipe systems', have two separate pipes deliver drinking and non-drinking water into homes and commercial/industrial in new developments. The non-drinking pipe water source may be recycled water, greywater, stormwater or groundwater.[175] Dual reticulation schemes are likely to be most viable for new developments in regional areas where scheme water supply is scarce and augmentation is costly. They are also expected to be viable for the irrigation of public open space and for large scale industrial developments. The Water Corporation works with local governments to identify all non-drinking water alternatives to scheme water use for the irrigation of public open space for new developments. Some pilot programs are in place, and a dual reticulated scheme is being considered for Karratha to irrigate residential gardens as well as public open space. Greywater recycling is a good way to return water back to the environment.

➤ For more information, see:

Department of Water's website: www.water.wa.gov.au/Managing+water/Recycling/Waterwise+community+toolkit/Non-drinking+water+sources/default.aspx

Water Corporation's website: www.watercorporation.com.au/about-us/the-way-we-work/our-strategies

Alternative water source options for landowners and developers are outlined at: www.watercorporation.com.au/Home/Builders%20and%20developers/Subdividing/Non%20drinking%20water%20options

Sewerage recycling

Sewer mining is also a potential future recycling method. Sewer mining is the process of extracting, treating and using wastewater before it reaches a wastewater treatment plant. Sewer mining is not practiced widely in Perth as groundwater is often a cheaper alternative. It may become a more attractive option with groundwater sources becoming fully allocated.[181] The Water Corporation states that this water source is under investigation, with several sewer mining proposals being assessed and the corporation potentially interested into looking into more opportunities in the future. The Town of Vincent has announced that it is investigating sewer mining as a potential water source for the Hyde Park lakes (www.vincent.wa.gov.au/Services/Environment_Sustainability/Green_Initiatives/Sewer_Mining).

Sewer mining: the process of extracting untreated wastewater from the sewerage network and treating it on-site in a treatment plant for reuse

Mine dewatering surplus

With over 200 licences to take water for dewatering and dewatering volumes exceeding 300 gigalitres per year, the use of this water as a resource is significant. Water generated via mine dewatering is required first and foremost to mitigate any environmental impacts and secondly for mine site uses. Historically water left over following this has been disposed of via aquifer injection or discharge to wetlands or watercourses over and above their needs. Now there is a stronger push to use any surplus left following these uses in a way that harnesses water as a resource, such as in other mining operations or sectors such as irrigated agriculture, industry or recreational or social needs of the community. The Department of Water has established this position and how opportunities for doing so may be facilitated in *Strategic Policy 2.09: Use of mine dewatering surplus*.[153]

Harvesting alternative water sources

Desalination

Almost half of Perth's scheme water needs, about 150 gigalitres (150 billion litres) of water a year, is now supplied by the Perth Seawater Desalination plant and the Southern Seawater Desalination plant. The use of these alternatives to dams and groundwater is likely to be the most important water supply action taken to date to improve water security for the wetlands of the Gnangara Mound in Perth.

The Water Corporation has published a target of developing up to 100 gigalitres of new water sources.[175] Although desalination is identified as a cornerstone of Perth's water supply, it is not considered by the Water Corporation to be a sole solution. It estimates that to rely solely on desalination for Perth's needs would necessitate ten new 50 gigalitre desalination plants by 2060. This would entail significant public and/or private investment in capital; a six-fold increase in energy use over current levels and a doubling in water bills.[181]

Stormwater and rainwater harvesting

Stormwater and rainwater harvesting is a viable form of water reuse in some areas of Australia. However, stormwater high in the catchments is a natural source of water for wetlands lower in the catchment, and should be infiltrated into the groundwater or take flow paths that mimic their natural flow to wetlands wherever possible (outlined in the sections 'Infiltrating stormwater at-source in urban catchments' and 'Using overland flow paths for stormwater entry into wetlands'). Excess stormwater at the bottom of the catchment offers more of an opportunity for harvesting.

Drainage in the region around Perth removes more water than all the bores in the superficial aquifer in the same area. A study published in 2008[182] found that the median annual discharge of stormwater from the Perth and Peel metropolitan regions was estimated as 120 gigalitres with approximately 67 per cent from the Swan-Canning catchment (exclusive of Avon and Helena rivers; and Ellen, Jane and Susannah brooks), 16 per cent from the coastal main drains (Carine, Herdsman and Subiaco) and 17 per cent from the Peel's main drains. This stormwater volume is equivalent to approximately two Mundaring Weirs at full storage capacity (63.6 gigalitres) or two and a half Perth Seawater Desalination plants (45 gigalitres). This is also greater than the potential volume from rainwater harvesting of the region's residential roofs. Some local governments collect stormwater from drains and use it locally for irrigation purposes.

Abstract groundwater from deep aquifers and coastal superficial aquifers

Abstraction from the superficial aquifers has a direct effect on wetlands fed by superficial groundwater. Because of these direct impacts, deep aquifers are increasingly considered more appropriate sources. For example, the Department of Water is working with the Water Corporation to investigate opportunities for, and the possible effects of, increasing the proportion of water abstracted from the confined aquifers relative to that abstracted from the superficial aquifer of the Gnangara groundwater system.[36] The Water Corporation has stated that in relation to Perth's water needs, the superficial inland (that is, not coastal) aquifers are now relied upon only in the very driest of years and only for about 10 per cent of supply needs.[183] It has outlined that by 2022, around half of Perth's scheme water will come from secure deep groundwater sources. This is proposed to be coupled with replenishment of the Leederville and Perth Yarragadee aquifers with recycled water (see next section for more detail), and the development of coastal superficial groundwater schemes to use water that currently flows naturally into the ocean at Eglington and Yanchep.[183]

Recharging aquifers through managed aquifer recharge

Managed aquifer recharge (MAR) is the purposeful recharge of an aquifer under controlled conditions to store the water for later abstraction, to achieve environmental benefits or to mitigate the impacts of abstraction. It can be achieved by injection by a bore or series of bores, or by infiltration using infiltration ponds or trenches.

The Department of Water is primarily responsible for administering managed aquifer recharge via the *Rights in Water and Irrigation Act 1914* (the *Environmental Protection Act 1986* may also be triggered under certain circumstances). The Department of Water recognises the potential to use MAR to recharge an aquifer near a valued wetland to maintain the wetland's water levels, while either recovering water elsewhere within the aquifer or connected aquifers where impacts would be minimal, or not seeking recovery of any of the water.[184]

The Department of Water's list of potential sources of water for MAR includes but is not limited to:

- groundwater drawn from other aquifers
- water from streams, lakes or dams
- treated wastewater sourced from industrial sites or sewerage treatment plants
- dewatering excess from mine sites or construction sites
- excess stormwater or stormwater redirected from existing drainage systems
- excess agricultural runoff.[184]

Groundwater replenishment

Groundwater replenishment is one form of managed aquifer recharge. Groundwater replenishment has been announced by the Government of Western Australia as the next new climate independent water source for Perth. This follows a three year trial which involved treating 3.3 gigalitres (3.3 billion litres) of recycled wastewater to drinking water standards before injecting it 120–220 metres below the ground, into the confined Leederville aquifer underlying the Gnangara Mound[185] (Figure 33).

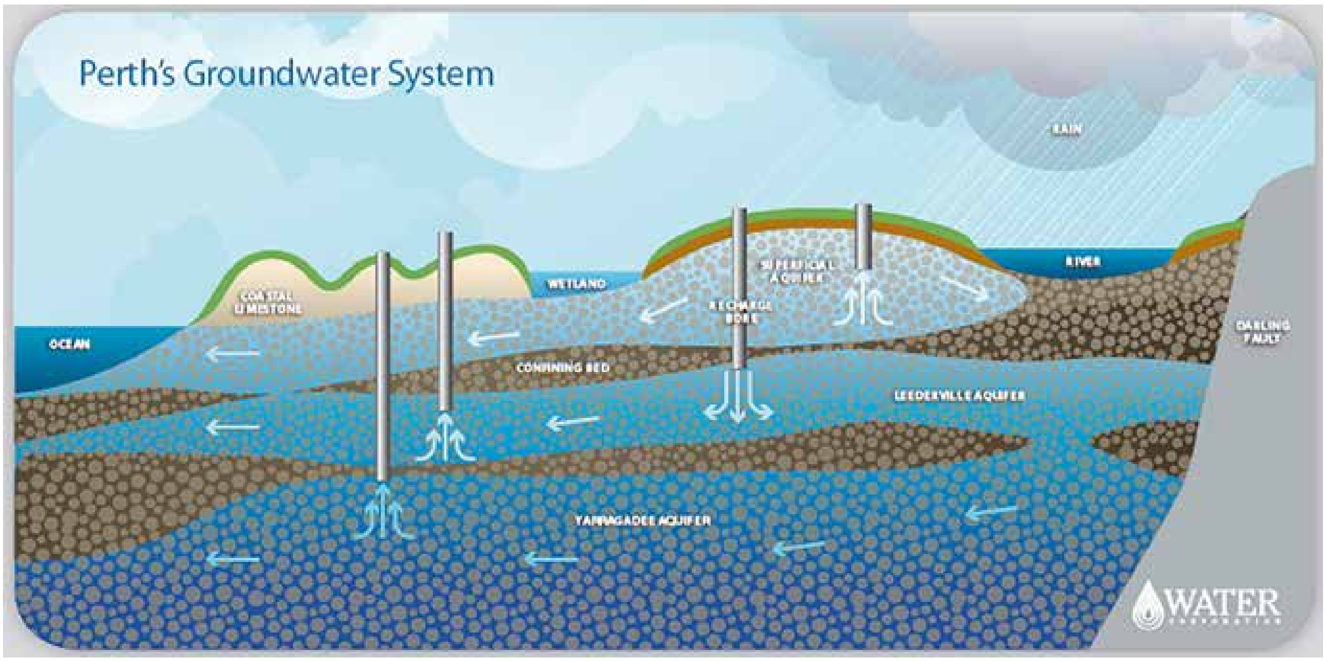


Figure 33. Replenishment of the Leederville aquifer will help to reduce pressure on the wetlands of the Gnangara groundwater system. Image source – Water Corporation[186]

The effects of this groundwater replenishment may potentially be two-fold. Firstly, the replenishment of the Leederville aquifer may reduce the downward flow of water from the superficial aquifer, which is the direct source of water for many groundwater fed wetlands. While replenished water is unlikely to move into shallow groundwater (because the pressure is not sufficient enough to allow upward movement of the recycled water into the superficial aquifer) the recharge increases groundwater pressure in the Leederville aquifer, reducing the downward flow of water from the superficial aquifer.

Secondly, this groundwater replenishment will provide an alternative water supply source, thereby reducing abstraction of the remaining groundwater. This will reduce drying of wetlands fed by the Gnangara groundwater system, by reducing the net amount of water abstracted from it. Groundwater replenishment will initially supply seven gigalitres (7 billion litres) of water a year. The Beenyup replenishment site has the potential to recycle up to 28 gigalitres annually, enough to supply 140,000 households with drinking water each year. By 2060, groundwater replenishment could contribute 115 gigalitres each year by recycling water from Perth's four major wastewater treatment plants. Groundwater replenishment could account for up to 20 per cent of Perth's total yearly drinking water supply.[187]

It is thought that the water will undergo natural filtration for up to 30 years before extraction. The Water Corporation has reviewed the trial, involving more than 62,000 water samples and 254 health guidelines, and published a report stating that recharge of highly treated recycled water into the confined Leederville aquifer does not pose any risk to the environment nor to public health.[187]

Other benefits of Perth's groundwater replenishment scheme are that it is cheaper and uses about half the energy of a desalination plant.

➤ For more information, see:

Department of Water's website: www.water.wa.gov.au/Managing+water/Managed+aquifer+recharge/default.aspx

Water Corporation's website: www.watercorporation.com.au/water-supply-and-services/solutions-to-perths-water-supply/groundwater-replenishment

Recharge aquifers to moderate water level decline

Re-injecting treated wastewater into aquifers has been suggested[188,189] as a way to moderate water level decline on the Gnangara Mound and seawater intrusion from the coastal side. Groundwater from the Gnangara Mound ultimately flows to the coast. Injecting treated wastewater at the coast has been suggested, in order to create a barrier that prevents the intrusion of seawater into the aquifer from the coastal side. It would also allow groundwater to bank up behind the barrier of injected water and increase the water level in the superficial aquifer. This may lessen the degree to which groundwater dependent wetlands dry.

The CSIRO Perry Lakes Aquifer Replenishment Study proposed to divert treated water from the Subiaco wastewater treatment plant to underground filtration galleries on the western side of the Perry Lakes (west lake and east lake), with the aim of creating localised groundwater mounding, to help to increase wetland water levels.[190,191] A trial has been carried out over 18 months at CSIRO Floreat to understand the likely water quality outcomes. The Town of Cambridge has published its decision not to proceed with the replenishment scheme at this time, citing the determination that significantly higher ongoing costs are required to operate the system along with the possibility of further unforeseen risks.[192]

CSIRO is currently conducting preliminary investigations into the potential to recharge the surficial aquifer system in coastal locations in the Cockburn, Kwinana and Rockingham local government areas with treated wastewater. Investigations encompass the costs and environmental risks of enabling heavy industry to access appropriately treated water recharged to the aquifer. Potential benefits may include a reduced risk of seawater intrusion, improved throughflow to coastal wetlands and provision of irrigation water for local government.

➤ For more information on the project, see www.australianwaterrecycling.com.au/projects/recycled-water-for-heavy-industry

Developing alternative water sources

The Water Corporation has published a target of developing up to 100 gigalitres of new water sources.[175]

It has provided a summary of current positions regarding some of the alternative/novel water sources that have been considered to date, including:

- Water from the Kimberley

  An independent expert panel commissioned by the Government of Western Australia evaluated the technical and financial viability of bringing water from the Kimberley to Perth and found the project was high risk, high cost and generally impractical. These findings are presented in the report, *Options for bringing water to Perth from the Kimberley: an independent review.*

- Cloud seeding

  Cloud seeding is the process of artificially generating rain by implanting clouds with particles such as silver iodide crystals. After extensive testing, the CSIRO has determined that cloud seeding is unlikely to be effective in much of Australia. Concerns have also been raised about the long term environmental effects of using silver iodide crystals.

➤ For more information and links to relevant reports, see the Water Corporation's website: www.watercorporation.com.au/home/faqs/water-supply-and-services/why-dont-you-build-the-kimberley-pipeline-or-canal www.watercorporation.com.au/home/faqs/water-supply-and-services/is-cloud-seeding-a-viable-solution-to-perths-water-supply

Positioning abstraction bores away from wetlands and configuring them to minimise drawdown

The most effective way to reduce the impacts of drawdown on ecosystems is simply to extract less water. For example, harvesting less water from a wetland for self-supply can lead to immediate changes in wetland hydrology. Extracting less water can be achieved by using water more efficiently, using alternative water sources or changing land use.

Where abstraction is required, abstraction bores should be positioned away from wetlands, so that the groundwater drawdown cone, also known as the 'cone of depression', does not reach them. In addition to helping protect wetlands, this can minimise the risk of causing acidification due to drawdown in areas of potential acid sulfate soils.

As well as position bores away from wetlands, hydrogeologists may be able to design a configuration of abstraction bores that further reduces impacts. For example, depending on the area's hydrological characteristics, it may be preferable to position many bores over a wide area, rather than drawing a lot of water from a single bore. This may spread the impacts, reducing the drawdown depth and the magnitude of the impact at any one point.

Domestic garden bore scale

The Department of Water generally does not support the installation and use of domestic groundwater bores in the vicinity of significant wetlands in the Perth area, as outlined in Operational policy 5.[17] *Metropolitan domestic garden bores*.[177] This is reflected in the mapping of suitable and unsuitable areas for new domestic garden bores within the *Perth Groundwater Atlas*[193] (Figure 34).

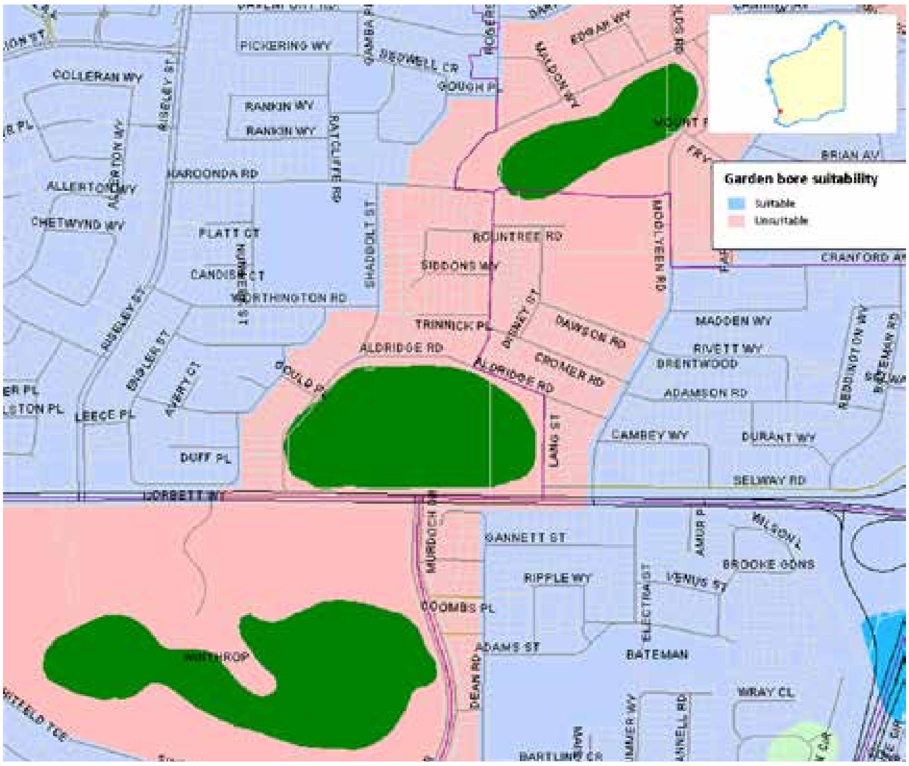


Figure 34. This excerpt from the *Perth Groundwater Atlas* dataset shows that areas around significant wetlands, such as the conservation management category wetlands Blue Gum Lake, Booragoon Lake and Piney Lake, are designated (via pink shading) as unsuitable for installing groundwater bores because of the potential impacts on the wetlands. Image – excerpt of the *Perth Groundwater Atlas*, Department of Water.[193]

Commercial-scale

Licences to take water are administered by the Department of Water under sections 5C and 26D of the *Rights in Water and Irrigation Act 1914*. When a water licence is applied for, the decisions made by the department are guided by water allocation plans (as described earlier in this topic) and these are particularly useful in taking into account the cumulative impacts of abstraction. However, each licence application is also assessed with regard to the location of proposed abstraction points near wetlands. For example, on the Gnangara Mound, in response to declining groundwater levels across the plan area, the department has developed an internal policy to limit or restrict use of groundwater in environmentally sensitive areas (*Internal Allocation Note – Managing abstraction in areas of declining water levels affecting groundwater-dependent ecosystems on the Gnangara Mound,* Department of Water 2005).[36] This policy helps departmental officers to assess water licence applications in areas where groundwater-dependent ecosystems are at high risk of impact from abstraction. Refusal to grant a licence may occur if the application is considered environmentally unacceptable or unsustainable.

➤ The process, and opportunities for stakeholder participation in water allocation planning, are explained in the report *Water allocation planning in Western Australia: a guide to our process*.[172]

Drinking water production bores scale

To ensure the protection of groundwater-dependent ecosystems in the vicinity of production wells, the Department of Water works with the Water Corporation each season to reduce public water supply abstraction in areas that can have a significant impact on wetland hydrology and other groundwater dependent vegetation. Bores are classified as most (environmental) sensitivity, medium sensitivity and least sensitivity, and managed accordingly. This approach has been implemented at a number of production bores on the Jandakot and Gnangara mounds, with some Gnangara bores being turned off for several years due to their impact on declining water levels, and concern regarding impacts on groundwater dependent vegetation.[194]

Minimising drawdown near wetlands via abstraction depth, rate and timing

Minimise magnitude and rate of abstraction to minimise drawdown depth

It is critical to minimise the abstraction rate in order to limit the depth of drawdown experienced by wetlands. As a guide, the depth of the cone of drawdown is dictated by the pumping rate, the slope of the cone is dictated by the characteristics of the aquifer medium (storativity and hydraulic conductivity), while the radius is dictated by the duration of pumping. Determining a depth of drawdown should be guided by the environmental water requirements of the wetland species and using knowledge of potentially acidic locations or layers in the soil. The risk of impact is likely at 30 centimetres or more, but in many wetlands the impact of drawdown is highly likely at less than 30 centimetres (Figure 35).

Making drawdown as gradual as possible may allow the wetland ecosystem to adapt to some degree to the water level decline. Sudden groundwater drawdown events can lead to the death of wetland vegetation that draws water from the water table, because the roots are suddenly left with no access to the water table. In contrast, slow groundwater drawdown increases the chance for individual plants, particularly trees, to extend roots in pursuit of the declining water table, and survive. Similarly it allows for intervening recruitment events, with young trees potentially able develop root morphologies that are more adapted to the new conditions.

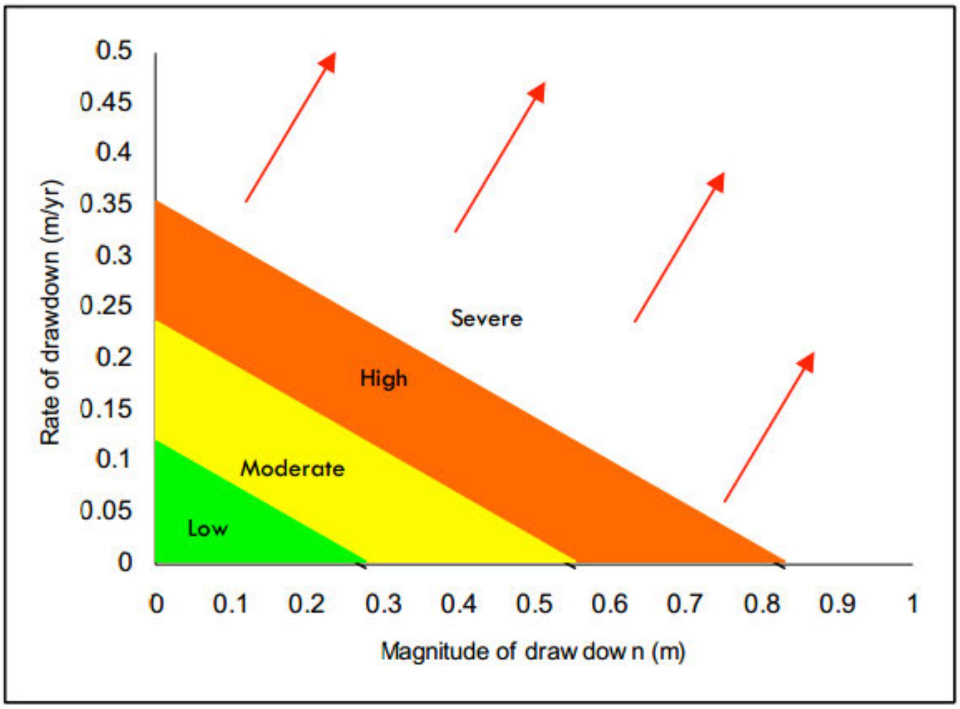


Figure 35. Risk of impact categories for wetland vegetation based on cumulative rate and magnitude of groundwater level change. Source - image in Sommer and Froend[101], citing Loomes and Froend (2004).

Manage drawdown timing (season, duration or frequency)

In combination with managing the drawdown depth, managing the season, duration and frequency of water abstraction may lessen the impacts of drawdown on wetlands. For example, in a permanently inundated wetland, dry season drawdown, in combination with natural decline in the surface water level, may result in drying and triggering acidification of acid sulfate soils. In such systems it may be preferable for drawdown to occur when the wetland water level is highest. As this is often when water is less needed (for example, by horticultural operations during the winter/wet season), storage may potentially be of use where feasible and legal.

Another key consideration is the time when plants and animals will be least sensitive to water loss. This timing can vary, depending on the suite of plants, animals and other life in the wetland. For example, if a wetland's waterbirds need a high spring water level to breed, drawdown should not occur from or near that wetland in spring. Similarly, if wetland plants rely heavily on groundwater over the dry season, then drawdown should occur over the wet season when rainwater is available as an alternative water source.

➤ Broad-scale risk maps have been compiled by DEC for several coastal regions of WA where a high or moderate probability of ASS occurrence has been identified. This risk mapping of acid sulfate soils is available via the DEC website: www.dec.wa.gov.au/management-and-protection/land/acid-sulfate-soils/ass-risk-maps.html

Infiltrating stormwater at-source in urban catchments

Maintaining stormwater infiltration 'at-source' is an important tool for maintaining the water regime of wetlands located in urban environments. In essence, at-source infiltration seeks to replicate the natural process of rainfall percolating into the soil at, or very close to, the location that it has fallen in the catchment, giving rise to the term at-source (Figure 36). In comparison, traditional drainage systems capture and pipe or drain stormwater to a point of discharge such as a wetland or the ocean, often distant from its point of capture.

Figure 36. Vegetated swales and flush kerbs capture and infiltrate rainfall along the length of this road in The Glades, Byford. Photo – courtesy www.newWAterways.org.au.

At-source infiltration helps to mimics the natural catchment flows including:

- peak flows into wetlands
- seasonality of flows into wetlands
- discharge pathways into wetlands
- water quality entering wetlands
- annual frequency of flows into wetlands
- level and duration of inundation of wetlands.

By doing so, it achieves three critical outcomes:

1. all other things being equal, it contributes to the management of the water balance in urban catchments, helping to maintain the normal volume of water to reach those wetlands that are naturally groundwater fed. This is where sound water planning is critical, because the balance depends on managing decreased groundwater levels due to abstraction and climate change with increased runoff due to clearing and impervious surfaces.

2. it reduces the velocity at which water flows into wetlands. The flow of water reaching the wetland by groundwater is moderated compared to higher-velocity surface flows running off impervious surfaces.

3. it improves the quality of water flowing into wetlands and has a strong influence on the natural water chemistry that shapes the character a wetland. The percolation of water through the aquifer removes certain dissolved and particulate materials. The water chemistry also changes as it moves through the aquifer, for example, ‘picking up’ dissolved ions and salts.

At-source infiltration is possible in catchments with permeable soils, such as sand, that readily allow water to infiltrate. This is the case for large areas of the Swan Coastal Plain

(Moore River–Dunsborough), including the Quindalup, Spearwood and Bassendean Dunes. At-source infiltration requires land that is permeable, that is, not covered with concrete or other impermeable materials. However, it is aided by structural devices such as soakwells, infiltration basins and trenches, swales, pervious paving and flush kerbs.

Using overland flow paths for stormwater entry into wetlands

In moderate to large rainfall events, stormwater would naturally flow into those wetlands that are low in the catchment. To mimic natural flow paths, this water should reach wetlands by overland flow paths across vegetated surfaces, rather than by discharge of pipes or drains. Overland flow paths benefit wetlands by helping to maintain water regime and water quality.

The placement and design of these overland flow paths must, however, consider potential impacts on infrastructure through which they pass if there is potential for flooding to occur.

Minimising subsoil drainage effects on wetlands, using alternatives

Subsoil drainage needs to be well designed in order to minimise the effect on any nearby wetlands. In particular, subsoil drainage needs to be separated (horizontally) from the wetland to ensure normal interaction of the groundwater table with the wetland is maintained. The drawdown curve of each pipe is limited by factors such as the size of the pipe, the hydraulic conductivity of the soil and the hydraulic head (that is, regional recharge). A number of factors are assumed when calculating the likely drawdown, including the uniformity of the soil hydraulic conductivity in a soil layer (such as in a sand layer or in a clay layer) in all directions. As important as the drawdown curve of each pipe is the number and therefore the spacing of pipes in a development near a wetland.

Alternatives to subsoil drainage are available, and include alternative construction methods, a number of which are more common in the eastern states of Australia. Very deep controlled groundwater levels are likely to require ‘sump and pump’ infrastructure.

The state government has formally established new standards for the management of groundwater levels in new urban developments. These standards are outlined in documents including *Better Urban Water Management*[169] and the *Stormwater Management Manual for Western Australia.*[59] These standards address many objectives, including the protection of high conservation value wetlands. These standards establish the expectation that the condition/health of these wetlands will be maintained or improved during land development by not altering the groundwater regime by greater than normal climatic variances.[195] Proposals to modify the groundwater levels via the installation of controlled groundwater levels (CGLs) must demonstrate that they meet this criterion. The Department of Water is responsible for approving controlled groundwater levels, and it has outlined the considerations required when setting CGLs in the document *Water resource considerations when controlling groundwater levels in urban development*.[195] Sub-soil drainage setbacks are one way of minimising the effect upon wetlands. The land development industry is required to carry out both pre- and post-development monitoring and report upon their adherence to what was proposed and predicted, as outlined in *Water monitoring guidelines for better urban water management strategies/plans*.[196]

➤ The subsoil drainage policy of the Department of Water is outlined in the document *Water resource considerations when controlling groundwater levels in urban development guidelines*[195]

Avoiding or minimising dewatering impacts near wetlands

Use alternatives to dewatering

There are alternatives to dewatering near wetlands. Driven pile construction, sheet piling and slurry walls can avert the need for dewatering associated with various types of construction. Trenchless technologies for installing or repairing underground cables and pipelines, such as microtunnelling, avoid the need for open trenching or dewatering.

➤ The Australasian Society for Trenchless Technology website (www.astt.com.au) is a source of information on potential alternatives to trenching and dewatering.

Design and operate dewatering to minimise impacts

Dewatering techniques differ in their potential to affect nearby wetlands. For example, an array of dewatering well-points or spears connected to a common suction pump or vacuum extraction system is a technique that can have a larger radius of influence than sumps with submersible pumps at their base.[197]

Carrying out works when the watertable is lowest in summer can reduce the depth and/or size of the dewatering footprint and rates. Using groundwater recharge trenches to constrain the lateral extent of the cone of depression by creating a hydraulic barrier between the wetland and the cone of depression is another important technique. Examples of this can be found in the Pilbara.[184]

Dewatering is regulated via groundwater abstraction licences from the Department of Water, except if an exemption applies. If a hydrological impact assessment shows that impacts are likely, dewatering management plans may be required as a condition of licence. The Department of Water must inform the Environmental Protection Authority if a water licence being sought under the *Rights in Water and Irrigation Act 1914* would have a significant effect on the environment. As outlined in the Department of Water's *Western Australian water in mining guideline*[198] and the *Strategic policy 2.09: Use of mine water surplus*[153], water generated by mining dewatering operations must first be used for the mitigation of environmental impacts. This involves ensuring that water is returned to the environment, through injection back into the aquifer or augmenting reduced environmental flows of groundwater-dependent wetlands. This is usually enforced via conditions of the licence.

➤ *Dewatering of soils at construction sites*[199] outlines how the Department of Water assesses impacts of dewatering associated with construction.

DEC also has requirements for proposed dewatering in proximity to wetlands. The document *Treatment and management of soils and water in acid sulfate soil landscapes*[197] (section 5.3.9) states that dewatering must not alter the wetland water level or water quality of valuable wetlands (such as conservation and resource enhancement management category wetlands). Proposals to dewater within 500 metres of a valuable wetland must implement a range of management measures to protect the wetland. These include:

- baseline laboratory analysis of wetland water quality data, capturing seasonal variation
- baseline water level monitoring
- water level and water quality monitoring during dewatering
- a range of monitoring, mitigation and remediation measures in the event of changes in water quality or water level.

Adding wetland water artificially using dewater

Managed aquifer recharge can be used to minimise the impacts on wetland water regimes. Abstracted groundwater may be re-injected into aquifers that are connected to a wetland to allow the recharge water to flow naturally into the wetland, rather than being discharged directly into it. This is being done at several mine sites in the Pilbara and is also becoming an alternative method of disposal at construction sites.[184]

Adding wetland water artificially using harvested stormwater/ rural drainage

Harvested stormwater and rural drainage water represents a considerable resource.

For example, drainage in the region around Perth removes more water than all the bores in the superficial aquifer in the same area. A study published in 2008[182] found that the median annual discharge of stormwater from the Perth and Peel metropolitan regions was estimated as 120 gigalitres with approximately 67 per cent from the Swan-Canning catchment (exclusive of Avon and Helena rivers; and Ellen, Jane and Susannah brooks), 16 per cent from the coastal main drains (Carine, Herdsman and Subiaco) and 17 per cent from the Peel's main drains. This stormwater volume is equivalent to approximately two Mundaring Weirs at full storage capacity (63.6 gigalitres) or two and a half Perth Seawater Desalination plants (45 gigalitres). This is also greater than the potential volume from rainwater harvesting of the region's residential roofs.

Key considerations are cost of installing and maintaining infrastructure and the quality of the water harvested.

Adding wetland water artificially using groundwater

Artificial maintenance of water levels can be achieved by pumping groundwater into a wetland. It is usually very expensive, and therefore has been used relatively sparingly in order to achieve a particular management purpose at high conservation value wetlands (for example, to maintain waterbird habitat or to prevent acidification).

Artificial maintenance has been undertaken in several wetlands on the Swan Coastal Plain suffering from drying, with varying degrees of success. It is an extreme hydrological intervention, and itself carries a risk of unintentional ecosystem degradation. Designing an appropriate program of supplementation depends on an accurate understanding of local and regional hydrology, and its interaction with ecology. Unfortunately, information of this detail is often lacking, or can easily be incorrectly interpreted because of its complexities. The below case study provides two examples of water level maintenance, one considered to be acceptable and one that is thought to have contributed to ecosystem decline.

case study

Artificial supplementation of water levels at Lake Nowergup and Lake Jandabup: a tale of two wetlands

Artificial supplementation at Lake Nowergup

Lake Nowergup in the City of Wanneroo is thought to be the deepest wetland on the Gnangara Mound. Part of the lake is located within Lake Nowergup Nature Reserve, which is managed by DEC. Water levels at the wetland have been falling since the 1970s in line with regional water levels across the mound, and have been artificially supplemented using water from the Leederville aquifer since 1989. To maintain water levels, the lake is supplemented with approximately 1.2 gigalitres of water per year, sourced from the Leederville aquifer, at a cost of about $50,000 per year.[140] The purpose of this supplementation has been to assist in meeting a legislated minimum peak water level in spring. The absolute spring minimum peak for Lake Nowergup is 16.8 metres Australian height datum (AHD), with a preferred spring minimum peak of 17 metres AHD, with no more than two years in six where this is not achieved (Figure 37). This water level was designed to support the wetland's role in providing habitat for waterbirds, as well as other wetland fauna and vegetation. In the first few years, the minimum water level criterion was met using groundwater pumped from the Leederville aquifer. However, as regional water table levels continue to decline, more water has been needed to ensure the minimum water level is reached each year.

In autumn 2002, despite artificial supplementation, wetland vegetation on the western side of the wetland died suddenly. On inspecting the hydrographs (data collected from monitoring bores, graphed to show patterns and trends over time) for the western side of the wetland, artificial supplementation was identified as a likely cause. The hydrographs showed that as soon as supplementation ceased after the minimum water level criterion was reached each spring, water would drain quickly through permeable limestone on the western side of the wetland, until the wetland water was at a similar level to the regional water table. Although the wetland trees had been experiencing the same peak water level every spring, the autumn minimum was falling lower each year. With every year, the seasonal fluctuation in water levels increased. By 2002 when the tree deaths occurred, the water level fell nearly 3 metres in six months.[200] This is compared with normal seasonal fluctuations of up to 1 metre on the Gnangara Mound. It is thought that if wetland levels had been allowed to decline gradually (along with the regional water table), then the trees may have had some chance to adjust to the gradually drier conditions. However, if this had occurred, other species would not have had their water requirements met, and processes such as acidification could occur.

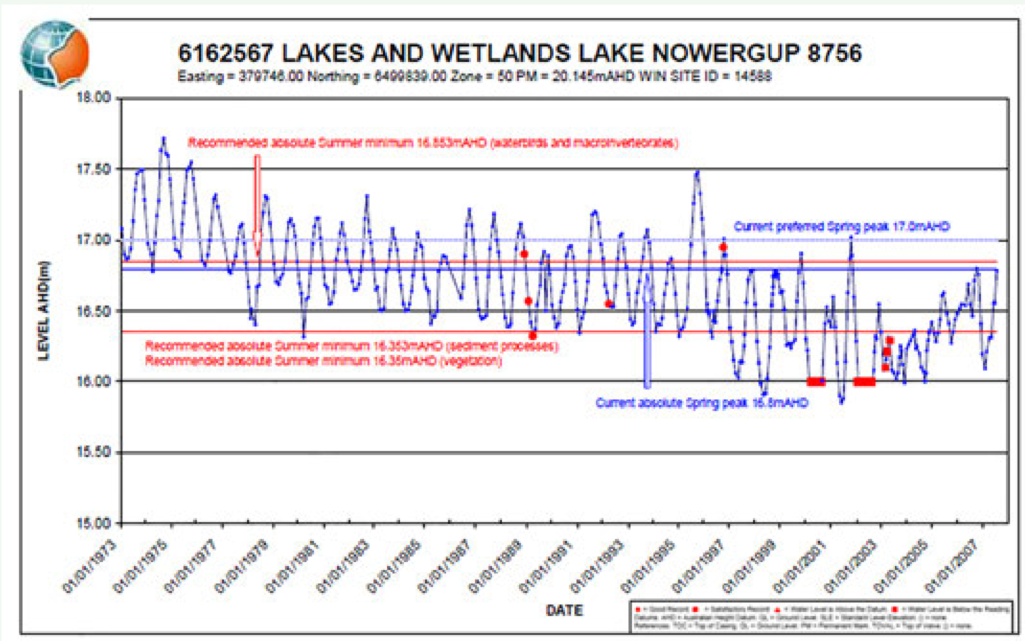


Figure 37. Hydrograph showing water level changes at Lake Nowergup. Image – Department of Water.

case study

Water is currently pumped into the wetland all year round. If pumping is stopped, water levels decline rapidly. The current pumping regime tries to approximate a rate of rise/fall that is closer to what would naturally, historically have occurred. In 2009/10 the management approach was to target a spring peak of 16.5 m AHD and a summer minimum of approximately 15.9 m AHD. However, it has been acknowledged that these targets would not meet the legislated criteria or the environmental water requirements for the wetland, but that the volume of supplemented water required to meet these levels and the high cost of providing such a large quantity of water was deemed prohibitive.

A local area hydrogeological model of the Nowergup area was developed by Sinclair Knight Mertz[201] in 2009 and a detailed study of the wetland's hydrology[202] was carried out in 2011 by the Department of Water. On the basis of this study, it has been recommended that the current artificial maintenance regime should be continued, but it should be re-assessed as part of the next Gnangara groundwater allocation plan review (scheduled to occur in 2016). It was also recommended that a revised spring peak minimum criteria of 16.2 m AHD be proposed under section 46 of the *Environmental Protection Act 1986* and that it be achieved by gradually reducing it by 0.1 metres per year from the 2009 spring peak of 16.5 m AHD.[202] Additional recommendations, including recommendations regarding the regional groundwater level and allocations in the Wanneroo groundwater area and Nowergup subarea were also made in the report.

This experience is a lesson that wetland managers must understand the local hydrogeology, and think broadly about what the ecological implications are, before taking management actions that will affect a wetland's hydrology.[203,194,204] A review of the program's success to date found that:

"Artificial maintenance requires:

- a management regime that considers not only static water levels, but also rates of water level rise, rates of fall, inter-annual variation or fluctuation and the quality of the water being used
- sufficient knowledge of the hydrogeological system to achieve appropriate water levels, rates of change and water quality requirements.

Artificial maintenance is practical only in a very limited number of situations as it requires a management regime that meets environmental objectives and that is feasible in terms of implementation and cost."[202]

Artificial supplementation at Lake Jandabup

Lake Jandabup on the Gnangara Mound has also been artificially supplemented using water from the superficial aquifer: sporadically since 1989 and more consistently since 1999. A decline in the groundwater table had caused the wetland to dry and acidify, and macroinvertebrate populations in the wetland were severely affected. To maintain water levels, the lake is supplemented with approximately 1.2 gigalitres of water per year. The cost of supplementing the wetland has been estimated at almost $9 million over a ten-year period.[92]

Assessments of the supplementation have been positive. In 2009, researchers concluded that "The recovery has been sound, with the return of aquatic macroinvertebrate communities in less acidic waters, despite the resulting water chemistry and community structure being somewhat different to the original".[92] While artificial supplementation has been successful in preventing further acidification events in the wetland to date[205] Sommer and Horwitz found that artificial augmentation diminished the seasonal signal in macroinvertebrate composition and caused some taxa to increase in abundance or to appear in the wetland for the first time, which they coined as 'augmentation beneficiaries'.[206]

Sommer et al[207] found that: 'Artificial supplementation can be appropriate under certain circumstances (as the successful example of Lake Jandabup has shown). However, one must be very aware that such a management strategy is trying to solve one problem whilst exacerbating another *[groundwater decline]*. Because of this, wetland supplementation schemes in Perth should be supported by somewhat more rigorous scientific backing than they appear to be at the present time.'

More recently, with the Gnangara Mound's continued falling water levels, it has been reported that the artificial supplementation regime is not keeping up.[208]

Designing, operating and retrofitting tree plantations to minimise drawdown

Unlike abstraction bores which can be switched on and off, the rate at which plantation trees use water is not easily controlled. The interception of rainfall, extent of runoff, and groundwater extraction rate and location can only be coarsely managed in the planning phase. Factors include carefully choosing the location of the plantation (higher vs. lower elevations), the species planted and the density of trees, the plantation design (blocks vs. strips, perpendicular vs. parallel to the contour) and phasing of planting, in order to influence the location of drawdown, and the rate of drawdown over time. The decision-making authority for plantation proposals is the relevant planning authority, typically local government.

While water access entitlements can be granted for the purposes of irrigated agriculture, plantation water use cannot be regulated under the *Rights in Water and Irrigation Act 1914*. The background discussion paper of the proposed Water Resources Management Act states that the interception of water by plantations is proposed to be regulated in areas where high levels of water use (not where plantations assist with salinity and land management).[6] Proposed plantations with the potential to cause significant environmental impacts may be referred for environmental impact assessment under Part IV of the *Environmental Protection Act 1986*.

Thinning or harvesting of a plantation may alleviate drawdown. However, commercial and legal constraints often apply. For example, in the Gnangara groundwater area, the pine plantations are managed in accordance with the *Wood Processing (Wesbeam) Agreement Act 2002* which commits the state government to provide wood to the Wesbeam plant until 2029.[29] In some circumstances environmental constraints may also apply; for example, some plantations are used by native cockatoos. The Gnangara pines are a key food source for Carnaby's black cockatoo, *Calyptorhynchus latirostris,* during the non-breeding season (January-June). As part of implementing the Gnangara Sustainability Strategy, the Forest Products Commission is investigating the potential of modifying harvesting strategies within the constraints of the acts to assist in increasing recharge to the Gnangara system.[36]

Using wastewater on plantations is also being investigated, for example, by the Water Corporation in the south coast.

➤ The report *Plantation forestry and water management guideline*[29] provides a brief overview the Department of Water's role in the management of plantation forestry.

➤ A number of studies on the Gnangara pine plantation were undertaken for the Gnangara Sustainability Strategy and are available from the strategy website: www.water.wa.gov.au/sites/gss/reports.html

Modifying current vegetation

Forest management, by selectively removing crowded trees, controlling re-growth and gradually replacing introduced species of trees with native species is a form of catchment thinning trialled in the Wungong Catchment.

➤ For more information, see the Wungong Catchment Trial in which forests were subject to thinning: www.watercorporation.com.au/water-supply-and-services/ongoing-works/wungong-catchment-trial.

Burning native vegetation removes plants which would otherwise intercept and transpire water, and allows increased infiltration of rainfall to the aquifer. It has been suggested as one of the ways to increase aquifer recharge on the Gnangara Mound, therefore helping to balance the impacts of groundwater drawdown on wetland water regimes.

This option is being investigated by CSIRO and DEC, however there are serious concerns regarding the impact on the burnt ecosystems, as well as human health and safety.[190]

Replacing introduced planted trees which have a high water demand, such as pines, with native vegetation such as Banksia woodland also has the potential to increase groundwater recharge. Active revegetation may not be necessary, as some areas of pines which were killed by wildfire have regenerated into moderately diverse native vegetation.[190]

Retrofitting rural drainage networks to drain less water

Retrofitting open rural drains to export less water from an area is technically feasible. It is generally a case of making them shallower and wider so that they do not intercept groundwater and drain it away (known as exfiltration), or so they intercept groundwater less deeply than before. Drains require a consistent grade, so changes to the base level of the drain (the invert level) would need to be made across the entirety of the drain and its network to allow it to function. Changes of this nature will mean that the maximum groundwater level won't be 'capped' as much as before. It may also mean land needs to be provided in order to widen the existing drainage channel. While technically feasible in some areas, the impacts of higher maximum groundwater levels to landholders and infrastructure in the catchment area needs to be part of a feasibility assessment when work of this nature is being considered, and the capacity of the drain to provide protection from floods needs to be retained.

Installing water control structures in wetlands to increase water

Boards, weirs and gates are used in many rural and metropolitan wetlands to control water levels. This may be an option in wetlands that are connected to a defined channel by way of an inlet (originating from a waterway or drain) or an outlet (flowing to a waterway or drain). Many such devices were installed many years ago, and their original purpose was usually not to maintain the natural water regime of wetlands. The reasons varied from enhancing conditions for waterskiing and other recreational opportunities to improving conditions for agriculture in or near wetlands. Yenyening Lakes, Lake Towerrinning and Benger Swamp are just some of the affected wetlands.

In recent decades, water control structures have been employed in a number of wetlands to ensure enough water is maintained in them to protect or reinstate conservation values. Lake Mealup, West Pinjarra, is one such wetland, as outlined below. This form of structural control provides an option for managing many wetlands in urban areas that form part of the arterial drainage network but which are being impacted by drying.

This form of structural control needs to be designed so as to ensure that the wetland is not affected by large volumes and high speed (velocity) flows or water that is significantly different in chemistry or of poor quality. This form of structural control can also have serious effects on downstream environments, such as waterways or connected wetlands, because their hydrology is likely to be altered. Structural controls may also be physical barriers to fauna such as fish. For these reasons proposals may be subject to environmental impact assessment under Part IV of the *Environmental Protection Act 1986*. Furthermore, detaining water can be a serious safety hazard and structures generally need to be designed by a suitably qualified engineer.

case study

Installing weirs to combat the acidification of Lake Mealup, West Pinjarra

Declining water levels in Lake Mealup culminated in the annual drying of the wetland each year from 1994 until 2012. This is thought to be due to a combination of reduced rainfall and a reduction in surface water flowing into the wetland, due to the closure of a shallow channel that had previously connected the wetland to the Water Corporation's Mealup Main Drain. Signs of drying and acidification were abundant: the pH dropped from 7 to below 3, algal blooms were common, waterbirds were less common and the invasive introduced bulrush *Typha orientalis* expanded to cover 80 per cent of the wetland. The Lake Mealup Preservation Society worked to secure the involvement and collaboration of many people and organisations in order to halt Lake Mealup's ecological decline. Studies confirmed the presence of actual acid sulfate soils. Approvals and funding were sought and provided to divert drainage flows from the Mealup Main Drain into Lake Mealup by way of a variable height weir on the drain. The first diversion of drain water was carried out in June 2012. The pH has stabilised at 7 and the signs of life are reappearing, with frogs and waterbirds evident. A close eye is kept on the wetland's water chemistry, with fortnightly monitoring of pH, oxygen reduction potential and dissolved oxygen. More information on this project is available from the topic 'Roles and responsibilities' in Chapter 5.

Figure 38. The dry sediment in an area of Lake Mealup, showing signs of acidification prior to the diversion of drainage flows into the wetland.
Photo – H Bucktin/DEC.

Figure 39. The adjustable height weir, receiving flows diverted from the Mealup Main Drain.
Photo – H Bucktin/DEC.

Figure 40. Lake Mealup, full in August 2012. Photo – R Rose.

case study

Managing both water rise and decline: urban catchments

Urban water encompasses all water that enters urban catchments, including stormwater, groundwater, water present in ecosystems such as wetlands, wastewater, scheme water and other sources of drinking water.

While one of the principles of urban water management is to retain natural drainage systems and protect ecosystem health, when areas are urbanised the natural catchment hydrology can change through the:

- clearing of vegetation (increasing the amount of water)
- creation of vast expanses of impermeable surfaces including buildings, roads, car parks (increasing the amount of water)
- taking of water for domestic, commercial and industrial purposes, and then discharging it to the ocean (reducing the amount of water)
- redirection of stormwater (increasing water in some areas, and reducing in others)
- development occurring over some wetlands (reducing natural flood storage).

Because these activities can offset or compound each other, managing urban catchments can be complex. Similarly, the effects on wetlands can be complex. The example below demonstrates how multiple threats can interact (Figure 41).

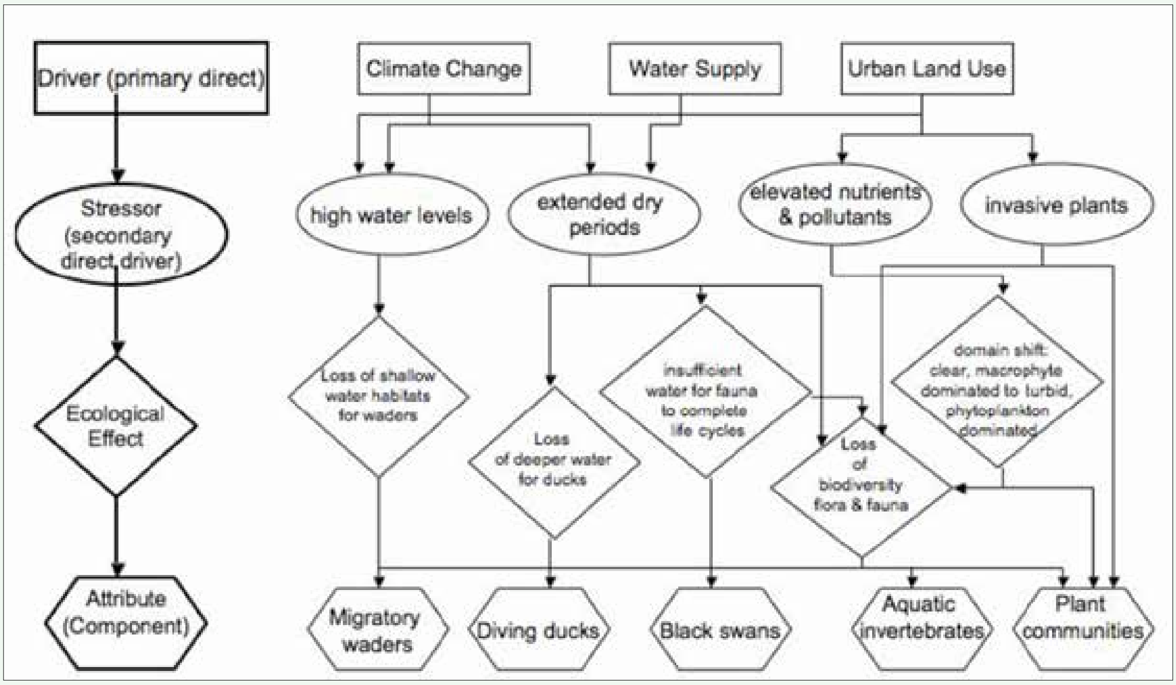


Figure 41. The interaction of different threats at Forrestdale and Thomsons Lake, in Perth's southern suburbs. Source: Maher and Davis 2009.[107]

New urban catchments offer the best opportunities for managing urban water. Being intensively developed, the economies of scale are suitable to design, install and manage the water management infrastructure needed to balance the needs of the environment with the protection of humans and infrastructure from stormwater, groundwater and wastewater. The extent to which best practice water management is achieved in urbanising areas is largely attributable to the development industry, and in turn, the ability of government to regulate the industry, enforce technical standards and foster best practice through incentives, to ensure water and environmental protection. As corporate citizens, companies in the development industry may voluntarily seek to improve standards, but market forces driven by profit margins and consumer choices heavily influence the willingness of companies to do so. Ultimately, the cost of poor management affects everyone in the community, not just those purchasing real estate. Industry and non-industry recognition of the companies that are achieving best

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practice or developing innovative approaches is one method of increasing consumer awareness of the environmental footprint of their new house or a new commercial or industrial district.

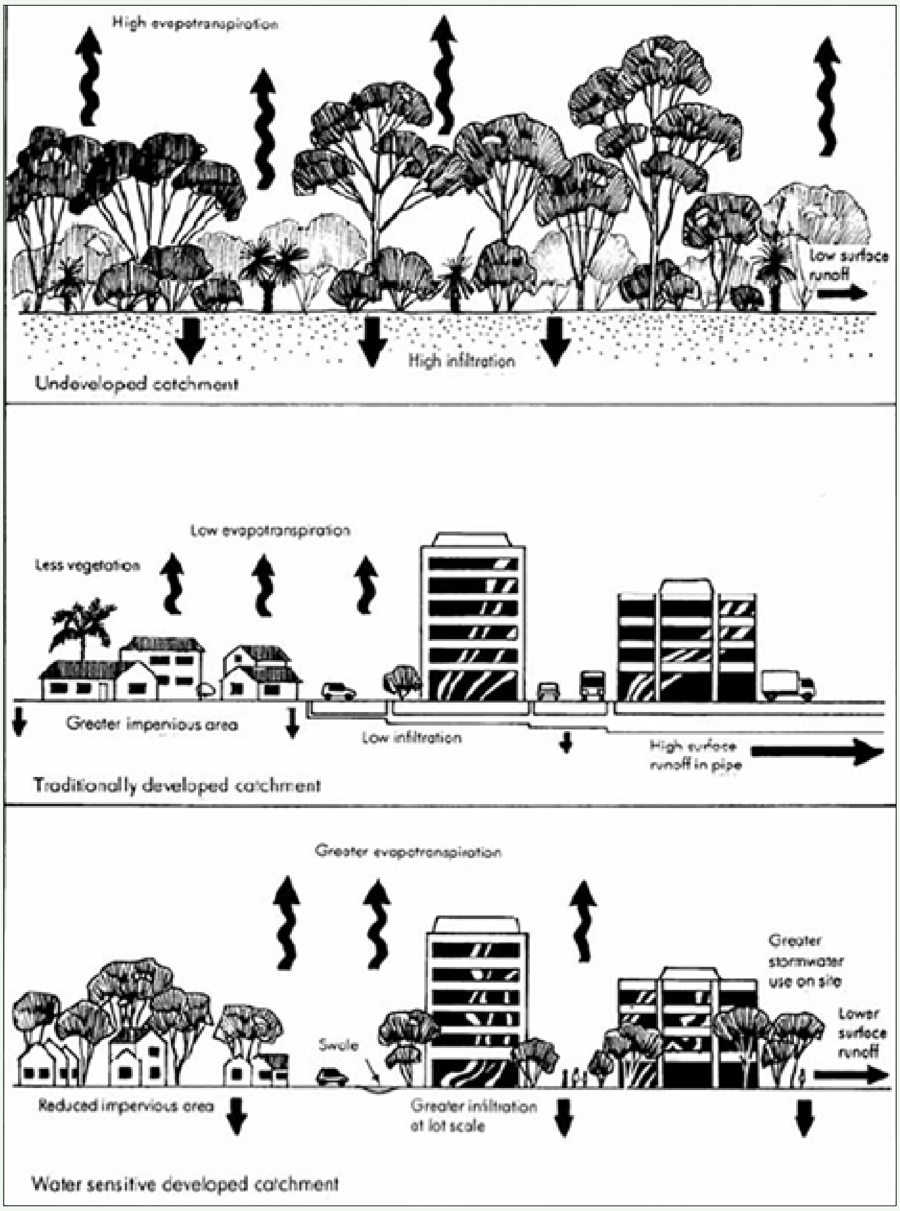

Figure 42. Water in natural catchments (top) traditionally-developed urban areas (middle) and urban areas where water-sensitive urban design has been applied (bottom). Diagram from the *Stormwater management manual for Western Australia.*[59]

Urban water should mimic the natural wetland water regime of conservation value wetlands, including:

- peak flows into wetlands
- seasonality of flows into wetlands
- discharge pathways into wetlands
- water quality entering wetlands
- annual frequency of flows into wetlands
- level and duration of waterlogging or inundation of wetlands.

Stormwater is a precious resource that, with good management, is an essential water management tool. Especially in a drying climate, stormwater is almost always an important source of water for a

case study

wetland. In urban catchments, good stormwater design maintains the natural wetland water regime. In new urban developments, this objective is a requirement of stormwater design. In older areas, where traditional stormwater design often resulted in wetlands receiving too much, too little or very poor quality stormwater, infrastructure can be retrofitted to improve the hydrology of wetlands in the catchment. Retrofitting is the process of installing or undertaking additional or alternative stormwater management devices or approaches in an existing developed area.

Maintaining the pre-development water regime of wetlands can be achieved by designing stormwater systems that mimic stormwater flows before development, including:

- infiltrating water throughout the catchment in small rainfall events, rather than directing it into pipes or open drains
- using well-designed public open space, road reserves and wetlands to receive stormwater in moderate to large rainfall events by overland flow paths across vegetated surfaces
- adequately separating sub-soil drainage systems from wetlands

Stormwater design in new developments is governed by policies that take into account the significant environmental values of water, including:

- *Better Urban Water Management*[169]
- *Stormwater Management Manual for Western Australia*[59]
- *Decision process for stormwater management in WA*[180]
- *Towards a water sensitive city: the urban drainage initiative – Phase 2*

Resources include:

- New WAterways: a resource for urban water management in Western Australia. The website is www.newwaterways.org.au.
- Australian National Hydropolis Conference: www.hydropolis.com.au/papers.htm

Regulatory control of urban water management is via plans that establish water management at increasing finer scales of land development, from the district scale down to individual lots (Table 11). The development of these plans is typically triggered by proposals to rezone or develop large areas of land.

➤ For more information on the water planning process for urban developments, see:

the Department of Water's webpage on water and land use planning: www.water.wa.gov.au/Managing+water/Water+and+land+use+planning/default.aspx

the guidance note, *Water management reports in the land planning process.*[209]

Table 11. Urban water management plans that determine urban water management outcomes

Geographic scale	Land planning tool	Associated water planning report	What the water planning report establishes
Regional	Regional or sub-regional strategy, regional or sub-regional structure plan or region scheme	Regional water management strategy	Likely areas for land use change that may impact the use and management of water resources
District	District structure plan, local planning strategy, region scheme amendment	District water management strategy	Whether the area is capable of supporting urban development, and if so, how water in the landscape will be managed
Local	Local planning scheme amendment, local structure plan	Local water management strategy	How the proposed urban structure will address water use and management
Local	Subdivision proposal	Urban water management plan	How the final urban form will use and manage water
Local	Condition of development approval	Wetland management plan	How a wetland is managed, including wetland hydrology

Glossary

Abstract: to take, remove, extract

Acid sulfate soils: includes all soils in which sulfuric acid is produced, may be produced or has been produced in quantities that can affect the soil properties. Also referred to as acid sulphate soils.

Allocation limit: annual volume of water set aside for consumptive use from a water resource

Annual: a plant that completes its life cycle within a single growing season (from germination to flowering, seed production and death of vegetative parts)

Benthic microbial communities: bottom-dwelling communities of microbes (living on the wetland sediments)

Catchment: an area of land which is bounded by natural features such as hills or mountains from which all surface runoff water flows downslope to a particular low point or 'sink' (a place in the landscape where water collects)

Check: a concrete frame with boards slotting into it, creating a barrier across the drain. The checks are opened or closed by addition or removal of the boards.

Climate change: a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.[18]

Climate change adaptation: actions undertaken to reduce the adverse consequences of climate change, as well as to harness any beneficial opportunities

Climate change mitigation: actions that are intended to reduce the magnitude of our contribution to climate change, including strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks

Community: a general term applied to any grouping of populations of different organisms found living together in a particular environment

Cone of drawdown: the depression of the potentiometric surface. Also known as a cone of depression.

Confined aquifer: an aquifer deep under the ground that is overlain and underlain by relatively impermeable materials, such as rock or clay, that limit groundwater movement into or out of the aquifer

Contour banks: mounds of earth which follow hillslope contours to arrest flowing water and allow infiltration

Controlled groundwater level: the invert level of a groundwater management conduit such as a drain or channel in metres Australian Height Datum (AHD)

Culvert: a conduit used to enable water flow beneath a structure such as a road, causeway, railway or track

Dewatering: the process of removing underground water to facilitate construction or other activity. It is often used as a safety measure in mining below the watertable or as a preliminary step to development in an area.

Drawdown: the lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure

Ecological community: naturally occurring biological assemblages that occur in a particular type of habitat

Endemic: naturally occurring only in a restricted geographic area

Environmental water provision: the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements.

Environmental water requirement: the water regime needed to maintain the ecological values (including, assets, functions and processes) of water-dependent ecosystems at a low level of risk

Facultative wetland plants: plants that can occur in both wetlands and dryland under natural conditions in a given setting

Gigalitres (GL): one thousand million litres (L); that is, one billion litres

Gnamma: a hole (commonly granite) that collects rainwater, forming a wetland. This word is of Nyungar origin.

Gnangara groundwater system: the groundwater system formed by the superficial, Leederville and Yarragadee aquifers located in northern Perth, east to Ellen Brook, south to the Swan River, west to the Indian Ocean and north to Gingin Brook

Grassed waterway: a vegetated channel which directs water flow paths. The vegetation slows surface flows.

Groundwater: water occurring beneath the ground surface in spaces between soil grains and pebbles and in fractures or crevices in rocks

Groundwater capture zone (wetland): the area within which any recharge (infiltrating water) eventually flows into the wetland

Groundwater dependent ecosystems: those parts of the environment, the species composition and the a term used to describe ecosystems which derive part or all of its water from groundwater

Groundwater model: a simplified representation of a groundwater system and it captures and synthesise all of the known information, and where information is not known, identifies any assumptions being made about how the system is thought to work

Groundwater table: the upper surface of groundwater in an unconfined aquifer (top of the saturated zone). In technical terms, the surface where the water pressure head is equal to the atmospheric pressure.

Held environmental water: water available under a water access right, a water delivery right or an irrigation right for the purposes of achieving environmental outcomes

Hydraulic conductivity: a measure of the ease of flow through a pore space or fractures. Hydraulic conductivity has units with dimensions of length per time (for example, metres per second, metres per minute or metres per day).

Hydrology: the properties of the Earth's water, particularly the distribution and movement of water between the land surface, groundwater and atmosphere

Hydroperiod: the periodicity (permanent, seasonal, intermittent) of waterlogging or inundation of a wetland

Hysteresis: the condition that caused a shift from one state to another does not necessarily result in a shift back to the first state when the condition is simply reversed

Impermeable surface: the part of the catchment surfaced with materials, either natural or constructed, which prevent or limit the rate of infiltration of stormwater into the underlying soil and groundwater and subsequently increases stormwater runoff flows. Also referred to as impervious surfaces.

Invert: the level of the lowest portion at any given section of a liquid-carrying conduit, such as a drain or a sewer, and which determines the hydraulic gradient available for moving the contained liquid

Invertebrate: an animal without a backbone

Limits of acceptable change: variation that is considered acceptable in a particular component or process of the ecological character of the wetland, without indicating change in ecological character that may lead to a reduction or loss of the criteria for which the site was Ramsar listed

Managed aquifer recharge: recharging an aquifer under controlled conditions to store the water for later abstraction, to achieve environmental benefits or to mitigate the impacts of abstraction

Mound spring: an upwelling of groundwater emerging from a surface organic mound

Obligate wetland species: species that are generally restricted to wetlands under natural conditions in a given setting

Oil mallee: multi-stemmed eucalypt planted on agricultural land, with the stems arising from an underground root mass known as a lignotuber. Stems can be harvested for products such as eucalyptus oil.

Palusplain: a seasonally waterlogged flat wetland

Peat: partially decayed organic matter, mainly of plant origin

Perched: not connected to groundwater

Perennial: a plant that normally completes its life cycle in two or more growing seasons (from germination to flowering, seed production and death of vegetative parts)

Plantation forest: non-irrigated crop of trees grown or maintained so that the wood, bark, leaves or essential oils can be harvested or used for commercial purposes, including through commercial exploitation of the carbon absorption capacity of the forest vegetation

Precautionary principle: where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation[123]

Recharge: water infiltrating to replenish an aquifer

Roaded catchment: a catchment where a series of adjacent v-shaped (in cross section) channels are created in the landscape to channel water to a downslope water storage

Quadrat: a plot (often square) that is marked, either temporarily or permanently, to facilitate counts of plants in a given area

Secondary salinisation: a human-induced process in which the salt load of soils, waters or sediments increases at a faster rate than naturally occurs

Self-supply water: water sourced on-property by landholders

Sewer mining: the process of extracting untreated wastewater from the sewerage network and treating it on-site in a treatment plant for reuse

Species composition: the species that occur in a community

Stormwater: water flowing over ground surfaces and in natural streams and drains as a direct result of rainfall over a catchment[60]

Swan Coastal Plain: a coastal plain in the south west of Western Australia, extending from Jurien south to Dunsborough, and the Indian Ocean east to the Gingin, Darling and Whicher Scarps

Suckering: growing roots laterally under the soil, which project shoots to emerge in a new location away from the base of the parent plant

Sustainable yield: the amount of water that can be taken from a water resource system (expressed as an extraction regime) without causing unacceptable impacts on the environment

Threatened ecological community: naturally occurring biological assemblages that occur in a particular type of habitat that has been endorsed by the WA Minister for Environment as being subject to processes that threaten to destroy or significantly modify it across much of its range

Thresholds: points at which a marked effect or change occurs

Transpiration: the process in which water is absorbed by the root systems of plants, moves up through the plant, passes through pores (stomata) in the leaves and other plant parts, and then evaporates into the atmosphere as water vapour

Turbid: the cloudy appearance of water due to suspended material

Unconfined aquifer: an aquifer close to the land surface which receives direct recharge from rainfall. Its upper surface is the water table. Also known as a superficial, or surficial, aquifer.

Vegetative reproduction: a type of asexual reproduction found in plants. Also called vegetative propagation or vegetative multiplication.

Water allocation plan: a plan that determines and licenses how much groundwater or surface water can be taken from a region for domestic or commercial purposes without adversely affecting ecological, recreational and cultural values

Water budget: the balance of all of the inflows and outflows of water

Water licence: a formal permit which entitles the licence holder to 'take' water from a watercourse, wetland or underground source under the *Rights in Water and Irrigation Act 1914*

Water regime (wetland): the pattern of when, where and to what extent water is present in a wetland. It includes the timing, duration, frequency, extent, depth and flow, and the variation in these features over time.

Water requirements: the water required by a species, in terms of when, where and how much water it needs, including timing, duration, frequency, extent, depth and variability of water presence

Water table: the upper surface of the groundwater in an unconfined aquifer (top of the saturated zone). Also known as the groundwater table.

Wetland hydrology: the movement of water into and out of, and within a wetland

Wetland water regime: the pattern of when, where and to what extent water is present in a wetland. It includes the timing, duration, frequency, extent, depth and flow, and the variation in these features over time.

Wetland water budget: the difference in volume between the inputs (water sources) and outputs of water over a set period of time

Personal communications

Name	Date	Position	Organisation
Margaret Smith	14/07/2009	Hydrologist	Department of Environment and Conservation, Western Australia
Gavan Mullan	17/08/2009	Recovery Catchment Officer	Department of Environment and Conservation, Western Australia

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A guide to managing and restoring wetlands in Western Australia

Wetland weeds

Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Wetland weeds' topic

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Contents

Case studies

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

Ecosystem services: the processes by which the environment produces resources that provide benefits to humans, e.g. flood and disease control, clean air, waste recycling, plant pollination[2]

Introduction

Weeds pose a serious threat to Western Australia's environment, society and the economy. Weeds threaten primary production, and the biodiversity and conservation values of Western Australian ecosystems.[1] They impact severely on agriculture and biodiversity by competing with crops and out-competing native plants and degrading habitat. The cost to Australian agriculture alone of managing weeds is estimated to be over $4 billion a year and in Western Australia, as much as 20 per cent of annual production costs.[2]

The cost of weeds from loss of biodiversity and **ecosystem services** is likely to be of a similar magnitude.[2] At present, environmental weeds are generally not managed to the same extent as agricultural or pastoral weeds.

In recognition of existing and potential impacts of weeds, in 2001 the Western Australian Government released *A Weed Plan for Western Australia*[1] to coordinate effective weed management across the state. The *State of the Environment Report: Western Australia 2007* further highlights the significance of weeds by identifying them as a number one priority for management.[2]

What is a weed?

In general terms, a **weed** can be defined as 'a plant that requires some form of action to reduce its harmful effects on the economy, the environment, human health and amenity, and [the term weed] can include plants from other countries or other regions in Australia or Western Australia.[2]

This topic focuses on '**environmental weeds**', which refers to plants that become established in natural ecosystems, altering natural processes and leading to the decline of the communities they invade.[3,1]

Naturalised: plants that spread and persist outside of their normal range of distribution

Where do weeds come from?

Most Western Australian weeds originate from South Africa, Europe, Asia and America, brought in by early settlers as ornamental garden plants or for aquaculture, pastoral and agricultural production.[4,5] It is estimated that about two thirds of the weeds now established in Australia originated from gardens[2] (see Figure 1). Some weeds were also introduced unintentionally transported in soil, in water and in animal fur and feed.

However, not all weeds originate from other countries. Some Australian native species have become **naturalised** outside their normal range of distribution and are considered weeds when they disrupt the structure and diversity of other native plant communities.

Figure 1. Native to South Africa, arum lily *(Zantedeschia aethiopica)* was first introduced as a garden plant and is still used in the floriculture industry. It is a major wetland weed that is very difficult to eradicate once established.
Photo – B Huston/DEC.

Weed distribution in Western Australia

About 10 per cent of Western Australia's flowering plants are introduced weeds and these comprise more than half of the recognised weeds in Australia. It is estimated that of the 1,233 identified weed species in WA, around 55 per cent are classified as environmental weeds, most of which (around 800 identified species) are found in the Swan Coastal Plain **bioregion** (see Figure 2).[2] Over 300 identified weed species occur in the South West region and between 100 and 200 identified species occur in parts of the Goldfields, Mid West, Pilbara and Kimberley regions. Weed numbers in the central desert area of WA is low in comparison, with less than 30 identified species.[2]

Bioregion: a territory defined by a combination of biological, social and geographic criteria rather than by geopolitical considerations; generally, a system of related, interconnected ecosystems[1]

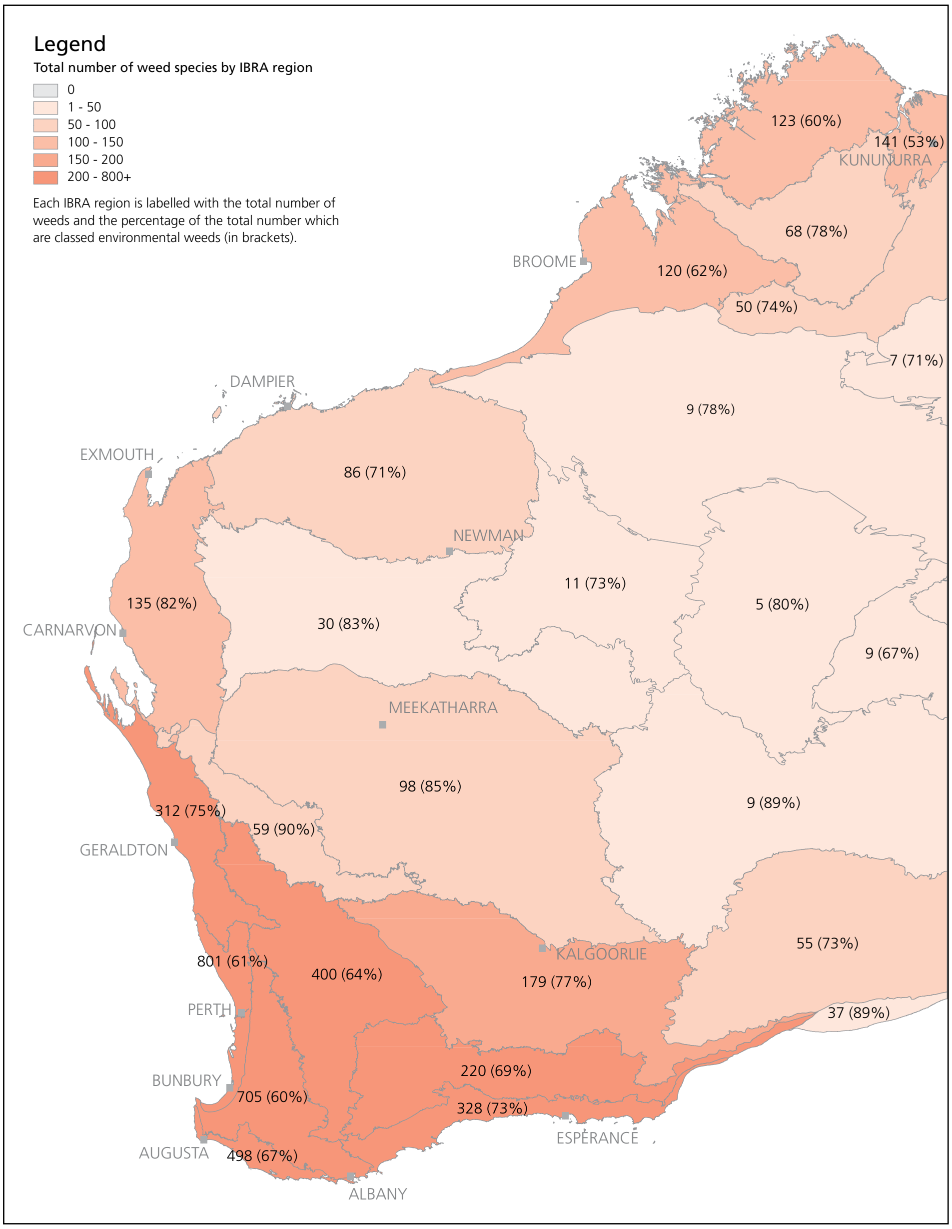


Figure 2. Total number of weed species found per bioregion and percentage that are environmental weeds (in brackets). Source: *State of the Environment Report: Western Australia 2007*.[2]

What causes weeds to occur and spread in wetlands?

In the south-west of Western Australia, weeds have invaded almost every wetland.[5] Weeds that flourish in wetlands often have broad tolerance limits to nutrients, pH, salinity and hydrological regimes and many are '**disturbance opportunists**', responding positively and rapidly to habitat disturbance. Understanding how weeds spread is essential in preventing them from becoming established in wetlands, and managing existing infestations.

Wetlands are vulnerable to weed invasion where there is disturbance of the soil and native vegetation, leaving the soil bare and ideal for germination of weed seeds. Disturbed edges of wetlands are most at risk from weed invasion, for example where they are located within or adjacent to highly disturbed landscapes such as housing settlements, parklands, paddocks, road verges and tracks.

When a wetland is disturbed, space and light conditions increase, creating favourable conditions for weed growth. Disturbance events in wetlands may be natural or resulting from human activities. Natural events in wetlands such as drying and wetting, drought and fire can lead to mass germination of many weed species.

Human activities that contribute to the introduction and spread of weeds include altering hydrology, clearing native vegetation, dumping garden waste, livestock access and vehicle movement (see Figure 3). Frequent fires and spread of dieback in urban wetlands and surrounding bushland also favour weed invasion and establishment.

Figure 3. (below) Weeds are introduced and spread around wetlands by many means including (a) dumping of garden waste such as prunings, lawn clippings and soil, (b) grazing livestock, and (c) vehicles in wetlands. Photos – T Bell/DEC.

(a)

Figure 3. (continued)

(b)

(c)

In comparison to disturbed areas, intact, undisturbed densely vegetated areas are more resilient to weed invasion as weeds are less able to get a foothold and compete for light, moisture and nutrients[5] (see Figure 4).

Figure 4. Wetlands with an intact understorey and few disturbances are more resilient to weed invasion. Photo – J Higbid/DEC.

Once established, weeds can very quickly dominate and degrade natural ecosystems by out-competing and replacing native plants, which may not be able to maintain their dominance or territory as a result (see Figure 5).

Figure 5. The understorey of this wetland has been completely replaced with kikuyu grass (*Pennisetum clandestinum*). Photo – T Bell/DEC.

Weeds can also occur in inundated areas of wetlands in which introduced aquatic plants can cover water surfaces and shade out submerged native aquatic plants and animals.[6] Aquatic weeds can be introduced into wetlands through disposal of ornamental aquatic plants from ponds or aquariums into wetlands or waterways and drains that feed into them (see Figure 6).

Seed dispersal mechanisms: the means by which plants distribute their seeds, for example via wind, water, birds and insects

The rate of weed invasion in wetlands depends on the type and level of disturbance(s) and the growth and reproductive characteristics of the weed. Other factors that influence weed invasion include climate, season, soil type, water and nutrient availability, extent, type and condition of native vegetation and presence of seed dispersal mechanisms.

Characteristics that give weeds a competitive advantage over many native species and assist in their spread include production of large numbers of highly viable seeds, multiple **seed dispersal mechanisms**, seed dormancy, underground storage organs and the ability to germinate and spread rapidly.[5] The absence of predators and diseases that would otherwise keep weeds in check in their countries of origin also provides a competitive advantage.[7]

Figure 6. Salvinia (*Salvinia molesta*) is a free-floating fern and a serious aquatic weed that forms dense masses on the water surface. It was originally introduced from South America as a pond ornamental. Photo – K Tripp/Shire of Wyndham East Kimberley.

Whilst many weeds are introduced to wetlands due to human activities, some invade by themselves through the dispersal of seed and vegetative propagules (see Figure 7). Weeds have a variety of adaptations that can help them disperse more effectively, such as sticky, hooked or light weight seeds that are ideal for catching a ride in fur, wool, clothing, wind or water. Some seeds are ingested by animals and birds and deposited in faeces in a different location.

Figure 7. Pasture grasses are common wetland weeds. Kikuyu grass (*Pennisetum clandestinum*) is spreading from this horse property across a firebreak into the vegetation of an adjacent wetland. Photo – T Bell/DEC.

Humans can assist in spreading weeds by transporting seeds attached to shoes, clothing or vehicles or by dumping soil fill (containing weed seeds or vegetative material), garden prunings or lawn clippings in and around wetlands. Wetland weeds generally produce large numbers of highly viable seed that are easily spread. For example, a major wetland weed, pampas grass (*Cortaderis selloana*), produces up to 100,000 seeds per flower plume, which are readily spread over long distances by wind and water[5] (see Figure 8). Bridal creeper, blackberry, olive tree and Japanese pepper have seeds encased in fleshy fruits that are rapidly dispersed by birds and foxes.[5]

Figure 8. Producing around 100,000 seeds per flower head, pampas grass (*Cortaderia selloana*) seeds are easily spread by wind and can travel for long distances. Photo – T Bell/DEC.

What effects do weeds have on wetlands?

Weed invasion poses a serious threat to the biodiversity and conservation values of wetlands and can disrupt key ecosystem functions.[5] The development of native seedlings can be hindered by the competition created by weeds for light, nutrients and moisture. This can lead to displacement of native plants and loss of biodiversity due to degradation and simplification of the wetland plant community. Weeds can also increase fire risk by increasing fuel loads in summer, contribute to soil erosion problems, reduce native fauna habitat and reduce overall ecosystem resilience[5] (see Figure 9).

Figure 9. Weeds can pose a serious fire risk in wetlands, particularly during summer when annual weeds die off, increasing fuel loads. Photo – Environmental Protection Branch/Fire and Emergency Services Authority.

Weeds can also contribute to reduction in water quality of wetlands, which in turn can lead to midge problems, algal blooms, loss of natural invertebrate communities, displacement of native species and a reduction in aesthetic and recreational values. Heritage values can also be affected by weeds, for example where traditional Aboriginal bush tucker plants are displaced or watering holes and camping sites are degraded.[5] The control of weeds is therefore essential for the long-term protection, management and restoration of wetlands.

Broadleaf: plants that possess relatively broad flat leaves rather than needle-like leaves

Succulent: plants which have specialised fleshy, soft and juicy tissues designed for the conservation of water e.g. cacti

Weed impact at a glance

The impact of environmental weeds on wetlands can be significant where they compete with native vegetation, inhibiting growth and natural regeneration. This can result in:

- loss of biodiversity as weeds replace native plants
- loss of habitat and food source for wetland birds and other fauna (e.g. replacement of native shrubs and groundcovers with grasses)
- increased fire risk
- increased erosion risk (e.g. bank erosion)
- altered nutrient recycling
- altered soil quality
- reduced water quality (e.g. reduction of light and oxygen from aquatic weeds)
- loss of aesthetic amenity and recreational value
- increased management costs.

The control of weeds is therefore essential for the long-term protection, management and restoration of wetlands.

What types of weeds affect wetlands?

To control wetland weeds successfully, it is vital to understand the different types of weeds that exist and how (and when) they grow, reproduce and spread. Without this knowledge, weed control measures may not be effective and may result in wasted time, money and effort. Inappropriate weed control may also result in direct or indirect damage to native flora and fauna and can exacerbate the weed problem.

Weeds can be divided into three broad types: non-woody weeds, woody weeds and aquatic weeds. Non-woody weeds are weeds with a non-woody green stem (i.e. are herbaceous), woody weeds have a woody stem and aquatic weeds are those that grow partly or wholly submerged in water.

Non-woody weeds

Non-woody weeds refer to weeds with a non-woody green stem. They include grasses, **broadleaf** herbs, rushes and sedges, **succulents**, ferns, some vines and plants that develop specialised underground storage organs known as bulbs, corms and tubers.

extra information

Weed life cycles and reproduction

Weeds have either an **annual**, **biennial** or **perennial** life cycle. Most wetland weeds are annual species, which means they normally complete their life cycle within a single growing season (from germination to flowering, seed production and death of vegetative parts). Biennial weeds normally complete their life cycle within two years while perennial weeds, often the most invasive type of weed, normally live for two or more growing seasons.

Weeds reproduce sexually through the production of seed, or asexually (or vegetatively), in which parts of the parent plant (e.g. spores, rhizomes, stolons, bulbs, tubers, corms and buds) detach and generate new individuals. Some weeds reproduce both sexually and asexually.

Life form: the shape or appearance of a plant that mostly reflects inherited or genetic influences

Grasses

Grasses can be one of the most serious and difficult weeds to control in wetlands. Once established, they can spread very quickly, smothering native vegetation, and in the case of many annual grasses (which die off during the summer months), significantly increasing wetland fuel loads and fire hazard. Many grasses are also extremely resilient and can re-sprout after damage from trampling, grazing, drought or fire.

Grasses are highly successful colonisers due to their specialised **life forms** and reproductive strategies. Understanding the growth and reproductive strategies of grass weeds is essential in order to identify the most appropriate control methods and how and when they are best applied.

Annual grasses

Completing their life cycle within a year, annual grasses produce seeds which can be dispersed very efficiently by one or more means including wind, water, native and domestic animals and vehicles. Individual plants may produce hundreds or thousands of seeds, which can remain dormant in the soil, waiting to germinate when conditions are favourable. Minimising soil disturbance, which exposes buried weed seeds, is a key strategy in controlling the germination and spread of annual weeds.

Fire can also trigger germination of dormant seeds, with the resulting bare soil and increased light and nutrient availability following a fire providing ideal conditions for grasses to become established.[5]

Examples of annual grass weeds that grow in wetlands include (see Figure 10):

- annual veldt grass (*Ehrharta longiflora*)
- barb grass (*Parapholis incurva*)
- fountain grass (*Pennisetum setaceum*)
- great brome (*Bromus diandrus*)
- blowfly grass (*Briza maxima*)
- rye grass (*Lolium* spp.)
- shivery grass (*Briza minor*)
- wild oat, bearded oat (*Avena fatua, A. barbata*).

Figure 10. **(below)** Examples of annual grass weeds that grow in wetlands. Photos – (a) and (b) R Randall/Western Weeds; (c) L Fontanini and KC Richardson; (d) A Ireland and KR Thiele; (e) L Fontanini; (f) J F Smith. Images (c)–(f) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) annual veldt grass (*Ehrharta longiflora*)

(b) bearded oat (*Avena barbata*)

(c) great brome (*Bromus diandrus*)

(d) blowfly grass (*Briza maxima*)

(e) shivery grass (*Briza minor*)

(f) annual barbgrass (*Polypogon monspeliensis*)

Perennial grasses

Perennial grasses can survive for several or more years, often producing highly viable seed each year that can be spread by wind, water, native and domestic animals and vehicles. Perennial grasses also reproduce **vegetatively** from **stolons**, **rhizomes** and occasionally corms, which store energy reserves that allow the plant to survive during dormancy or extreme conditions such as fire or drought. Stolons are stems that usually run horizontally along the soil surface and rhizomes are stems that are buried underground. Both types of stems have dormant buds that can produce new roots and shoots and allow rapid lateral (sideways) growth of plants, particularly after fire.[5] Perennial grasses are either summer or winter growing, forming tussocks or mats that can quickly smother native plants.

Vegetative reproduction: a type of asexual reproduction found in plants. It is also called vegetative propagation or vegetative multiplication

Examples of perennial grass weeds that grow in wetlands include (see Figure 11):

- African lovegrass (*Eragrostis curvula*)
- buffalo grass (*Stenotaphrum secundatum*)
- couch (*Cynodon dactylon*)
- kikuyu (*Pennisetum clandestinum*)
- paspalum (*Paspalum dilatatum*)
- perennial rye grass (*Lolium perenne*)
- perennial veldt grass (*Ehrharta calycina*)
- phalaris (*Phalaris aquatica*)
- sweet vernal grass (*Anthoxanthum odoratum*)
- tambookie grass (*Hyparrhenia hirta*)
- yorkshire fog (*Holcus lanatus*).

Tall (or giant) perennial grasses:

- African feather grass (*Pennisetum macrourum*)
- bamboo (*Bambusa* spp.)
- elephant grass (*Pennisetum purpureum*)
- fountain grass (*Pennisetum setaceum*)
- giant reed (*Arundo donax*)
- pampas grass (*Cortaderia selloana*).

Figure 11. (below) Perennial grass weeds that grow in wetlands. Photos – (a) JF Smith; (b) V English/DEC; Trevor Hall/DEEDI © The State of Queensland, Department of Employment, Economic Development and Innovation (Trevor Hall), 1995; (c) L Fontanini; (d) R Randall/ Western Weeds. Image (a) and (c) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) fountain grass (*Pennisetum setaceum*)

(b) buffel grass (*Cenchrus ciliaris*)

Figure 11. (continued)

(c) Yorkshire fog (*Holcus lanatus*)

(d) giant reed (*Arundo donax*).

Grass growth forms

Grasses fall into one of three descriptive growth forms; tussock, stoloniferous or rhizomatous. Understanding the different growth forms is a key consideration when deciding on the best control methods for specific weeds.

Tussock grasses

Tussock grasses are the most common grass growth form, usually forming dense, erect clumps that can create large fuel loads as they age and die off (see Figure 12). They reproduce by seed and/or by sprouting new shoots located at the base of the plant. Most annual grasses are tussock forming, such as annual veldt grass (*Ehrharta longiflora*), fountain grass (*Pennisetum setaceum*) and wild oat (*Avena fatua*). Examples of perennial tussock grasses that can occur in wetlands include pampas grass (*Cortaderia selloana*), perennial veldt grass (*Ehrharta calycina*) and tambookie grass (*Hyparrhenia hirta*).

Figure 12. Example of a tussock grass (perennial veldt grass, *Ehrharta calycina*). Photo – R Cousens/Western Weeds.

Stoloniferous grasses

These grasses possess specialised stems called stolons that store energy reserves and spread laterally across the soil surface, sprouting new shoots and roots. Stoloniferous grasses also produce seed, which in combination with reproduction by runners, makes them extremely invasive, particularly where moist, fertile soils are present. Examples of species that can occur in wetlands include kikuyu (*Pennisetum clandestinum*), couch (*Cynodon dactylon*) and saltwater couch (*Paspalum vaginatum*).

Rhizomatous grasses

Rhizomatous grasses spread laterally by means of special underground stems called rhizomes, which sprout new roots and shoots as they grow. Like stoloniferous grasses, rhizomatous grasses can also reproduce by seed, making them extremely invasive. Rhizomes store energy reserves and being underground, they are protected from extremes in climate (e.g. during drought or fire), allowing them to re-sprout vigorously if the above ground portion of the plant is damaged or killed. They are highly invasive, particularly where moist, fertile soils are present. Examples of species that can occur in wetlands include giant reed (*Arundo donax*), perennial veldt grass (*Ehrharta calycina*) and kikuyu (*Pennisetum clandestinum*). Some grasses, such as kikuyu, produce both rhizomes and stolons.

extra information

Native grasses that look like weeds

Western Australia has many species of native plants that can be mistaken for weeds. Native grasses are particularly prone to mistaken identity (see Figure 13). For this reason, it is essential to accurately identify weed species before implementing a weed control program.

(a) (b)

Figure 13. The weed tambookie grass (a) (*Hyparrhenia hirta*) is sometimes mistaken for native kangaroo grass (b) (*Themeda triandra*). Photos – P Hussey/Western Weeds.

➤ For additional detail on weed identification see the section 'Sources of more information on managing weeds in wetlands' at the end of this topic.

Broadleaf herbs

As with grass weeds, it is important to distinguish between annual and perennial herbs as this helps to determine the most appropriate management and control strategy.

Annual herbs

Most annual herbs in south-western Australia germinate with the first rains of autumn and set seed and die during the following summer months.[8] However, in wetlands, some annual weeds germinate when water levels drop during spring and set seed the following autumn. Other species are more opportunistic, sometimes germinating, flowering and setting seed more than once a year when conditions are favourable.[8] Examples of common annual herbs that can occur in wetlands include (see Figure 14):

- blackberry nightshade (*Solanum nigrum*)
- bushy starwort (*Symphyotrichum squamatum*)
- flaxleaf fleabane (*Conyza bonariensis, C. parva*)
- Paterson's curse (*Echium plantagineum*)
- tall fleabane (*Conyza sumatrensis*)
- white bartsia (*Bartsia trixago*)
- wild radish (*Raphanus raphanistrum*).

Figure 14. (below) Annual herb weeds that grow in wetlands. Photos – (a) SM Armstrong, KC Richardson and JF Smith; (b) R Randall; (c) G Byrne and KC Richardson; (d) J Dodd and R Knox; (e) L Fontanini, KC Richardson and JF Smith; (f) S M Armstrong. Images (a) – (f) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) blackberry nightshade (*Solanum nigrum*)

(b) flaxleaf fleabane (left, *Conyza bonariensis* and right, *Conyza parva*)

Figure 14. (continued)

(c) white bartsia (*Bartsia trixago*)

(d) Paterson's curse (*Echium plantagineum*)

(e) wild radish (*Raphanus raphanistrum*)

(f) bushy starwort (*Symphyotrichum squamatum*)

Perennial herbs

Perennial herbs have a life cycle of two or more years. Depending on species, they can reproduce by seed, stolons and rhizomes. Examples of perennial herbaceous weeds that can occur in wetlands include (see Figure 15):

- castor oil plant (*Ricinus communis*)
- dock (*Rumex* spp.)
- gentes herb (*Canna x generalis*)
- pennyroyal (*Mentha pulegium*)
- sorrel (*Acetosa vulgaris*).

Figure 15. (below) Perennial herbs that grow in wetlands. Photos – (a) I Morley/DEC; (b) G Keighery/Western Weeds; (c) JF Smith (d) J Dodd and KR Thiele; (e) R Knox; (f) K Brown/DEC. Images (c) – (e) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) curled dock (*Rumex crispus*)

(b) fiddle dock (*Rumex pulcher*)

(c) canna hybrid (*Canna* spp.)

(d) castor oil plant (*Ricinus communis*)

(e) pennyroyal (*Mentha pulegium*)

(f) blue periwinkle (*Vinca major*)

Sedges

Sedges are also classed as herbs or graminoids and refer to the grass-like species from the plant families including Juncaceae and Cyperaceae. The 'bulrush' refers to plants within the family Typhaceae (see below). Native sedges perform a vital role in wetlands, controlling erosion, maintaining water quality and providing habitat. However there are some species (both native and introduced) that can become invasive weeds in wetlands. Examples of weed species of sedges that can occur in wetlands include (see Figure 16):

- jointed rush (*Juncus articulatus*)
- spiny rush (*Juncus acutus*)
- tiny rush (*Juncus microcephalus*).
- budding club-rush (*Isolepis prolifera*)
- bunchy sedge (*Cyperus polystachyos*)
- club-rush (*Isolepis hystrix*)
- dense flat sedge (*Cyperus congestus*)
- divided sedge (*Carex divisa*)
- umbrella sedge (*Cyperus eragrostis*).

Sedge: tufted or spreading plant from the families Cyperaceae, Centrolepidaceae, Hydatellaceae, Juncaginaceae, Restionaceae, Juncaceae, Typhaceae and Xyridaceae. In these plants the leaf sheath is generally not split, there is no ligule, the leaf is not always flat and there is an extended internode below inflorescence. Some sedges are also known as rushes.

Figure 16. (below) Examples of rushes that are weeds that occur in wetlands. Photos – (a) GJ Keighery and JF Smith; (b) K Brown/DEC; (c) J F Smith; (d) K Bettink/DEC; (e) GJ Keighery and JF Smith; (f) BA Fuhrer. Images (a), (c), (e) and (f) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) bulrush (*Typha orientalis*)

(b) sharp rush (*Juncus acutus*)

(c) dense flat sedge (*Cyperus congestus*)

(d) *Isolepis hystrix*

Figure 16. (continued)

(e) bunchy sedge (*Cyperus polystachyos*)

(f) capitate rush (*Juncus capitatus*)

Typha

One of the most aggressive weeds of Western Australian wetlands is the introduced species *Typha orientalis*, a native of eastern Australia[9] (see Figure 17). The native species, *Typha domingensis*, is often mistaken for the introduced species, and both are commonly referred to as 'bulrush'. *Typha orientalis* is generally taller, with wider leaves and flower heads. The leaf blade of *T. domingensis* does not exceed 8 millimetres in width while the leaf blade of *T. orientalis* can be up to 14 millimetres wide (although exceptions exist making it difficult to distinguish between the two). Spreading from rhizomes, once established, *T. orientalis* rapidly forms a dense monoculture, suppressing all other vegetation. With each seed head producing up to 300,000 seeds, control is very difficult once established and requires vigilance for several years. *Typha* infestations can be linked to excessive nutrients within wetlands and/or altered hydrology whereby changes in wetland natural wetting/drying cycles can favour their establishment and dominance over native aquatic vegetation.

Figure 17. (below) (a) The introduced bulrush (*T. orientalis*) has formed a dense monoculture in Lake Mealup; (b) introduced typha seeds covering the soil surface; (c) seeds are easily spread by the wind. Photos – (a) N Landmann/DEC; (b) and (c) T Bell/DEC.

(a)

(b)

(c)

Weeds with corms, bulbs and tubers

This group of weeds possesses specialised underground fleshy storage organs known as corms, bulbs or tubers. These organs allow them to flourish in nutrient deficient soils or die back and enter a state of dormancy when conditions are extreme, such as during fire or drought.[8] Many species have spread from gardens, where they have been grown as ornamentals (for example arum lilies and freesias). Dumping of garden waste and soil in or near wetlands has assisted their spread and establishment. Their seed and underground reproductive structures can also be spread by water, wind, animals and by other human activities. Fire can also play a role in stimulating sprouting of dormant corms in the soil, which can remain viable for many years, in some cases longer than seed.

Figure 18. Two-leaf cape tulip (*Moraea miniata*) cormels. Photo – R Knox/Western Weeds.

The competitive advantage these weeds possess as a result of their underground storage organs, diverse reproductive strategies and ability to spread is considerable and, as such, they are a highly invasive and persistent group of weeds. Once established, they are extremely difficult to eradicate, particularly if a bank of dormant corms or bulbs has built up in the soil (see Figure 18). As a result, follow-up control may need to be undertaken for some years. Table 1 compares the differences between corms, bulbs and tubers.

Table 1. Comparison of life cycle and reproductive strategies of corms, bulbs and tubers

Type	Location of storage organ	Typical life cycle	Reproduction
Corms	Swollen underground stems or stem bases	Summer dormant, sprouting from corms in autumn. Produces one or two daughter corms annually	• Daughter corms • Cormels (small corms formed around the parent corm) • Axillary buds (that form new plants when the main growing shoot is removed) • Seed
Bulbs	Swollen underground leaf bases	Summer dormant, sprouting new leaves in autumn. Perennials produce one or two daughter bulbs annually	• Daughter bulbs • Bulbils (small bulbs formed at base of leaves or on underground stems, form new plants when detached) • Seed
Tubers	Swollen underground stems or roots, forming dense tuberous root mats	Usually summer dormant, re-sprouting in autumn	• New shoots arising from rhizomes • Seed

Examples of weeds with corms, bulbs and tubers that can occur in wetlands include (see Figure 19):

Corms

- freesia (*Freesia alba x leichtlinii*)
- harlequin flower (*Sparaxis bulbifera*)
- one-leaf cape tulip (*Moraea flaccida*)
- two-leaf cape tulip (*Moraea miniata*)
- watsonia (*Watsonia meriana*)

Bulbs

- belladonna lily (*Amaryllis belladonna*)
- soursob (*Oxalis pes-caprae*)
- three-cornered garlic (*Allium triquetrum*)

Tubers

- asparagus fern (*Asparagus aethiopicus*)
- arum lily (*Zantedeschia aethiopica*)
- bridal creeper (*A. asparagoides*)
- bridal veil (*A. declinatus*)

Figure 19. (below) Examples of cormous, bulbous and tuberous weeds that occur in wetlands. Photos – (a) L Fontanini; (b) A Shanahan/DEC and R Knox; (c) R Randall; (d) JP Pigott and R Randall; (e) R Randall; (f) KC Richardson and KR Thiele. Images (a) – (f) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

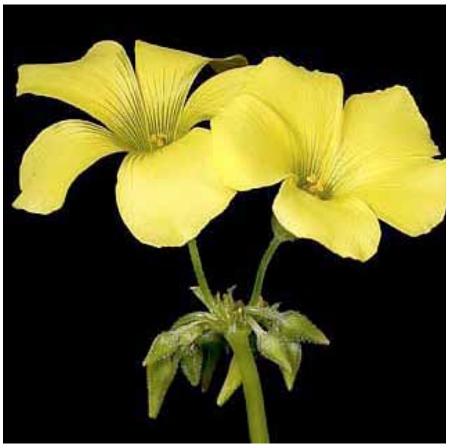
(a) three-cornered garlic (*Allium triquetrum*)

(b) two-leaf cape tulip (*Moraea miniata*)

(c) watsonia (*Watsonia meriana*)

(d) bridal creeper (*Asparagus asparagoides*)

(e) harlequin flower (*Sparaxis bulbifera*)



(f) soursob (*Oxalis pes-caprae*)

Woody weeds

Woody weeds are perennial weeds with woody stems including shrubs, trees and some vines. Most woody weeds reproduce by seed and some have a further advantage of being able to re-sprout from stems or branches (for example, after fire or lopping) or by means of a suckering root system (that is, re-sprouting from lateral roots). Woody weeds such as some vines can be problematic in wetlands when they form dense, impenetrable thickets which shade out and prevent germination of native species (see Figure 20). Removal of large woody weeds can be problematic, resulting in damage to surrounding vegetation, spread of seeds and secondary invasion of other weeds when light availability and temperature are increased following their removal (see Figure 21).

Figure 20. Passion vine (*Passiflora foetida*) infestation at Windjana Gorge. The fruits of this species are readily eaten by birds and mammals and distributed widely throughout the Kimberley. Passion vine dominates and smothers native vegetation, creating a higher fuel load in fire-sensitive ecosystems. Photo – L Williams/Environs Kimberley.

Figure 21. Coffee bush (*Leuceana leucocephala*) infestation along the foreshore of Roebuck Bay (Ramsar wetland). Spread by cattle and through water and soil movement, this species easily invades and dominates areas that have a history of disturbance. Photo – L Williams/Environs Kimberley.

Management and control of woody weeds should take into account re-sprouting/suckering ability, risk of spreading seed and damage to surrounding vegetation, and secondary weed invasion. Examples of woody weeds that can occur in wetlands include (see Figure 22):

Trees

- athel pine (*Tamarix aphylla*)
- coral tree (*Erythrina* spp.)
- date palm (*Phoenix dactylifera*)
- poplar tree (*Populus* spp.)
- willow (*Salix babylonica*)

Small trees and shrubs

- buckthorn (*Rhamnus alaternus*)
- edible fig (*Ficus carica*)
- flax leaf paperbark (*Melaleuca linariifolia*)
- Japanese pepper (*Schinus terebinthifolia*)
- lantana (*Lantana camara*)
- olive (*Olea europaea*)
- sweet pittosporum (*Pittosporum undulatum*)
- Sydney golden wattle (*Acacia longifolia*)
- tagasaste (*Chamaecytisus palmensis*)
- taylorina (*Psoralea pinnata*)
- victorian tea tree (*Leptospermum laevigatum*)

Vines

- blue periwinkle (*Vinca major*)
- dolichos pea (*Dipogon lignosus*)
- Japanese honeysuckle (*Lonicera japonica*)
- morning glory and coast morning glory (*Ipomoea indica, I. cairica*)

Figure 22. (below) Examples of woody weeds that occur in wetlands. Photos – (a) I Morley/DEC and A Fairs/DEC; (b) TC Daniell and M Hancock; (c) KC Richardson; (d) L Fontanini; (e) KC Richardson; (f) K Bettink/DEC; Images (b) – (e) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) common fig (*Ficus carica*)

(b) Sydney golden wattle (*Acacia longifolia*)

(c) victorian tea tree (*Leptospermum laevigatum*)

(d) sweet pittosporum (*Pittosporum undulatum*)

(e)) athel pine (*Tamarix aphylla*)

(f) morning glory (*Ipomoea indica*)

extra information

Natives behaving like weeds

Some species of native wetland plants can behave like weeds if the wetlands in which they grow naturally are disturbed, or they are introduced (or spread) into areas outside of their natural range. Like weeds, these natives are opportunists that can take advantage of disturbed conditions, rapidly colonising areas to the exclusion of other native species. Native plants such as bracken fern (*Pteridium esculentum*) can form dense monocultures that alter the structure and diversity of wetland ecosystems (see Figure 23). Other examples of natives that can behave like weeds include:

- golden wreath wattle (*Acacia saligna*)
- native typha (*Typha domingensis*)
- marsh club-rush (*Bolboschoenus caldwellii*)
- white cedar (*Melia azedarach*).

Figure 23. (below) Photos – (a) T Bell/DEC; (b) A Ireland and J Smith. Image (b) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) Bracken fern (*Pteridium esculentum*) is an opportunist species.

(b) It can form dense thickets that smother out other native understorey vegetation.

Legislation and weeds

Declared plants in Western Australia

Plants that pose a serious threat to agriculture are declared under the *Agriculture and Related Resources Protection Act 1976*. Any landholder with declared plants on their property is required to control them at their own expense. For a complete list of declared plants in Western Australia, see the Department of Agriculture and Food WA website (www.agric.wa.gov.au).[10]

Weeds of national significance

Through the National Weeds Strategy framework, the Australian Government has identified twenty weeds of national significance (WONS). Due to their invasiveness, impacts and potential for spread, these weeds pose a serious threat to agriculture, forestry and the environment. Landowners with WONS on their property are responsible for their management at their own expense. A full list of WONS and management guidelines are available at www.weeds.gov.au.[11]

Aquatic plants: a plant that grows for some period of time in inundated conditions and depends on inundation to grow and, where applicable, flower

Aquatic weeds

Native aquatic plants perform vital functions in wetlands; they bind the sediment, provide habitat for aquatic fauna and help maintain optimal water quality. However, when some species (native and introduced) become highly abundant under certain conditions, they can severely alter wetland ecology.

- For additional detail on in the role of aquatic plants in wetlands, see the topic 'Wetland ecology' in Chapter 2.

Aquatic plants include plants that float with roots trailing in the water surface (floating aquatics) and those that are fully or partly submerged in the water with roots attached to the sediment (submergent aquatics). Introduced species of aquatic plants can enter wetlands in a number ways, for example, directly from disposal of pond, dam and aquarium plants and waste into wetlands, or indirectly via waterways and stormwater drains that feed into wetlands. Birds and other animals can also transport seed and plant material from backyard ponds or dams into wetlands.

Prolific growth of aquatic weeds is often a symptom of elevated levels of nutrients in the water or sediments, which can cause an increase in plant growth. If the right conditions occur, such as increased light intensity and water temperature in combination with high nutrient levels, an explosion in plant growth can occur. Factors that contribute to elevated nutrient levels may include the discharge of nutrient-rich stormwater into wetlands, uncontrolled livestock access or leaching of fertiliser from nearby agricultural areas and urban gardens and lawns. Elevated light intensity and water temperature in wetlands can result from a reduction in shading due to clearing of wetland vegetation such as overhanging trees.

- Algal blooms are also a symptom of elevated nutrients in wetlands. This is discussed in more detail in the topic 'Water quality' in Chapter 3.

A common feature of aquatic weeds is their ability to form a dense layer, or 'mat', above or below the water, blocking out light and depleting the water body of oxygen.[6] This can lead to the death of fish and other aquatic life and shading out of native aquatic plants. Salvinia (*Salvinia molesta*) is an example of an aquatic weed that forms a dense mat on the water surface, shading the water beneath it and restricting growth of algae and submerged aquatic plants (Figure 28). This prevents air entering the water body and subsequent deoxygenation can kill fish and other organisms.[6,12] Salvinia is listed as a declared plant in Western Australia and a WONS.

Serious aquatic weeds include (see Figure 24):

- alligator weed[2,3] (*Alternanthera philoxeriodes*)
- arrow head[3] (*Saggitaria montevidensis*)
- Brazilian water milfoil[3] (*Myriophyllum aquaticum)*
- Canadian pond weed[3] (*Elodea canadensis*)
- fanwort[2,3] (*Cabomba caroliniana*)
- horsetails[3] (*Equisetum arvense*)
- hydrocotyle[3] (*Hydrocotyle ranunculoides*)
- lagarosiphon[2,3] (*Lagarosiphon major*)
- leafy elodea[3] (*Egeria densa*)
- saggitaria[3] (*Saggitaria platyphylla*)
- salvinia[2,3] (*Salvinia molesta*)
- strap weed (*Vallisneria australis*)
- watercress (*Rorippa nasturtium-aquaticum*)
- water hyacinth[1,3] (*Eichhornia crassipes*)
- water lettuce[3] (*Pistia stratiotes*).

1 Appears on '100 of the World's Worst' invasive species list
2 Weed of National Significance
3 Declared in WA

Figure 24. (below) Examples of aquatic weeds that occur in wetlands. Photos – (a) BA Fuhrer; (b) R Knox and WA Herbarium; (c) R Knox and J Dodd; (d) R Davis; (e) AGWEST; (f) DJ Edinger. Images (a) – (f) used with permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 6/11/2009.

(a) *Crassula natans*

(b) water hyacinth (*Eichhornia crassipes*)

(c) hydrocotyle (*Hydrocotyle ranunculoides*)

(d) watercress (*Rorippa nasturtium-aquaticum*)

(e) water lettuce (*Pistia stratiotes*)

(f) common starwort (*Callitriche stagnalis*)

Priority wetland weeds for management in Western Australia

The Department of Environment and Conservation has identified weeds that are priorities for management in WA regions to protect environmental assets from the threat posed by established weeds and to allow more effective use of available resources for management. Priority wetland weeds are summarised in Table 2. Priority weeds for control have been determined according to their ecological impact, invasiveness, current and potential distribution and feasibility of control.

Table 2. Priority wetland weeds for management in Western Australia by region

(K Agar 2009, pers. comm.); based on Keighery G and Longman V (2004). ***The naturalised vascular plants of Western Australia 1: Checklist of environmental weeds and distribution in IBRA regions,*** Plant Protection Quarterly, Volume 19 (1), 2004)

Common name	Scientific name
Swan Region	
Athel pine	*Tamarix aphylla*[1,2,3]
Baboon flower	*Babiana angustifolia*
Blackberry	*Rubus* spp.
Brazilian pepper	*Schinus terebinthifolius*
Bulrush	*Typha orientalis*
Burrgrass	*Cenchrus echinatus*
Castor oil plant	*Ricinus communis*
Clubrush	*Isolepis hystrix*
Couch	*Cynodon dactylon*
Crassula	*Crassula natans* var. *natans*
Date palm	*Phoenix dactylifera*
Divided sedge	*Carex divisa*
Fern cotula	*Cotula bipinnate*
Haas grass, tribolium	*Tribolium uniolae*
Harlequin flower	*Sparaxis bulbifera*
Pampas grass	*Cortaderia selloana*
Parrot's feather or brazilian water milfoil	*Myriophyllum aquaticum*
Pond stonecrop	*Crassula natans* var. *minus*
Robust pennywort	*Hydrocotyle ranunculoides*
Sagittaria	*Sagittaria platyphylla*
Salvinia	*Salvinia molesta*[2,3]
Slender thistle	*Carduus pycnocephalus*
Sparaxis	*Sparaxis bulbifera*
Spiny rush	*Juncus acutus*
Sweet pittosporum	*Pittosporum undulatum*
Taro	*Colocasia esculenta* var. *esculenta*

Common name	Scientific name
Water hyacinth	*Eichhornia crassipes*[1,3]
Wavy gladiolus	*Gladiolus undulates*
South West Region	
African feather grass	*Pennisetum macrocouru*
Athel pine	*Tamarix aphylla*[1,2,3]
Blackberry	*Rubus* spp.
Brazilian pepper	*Schinus terebinthifolius*
Bulrush	*Typha orientalis*
Burrgrass	*Cenchrus echinatus*
Castor oil plant	*Ricinus communis*
Clubrush	*Isolepis hystrix*
Couch	*Cynodon dactylon*
Date palm	*Phoenix dactylifera*
Divided sedge	*Carex divisa*
Harlequin flower	*Sparaxis bulbifera*
Kikuyu	*Pennisetum clandestinum*
Puccinellia	*Puccinellia ciliata*
Salvinia	*Salvinia molesta*[2,3]
Spiny rush	*Juncus acutus*
Water hyacinth	*Eichhornia crassipes*[1,3]
Watercress	*Rorippa nasturtium-aquaticum*
Midwest Region	
African love grass	*Eragrostis curvula*
Athel pine	*Tamarix aphylla*[1,2,3]
Bulrush	*Typha orientalis*
Burrgrass	*Cenchrus echinatus*
Castor oil plant	*Ricinus communis*
Clubrush	*Isolepis hystrix*
Couch	*Cynodon dactylon*
Cyperus	*Cyperus* spp.
Date palm	*Phoenix dactylifera*
Divided sedge	*Carex divisa*
Feather top	*Pennisetum villosum*
Harlequin flower	*Sparaxis bulbifera*
Kikuyu	*Pennisetum clandestinum*
Morning glory	*Ipomoea cairica* and *I.indica*

Common name	Scientific name
One-leaf cape tulip	*Moraea flaccida*
Paspalum	*Paspalum dilatatum*
Salvinia	*Salvinia molesta*[2,3]
Spiny rush	*Juncus acutus*
Water hyacinth	*Eichhornia crassipes*[1,3]
Waterbuttons	*Cotula coronopifolia*
Watercress	Rorippa nasturtium-aquaticum
Pilbara Region	
African love grass	*Eragrostis curvula*
Athel pine	*Tamarix aphylla*[1,2,3]
Butterfly pea	*Clitoria ternatea*
Castor oil plant	*Ricinus communis*
Cotton palm	*Washingtonia filifera*
Cyperus	*Cyperus involcratus*
Date palm	*Phoenix dactylifera*
Parkinsonia	*Parkinsonia aculeata*
Stinking passion flower	*Passiflora foetida*
Bulrush	*Typha orientalis*
Goldfields Region	
Annual barbgrass	*Polypogon monspeliensis*
Athel pine	*Tamarix aphylla*
Blackberry nightshade	*Solanum nigrum*
Blue pimpernel	*Lysimachia arvensis*
Bulrush	*Typha orientalis*
Couch	*Cynodon dactylon*
Tamarisk	*Tamarix ramossisima*
Toad rush	*Juncus bufonius*
Kimberley Region	
Castor oil plant	*Ricinus communis*
Couch	*Cynodon dactylon*
Giant rubber bush	*Calotropis gigantea*
Mimosa, giant sensitive plant	*Mimosa pigra*
Mint weed	*Hyptis suaveolens*
Morning glory	*Ipomoea* spp.
Paragrass	*Urochloa mutica*
Parkinsonia	*Parkinsonia aculeata*

Common name	Scientific name
Rosella	*Hibiscus sabdariffa*
Rubber bush	*Calotropis procera*
Rubbervine	*Cryptostegia grandiflora*
Salvinia	*Salvinia molesta*
Stinking passion flower	*Passiflora foetida*
Water hyacinth	*Eichhornia crassipes*
Windmill grass	*Chloris virgata*
Zornia	*Ziziphus mauritiana*
Warren Region	
African feather grass	*Pennisetum macrocourum*
Athel pine	*Tamarix aphylla*[1,2,3]
Blackberry	*Rubus* spp.
Brazilian pepper	*Schinus terebinthifolius*
Bulrush	*Typha orientalis*
Burrgrass	*Cenchrus echinatus*
Castor oil plant	*Ricinus communis*
Clubrush	*Isolepis hystrix*
Couch	*Cynodon dactylon*
Date palm	*Phoenix dactylifera*
Divided sedge	*Carex divisa*
Harlequin flower	*Sparaxis bulbifera*
Kikuyu	*Pennisetum clandestinum*
Puccinellia	*Puccinellia ciliata*
Salvinia	*Salvinia molesta*[2,3]
Spiny rush	*Juncus acutus*
Water hyacinth	*Eichhornia crassipes*[1,3]
Watercress	*Rorippa nasturtium-aquaticum*
Wheatbelt Region	
Annual barbgrass	*Polypogon monspeliensis*
Blackberry nightshade	*Solanum nigrum*
Blue pimpernel	*Lysimachia arvensis*
Couch	*Cynodon dactylon*
Spiny rush	*Juncus acutus*
Tamarisk	*Tamarix parviflora*
Toad rush	*Juncus bufonius*
Bulrush	*Typha orientalis*

Common name	Scientific name
South Coast Region	
African love grass	*Eragrostis curvula*
African scurfpea	*Psoralea pinnata*
Arum lily	*Zantedeschia aethiopica*
Blackberry	*Rubus* spp.
Blue periwinkle	*Vinca major*
Cotton bush	*Gomphocarpus fruticosus*
Couch	*Cynodon dactylon*
Hedera	*Hedera helix*
Lantana	*Lantana camara*
Lesser canary grass	*Phalaris minor*
Morning glory	*Ipomoea indica*
Myrtleleaf milkwort	*Polygala myrtifolia*
Nutgrass	*Cyperus rotundus*
Pampas grass	*Cortaderia selloana*
Sagittaria	*Sagittaria platyphylla*
Saltwater couch	*Paspalum vaginatum*
Salvinia	*Salvinia molesta*
Senecio	*Senecio angulatus*
Sparaxis	*Sparaxis bulbifera*
Spiny rush	*Juncus acutus*
Stinkwort	*Dittrichia graveolens*
Sweet pittosporum	*Pittosporum undulatum*
Sydney golden wattle	*Acacia longifolia*
Three-cornered garlic	*Allium triquetrum*
Bulrush	*Typha orientalis*
Water couch	*Paspalum distichum*
Water hyacinth	*Eichhornia crassipes*
Watercress	*Rorippa nasturtium-aquaticum*
Watsonia	*Watsonia meriana* var. *bulbifera*
Wavy gladiolus	Gladiolus undulates

1 Appears on '100 of the World's Worst' invasive species list
2 Weed of National Significance
3 Declared plant in Western Australia

Key techniques for managing weeds in wetlands

Once established, weeds can be extremely difficult to eradicate and require consistent and sustained effort over time to bring them under control. Where infestations are severe, it may not be possible to completely remove weeds and ongoing efforts must instead focus on containment to prevent further spread. Before embarking on a weed control program, some guiding principles should first be considered to ensure success and avoid wasted time, money and effort.

Despite the very best intentions, weed control programs almost always fail if vital information about the weeds and site conditions are not taken into account. It can also be easy to underestimate how much time may be required for follow-up weed control and therefore initial plans may need to be scaled back once all the information is taken into account to ensure a successful result. To fail to plan is to plan to fail!

Aim of weed control

The weed control strategies presented in this topic are aimed at protecting and conserving wetland values, particularly biodiversity. Weed control measures that have the potential to have direct or indirect adverse effects on biodiversity should be carefully considered before being implemented. For example, the use of certain herbicides that are extremely effective in controlling particular weeds may have unacceptable impacts on non-target native plants and/or wetland animals. Similarly, the removal of weeds that provide habitat for native fauna may result in fauna losses due to predation, exposure to the elements and removal of food sources.

In such cases, weed management measures may need to be modified, or perhaps even abandoned if damage to the environment is at a level considered to be detrimental to biodiversity conservation aims. Where negative impacts are likely, but at a manageable level, it is important to assess which native species are likely to be affected, what the level of impact will be, how impacts will be managed and the pros and cons of these impacts versus the long-term benefits to biodiversity.

Ideally, a weed control program should form part of an overall wetland management plan to ensure that weed control activities not only meet wetland management goals but are undertaken at the most appropriate time in conjunction with other wetland management activities, including encouraging native vegetation regeneration. A wetland management plan will assist in identifying priority wetland management actions and where, when and how these should be undertaken. For example, in some situations, weed control may not be the highest priority for management where other issues pose a higher threat to wetland biodiversity values.

➤ For additional detail on wetland management planning, see the topic 'Wetland management planning' in Chapter 1.

Weed management versus weed eradication

It should be noted that weed management does not necessarily imply complete and permanent removal of every single weed in a given area. In many cases, complete removal of weeds is not feasible or desirable for many reasons; for example, limited resources, increased potential for erosion or other adverse environmental impacts.

Prevention is the key

The best strategy for controlling weeds is to prevent weeds from becoming established in the first place and to act quickly following any new weed invasions. Once weeds have become established, weed control should ideally start in the least affected areas and move towards the most affected areas.

Consideration of the causes of weed infestations may identify other factors that may need to be addressed prior to, or simultaneously with, weed control. For example, where excess nutrients are stimulating growth of aquatic weeds, removal of the source or implementation of measures to ameliorate the impacts of nutrients may need to be undertaken as a matter of priority.

Guiding principles to prevent weeds from becoming established in wetlands include:

Prevent introduction of weeds from wind and water:

- Identify where weeds could be transported from via wind and water and implement measures to reduce the risk of invasion (for example, undertaking weed control in nearby paddocks or road verges).
- Remove known aquatic weeds from nearby garden ponds, drains or dams.
- Restore native dryland vegetation adjacent to wetlands and establish **shelterbelts** around property boundaries (using fast-growing **indigenous/local provenance** dryland plants) to stop weeds from blowing in or entering via runoff to act as a barrier to weed invasion.

Prevent introduction of weeds from human and livestock movement:

- Prevent or minimise access to wetlands via vehicles, livestock and humans.
- Before entry onto properties and/or wetland vicinity, clean weed seeds from vehicles, machinery, tools, pets and livestock, clothing and boots.
- Prevent disposal of garden prunings or lawn clippings from gardens into or around wetlands.
- Protect wetland vegetation from grazing, disturbance and clearing by fencing off areas of native vegetation.
- Prevent direct disposal of aquatic plants from ponds, dams or aquaria into wetlands, waterways or drains.

Reduce susceptibility of the site to weed establishment:

- Avoid disturbing existing native vegetation as this is where weeds will invade.
- Reduce or eliminate sources of nutrients entering wetlands that could stimulate the growth of weeds (for example, by ensuring fertiliser applied to gardens, lawns and paddocks does not leach into wetlands).
- Reduce fuel loads and risk of fire (and hence growth of weeds following an unplanned fire).

Early detection and control:

- Undertake regular monitoring to check for new weed infestations and remove them as soon as possible.

Indigenous: a species that occurs at a place within its historically known natural range and that forms part of the natural biodiversity of a place

Local provenance: indigenous plants propagated from collections from locations as close as geographically (in terms of habitat) practicable to the location where the propagated plants are to be planted. This ensures that genetic integrity is maintained

Shelterbelts: belts or rows of trees and shrubs planted to provide protection against prevailing winds

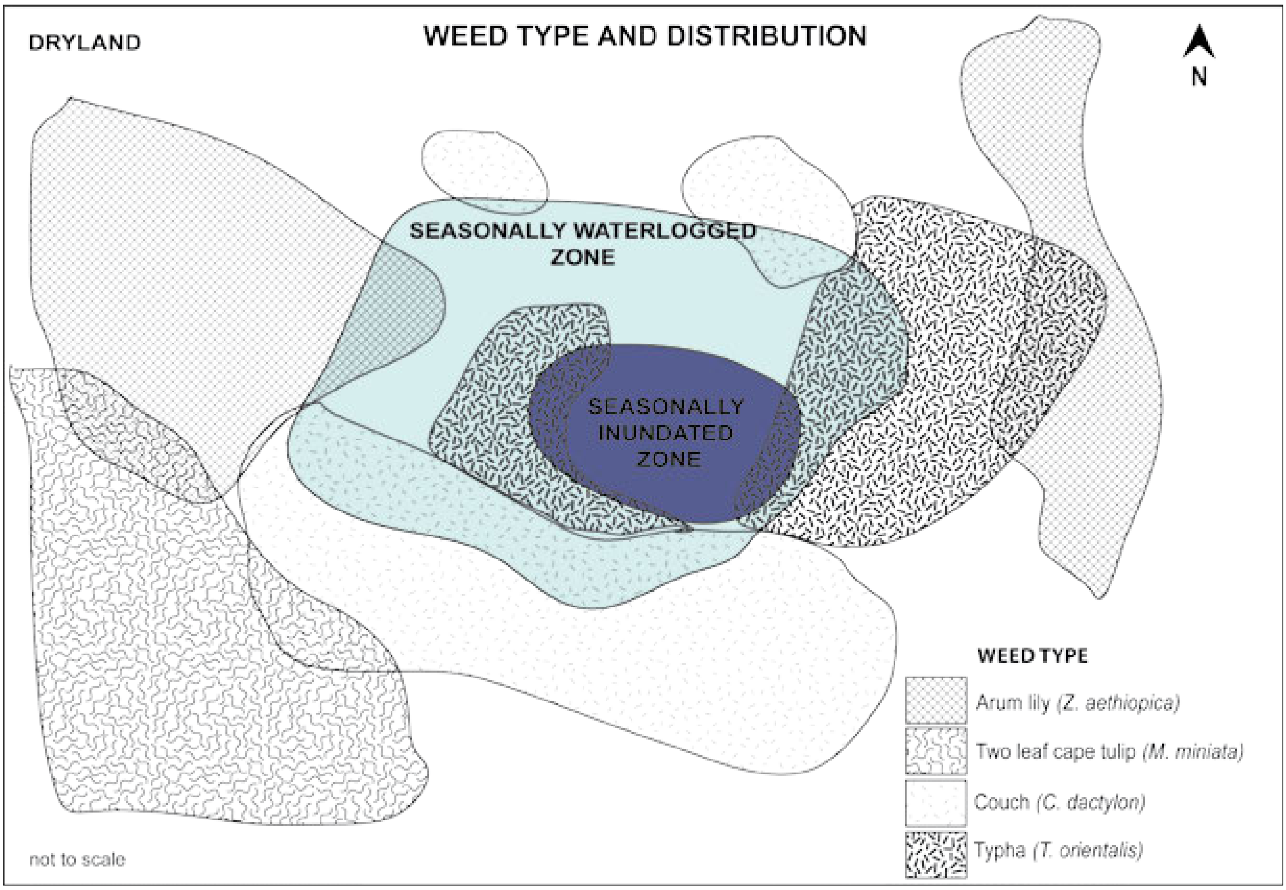
Weed identification is the key to successful weed control

For weed control to be successful, it is essential to accurately identify weed species to ensure that the most appropriate control methods are chosen. This will also minimise the risk of mistaking 'weedy' looking native plants as weeds! For additional detail on weed identification see the 'Sources of more information' section at the end of this topic

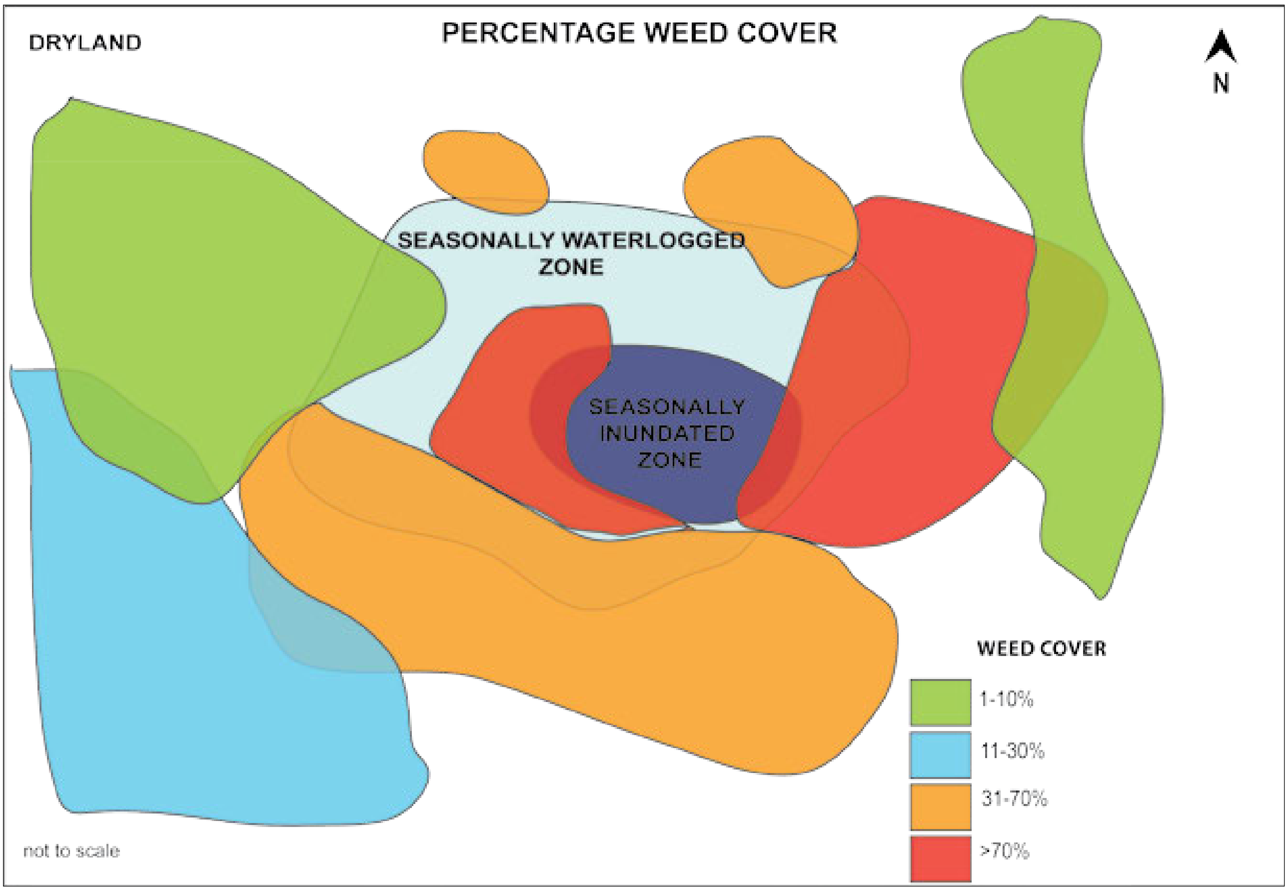
Weed mapping

Mapping individual weed species can assist in prioritising weeds for control. Ideally, weed mapping should be done in conjunction with mapping wetland vegetation communities to identify areas of native vegetation that are priorities for preventing and/or controlling weed invasion. Vegetation maps can be overlain with a weed map to show where serious weeds occur, extent of infestations (distribution and percent cover) and the rate and direction in which they are spreading. Not all weeds need to be mapped, just those that have the most serious, or potential for serious impacts on the site (see Figure 25). An aerial photo of the site provides a good basis for developing vegetation and weed maps to ensure that maps are to scale and important features in and around the wetland are incorporated.

Figure 25. (below) Examples of simple wetland weed maps which overlay an aerial photograph of the wetland and a wetland vegetation condition map – (a) weed type and distribution and (b) percentage weed cover.



(a)



(b)

Weed mapping can also help identify how and from where weeds are spreading, or have the potential to spread into the wetland area. For instance, tracks through the wetland or adjacent paddocks may be the source of highly invasive grass (pasture) weeds such as couch (*Cynodon dactylon*) and kikuyu (*Pennisetum clandestinum*). Similarly, agricultural or stormwater drains that are connected to wetlands may be the source of aquatic weeds. If weeds originate from neighbouring properties, working with neighbours in a joint effort to control weeds will ensure a more effective long-term outcome and better use of resources.

Mapping can also identify other areas of the wetland that are disturbed (or at risk from disturbance), or influenced by other factors that promote weed invasion. High fire risk areas can also be identified, which may be a critical factor in determining priority areas for weed control. Consideration of other factors such as climate, season, topography, wetland hydrology and fauna communities will also assist in deciding where, when and how weed control efforts will be most effective.

A weed map does not need to be complicated and requires only a few items including an aerial photograph of the wetland or property (on a size A4 or A3 sheet, at a scale of between 1:1,000 and 1:2,000 is ideal, depending on the size of the wetland), plastic overlay sheets and permanent marker pens.

➤ Aerial photographs may be sourced from local government authorities (councils or shires) or landcare centres. Rural landholders can source them from the Small Landholder Information Service (Department of Agriculture and Food, www.agric.wa.gov.au). Alternatively, Google Maps can also be useful for printing out reasonable quality aerial photos at no cost.

Mapping one weed at a time is the simplest approach (and remember, not all weeds need to be mapped, just those that present the greatest threat to the wetland). Many weeds grow in distinct zones. Use easily distinguishable features on the aerial photograph to assist in determining the boundaries of weed infestation zones (such as large trees, tracks, fence lines, inundated areas and so on). The boundary around each zone should be drawn on the plastic sheet (overlaying the aerial photograph) using the marker pens, indicating the name of the weed(s) in each zone. It can also be helpful to estimate the per cent of weed cover for each weed species, indicated using a colour code. For example:

- light infestation (i.e. weed forms 1–10 per cent of ground cover) = green
- light – medium infestation (i.e. weed forms 11–30 per cent of ground cover) = blue
- medium – heavy infestation (i.e. weed forms 31–70 per cent ground cover) = orange
- heavy infestation (i.e. weed forms greater than 70 per cent ground cover) = red.

Once the map is completed, this can be used to overlay a vegetation condition map to determine the highest priority areas for control. Small isolated patches of serious weeds in relatively undisturbed areas of native vegetation are usually the highest priorities for weed control (that is, following the weed control principle of working from the least weed affected areas, outwards towards the worst affected areas). Overlaying the weed map over the vegetation condition map is also useful for highlighting particular associations between certain weed species and plant communities or soil types.

➤ The step-by-step instructions used by DEC officers to map weeds are available at www.dec.wa.gov.au/monitoring/standard-operating-procedures.html

➤ For additional detail on wetland vegetation mapping, see the topic 'Managing wetland vegetation' in Chapter 3.

The basic principles of a weed management program

- Prevent spread, or further spread, of serious weeds into areas of intact vegetation.
- Avoid disturbing intact vegetation as this can lead to weed invasion.
- Work in areas that have the capacity to regenerate (i.e. where native vegetation can recover and grow back naturally following weed control).
- Develop a weed management plan (incorporating weed and vegetation condition maps to identify priorities for weed control).
- Control weeds as soon as they appear, working from areas least affected towards areas most affected.
- Where possible, revegetate disturbed or degraded areas that harbour serious weeds and that continue to provide a source of seed that can spread into other areas. Although this is a lower priority than protecting the least invaded areas of vegetation, it should be incorporated into long-term weed control program actions.
- Undertake a social program to educate neighbours and others contributing to the spread of weeds, and encourage their active participation in the solution.

How much weed control and when?

Resources and timing

The size of the area, amount of weeds to be controlled and rate of control should be dictated by the resources available and the rate at which natural regeneration or revegetation is expected to occur following removal of weeds. This will ensure that weed control measures and follow-up weed control is manageable, and bare areas left by weed control will be colonised by native plants and not the next crop of weeds. The best time to control weeds is as soon as possible after invasion, while numbers are low. Once weeds have become established and a major infestation results, weed control is much more difficult and costly in terms of time, labour and money.

Planning and prioritisation

In order to achieve successful outcomes, a detailed implementation plan is essential. The plan should identify priority weeds for control, how weeds will be controlled, when weeds will be controlled, and required materials, labour and costings for each phase of the weed control program. Details for follow-up weed control should be also be included, as well as requirements for ongoing monitoring of the site.

Prioritising weed species for control should take into account their invasiveness, distribution and impacts on the wetland. Prioritisation of weeds can be assisted by undertaking a weed map of the site, identifying the areas or zones where control should occur (discussed in more detail under the heading 'Weed mapping'). The plan may need to be modified if unexpected events occur, such as fire, disease or reduction in the level of resources (for example, available time and money) to undertake planned activities. In the case of a fire, weed control may need to be diverted to areas that have been burned to minimise the risk of major weed infestation post fire. Growth of annual grasses and weeds with bulbs and corms can be especially vigorous post fire and therefore weed control should be undertaken as soon as germinants start to appear (see Figure 26).

Figure 26. Weed control should be undertaken as soon as weed germinants appear following a fire. Photo – N Hamilton/DEC.

Table 3 provides an example of a basic weed control implementation plan (note: different weed species require control at different times of the year and a weed control implementation plan should reflect this).

Follow-up

With most weed control programs, it is necessary to weed the site more than once to get the weed population(s) under control. When weeds are killed (for example, by spraying) or physically removed (for example, digging out or hand pulling), this can create conditions that stimulate further germination of weed seeds, corms or bulbs lying dormant in the soil. For weed control to be successful, follow-up weeding is essential to ensure the new batch of weeds does not become established and out-compete regenerating native plants or seedlings.

Weed succession

Sometimes the removal of one type of weed can encourage the growth of other weed species, so follow-up weed control may need to employ a different strategy to the initial control. Follow-up weeding will need to be ongoing and for several years at least, depending on the site conditions, weed species present and rate and success of regeneration or revegetation. Progressively less follow-up weeding should be required once native plants are regenerating well and at a rate faster than weeds can become re-established.

Most weed species maintain a soil seed bank for at least several years, and others will continue to re-invade until re-established native vegetation has reached sufficient density. A program of at least three years will be required to achieve maintenance level management; in almost all cases, weed control maintenance will need to continue over the long term (at least 10 years), unless the original disturbance mechanisms have been arrested, and adjacent weed sources controlled.[5]

In some instances, it may be more effective to manage weeds at a local catchment scale, especially if they originate from outside the property boundary. Working with neighbours or the local government council in a joint effort to control the most problematic weeds in a local area may be a more effective use of resources, and increase the likelihood of success in the long term.

Table 3. Basic weed control implementation plan

				Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Activity	**Who**	**Cost**	**Hours**	**2009**	**2009**	**2009**	**2009**	**2010**	**2010**	**2010**	**2010**	**2010**	**2010**	**2010**	**2010**	**2010**	**2010**	**2010**	**2010**
Weed mapping	Mary	$ -	4																
Mark zones for control	Mary	$ -	1																
Order native seedlings, fertiliser	Mary	$150	2																
Purchase chemical, backpack/ sprayer	Mary	$300	2																
Book spray contractor	Mary	$-	0.5																
Weed control zones 1 and 2	Contractor	$250																	
First follow-up weed control	Contractor	$100																	
Revegetation* zones 1 and 2	Mary	$ -	10																
Second follow-up weed control	Mary	$ -	4																
Third follow-up weed control	Mary	$-	4																
Monthly monitoring of weeds and native seedlings	Mary	$ -	6																
TOTAL		$800	33.5																

*Note: In some situations, weed control may need to be continued for several years before revegetation (or natural regeneration) can occur.

The big picture

Finally, proposed or existing weed management programs should be considered in view of the ecosystem as a whole to avoid causing more harm than good. For example, there may be instances where weeds are not causing significant impacts on biodiversity (and are not likely to in the future) and removal of these weeds may result in more aggressive weeds replacing them. This is especially critical in situations where follow-up weed control and/or regeneration or revegetation is unlikely to occur or may be unreliable (for example, due to limited labour or resources, other difficulties such as site access etc).

extra information

Benefits of weeds in wetlands

In some circumstances, weeds may provide a source of food or habitat for native fauna and a corridor for them to move safely from one area to another. Ideally, weed control should be undertaken gradually to allow fauna time to find alternative habitat and followed up with revegetation with native species. Weeds can also play an important role in reducing nutrients and sediments from entering wetlands and affecting water quality. In this situation, interim soil stabilisation and/or sediment trapping methods may be required between weed removal and natural regeneration or revegetation.

Weed control methods

This section outlines the main methods of control of wetland weeds and when they are best used. The weed control methods include:

- manual control
- mechanical control
- suppression
- barriers
- flame and steam weeding
- biological control
- controlled grazing
- chemical control
- integrated weed control.

To achieve best results, one method or a combination of methods (integrated weed control) is often the best approach, depending on the type and extent of the weed problem, site conditions and available resources (for example, time, labour, money).

Table 4 summarises the control options for the major types of wetland weeds. These are discussed in more detail in the following sections.

Table 4. Control options for major types of wetland weeds

Weed type	Control options
Annual grasses	Small infestations: • Hand pull or dig up entire plant prior to seed set (note: crowning may be a better option where pulling up or digging out weeds is difficult or causes major soil disturbance); and/or • Flame or steam weed (note: first assess the level of risk for causing fires, especially in peat areas). Larger infestations: • Mow or slash prior to seed set; and/or • Apply recommended herbicide early in the growing season when plants are small (3–5 leaf stage). Use a grass-selective herbicide if grass is growing amongst native vegetation and ensure native grasses will not be damaged.
Perennial grasses	*Tussock grasses* Small infestations: • Remove entire plant prior to seed set, or when dealing with larger areas or difficult-to-remove plants, use a knife to cut through roots below crown tissue at the base of the stem (removing all dormant buds at the base). Larger infestations: • Mow or slash after the flower head has emerged but prior to seed set. Slashing is most effective when followed up with herbicide treatment. *Stoloniferous or rhizomatous grasses* Small infestations: • Hand weeding is not recommended due to the difficulty in removing all stem and root material and the resulting soil disturbance; • Flame or steam weeding; follow-up treatments may be required; and/or • Solarisation; for summer active plants in moist soil. Larger infestations: • Weed barriers; constructed or through revegetation; • Shading out through revegetation; and/or • Apply recommended herbicide during the growing season when plants are small.
Broadleaf herbs	Small infestations: • Hand pull or dig up entire plant before seed set; and/or • Flame or steam weeding. Larger infestations: • Mow or slash after flower head has emerged but prior to seed set; and/or • Apply recommended herbicide during the growing season before flowering when plants are small and actively growing.
Corms, bulbs and tubers	Small infestations: • Remove entire plant (usually early in the growing season, before seed set), ensuring no bulbils or daughter corms are left in the soil. Larger infestations: • Undertake repeated mowing or slashing after flower head has emerged but prior to seed set to avoid spreading seed. Slashing is most effective when followed up with herbicide treatment; and • Apply recommended herbicide at the correct stage of lifecycle, usually just before or just on flowering (this can vary depending on the species, seek expert advice).
Woody weeds	Small infestations: • Remove entire plant (hand pull, digging out). Larger infestations: • Apply recommended herbicide using most appropriate technique, i.e., foliar spray, cut and paint, basal bark spraying, scrape and paint, stem injection, stem and leaf wiping.

Manual control

This includes hand pulling and digging, crowning, and hand removal of aquatic weeds. Manual control methods are useful where there may be concerns about the impact of machinery or herbicides on the environment, and where there are smaller areas of weed infestation. Where appropriate, manual control may be more effective when combined with herbicide application to minimise soil disturbance.

Hand pulling and digging

This method can be used with success where weed numbers are low, where weed control is taking place in a localised area and if the weeds are easy to pull or dig up. It may be the preferred method where weeds are growing amongst sensitive areas of vegetation, where other methods of removal may cause an unacceptable level of disturbance or risk damage to native plants. The keys to success are to ensure that hand pulling and digging is done prior to the weeds seeding and that all of the plant material that is capable of germinating or regenerating is removed from the soil. This includes seed pods and capsules, roots, bulbs, corms, tubers, rhizomes and stolons. In the case of weeds with bulbs and corms, following removal of the parent bulb/corm, the remaining soil must be carefully checked to ensure that any daughter bulbs or corms are not left behind as these can sprout and grow rapidly to form a secondary infestation. If bulbs and corms are present, they must be bagged and removed from the site together with the immediately surrounding soil. It should be noted that soil disturbance from hand pulling and digging can encourage weed seeds to germinate; therefore, follow-up weed control is likely to be required.

Crowning

This technique is useful for weeds that can re-sprout from structures beneath the soil, such as crowns, corms and rhizomes, and clumped or tufted fibrous root systems. A knife or other sharp object is inserted at an angle into the soil and the roots are severed to enable the plant to be removed. It is essential to remove the section the roots attach to, the '**crown**', as this can re-sprout if left in the ground.

Hand removal of aquatic weeds

Floating and submerged aquatic weeds are often best removed by hand to avoid damage to native aquatic vegetation and risks associated with using herbicides in wetlands. Floating aquatic weeds can be harvested by hand, using long-handled rakes for instance, and collected plant material stored in bags for solarisation, composting or landfill disposal. Use of bunds may be useful for larger areas to prevent aquatic weeds from entering 'weeded' out or uninfested areas.

Mechanical control

Mechanical removal is suited to managing large areas of weeds, inaccessible areas due to thick infestations and for aquatic weeds. Methods include mechanical slashing, mowing, cutting, cultivation, scraping and harvesting.

Crown: the region of compressed stem tissue from which new shoots are produced, generally found near the surface of the soil

Slashing, mowing and cutting

In the case of areas completely dominated by annual grasses, this option provides the added advantage of reducing fuel load and hence fire risk when weeds die off over summer. This method is suitable for areas in which native vegetation is not present or is growing in isolated patches that can be avoided, thereby minimising damage from machinery. Slashing and mowing should be done before seed set, to avoid spreading seed around the site. This method does not usually kill weeds straight away, but it serves to deplete their energy reserves and prevent seeding.

Slashing and mowing may need to be repeated several times over the year following if regrowth occurs. This method can be used in combination with chemical control, by spraying regrowth with an appropriate herbicide following slashing and mowing. Using heavy machinery to control weeds should be considered very carefully as it has the potential to compact wetland soils (see Figure 27). This soil damage can in turn make it harder to revegetate the area, reduce the habitat of soil dwelling and burrowing animals, and alter drainage patterns.

Figure 27. Slashing bulrush (*Typha orientalis*) at Forrestdale Lake. Stems are sprayed following slashing to prevent regrowth. Photo – T Bell/DEC.

case study

Salvinia and native bulrush control in Lily Creek Lagoon, Kununurra

Approximately 135 hectares in area, Lily Creek Lagoon in Kununurra is part of the Ramsar wetland site that encompasses Lakes Kununurra and Argyle. It is directly connected to Lake Kununurra, the supply dam for the irrigation area and environmental flows to the Lower Ord River. The township of Kununurra wraps around Lily Creek Lagoon, which is an important habitat for migratory birds, freshwater crocodiles and numerous species of fish. It also provides an attractive backdrop and recreational area for the town.

A small infestation of salvinia (*Salvinia molesta*) was first discovered by a local resident in May 2000. It was immediately identified to be of major concern due to its potential to completely smother the water body and cause damage to the native aquatic ecosystem. It is also of concern as this is the only current infestation in the north of WA and establishment could see it spread through the use of boat trailers to the pristine waterways of the Kimberley.

The control and eradication process of salvinia has been a joint effort of the Shire of Wyndham-East Kimberley, Ord Land and Water, Water Corporation, Department of Water, Department of Environment and Conservation, Department of Agriculture and Food and Save Endangered East Kimberley Species. The initial short-term goal was to contain the isolated infestation, preventing it from spreading throughout Lily Creek Lagoon, Lake Kununurra and Lower Ord River. The long-term goal was for complete eradication due to the serious nature of the weed and the small scale of the infestation.

Several different methods have been used over the past nine years to eradicate salvinia. Initial controls involved the containment of the weed through a boom fence and the manual removal of the bulk of the salvinia where possible. This was followed up by spraying with Roundup Biactive®, and installation of more boom fences (see Figure 28).

The floating boom fences, which are partly submerged beneath the surface to about 35cm depth, are designed to trap salvinia and prevent it from spreading to uninfested areas. Initially one boom fence was used for containment, with more booms being installed later to create additional holding cells. The holding cells served two functions, to trap salvinia that was regenerating from small pieces missed hiding in the native typha stands, and to trap any new plants entering the lagoon from the drain leading into it.

The major difficulty of salvinia being trapped within dense stands of native typha made access for control and removal very difficult. A clearing permit was obtained to remove a small area of native typha in order to allow greater access to the salvinia infestations. The most successful strategy for controlling native typha was mechanical removal with follow up spraying of regrowth. An excavator was used to remove approximately 600 square metres of native typha, which created an open water area which allowed access for eradication of salvinia. Removal of native typha was undertaken outside the breeding season of the swamp hen, which relies on the dense stands for nesting.

Given the total area of native typha within Lily Creek Lagoon is approximately 72 hectares, the loss of this small section has prevented salvinia from invading the remaining native typha in the lagoon, which would have been disastrous. Its removal from the control area improved the effectiveness of the salvinia control as only several small clumps have since been found and these were easily removed by hand.

Monthly monitoring is undertaken to ensure any new infestation are identified and eradicated early. No salvinia has been found since October 2007 and therefore it is likely that it has been eradicated. Lilies and other aquatic plants have regrown in the control area effectively rehabilitating it. If by October 2009 no salvinia is found, the area will be declared clear of salvinia and monitoring frequency will be reduced.

A pamphlet was produced for the community describing salvinia and the threat it poses to the environment, industry and lifestyle. A media campaign was also run, with articles in local papers, radio interviews and displays at the Kununurra Show, natural resource management field days and conferences. Signs have also been erected at the site informing the public of the salvinia quarantine area.

Figure 28. (below) (a) Salvinia monitoring and collection; (b) salvinia trapped within stands of native typha; (c) salvinia containment area using boom fences. Photos – D Pasfield/Ord Land and Water.

(a)

(b)

(c)

Cultivation and scalping

Cultivation is generally not recommended for weed control in a bushland or wetland environment as it involves breaking up the weeds and turning the soil. This can spread weed seeds and other plant parts capable of regenerating, damage native plants and create conditions that favour secondary weed invasion, such as increased space and light. This method may be useful in large, degraded areas where there is no native vegetation present or as a pre-cursor to direct seeding, which requires a completely weed free environment.

Follow-up weed control after direct seeding a cultivated site needs to be vigilant to prevent establishment of the next weed crop that is guaranteed to emerge. This may best be achieved by using an appropriate selective herbicide, and when planting native seedlings a thick layer of mulch can be applied to suppress secondary weed growth.

Scalping involves slicing off the top layer of soil which contains the weeds and weed seeds, leaving the surface bare in preparation for revegetation. Scalping can be done by hand using a sharp shovel for small areas, or with a tree planting machine or road grader for larger areas. Once again, follow-up weed control is important to deal with secondary weed growth which may out-compete establishing native vegetation.

Aquatic weed harvester

In situations where aquatic weeds dominate large wetlands (particularly lakes) and where hand harvesting, spraying or other weed control options are not feasible, aquatic weed harvesters can be used to remove large amounts of weeds. These machines can be purchased in Australia and have been used with varying degrees of success in Western Australia. An aquatic weed harvester typically has large cutting blades that cut the weed above the sediment layer (see Figure 29). Harvesters remove submerged aquatic weeds such as introduced or native typha and floating aquatic weeds such as salvinia. The disadvantage with aquatic weed harvesters is they are expensive to purchase and they can cause damage to native aquatic vegetation and disturb the sediment layer, causing increased turbidity and re-suspension of nutrients or other pollutants. Harvested weeds must be disposed of appropriately to avoid causing odour or other problems (such as leaching of nutrients) from decomposition of plant material.

Figure 29. Aquatic weed harvester removing native typha and salvinia. Photo – K Tripp/Shire of Wyndham East Kimberley.

Weed suppression

Weed suppression methods aim to suppress conditions that favour weed establishment such as soil disturbance and increased light, nutrients and space. Weeds can be suppressed by smothering, mulching, solarisation and drowning.

Smothering and mulching

Depending on the site and type of weeds present, using thick layers of mulch or other materials, including carpet or weed matting, can be very useful in discouraging weed growth. The layers of mulch or matting effectively reduce light and thus prevent weeds from **photosynthesising**. For very aggressive or persistent weeds, conveyor belt rubber is excellent as it forms an impenetrable layer which can be removed once weeds have completely died off. The smothering technique is particularly useful in areas that are dominated by weeds and have no native plants present, where very vigorous and invasive weeds such as couch (*Cynodon dactylon*) and kikuyu (*Pennisetum clandestinum*) are present, or in situations where use of chemicals or other methods are unsuitable.

Solarisation

This method involves covering weeds with ultraviolet-resistant black plastic sheeting and making use of the sun's energy to kill weeds and weed seeds. This method is useful for treating summer-growing grasses in highly disturbed areas during summer, where the soil is moist. The time taken to kill weeds will depend on the weed species, season applied and intensity of the sun. A minimum of four weeks is usually required. Follow-up chemical control may be required, particularly in the case of stoloniferous or rhizomatous grasses such as kikuyu (*P. clandestinum*) and couch (*C. dactylon*), which may re-sprout following treatment. Plastic bags can also be used to sterilise weeds that need to be removed from the site and disposed of, thus reducing the chance of spreading seed or plant parts that can re-sprout. This usually involves placing weed seed heads that have been removed into black plastic bags and placing these in the sun until all plant parts are 'cooked' before disposal.

Drowning

This method can be effective for **emergent** aquatic weeds such as *Typha orientalis*. The plant is drowned by cutting the shoot below the water surface. This may need to be repeated several times over a season to completely kill the plant. There may be insufficient water depth for this method to be effective in killing weeds growing near the water's edge.

Barriers

Natural and constructed physical barriers can be effective weed control measures.

Revegetation

Dense native vegetation can provide an excellent natural weed barrier and therefore weed control programs should include restoration of native vegetation wherever possible. Native vegetation not only competes with weeds for light, nutrients and moisture, it provides a physical barrier which can prevent the entry of wind and water borne seeds into sensitive areas (see Figure 30).

Constructed weed barriers

These can be very effective by providing a physical obstacle that prevents the spread of turf grass or pasture (for example, couch, kikuyu, buffalo grass) from lawn areas or paddocks into sensitive natural areas. The barriers are constructed along the boundary of the area to be protected by digging a trench at least 50–60 centimetres deep and placing materials such as weed mesh or rubber conveyor belt vertically into the ground as a barrier to stop rhizomes from creeping through. The trench is backfilled and, where appropriate, concrete kerbing (or similar) may be placed on top to provide a 'mowing'

Photosynthesis: the process in which plants, algae and some bacteria use the energy of sunlight to convert water and carbon dioxide into carbohydrates they need for growth and oxygen

Emergent: a plant that is protruding above the surface of the water or, where a water column is not present, above the wetland soils (as distinct from floating or submerged plants)

Figure 30. Couch (*Cynodon dactylon*) and kikuyu (*Pennisetum clandestinum*) are unable to penetrate a dense stand of the native sedge *Baumea articulata*. Photo – T Bell/DEC.

Figure 31. Concrete kerbing provides an ideal weed barrier, preventing grass weeds from nearby lawn areas from invading newly revegetated areas. Photo – D Moort/City of Rockingham.

edge and further barrier for stolons creeping across the soil surface (see Figure 31). Pedestrian footpaths can also be used as an effective barrier.

Controlled grazing

In certain circumstances and with proper management, controlled grazing can be used to keep weeds, particularly pasture grasses, under control. It must only be used when grazing is a legal activity and does not have the potential to cause environmental harm. It is important to be aware that grazing is a form of clearing (due to its impact on native vegetation) that is subject to regulations of the *Environmental Protection Act 1986*. Furthermore, grazing should not be introduced to areas where it has not previously occurred. Activities such as increasing the stocking rate on native pastures or grazing regenerated areas may constitute clearing of native vegetation and will require a clearing permit if an exemption does not apply.

➤ For additional detail on clearing regulations and managing livestock in wetlands, see the topic 'Livestock' in Chapter 3.

Grazing is most suited to situations in which livestock access can be strictly controlled within specific areas. Controlled grazing can have multiple benefits including:

- reducing weed biomass, making follow up spraying more effective
- reducing weed competition with native plants
- preventing weeds from flowering and setting seed
- reducing fire risk
- providing a feed source for livestock.

Livestock should not be allowed to roam freely throughout wetlands as they can cause significant damage to native vegetation, spread weeds and dieback, foul water bodies, damage banks and cause soil erosion. Ideally, grazing should be limited to short 'crash grazing' episodes, best done during dry times so that livestock can access margins of the wetland without damaging banks or native vegetation. Livestock movement can be very effectively managed using portable electric fencing.

Pasture grasses such as kikuyu (*Pennisetum clandestinum*), couch (*Cynodon dactylon*), wild oat (*Avena fatua*) and African love grass (*Eragrostis curvula*) are palatable to most livestock so they can be very efficient at keeping them under control. However, weed seeds can be spread in manure so it may be necessary to place livestock in holding yards for a few days before moving them into other areas. Care should be exercised to ensure weed species present are not toxic to livestock (for example, cape tulip (*Moraea* spp.), Paterson's curse (*Echium plantagineum*)). Where appropriate, follow-up spraying after grazing provides for more complete weed control, particularly where grazing is intended as a short-term measure only.

Fire

The use of fire to control weeds in wetlands is generally not recommended, due to the complex behaviour and impacts of fire. Fires can cause a range of problems in wetlands, including the risk of exacerbating weed problems and endangering native plants and animals and starting underground peat fires. The use of fire requires careful consideration and a thorough understanding of the impact of fire on weed populations and wetland ecology and should only be undertaken by those with expert knowledge and the necessary authorisations.

Figure 32. After a fire, bare soil, increased light availability and nutrients in the soil provide ideal conditions for germination of weeds. Photo – T Calvert/DEC.

Inappropriate use of fire (for example, too frequent, too hot, wrong time of year) can lead to loss of habitat and native species diversity, and pose a risk to people and property (see Figure 32). Wetlands and bushland experiencing fires that are too frequent or intense can result in native species decline and the area becoming dominated by weeds. Although fire can be a useful tool in stimulating regeneration of native vegetation, not all weeds are fire sensitive and some may actually flourish after a fire. Where unplanned wildfires do occur, this can provide a window of opportunity to control a range of weeds that germinate in response to fire (as weed germination is often faster than native vegetation and therefore the weeds are easy to find and treat).

The invasion of annual grass weeds is of particular concern as increased soil nutrients, light and space availability after a fire favour their rapid germination and spread, out-competing regenerating native plants. Grasses such as perennial veldt grass (*Ehrharta calycina*) and African lovegrass (*Eragrostis curvula*) are common examples of weeds which flourish after a fire. These weeds can dramatically alter wetland vegetation composition in the long term if left unchecked.

Use of controlled managed burns (for example, spot or mosaic burns) may be appropriate under certain circumstances: for instance, in controlling large and difficult weeds such as introduced bulrush (*Typha orientalis*) or pampas grass (*Cortaderia selloana*). The aim of a controlled managed burn is to burn only the desired area in a manner that minimises damage to the environment, people and property. Weed control following fire must be vigilant in order to kill newly germinated weeds as soon as they appear. Where appropriate, follow-up spraying is a very effective as a post-fire control strategy.

Controlled burns require a permit

It is important to seek expert advice before undertaking any controlled burns in or around a wetland or property. A permit from the local government authority is required before undertaking any burning on rural properties. Many local government authorities enforce a total fire ban during the summer - early autumn period and fines are applicable if burning is undertaken at this time.

Flame and steam weeding

These methods involve the use of extreme heat to kill non-woody weeds by rupturing plant cell membranes, thus rendering the plant unable to retain moisture and causing it to die off. These methods are best suited to annual grasses and herbs. Repeat applications may be required as only the leaf/stem material is killed and the roots are left intact, meaning plants may re-sprout.

Flame weeding is done using a portable unit, usually comprising of a gas bottle (liquefied petroleum gas or propane) and hand wand. Vehicle mounted units can be used for larger jobs. A direct flame or infra-red burner is applied to the weeds using a hand wand until the plant leaves are severely wilted (not burnt). Flame weeders should be used with extreme caution in fire risk areas. Although flame weeding is not yet widely used in Australia, it has been used successfully for many decades in Europe for weed control on organic farms and on hard surfaces in urban areas.

Steaming involves delivery of pressurised heated water directly onto plant leaves using a hand wand or similar apparatus. Some local government authorities in Western Australia have used steam weeding to control weeds on road verges or footpaths, where use of chemicals is undesirable due to pedestrian use, or where the weeds occur within environmentally sensitive areas. Repeated applications may be needed, particularly on mature perennial weeds.

Although both these methods hold promise as alternatives to herbicides, more research is required to fully assess their effectiveness on a range of weed types and conditions.

Biological control: the control of an introduced plant or animal by the introduction of a natural predator or pathogen, usually bacteria, viruses or insects, or by biological products such as hormones

Biological control

Many introduced plants that have become environmental weeds in Western Australia are not a problem in their native environment, due to the presence of natural competitors such as insects, herbivores and pathogens that keep their numbers and growth under control. **Biological control** of weeds refers to the introduction of predators or pathogens that will attack and debilitate weeds without becoming pests themselves or adversely affecting native flora and fauna, agricultural crops and livestock. The aim of biological control agents is not necessarily to eradicate a weed but to reduce its population to a more manageable level.

The use of biological control agents for environmental weeds is not yet widespread due to the huge costs involved in conducting research and testing of the agent. Additionally, not all weed species are suitable for biological control. Although relatively few environmental weeds have been subject to biological control programs in Australia, examples of some that have include skeleton weed (*Chondrilla juncea*), salvinia (*Salvinia molesta*), bridal creeper (*Asparagus asparagoides*), blackberry (*Rubus ulmifolius*), cape tulip (*Moraea* spp.), water hyacinth (*Eichhornia crassipes*) and Paterson's curse (*Echium plantagineum*).

➤ For more information on biological control of weeds, contact the Department of Agriculture and Food or see www.agric.wa.gov.au.

Chemical control

In some situations, use of herbicides is the most cost-effective, practical and efficient means of controlling weeds. Herbicides can be used as the sole means of controlling weeds or in combination with other methods. Two major advantages of using herbicides are that weeds can be selectively targeted where necessary, and soil disturbance is kept to a minimum. Disadvantages of using herbicides are their toxic nature and potentially harmful effects on humans, livestock and the environment if used incorrectly. Use of herbicides around wetlands in particular needs careful consideration and care due to the risks of chemicals contaminating the water and damaging or killing aquatic life. At present, Roundup Biactive® is the only registered herbicide for use near water in Australia. If herbicides are to be used, application methods that have the least potential for damaging non-target species should be considered first, for example, cut stump, wiping or injecting instead of spraying, which has the potential for spray drift related impacts.

When using herbicides, it is essential to apply the correct herbicide, in the right dose, at the right time, using the correct application method. Use only registered herbicides, follow manufacturer's instructions on the label, and wear the appropriate protective clothing during handling. All registered herbicides are labelled with important information to assist in selecting the correct product and give the recommended application methods and dose. Labels also provide safety and poisoning information and recommended disposal methods.

extra information

Legal obligations for herbicide users

The *Pesticides Act 1999* provides for the registration of herbicides, labels and containers.

In Western Australia, anyone who uses herbicides is bound by the Health (Pesticides) Regulations 1956. These regulations were developed to provide protection for the applicator, the public and the environment from misuse of pesticides and herbicides. Herbicide labels are written in accordance with the regulations and therefore any herbicide user has a legal obligation to read and follow instructions on the label. The label provides directions for use, and for the protection of the environment, information about storage and disposal, recommendations for personal protective equipment and information about the weeds that can be treated.

Despite the provision of these details, many environmental weeds are not listed for use on herbicide labels and therefore an off-label permit may be required. The Department of Agriculture and Food has obtained a minor use off-label permit for a number of herbicides to be used specifically on environmental weeds in non-crop areas (including wetlands and bushland) until March 2017. This permit (PER13333) provides for the use (by any person in Western Australia) of a herbicide product in a manner other than that specified on the approved label of the product. However, persons who wish to use herbicide products in ways other than those specified on the approved label, must read and follow the permit instructions. For more information see www.apvma.gov.au/permits.[13]

Ideally, all herbicide users should undertake training in correct preparation, handling, application, transport and storage of herbicides. Although there is currently no legal requirement for herbicide users (other than paid contractors) to undertake training in the use of herbicides, legislation for use of chemicals is under review and this may change in the future.

Wetting agent: a substance that helps water or other liquid to spread or penetrate (also known as a surfactant or penetrant)

➤ For additional detail on herbicide use, products available, safety and environmental considerations and recommended herbicides for weeds see 'Sources of more information' at the end of this topic.

Use of herbicides in and around wetlands

The use of herbicides in and around wetlands should be undertaken with great caution, and only as a last resort, when non-chemical weed control methods are not realistic or viable. There is potentially a great risk to aquatic life if herbicides enter wetlands or waterways. Of particular concern is the impact of herbicides and associated **wetting agents** on frogs. Studies have shown that tadpoles and mature frogs have been found to be extremely sensitive to these chemicals, which may cause damage to their skin and gills, resulting in death (see Figure 33).

Figure 33. Frogs and tadpoles are extremely sensitive to certain herbicides and wetting agents. Seek advice from organisations such as the Department of Environment and Conservation or Department of Agriculture and Food before using herbicides in and around wetlands where frogs are present. Photo – C Mykytiuk/DEC.

Tips on reducing environmental risks associated with herbicide use near wetlands

Adapted from Cooperative Research Centre for Australian Weed Management's Introductory Weed Management Manual.[7]

- Use only herbicides that are registered for use in wetlands and/or are documented to have low toxicity to aquatic organisms (for example, Roundup Biactive®, Fusilade®).
- Apply herbicide at the recommended rate.
- Ensure that weeds are treated at the appropriate time (when surface water levels are low) to reduce the need for repeated follow-up treatments.
- Mix herbicides with a coloured dye to mark areas that have been sprayed.
- Avoid using wetting agents, as many of these are more toxic to wetland fauna than the actual herbicide.
- If contractors are to be used for herbicide application, ensure they follow procedures to minimise risks to wetland fauna.
- If possible, treat weeds close to water bodies progressively rather than in one large-scale operation, to minimise risks to wetland fauna, and to reduce erosion and habitat loss where weeds are binding the soil or providing habitat.
- Mixing of chemicals and cleaning of equipment should be done away from the wetland and in a location where any accidental run-off will not directly enter the wetland.
- Wherever possible, direct the spray away from water bodies, when there is no wind.
- When spraying around drains that feed into wetlands, move upstream when spraying rather than downstream to aid dilution of any contamination and to avoid creating a 'slug' of herbicide entering the wetland.
- Spray only when rain is not expected for several days.
- Check with the local government authority to find out what regulations apply for the application of herbicides near wetlands.

The only herbicide registered for use around wetlands at present is Roundup Biactive®, which is a broad spectrum, non-selective herbicide reported to be 100 times safer for frogs than the original Roundup formulation.[14] To minimise potential impacts on frogs, the use of herbicides should be avoided between late autumn and early spring, when egg-laying, hatching and subsequent dispersal of juvenile frogs takes place. Timing may vary between species, so it is important to seek expert advice for assistance in identifying frog species present in wetlands, and to confirm the timing and duration of their breeding cycles before herbicide application takes place.

Fusilade®, a selective grass-specific herbicide (commonly used to control annual and perennial veldt grass, kikuyu, couch and water couch) has been tested in Western Australia and found to be highly effective in removing introduced grasses. Care should be taken when using Fusilade® and the stronger preparation Fusilade Forte® in and around wetlands as recent studies have shown that it can have a negative effect on native seed germination.[15] Fusilade® is slightly soluble in water and has low toxicity to aquatic organisms. To minimise risk of negative impacts on wetland flora and fauna, always follow the manufacturers instructions on the label and apply carefully to target weeds, avoiding contact with the soil, water and non-target species as much as possible.

How herbicides work

Herbicides kill weeds by disrupting essential biochemical processes within the plant. Herbicides act in two ways, either via direct contact with plant surfaces (for example, leaves and stems) or when translocated through the plant's circulatory system. There are different types or herbicides including **selective**, **non-selective**, **residual**, **non-residual** and **pre-emergent**.

Non-synthetic herbicides

There are a number of **non-synthetic** herbicides on the market that may be effective against a range of weeds. These herbicides contain active ingredients such as pine, cinnamon and clove oils, petroleum or mineral oils, acetic and pelargonic acid or potassium salts. Many of these products such as those containing acetic acid or pelargonic acid are designed to 'burn' foliage, causing dessication of plant cells. Any herbicide, whether synthetic or non-synthetic, has a degree of risk associated with its use, and products that are marketed as non-synthetic, natural, or organic may still have the potential to cause harm to the environment, people or animals. Caution should therefore be exercised during use and instructions on the label for storage, handling, application and disposal should be strictly adhered to.

Timing

The best time to treat weeds with herbicides is when they are small, actively growing and have not yet set seed. Weeds are easier to kill and require less herbicide when they are small. The most effective translocation of herbicide throughout the plant occurs if herbicide is applied when transpiration is greatest, usually during midday on a sunny clear day, provided there is no wind which (if spraying) could carry spray drift onto non-target species. Avoid treating weeds when rain is expected or when they are under stress (for example, during extremes in temperature, drought or if they are diseased) as they will be less likely to respond to treatment. The timing of application may also depend on the objective of weed control: for example, spraying weeds early in the growing season when they are small will give native plants more chance of surviving due to reduced competition. Bulbs, corms and tubers are ideally treated when the underground storage organs are depleted; woody weeds, when they are actively growing; and perennial grasses, when they are actively growing (before flowering). However, spraying later in the growing season may make it unnecessary to follow up with treatment for late germinants or weeds that germinate following initial spraying.

Selective: have been developed to kill a particular type of plant (e.g. grasses)

Non-selective: (or broad spectrum) herbicides kill a wide range of plants

Residual: remain active in the soil for some time and may kill germinating seeds and susceptible plants

Non-residual: (or knockdowns) kill existing weeds but have no effect on germinating seeds

Pre-emergent: kills germinating seedlings when applied to the soil before germination[8]

Non-synthetic: of natural origin; not derived artificially by chemical reaction, and free from chemical treatments or additives. Other terms commonly used to describe non-synthetic herbicides include natural or organic herbicides.

Techniques for herbicide application

There are many techniques for herbicide application. Selection of the most appropriate technique will depend on a range of factors including the weed species, extent and severity of infestation to be treated, nature of associated vegetation/habitat, available equipment and resources.

Herbicide wipe

This method is ideal for areas where spraying is not suitable: for example, where weeds are growing in environmentally sensitive areas that may be adversely affected by spray drift, such as within dense native vegetation or around inundated or waterlogged areas. Herbicide is wiped or brushed onto the leaves using equipment with materials soaked in herbicide such as a wick applicator, a modified hand sprayer or glove with foam attached. This method can be time consuming in areas where infestation is severe. Care needs to be taken to ensure that herbicide does not drip from weeds onto non-target species.

Foliar spraying

Foliar spraying is a good option for controlling wetland weeds where the risk of spray drift onto native vegetation (non-target species), inundated or waterlogged areas is minimal. Spraying should only be undertaken on fine, still days to minimise risk of run-off of chemical and/or spray drift. Foliar spraying techniques include spot spraying and blanket spraying, using equipment from hand sprayers, backpack sprayers to boom sprays operated from vehicles (see Figure 34). Whichever method is chosen, it is important that the operator knows the difference between weeds species and native species, particularly in areas where native grasses could be mistaken for weeds. The site should be inspected prior to spraying to ensure familiarity with target and non-target species. It is not recommended for saplings or mature trees with thick, waxy leaves (which limits absorption of herbicide) or where it is difficult to treat the canopy without off-target damage.

Figure 34. Spot spraying weeds using a backpack and hand held applicator minimises damage to non-target species. Photo - T Schwarten/Syrinx.

- ➤ For additional detail on herbicide application see section in this topic on ‘Using contractors’.

Spot spraying

Using a handsprayer or backpack, this method allows selective targeting of weeds and is useful where weeds are growing in sensitive areas and more accuracy is required to avoid damage to non-target species.

Blanket spraying

Using a backpack or a boom spray operated from a vehicle is useful for treating large or dense infestations where potential for damage to off-target species is low.

case study

Challenges in wetland rehabilitation at Bibra Lake

By Denise Crosbie (Cockburn Wetlands Education Centre)
and Norm Godfrey (Wetlands Conservation Society)

Wetlands are dynamic in nature. Bibra Lake in Perth's southern suburbs experiences seasonal patterns of wetting and drying. Developing an understanding of these patterns has assisted in the development of a successful rehabilitation program at Bibra Lake.

Zoning in wetlands

Bibra Lake is a permanently inundated wetland approximately 135 hectares in size with a maximum depth of 2.5 metres. The area of the lake that is inundated fluctuates from season to season and year to year. Water levels are largely influenced by rainfall, groundwater flows and evaporation, peaking in October and falling to minimum levels during April. Different wetland plants and weeds are associated with different zones of the wetland and this has implications for rehabilitation activities (see Figure 35).

Getting started

Maps were prepared to gain a better understanding of site conditions including water levels, topography, type and extent of existing native vegetation and weeds.

Weed control

Moving from the seasonally inundated zone towards the waterlogged zone, Bibra Lake is ringed by water couch (*Paspalum distichum*), paspalum (*Paspalum dilatatum*) and kikuyu (*Pennisetum clandestinum*). Nutgrass (*Cyperus* spp.), spear thistle (*Cirsium vulgare*) and bushy starwort (*Symphotricum squamatum*) invade bare spaces amongst the grasses. Weed control has been a major task as the removal of these primary weeds creates a space for others (secondary weeds). A combination of manual and chemical control, combined with mulching and saturation planting, has been very effective (see Figure 36).

The weed control efforts at Bibra Lake provided the following learnings:

- Chemical treatment is best applied during summer when weeds are actively growing and water levels have receded.
- Roundup Biactive® has been effective for all primary and secondary weeds (no bulbous species were present).
- A staged approach has been essential because active growth of weeds is staggered as water levels recede.
- Commitment to monthly weed control has been required because weeds actively grow in waterlogged zones during periods of maximum water level, and grow in seasonally inundated zones at minimum water level.
- Weed biomass did not require slashing in the seasonally inundated zone because it decomposed during and after flooding events. It required mowing in the waterlogged zone in readiness for a planting event, as it took years to decompose.

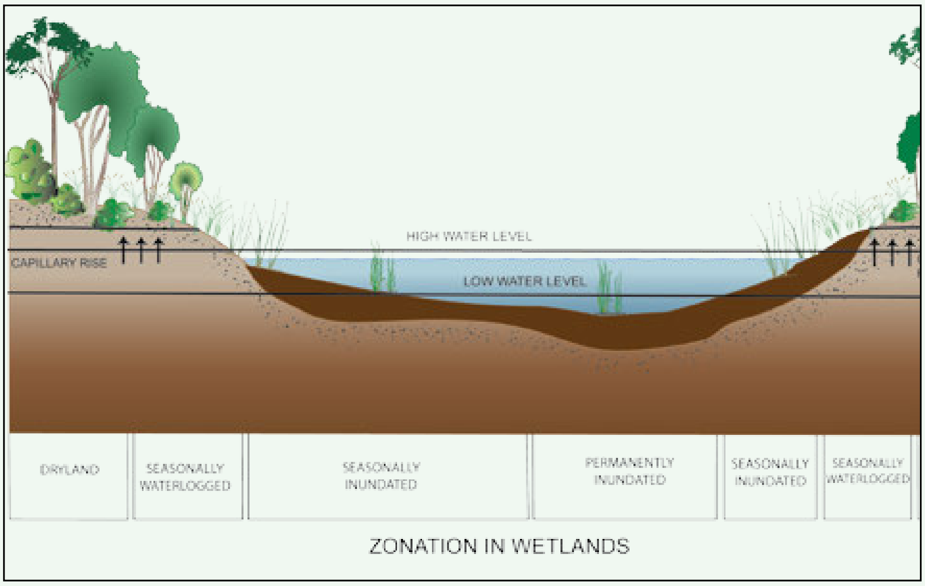


Figure 35. When controlling weeds, it is important to consider the different wetland zones and how they might influence where, when and how weed control should be undertaken. Adapted from - D Crosbie/Cockburn Wetlands Education Centre.

case study

- Mulching of the lower waterlogged to upper seasonally inundated zone with suitable mulch (the weediest zone) reduces the frequency of weed control (if using mulch, consideration should be given to dieback, weeds and nutrient input).
- Jute and paper weed matting barriers were ineffective where healthy populations of purple swamphens (*Porphyrio porphyrio*) exist.

Trials and tribulations

During the early days of rehabilitation at Bibra Lake the following problems were encountered:

- Timing of grants restricted the ability to order seedlings early and thus limited species availability.
- Chemically treated weeds did not mulch down in time for planting.
- Numerous seedlings needed replanting because they were established in the slashed weed biomass instead of the soil.
- Late plantings (September) required summer watering of the seasonally waterlogged zone.
- Secondary weed invasion was extensive.
- Planted sedges were predated by waterbirds.

Although wetland trees and tall shrubs were able to be established in weedy environments (though they grow more slowly), the object was to re-introduce understorey and attain a reasonably 'self-sustaining system' through dedicated weed control efforts.

Revegetation

Due to the dynamic nature of wetlands, many native plants may be growing outside of their optimal establishment zone. Be careful! Look at historical water data for the wetland, and at other wetland sites prior to planting. It is also difficult to predict future water levels, and during some years you may lose plants – this is part of the challenge.

Wetlands plants grow rapidly and are much quicker to reward you than their slower bushland counterparts. The planting efforts at Bibra Lake included:

- saturation planting to out-compete the weeds
- planting transitional, waterlogged and upper seasonally inundated zones during winter months
- staging planting of the lower seasonally inundated zones following a fall in water level (approximately November onwards)
- organising planting days after the maximum water levels
- removing tree guards the following winter to avoid summer predation by rabbits
- propagating locally sourced seed and establishing a wetland seed production area for future supplies.

So, can we really bring back the understorey?

Unfortunately there are no quick solutions when it comes to rehabilitation activities. The understorey is looking fantastic, bandicoot diggings are evident, and the frogs and birds are breeding. Bushy starwort, spear thistle, nutgrass and lotus invade bare areas where saturation planting has not been achieved. Our knowledge is growing and we need to continue long-term monitoring and evaluation to determine the true outcomes of our trials.

Established in 1993, the Cockburn Wetland Education Centre is an independent, not-for-profit community organisation dedicated to wetlands, restoration activities, environmental education, youth services and facility hire. Numerous volunteers implement the centre's activities along with the assistance of a small band of dedicated staff. The centre lies in the suburb of Bibra Lake, 15 kilometres south of Perth, Western Australia. It provides a gateway to Beeliar Regional Park, which contains 27 wetlands within two parallel wetland chains.

case study

Figure 36. (below) Weed control and revegetation at Bibra Lake. (a) pre-weed control, the three main grass weeds: kikuyu, paspalum and water couch; (b) the site post-spraying and preparation for revegetation; (c) post-mowing ready for planting; (d) seedlings were planted with tree guards and weed mats to help combat weed regrowth; (e) secondary weed growth – weed regrowth was less where mulch had been applied; (f) the site two years later following revegetation; (g) water couch (background) during the winter months when dormant and not actively growing. The inundated area in the foreground is where the water couch was treated the previous year and replanted with sedges; (h) water couch during the summer months when it is actively growing and the best time to spray. Photos – D Crosbie/Cockburn Wetlands Education Centre.

(a) (b) (c) (d) (e) (f) (g) (h)

Stem injection

Stem injection is used to treat woody weeds such as trees and large shrubs which would be very difficult to physically remove, or those that produce suckers in response to damage to their roots or canopy. Physical removal of trees and large shrubs risks major disturbance and damage to non-target species. Stem injection involves drilling holes into the trunk or main stem, and injecting herbicide into the holes. The holes must penetrate the **sapwood tissue** to ensure that the herbicide will be transported throughout the plant. Ideally, holes should be drilled at 5–8 centimetre intervals and at a downward angle of 45 degrees to reduce the risk of spillage. Herbicide should be injected within 10 seconds of drilling to maximise uptake in the sapwood tissue (before the plant begins to 'seal' the wound and inhibit uptake).

This method allows selective treatment of individual plants with minimal risk to non-target species. Equipment used includes a cordless drill, drill bit and an injection gun or syringes for injecting the correct dose of herbicide. If a drill or injection equipment is not available, angled cuts can be made around the stem using a chisel or tomahawk (referred to as 'chipping' or 'frilling'). When using this second method, more care is required to avoid herbicide leaking from the cuts and dripping down onto the soil or other plants.

Cut and paint

This method is used for large trees or shrubs that re-sprout and involves cutting off the trunk or main stem horizontally, as close to ground level as possible. Herbicide is then painted or sprayed immediately onto the sapwood (not the **heartwood** which is inactive and will not circulate the herbicide around the plant). Equipment required to cut down woody weeds include secateurs, loppers, hand saws and chainsaws. Herbicide can be applied with a paint brush, squeeze or spray bottle, or wick wiper. If removing the cut plant material from the site, care should be taken to minimise damage to non-target species and prevent spreading seeds. This technique is not suitable for large infestations of mature trees as felling them may cause damage to surrounding native vegetation. In addition, painting the cut stems may not deliver enough herbicide to kill the rootstock.

Basal bark spraying

This method can be used to treat woody weeds such as larger trees with thin bark and small stems (less than 20 millimetres diameter): for example, saplings, regrowth and multi-stemmed shrubs and trees. Herbicides need to be oil soluble and mixed in an appropriate oil-based substance (such as diesel) and sprayed around the full circumference of the trunk or stem. Spraying should be from ground level up to 60 centimetres in height. Care should be exercised to ensure that the bark is dry and free from dirt and that the treatment solution does not drip or run off onto non-target vegetation, soils or into water bodies. This method is quicker than cut and painting or injection as it evenly distributes the herbicide throughout the sapwood.

Scrape and paint

This method is useful for vines or other creeping plants with a woody stem that cannot be injected or cut off at the stem and painted due to too small an area for herbicide uptake. It involves scraping off 20 millimetres to 1 metre of bark along the length of the stem and applying herbicide to the exposed sapwood. Stems smaller than 10 millimetres in diameter can be scraped on one side and those above 10 millimetres should be scraped on two sides. Care should be taken not to **ringbark** the stem as this will inhibit transport of herbicide throughout the plant.

If vines are tangled in amongst native vegetation, it may be best to leave them in place once they have been killed, as removing them may damage native plants.

Sapwood tissue: specialised plant tissue that transports water and minerals upwards from the roots to the stem, via capillary action

Heartwood: the central, woody core of a tree, no longer serving for the conduction of water and dissolved minerals, usually denser and darker in colour than the outer sapwood

Ringbark: to completely remove a strip of bark around the trunk or main stem of a tree or shrub, causing its death

Keeping records of herbicide use

It is important to keep records of herbicide use to monitor success of the weed control program. Details that should be recorded include:

- herbicides used
- rate of application
- weeds treated
- size of the area treated
- date and time of treatment
- method of application
- weather conditions.

This information will help determine which methods have been successful and which haven't, so that any follow-up weed treatment can be modified if required.

Integrated weed control

Integrated weed control involves the use of a combination of control methods to achieve the best results in the most cost effective and practical way. The aim of integrated weed control should be to achieve long-term weed control without damaging the environment. Integrated weed control methods should reinforce each other and, where appropriate, assist in reducing reliance on herbicides in the long term. Integrated weed control is particularly effective when used in combination with other land management methods (for example, fencing off wetlands from livestock, planting shelterbelts) that ultimately help to prevent and reduce the spread of weeds and improve the overall condition of the natural environment.

Good planning and understanding of the site conditions (for example, soil, topography, other vegetation, climate) and the life cycle and biology of weeds is essential to ensure that the various control techniques are applied in the correct manner, at the correct time(s) and reduce future effort and cost of weed control.

Summary of weed control methods

A summary of the weed control methods, their advantages and disadvantages and types of weeds they are best suited to is provided below in Table 5.

Table 5. Comparison of weed control methods (adapted from Cooperative Research Centre for Australian Weed Management, 2004)[7]

Treatment	Advantages	Disadvantages	Suitable for control of
Manual removal (hand pulling, digging etc)	• Selective • Minimises risk to surrounding plants • Supplements other techniques • Can prevent seeding and spread • Effective on small infestations • Enhances plant identification skills and familiarity with sites	• Can disturb soils if poorly done • Timing limitations, needs moist soils • Can spread weed propagules • Unsuited to large infestations • Inappropriate for some weed species and large plants • Labour intensive	• Annual grasses • Perennial grasses • Broadleaf herbs • Corms, bulbs, tubers • Aquatic weeds

Treatment	Advantages	Disadvantages	Suitable for control of
Soil cultivation and scalping	• Can eradicate weeds • Reduces nutrient loads • Removes soil-stored weed seed bank • Can aid site rehabilitation	• Non selective • Disturbs and potentially damages wetland soil values • Spreads propagules • Destroys local flora and fauna habitat • Removes soil stored local flora seed bank • Potential for erosion/run off • Expensive • Site rehabilitation required • Technical proficiency required	• Annual grasses • Broadleaf herbs
Slashing, mowing, cutting (brushcutters, mowers, slashers)	• Minimises soil disturbances • Mimimises risk to local flora • Can prevent seeding and spread • Removes excess foliage (or follow-up treatments) • Supplements other methods • Helps to weaken plants, making them susceptible to other forms of control • Inexpensive	• Usually doesn't eradicate weeds • Can prevent seeding by local flora • Can introduce/spread weed propagules • Can encourage weed growth • Can increase fuel loads (dried material)	• Annual grasses • Perennial grasses • Annual herbs
Competition strategies (direct seeding, plantings, natural recruitment)	• Suppresses weeds • Can alter light levels and nutrient-moisture availability • Restores vegetation structure • Restores floristic diversity • Enhances fauna habitat	• Altered conditions can favour weeds • Can undermine vegetation structure with inappropriate species selection • Often entails intensive management input during establishment phase • Can be labour intensive (costly) • Specialist knowledge required	• Annual grasses • Perennial grasses • Broadleaf herbs • Corms, bulbs, tubers (during flowering) • Aquatic weeds
Mulches and smothering treatments	• Inhibits/prevents weed seeding and spread • Can complement site rehabilitation • Erosion/run-off control • Aesthetics enhanced (mulches)	• Usually non-selective • Can encourage weed growth • Prevents local plant growth and spread • Can introduce weed propagules • Can alter soil chemistry • Affects soil conditions and soil microfauna • Ongoing maintenance required • Aesthetics undermined • Costly and labour intensive	• Annual grasses • Broadleaf herbs
Weed barriers	• Selective • Reduces reliance on herbicides • Supplements other methods • Can be incorporated into hard landscaping	• Constructed barriers can be expensive and labour intensive • Not suitable for large areas	• Annual grasses • Perennial grasses
Solarisation (clear or black UV plastic)	• Can be selective • Can control tenacious weeds • Inhibits/prevents seeding and spread • Supplements other methods • Appropriate on a small scale • Low costs (once installed)	• Usually non selective • Ineffectual on many weeds • Unsuitable for large infestations • Prevents local plant growth and spread • Affects soil conditions and soil micro-fauna • Ongoing maintenance require	• Annual grasses • Perennial grasses

Treatment	Advantages	Disadvantages	Suitable for control of
Fire (control burns, spot-burns)	• Removes dead and excessive foliage (for follow-up spray treatments) • Supplements other methods • Can encourage local flora regeneration • Encourages germination of soil stored weed seed bank (for follow-up treatments) • Relatively inexpensive • Can kill some weed seed banks	• Usually does not eradicate weeds • Inappropriate for non-fire adapted ecosystems • Damages native vegetation/fauna if used incorrectly • Seasonal and timing limitations • Encourages weed growth/ germination • Altered nutrient-moisture availability can favour weeds • Potential for run-off/erosion • Fauna, people, property risks • Can be costly if establishment of fire breaks and personnel to control fire are involved • Specialist knowledge required	• Not recommended in general
Flame and steam weeding	• Selective • Reduces reliance on herbicide in sensitive areas • Minimal soil disturbance • Minimal environmental impact	• Can be expensive to use • May require repeated applications • Labour intensive • Variable results • Risk of off-target damage • Risk of fire • Specialist knowledge required	• Annual grasses • Annual broadleaf
Biological controls	• Selective • Can suppress weed growth and spread • Supplements other methods • Long-term value for money • Minimal labour input (in the field) • Minimal direct environmental impacts	• Timing limitations • Variable results • Does not eliminate weeds • Other controls required • Expensive to develop • Limited range of weeds can be targeted	• Bridal creeper • Blackberry
Herbicides (foliar application)	• Selective (depending on choice of herbicide, timing, plant life cycles, operator skill) • Can prevent weeds seeding and spreading • Appropriate on small and large weed infestations • Minimises direct soil disturbances • Inexpensive	• Potential for non-selective damage/ may destroy local flora • Potential impacts on the broader environment • Technical proficiency required • Operator/public hazards	• Annual grasses • Perennial grasses • Broadleaf herbs • Corms, bulbs, tubers (at or during flowering) • Aquatic weeds
Woody weed treatments (cut and wipe, stem injection, scrape and paint etc.)	• Selective • Minimises risks to local flora • Prevents seeding and vegetative spread • Inexpensive (on small infestations)	• Site disturbances can be excessive, care is needed • Can spread weed propagules (by removal of plant material from the site) • Can destroy native fauna habitat • Can encourage weed growth/ germination • Operator/public hazards • Costly and labour intensive (on large infestations)	• Trees, large shrubs

Monitoring weed control

Monitoring is an important aspect of weed management. It helps to identify where weed control efforts have been successful (or otherwise) and where efforts may need to be continued or modified in the future. Regular monitoring (at least twice a year) will also indicate areas in which weeds are re-invading and therefore where prompt treatment is required while plants are still in the early stages of growth.

➤ For additional detail on wetland monitoring, refer to the topic 'Monitoring wetlands' in Chapter 4.

Long-term monitoring will help to finetune existing and future weed management programs and optimise the use of available resources. Weed surveys and mapping are useful ways of monitoring and recording the success of weed control measures. Taking photographs (photo points) is also a good way of recording weed mortality, regrowth and also any natural regeneration occurring after weed control.

Using contractors

When using contractors to undertake weed control, it is essential that they are trained and experienced in working in a wetland or bushland setting and will do everything necessary to ensure that weeds are not spread and environmental damage is avoided, particularly where herbicides are to be used. Spray contract businesses must be registered with the Pesticide Safety Section (PSS) of the Health Department of Western Australia.

Spray contractors must be able to tell the difference between weeds and native plants and be prepared to use equipment that minimises the risk of off-target damage (for example, use of backpacks or other hand-held sprayers or wiping devices). They should also be familiar with the risks of herbicide use near wetlands and understand the most appropriate chemicals and application rates for the target weed species.

It is helpful to provide contractors with a weed map and a guided site visit to ensure that they know the exact location of weeds to be controlled, their relationship with native vegetation and how to access those areas. They should also follow standard hygiene practices to avoid spreading seed and dieback to and from the site, e.g. by cleaning tools, equipment, machinery, vehicles (especially tyres) and boots appropriately.

Whether or not to manage weeds in a wetland

When deciding whether or not to manage weeds in wetlands, there are a number of factors that should be considered including: the biodiversity and other value(s) under threat; how practical and effective management will be; and the amount and availability of resources to undertake management (time, money and labour). As resources for weed control tend to be limited it is also important to consider the impact and invasiveness of various species and their current distribution. There may be a number of weed species present in or around a wetland and available resources may mean that not all of them can be dealt with. Therefore, priorities for control may be weeds with the greatest potential for rapid spread and environmental damage, for which effective control is achievable.

Some questions to help focus the decision-making process include:

- **Is the weed a declared plant species or a weed of national significance (WONS)?**

  Landholders are obliged to control these plants at their own expense. Declared plants and WONS can cause significant damage to ecosystems and agricultural productivity if not controlled. Early intervention provides the best chance of preventing long-term damage to wetlands.

- **Do the weeds pose a fire hazard?**

  Weeds that present a fire hazard should be controlled as a matter of priority. The impacts of a fire are far-reaching and can not only damage wetlands, they can also put human lives and infrastructure at risk.

- **Are the weeds inhibiting native plant growth and/or regeneration?**

  If weeds are preventing the growth or regeneration of native vegetation, it is likely that the vegetation structure of the wetland is becoming degraded and biodiversity values reduced. Over time, if weeds are allowed to dominate the understorey, the wetland will have reduced biodiversity value, and the scale of the weed problem may become unmanageable.

- **Are the weeds degrading native fauna habitat?**

  If habitat for native fauna is degraded by weeds, the decline in habitat diversity will reduce the biodiversity of the wetland. In cases where weeds provide some fauna habitat (for example, introduced bulrush can provide waterbird habitat), removal should be gradual to allow fauna time to adapt until natural regeneration (or revegetation) occurs.

- **Are any threatened fauna, declared rare flora (DRF) or threatened ecological communities (TECs) present?**

  Under the *Wildlife Conservation Act 1950*, individual species of plants and animals are protected, with the level of protection varying depending on whether the species is rare or endangered. Weeds can pose a threat to these values by altering vegetation structure and diversity and degrading fauna habitat. Landholders with identified threatened fauna, DRF or TECs on their land should contact the Department of Environment and Conservation before undertaking weed control or any other activity that has to potential to negatively impact on protected species.

  ➤ For additional detail on DRF and TECs see the topic 'Wetland vegetation and flora' in Chapter 2.

- **Are the weeds a potential threat to other values?**

  The potential for weeds to threaten other values both within and outside the wetland or property boundaries should be considered. For example, aesthetic and/or real estate values may be compromised, health problems may occur (for example, pollen or grass seeds causing allergies in humans, pets or livestock), or there may be the potential for weeds to spread into adjacent properties or wetlands.

Topic summary

- Weeds can be defined as 'plants that become established in natural ecosystems, altering natural processes and leading to the decline of the communities they invade.'[3,1]
- Weeds threaten primary production, and the biodiversity and conservation values of Western Australian ecosystems. They affect severely on agriculture and biodiversity by competing with crops and out-competing native plants and degrading habitat.
- Weeds respond rapidly to disturbance, out-competing native plants for available light, water, space and nutrients. They also have fewer natural predators, pests or diseases than native plants, which assists them to grow and spread virtually unchecked.
- Weeds tend to invade areas where disturbance of soil or natural vegetation has occurred or where the natural fire regimes have changed. Activities that disturb natural areas such as clearing native vegetation for agriculture, settlement and transport, logging, rubbish dumping and livestock and vehicle movement contribute to the introduction and spread of weeds.
- Wetlands are particularly vulnerable to weed invasion where moist productive soils are present in association with disturbance factors, Phytophthora dieback and altered fire regimes.

- Understanding the life cycle and biology of weeds is essential for successful management.
- Weed management does not necessarily imply complete and permanent removal of every single weed in a given area. In many cases, complete removal of weeds is not desirable or feasible for many reasons – for example limited resources, increased potential for erosion or other adverse environmental impacts.
- Guiding principles for successful weed control include preventing weeds from becoming established in the first instance, accurately identifying weed species, mapping weeds and native vegetation, controlling weeds while in the early stages of growth (and before seed set), working from the least affected areas towards the worst affected areas using a combination of methods if possible, and hygiene management to avoid spreading weeds.
- Integrated weed management combines a number of weed control strategies to ensure the best possible result and most cost effective use of resources.
- Natural regeneration or revegetation should occur following weed control to minimise new weed invasions.
- Monitoring and recording the progress of weed control is essential to determine what has worked, what hasn't worked and how future weed control is best undertaken.
- When deciding whether or not to manage weeds in wetlands, a number of factors should be considered such as: impacts, invasiveness and current/potential distribution; the biodiversity and other value(s) under threat from both the weeds themselves and proposed control strategies; how practical and effective management will be; and the amount and availability of resources to undertake management over the timeframe necessary to achieve desired outcomes.

Sources of more information on managing weeds in wetlands

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Useful websites

Australian Pesticides and Veterinary Medicines Authority (APVMA)
www.apvma.gov.au
Herbicide registration information

Commonwealth Department of Sustainability, Environment, Water, Population and Communities
www.weeds.gov.au

Council of Australasian Weed Societies (CAWS)
www.caws.org.au

CSIRO Entomology (weed ecology and biological control)
www.csiro.au/science/InvasivePlants.html

Department of Agriculture and Food
www.agric.wa.gov.au
Declared Plants and their control, State Weed Plan for WA, Permitted and Prohibited species lists

Department of Environment and Conservation
www.dec.wa.gov.au/content/category/31/936/2275/
FloraBase, Urban Nature

Department of Water
http://portal.water.wa.gov.au/portal/page/portal/WaterQuality/Publications/WaterNotes?pAP=WaterManagement&pAS=Waterways
Water notes: advisory notes on river and wetland restoration

Environmental Weeds Action Network of WA (Inc.)
www.environmentalweedsactionnetwork.org.au

Global Compendium of Weeds
www.hear.org/gcw

HerbiGuide
www.herbiguide.com.au
Herbicide, weed and control information

Northern Australian Quarantine Strategy (NAQS)
www.aqis.gov.au/naqs
Target list of weeds

RG & FJ Richardson
www.weedinfo.com.au
Publishers

Weedbuster Week
www.weedbusterweek.info.au

Weeds Australia
www.weeds.org.au

Weeds Society of WA (Inc.)
www.wswa.org.au

Glossary

Annual: a plant that normally completes its life cycle (from germination to flowering, seed production and death of vegetative parts) within a single growing season

Aquatic plants: a plant that grows for some period of time in inundated conditions and depends on inundation to grow and, where applicable, flower

Biennial: a plant that normally completes its life cycle (from germination to flowering, seed production and death of vegetative parts) within two years

Biological control: the control of an introduced plant or animal by the introduction of a natural predator or pathogen, usually bacteria, viruses or insects, or by biological products such as hormones

Bioregion: a territory defined by a combination of biological, social and geographic criteria rather than by geopolitical considerations; generally, a system of related, interconnected ecosystems[1]

Broadleaf: plants that possess relatively broad flat leaves rather than needle-like leaves

Corms, bulbs, tubers: specialised underground fleshy storage organs that allow plants to flourish in nutrient deficient soils or to die back and enter a state of dormancy when conditions are extreme, such as during fire or drought[8]

Crown: the region of compressed stem tissue from which new shoots are produced, generally found near the surface of the soil

Cultivation: methods of breaking up and turning the soil

Disturbance opportunists: responding positively and rapidly to habitat disturbance

Ecosystem services: the processes by which the environment produces resources that provide benefits to humans, for example, flood and disease control, clean air, waste recycling, plant pollination[2]

Emergent: a plant that is protruding above the surface of the water or, where a water column is not present, above the wetland soils (as distinct from floating or submerged plants)

Environmental weeds: plants that become established in natural ecosystems, altering natural processes and leading to the decline of the communities they invade[3,1]

Heartwood: the central, woody core of a tree, no longer serving for the conduction of water and dissolved minerals, usually denser and darker in colour than the outer sapwood

Indigenous: a species that occurs at a place within its historically known natural range and that forms part of the natural biodiversity of a place

Life form: the shape or appearance of a plant that mostly reflects inherited or genetic influences

Local provenance: indigenous plants propagated from collections from locations as close as geographically (in terms of habitat) practicable to the location where the propagated plants are to be planted, ensuring that genetic integrity is maintained

Naturalised: plants that spread and persist outside of their normal range of distribution

Non-residual herbicides: (or knockdowns) herbicides that kill existing weeds but have no effect on germinating seeds

Non-selective herbicide: (or broad spectrum) herbicides that kill a wide range of plants

Non-synthetic: of natural origin; not derived artificially by chemical reaction, and free from chemical treatments or additives. Other terms commonly used to describe non-synthetic herbicides include natural or organic herbicides

Non-woody weeds: weeds with a non-woody green stem

Perennial: a plant that normally completes its life cycle (from germination to flowering, seed production and death of vegetative parts) in two or more growing seasons

Photosynthesis: the process in which plants, algae and some bacteria use the energy of sunlight to convert water and carbon dioxide into carbohydrates they need for growth and oxygen

Pre-emergent herbicides: herbicides that kill germinating seedlings when applied to the soil before germination[8]

Residual herbicides: herbicides that remain active in the soil for some time and may kill germinating seeds and susceptible plants

Rhizomes: stems that are buried underground

Ringbark: to completely remove a strip of bark around the trunk or main stem of a tree or shrub, causing its death

Sapwood tissue: specialised plant tissue that transports water and minerals upwards from the roots to the stem, via capillary action

Scalping: involves slicing off the top layer of soil which contains weeds and weed seeds, leaving the surface bare in preparation for revegetation

Sedge: tufted or spreading plant from the families Cyperaceae, Centrolepidaceae, Hydatellaceae, Juncaginaceae, Restionaceae, Juncaceae, Typhaceae and Xyridaceae. In these plants the leaf sheath is generally not split, there is no ligule, the leaf is not always flat and there is an extended internode below inflorescence. Some sedges are also known as rushes.

Seed dispersal mechanisms: the means by which plants distribute their seeds, for example via wind, water, birds and insects etc

Selective herbicide: refers to herbicides that have been developed to kill a particular type of plant (for example, grasses)

Shelterbelts: belts or rows of trees and shrubs planted to provide protection against prevailing winds

Stolons: stems that usually run horizontally along the soil surface

Succulent: plants which have specialised fleshy, soft and juicy tissues designed for the conservation of water, for example, cacti

Vegetative reproduction: a type of asexual reproduction found in plants. It is also called vegetative propagation or vegetative multiplication

Weed: a plant that requires some form of action to reduce its harmful effects on the economy, the environment, human health and amenity, and [the term weed] can include plants from other countries or other regions in Australia or Western Australia[2]

Wetting agent: a substance that helps water or other liquid to spread or penetrate (also known as a surfactant or penetrant)

Woody weeds: perennial weeds with woody stems including shrubs, trees and some vines

Personal communications

Name	Date	Position	Organisation
Kellie Agar	September 2009	Program Coordinator – Invasive Plants	Department of Environment and Conservation, Western Australia

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A guide to managing and restoring wetlands in Western Australia

Water quality

In Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Water quality' topic

Acknowledgments

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Recommended reference

When referring to the guide in its entirety, the recommended reference is: Department of Environment and Conservation (2012). *A guide to managing and restoring wetlands in Western Australia*. Department of Environment and Conservation, Perth, Western Australia.

When specific reference is made to this topic, the recommended reference is: Department of Environment and Conservation (2012). 'Water quality', in *A guide to managing and restoring wetlands in Western Australia*, Prepared by J Lawn and T Bell, Department of Environment and Conservation, Perth, Western Australia.

Contents

Case studies

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

Introduction

The quality of water in a wetland has a significant influence on the natural characteristics and values of the wetland. The native plants, animals, fungi, algae and bacteria of wetlands are adapted to particular water quality conditions, which are critical to their ability to survive. If water quality is changed to the extent that it exceeds the **tolerance limits** of wetland **organisms**, loss of individual organisms, **species**, habitat and ultimately **biodiversity** can occur. The nature of wetlands and the functions they perform can alter when water quality declines. For these reasons, understanding, protecting and managing water quality is essential to wetland management and critical to conserving wetland biodiversity in the long term. Poor water quality can also reduce people's enjoyment and use of wetlands, with nuisance midge populations and odours among the problems it can cause.

This topic focuses upon the management of human-caused changes to water quality in order to protect and maintain the natural characteristics of wetlands of conservation value in Western Australia. It includes individual sections on excess nutrients, acidification, turbidity and pollution by pesticides, metals, hydrocarbons (oils), pathogens, heated water and litter. While other water quality problems are beyond the scope of this version of this topic, many of the general principles for managing water quality covered in this topic will apply to other problems.

Tolerance limits: the upper and lower limit to the range of particular environmental factors (e.g. light, temperature, salinity) within which an organism can survive. Organisms with a wide range of tolerance are usually distributed widely, while those with a narrow range have a more restricted distribution.

Organism: any living thing

Species: a group of organisms capable of interbreeding and producing fertile offspring, for example, humans (Homo sapiens)

Biodiversity: encompasses the whole variety of life forms—the different plants, animals, fungi and microorganisms—the genes they contain, and the ecosystems they form. A contraction of 'biological diversity'.

Important note

Natural wetland water conditions are covered in more detail in the topic 'Conditions in wetland waters' in Chapter 2.

This topic has been written with the assumption that the reader has a certain amount of knowledge about natural wetland water conditions. This topic builds on the 'Conditions in wetland waters' topic by outlining the causes and effects of reduced water quality and strategies for preventing and managing impacts to water quality.

What is water quality?

Water quality is a term used to describe the condition of water relative to meeting certain standards for its intended purpose, such as drinking water or irrigation. Importantly, in this topic, the term **water quality** is used specifically to refer to the quality of water in the environment, such as a wetland, relative to its natural, undisturbed state. The closer it is to its natural state, the 'better' it is said to be.

However, wetlands each have their own individual natural water chemistry. This is the challenge in managing water quality - there is no simple water quality target that applies to all wetlands in WA. So what determines a wetland's natural water chemistry? The incoming surface water and groundwater are an important influence upon the water quality of a wetland, and the incoming water in turn is heavily influenced by the characteristics of the surrounding geology (rocks and soils) that the water flows through to reach the wetland. For example, the water picks up various salts and other materials in various concentrations depending upon the local geology. This influences the salinity (concentration of salts) and water softness/hardness (concentration of calcium, magnesium and bicarbonate) of water. Wetlands in WA range from fresh to hypersaline (that is, many times more saline than seawater), and from soft to extremely hard. How fresh or saline water is, and how hard or soft it is, can influence the organisms that occur in a wetland and also influence how a wetland is affected by nutrients, acid and pollutants.

Importantly, wetland water chemistry is not constant. It changes in response to environmental variables. In addition to the geology of an area and the quality of the incoming water, the **water regime** and **sediment** of the wetland also has a strong influence on its water chemistry. Wetting and drying, for example, dilute and concentrate salts, and drying exposes sediment to oxygen, triggering chemical changes in the sediment, which is typically where most of a wetland's nutrients are stored. Nutrients can be bound to the sediment or liberated from sediment depending on the composition of the sediment and the prevailing conditions. Permanently inundated wetlands tend to have less pronounced changes in water chemistry compared to those that wet and dry. Because decomposition processes are less vigorous in these wetlands, they also usually have a greater store of organic matter in their sediments. In turn, the composition of the sediment has a strong influence on water chemistry, with the mineral and organic particles present having differing affinities for binding with nutrients, metals and pollutants and for buffering acidity. These factors are described in more detail in this topic.

Water quality is often measured against a range of **physical, chemical** and **biological** characteristics or parameters such as turbidity, salinity and algal concentration. These parameters often influence each other (that is, they interact) and may vary seasonally, depending on a variety of factors.

Water quality: the quality of water relative to its natural, undisturbed state

Water regime: the specific pattern of when, where and to what extent water is present in a wetland. The components of water regime are the timing, frequency, duration, extent and depth and variability of water presence.

Sediment: in general terms, the accumulated layer of mineral and dead organic matter forming the earth surface of a wetland. Used interchangeably in this guide with the terms 'wetland soil' and 'hydric soil', although all three of these terms have more specific meaning in wetland pedology.

Physical parameters: physical characteristics of water such as temperature, turbidity, colour

Chemical parameters: chemicals found in water such as dissolved oxygen, pH, nutrients and pollutants

Biological parameters: organisms that inhabit wetlands such as algae, macroinvertebrates, fish

What are the most common water quality problems in WA wetlands?

Detrimental changes to wetland water quality have occurred in many wetlands in WA, particularly those in heavily populated, farmed, grazed and mined areas. In the past, the value of wetlands as unique ecosystems worthy of conservation and protection in their natural condition has been secondary to their usefulness to humans. Wetlands have been cleared, filled, drained and modified as a result of urban, agricultural, mining and industrial development. A number have been dug out to look more like the deep lakes of the northern hemisphere and to contain large volumes of stormwater and pollutants. Table 1 summarises the most common water quality problems in WA wetlands.

Table 1. A summary of common water quality problems applicable to WA wetlands.

Water quality problem	Potential impacts to plants, animals and humans	Indicators	Causes	Refer to
Excess nutrients (eutrophication)	Less nutrient-sensitive species and potentially more nutrient-tolerant species Algal and cyanobacterial blooms Odours Bird illness and death (avian botulism) Fish deaths Weeds Nuisance midge populations Reduced biodiversity of plants and animals	High nutrient levels in water High chlorophyll *a* levels Low dissolved oxygen levels/high biological oxygen demand High levels of ammonia Low light levels	Nutrient pollution of surface water and groundwater in the catchment Artificial permanent inundation of seasonally drying wetlands Landfill within the wetland (uncommon) Under some circumstances, wetland acidification	Page 36
Acidification	Impaired health of plants and animals Death of plants and animals Less acid-sensitive species and more acid-tolerant species Altered composition of plant and animal species Reduced biodiversity of plants and animals Increase in acid-tolerant mosquitoes	Marked reduction in pH of water or sediment Increased net acidity Jarosite in sediment Sediment scalds Water that is crystal clear, yellow/orange/brown or milky-white Reduction in oxygen levels Release of metals from sediment to water	Mobilisation of acidic groundwater via rising groundwater and deep drainage Generation of acids by exposing sulfides in soil to air, through drying and/or soil disturbance	Page 82
Secondary salinity	Impaired health of plants and animals Death of plants and animals Less salt-sensitive species and more salt-tolerant species Altered composition of plant and animal species Reduced biodiversity of plants and animals	Salinity of water (various measurements possible) Disappearance of salt-sensitive species Appearance of salt-tolerant species Death of trees and shrubs Salt scalds Deposits of solid salt	Rising saline groundwater Seawater intrusion Reduction in freshwater entering wetland due to various causes	'Secondary salinity' topic in Chapter 3
Pesticides	Impaired health of plants and animals Reduced ability of plants, algae and cyanobacteria to photosynthesise Disrupted fertility, reproduction and growth in plants and animals Death of plants and animals Less pesticide-sensitive species and more pesticide-tolerant species Altered composition of plant and animal species Reduced biodiversity of plants and animals	Pesticide levels in sediment and water Pesticide levels in incoming water (e.g. following heavy rain) Pesticide levels in affected organisms	Pollution	Page 111

Water quality problem	Potential impacts to plants, animals and humans	Indicators	Causes	Refer to
Excess metals	Impaired health of plants and animals Reduced reproductive success of plants and animals Birth defects Death of plants and animals Less metal-sensitive species and more metal-tolerant species Altered composition of plant and animal species	Metal levels in sediment and water Water appearance (in the case of aluminium and iron pollution) Metal levels in affected organisms	Pollution Acidification	Page 117
Hydrocarbons	Impaired health of plants and animals Death of plants and animals Altered habitat Altered composition of plant and animal species	Slicks on water Hydrocarbons in sediment and water Coatings on animals	Pollution	Page 124
Excess pathogens	Unusual behaviour and/or distress in animals Disease in plants and animals Death of plants and animals Changes in abundance and diversity of sensitive species	Pathogen levels in water	Pollution	Page 127
Unnatural turbidity	Reduced ability of plants, algae and cyanobacteria to photosynthesise Impaired health of plants and animals Death of plants and animals Less turbidity-sensitive species and more turbidity-tolerant species Altered composition of plant and animal species	Increased cloudiness or muddiness of water Smothering of benthic organisms	Vegetation clearing, grazing in catchment Loss of wetland vegetation Other including waterskiing, fires, inappropriate stormwater management practices and introduced animals.	Page 130
Thermal pollution	Reduced ability of plants, algae and cyanobacteria to photosynthesise Death of animals Altered composition of plant and animal species	Fish 'gasping' for oxygen at the water surface Temperature measurements	Pollution	Page 137
Litter and debris	Variable	Foreign material in/around wetlands	Pollution	Page 139
Loss of 'colour' (reduction in concentration of dissolved substances, commonly organic materials but may also include iron, manganese and copper). Colour affects the total incidence of light, and the wavelengths of light, that can penetrate the water column.	Increased susceptibility to algal and cyanobacterial blooms Increased susceptibility to nuisance populations of midge Altered composition of plant and animal species	Reduction in colour (measured in gilvin or true colour units).	Clearing in wetland and/or catchment reducing incoming dissolved organic matter Acidification (oxidation of organic matter, and flocculation and precipitation of tannins under low pH conditions)	For more information on colour, see the topic 'Conditions in wetland waters' in Chapter 2.

What are the causes of poor water quality?

Wherever land is used for urbanisation, agriculture, mining or industry, water quality of associated wetlands will be at risk from becoming degraded as a result of these activities. Poor water quality is not just about pollution. There are in fact three main causes of poor water quality in WA wetlands:

1. poor quality of incoming surface water or groundwater
2. poor quality of wetland water due to alterations to a wetland's water regime (for example, wet or dry longer than natural)
3. poor quality of wetland water due to other wetland disturbances (for example, clearing, grazing and soil disturbance)

Many wetlands in WA experience poor water quality because of one or more of these factors.

There is now a far greater appreciation that land uses and activities occurring kilometres away from wetlands can affect their water quality. The quality of the water a wetland receives from its surface water **catchment** and **groundwater capture zone** is critical. For example, one of the most common water quality problems in all types of aquatic ecosystems is an excess of nutrients, which can cause imbalances in their chemistry and ecology. A visible outcome of this is nuisance and toxic **algal** and **cyanobacterial** blooms. These are not uncommon in wetlands in highly developed areas of Perth, Peel, the south-west and south coast, and have also been reported from the Pilbara and Kimberley. Excess nutrients discharged from agricultural, urban and industrial land uses within the catchment of a wetland can enter wetlands from surface waters, such as overland flow, drains and waterways—that is, **stormwater**. They can also be washed into the soil, reaching the groundwater and then entering down-gradient wetlands via the groundwater.

Links to more information on catchments and capture zones

Identifying surface water catchments and groundwater capture zones are covered in more detail in the topic 'Wetland hydrology' in Chapter 2. A quick guide to identifying a wetland's surface water catchment is provided in the text box at the end of this section.

But pollution is only part of the problem. Poor water quality is also linked to alterations to surface water and groundwater flows. Urban areas are a good example. Before they are developed for urban land use, catchments are covered in native vegetation, and a high proportion of rainfall is **transpired** by vegetation or infiltrates into the ground to become groundwater. These two processes slow down the water, and as it travels over and through vegetation, soil and groundwater aquifers, it picks up materials in dissolved and **particulate** forms. For example, if the water flows through limestone on its way to a wetland, it may naturally pick up bicarbonates that buffer it against acidic water. Or, if it flows over granite, it may cause the water to naturally become more acidic. As it flows through vegetation, water can pick up soil particles, dissolved plant matter such as tannins, which have an influence on water chemistry, and other organic matter that provides energy that travels through wetland food webs. The process of flowing through soil and aquifer materials often also attenuates (removes) some materials in the water, such as nutrients.

Catchment: an area of land which is bounded by natural features such as hills or mountains from which surface water flows downslope to a particular low point or 'sink' (a place in the landscape where water collects)

Groundwater: water occurring beneath the ground surface in spaces between soil grains and pebbles and in fractures or crevices in rocks

Groundwater capture zones: the area within which any recharge (infiltrating water) eventually flows into the wetland

Algae: a general term referring to the mostly photosynthetic, unicellular or simply constructed, non-vascular, plant-like organisms that are usually aquatic and reproduce without antheridia and oogonia, that are jacketed by sterile cells derived from the reproductive cell primordium; includes a number of divisions, many of which are only remotely related to each other

Cyanobacteria: a large and varied group of bacteria which are able to photosynthesise

Stormwater: water flowing over ground surfaces, in natural streams and drains as a direct result of rainfall over a catchment. It consists of rainfall runoff and any material (soluble or insoluble) mobilised in its path of flow.

Transpiration: the process in which water is absorbed by the root systems of plants, moves up through the plant, passes through pores (stomata) in the leaves and other plant parts, and then evaporates into the atmosphere as water vapour

Particulate: in the form of particles (small objects)

In comparison, traditionally designed urban land uses in WA generate significantly more stormwater compared to undeveloped catchments. This is because the vegetation is cleared to make way for roads, houses and other buildings. These **impermeable** surfaces in urban areas don't use water and they don't allow the same volume of water to infiltrate into the soil, meaning that natural water loss is minimised, and that water flow paths and their associated filtration and accumulation processes are bypassed. As Perth and other urban areas around WA have grown, the easiest way to deal with this excess water has been to direct it into the most convenient receiving environment by pipe—be it a wetland, waterway or the ocean—or to create a depression to store the water. As a result, some wetlands are now much wetter for much longer, changing their water regime and altering the types of physical, chemical and biological changes that occur in the sediment. Because the water in these wetlands has not flowed through soil, vegetation and aquifers before reaching them, it hasn't accumulated natural dissolved and particulate materials, but it has picked up pollutants from roads and other built surfaces. These pollutants compound the problems caused by alterations to their water regime.

Impermeable: does not allow water to move through it

Changes to the natural stormwater and groundwater patterns, and their impacts on wetlands, are a legacy of historical urban and rural development. Without drains, many wetland areas of Perth and Peel, as well as other areas of WA, would not have been able to be used or converted to dryland for use as farming and residential land, and later for commercial and industrial land. Extensive networks of drains were installed to remove water from wetlands, and these remain today. As well as being a means of destroying or significantly altering many wetlands, the environmental impact of these drains was compounded, because the water from these drained wetlands were often directed into many of the remaining wetlands. In Perth, for example, large chains of wetlands are influenced by 'main drains'. The excess of water has changed the character of many of these wetlands. Importantly, unlike the urban drainage of other Australian cities, Perth's main drains are designed to intercept and convey shallow groundwater in addition to surface overland flow.[1]

Stormwater has been a significant source of pollutants for many WA wetlands. In addition to rainfall runoff, stormwater consists of material (soluble or insoluble) mobilised in its path of flow. Stormwater may discharge nutrients, acidic waters, suspended particulates, pesticides, metals, hydrocarbons, pathogens and litter into wetlands. Some stormwater reaches wetlands by overland flow, while some is captured by stormwater infrastructure such as drains, pipes and basins (particularly in urban areas) which then discharges into wetlands, waterways or the ocean (Figure 1). For example, stormwater

Figure 1. Pipes discharge stormwater into Lake Monger, Perth.
Photo – L Mazzella/Department of Water.

pollutants discharged into Herdsman Lake have been described in the thesis *Land use changes and the properties of stormwater entering a wetland on the sandy coastal plain in Western Australia.*[2]

Groundwater plume: body of polluted water within an aquifer

Wetlands are also receiving environments for discharge water from mining operations, which in addition to altering natural water regime, can be laden with acids, salts and pollutants.

Groundwater pollution is associated with a range of land uses. **Groundwater plumes** from a range of contaminants are evident in a number of locations in WA. For example, in the Perth metropolitan area, groundwater plumes are documented in association with landfill sites, residential development, waste recycling and treatment facilities, underground hydrocarbon storage tanks, liquid waste disposal sites, fertiliser manufacturing sites, railway workshops and mixed urban land uses.[3]

In a number of areas of WA, human alterations to groundwater are also a source of water quality problems in wetlands. Over-use of groundwater can cause groundwater dependent wetlands to become drier than natural, which is one of the causes of wetland acidification—via acid sulfate soils—that is especially prevalent in the south west of WA. In contrast, extensive clearing in the Wheatbelt has caused the groundwater table to rise significantly, making wetlands far wetter than natural, and far saltier than natural due to the mobilisation of salts present in the soil, and in some circumstances, far more acidic than natural.

➤ Secondary salinity is a complex water quality issue, covered in more detail in the topic 'Secondary salinity' in Chapter 3.

extra information

Determining the surface water catchment of a wetland

Topographic contours—lines showing the height of the land—and knowledge of the area are key to determining the surface water catchment of a wetland. Topographic contours can be obtained from sources such as Landgate's WA Atlas (www2.landgate.wa.gov.au/web/guest/wa-atlas). Of most use is a map (hard copy or digital) that shows aerial photography and is overlain with topographic contours.

First, mark the location of your wetland on the map. In most cases the wetland will be at a low elevation and the height of the surrounding land will rise; the numbers showing the height in metres on the lines of the topographic map will increase. Start at the north end of your wetland and, moving northerly, follow the rising topography lines until you reach the spot where the land elevation starts to decrease. The highest elevation point marks the edge of the wetland's catchment at that point. The water that falls on land north of this spot will flow away from your wetland; that which falls south of it will flow toward your wetland. Use this same exercise to mark the southern, eastern, and western boundaries of the watershed. Then connect the dots by a line between them that follows the land's topography. This is the boundary of your natural catchment. If you have trouble drawing in the line, imagine dropping a ball in the area and think again about which direction it would roll. If it would roll toward your wetland, then the area is within your wetland's watershed. However, sometimes the topography is not uniform, and the boundary can be complex, including water initially flowing away from the wetland before being directed back to it. So you may need to follow the route the water takes where a clear catchment boundary is not evident. Urban drainage can also change the rules, where water is artificially moved between natural catchments. Planners in the relevant local government authority (council or shire) may be able to tell you when this is the case.

Once you have determined what land drains to your wetland, it will be easier for you to recognise what or who else may be affecting your wetland. You may want to continue working with your map, labelling or marking where different activities are occurring and thinking about the likely effects on your wetland. For example, is there a new subdivision or a plan for one in the catchment? How about shopping malls? What fields are irrigated nearby? Where are animals pastured? Where are manure, fertilisers, or pesticides being spread or sprayed?

Acknowledgement: adapted from *At home with wetlands: a landowner's guide.*[4]

Who is responsible for managing wetland water quality?

Responsibility for managing wetland water quality generally lies with the landowner or land manager. The three main groups with responsibility are landowners, local governments, and pastoral lessees; with DEC another major wetland manager in many areas the state.

Of course, landowners often have little direct control over the quality of the water reaching their property from surrounding properties. There are many groups with a role or responsibility in ensuring that water that enters a wetland from the broader catchment is of an appropriate quality (as outlined in the next section). Landowners with concerns about the quality of water entering their property can liaise with these groups. There are also a range of government and non-government programs to assist private landowners with on-ground wetland water quality activities. For example, DEC's *Healthy Wetland Habitats* program: eligible landowners on the Swan Coastal Plain (from Moore River to Dunsborough) can receive management advice and funding to manage water quality. For more information telephone the *Healthy Wetland Habitats* program coordinator on (08) 9334 0333.

➤ For more information on various programs that provide landowners with assistance, see the topic 'Funding, training and resources' in Chapter 1.

Land developers have a specific role in wetland water quality management during the course of, and in the years following, the subdivision and development of an area of land. If a wetland is located within the parcel of land, it may be required to be ceded to the Crown as 'public open space' (often abbreviated to POS) through the subdivision or development approval process. For wetlands retained in areas of public open space within a residential development, for example, it is common for developers to be assigned responsibility for the management of the wetland for a period (usually three years) following the completion of a development. They are generally required to manage the wetland and associated buffer in accordance with a wetland management plan that has been prepared in liaison with, and approved by, relevant authorities (for example, DEC and/or the local government). DEC's *Guidelines checklist for preparing a wetland management plan*[5] forms DEC's key reference for this process, and includes a requirement to address wetland water quality. After the designated management period, if the developer has satisfied the requirements and implemented all management actions outlined in the approved wetland management plan, transfer of the open space and therefore responsibility for the management of the wetland passes to the nominated vesting body, typically the local government. The community can have an important role in the scoping, drafting and implementation of the wetland management plan and should be consulted by the land developer during the development of the plan.

DEC is the state government agency with the lead role in the protection and management of wetlands. DEC contributes to the management of wetland water quality through various statutory and non-statutory processes. DEC also provides an online map and data for WA's wetlands called *WetlandBase*. As well as showing the location of wetlands, it can display the survey data for individual wetlands. Survey data include water chemistry data, as well as survey records for waterbirds, aquatic invertebrates and vegetation, where available. The survey data is collated from a number of survey sources, including a range of government and university survey programs. It is available via http://spatial.agric.wa.gov.au/wetlands. DEC is preparing an alternative to *WetlandBase,* scheduled for release in 2014, that will continue to make this data publicly available.

There is no dedicated program for surveying or monitoring the water quality of WA's wetlands. Much of the surveying that occurs is a result of specific programs that may apply to certain geographic areas for particular time periods, in response to particular concerns and as funding opportunities allow. Other monitoring is carried out by landowners or their consultants in accordance with government requirements (for example, by a developer's environmental consultant in order to fulfil a condition of subdivision approval of a parcel of land containing the wetland).

Who is responsible for managing catchment water quality?

Wetland water quality is generally a product of actions in the broader catchment. In WA, there are many groups and organisations that have either a responsibility or role in ensuring that water in the catchment is of an appropriate quality. Effective management of water quality involves cooperation between member of the public, landholders, community groups, regional management authorities and local and state governments.

Individual responsibilities

All individuals are responsible for ensuring that their actions do not harm the environment. Releasing chemicals or carrying out activities that have an effect on the environment may constitute 'environmental harm' under the *Environmental Protection Act 1986*.

➤ For more information on environmental harm provisions, see the topic 'Legislation and policy' in Chapter 5.

There are many local, state and Australian government initiatives and community-based initiatives to assist individuals to use, store and dispose of chemicals such as nutrients, paints, oils, batteries and pesticides correctly and to manage other potentially harmful activities. A number of these are outlined in this topic.

There has been an overwhelmingly positive response amongst residential gardeners to reduce their fertiliser applications in order to reduce the impacts of nutrients on WA's wetlands and waterways. Significant reductions in nutrient levels in some areas demonstrate what can be achieved by individuals collectively working to improve water quality of wetlands.

Community-based initiatives

The community is at the forefront of a range of on-ground catchment water quality management initiatives in WA. Individuals, organisations and community groups such as 'Friends of' groups can play an important role in pollution prevention and control in the community. Grass-roots education activities and passive surveillance can be important drivers of behavioural change, improving compliance by industry and the uptake of best practice by businesses and the community in general.

Regional natural resource management (NRM) organisations can also play an integral role. The Light Industry Audit Project is an example of one such program. The project was delivered by Perth Region NRM between 2007 and 2012. The aim of the project was to minimise the discharge of nutrients and contaminant sources from small and medium sized enterprises by auditing the use, storage and disposal of all types of solid and liquid materials with the requirements of relevant environmental legislation. Typical activities of small and medium sized enterprises include mechanical repair, vehicle smash repair, engineering and metal fabrication, metal finishing, machinery hire, chemical manufacture and blending, transport depots, concrete products, landscape supplies and printing. In WA these industrial premises have been identified as representing a significant cumulative risk to the health of water resources.[6] Perth Region NRM completed a light industry audit and education program at the end of the project. The report identified that the main areas where businesses failed to minimise or mitigate the risk of pollution were:

- inappropriate liquid storage and spill management infrastructure
- inappropriate disposal of wastewater
- wastewater containing detergents, degreasers or sediments not properly treated and/or being discharged to open ground, septic tank system or stormwater drainage
- no emergency spill kit
- no emergency spill management plan and/or staff training for managing spills
- Material Safety Data Sheets not held on site for all chemicals used.

➤ Information on the Light Industry Audit Project is available on the Swan River Trust website: www.swanrivertrust.wa.gov.au/the-river-system/tackling-the-issues/addressing-contaminants/light-industry-program

The extensive range of catchment water quality improvement initiatives being undertaken by the Peel-Harvey Catchment Council is another example of the pivotal role regional NRM groups can play. These include nutrient filtering projects, broader stormwater quality improvement projects, drainage reform projects and delivery of the *Water quality improvement plan for the rivers and estuary of the Peel-Harvey system – phosphorus management*.[7] The Peel-Harvey Catchment Council has been recognised for this work, receiving the 'Rivers, estuaries and wetlands' award in the 2012 Western Australian Environment Awards.

The Phosphorus Action Project, hosted by the South East Regional Centre for Urban Landcare Inc. (SERCUL) and supported by the Swan River Trust, is another example of a water-quality focused community-based initiative. The Phosphorus Action Project has spearheaded a community education campaign to achieve greater awareness of how to minimise nutrient pollution. Its initiatives include an annual nutrient survey for local governments in the Perth metropolitan area, to identify the extent to which best management practices are being achieved and how improvements can be made.

➤ More information on the role that community and regional NRM organisations can play in wetland management protection is provided in the topic 'Roles and responsibilities' in Chapter 5.

Government programs

Various Western Australian government agencies coordinate and participate in the regulation, research and monitoring of water quality.

Industry regulation

Preventing the discharge of pollutants into the environment is the most effective and efficient way to protect wetlands from pollution. This may be achieved by preventing or minimising the generation of pollutants and their export from the source. Pollutants are generated by both industry and domestic sectors. DEC is responsible for regulating the emissions or discharge of a range of commercial and industrial activities that would otherwise pose a significant environmental risk. It has powers to investigate, enforce and to order pollution to be abated and remediated. DEC carries out these responsibilities in accordance with Part V of the *Environmental Protection Act 1986*. In particular, DEC manages 'prescribed premises' through works approvals and licences. Licensing of prescribed premises allows DEC to regulate emissions and discharges from these premises, through conditions contained within licences that relate to the prevention, reduction or control of particular emissions and discharges, and to the monitoring and reporting of them.

➤ DEC publishes details of granted and refused licences for prescribed premises. These are available to view at the 'Licensing and regulation' webpage of the DEC website www.dec.wa.gov.au/pollution-prevention/licensing-and-regulation.html.

Relevant regulations under the Act include:

- Environmental Protection (Abattoirs) Regulations 2001
- Environmental Protection (Abrasive Blasting) Regulations 1998
- Environmental Protection (Concrete Batching and Cement Product Manufacturing) Regulations 1998
- Environmental Protection (Controlled Waste) Regulations 2004
- Environmental Protection (Fibre Reinforced Plastics) Regulations 1998
- Environmental Protection (Metal Coating) Regulations 2001
- Environmental Protection (NEPM-NPI) Regulations 1998
- Environmental Protection (Packaged Fertiliser) Regulations 2010
- Environmental Protection (Petrol) Regulations 1999
- Environmental Protection (Rural Landfill) Regulations 2002
- Environmental Protection (Unauthorised Discharges) Regulations 2004

Figure 2. A DEC Compliance Officer inspecting tyre and battery storage during an industry regulation compliance inspection. Photo – DEC.

A range of industry activities are regulated by local governments. Local government approval is required for a range of activities through land use planning, extractive industry and offensive trades approvals and local government by-laws.

Department of Mines and Petroleum approvals apply to mine sites, petroleum industries and dangerous goods storage facilities.

Hazardous household waste

There are eight metropolitan and six regional centre permanent hazardous household waste facilities in WA, which are complemented by collection days in other areas of the state. These services provide householders with the opportunity to dispose of flammable, toxic, explosive and corrosive materials including substances such as batteries, paints and pool chemicals, at no charge.

➤ For more information on hazardous waste facilities, see the Western Australian Local Government Association website: www.walga.asn.au and Wastenet: www.wastenet.net.au/programs/hhwprog

Management of pollution incidents, contaminated sites and acid sulfate soils

DEC is responsible for investigating environmental harm caused by pollution. Wetlands are protected by environmental harm provisions under the *Environmental Protection Act 1986* (EP Act). Under the EP Act, an 'alteration of the environment to its detriment or degradation or potential detriment or degradation' or an 'alteration of the environment to the detriment or potential detriment of an environmental value' is considered environmental harm.

➤ To report pollution, call the Pollution Watch Hotline, 1300 784 782 (24 hours) or email pollutionwatch@dec.wa.gov.au.

➤ In the event of a hazardous materials release or life-threatening incident, call 000 and ask for Fire and Rescue.

➤ In the event of pollution, DEC may issue an environmental field notice to the responsible person or organisation requiring site remediation under the Environmental Protection (Unauthorised Discharges) Regulations 2004.

Figure 3. Officers of DEC's Pollution Response Unit. Photo – P Nicholas/DEC.

DEC is also responsible for administering WA's contaminated sites legislation, the *Contaminated Sites Act 2003*. This Act aims to protect people's health and the environment from harm. Under the Act, contaminated sites must be reported to DEC, investigated and, if necessary, cleaned up.

DEC is also the lead agency for the management of acid sulfate soils in WA.

➤ Contaminated wetlands and groundwater are identified in the *Contaminated Sites Database*, available from https://secure.dec.wa.gov.au/idelve/css/. This database also provides reports outlining the status of contamination for individual sites.

➤ For more information on DEC's role in pollution incidents, contaminated sites and acid sulfate soils, see www.dec.wa.gov.au/pollution-prevention.html.

Management of pesticides

Before a pesticide can be used in Australia, it must be registered by the Australian Pesticide and Veterinary Medicines Authority, an Australian Government body. The WA Department of Health and the Department of Agriculture and Food, as well as other state government agencies, play an important role in managing the use of registered pesticides to ensure they do not have untoward effects on humans, animals, agriculture or the environment. These agencies are represented on the Pesticide Advisory Committee. Local governments also play an important role in investigating pesticide misuse and minimising the approval of incompatible land uses in proximity to each other.

➤ More information on the roles and responsibilities of organisations and individuals is outlined in the document *Quick contacts for the use of pesticides in WA*.[8]

Agricultural best practice

The Department of Agriculture and Food provides advice to agricultural producers regarding best practice farming methods, including the efficient use of water, pesticides and fertilisers and the minimisation of erosion and other off-site impacts.

The Department provides a range of resources, tools and services, such as the Small Landholder Information Service.

➤ More information for small landholders on the management of pesticides, fertilisers and other agricultural chemicals is available via www.agric.wa.gov.au/PC_92609.html

Sewage and wastewater management

The Water Corporation removes about 432 million litres of wastewater a day and operates 106 wastewater treatment plants across the state. It also administers the Infill Sewerage Program, a WA Government initiative. It aims to provide sewerage connections to properties where the use of septic tanks poses a risk to public health and the environment. Infill sewerage is a system of buried pipes that takes wastewater away from residential properties for safe and healthy treatment and disposal.

A number of priority areas have been agreed with the State Government, based primarily on public health and environmental considerations. Current priorities are Bridgetown, Bunbury, Busselton, City Beach, Dawesville, Esperance, Falcon, Geraldton, Greenough, Kwinana, Mandurah, Port Hedland, Quinns Rocks, Ravenswood and Rockingham.

There are also controls on the use of on-site sewerage systems near sensitive receiving environments. The WA Government is currently reviewing its draft policies for the use and siting of on-site sewerage systems such as septic tanks.

Catchment water quality management and monitoring

The Department of Water is responsible for overseeing surface water and groundwater management policy in WA. It also has lead responsibility for policy regarding waterway management, while DEC has lead responsibility for policy regarding wetland management. The Department of Water provides advice on the quality of groundwater to support state development and the provision of drinking water. It carries out research and environmental investigations into salinity and conducts specific groundwater, river and estuary investigations into contamination. It provides a range of guidance material to assist people in understanding water quality issues and practical measures to protect water resources from harm (see www.water.wa.gov.au/Managing+water/Water+quality/Overview/default.aspx for publications). The Department also monitors flows and water quality in a number of the state's rivers.

Stormwater management in urban catchments

In liaison with the Department of Planning, the Department of Water provides guidance on appropriate stormwater management through guidelines including:

- *Stormwater management manual for Western Australia*[9]
- *Better Urban Water Management*[10]
- *Decision process for stormwater management in Western Australia*[11]

In collaboration with partners it also provides WA resources and training through the 'New WAter ways' program (www.newwaterways.org.au), which was formed in 2006 to build the water sensitive urban design capacity of government and industry to improve the delivery of urban water management and water sensitive cities. Project partners are the Department of Planning, Department of Water, the Western Australian Local Government Association, Urban Development Institute of Australia (WA) and Swan River Trust.

Over the past decade, significant reform in urban water management has been achieved in WA through the introduction and implementation of the above policies and associated initiatives. As a result, stormwater is much better managed to protect the environment in new urban developments in WA. However, there is much that can be done to improve stormwater management in older urbanised areas of the state as well as in rural areas, in collaboration with the relevant organisations. Table 2 outlines the roles of key water management organisations.

Figure 4. A main drain in Baldivis, south of Perth. Photo – J Higbid/DEC.

Most urban drains are managed by local governments. In the Perth region, these are typically smaller drains. Many of these feed into a network of 'main drains' managed by the Water Corporation (Figure 4). The Main Roads Department and the Public Transport Authority also manage drainage associated with their infrastructure.

While the Water Corporation is responsible for providing and managing part of the urban and rural drainage networks, the Economic Regulatory Authority operating licence does not require the Water Corporation to control water quality within the main drains. The Water Corporation's stated responsibilities lie in design, construction, operation and maintenance of the drainage networks that convey drainage water to meet the flood protection requirements of the Economic Regulatory Authority operating licence.[1] However the Water Corporation has recently stated that it recognises a holistic and integrated catchment scale approach is required for the adequate management of water quality.[1] It has recently funded research into the water quality of its main drains[1] and undertaken a revegetation trial for a section of a branch drain with the objective of developing a more environmentally sustainable approach to urban drainage management and reducing maintenance by installing long term native vegetation that, once established, would significantly reduce maintenance cost.

Where resources allow, local governments are well placed to make significant improvements to the water quality of the estimated 3,000 kilometres of drains within their networks. In WA, there has been a significant uptake of water quality management initiatives by local governments. For example, more than forty local governments are participants of the Water Campaign™ run by the International Council for Local Environmental Initiatives. As participants, these councils have identified the changes that they will make to the management of water within the local government area.

➤ Individuals and community groups can find out if their local government is a participant, and what changes they have committed to, at the ICLEI website: http://iclei.org/index.php?id=2389te.

Water management in rural catchments

Outside of the Perth metropolitan area the Water Corporation is responsible for maintaining rural drainage in six gazetted drainage districts: Mundijong, Waroona, Harvey, Roelands, Busselton and Albany. The rural drainage service was initially provided only to make land viable for agriculture. It provides a limited flood protection service, allowing adjacent land to be inundated following major storms.

Rural drainage is also governed by the Soil and Land Conservation Regulations 1992 under the *Soil and Land Conservation Act 1945*. The Act prescribes the assessment of proposals to construct drains or pump groundwater in agricultural regions by the Soil and Land Commissioner. The principles for assessing drainage proposals are outlined in the 2012 Department of Water document, *Policy framework for inland drainage*.[12]

➤ More information on the assessment of new drainage proposals is available from:

- the Department of Agriculture and Food website www.agric.wa.gov.au/PC_93235.html
- the topic 'Legislation and policy' in Chapter 5.

Landscape-scale salinity management in WA is primarily addressed by the Department of Water, Department of Agriculture and Food and Department of Environment and Conservation. One of the major programs that focus upon wetlands is the 'Natural Diversity Recovery Catchments' program. It is aimed at protecting areas of WA with high natural diversity that are threatened by rising water tables, salinity and associated poor water quality problems. A number of very significant wetlands are located within the six natural diversity recovery catchments: Buntine-Marchagee, Drummond, Lake Bryde complex, Lake Muir-Unicup, Lake Warden and Toolibin Lake.

➤ Information on the natural diversity recovery catchments program can be found at DEC's website and in the topic 'Salinity' in Chapter 3.

Water use

The Department of Water is the state government agency with the lead protection for the management of water resources in WA. It regulates the use of groundwater, which is a very important factor affecting the water levels and water quality of wetlands that are fed by groundwater. It licenses the taking of water and through this process it can apply conditions in licences that outline a licensee's responsibilities for managing the water resource.

➤ The allocation of groundwater and the regulation of its use is detailed in the topic 'Managing hydrology' also in Chapter 3.

➤ More information is also available from the licensing pages of the Department of Water website: www.water.wa.gov.au/Business+with+water/Water+licensing/default.aspx#1

Collaborations: non-government and government working together

A number of collaborations exist between non-government and government to achieve outcomes that could not be achieved by either party acting in isolation.

The Fertiliser Partnership

An important collaboration aiming to improve water quality in WA is the Fertiliser Partnership 2012–2016. This partnership between the State Government, the fertiliser industry, fertiliser user groups, and peak non-government organisations aims to foster a cooperative working relationship to reduce fertiliser nutrient loss to aquatic environments. The government also recognises that this can only be achieved through collaborative effort with, and involvement of, the broad community. The Fertiliser Partnership 2012–2016 supersedes the *Fertiliser Action Plan* (2007).

The objectives of the Fertiliser Partnership 2012–2016 are to:

1. contribute to a goal of 50 per cent reduction in nutrient loss to waterways and wetlands on the Swan and Scott Coastal Plains
2. optimise the content of fertiliser and nutrient binding soil amendment products to better suit conditions on the Swan and Scott Coastal Plains
3. improve fertiliser and water use efficiency in both commercial and residential settings whilst maintaining productivity of agriculture and related commercial operations
4. educate the community on the environmental and social values of aquatic ecosystems, including waterways and wetlands
5. educate the community on fertiliser efficiency, water use efficiency and the benefits of managing soil acidity

Strategies to achieve the objectives of the Fertiliser Partnership 2012–2016 are the:

- development and promotion of low phosphorus fertiliser products
- development and promotion of 'best practice' fertiliser use and management in broadscale agriculture, horticulture and other related commercial activities and urban land use applications
- development and promotion of 'best practice' based on relevant accredited programs and advisors
- research, development and trials of nutrient binding soil amendment products to improve nutrient use efficiency and reduce nutrient loss to waterways
- development and promotion of educational material on fertiliser use efficiency.

➤ The webpage for the Fertiliser Partnership 2012–2016 is www.fertiliserpartnership.agric.wa.gov.au

Table 2. The role of organisations in water management in Western Australia

Responsibility		Water Corporation	Department of Water	Swan River Trust	Department of Environment & Conservation	Local Government	Harvey Water	Ord Irrigation
POLICY	Develops policy for water resource management in WA		✔					
	Provides input into policy and regulation that affects wetlands		✔		✔	✔		
LICENCES	Licences groundwater and surface water abstraction		✔					
SERVICE DELIVERY	Delivers clean drinking water	✔						
	Removes wastewater	✔						
	Maintains drinking water, drainage network and sewage pipelines from residential and commercial properties to main network	✔						
	Maintains local government drains					✔		
	Pipes irrigation water from local dams to shareholders in Collie, Harvey and Waroona for agricultural use						✔	
	Pipes irrigation water to shareholders from Lake Argyle to the Ord irrigation area in Kununurra for agricultural use							✔
DEVELOPMENT / LAND USE PLANNING	Ensures future development and land use planning enhances ecological health and amenity of the Swan- Canning Rivers			✔				
	Provides advice on development and land use planning that has the potential to affect waterways, groundwater and catchments		✔					
	Provides advice on development and land use planning that has the potential to affect wetlands		✔		✔			
	Decision-making authority for development proposals					✔		
PROTECTION / RESTORATION	Protects waterways and catchments in WA		✔					
	Protects wetlands in WA		✔		✔			
	Manages wetlands and waterways within reserves				✔	✔		
	Protects and enhances the ecological health and community benefit of the Swan-Canning rivers			✔				
	Catchment management programs and activities e.g. conversion of stormwater drains to 'living streams'		✔	✔	✔	✔		
MONITORING	Monitors surface and groundwater (quality and water levels)		✔				✔	✔
	Monitors drinking water quality	✔						
	Monitors water quality and water level of Swan-Canning rivers			✔				
	Monitors water quality, quantity and treatment in dams, storage facilities and Perth desalination plant	✔						

What water quality survey data exists in WA?

As outlined in the previous section, responsibility for water quality management lies with many agencies and individuals in WA. Table 3 outlines some of the larger sources of water quality data in WA but is by no means a comprehensive listing. The Australian Government has announced the National Plan for Environmental Information initiative (www.bom.gov.au/environment/NPEI_info_sheet.pdf; www.bom.gov.au/jsp/eiexplorer/), which in years to come may provide wetland water quality data access options.

Table 3. A guide to sources of wetland water quality data in WA

Group, database or program	Data type	Available from
WetlandBase	Compilation of various water quality studies including: DEC's Inland aquatic integrity resource condition monitoring (RCM), 45 significant WA wetlands 40 Wetlands Study, Murdoch University South West Wetlands Monitoring Program, Department of Environment and Conservation (DEC) Aquatic Projects Database (Salinity Action Plan Survey), DEC South Coast Regional Wetland Monitoring Program, Department of Water Jandakot Mound Monitoring Program, Murdoch University Gnangara Mound Monitoring Program, Edith Cowan University	http://spatial.agric.wa.gov.au/wetlands Note: DEC is preparing an alternative to *WetlandBase*, scheduled for release in 2014, that will continue to make this data publicly available.
Local government authorities	Data for wetlands under their management	Relevant local government authority
Regional natural resource management organisation	Data for wetlands that fall within regional NRM organisation projects	Relevant regional NRM organisation
Department of Water	Waterway water levels, flows and quality, drinking water and groundwater levels and quality; some wetland water quality and level data	http://wir.water.wa.gov.au/SitePages/SiteExplorer.aspx www.water.wa.gov.au/Tools/Monitoring+and+data/default.aspx
Natural diversity recovery catchment program monitoring	Data for wetlands in natural diversity recovery catchments program: Buntine-Marchagee Drummond Lake Bryde complex Lake Muir-Unicup Lake Warden Toolibin Lake	DEC's Natural Resources Branch
Ramsar wetland data	Data for WA Ramsar wetlands	DEC's Wetlands Section

How is wetland water quality measured?

A number of physical, chemical and biological parameters and **indicators** are used when characterising or assessing water quality. Common indicators of wetland water quality include dissolved oxygen, acidity, salinity and nutrients. Table 4 outlines why these indicators are useful.

Where concerns warrant further investigation, diagnostic tests can confirm the presence of metals, pathogens, pesticides and hydrocarbons (referred to as 'pollutants' where they are introduced into, or liberated in, wetlands as a result of human activities).

Biological parameters that may be used as indicators of water quality condition include plants, animals, algae and cyanobacteria. Assessment of biota (living things) may involve studies of abundance, reproduction and health of individual organisms or populations. Biological indicators can provide a more direct measure of ecosystem health than episodic sampling of physical and chemical parameters.[13] However, living things respond to a wide range of factors besides water quality, and it can be difficult to conclusively identify cause and effect, especially with limited data. For example, diversity of macroinvertebrates can be linked to the seasonal weather trends and amount of water in a wetland.

Many wetlands have a water column for periods of time—wetlands that are inundated either permanently, seasonally or intermittently. However many wetlands do not support a water column; these wetlands are waterlogged such that their sediment is saturated for a period of time, but standing water is not typically present above the soil surface except after heavy rainfall. Regardless of whether wetlands are waterlogged or inundated, the **sediment pore waters** (or interstitial waters) are extremely influential to water quality. The sediment, especially near the interface with overlying water, plays a very important role in the removal of many chemicals (natural or otherwise) from water and their release to water. Despite this, the characteristics of pore waters and sediment tend to be sampled less often than the water column. This is partly because the conservation and science of waterlogged wetland types lags behind that of inundated wetland types, and also because sediment pore waters can sometimes be more difficult to sample, particularly when there is an overlying water column. Managing the water quality of waterlogged wetlands is important and will improve as more stakeholders take an interest in their management and protection.

In inundated wetlands, when the concentration of contaminants in sediment pore waters exceeds that of the overlying water column, diffusion to the water column will occur. Where required, the measurement of the fluxes of contaminants can be obtained using dialysis samplers (pore water peepers), benthic chambers or corer reactors.[14]

Indicators: the specific components and processes of a wetland that are measured in a monitoring program in order to assess changes in the conditions at a site.

Sediment pore waters: water which is present in the spaces between sediment grains at or just below the land surface. Also called interstitial waters.

Table 4. Common water chemistry parameters, their roles, measurement and effects of change on wetland ecosystems. For more detail, see the topic 'Conditions in wetland waters' in Chapter 2.

Physical parameter	**Indicator:** Light
	What this indicator measures: Light penetration in the water column
	Role in wetland ecosystems: Light enables primary producers (plants, algae, photosynthetic bacteria) to produce their own energy needed for growth and survival, via photosynthesis. In wetlands with a water column, the amount of light entering the water directly affects the growth and survival of primary producers, which in turn affects the animals that rely on them for food and shelter. Light is also the major source of heat, which affects water temperature, which influences which species can occur in a wetland. Water temperature also influences other water quality parameters such as dissolved oxygen and pH.
	What is measured: Colour: a measure of how much light is absorbed or scattered by dissolved substances such as tannins and humic acids. Clarity and penetration: a measure of how much light is absorbed or scattered by suspended particulate matter.
	Effects of changes on wetland ecosystems: Increasing colour and turbidity reduce light penetration, decreasing photosynthetic capability and productivity of wetlands. Increased light penetration (e.g. as a result of removal of native overstorey wetland vegetation, changes in water depth, loss of colour) can lead to algal and cyanobacterial blooms and UV damage to wetland organisms.

Physical parameter	**Indicator:** Turbidity
	What this indicator measures: Concentration and mass of suspended particulate matter in the water column. Turbid conditions (cloudy-looking water) are caused by the presence of particulate matter such as silt and clay, organic and inorganic matter, and living or dead microscopic organisms, suspended in water.
	Role in wetland ecosystems: Turbidity affects the light and temperature in wetland waters. Increasing turbidity reduces light and increases temperature. Turbidity also affects predator-prey relationships. Some wetland species are adapted to naturally turbid conditions e.g. in claypans.
	What is measured: Turbidity is a measure of light passing through the water—the extent to which light is scattered, absorbed and reflected by particles suspended in the water column—and is usually measured with a turbidity tube or meter, or secchi disk.
	Effects of changes on wetland ecosystems: Increases in particulate matter can reduce light penetration and photosynthesis. Beyond normal variations it can smother or clog respiratory or feeding apparatus of aquatic fauna. It can contain metals and nutrients.

Physical parameter	**Indicator:** Temperature
	What this indicator measures: Temperature variations and/or stratification
	Role in wetland ecosystems: Temperature varies naturally both over time (temporally) and over the area (spatially) in wetlands. It affects the growth and survival of plants and animals via their metabolic processes as well as via oxygen levels in water and the chemical form (dissolved or precipitated) that toxicants and other substances take.
	What is measured: Water temperature
	Effects of changes on wetland ecosystems: Biota can be affected when temperature fluctuations exceed their thermal tolerance range e.g. affecting growth, spawning and reproduction.

Chemical parameter

Indicator: Dissolved oxygen (DO)

What this indicator measures: The equilibrium between oxygen-consuming processes, such as respiration, and oxygen-releasing processes, such as photosynthesis and transfer of oxygen from the atmosphere to the wetland.

Role in wetland ecosystems: Most aquatic organisms depend on oxygen for respiration. Via redox reactions, dissolved oxygen levels also affect the solubility of a range of chemicals, including nutrients and metals, and so the levels at the top of the sediment pore water is particularly important. The amount of dissolved oxygen in the water is influenced by the amount of respiration and photosynthesis occurring, as well as atmospheric pressure, temperature and concentration of other dissolved substances in the water (e.g. salts).

What is measured: Dissolved oxygen level

Effects of changes on wetland ecosystems: Reduced dissolved oxygen concentrations can have direct and indirect adverse effects on wetland organisms. An extreme reduction can result in the death of oxygen-dependent organisms (for example, fish, other vertebrates, invertebrates) and their replacement by a small suite of organisms that can tolerate very low oxygen levels. The toxicity of certain compounds such as many metals can increase at reduced DO concentrations, which can also have a detrimental effect on wetland organisms.

Chemical parameter

Indicator: Acidity and alkalinity

What this indicator measures: The acidity and alkalinity of water

Role in wetland ecosystems: Aquatic organisms are adapted to particular ranges of acidity or alkalinity in order to maintain normal physiological processes. Acidity also affects the solubility of compounds in water, including compounds that are required by or toxic to wetland organisms. The natural acidity or alkalinity of wetlands depends on factors such as the acidity of incoming water, sediment type, rate of photosynthesis and respiration occurring in the water and presence of humus. There are significant differences between wetlands that are naturally acidic and those that have become acidic due to human-induced changes, as explained in the 'Managing acidification' section later in this topic.

What is measured:

pH: concentration of hydrogen ions (water becomes more acidic with increasing concentration of hydrogen ions)

Acidity, as total titratable acidity: the weight of calcium carbonate (pure limestone, $CaCO_3$) or the equivalent such as sodium hydroxide (NaOH), needed to neutralise all of the acidity in a litre of water to pH 8.3.

Alkalinity: in waters with a pH greater than 4.5 is the amount of hydrochloric acid (HCl) needed to lower pH of a litre of the solution to pH 4.5.

Effects of changes on wetland ecosystems: Changes beyond normal variations can have serious effects on wetland organisms. Very acidic or alkaline waters may be directly toxic to biota. Very acidic waters can liberate toxic compounds such as metals. Very alkaline waters can lead to increased ammonia levels which can have toxic effects on biota.

Chemical parameter

Indicator: Water hardness

What this indicator measures: The concentration of calcium (Ca) and magnesium (Mg) ions in water, frequently expressed as milligrams per litre calcium carbonate equivalent.

Role in wetland ecosystems: Hardness affects the toxicity of some metals, such as aluminium, cadmium and copper, and the bioavailability of some nutrients, such as phosphorus, in water. In general, soft waters with low alkalinities have a low buffering capacity to resist pH fluctuations, and are more susceptible to acidification. Hard waters usually have high alkalinities, a high buffering capacity, and are less sensitive to acidification.

What is measured: Typically calcium carbonate concentration

Water hardness category[15]	Calcium carbonate milligrams per litre ($CaCO_3$ mg/L)
Soft	0–59
Moderate	60–119
Hard	120–179
Very hard	180–240
Extremely hard	400

Effects of changes on wetland ecosystems: Increasing hardness, particularly magnesium, can have adverse impacts on species adapted to soft water. Groundwater is usually harder than surface water. Changes in water sources may affect hardness and therefore acidity and nutrient and metal solubility.

Chemical parameter

Indicator: Salinity

What this indicator measures: Total concentration of salts in the water. Salts are compounds of cations (such as sodium Na^+, potassium K^+, calcium Ca^{2+}, magnesium Mg^{2+}) with anions (such as chloride Cl^-, sulfate SO_4^{2-} and bicarbonate HCO_3^-).

Role in wetland ecosystems: Salinity is an expression of the concentration of ions and determines the difference between 'freshwater' and 'saline' water. An excess of common salt, sodium chloride, is the main cause of water salinity problems and it can affect both freshwater and saline wetlands, although a sudden freshening of saline waters can also be detrimental. Wetland organisms are adapted to particular salt tolerance regimes in order to maintain normal physiological processes.

What is measured: There are several units of measurement used to express salinity including total dissolved salts and electrical conductivity.

- TDS: total dissolved salts (concentration of salts) – see table below
- EC: electrical conductivity (ability of water to conduct an electric current)
- Ionic composition (the types of salts present; the sum total provides total dissolved salts)

Salinity ranges commonly used in WA	Salt lake category (after Hammer[16])	Minimum total dissolved salts (TDS) (milligrams per litre, mg/L)	Maximum total dissolved salts (TDS) (milligrams per litre, mg/L)
Fresh	Fresh	0	500
Fresh	Subsaline	500	3,000
Saline	Hyposaline	3,000	20,000
Saline	Mesosaline	20,000	50,000
Hypersaline	Hypersaline	50,000	NaCl saturation (about 360,000)

Effects of changes on wetland ecosystems: Changes in salinity beyond normal variations can have direct toxic affects on aquatic biota by affecting physiological processes such as osmoregulation. Salts interact with other ions and compounds in water, so they influence other water chemistry processes.

Chemical parameter

Indicator: Nutrients

What this indicator measures: Nutrient levels and susceptibility to excessive plant, algal and cyanobacterial growth e.g. algal blooms

Role in wetland ecosystems: Nutrients such as nitrogen and phosphorus are essential for all wetland organisms. They flow through the food web, from the algae and plants through to animals and other organisms. Dissolved phosphate is the fraction of total phosphorus that is free in the water. High levels of phosphorus in wetlands can fuel algae growth to the extent that algal and cyanobacterial blooms occur.

What is measured: A range of chemical forms of nitrogen and phosphorus such as total nitrogen (TN), dissolved inorganic nitrogen, ammonium, total phosphorus (TP) and filterable reactive phosphorus (FRP).

Effects of changes on wetland ecosystems: Growth of plants, algae and cyanobacteria rely on nutrients. If nutrient levels are too low, growth of plants and algae is limited, which in turn affects productivity of organisms that feed on them. If too high, algal and cyanobacterial blooms and weeds may flourish and other related impacts can occur, leading to loss of wetland organisms.

Biological parameter	
	Indicator: Chlorophyll a
	What this indicator measures: Primary productivity and nutrient levels
	Role in wetland ecosystems: Chlorophyll *a* is the main light-capturing substance enabling photosynthesis in plant, algal and cyanobacterial cells. It is present in all green alga, diatoms and in some bacteria.
	What is measured: Chlorophyll *a* levels
	Effects of changes on wetland ecosystems: High levels of chlorophyll *a* can be indicative of nutrient enrichment and potential for algal and cyanobacterial blooms and related impacts.

Biological parameter	
	Indicator: Biological oxygen demand (BOD)
	What this indicator measures: The amount of oxygen being used by microorganisms to decompose detritus (the source of which may be pollution).
	Role in wetland ecosystems: Microorganisms such as bacteria are responsible for decomposing detritus such as dead plants and animals and their faeces, as well as leaves, grass clippings, faeces and sewage washed into wetlands. Bacteria break down this material in order to extract energy from it. If oxygen is available, they will use it during this process, depleting the dissolved oxygen, and reducing the amount available to larger wetland organisms.
	What is measured: Consumption of dissolved oxygen by microorganisms
	Effects of changes on wetland ecosystems: A high level of biological oxygen demand is likely to reduce oxygen levels, reducing the amount of oxygen available for respiration by water-dwelling wetland organisms and affecting the toxicity of a range of compounds such as metals (see dissolved oxygen parameter above for more information). If BOD is high enough, it may reduce oxygen levels enough to trigger phosphorus release from the sediment into the wetland water column (due to iron reduction).

Measuring water quality

A common experience amongst wetland managers is spending time, effort and money measuring water quality with the expectation that it will provide the answers needed, and being disappointed when this doesn't eventuate. The decision to measure a water quality indicator should be based on a sound analysis that really hones in on the reasons for investigating water quality. Is the purpose to:

- develop a baseline of the existing conditions via a survey?
- investigate a particular concern by starting with a single measurement or set or measurements?
- conduct an ongoing monitoring program that detects trends that indicate whether management is having the expected outcome?
- or something else?

The topic 'Monitoring wetlands' in Chapter 4 provides some guidelines on wetland monitoring. For more detailed guidelines, a range of resources are available, including:

- *Field sampling guidelines: A guideline for field sampling for surface water quality monitoring programs*[17]
- *Surface water sampling methods and analysis-technical appendices*[18]
- *Water quality protection note no. 30: Groundwater monitoring bores*[19]

For detailed guidelines on water quality sampling and monitoring for more complex or stringent purposes, see:

- *Australian guidelines for water quality monitoring and reporting*[20]
- *Water quality – Sampling. Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples*[21]
- *Water quality – Sampling. Part 11: Guidance on sampling of groundwater.*[22]

New technologies are helping to refine sampling results and reduce costs. For example, passive samplers remain in situ, sample herbicides, pesticides and polyaromatic hydrocarbons and can detect contaminants at trace levels. For an example of how they are being employed locally, see the report *A baseline study of organic contaminants in the Swan and Canning catchment drainage system using passive sampling devices.*[23]

Figure 5. A passive sampler. Photo – courtesy of Department of Water.

extra information

Whether to monitor or survey?

The term 'monitoring' is often used in a casual sense to mean the act of measuring or observing something. However, in scientific terms, monitoring more accurately refers to the systematic collection of data, over time, in order to test a hypothesis. For example, a wetland manager may monitor the water quality of a wetland over a length of time, before and after carrying out a range of management activities, to determine the effect of those activities upon the water quality.

A survey is an exercise in which a set of observations are made about some components of an ecosystem. For example, surveying might involve measuring the water quality at a wetland on a single occasion or on an ad-hoc basis over time. This is not monitoring; as monitoring entails measurements being repeated over time, and designed in such a way as to test a theory about the effect of an action upon the water quality.

A 'baseline' survey refers to an initial measurement that may be used as a basis for future comparison.

The topic 'Monitoring wetlands' in Chapter 4 outlines how to design a wetland monitoring program, but also provides information relevant to wetland surveying.

What should a wetland's water quality be?

There is no set of numerical criteria, limits or concentrations that define the ideal water quality of a wetland in WA. The following information outlines how managers can make use of published water quality *guidelines* and/or develop their own water quality *objectives* for a wetland.

Water quality guidelines

Water quality guidelines are used to help manage the quality of a water resource in relation to its intended purpose. At a national level, the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[14], or ANZECC guidelines as they are often called, provide guidelines regarding acceptable water quality, to ensure there are no significant impacts for the purposes that water resources are intended to support. The guidelines include acceptable quality for human drinking water, maintenance of aquatic ecosystems, primary industries (food production and industrial use) or recreational and aesthetic purposes. As the purpose of this guide is to provide guidance on the management and protection of the ecological values of wetlands, the section of the ANZECC guidelines referred to here are those that were developed for the maintenance of aquatic ecosystems.

In effectively unmodified wetlands, with high conservation/ecological value, the most appropriate guidance is that there should be no detectable change beyond natural variability. For **slightly disturbed** freshwater wetlands of south-west and north-west Australia, the ANZECC guideline default **trigger values** for physical and chemical parameters apply. These are summarised in Table 5, and are the concentrations or loads of a water quality parameter measured in an ecosystem, below which, or within which (in the case of those with a range), there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk if exceeded and should trigger some action; either investigation or management/remediation.[14]

ANZECC guidelines under review

The Council of Australian Governments has announced that the ANZECC guidelines are under review. This review includes the revision of sediment water quality guidelines, nitrate trigger values and toxicant trigger values. For more information, see www.environment.gov.au/water/policy-programs/nwqms/index.html#revision.

Slightly disturbed: ecosystems that have undergone some changes but are not considered so degraded as to be highly disturbed. Aquatic biological diversity may have been affected to some degree but the natural communities are still largely intact and functioning. An increased level of change in physical, chemical and biological aspects of these ecosystems is to be expected.[13]

Trigger values: quantified limits that, if exceeded, would indicate a potential environmental problem, and so 'trigger' a management response e.g. further investigation

Table 5. Default trigger values for physical and chemical parameters for unmodified and slightly disturbed freshwater wetlands in Western Australia, from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.*[14]

	Effectively unmodified wetlands, with high conservation/ecological value	**Slightly to moderately disturbed freshwater wetlands**	
Water quality parameter		Trigger value, south-west Australia	Trigger value, north-west Australia
Chlorophyll *a* (micrograms per litre, μgL^{-1})	No detectable change beyond natural variability	30[a]	10
Total phosphorous (micrograms per litre, μgL^{-1})		60[a]	10–50[b]
Filterable reactive phosphate (micrograms per litre, μgL^{-1})		30[a]	5–25[b]
Total nitrogen (micrograms per litre, μgL^{-1})		1500[a]	350–1200[b]
Oxides of nitrogen (NO_x micrograms per litre, μgL^{-1})		100[a]	10
Ammonium (NH_4^+ micrograms per litre, μgL^{-1})		40[a]	10
Dissolved oxygen (% saturation)		Less than 90 and more than 110	Less than 90 and more than 120
pH		Less than 7.0 and more than 8.5[c]	Less than 6.0 and more than 8.0
Salinity (microSiemens per centimetre, μScm^{-1})		300–1500[d]	90–900[e]
Turbidity (nephelometric turbidity units, NTU)		10–100[f]	2–200[f]
Toxicants, such as types of metals, pesticides, hydrocarbons etcetera.		Refer to Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*	

Explanatory notes

a: elevated nutrient concentrations in highly coloured wetlands (gilvin >52 $g_{440}m^{-1}$) do not appear to stimulate algal growth

b: higher values are indicative of tropical WA river pools.

c: in highly coloured wetlands (gilvin >52 $g_{440}m^{-1}$), pH typically ranges from 4.5-6.5.

d: values at the lower end of the range are observed during seasonal rainfall events. Values higher than 1500 μScm^{-1} are often found in saltwater lakes and marshes. Wetlands typically have conductivity values in the range 500-1500 1500 μScm^{-1} over winter. Higher values (>3000 μScm^{-1}) are often measured in wetlands in summer due to evaporative water loss.

e: higher conductivity values will occur during summer when water levels are reduced due to evaporation. WA wetlands can have values higher than 900 μScm^{-1}.

f: most deep lakes and reservoirs have low turbidity. However, shallow lakes and reservoirs may have higher turbidity naturally due to wind-induced re-suspension of sediments. Lakes and reservoirs in catchments with highly dispersible soils will have high turbidity. Wetlands vary greatly in turbidity depending on the general condition of the catchment or river system draining into the wetland and the water level in the wetland.

Benchmark: a standard or point of reference; a predetermined state (based on the values that are sought to be protected) to be achieved or maintained

Reference range: a quantitative and transparent benchmark appropriate for the type of wetland

Wetland managers in WA are fortunate to have these guidelines, with very few other Australian jurisdictions nominating trigger values for wetlands. These trigger values are an extremely useful guide if used with a proper understanding of their purpose. They are designed to be used in conjunction with professional judgement, to provide an initial assessment of the state of a wetland.[15] The difficulty with setting trigger values is that there is natural variation amongst wetlands, with the natural conditions in many wetlands being above or below these trigger values. For example, some wetlands have naturally high levels of salinity, turbidity, or naturally high or low pH. The topic 'Conditions in wetland waters' in Chapter 2 describes the reasons and patterns for natural variations in wetland water quality in WA.

The trigger values for the south-west of WA have been derived from a limited set of data (two years) collected at forty-one wetlands within and near Perth (Davis et al 1993[24]) and are representative of basin wetlands of this region that are permanently or seasonally inundated. Care should be used when extrapolating to other wetland types (such as seasonally waterlogged wetlands) and other areas of the south-west of the state. The exception is the toxicant trigger levels, which were developed through a different process. The trigger values from the north-west of the state are derived from an even more restricted study (less than one year) in the Pilbara region.[14] Furthermore, the trigger values have not been designed specifically for application to naturally saline (primary saline) or secondary saline sites.

As the default trigger values do not fully reflect the potential range of natural wetland conditions in WA, the guidelines are not mandatory and have no formal legal status, nor do they signify threshold limits of pollution.[14]

Before using the trigger values in Table 2 to make decisions about a particular wetland or group of wetlands, it is a good idea to consider whether it is appropriate to apply the trigger values to them. Where possible, the aim of management should be to maintain the natural conditions of a wetland. In many landscapes it is often difficult to determine the natural conditions (and in many areas the extent of changes to the broader environment means that a return to natural conditions is unlikely to be achievable). Long-term monitoring data of a wetland aid this decision, but it is quite uncommon to have access to long-tem data. In its absence, the best approach is usually to combine an analysis of available data, and local and professional knowledge to reach a decision about suitable targets, **benchmarks***,* **reference ranges** or trigger values, taking into consideration the natural factors affecting the water quality in wetlands, as outlined in the topic 'Conditions in wetland waters' in Chapter 2. Monitoring is a good way to build up a long-term picture of the water quality of a wetland, and can enable wetland managers to establish trends and refine targets along the way.

➤ For information on how to design a monitoring program, see the topic 'Monitoring wetlands' in Chapter 4.

As stated above, these guidelines are for the maintenance of aquatic ecosystems. Different guidelines exist for the assessment levels used by accredited contaminated sites auditors and DEC to determine whether a site is potentially contaminated and whether further investigation is required, as outlined in the document *Assessment levels for soil, sediment and water*.[25]

Water quality objectives

As outlined above, water quality guidelines are often, but not always, suitable for guiding the management of water quality in a wetland. Water quality objectives, on the other hand, tend to be targets based on knowledge of site-specific conditions. These are often identified by analysing available data, and taking into account local and professional knowledge and the natural factors affecting the water quality in wetlands.

Sometimes the use of a reference wetland may be a useful benchmark. For example, the trigger value may be set at a percentile of the reference wetland's distribution. The ANZECC guidelines provide guidance on refining trigger values for a particular wetland. See Sections 8.2 'Physical and chemical stressors' in Volume 2 and 3.3.2.3 'Defining low-risk guideline trigger values' in Volume 1) at www.environment.gov.au/water/policy-programs/nwqms/index.html#revision.

There may be enough research and expert knowledge to refine water quality targets for a particular region, sub-region or local area. For example, researchers have established references ranges for pH of inundated wetlands of the central Wheatbelt region.[26] These reference ranges have been developed by analysing existing pH data from the region, which is relatively data-rich due to the surveying conducted with funding under the Salinity Action Plan and State Salinity Strategy. Firstly, permanently or seasonally inundated wetlands that had been sampled in the region were identified as either saline basins, freshwater basins or turbid claypans. Following this, the least disturbed wetlands of each group were identified using expert opinion, and then the data of the least disturbed wetlands were analysed in order to establish a range in pH that may approximate the natural range.

There are some naturally extremely acidic wetlands in the region, particularly in the eastern area. Naturally acidic wetlands identified using a set of decision rules were excluded from this process. Excluding naturally acidic wetlands, the reference ranges for pH are as follows:

- naturally saline basins: 7.8–8.7
- freshwater basin wetlands: 6.8–8.1
- turbid claypans: 8.6–8.9.[26]

As per the ANZECC trigger values, these reference ranges should be used as a guide only and should be supported by site-specific studies if needed, due to the natural variability in acidity between wetlands.

Target setting requires research and data collection. The WA government endeavours to provide guidance for priority issues; for example, acidity/pH target values for aquatic ecosystems are the focus of ongoing work by the Department of Water and Department of Environment and Conservation.

Key techniques for managing wetland water quality

The techniques for managing water quality outlined in the following sections are focused on protecting and maintaining wetland biodiversity and conservation values.

Three 'scales of approach' for managing wetland water quality are presented here:

1. preventing the causes of poor water quality
2. intervening at the scale of the surface water catchment or groundwater capture zone
3. intervening at the wetland scale.

The most effective long-term strategy for managing water quality is preventing the causes: reducing pollution and preventing acidification. Intervention techniques, whether at the catchment or wetland scale, can be expensive, inefficient and require long term management.

It is not unusual to find that a combination of techniques from all three scales is needed. Both short and medium to long-term management strategies are outlined in the following sections. Short term strategies tend to alleviate the problem for a short time only, and focus on addressing symptoms rather than causes. Medium to long-term management strategies are typically required to address water quality problems.

Preventing the causes of poor water quality

Pollution prevention is critical to the management of wetland water quality because once many types of pollutants enter wetland water and sediments they can be extremely difficult to remove or remediate without significant effects to the wetland. Similarly, the process of wetland acidification can be difficult to treat.

As outlined in the previous section entitled 'Who is responsible for managing catchment water quality?', state and local government agencies play an important role in preventing and policing pollution in WA through regulation. However, awareness raising and incentives are important methods of achieving behavioural change and through these measures, individuals and groups can play an important role in further reducing the generation, use and release of pollutants, particularly nutrients, pesticides, litter and debris; and the process of acidification. Each section below (nutrients, acidification, pesticides, metals etcetera) lists relevant pollution prevention guidelines and techniques.

Awareness raising and incentives are often called 'non-structural controls' because they don't rely on changes to infrastructure. They include public education programs that can encourage the adoption of wetland-friendly practices in households (Figure 6), and local councils improving management of public open spaces (such as using less water, fertiliser and pesticides on lawns and gardens). A number of community education programs have been trialled and assessed in WA. For example, the South East Regional Centre for Urban Landcare (SERCUL) undertook a trial of a 'fertilise wise' community education program in new suburbs south of Perth for the City of Armadale.[27] In the long term, non-structural control options are more efficient and cost effective in reducing pollutants from entering wetlands than installation of structural control options as the sole means of reducing pollutants.

Figure 6. The green frog drain stenciling project by the Friends of Yellagonga Regional Park, the City of Joondalup and local schools is part of campaign to improve stormwater quality of wetlands in the Yellagonga catchment by changing people's behaviour. Photo – courtesy of Keep Australia Beautiful WA.

Reducing the potential for pollution: the importance of appropriate land use planning, setbacks and wetland buffers

Despite best efforts to manage pollutants appropriately, pollution events can and do occur. This is why sound decisions are needed about what land uses are appropriate near wetlands, and about what wetland buffers and setbacks are needed.

These decisions are made via the system widely referred to as the 'land use planning process'. In WA, the statutory basis for this process is the *Planning and Development Act 2005,* which is primarily administered by the Western Australian Planning Commission and the Department of Planning, and overseen by the State Government Minister for Planning. Under the *Environmental Protection Act 1986* the Environmental Protection Authority is empowered to assess land use proposals that have the potential to have a significant effect on the environment, and to make recommendations to the State Government Minister for Environment. The process enables the community to participate in land use planning, providing an opportunity to provide input. More information on how community can participate in the land use planning process is outlined in the topic 'Roles and responsibilities' in Chapter 5.

The EPA states that, where high value wetlands are located in areas to be developed:

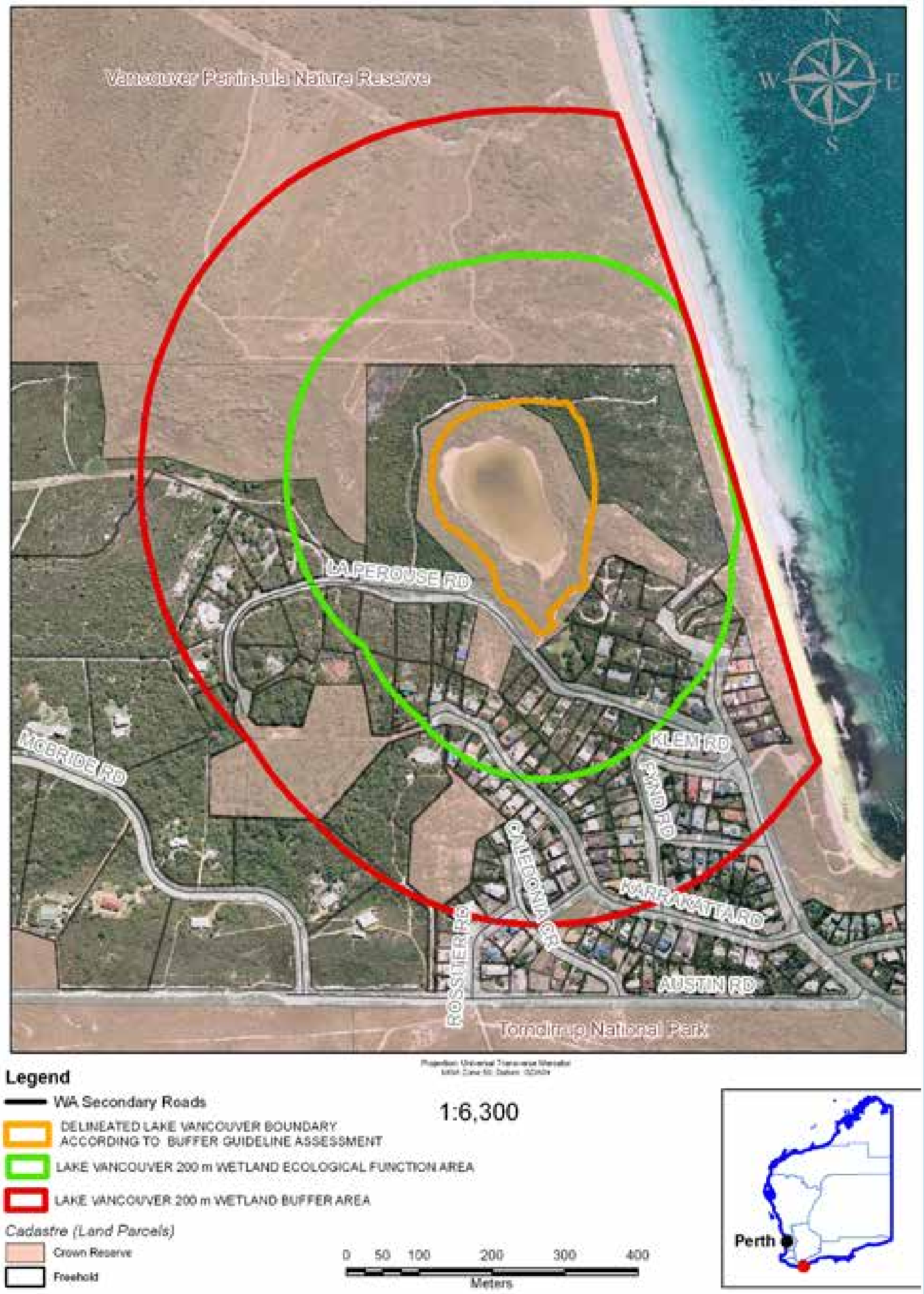
- when considering planning options for the study area, take into account the potential for adverse impacts (direct, indirect and cumulative) on wetlands given the site specific conditions. Avoid locating development where a high level of management is required to protect significant wetlands. For example, general industrial development is not an optimal land use over transmissive soils near significant wetlands.
- determine, protect and manage a buffer between a wetland and existing or proposed land uses. This is crucial to maintain or improve wetland values. A wetland buffer is the designated area adjoining a wetland that is managed to protect the wetland's ecosystem health. The buffer adjoining a wetland helps to maintain the ecological processes and functions associated with the wetland, and aims to protect the wetland from potential adverse impacts. A buffer can also help to protect the community from potential nuisance insects, for example, midges.
- setbacks for land uses with a relatively high potential for site contamination or nutrient export: the setback should take into account the potential of the development to adversely impact on the wetland, the proposed management of environmental impacts, and the extent to which enforceable conditions on the development will be imposed by decision-making authorities. Land uses associated with a relatively high potential for site contamination or nutrient export (for example, some forms of intensive agriculture, industry and some effluent treatment facilities) may need to be located farther away from the wetland than the determined wetland buffer.

- excerpts from Chapter B4 of the EPA *Environmental guidance for planning and development*.[28]

Reducing the potential for pollution: the importance of appropriate land use planning, setbacks and wetland buffers (cont'd)

A wetland buffers guideline has been prepared for the purpose of providing guidance to development proponents on how to determine the wetland buffer needed to protect a wetland from a proposed land use. Following its finalisation, the *Guideline for the determination of wetland buffer requirements* will be available from the 'Wetlands' webpage of the DEC website. Figure 7 shows an example of a wetland buffer requirement between Lake Vancouver in Albany and residential development.

Figure 7. The wetland buffer requirement (delineated in red) for Lake Vancouver in Albany, based upon residential land use. Image – A Shanahan/DEC.



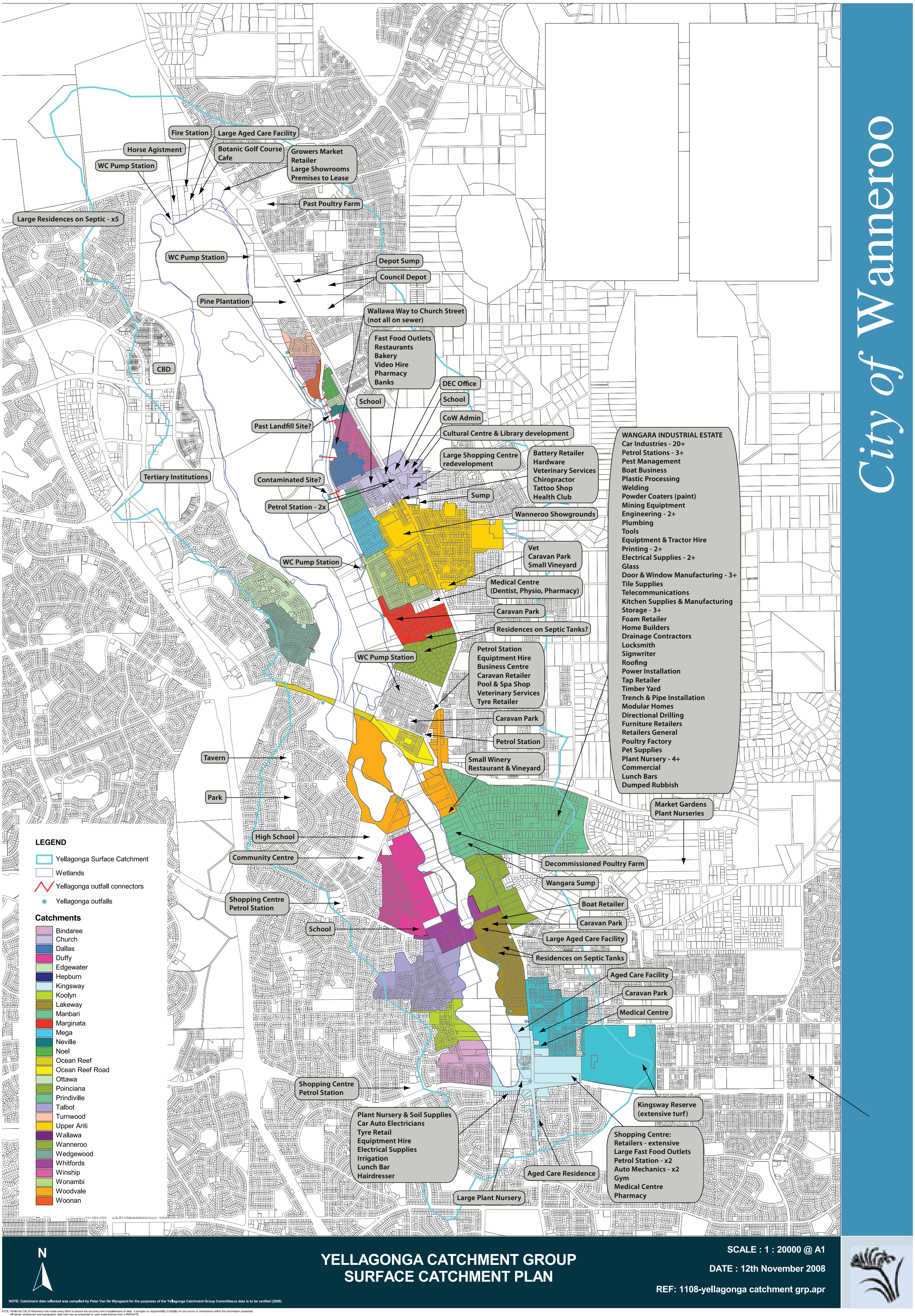
Intervening at the scale of the surface water catchment or groundwater capture zone

Improving water quality before it reaches a wetland is mostly achieved via catchment management. Catchment management activities that maintain or improve water quality include:

- matching land use with land capability so that highly degrading or polluting land uses are not sited in sensitive or transmissive environments
- using land and water appropriately to minimise changes in ground and surface water in the catchment, through appropriate agricultural and urban land uses, agricultural and urban land use design/retrofitting, water allocation and stormwater management
- protecting existing native vegetation through fencing, strategic revegetation/ regeneration of native vegetation
- employing agricultural and urban practices that minimise erosion (such as perennial pastures, no-till farming, suitable stocking rates accounting for total grazing pressure, contour farming, best practice construction methods)

Catchment management plans are an effective tool for identifying the causes of poor water quality and prioritising intervention measures at a catchment scale. For example, the *Yellagonga Integrated Catchment Management Plan 2009–2014*[29] highlights the potential sources of pollutants to the wetlands within the catchment (Figure 8).

Figure 8. A spatial summary of land uses can be an effective way to informally identify and rate potential pollutant sources within a catchment. Image – *Yellagonga Integrated Catchment Management Plan 2009–2014*.[29]



Stormwater management is commonly targeted when seeking to improve wetland water quality. Aspects of stormwater management include overland flows, waterways, water conveyed in drains and pipes and stormwater percolation to groundwater. In both urban and rural catchments, well-managed stormwater (sometimes referred to as 'runoff' or 'drainage') is important in contributing water to wetlands (other sources are groundwater and rainfall). Stormwater in well-managed catchments mimics the natural quantity and quality of water that would have reached a wetland prior to changes to a catchment, as well as the patterns of timing and frequency of flow. Groundwater intervention (treatment) is a much more difficult and expensive proposition, and is rarely used as a method to improve the water quality of individual wetlands.

Where stormwater is a significant cause of poor water quality in a wetland, improving the quality of stormwater in the catchment is typically much more effective and efficient than working at the wetland scale to improve the water quality of the receiving wetland. In such cases, the wetland manager should identify the relevant stormwater manager/s (in urban areas, usually local government) and work with them to identify the most appropriate techniques, both structural and non-structural, to improve water quality. Any modifications to stormwater systems or infrastructure, or their management, require the approval of the managing authority. Key concerns of managing authorities will include whether changes to waterways, pipes, drains or overland flows will increase the risk of flooding, or reduce the ease of management or public safety. Any proposed changes to the banks, cross-sectional area and levels of drains will require a professional hydrological assessment.

In urban environments, both structural and non-structural controls are needed to manage stormwater to protect wetlands and other natural areas. Structural control options minimise pollution through engineering solutions such as:

- gross pollutant traps
- oil-water separators
- constructed wetlands
- biofilters
- trash screens
- grass swales
- sediment detention basins.

In agricultural environments, land use changes such as strategic vegetation with deep-rooted perennials, contour farming, plantations and stocking and cropping modifications can be complemented by stormwater structural controls such as:

- fencing, stabilisation and rehabilitation of waterways that flow into wetlands
- creation of living streams
- creation of constructed wetlands
- creation of sediment detention basins.

These controls can help to reduce flow velocity, retain sediments, attenuate pollutants, increase shading, reduce water temperature, increase colour, increase biodiversity and increase water percolation to groundwater.

Factors that should be considered when designing structural controls include the type of pollutants to be removed, effectiveness in removing pollutants, maintenance requirements and cost, site constraints and ease of installation.

Stormwater management options

There are many structural and non-structural control options that can be used to improve water quality in wetland catchments.

The *Stormwater management manual for Western Australia*[30] has been developed to provide local government, industry, developers, state agencies, service providers and community groups with information on policy and planning principles and best stormwater management practices. For further information, see www.water.wa.gov.au.

For general information on managing stormwater quality in WA, see the 'Stormwater' webpage of the Department of Water's website: www.water.wa.gov.au/Managing+water/Urban+water/Stormwater/default.aspx#

Resilience: capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks

Intervening at the wetland scale

Intervening at the wetland scale may be an option if poor water quality, particularly as a result of excess nutrients, acidification, or unnatural levels of turbidity. It is often less effective in addressing pesticides, metals, hydrocarbons, hot/cold water, pathogens and litter.

In ideal situations, the link between poor water quality cause, effect and solution is clear. However, a common occurrence is one change in water chemistry that creates a domino effect of cascading changes. More than one water quality issue due to one or more causes may be at play in a wetland. It is important to consider the potential for complicating factors and anticipate the potential for unintended ecological impacts before initiating an activity, particularly when considering intervening at the wetland scale, especially when it involves altering the amount of water or disturbing the sediment. Wherever possible, interventions at the wetland scale should be reversible in nature, so that unintended consequences can be mitigated. It is safest to seek expert advice to identify the most appropriate strategies.

Managing wetland water quantity is an important aspect of managing wetland water quality. The physical, chemical and biological processes in a wetland are driven by the natural patterns of water presence and absence, in terms of timing, duration, frequency, extent and depth, and variability. When these natural patterns, known as wetland water regime, are altered, the conditions in the soil and water are also altered, and the wetland's **resilience** to other impacts is reduced.

Although effects vary depending on the wetland, in general, a drier water regime (for example, from dewatering, over-extraction of groundwater and declining rainfall) can lead to:

- loss of plants and animals that need wetter conditions
- acidification via actual acid sulfate soils
- increased susceptibility to fire
- the terrestrialisation of wetland areas (that is, wetlands slowly becoming dryland)
- changes in the mobility and availability of nutrients and metals

A wetter water regime (for example, from discharge of mine water or drains, or digging out of wetlands) can lead to:

- loss of plants and animals that need drier conditions

- increasing pollutant loads, including nutrients, salts and acid
- changes in the mobility and availability of nutrients and metals
- increasing frequency and severity of algal blooms
- nuisance midge and mosquito populations
- odour issues.

The management of wetland water regime is so critical that a whole topic is dedicated to it. General guidance is also provided in the following sections.

➤ For information on the natural water regime of WA wetlands, see the topic 'Wetland hydrology' in Chapter 2.

➤ The causes, effects and management of altered water regimes are covered in the topic 'Managing hydrology' in Chapter 3.

Managing excess nutrients (eutrophication)

The nutrients nitrogen and phosphorus (commonly referred to as 'N' and 'P') are essential for living things due to their importance in the construction of living tissue and in metabolic processes. As well as being present in living things, nutrients can be dissolved in water or occur as part of coarse or fine particulate matter, and in wetlands phosphorus is often bound to sediment particles, for example. Plants, algae and some bacteria can make use of certain chemical forms of nutrients that are present in wetlands, or that washes into wetlands; these are known as **bioavailable** forms, as described in more detail in the topic 'Conditions in wetland waters' in Chapter 2. In turn, the nitrogen and phosphorus that animals, fungi and (other) bacteria consume originates from plants, algae or bacteria.

When phosphorus and/or nitrogen are in short supply, or not in a form that can be readily used, plant and algal growth is limited.[31] The soils of south-west Western Australia are old and weathered, and consequently have low natural levels of nitrogen and phosphorus (and many other nutrients). The native vegetation is adapted to low nutrients, and many plants have evolved mechanisms to increase their nutrient uptake. The most common problem associated with nitrogen and phosphorus in wetlands is when they are in excess amounts, that is, above the natural levels. Under the right conditions, for example, high light intensity and water temperatures, highly nutrient-enriched wetlands produce high rates of plant, algal and cyanobacterial growth and ultimately, the development of 'blooms'. These wetlands are said to be **eutrophic** and they often have low diversity of native species, which may be out-competed or suffer from nutrient toxicity; however they may have high abundances of algae, cyanobacteria, plants and animals tolerant of eutrophic conditions, including pest species of **midge**. Most permanently inundated wetlands in urban areas of metropolitan Perth and Peel are nutrient enriched.

Nutrient problems in wetlands: a summary

Causes: nutrient pollution, artificial maintenance of permanent inundation

Impacts: impaired health of native species, algal and cyanobacterial blooms, nuisance midge populations, reduced biodiversity of plants and animals, botulism, weeds

Indicators: high nutrient levels, high chlorophyll a levels, low dissolved oxygen levels, low light levels

Management options: a range of options for nutrient pollution prevention, catchment-scale stormwater intervention and wetland-scale intervention

Bioavailable: in a chemical form that can be used by organisms

Eutrophic: nutrient rich waters or soil with high primary productivity (plant/algal/cyanobacterial growth). From the Greek term meaning 'well nourished'.

Midges: biting and non-biting species of a number of families within the true flies (Diptera) including the Chironomidae and Ceratopogonidae

Causes of excess nutrients

While the addition of nutrients from outside the wetland drives eutrophication, it can be exacerbated by the loss of wetting and drying patterns, or the influx of sulfur, both of which can trigger the release of nutrients from the sediment. Each of these is described below.

Nutrient pollution

Human settlement is always associated with excess nutrients from fertilisers and wastes, particularly phosphorus, building up in the local environment.[32] Surface and groundwater contain nutrients originating from a range of sources. Nitrogen and phosphorus can be present in the water column dissolved in solution, or they can be attached to sediments, in solid form as particulates. In areas where rainfall results in most of the water infiltrating into the ground, nutrients can leach into wetlands through the groundwater. When more water travels across the land surface as stormwater, nutrients dissolved in the stormwater, or attached to eroded soil particles, can be washed into wetlands. The transport of large amounts of nutrients into wetlands often occurs during the **first flush.**[33] In the south-west, this is often the first large rainfall of autumn, while in the north, this is often the first large rainfall of the wet season. Unseasonal rainfall events may also result in high pollutant loads in stormwater.

In urban residential areas, nutrient inputs are most commonly from diffuse sources, such as fertiliser applied to lawns, gardens and recreation areas such as parks and sports fields, and from sewage from septic tanks and other types of on-site sewage disposal systems. This is especially an issue on the **Swan Coastal Plain** where the soils have low nutrient-holding capacity, and nutrients are readily leached into the groundwater. Rates of input of nutrients in residential areas are generally greater than in broad acre farming, but less than inputs from horticulture.[32] Rubbish tips, industrial sites and sewage treatment works can also discharge large amounts of nutrients. Commercial areas contain a variety of potential sources of nutrients, including nurseries and garden centres. Industrial areas, particularly where fossil fuels are combusted, discharge gases and particulates that can end up in wetlands via atmospheric deposition; reducing this form of nutrient source is rarely considered a feasible or effective strategy for reducing wetland nutrient levels.

Wetlands that are within designated areas of public open space, especially with grassed areas, tend to receive large amounts of nutrients due to over-fertilisation, over-watering and feeding of waterbirds. Simple activities such as regular feeding of bread to birds can add significant amounts of nutrients. Researchers estimated that, in the early 1990s, up to 50 loaves of bread were fed to birds at Lake Monger each day.[34] Put into context, a loaf of bread contains between 1 and 2 grams of phosphorous, enough to turn a wetland with 50 cubic metres of water (equivalent to the size of a backyard swimming pool) eutrophic.[32] In addition, animals visiting wetlands, such as large flocks of native birds and introduced feral animals such as pigs, can import considerable amounts of nutrients in faeces.

In peri-urban and rural areas additional diffuse sources include horticulture, such as market gardens, turf farms, viticulture, hobby farms; broad-acre agriculture and animal-keeping businesses such as dog kennels and horse stables. Intensive animal farming, such as poultry farms, dairies and piggeries can be significant point sources of nutrient pollution. Wetlands are often favoured for some forms of agricultural production, such as horticulture and grazing, which can add large amounts of nutrients. At Benger Swamp in Benger, for example, it is estimated that 12,000 tonnes of superphosphate have been applied directly to the dry bed over the last forty years.[35] Horses, cows and other livestock can also add very significant amounts to wetlands.

First flush: the first rainfall for a period of time, resulting in stormwater dislodging and entraining relatively high loads of sediments, particulates and pollutants that have built up in the intervening period between rainfall events, and typically carrying a higher pollutant load than subsequent events

Swan Coastal Plain: a coastal plain in the south west of Western Australia, extending from Jurien south to Dunsborough, and the Indian Ocean east to the Gingin, Darling and Whicher Scarps

extra information

Horses, cows and nutrient pollution

Horses and cattle produce large amounts of faeces and urine. A standard light horse (450 kilograms) produces approximately 5.5 tonnes of wet faeces and 5.5 kilolitres of urine each year. This volume of waste contains 62 kilograms of nitrogen and 5.5 kilograms of phosphorus.[36] Cattle in feedlots produce an estimated 20–30 kilograms per year of nitrogen and more than 6 kilograms per year of phosphorus.[37]

Figure 9. Cows, such as this one grazing in a seasonally waterlogged wetland, can cause significant nutrient enrichment when allowed in and near wetlands. Photo – M Bastow/DEC.

High water soluble phosphorus fertilisers: products containing greater than 2 per cent total phosphorus and greater than 40 per cent of the total phosphorus as water soluble phosphorus

Phasing out the widespread use of **highly water soluble** forms of phosphorus fertilisers have been the focus of multiple campaigns in WA. Studies of the Peel-Harvey estuary and its hinterlands found that a high proportion (up to 80 per cent) of phosphorus in 'superphosphate', which is commonly used for agriculture, leaches through soil and is lost to production with winter rain.[7] Phosphorus has been the focus of campaigns because the loss pathways from the catchment source to the receiving wetlands, waterways and estuaries are better understood than nitrogen, and because effective change management options are available.[39]

There are also rural industrial sources of nutrient pollution. For example, it has been suggested that anecdotal evidence indicates that blast chemicals used in mining pits may be a source of nitrogen in dewatering discharge water in Goldfields salt lakes.[40]

Finally, chemicals applied to wetlands can contain nutrients. For example, organophosphate insecticides applied to wetlands in order to control midges have been implicated as a source of phosphorus in WA wetlands, while some fire retardants have been shown to increase the soluble nutrient load.[41]

The *Survey of urban nutrient inputs on the Swan Coastal Plain*[38] provides nutrient inputs rates of various land uses. Data compiled in the survey are shown in Figure 10 and Figure 11 for nitrogen and phosphorus respectively.

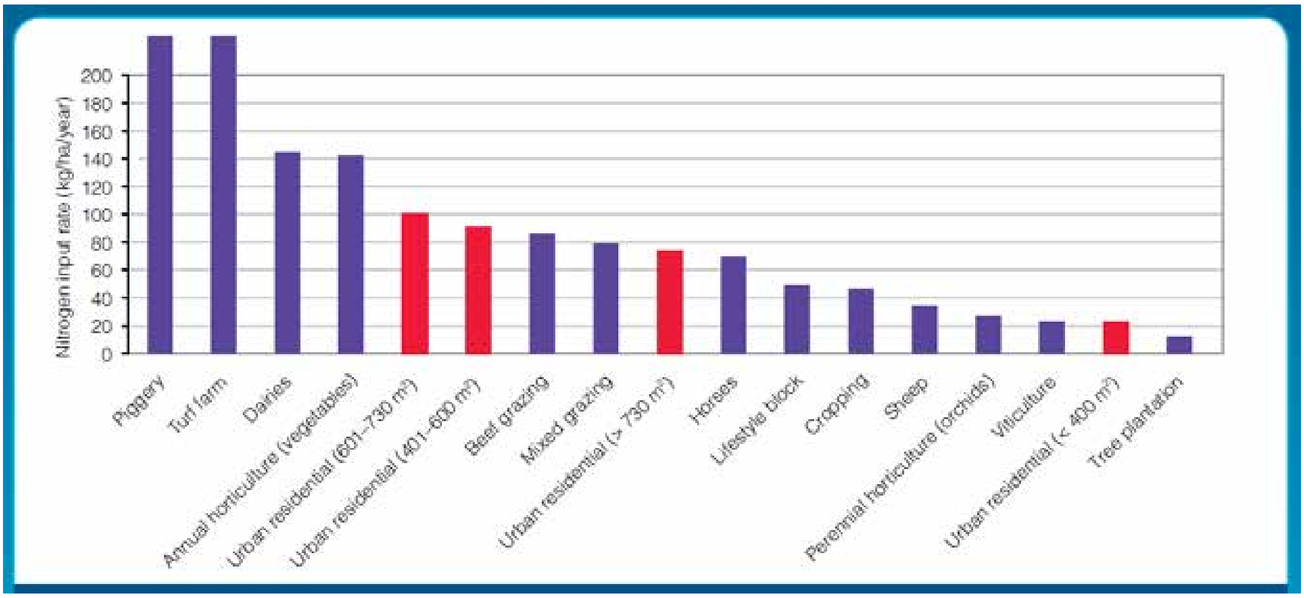


Figure 10. Total nitrogen input rates for rural and urban residential land uses ('piggery' inputs of 630 kg/ha/year and 'turf farm' of 433 kg/ha/year not fully displayed). Figure – Kelsey et al 2010.[38]

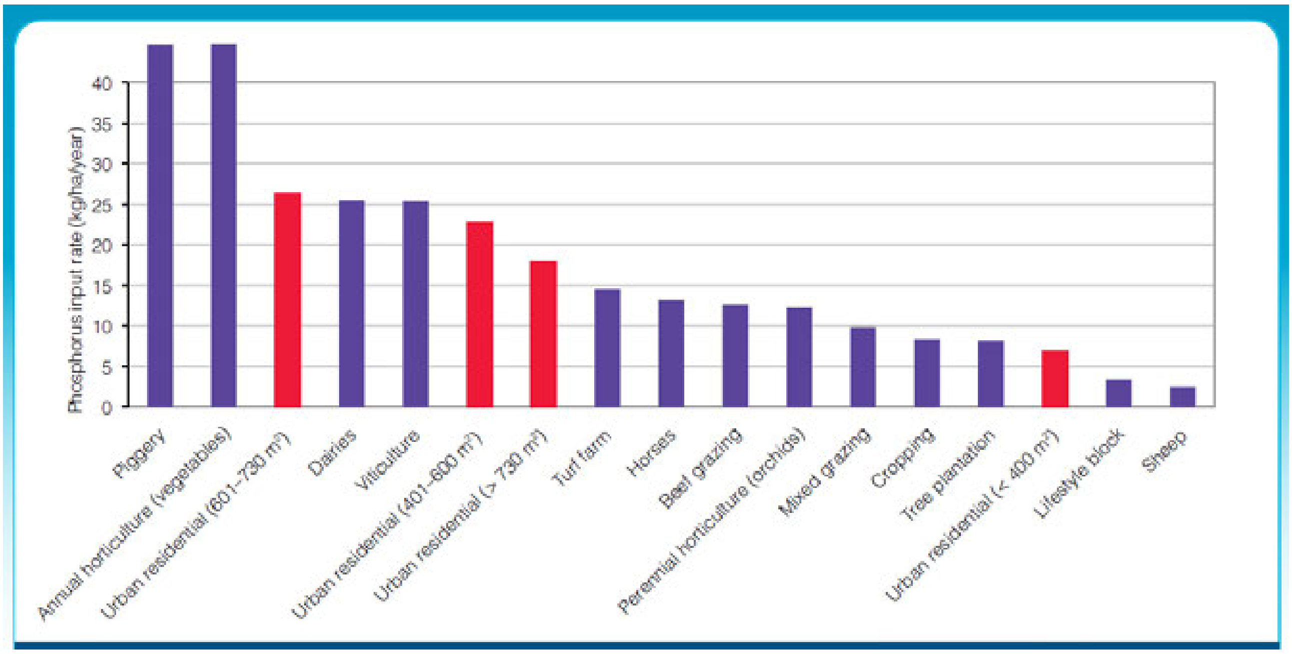


Figure 11. Total phosphorus input rates for rural and urban residential land uses ('piggery' inputs of 145 kg/ha/year and 'annual horticulture (vegetables)' of 130 kg/ha/year not fully displayed). Figure – Kelsey et al 2010.[38]

Loss of natural wetting and drying pattern

Wetting and drying on a seasonal or intermittent basis is a feature common to the majority of WA wetlands. However, human-induced changes means that many such wetlands are now permanently inundated, particularly those in urban environments in the south-west of the state. It can require investigations to determine whether this has occurred at a given wetland, especially when multiple changes occur in catchments, such as rising groundwater due to clearing, following by dropping groundwater levels due to water abstraction, as well as increased drainage inputs and drying due to climate change. Information on determining a wetland's natural hydrology is provided in the topics 'Wetland hydrology' in Chapter 2 and 'Managing hydrology' in Chapter 3.

Wetlands that naturally wet and dry do not tend to have severe problems associated with excess nutrients. The reasons for this vary, and include:

- In the south of the state, many seasonally inundated wetlands are dry during the hottest months of the year. Not having standing water during hot weather means that they are less susceptible to algal and cyanobacterial blooms, and blooms that do occur are likely to be for shorter periods of time (for example, as the water level drops and nutrients become concentrated prior to drying out).
- When sediments dry they are usually exposed to air. **Decomposition** is far more efficient in **aerobic** (oxygenated) conditions, meaning that decomposition processes are stimulated. This can result in more organic matter being removed as a potential energy store from the sediment and keeping the accumulation of organic matter in check.
- When wetland sediments are oxygenated, phosphorus tends to bond with iron and aluminium in the sediment, meaning there is less phosphorus available for plants, algae and bacteria. Similarly, when wetland sediments are oxygenated, nitrogen can be exported from wetlands as a gas, meaning there is less nitrogen available for plants, algae and bacteria. This point is explained further in the following paragraphs.

Sediments typically contain the largest proportion of nutrients in a wetland[15], compared to the proportions of nutrients present in the water column and in living things. However, sediments cannot indefinitely go on storing sediments, and at saturation will release nutrients into the water column. Alternatively, wetland sediments may release nutrients into the water column if conditions in the sediment pore water are suitable. This form of water column nutrient loading is known as 'internal loading' and can cause '**internal eutrophication**', and explains why high nutrient levels can persist in wetlands long after nutrient pollution has been minimised.

Human-induced changes to wetlands can promote the conditions that trigger nutrient release from the sediment. In particular, the conversion of naturally wetting and drying wetlands to permanently inundated wetlands has been linked with internal eutrophication. Many wetlands, particularly those in urban areas and the Wheatbelt, no longer have a 'dry' phase that was naturally part of their water regime. If sediments become permanently inundated, lower oxygen levels in the sediment pore waters and at the interface between the water column and the sediment pore waters may be sustained (Figure 12) and **anoxic** conditions may even occur. In contrast, wetlands that naturally have either a natural low water/partial drying phase that exposes more of the wetland soils or shallow water to air, or a dry phase with complete drying down, undergo changes to the chemical makeup of their sediment and water. These natural changes are largely driven by the greater amount of oxygen in the sediment pore water and/or the interface between the sediment and the water column, which drives changes in the redox potential.

Decomposition: the chemical breakdown of organic material mediated by bacteria and fungi, while 'degradation' refers to its physical breakdown. Also known as mineralisation.

Aerobic: an oxygenated environment (organisms living or occurring only in the presence of oxygen are aerobes)

Internal eutrophication: eutrophication of wetland surface waters as a result of changes in water quality without additional external supply of nutrients[42]

Anoxic: deficiency or absence of oxygen

These changes typically result in more of the phosphorus being bound to iron in the sediment and therefore less available in the water column for algal and cyanobacterial overgrowth and blooms (particularly in wetlands that don't have much calcium present). The changes stimulated by drying also affect the nitrogen levels, with shallow water often promoting the loss of nitrogen in gaseous forms from wetlands.

When the naturally drying phase no longer occurs, less nitrogen may be exported from the wetland, and more of the nitrogen and phosphorus is likely to be present in the sediment pore waters and water column in a chemical form that is available to plants, algae and bacteria, stimulating increased growth and productivity. Beyond a certain point, this increased productivity may be in the form of blooms and weeds, which tends to reduce biodiversity and if sustained may result in a shift in the ecological character of the wetland.

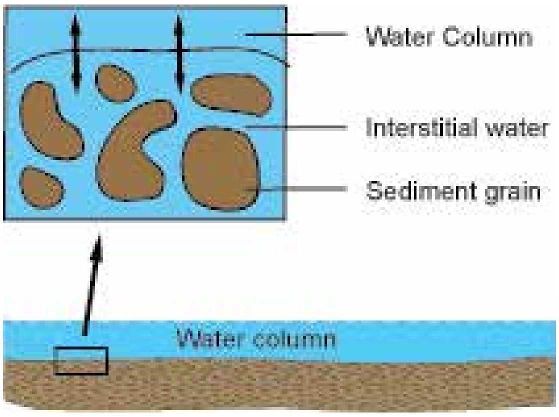


Figure 12. The very top of the sediment pore water, and the interface between the water column and the sediment pore water, is where a lot of chemical transformations take place. The dissolved oxygen levels in this zone are very influential. Oxygen is generally limited to the upper 10 millimetres.[42] Image – J Higbid/DEC.

extra information

The effect of wetting and drying on nutrients: a closer look

Phosphorus

Phosphorus has an affinity for calcium, iron and aluminium, and will bind with these elements when they are available, taking phosphorus out of the water column. Wetting and drying influences the extent to which iron and aluminium will bind with phosphorus.

In wetlands that experience inundation, when their water levels fall enough that there is shallow water and/or exposed sediments, much greater amounts of oxygen can reach the wetland sediment. The increase in oxygen creates more oxidising conditions, which promotes changes in the chemical form of iron present in the sediment. In these conditions, the chemical form that iron takes (ferric iron) significantly increases the ability of phosphorus to bind with it, via the processes of **adsorption** and **precipitation**. Through these processes, sediments can become a phosphorus sink. This is particularly relevant in wetlands with circumneutral or acidic conditions. In alkaline wetlands, the calcium concentration influences the precipitation of phosphorus, but this process isn't linked to wetting and drying.

In contrast, when wetlands are permanently inundated, the sediments are likely to have lower amounts of oxygen (plants are an important source of oxygen in these sediments, as they leak oxygen from their roots into an area of soil around the roots called the rhizosphere). As oxygen levels falls, conditions become more reducing and phosphorus desorption occurs: the chemical form iron takes (ferrous iron) does not bind with phosphorus and the formerly adsorbed phosphorus is released into sediment pore waters. Unless there is an oxidised soil layer above this, the phosphorus can diffuse into the water column.

extra information

The effect of wetting and drying on nutrients: a closer look (cont'd)

The solubility of oxygen declines as salt content increases, so secondary salinity (that is, human-induced salinity) can compound nutrient problems in affected wetlands. In saline wetlands, where there are greater concentrations of sulfur, another process is also significant: iron preferentially binds with sulfide over phosphorus.

Nitrogen

The changes stimulated by drying also affect the nitrogen levels, with oxygen availability associated with shallow water and exposed sediments often promoting the loss of nitrogen in gaseous form from freshwater wetlands through coupled **nitrification** (ammonium is converted to nitrate) and **denitrification** (nitrate is converted to nitrogen gas or nitrous oxide that can then leave the wetland) as well as ammonia volatilisation (ammonia is produced).

When the wetting-drying pattern is changed to permanent inundation and oxygen levels are low, levels of a form of nitrogen known as ammonia may build up to toxic levels. Ammonia is made up of nitrogen and hydrogen. Its chemical symbol is NH_3 (not to be confused with ammonium, NH_4^+). Its concentration increases with increasing pH. In high concentrations, ammonia is acutely toxic to invertebrates, frogs and fish.

Influencing factors

A range of factors heavily influence these processes. The extent to which they will occur in a particular wetland depends upon the interplay of many physico-chemical and biological factors in a wetland. These include the frequency with which wetting and drying occurs, the duration of each phase, the redox potential, iron, sulfur, aluminium, calcium, magnesium, salinity, pH, acid neutralising capacity and microbial processes, covered in detail in the topic 'Conditions in wetland waters' in Chapter 2.

Reinstating the natural wetting and drying cycle would seem the logical solution to this problem. However, drying of sediments that have long been inundated poses significant risks. Long-term inundation not only leads to the build up of nutrients; it can also lead to the build up of sulfides, which if exposed to air, can react to form harmful acids (actual acid sulfate soils)—an impact that can be much harder to mitigate than eutrophication. Any attempt to reinstate drying should be carried out carefully and with expert advice. More advice is provided below.

Release of sediment nutrients due to sulfate pollution

Sulfur is an important element in the environment, and is present in the atmosphere, soil and water as well as being present in organisms. Sulfur is naturally occurring in wetlands, with greater amounts present in saline wetlands; sulfur is one of the salts that contribute to salinity (for more information, see the 'Salinity' section in the topic 'Conditions in wetland waters' in Chapter 2).

Sulfur has a strong influence on phosphorus in wetlands. Phosphorus in the sediment is often bound to iron or aluminium in the sediment. If sulfur is added to a wetland, under the right conditions the sulfur, in the form of sulfate, can preferentially bind with the iron, releasing the phosphorus and making it available for cyanobacterial and algal use. This modification to the iron-phosphorous cycle is one form of '**sulfate-mediated eutrophication**'.

Nitrification: the conversion of ammonia (NH_3) or ammonium (NH_4^+) to nitrate (NO_3^-) in freshwater wetlands under oxygenated conditions, facilitated by specialised bacteria, if conditions (pH, temperature, organic carbon availability) are suitable

Denitrification: the conversion of nitrate (NO_3^-) to elemental nitrogen (N_2) under deoxygenated conditions, facilitated by specialised bacteria

Sulfate-mediated eutrophication: eutrophication of wetland surface waters as a result of changes in water quality associated with sulfate rather than additional external supply of nutrients

Sulfate pollution can greatly increase the release of phosphorus from the sediment, causing eutrophication. Human activities can significantly increase the amount of sulfur entering wetlands from the surrounding landscape and atmosphere. Sulfates are applied to catchments in fertilisers, causes include sulfate air pollution from the burning of fossil fuels; sulfates from industrial land uses entering via stormwater; acid mine drainage; rising saline groundwater and seawater intrusion. Under the right conditions, sulfate in the wetland can also be mobilised by other compounds.[42]

Stratification: the division of the water column into distinct layers called the epilimnion (top), the metalimnion (middle) and the hypolimnion (bottom), due to differences in water density between the layers

extra information

Other effects of sulfur in wetlands

Under the right conditions, sulfur in the form of sulfates can be converted to sulfides, which can also pose problems in wetlands. This process can result in increased anoxia (depletion of oxygen) in the wetland. The conversion to sulfides also enhances the methylation of mercury (commonly referred to as MeHg), which increases the toxicity and bioavailability of mercury in wetlands.[43] This is not well studied in WA but potentially has significant ecological implications. Research suggests that sulfate needs to be kept below 1 milligram per litre to manage this problem.

If sustained, concentrations of free sulfide may also accumulate in the sediment pore water to levels toxic to rooted submerged plants.[42] Elevated sulfides can change species composition and favour weeds. In Florida, *Typha domingensis* (native to areas of WA) has been found to have a higher tolerance to sulfide toxicity than many wetland plants, and in Florida it tends to invade wetlands where sulfate pollution is occurring.[44] It is possible that the introduced species of bulrush, *Typha orientalis*, is also tolerant due to similar physiological traits (hollow stems that efficiently transport oxygen to roots to detoxify the root zone). Internationally, some jurisdictions have established interim trigger values, such as Minnesota Department of Environment's interim value of 10 milligrams of sulfate per litre to protect an endangered wetland plant. In the absence of trigger values, it may be possible to determine locally appropriate levels using mesocosm experiments (for an example, see the journal article by Geurts et al 2009[45]).

Impacts

Impacts of excess nutrients include:

- algal and cyanobacterial blooms
- botulism
- poor health/death of native fauna
- smelly gases
- nuisance midge levels
- reduced biodiversity of native species
- increased weeds

These are described below.

Importantly, wetlands receiving the same amount of nutrients may not show the same impacts. The impact depends on a number of factors including the wetland's water hardness, salinity, colour, pH, and the extent to which resuspension, **stratification**, flushing and mixing occur. For this reason, characterising a wetland's water chemistry is recommended prior to identifying management strategies, as their effectiveness will vary.

For example, phosphorus has an affinity for calcium, and will often bind with it to form a precipitate, removing it from the water column. This process may reduce the eutrophication of calcareous wetlands (that is, wetlands with a lot of calcium, often in the form of calcium carbonate).

Algal and cyanobacterial blooms, smelly gases and nuisance midge levels

Algae and cyanobacteria are a natural part of wetland ecosystems and play an important role in food webs. The types that occur in WA and their natural ecological roles are described in the topic 'Wetland ecology' in Chapter 2. Algae and cyanobacteria obtain dissolved nutrients from the surrounding water. When they reach a certain density in the water column, algae and cyanobacteria are said to be in '**bloom**'. In many wetlands they will never form blooms, while in other wetlands they may bloom for a few days or weeks at times of the year as part of the normal wetland cycle without causing a problem. Although nutrients are necessary for the development of algal and cyanobacterial blooms, other factors such as their concentration, bioavailability, light availability, pH, degree of detention and stratification, salinity and temperature also influence the composition of the bloom[46] and competition and predation are also important. Data for Perth and surrounds indicates that high water temperatures (20–30 degrees celsius), high pH (8–10), calm water and low light intensity favour the development of cyanobacteria.[46]

Bloom: rapid, excessive growth, generally caused by high nutrient levels and favourable conditions

Benthic: the lowermost region of a wetland water column; the organisms inhabiting it are known as benthos

Some algae and cyanobacteria, such as species of green algae *Cladophora* and *Enteromorpha*, can significantly alter wetland ecosystems when in bloom proportions, forming extensive mats that cover the water surface, shading out and restricting growth of submerged aquatic plants and other algae below (Figure 13). Algae attached to the leaves of submerged aquatic plants can have a similar effect when in bloom proportions, by blocking out available light and preventing photosynthesis. If algal blooms are prolonged, submerged aquatic plants can die. **Benthic** blooms may also occur, covering large areas of sediments. Large scale detachment and drift of benthic cyanobacteria can occur, with masses of floating clumps potentially appearing similar to a surface bloom.

(a) (b)

Figure 13. Blooms can cover the entire water surface of wetlands, blocking light from reaching plants and animals below the water's surface; (a) constructed lake, Perth (b) Herdsman Lake, Herdsman. Photos – J Lawn.

Algal and cyanobacterial blooms eventually collapse. This may be due to the exhaustion of nutrient or oxygen supply, changes in water chemistry, or damage due to prolonged UV exposure of the individuals at the top of the water column. The spike of available algal or cyanobacterial material represents a massive food source for bacteria and animals that can cope with the bloom conditions, such as midge larvae. In consuming and decomposing the dead algae or cyanobacteria, these organisms use oxygen, to the extent that the decomposition of large blooms results in the depletion of oxygen from the water. The impacts of the anoxic conditions are two-fold: firstly, other life in wetlands are deprived of oxygen they need to survive, and secondly, they promote the release of nitrogen and phosphorus from the sediments, further 'feeding' algae and cyanobacteria populations.[47] The death of fish *en masse,* known as 'fish kills' is often due to oxygen falling below levels needed by fish; although other causes, such as diseases or toxins, may be to blame. It is thought that fish cannot survive less than 30 per cent oxygen saturation.[48] Anoxic conditions can lead to noxious odours due to the release of hydrogen sulfide and other compounds associated with changing chemical conditions. There may be discolouration of the water, such as white areas. Outbreaks of large populations of nuisance insects such as midges are also common, because midge larvae feed on live and dead algae and they are adapted to anoxic conditions.

Detritus: organic material originating from living, or once living sources including plants, animals, fungi, algae and bacteria. This includes dead organisms, dead parts of organisms (e.g. leaves), exuded and excreted substances and products of feeding.

➤ For additional details on midges see the topic 'Nuisance midges and mosquitoes' in Chapter 3.

These conditions can also be suitable for the build up of ammonia to toxic levels. Ammonia is made up of nitrogen and hydrogen. Its chemical symbol is NH_3 (not to be confused with ammonium, NH_4^+). Ammonia can be produced via the decomposition of **detritus** (specifically, via 'ammonification') and by dissimilatory ammonia production in sediments with low levels of oxygen. In high concentrations, ammonia is acutely toxic to invertebrates, frogs and fish. It is taken up by tadpoles and fish via their gills. Acute exposure may be lethal or sub-lethal, while chronic exposure can be sub-lethal. Several factors are known to affect the development and toxicity of ammonia, including pH, dissolved oxygen concentration, temperature, salinity and carbon dioxide concentrations. A pH of more than 9 can cause a shift from ammonium to ammonia.

➤ As a potential toxicant, trigger values for ammonia in wetlands is provided in Table 3.4.1 in Volume 1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* which needs to be cross-referenced with Table 8.3.6 in Volume 2 of the guidelines.[15,14]

Some cyanobacteria species produce toxins that can harm or kill plants, animals and algae. Cyanobacteria that produce these toxins include *Anabaena*, *Microcystis*, *Nodularia* and *Oscillatoria*. Toxins produced by cyanobacteria include neurotoxins (affecting the nervous system), hepatotoxins (affecting tissues and liver) and lipopolysaccharides (causing gastroenteritis).[46] Toxins can persist for more than three months before being degraded by sunlight and microbial activity.[49] In Australia, toxins have been implicated in the poisoning of native animals including kangaroos, rodents, amphibians, fish, bats, waterbirds and zooplankton, and reductions in dragonflies and aquatic beetles has also been attributed partially to toxins and partially to low oxygen levels.[50] Cows, sheep and goats are susceptible to toxins, and consuming as little as one cup of toxic water can cause death. They usually develop muscle tremors and start staggering within 30 minutes of drinking toxic water, and lie down and die with convulsions within 24 hours. Animals that survive develop liver damage, jaundice and photosensitisation.[49]

Exposure to cyanobacteria is linked to increased incidence of several neurodegenerative diseases. Recent research suggests that these toxins could be a contributing factor triggering a motor neuron disease, amyotrophic lateral sclerosis, in humans.[51] While it is likely that it is a multifactorial condition requiring several factors to come together to trigger disease, an analysis of New Hampshire in the United States tracked patients of the motor neurone disease to having lived by lakes or other bodies of water that were subject to frequent algal blooms.

➤ A summary of cyanobacterial toxins can be found in the document *Cyanobacteria: management and implications for water quality*.[52]

Figure 14. Black swans in Lake Monger, in the suburb of Leederville, with their undersides covered in unidentified algae/cyanobacteria. Photo – M Blythman/DEC.

Protecting humans and animals from toxic algae and cyanobacteria

If poisoning from algal or cyanobacterial blooms is suspected, the wetland should be closed off immediately from people, livestock and pets, and no water, fish, shellfish or other foods from the wetland should be consumed. If livestock or pets have been exposed, seek veterinary advice. People should seek medical advice without delay. Sick native birds or other native animals should be reported to the Wildcare Helpline on 08 9474 9055, which operates 24 hours a day. It may be appropriate to employ noise or visual disturbance to discourage birds from the wetland as a short-term option.

In the case of public lands, the responsible authority should be notified, for example, the local government authority, the land manager or relevant state government department. When an algal bloom of human health concern is detected at potentially harmful levels on public lands the Department of Health is advised and a public warning may be issued. Warning signs will be located in affected areas and messages may be broadcast on television, radio, in local or regional newspapers and on the Department's website (www.health.wa.gov.au/press/index.cfm). The Department of Health's Environmental Health Directorate can be contacted on 08 9388 4999 or by email: algalblooms@health.wa.gov.au.

Botulism

Outbreaks of the bacteria *Clostridium botulinum* are almost always associated with decomposing blooms and anoxic conditions in nutrient enriched wetlands. Inhabiting soil and sediments, spores of *C. botulinum* germinate in warm, anoxic conditions, producing a potent nerve toxin. If the toxin is ingested or wounds are exposed to it, birds, fish, frogs and mammals including humans can become very sick, and die. This form of bacterial poisoning is known as botulism, and more specifically avian botulism in bird populations (Figure 15). A cycle of infection can occur if birds ingest fly larvae that have absorbed the toxin from feeding on dead infected birds.[46] One outbreak at Toolibin Lake in 1993 caused the death of 450 birds[53], while an outbreak at Mary Carroll Park wetlands in Gosnells was reported to affect over 2000 birds.[54] Symptoms of botulism in birds are similar to symptoms of cyanobacterial poisoning and include inability to stand, fluffed out feathers and wings not crossed above the tail. Onset of paralysis renders birds unable to fly, instead propelling themselves across the water using their wings. In advanced cases, total paralysis and respiratory distress (gasping) may occur, followed by death.[46]

Although outbreaks of *C. botulinum* can occur at any time, temperature, oxygen and a suitable energy source are thought to be the factors that determine whether an outbreak of *C. botulinum* will occur. Outbreaks tend to be more severe in warm conditions, often between November and April. In wetlands, warm weather and anoxic conditions are optimal conditions for an outbreak, and this is why avian botulism is commonly associated with algal or cyanobacterial blooms. The spores of *C. botulinum* can lie dormant for many years, germinating and multiplying when conditions are right.[55]

Botulism in humans is generally food-borne rather than due to exposure from a wetland, and no cases have been reported in WA since it became a statutory notifiable infectious disease in 2001.[56]

Figure 15. Botulism is a serious consequence of algal blooms and can cause death of wetland fauna. Photo – D Mort/City of Rockingham.

Protecting humans and animals from botulism

If botulism is suspected, the wetland should be closed off immediately from people, livestock and pets, and no water, fish, shellfish or other foods from the wetland should be consumed. If livestock or pets have been exposed, seek veterinary advice. People should seek medical advice without delay. Sick native birds or other native animals should be reported to the Wildcare Helpline on 08 9474 9055, which operates 24 hours a day. It may be appropriate to employ noise or visual disturbance to discourage birds from the wetland as a short-term option.

In the case of public lands, the responsible authority should be notified, for example, the local government authority, the land manager or relevant state government department. When botulism is detected at potentially harmful levels on public lands the Department of Health is advised and a public warning may be issued. Warning signs will be located in affected areas and messages may be broadcast on television, radio, in local or regional newspapers and on the Department's website (www.health.wa.gov.au/press/index.cfm). The Department of Health's Environmental Health Directorate can be contacted on 08 9388 4999 or by email: algalblooms@health.wa.gov.au.

Endemic: naturally occurring only in a restricted geographic area

Invertebrate: animal without a backbone

Reduced biodiversity of native species, increased weeds

Plants, algae and cyanobacteria respond to nutrient enrichment in varying ways. In general terms, nutrient enrichment can increase the total biomass (growth and abundance) and change the species composition of plants, algae and cyanobacteria in a wetland, with winners and losers. Many important **endemic** wetland plants of a region that are adapted to low nutrient levels are likely to be losers. The highest diversity of wetland plant species is often found at intermediate dissolved nutrient levels. Significant nutrient enrichment of permanently inundated wetlands (lakes) typically results in the loss of submerged aquatic vegetation and substantial increases in algae and cyanobacteria.

Changes to plants and other primary producers can have profound effects on wetland animals, because primary producers can have such an influence on animal habitat, in terms of both its physical and chemical characteristics. **Invertebrates**, which play a key role in many wetland ecosystems, demonstrate the profound effects that nutrient enrichment can have on biodiversity. Moderately nutrient enriched wetlands in WA generally support the richest invertebrate fauna and the greatest number of rare species.[24,57] The increased productivity of plants and algae often fuels an increase in grazing and predatory invertebrates. In very nutrient enriched wetlands, there is an abundance of a few tolerant species. There tends to be a progressive disappearance of invertebrate species, leading to a decrease in species richness and ultimately the wetland is inhabited by very large numbers of the few tolerant invertebrate species.[24,57] These changes tend to have effects up the food chain, affecting larger animals.

Weeds that flourish in wetlands often have broad tolerance limits to nutrients, pH, salinity and hydrological regimes and many are 'disturbance opportunists', responding positively and rapidly to habitat disturbance. Elevated nutrient levels can favour weeds over native plant species. For example, a study carried out at four wetlands in Perth found that elevated sediment nutrient concentrations favoured the growth and reproduction of the introduced bulrush *Typha orientalis* over that of *Baumea articulata*[58], a sedge common to many wetlands of the south-west of the state. It has been suggested that the nutrient stripping ability of introduced bulrush is generally inferior to local species that grow in the same environment and are less seasonal in the growth cycle.[59] Weeds are able to respond to nutrient enrichment in all types of wetlands, including those with waterlogged soils. Elevated sulfides can also change species composition, and favour weeds. In Florida, *Typha domingensis* (native to areas of WA) has been found to have a higher tolerance to sulfide toxicity than many wetland plants, and in Florida it tends to invade wetlands where sulfate pollution is occurring. It is possible that the introduced species of bulrush, *T. orientalis*, is also tolerant due to similar physiological traits.

Macroalgae: algae large enough to be seen with the unaided eye

Microalgae: microscopic algae

Indicators

Indicators of excess nutrients include:

- algal and cyanobacterial blooms
- high nutrient levels in water
- high chlorophyll *a* levels

Algal and cyanobacterial blooms

It is important to distinguish between wetlands with normal levels of nutrients and algal growth and those that are eutrophic that have developed, or are at risk of developing serious algal blooms. As discussed previously, algae form an important component of wetland ecosystems and may become abundant at various times of the year as part of the normal wetland cycle. In contrast, rapid algal growth may occur in eutrophic conditions, more frequently and last longer than natural bloom cycles during warm weather (from late spring through to summer).

The most easily recognisable type of algal bloom in wetlands are filamentous green algae (a form of **macroalgae**), which looks like green slime comprised of individual strands or filaments. In the late stages of a bloom, it forms extensive mats covering the water surface, which may accumulate in shallow areas and on wetland banks where it can start to rot and produce noxious odours (Figure 16). Other types of blooms involving **microalgae** may appear as a coloured 'scum' on the water surface (Figure 17) or throughout the water column. Depending on the type of microalgae present, scums can appear green, blue-green, reddish, yellowish, orange or brown in colour.

extra information

Natural blooms and scums

Not all blooms and scums in wetlands are harmful and they may be a natural, seasonal feature such as naturally occurring oils and foams produced by harmless bacteria and algae or from breakdown of organic matter. Pollen that has accumulated in wetlands is often mistaken for an algal bloom. The *Scum book*[60] is an excellent, WA-produced resource providing a local guide to oils, foams and scums.

As a precaution, if any type of bloom or scum is present in wetlands, contact by both humans, pets and stock should be avoided. In the case of public lands, the responsible authority should be notified (for example, local government, the land manager or relevant State Government department). Where warranted, the Health Department may also be involved.

Figure 16. Filamentous green algal bloom. Photo - D Mort/City of Rockingham.

Figure 17. Some algal blooms appear as a 'scum' on the water surface. Photo – W Van Lieven/City of Gosnells.

extra information

When is a bloom officially a bloom?

Microalgal cell counts also provide a direct indicator of the presence and severity of algal blooms. When algal cells of a moderate to large size (greater than 15 to 20 microns (µm) in diameter) exceed 15,000 cells per millilitre of water, it is referred to as a bloom.[61] Smaller sized microscopic algae (less than 1 to 5 microns in diameter) are considered to be in bloom proportions at around 100,000 cells per millilitres[61]; they discolour the water at much higher densities. Cyanobacterial densities in excess of 15,000 cells per millilitre make the water unsafe for people to drink, and even densities of 500 to 2,000 cells per millilitre require action by water managers. These levels are a guideline only; detrimental impacts on wetlands, humans or animals may result from much lower densities, particularly if toxic species are present, in which densities as low as 5 cells per millilitre may pose a threat.[61]

The concentration of algal cells on the surface can vary during the day, and can be 20–50 times the 'integrated' density in calm conditions (an integrated sample is the combined sample from a range of depths in a water column). Measurement of microalgal counts in water samples taken from wetlands should be undertaken by a laboratory.

- Source: Water facts 6: *Algal blooms,* originally published by the Water and Rivers Commission in 1998, and available from the Department of Water website: www.water.wa.gov.au/PublicationStore/first/10085.pdf.
- Identification and cell count services are carried out by specialised laboratories, such as the Phytoplankton Ecology Unit of the Department of Water, various private industry and university specialists, for example, the algae and seagrass research group at Murdoch University. Identification is reliant upon the appropriate collection, storage and preservation of algae prior to its identification. The WA Herbarium and associated regional herbaria do not specialise in the identification of wetland algae and do not maintain wetland algae collections (marine algae collections are maintained).

Water nutrient levels

The absence of obvious symptoms of eutrophication, such as algal blooms, does not mean that a wetland is not eutrophic and therefore not at risk of developing blooms in the future. Water quality often declines over many years before catastrophic symptoms such as algal blooms appear.[61] Measuring nitrogen and phosphorus over time can provide insight into seasonal fluctuations and longer-term trends. Levels can be compared with those in Table 6.

Trophic: from the Greek word for 'feeding', it relates to food and nutrition

Trophic classification: the classification of an ecosystem on the basis of its productivity or nutrient enrichment. The three main trophic classes are oligotrophic, mesotrophic and eutrophic.

Limiting nutrient: the nutrient in an ecosystem which limits further growth because it is available at proportionately lower levels with respect to other nutrients needed for primary producers to increase their abundance

Table 6. Default trigger values relating to nutrient enrichment for slightly disturbed wetlands in WA, from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[14]

Water Quality Parameter	Trigger Value Southwest Australia	Trigger Value Northwest Australia	Notes
Unit of measurement	Micrograms per litre, μg/L		d: higher values are indicative of tropical WA river pools
Total phosphorous	60	10-50 [d]	
Filterable reactive phosphate	30	5-25 [d]	
Total nitrogen	1500	350-1200 [d]	
Oxides of nitrogen (NO_x)	100	10	
Ammonium (NH_4^+)	40	10	

Measuring the total concentration of a nutrient (for example, total nitrogen or total phosphorus) can over-estimate the proportion of nutrients that are actually available for plant, algae or cyanobacterial growth at a point in time.[14] For example, total phosphorus is a measure of the dissolved and particulate forms of inorganic and organic forms of phosphorus in the water, including the bioavailable (soluble reactive phosphorus/ filterable reactive phosphorus/orthophosphate) and unavailable (or potentially available) forms. However, it can provide an understanding of the total 'pool' of these nutrients in the water that may become available under the right conditions, to guide long term management actions. Measuring the inorganic fraction of a nutrient, such as phosphate, nitrogen oxides (nitrate, nitrite) and ammonium provides an idea of what proportion of the total is available to plants, algae and cyanobacteria, although it too is a snapshot of a point in time. Measuring nutrients in the water column does not take into account nutrients stored in the sediments which can become available for plant and algal growth.

Determining the **trophic** status of wetlands can be useful in assessing nutrient levels and potential of algal blooms developing in the future. **Trophic classifications** are used to describe the amount of productivity (usually algal) or nutrient richness occurring within wetlands[62,63] and result in a wetland being identified as eutrophic, oligotrophic or mesotrophic. Of the many methods for determining the trophic classification of wetlands, the Pan American Center for Sanitary Engineering and Environmental Sciences criteria[64], known as CEPIS criteria, developed for warm-water tropical lakes are most often used for WA wetlands.[65] This system uses total phosphorus as the basis for classification. This is because phosphorus tends to be the main **limiting nutrient** in freshwater wetlands, so it is often what determines the presence and extent of algal blooms.[31] The mean and range (within two standard deviations) of annual mean total phosphorus concentrations are used to define trophic categories under the CEPIS scheme, shown in Table 7.

Table 7. CEPIS trophic state classification system based on total phosphorus[64]

	Oligotrophic	Mesotrophic	Eutrophic
Unit of measurement	Micrograms per litre, μg/L		
Mean (average) annual total phosphorus	21.3	39.6	118.7
Range ± 2 standard deviations	10–45	21–74	28–508

The term 'hypertrophic' is sometimes applied to those that are grossly enriched[46] while wetlands that have dark-coloured water from naturally occurring tannins and low pH are referred to as **dystrophic**.[46]

Dystrophic: a wetland that suppresses increased algal, cyanobacterial and plant growth even at high nutrient levels due to light inhibition

➤ For additional detail on nutrients in wetlands see the 'Nutrients' section of the topic 'Conditions in wetland waters' in Chapter 2.

➤ For information on taking wetland water quality samples, see the topic 'Monitoring wetlands' in Chapter 4.

Research conducted by the Cooperative Research Centre for Water Quality and Treatment resulted in the below findings about the nutrient concentrations required to sustain cyanobacterial growth.

Table 8. Nutrient concentrations limiting cyanobacterial growth as defined by the CRC for Water Quality and Treatment.[66]

Water Quality Parameter	Concentration	Application
Unit of measurement	Micrograms per litre, µg/L	
Filterable reactive phosphorus	Less than 10	Concentrations less than this are considered to be growth limiting
Soluble inorganic nitrogen	100	This concentration is considered to be the minimum required to maintain growth during the growing season

Chlorophyll *a*

Nutrient levels can also be indirectly assessed by measuring the concentration of chlorophyll present in the water column. Chlorophyll *a* is one of the pigments required for photosynthesis in plants, algae and cyanobacteria. Its concentration in a water sample is the best indicator of the growth response of the existing algal biomass in the water column. Very high chlorophyll *a* levels may indicate an algal or cyanobacterial bloom due to nutrient enrichment of the wetland. Concentration of chlorophyll *a* in samples taken from wetlands can be assessed against the trigger value for chlorophyll *a* for wetlands in the south-western or north-western Australia specified in the ANZECC guidelines. Measurement of chlorophyll *a* in water samples taken from wetlands should be undertaken by a laboratory.

Table 9. Default trigger values for chlorophyll ***a*** for slightly disturbed wetlands in WA, from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[14]

Water Quality Parameter	Trigger Value Southwest Australia	Trigger Value Northwest Australia
Units of measurement	micrograms per litre, µg/L	
Chlorophyll *a*	30	10

➤ For information on sampling chlorophyll *a* in wetlands, see the topic 'Monitoring wetlands' in Chapter 4.

Managing nutrients, algal and cyanobacterial blooms

Table 10 provides a summary of the potential strategies for managing excess nutrients and associated blooms. They focus at one or more of three scales:

1. preventing the causes of poor water quality
2. intervention at the catchment scale
3. intervention at the wetland scale.

As outlined earlier, some strategies that may be considered suitable for artificial wetlands are not covered here. Similarly, strategies that may be viable in other countries but which have limited application in WA, such as lake flushing, are not covered.

Table 10. A summary of the main strategies that have been considered by wetland managers for managing excess nutrients in WA wetlands

Potential strategies
Preventing the causes of poor water quality
• reducing the amount of nutrients in the catchment
• reducing sulfate pollution
Intervention at the catchment scale
• stormwater treatment to reduce the amount of nutrients reaching the wetland
Intervention at the wetland scale
• not feeding waterbirds
• no-fertilising zones
• fencing out livestock and feral animals
• revegetating the wetland
• revegetating the dryland
• converting drains to overland flows
• aerating water
• eradicating introduced fish
• stopping/managing waterskiing, boating
• harvesting algae
• adding nutrient consuming bacteria
• adding bacteria-boosting enzymes
• remediating groundwater
• harvesting wetland plants
• reinstating the wetting and drying cycle
• diverting nutrient-laden inflows
• nutrient binding and sediment capping
• sealing the sediment
• removing sediments

Preventing nutrient enrichment: reducing the amount of nutrients in the catchment

Reducing the volume of nutrients entering wetlands is the most effective long-term strategy for preventing and managing nutrient enrichment and eutrophication. Intervention techniques, whether at the catchment or wetland scale, can be expensive, inefficient and require long term management.

Identifying the source of the nutrients is the first step to reducing nutrient inputs. This process may be relatively informal, based on a general understanding of the surrounding land uses. Figure 8, reproduced from the *Yellagonga Integrated Catchment Management*

Government action on fertilisers

The WA government has recognised the importance of preventing the causes of eutrophication in WA's wetlands, waterways and estuaries. In response, it has developed and enacted regulations that reduce the solubility of phosphorus in fertilisers: the Environmental Protection (Packaged Fertiliser) Regulations 2010 of the *Environmental Protection Act 1986*. The regulations are two-phased, with 2010 and 2013 cut-off dates for phasing out fertilisers with excess phosphorus.

It has also established the Fertiliser Partnership 2012–2016. This partnership between the State Government, the fertiliser industry, fertiliser user groups, and peak non-government organisations aims to foster a cooperative working relationship to reduce fertiliser nutrient loss to aquatic environments. This is described in more detail in the earlier section of this topic entitled 'Who is responsible for managing catchment water quality?'. The webpage for the Fertiliser Partnership 2012–2016 is www.fertiliserpartnership.agric.wa.gov.au

Plan 2009-2014, is an example of a concise spatial summary of land uses that can help identify and rate potential nutrient sources in a catchment. Alternatively more detailed studies of nutrient loadings and budget based on sampling and modelling of drains, groundwater and sediments in the catchment can be produced.

There are two potential sources of nutrients: the catchment and the wetland sediment (see the text box 'Determining the surface water catchment of your wetland' earlier in this topic for more guidance of the catchment extent). Gaining an understanding of the amount of nutrients coming into the wetland, and the amount of nutrients stored in the sediment, enables good decision making. If the nutrients are being internally recycled in the wetland, controlling catchment inputs alone will not always result in changes in condition. Sampling of sediment and sediment pore-water will indicate whether this is likely to be the case.

In terms of catchment sources of nutrients, an assessment of land use both immediately surrounding the wetland and within the wider catchment will assist in identifying existing and potential sources of nutrients. Sometimes it is historic, rather than current, land uses such as old landfill sites that are a large source of nutrients (often referred to as 'leachates'; in particular, nitrogen in the form of nitrate is very mobile and can leach from a site into the groundwater). This is the case in Bibra Lake, south of Perth, for instance, for which a 1998 study estimated that the nearby landfill contributed up 507 kilograms per year of phosphorus and 15,065 kilograms per year of nitrogen.[67] Where nutrients have been discharged into a wetland for a very long time or at very intense rates, the nutrient 'pool' in the sediment can form the main source of nutrients.

Depending on the severity of the problem, the complexity of nutrient sources and the values being threatened, the development of a nutrient balance or budget may be warranted. A nutrient balance quantifies the sources of nutrient inputs and outputs of a wetland. It typically accounts for the nutrients within the water column and the sediment, as well as incoming groundwater and surface water sources. Any areas of contamination, such as landfill within or adjacent to the wetland, are also accounted for. It is of most help in catchments with many current or historic land uses (such as landfill) which make identifying the relative contribution of different sources of nutrients a complex task. A nutrient balance should account for seasonal and longer-term fluctuations. The information in a nutrient balance can help wetland managers determine which management actions will have the most effect on nutrient levels.

The nutrient loading and dynamics of some riverine catchments are already well-studied and this information can be informative when developing a nutrient balance for wetlands in those catchments. For example:

- Avon River Basin: *Nutrient management for the Avon River Basin: A toolkit for managing nutrient loss to the environment from a range of land uses*[37]
- Peel Inlet and Harvey Estuary water quality improvement plan: www.fertiliserpartnership.agric.wa.gov.au/water-quality-improvement-plans; www.environment.gov.au/water/policy-programs/nwqms/wqip/wa/peel-harvey.html
- Swan Canning Estuary water quality improvement plan: www.fertiliserpartnership.agric.wa.gov.au/water-quality-improvement-plans; www.environment.gov.au/water/policy-programs/nwqms/wqip/wa/swan-canning.html
- Vasse Wonnerup and Geographe Bay water quality improvement plan: www.fertiliserpartnership.agric.wa.gov.au/water-quality-improvement-plans; www.environment.gov.au/water/policy-programs/nwqms/wqip/wa/swan-canning.html
- Leschenault water quality improvement plan: www.fertiliserpartnership.agric.wa.gov.au/water-quality-improvement-plans
- Hardy Inlet water quality improvement plan: www.fertiliserpartnership.agric.wa.gov.au/water-quality-improvement-plans

Once a better understanding of sources of nutrient input is gained, the best combination of preventative and intervention measures can be determined.

➤ For information on how to sample water for nutrients, see the 'Monitoring wetlands' topic in Chapter 4.

There are many ways to reduce the amount of nutrients being released into wetland catchments. The following strategies list some of the most pertinent methods, guidelines and contacts for assistance. The strategies are listed by type of catchment: urban or agricultural. Many peri-urban catchments will be able to use strategies from both groups.

Ways to reduce nutrient enrichment in urban catchments

Urban catchment **Strategy number 1: use fertilisers more efficiently and effectively in home gardens and lawns**	
Management actions	**How to**
Use low water solubility, slow release fertilisers instead of highly water soluble fertilisers.	A list of Fertilise Wise endorsed fertilisers is available from www.fertilisewise.com.au
Apply when plants are growing (in the south-west spring and early autumn (September–November; March–April).	
Water only as needed, to minimise leaching below plant roots.	See Water Corporation's water wise gardening tips: www.watercorporation.com.au
Use native plants, as they need less nutrients.	
Who to go to for assistance	
Great Gardens program.	http://greatgardens.info/
Associated benefits: reduced fertiliser use can significantly reduce costs.	

Urban catchment **Strategy number 2: use fertilisers more efficiently and effectively in parks and other maintained recreational areas**	
Management actions	**How to**
Develop a nutrient management plan or nutrient and irrigation management plan	*Nutrient and irrigation management plans* WQPN[68]
Use low water solubility, slow release fertilisers instead of highly water soluble fertilisers.	A list of Fertilise Wise endorsed fertilisers is available from www.fertilisewise.com.au
Use native plants, as they need less nutrients.	
Who to go to for assistance	
Industry training program Fertcare (Fertilizer Industry Federation of Australia and the Australian Fertiliser Services Association)	www.fertilizer.org.au
Turf managers: Fertilise Wise fertiliser training program.	www.fertilisewise.com.au www.fertilisewise.com.au/docs/ TurfTrainingAdvertGeneral.pdf
Associated benefits: reduced fertiliser use can significantly reduce costs.	

Urban catchment **Strategy number 3: contain point source nutrients on-site**	
Maintain best practice industry standards, including:	**How to**
Urban development industry water sensitive urban design develop using reticulated sewerage in sewerage-sensitive areas	New WAterways www.newwaterways.org.au
Nursery and garden centre industry	*Nurseries and garden centres* WQPN[69]
Light, general and heavy industry	*Industrial wastewater management and disposal* WQPN[70] *Light industry near sensitive waters* WQPN[71] *General and heavy industry near sensitive waters* WQPN[72] *Stormwater management at industrial sites* WQPN[73]
Building industry	'Construction practices' guidelines in Chapter 7, Section 2.1 of the *Stormwater Management Manual for Western Australia*[30]
Associated benefits: better on-site management can reduce costs, significantly improve compliance with regulations and lead to the recovery of resources.	

Ways to reduce nutrient enrichment in rural catchments

Rural catchment **Strategy number 1: improve nutrient management in agricultural industries**	
Management actions	**How to**
Develop a nutrient and irrigation management plan	*Nutrient and irrigation management plans* WQPN[68]
Develop a property plan	*Property planning manual for Western Australia*[74]
Maintain best practice industry standards, including:	
Irrigate and amend soil appropriately	*Irrigation with nutrient rich wastewater* WQPN[75] *Soil amendment using industrial by-products to improve land fertility* WQPN[76]
Dryland crop industry	*Agriculture - dry land crops near sensitive water resources* WQPN[77]
Floriculture industry	*Floriculture activities near sensitive water resources* WQPN[78]
Horticulture industry	*Best environmental management practices for environmentally sustainable vegetable and potato production in Western Australia: a reference manual*[79] *Code of practice for environmentally sustainable vegetable and potato production in Western Australia*[80]
Orchard industry	*Orchards near sensitive water resources* WQPN[81]
Turf industry	*Environmental guidelines for the establishment and maintenance of turf and grassed areas*[82]
Viticulture industry	*Environmental management guidelines for vineyards*[83] *Wineries and distilleries* WQPN[84]
Aquaculture industry	*Aquaculture* WQPN[85]
Animal industries	*Stockyards* WQPN[86]
Abattoir industry	*Rural abattoirs* WQPN[87]
Beef industry	*Guidelines for the environmental management of beef cattle feedlots in Western Australia*[88]
Dairy industry	*Dairy processing plants* WQPN[89] *Effluent management guidelines for dairy sheds*[90] *Effluent management guidelines for dairy processing plants*[91]
Horse industry	Environmental guidelines for horse facilities and activities[36]
Pastoral rangeland industry	*Pastoral activities within rangelands* WQPN[92]
Pig industry	*Environmental guidelines for new and existing piggeries*[93] *National Environmental Management Guidelines for Piggeries*[94]
Poultry industry	*Environmental code of practice for poultry farms in Western Australia*[95]
Associated benefits: cost effectiveness, compliance with environmental regulations, corporate citizenship.	
Who to go to for assistance	
Department of Agriculture www.agric.wa.gov.au Department of Water www.water.wa.gov.au Department of Environment and Conservation www.dec.wa.gov.au	
Relevant regulation	
Approval may be required to establish and operate an intensive animal industry. This may include a works approval, license or registration under the *Environmental Protection Act 1986.*	Department of Environment and Conservation

Rural catchment Strategy number 2: improve livestock management near wetlands and waterways	
Management actions	**How to**
Fence wetlands to significantly improve control of livestock in and near wetlands, and where possible, exclude livestock	'Livestock' topic, Chapter 3
Construct livestock crossings to improve control of livestock use of wetlands as water sources	'Livestock' topic, Chapter 3
Provide shade and livestock watering points away from wetlands and waterways	'Livestock' topic, Chapter 3
Associated benefits: Water quality is maintained for livestock use.	
Who to go to for assistance	
See the 'Livestock' topic, Chapter 3	

Preventing nutrient enrichment: reducing sulfate pollution

Sulfate pollution can be reduced by managing the sulfates being applied to catchments in fertilisers, in air pollution due to the burning of fossil fuels, sulfates from industrial land uses entering via stormwater, acid mine drainage, rising saline groundwater and seawater intrusion. Studies of the northern Everglades in Florida demonstrate that canals are a significant source of sulfate pollution for these wetlands.

Controlling fertiliser use has been identified as an important management measure internationally. There are no trigger values for sulfate; an appropriate trigger value will depend upon the wetland type. For example, inputs of less than 10 milligrams per litre of sulfate is estimated to be a suitable provisional target for managing the concentrations in Bassendean Dune wetlands on the Swan Coastal Plain. In the absence of trigger values, it may be possible to determine locally appropriate levels using mesocosm experiments (for an example, see the journal article by Geurts et al 2009[45]).

Catchment–scale intervention: stormwater treatment

Treating nutrients following their release in the catchment is a less effective and often much more expensive approach to managing nutrient levels than preventing them from being released in the first place. However they do play a role in managing nutrients, particularly combined with preventative measures. They are still far more effective long term measures than some forms of wetland-scale interventions.

Catchment-scale intervention measures include retrofitting or installing:

- conveyance systems (swales and buffer strips, bioretention systems, living streams)
- detention systems (detention areas and constructed wetlands)
- infiltration systems (soakwells, pervious pavement, infiltration trenches and basins)
- pollutant controls (sediment, litter and hydrocarbon controls)
- groundwater remediation downstream of significant nutrient sources, such as landfill (that is, redirection of groundwater to a stripping area for treatment).

- ➤ These intervention measures have been trialed and implemented in WA. Many can be viewed in person and there are a number of studies into their effectiveness at specific sites.
- ➤ Brochures with useful summaries of different intervention measures are available from the Department of Water's website: www.water.wa.gov.au/Managing+water/Urban+water/Water+Sensitive+Urban+Design+brochures/default.aspx#1
- ➤ Examples and detailed guidance on choosing and installing appropriate catchment intervention measures is provided in the Department of Water's *Stormwater Management Manual for Western Australia*[30], particularly 'Chapter 9: Structural controls'.
- ➤ Additional design guidance and information on trials on the effectiveness of bioretention systems and constructed wetlands is provided by the Swan River Trust:
    - *Manley Street bio-retention system assessment*[96]
    - *Constructed ephemeral wetlands on the Swan Coastal Plain: the design process*[97]

Catchment-scale intervention measures in urban areas need to be developed in liaison with relevant authorities, including the local government and the Department of Water. In the coming years, local investigations are likely to generate greater understanding of the efficiency of many of these intervention measures, which will aid developers and catchment management stakeholders in determining the most useful measures for a particular site.

Wetland scale intervention: managing nutrients

Wetland-scale management measures may vary between wetlands depending on a range of factors such as source(s) of nutrients, mode of entry into wetlands (for example, via surface or groundwater flows or other means), wetland shape and hydrology, climate and other factors that may influence how and when nutrients enter the wetland. Often, a combination of strategies may be required to achieve a reduction in nutrient levels, leading to improved water quality in the long term.

Reducing nutrient inputs into wetlands at the catchment scale, through prevention and intervention measures, is the most effective long-term strategy for preventing and managing the impacts of eutrophication, such as algal blooms. At the wetland scale, the most effective strategy is to increase the proportion of nutrients that are 'sequestered' (retained) within plants and the sediment in the long term, in order to reduce the proportion that is available for cyanobacteria, algae and weeds. Localised, short term measures, such as physical removal of excess algae or dredging nutrient-laden sediments from wetlands, may potentially reduce symptoms but fail to address the cause and thus prevent algal blooms from occurring in the future. The consequence of managing symptoms in isolation is that management actions will need to continue indefinitely as long as nutrient inputs remain the same or increase.

The techniques below do not include interventions that may potentially be applied to wetlands of low conservation value or to constructed wetlands, such as bioretention systems requiring earthworks and using materials such as cracked pea gravel, sand-sawdust mixes and zeolites (aluminosilicate minerals). These may be suitable for use upgradient of the wetland in order to improve water quality reaching the wetland, and are addressed under the previous section 'Catchment-scale intervention: stormwater treatment'.

Table 11 lists the wetland-scale techniques for managing nutrients presented in this topic.

Table 11. Wetland-scale nutrient management techniques, grouped and colour-coded according to their potential risk of unintended ecological effects.

✓ Typically low risk	
No feeding of waterbirds	Converting drains to overland flows
No-fertilising zones	Aerating the water
Fencing out livestock, feral animals	Eradicating introduced fish
Increasing wetland vegetation	Reducing/managing waterskiing, boating
Increasing dryland vegetation	Harvesting algae/cyanobacteria scums
✓ to ✗ Low to high risk	
Harvesting wetland plants	Reinstating natural wetting and drying
Diverting nutrient-laden inflows	
? Unassessed risk	**✗ Potentially high risk**
Remediating groundwater	Removing sediments
Adding nutrient-consuming bacteria	Nutrient inactivation, binding and sediment capping
Adding bacteria-boosting enzymes	Sediment sealing

No feeding of waterbirds

✓ Low risk

Preventing people from feeding waterbirds is an easy and cost-effective measure for reducing nutrients in wetlands. It can be achieved through a combination of public awareness campaigns and, preferably as last resort, enforcement of legislation such as local government authority by-laws. As well as reducing nutrient sources, stopping of bird feeding can also improve waterbird health.

No-fertilising zones around wetlands

✓ Low risk

No-fertilising zones around wetlands are an easy and cost-effective measure. No-fertilising zones work well with another low-risk strategy, dryland revegetation. Many local governments have formally designated no-fertilising zones in many public areas.

Fencing out livestock and feral animals

✓ Low risk

Fencing out livestock and other introduced animals such as cattle, sheep, horses and feral pigs prevents them from defecating and urinating in wetlands, compacting and eroding soils by overgrazing and creating direct damage from pugging, rooting, digging, burrowing or wallowing.

➤ A wide variety of techniques to minimise the impacts of livestock on wetlands are provided in the topic 'Livestock' in Chapter 3.

➤ Techniques to control and eradicate feral animals from wetlands are outlined in the topic 'Introduced and nuisance animals' in Chapter 3.

Increasing the amount of native vegetation in the wetland

✓ Often low risk, but can be a risk if wetland acidification may be an issue

There are three constraints to cyanobacteria in the water column: light, nutrients and temperature. Plants can effectively alter the conditions in a wetland so as to favour plant growth and reduce the suitability of conditions for algae and cyanobacteria. To differing degrees, plants can:

- compete with algae and cyanobacteria for nutrients and light
- increase shading
- reduce water temperature
- reduce turbidity
- increase oxygen in the sediment, which leads to phosphorus binding to sediment
- increase coloured dissolved organic matter in the water
- provide habitat for zooplankton such as the microcrustacean *Daphnia* that consumes some species of algae and cyanobacteria.

Regeneration can be used to increase the amount of native vegetation in wetlands. Regeneration occurs when natural processes of regrowth and recruitment of plants take place. Wetland managers can aid this process by weeding and reducing disturbances. Where regeneration/assisted regeneration is not possible, revegetation may be appropriate (for example, planting).

➤ Wetland vegetation management, including assisted regeneration and revegetation, are described in the topic 'Managing wetland vegetation' in Chapter 3.

Considerations

- Plants in growth phase take up nutrients. Some plants such as rushes and sedges and some submerged plants can act as nutrient 'sponges'. When nutrient availability is high, they are capable of taking up more nutrients than they need for current growth and storing them for future growth. The name of this process is '**luxury uptake'** (or luxury consumption). They can also internally recycle nutrients by withdrawing them from senescing leaves and stems for use in new growth.[98] This recycling ability also allows them to survive in naturally low nutrient level conditions. Trees provide long-term storage of nutrients while herbs have shorter life cycles and their nutrients are returned to the system more rapidly.
- Plants that can supply oxygen from their roots to the surrounding sediment can help retain phosphorus in the sediment (it bonds with iron in these conditions). Some plants are better at this than others. Plants known to do this include *Typha domingensis*, *Eleocharis sphacelata*, *Schoenoplectus validus, Baumea articulata* and *Cyperus involucratus*.[99]
- Aerobic bacteria also take up nutrients. Plants such as rushes and sedges provide habitat for bacteria, fungi and algae that grow on them as **biofilms**. Plants also support aerobic bacteria living in the sediment by leaking oxygen into the sediment around their roots (the 'rhizosphere').
- In addition to taking up nutrients, many plants, and particularly woody plants such as species of *Melaleuca* and *Eucalyptus,* produce tannins, which are thought to help reduce the incidence of blooms in freshwater wetlands. Tannins (a high molecular weight **polyphenol**) are dissolved organic materials derived from plant material. They impart a dark colour that are said to 'stain' or 'colour' the water. Water that is a yellow or tea colour is usually a product of tannins. These dissolved organic materials are thought to suppress algae and cyanobacterial growth. For more information see the topic 'Conditions in wetland waters' in Chapter 2.
- Because of the wide range of ecological roles wetland plants fulfill, wetland revegetation can improve many facets of water quality, not just nutrient reduction, as well as improve habitat and overall wetland condition.

Luxury uptake: the process by which some organisms take up more nutrients than they need for current growth, instead storing them for future growth

Biofilm: bacteria, microalgae, fungi and unicellular microorganisms enmeshed in a hydrated mucopolysaccharide secretion that sequesters ions and isolates microorganisms from the water column.[101] May be present on living and non-living surfaces and substrates.

Phenol: complex organic compounds derived from plant materials

- Very reductive sediments may prevent germination of seeds present in seed beds[42] (for more information on reductive soils, see the section on 'redox' in the topic 'Conditions in wetland waters' in Chapter 2). Similarly, the levels of phosphorus in extremely nutrient-enriched soils are toxic to some dryland species (for example, *Banksias*), and this may also be the case for some wetland species.
- In highly turbid conditions that algal and cyanobacterial blooms can create, submerged wetland plants may struggle to establish because the turbidity can stop light from reaching them, prevent them from photosynthesising (for more information, see the section 'Light availability' in the topic 'Conditions in wetland waters' in Chapter 2). It may be necessary to initially plant species that grow in the waterlogged zone, or emergent species such as rushes and sedges that won't be outcompeted by the algae and cyanobacteria.
- Trees and to a lesser extent shrubs can require considerable amounts of water for transpiration. A high density of trees may result in the use of a large amount of wetland water. Unless water levels are unnaturally high, this may pose a threat to the life within the wetland, arising from a reduction of water needed by organisms, and from the possible exposure of acid sulfate soils in the wetland due to lowered water levels. If this is a possibility, the use of wetland vegetation with a lower water use should be considered, for example, sedges and rushes. See the 'Managing acidification' section for more information on these soils, and the topic 'Managing hydrology' in Chapter 3 for more information on water use of trees in wetlands.
- Increasing salinity may affect a plant's ability to take up nutrients. For example, sodium may inhibit a plant's ability to take up ammonium.[100]

Increasing the amount of vegetation in dryland areas adjacent to wetlands

✓ Often low risk, but can be a risk if wetland acidification may be an issue

Regeneration can be used to increase the amount of native vegetation on lands surrounding wetlands. Native vegetation helps to maintain wetland water regimes and removes surface and groundwater nutrients. These vegetated zones may be included as part of the wetland buffer that assist in maintaining the natural character of a wetland. Where regeneration/assisted regeneration is not possible, revegetation may be appropriate.

➤ The process for formally designating dryland buffers to wetlands (that is, through government planning and environmental processes) is outlined in the *Draft Guideline for the determination of wetland buffer requirements* (DoP and DEC 2010).[102] Once finalised, the guideline will be available from the 'Wetlands' webpage of DEC's website: www.dec.wa.gov.au/wetlands.

Considerations

- If revegetation is necessary, planting/seeding using native species of local provenance is recommended. Planting non-native species can create additional water quality problems and change the ecological character of the wetland. For example, some deciduous trees can drop all of their leaves in short time period, and these soft leaves can create a 'spike' in nutrient levels entering wetlands.
- In addition to helping to take up nutrients, areas of native vegetation around wetlands provide habitat for wetland species such as turtles, frogs and birds. The vegetation contributes carbon and tannins to the wetland. It also helps to

moderate the speed and volume of overland flows and wind turbulence, reducing scouring, erosion, sedimentation and turbidity.

- Adding non-native grassed areas is not recommended. Grass maintenance can contribute to excess nutrient problems due to the fertilisation and mowing regimes, especially when lawn clippings reach the wetland (ride on mowers do not have the ability to catch lawn clippings). Short grass is also a poor habitat for native species such as turtles, frogs and bandicoots, as it provides relatively little cover or food.
- Trees and to a lesser extent shrubs can require considerable amounts of water for transpiration. A high density of trees may result in the use of a large amount of water that would otherwise 'feed' the wetland. Unless wetland water levels are unnaturally high, this may pose a threat to the life within the wetland, arising from a reduction of water needed by organisms, and from the possible exposure of acid sulfate soils in the wetland due to lowered water levels. If this is a possibility, the use of lower-water use species should be considered. See the 'Managing acidification' section for more information on these soils, and the topic 'Managing hydrology' in Chapter 3 for more information on water use of trees in wetlands.

Converting drains into overland flows through adjacent dryland vegetation

✓ Low risk

Drains that flow directly into wetlands bypass most of nature's nutrient-stripping methods. Drains can deliver high loads of nutrients to wetlands in single rainfall events, creating a massive 'pulse' in nutrients that can outstrip or even unbalance a wetland's natural nutrient management processes such as plant uptake and sedimentation.

Converting drains to overland flows prior to entering wetlands can address this. Overland flows through vegetation essentially recreate natural flow paths to wetlands. This form of runoff is described as 'sheet flow' compared with the channelised flow in drains, and works by distributing water across the landscape to a shallow depth only. The vegetation slows flows, enabling greater infiltration; and traps sediment and takes up nutrients. Stormwater managers describe this technique as 'disconnecting' receiving environments such as wetlands from pollution sources.

Overland flow through adjacent dryland vegetation is generally considered to be appropriate for WA wetlands. In contrast, the construction of new pipes or constructed stormwater channels into wetlands, especially those of conservation significance, is not supported. This position has been published in the *Decision process for stormwater management in WA*.[30] A range of other government documents support this approach, and encourage the replacement of inappropriate drainage facilities, for example, *Guidance Statement No. 33: Environmental Guidance for Planning and Development*.[28]

Converting drains to overland flows requires sound engineering design and approvals from relevant decision making authorities.

Considerations

- Drains can protect infrastructure such as roads and buildings from water damage such as flooding and waterlogging. It is important to ensure that the upstream environment is not at risk when converting drains to overland flows. This can be achieved with sound design, construction, monitoring and possibly maintenance.
- Disconnecting drains from wetlands also has the added benefit of reducing the potential for other contaminants to be conveyed directly to the wetland. For example, illegal dumping of unwanted chemicals, or accidental spills from petrol

tankers, industry and so on.

- Drains can present a range of safety hazards, as well as ongoing maintenance costs, so a full cost/benefit analysis may demonstrate that their conversion can have multiple environmental, social and economic advantages to landholders and the community.
- Overland flow through the dryland buffers can improve the condition of the buffer vegetation by reinstating or more closely imitating the natural water regime.

Aerating water

✓ Low risk, but requires sound design

Water aeration is the addition of oxygen to the water column of a wetland. The addition of oxygen works to reduce the incidence and severity of algal and cyanobacterial blooms in a number of ways.

Oxygen stimulates efficient decomposition of organic matter by aerobic bacteria and fungi, which reduces the energy store. Oxygen also helps to either export or bind nutrients in unavailable forms. It promotes the conditions needed to export nitrogen from wetlands as either the mobile nitrate form which can leach to groundwater under the right conditions, or in gaseous form which can diffuse to the atmosphere. Similarly in non-calcareous wetlands it promotes the conditions needed for phosphorus to bind with the sediment and in doing so, becoming unavailable for uptake by algae or cyanobacteria. In more technical terms, reduced ferrous iron becomes oxidised to ferric iron, which causes phosphate to bind with it, reducing phosphorus availability. Ammonium, a form of nitrogen, gets converted to nitrate, which is lost more easily from wetlands through leaching of groundwater and conversion to nitrogen gas via the process of denitrification. Finally, volatilisation of ammonia to the atmosphere is promoted. These processes are explained in the topic 'Conditions in wetland waters' in Chapter 2.

Adding oxygen may also help to physically mix layers that have developed in the water column that can promote low-oxygen conditions in deeper layers.

Additionally, because still water favours the development of cyanobacterial blooms, the agitation of the water column can also help reduce the risk of cyanobacterial blooms.

Aeration can be achieved by installing commercially available mechanical devices known as aerators, such as specially designed paddles or rotors, curtains of bubbles rising from near the bottom of the water column (bubblers, bubble plumes), and jets of water spraying into the air using waterfalls, fountains etc (Figure 28). Subsurface aeration employing fine bubbles is often effective because it adds oxygen and creates a moderate amount of mixing throughout the water column. Aeration using curtains of bubbles is likely to generate the least disturbance to sediment and fauna while enabling aeration and mixing. Recirculation systems may also be employed, achieving aeration by pumping low oxygen water out of the wetland, adding oxygen to it, and then returning it to the bottom of the water column, without disturbing sediments. This approach has been used in the Swan and Canning Rivers, using oxygenation plants on the bank of the Canning River and a mobile barge unit on the Swan River.

Considerations

- Bigger is not automatically better – systems that create a lot of surface or sub-surface disturbance in wetlands do not mimic natural conditions and pose a number of problems to natural wetland ecosystems.
- The presence of sulfidic sediment should be investigated prior to undertaking an aeration or oxygenation project due to the potential acidification that can occur

when these sediments are exposed to oxygen.[30] For guidance, see the following section of this topic, entitled 'Managing acidification'.

- Care should be taken to avoid aeration that involves the disturbance of sediments. Sediments stirred up by aeration rapidly remove dissolved oxygen, because dissolved oxygen is consumed by processes in the sediments.[31] Oxygen should not be pumped into the sediment itself.
- Aeration systems must be appropriate for the purpose and maintained to specifications to ensure that they do not pose a safety hazard and continue to operate efficiently and effectively.
- The water columns of most inundated wetlands in WA is less than 5 metres. In general, when employing bubble plumes in these wetlands, the individual air flow rates of the plumes must be very small to maintain efficiency.[52]
- The destratification of naturally stratified wetlands is not desirable. The aeration of naturally stratified water columns should be designed to replenish dissolved oxygen to address the deficit, while preserving stratification. If destratification occurs, nutrient-rich waters may be brought closer to the surface and stimulate algal growth.
- Many sedges are natural sediment aeration units. Many use internal spaces and pressurised gas flow to transport oxygen to their roots, and in the process some of this oxygen leaks into the sediment. This is why revegetation can be a good technique to couple with aeration.
- It is possible that aeration systems may affect the behaviour of fauna, with the potential for some fauna to be attracted to the area and some to be deterred from the area. It is also possible for chemical changes to have adverse impacts, for example, supersaturation can cause gas bubble disease in fish, which can be fatal.[31] Disruption of the water surface may reduce habitat for those invertebrates that inhabit the water surface and rely on surface tension, such as many of the true bugs (of the Order Hemiptera). However, aeration is unlikely to affect the entire water surface of a wetland. These issues should be accounted for when choosing the aeration system and, particularly if the wetland is important habitat for a fauna species, it may be important to monitor fauna to determine any effects.
- Aeration typically involves both capital costs to design and install infrastructure and ongoing expenditure to operate and maintain infrastructure.

Removing introduced fish

✓ Low risk

Mosquito fish (*Gambusia holbrooki*) (Figure 18) prey on water fleas (*Daphnia carinata*), an aquatic invertebrate that in turn feeds primarily on algae. Some species of *Daphnia* will eat cyanobacteria, which are unpalatable to many predators. In this way, the predation of water fleas by mosquitofish can increase the potential for algal blooms in a wetland.

In addition, European carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) vigorously stir up sediment while feeding, which can release phosphorus stored in the sediments.[103] Goldfish have also been found to stimulate the growth of some toxic cyanobacteria species that pass through their gut, such as *Microcystis aeruginosa*.[104] Under the right conditions species such as *Microcystis* can form blooms which can cause significant ecological impacts in wetlands. An increase in cyanobacteria can in turn provide goldfish with an abundant food source, creating the potential for an ongoing cycle of ecological impacts. Researchers found this to be an issue of significant concern for the Vasse River in the south-west of WA.[105]

➤ Introduced fish control and eradication techniques are outlined in the topic 'Introduced and nuisance animals' in Chapter 3. A case study of introduced fish control to improve water quality in a Perth wetland is included in this topic.

Figure 18. Eradicating the introduced mosquito fish, *Gambusia holbrooki,* can help to improve wetland water quality. Photo – C Lawrence/Department of Fisheries.

Reduce/manage boating, waterskiing

✓ Low risk

Engine-powered boating and water-skiing disturbs sediments and creates wash on the water's edge, which can reduce the suitability of conditions for plant establishment and growth. Furthermore by disturbing sediments, these activities can re-suspend nutrients in the water column. In addition, in order to access wetlands with water-skis and boats, vegetation clearing may occur, which further reduces the nutrient-stripping ability of the wetland. Access via unsealed entry points can also result in erosion and increased siltation of wetlands.

Harvesting surface scums of wetland algae, cyanobacteria

✓ Low risk

Some species of cyanobacteria form surface scums, for example, *Microcystis*, *Anabaena* and *Aphanizomenon*. They possess gas vacuoles that allow them to move up or down in the water column over the course of 24 hours to make the best use of sunlight to photosynthesise in the upper water column as well as to access nutrients present lower in the water column, and to avoid constant UV radiation. In suitable densities, it can be possible to harvest these scums, as well as dislodged, floating clumps of benthic cyanobacterial mats.

Manual harvesting may be carried out using rakes or skimmers. Oil-spill booms and skimmers have been used to remove surface cyanobacteria in wetlands and on the Swan River in Perth where in 2000, over 900 tonnes of *Microcystis aeruginosa* were removed and safely disposed using sewage treatment facilities.[106]

Considerations

- The personal safety of the people harvesting algae or cyanobacteria is a priority. A full risk assessment should be taken to avoid health issues arising from exposure to toxic algae, cyanobacteria or bacteria (for example, botulism from *Clostridium botulinum*).

- The disposal of the cyanobacteria should be to an appropriate waste disposal facility. This needs to be determined in advance of the harvesting.
- Optimal removal is likely to be in calm conditions in the early morning when cyanobacteria have migrated to the top of the water column.

Adding nutrient-consuming bacteria

? Unassessed risk

Nutrient-consuming bacteria can be added to a wetland in order to reduce nutrients available for algae and cyanobacteria. This technique has been used in highly degraded wetlands in the Perth metropolitan region.

Considerations

- Bacteria are ubiquitous and can naturally repopulate a wetland. This method seeks to rapidly repopulate a wetland. However, if the depletion of bacteria is due to unsuitable conditions in a wetland, and those conditions persist, this method will not be suitable.

Adding bacteria-boosting enzymes

? Unassessed risk

Enzymes are biological molecules (proteins) that catalyse (initiate and increase the rate of) biological chemical reactions. They can be specifically designed and manufactured for a wide range of purposes. The manufacture and addition of specifically designed enzymes to water may result in increased bacterial uptake of nutrients. Commercially available products are sold for this purpose in Western Australia. DEC has not assessed the effectiveness or ecological risk of these products, but notes the following considerations.

Considerations

- Bacteria use the enzymes, meaning that the treatment will need to be repeated over time to address nutrient levels.
- Some products marketed for the purpose of nutrient reduction in wetlands contain surfactants. Some surfactants are harmful to wetland organisms such as frogs.
- Wetlands with large volumes of water will require large doses of enzymes. This can be expensive in terms of cost and labour.
- Like all products, application must be in accordance with the instructions for use and the material safety data sheet (MSDS).
- Enzymes are reported to be more cost-effective than bacteria broadcasting.[30]

Groundwater remediation

? Unassessed risk

Intercepting and treating groundwater prior to it entering a wetland is a fairly new technique. Proposed methods include creating a trench up-gradient of a wetland along its groundwater capture zone and filling the trench with phosphorus-binding material. Suggested materials include crushed pea gravel or a soil-Phoslock®™ combination (for more information on Phoslock®™ see the 'sediment capping' section below).

Considerations

- There are relatively few examples of how this works in practice.
- It is a medium term option, as the material in the trench will eventually become saturated with phosphorus. After this time, the material will need to be replaced.

Harvesting wetland plants (natives and weeds)

✓ to ✗ Risk ranges from low to high

Harvesting is the removal of some or all parts of a plant. Under the right circumstances, the harvesting of wetland plants may reduce the nutrient levels in wetlands by exporting the nitrogen and phosphorus stored in some plants. Some sedges, for example, employ 'luxury uptake', which is the ability to take up and store more nutrients than they need. Harvesting may be manual or mechanical, with manual forms generally having a much lower impact on wetlands.

In considering plant harvesting, it is important to ensure that natural vegetation will be maintained in the wetland and its surrounds so that natural ecological processes are maintained. Any harvesting program should be supported by a clear understanding of the role of the vegetation and its capacity to regenerate after harvest.

In wetlands where acidification may potentially occur, removing wetland plants removes a source of carbon that can help mitigate acidification. In these wetlands, weeds should not be removed; while they can still be controlled, for example, through crushing of *Typha orientalis*, they should be left in-situ rather than harvested. Although this does not address the nutrient load within these weeds, it is a more manageable issue than a highly acidic wetland. For more information, see the 'Managing acidification' section later in this topic.

Legal authorisation is required

The harvesting of native plants, whether dead or alive, is with few exceptions a form of clearing as defined by the *Environmental Protection Act 1986* and as such is subject to the Act and the Environmental Protection (Clearing of Native Vegetation) Regulations 2004. Native plants are also protected flora under the *Wildlife Conservation Act 1950*, and a licence is required to take such plants from Crown lands. For more information, see the topic 'Legislation and policy' in Chapter 5 or the native vegetation legislation and flora licensing webpages of DEC's website www.dec.wa.gov.au.

Native species

Considerations

- Because of the significant ecological roles of plants in wetlands, the harvesting of all plants should be planned and carried out with due care, but especially the harvesting of native plants.
- During the planning phase, it is important to ensure that the plant material does not provide important fauna breeding habitat.
- Methods involving the removal of below-ground parts can have a detrimental effect on the sediment and should be avoided if possible.
- Floating plants (such as duckweed, a species of *Lemna* in WA's south-west) may be logistically easier to harvest with little disturbance to sediment.
- Plants compete with algae for nutrients. When harvesting plants, it is important not to alter the conditions that favour plants over algae. For example, clear water favour plants while turbid water conditions favour algae. Plants promote

clear water by physically increasing sedimentation and reducing resuspension of sediments. If all the plants are removed, or the harvesting process overly disturbs the sediment, the sediments may become much more susceptible to suspension, providing a competitive advantage to algae (Figure 19).

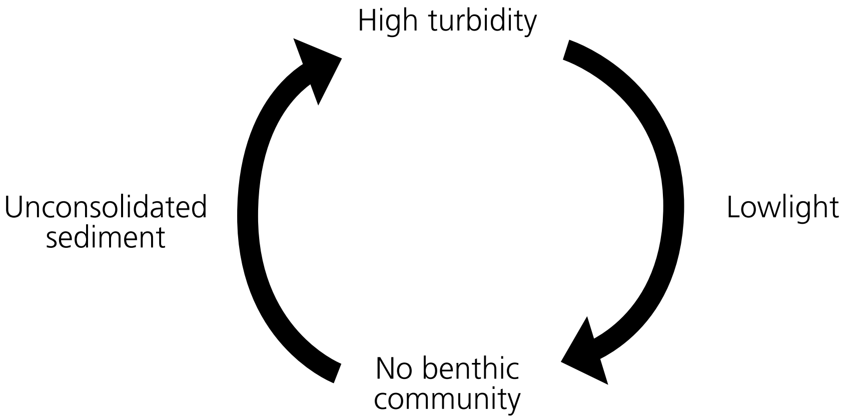


Figure 19. Feedback loop promoting turbid conditions in wetlands.

- Repeated removal of a portion of a plant's above-ground plant material over time is a relatively low-impact way of gradually removing nutrients from the wetland. For example, harvesting of sedges by removing a portion of their stem (but remaining above the waterline so as not to 'drown' them) enables them to continue to photosynthesise, thereby taking up more nutrients in order to fuel their growth.

Wetland weeds

Harvesting of wetland weeds can provide dual benefits of removing nutrients and reducing the current and future impact of those weeds on the wetland. This is particularly relevant for the control of extensive areas of wetland weeds where their control without removal may create ongoing problems in a wetland. For example, an extensive infestation of the floating weed water hyacinth *Eichhornia crassipes* (a weed of national significance) at Lake Monger in the 1950s was treated with herbicides. The dead plants then settled to the lake bed and provided an ongoing nutrient source for the lake.[34]

Considerations

- During the planning phase, it is important to ensure that the plant material does not provide important fauna breeding habitat.
- Matching the method with the weed is important; in some cases, fragmentation of plant parts during harvesting may contribute to their spread.
- If the harvesting of weeds is likely to result in plant death (or is planned as a weed removal option), regeneration of native species is the optimal outcome. If regeneration does not occur, a program of plant replacement with suitable native species should be carried out, to maintain vegetation function and natural ecosystem processes.
- The timing of harvesting should be appropriate for the weed in question. For example, the seed head of the introduced bulrush *Typha orientalis* can hold up to 300,000 seeds that are easily spread via disturbance and transport, so it should not be harvested when holding mature seed. In the south-west this is generally during January and February.

- Floating aquatic weeds can be harvested by hand, using long-handled rakes for instance.
- Methods involving the removal of below-ground parts can have a detrimental effect on the sediment and should be avoided if possible.
- Aquatic weed harvesters are sometimes used to remove large amounts of weeds. These machines can be purchased in Australia and have been used with varying degrees of success in WA. An aquatic weed harvester typically has large cutting blades that cut the weed above the sediment layer (Figure 20). Harvesters remove emergent weeds such as introduced bulrush (*Typha orientalis*) and floating weeds such as salvinia (*Salvinia molesta*). The disadvantage with aquatic weed harvesters is they are expensive to purchase and they can cause damage to native aquatic vegetation and disturb the sediment layer, causing increased turbidity and re-suspension of nutrients or other pollutants.
- It is important that weeds moved off-site are disposed of in a manner that prevents them from becoming weeds elsewhere. Collected plant material may be stored in bags for solarisation, composting or landfill disposal or used as stock feed if suitable. Use of bunds may be useful for larger areas to prevent aquatic weeds from entering 'weeded' out or uninfested areas.

Figure 20. Aquatic weed harvester. Photo – K Tripp/Shire of Wyndham East Kimberley.

case study

Case study - salvinia control in Lily Creek Lagoon, Kununurra

Approximately 135 hectares in area, Lily Creek Lagoon in Kununurra is part of the Ramsar wetland site that encompasses Lakes Kununurra and Argyle. It is directly connected to Lake Kununurra, the supply dam for the irrigation area and environmental flows to the Lower Ord River. The township of Kununurra wraps around Lily Creek Lagoon, which is an important habitat for migratory birds, freshwater crocodiles and numerous species of fish. It also provides an attractive backdrop and recreational area for the town.

A small infestation of salvinia (*Salvinia molesta)* was first discovered by a local resident in May 2000. It was immediately identified to be of major concern due to its potential to completely smother the water body and cause damage to the native aquatic ecosystem. The control and eradication process of salvinia has been a joint effort of the local and state government and non-government organisations.

Several different methods have been used over the past nine years to eradicate salvinia. Initial controls involved the containment of the weed through a boom fence and the manual removal of the bulk of the salvinia where possible. This was followed up by spraying with Roundup Biactive®, and installation of more boom fences (see Figure 21).

The floating boom fences, which are partly submerged beneath the surface to about 35 centimetres depth, are designed to trap salvinia and prevent it from spreading to uninfested areas. Initially one boom fence was used for containment, with more booms being installed later to create additional holding cells. The holding cells served two functions, to trap salvinia that was regenerating from small pieces missed hiding in the native typha (*Typha domingensis*) stands, and to trap any new plants entering the lagoon from the drain leading into it.

The major difficulty of salvinia being trapped within dense stands of native typha made access for control and removal very difficult. A clearing permit was obtained to remove a small area of native typha in order to allow greater access to the salvinia infestations. The most successful strategy for controlling native typha was mechanical removal with follow up spraying of regrowth. An excavator was used to remove approximately 600 square metres of native typha, which created an open water area which allowed access for eradication of salvinia. Removal of native typha was undertaken outside the breeding season of the swamp hen, which relies on the dense stands for nesting.

(a)

(b)

Figure 21. (a) Salvinia monitoring and collection (b) salvinia trapped within stands of native typha (c) salvinia containment area using boom fences. Photos – D Pasfield/Ord Land and Water.

(c)

Reinstating the natural wetting and drying pattern

✓ to ꗃ Risk ranges from low to high

In permanently inundated wetlands, there may be an annual release of nutrients from wetland sediments that were previously subject to a natural wetting and drying cycle. Where this is found to be the case, it may be appropriate to reinstate the wetland's natural hydroperiod, which in southern WA is usually seasonal, that is, wet in winter/spring and dry in summer/autumn.

For example, in the Perth region, many areas that were seasonally inundated in the 1800s became permanently inundated in the 1914–1920 period. For example, Butler's Swamp became Lake Claremont and Perry Swamps became Perry Lakes.[107] Many such lakes are now reverting back to seasonally inundated basins (that is, sumplands) with lower rainfall and abstraction of groundwater.

Reinstating the natural pattern in lakes for the purpose of managing excess nutrients is often not appropriate. Important considerations include:

- whether the ecological community that is present is adapted to permanent water, and the ecological values of this ecological community
- whether the wetland has already built up sulfidic material to the extent that reinstating the regime would trigger wetland acidification via acid sulfate soils
- whether there are other permanently inundated areas that provide refuge in prolonged dry weather/drought.

If, on the other hand, a wetland is drying due to causes such as low rainfall (climate change), this indicates further need to consider managing the wetland through the transition to a seasonally drying wetland.

Reinstating the natural wetting and drying pattern may help to alleviate eutrophication in a number of ways. As with aeration, drying enhances the decomposition of organic matter and the diffusion of oxygen to the sediment, which promotes a range of chemical reactions due to the change in the redox potential. See the 'aeration' technique earlier in this topic for more information. Susceptibility to blooms is minimised in wetlands in the south of the state that dry on a seasonal basis, because of the lack of water in hot conditions. They may also receive a smaller soluble nutrient load because of reduced flows in dry weather.

There are substantial risks associated with drying wetlands, and for this reason wetland scientists should be consulted prior to attempting these changes. Despite good intentions, because of the potential to cause environmental harm, a proposal to alter the wetland water regime may trigger referral to the Environmental Protection Authority for assessment under Part IV of the *Environmental Protection Act 1986*.

Reinstating a natural wetting and drying cycle is discussed further in 'Managing hydrology' in Chapter 3.

➤ For information on managing wetland hydrology, please refer to the topic 'Managing hydrology' in Chapter 3.

➤ For information on legislation and policy protecting WA's wetlands, see the topic 'Legislation and policy' in Chapter 5.

Diverting nutrient laden inflows

✓ to ⚠ Risk ranges from low to high

Diverting very high nutrient inflows can be very effective at reducing nutrients, but may deprive the wetland of water. It may also have downstream impacts. An example of where it has been used is in Jackadder Lake, in the Perth suburb of Woodlands. The water and nutrient balance conducted for Jackadder Lake informed the decision to reduce the volume of nutrient-rich water redirected into the wetland from the Osborne Park Main Drain in summer, which has been reported as reducing the susceptibility of the wetland to algal problems.[108] This water was previously directed into the wetland to maintain summer water levels.

Nutrient binding, nutrient inactivation and sediment capping

⚠ High risk

Nutrient binding, nutrient inactivation and sediment capping products are types of algistat, which are chemicals or additives added to water that inhibit or retard the growth of algae or cyanobacteria, either directly, or by chemical modification of the water column.[109] These materials are typically applied in a liquid, slurry or powder form from a boat. The material reacts with phosphorus dissolved in the water column, coagulating or adsorbing with it and then settling on to the sediment. It is thought that they then form a thin active barrier on the surface of the sediments, reducing nutrient exchange between the nutrient-enriched sediment and the water column and absorbing further phosphate from the water column.[110] In this way these materials may alter the chemical composition and the physical properties of a wetland. Materials that have been proposed previously include specific formulations of clay and limestone, salts of aluminium and iron and minerals based upon zeolite. Commercially available products include Phoslock®™ (a modified clay nanomaterial with rare earth elements) and Algalblock (a modified calcium carbonate product).

Because of the potential for significant environmental impact, proponents considering the application of products of this nature to wetlands should consult with the Office of the EPA to determine whether the referral of their proposal to the Environmental Protection Authority is required under Part IV of the *Environmental Protection Act 1986*.

Considerations

- The addition of chemicals to wetlands can alter the chemical composition of wetlands. For example, alum, or aluminium sulfate, increases the amount of the highly toxic heavy metal aluminium in the wetland, and under some circumstances may lead to highly toxic shock events, particularly at lower pH levels. The addition of sulfate can trigger phosphorus release from sediments under certain conditions as well as forming salts. Similarly, some products may directly change the pH, or the buffer solutions that are required to be added prior to products may change the pH.
- Wetland sediment is an extremely important part of a wetland. It helps to form the ecological character of a wetland, being important as habitat for a range of species and the site of the most important chemical processes in most wetlands. It also affects the wetland hydrology. Activities that alter the wetland sediment may have short, medium and long-term effects on wetland ecology, including potentially irreversible changes to wetlands. Manufacturer claims that products have no effect on benthic organisms have not been assessed by DEC. However, alterations to the physico-chemical nature of the sediment may affect benthic fauna.

- Disturbing and changing the chemical composition of sediments has the potential to mobilise contaminants, such as arsenic and lead, in toxic concentrations if they are present in the sediment.
- The change in sediment properties may reduce its hydraulic permeability. If the wetland is connected to groundwater, there may be reduced flushing of the wetland with groundwater. This can (a) alter wetland water regimes and (b) either reduce or increase the amount of nutrients entering the wetland depending on whether the groundwater has less or more nutrients than the wetland.
- If there are a lot of algae in the wetland water column, this proportion of the wetland's existing phosphorus load will not be capped.
- Sediment capping materials will not address new inputs of phosphate. Similarly, if large amounts of sediment enter the wetland following the sediment capping materials, they may be subject to burial, and it may be necessary to apply further sediment capping material.
- Plants may short-circuit the barrier, by taking up nutrients buried below the sediment surface. When they senesce and decay, they can release nutrients above-ground.[42]
- Animals may alter the layer, by disturbing or turning over sediment. This is known as bioturbation, and may be carried out by many animals, for example, birds, fish, turtles, insects, midge, crustaceans and mussels.
- The efficacy of using a product in a particular wetland needs to be carefully considered. Factors such as pH, redox and hardness need to be considered. For example:
  - aluminium sulfate, known as alum, has been used with the view of it forming a flocculent precipitate of aluminium hydroxide that binds phosphate ions and organic materials, which settle to the wetland bed.[111] Use around the world suggests varying levels of success. Trialled at Jackadder Lake in Perth's northern suburbs, 20 tons of alum failed to stop phosphorus levels from reaching pre-treatment levels within a matter of weeks.[110,108] The phosphorus binding capacity of alum is pH sensitive. A constant supply of sulfate-enriched water will interfere with the iron-phosphate bond, with iron bonding with sulfate and releasing phosphate.
  - lime application is thought to be more effective in hard water wetlands where the water may become supersaturated with calcium ions.[42]
- At thousands of dollars per hectare[108], costs may be considerable. For example, estimates provided for the application of Phoslock®™ to a 65 hectare area of Yangebup Lake, assuming a phosphorus concentration of 0.12 milligrams per litre, was $850,000 in 1995. At Bibra Lake an unspecified material was costed at $30,000 for a 2500 square metre trial area in 1998. Repeat applications may also be required for longer term benefit.
- The environmental cost of sourcing materials also needs to be taken into consideration, with mining of dryland and wetland environments. For example, lime is quarried from limestone. In WA a major source of bentonite clay is from threatened wetlands. The 'Herbaceous plant assemblages on Bentonite Lakes' ecological community of the Avon Wheatbelt is listed by the WA Minister for Environment as a threatened ecological community.
- Some studies suggest that products may have the potential to alter the microbial processes of coupled nitrification and denitrification and also to induce active element leaking from agents.

extra information

Phoslock®™, a new product

Phoslock®™ is a relatively new product (sold commercially since 2004) that is used for water quality management in a number of countries. In WA, it has been used at sites including the Vasse and Canning rivers and Emu Lake, Ballajura. It is marketed as a phosphorus inactivation product for those situations where phosphorus release from sediments is a main driver of algal bloom formation. Below are some of the considerations regarding its use.

Phoslock®™ forms a reactive permeable layer typically 1 millimetre in thickness on bottom sediments. Phoslock®™ contains lanthanum and bentonite; bentonite is a clay that occurs in wetlands and is mined from wetlands in WA for various applications. While lanthanum is thought to be toxic in dissolved or free forms, the manufacturer states that the lanthanum ions are locked in the structure in the Phoslock®™ mineral, thereby dramatically reducing the toxicity and availability of its free form, with the concentration of dissolved lanthanum stated to remain very low in the water body.[112] Studies reporting lanthanum release to the water column during trials cite levels of around 2 milligrams per metre per day over a fortnight[113] (see also van Oosterhout and Lrling[114]). In a comparison of the ecotoxicity of alum and Phoslock®™ the manufacturer of Phoslock®™ concluded that "Al [aluminium] poses more threat to aquatic life than that of lanthanum".[112] The manufacturer states that lanthanum is more likely to pose a risk of being present in dissolved form in the water column if applied to low alkalinity water at the wrong dose.[112] The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[15] do not specify a trigger value for lanthanum as a toxicant, due to insufficient data to derive a reliable trigger value (although it does provide an indicative interim working trigger value; for more information see Table 3.4.1 and section 8.3.7 of the guidelines).

Phoslock®™ has been used by the Swan River Trust and DEC in the Canning and Vasse Rivers. Following a trial conducted on Canning River, the Swan River Trust reported that "A comprehensive suite of indicators of environmental impacts, including fish, waterbirds, macro-invertebrates and periphyton, was measured before and after application of Phoslock®™. Interpretation of the data collected was affected by a number of events including heavy rains, and a fuel spill upstream of the trial area soon after the application. However results showed that the application of Phoslock®™ did not adversely affect populations of macro-invertebrates, freshwater shrimps or periphyton".[115] Laboratory testing of acute and chronic toxicity was undertaken by the CSIRO Centre for Advanced Analytical Chemistry Analysis on a species of cladocera (a microcrustacean), green alga and fish, and no toxicity effects were observed in these test species.[115] It has been reported by the WA Midge Research Group that "There is potential for Phoslock™ to cause acute toxicity to fish (LC50 = 4350 mg Phoslock™ L-1) (Martin and Hickey 2004) if the correct application rate is exceeded or if an accidental spill occurred and this should be considered before use".

International studies indicate that the efficacy of the treatment can vary, and that variables include water characteristics such as water softness/hardness and the concentration of humic acid.[116] It is stated that the optimal pH range is 6–9 but it operates over a pH of 4–11.[112] Reports state that cost of treating around 50 hectares of water can range from $100,000 to $500,000 depending on the problem and the dose rate.[117] The life of the treatment depends on the condition of the water body and the levels of nutrient inflows. In Emu Swamp, in the suburb of Ballajura north-east of Perth, yearly doses are likely to be necessary (Emu Lake was a natural wetland that has been modified). Analysis based on the use of Phoslock®™ in constructed lakes in Perth and the south-west suggest that, used alone, repeated treatments over the long-term would be required in eutrophic wetlands.[108]

Sediment sealing

ꕤ High risk

As the name suggests, sealing of sediments aims to prevent nutrient exchange between the sediments and the water column by installing an impermeable barrier between them. Impervious materials such as plastic sheeting and linings are used. This effectively smothers, and cuts off, benthic organisms from the water column, including insects, mussels, snails, roundworms, leeches and rotifers and rooted vegetation. It also cuts off wetland organisms from the sediment (for example, waterbirds that feed from the sediment, and oblong and flat-shelled turtles, some crayfish and some fish that **aestivate** or otherwise burrow in the sediment during dry conditions). Organisms such as insects, beetles, flies, midge, algae, bacteria and plants may inhabit sediment during stages of their lifecycle, in life forms including larvae, eggs, spores, cysts and seeds; hence the loss of sediment habitat can reduce wetland biodiversity.

Aestivating: being in a state of dormancy that occurs in some animals to survive a period when conditions are hot and dry

Considerations

- Wetland sediment is an extremely important part of a wetland. It helps to form the ecological character of a wetland, being important as habitat and the site of the most important chemical processes in wetlands. It also affects the wetland water regime. Sealing the wetland sediment can have short, medium and long-term effects on wetland ecology, including potentially irreversible changes to the ecological character of a wetland. Proposals of this nature can have significant ecological impacts and require referral to the Environmental Protection Authority under Part IV of the *Environmental Protection Act 1986.*
- Sealing does not remove the source of nutrients and is effective only up to the point where new sediments accumulate on the surface of the capping material.
- Materials such as plastic sheeting can be expensive, difficult to install and may be damaged, limiting its effectiveness.
- Sealing requires a uniformly cleared wetland floor that means the removal of any rooted vegetation from the area to be sealed. This can affect natural wetland ecology and functioning.
- Technical limitations such as the generation and release of gas from sediments below the seal need to be accounted for.
- The disturbance and mixing of sediments by sediment-dwelling organisms and waterbirds (known as bioturbation) could hasten the breakdown of capping.
- The breakdown of capping materials has the potential to affect wetland organisms.

Removing sediments

ꕤ High risk

Sediments can be a significant source of phosphorus, which can be released as the bioavailable form, phosphate, during periods of anoxia and bioturbation. Dredging, skimming and excavating sediment has been proposed at a number of Perth wetlands as a means of reducing the volume of phosphorus in the wetland.

Dredging has been carried out at some wetlands including Hyde Park Lakes and Mary Carroll Park Lake. Hyde Park Lake contained high levels of lead and sulfide. Consequently, an acid sulfate soil management plan was required to be prepared and implemented in order to remove the sediments, to limit the potential for lead mobilisation.

Because of the potential for significant environmental impact, proponents considering the removal of wetland sediments should consult with the Office of the EPA to determine whether the referral of their proposal to the Environmental Protection Authority is required under Part IV of the *Environmental Protection Act 1986*.

Considerations

- Wetland sediment is an extremely important part of a wetland. It helps to form the ecological character of a wetland, being important as habitat and the site of the most important chemical processes in wetlands. It also affects the wetland water regime. Removing wetland sediment can have short, medium and long-term effects on wetland ecology, including potentially irreversible changes to wetlands.
- Some wetland plants and animals rely on sediment for aestivation (such as turtles, some crayfish, some fish, many frogs, mussels, snails, roundworms, leeches and rotifers), or as habitat for vulnerable life stages such as larvae, eggs, spores, cysts and seeds (used by many insects, beetles, flies, midge, algae, bacteria and plants), hence the loss of natural sediment habitat can reduce wetland biodiversity.
- Disturbing the sediments can disturb acid sulfate soils and cause acidification of the wetland.
- Disturbing sediments has the potential to mobilise contaminants, such as arsenic and lead, in toxic concentrations if they are present in the sediment.
- Wetlands typically do not provide firm ground from which to operate conventional excavating machinery such as front-end loaders or scrapers. Geotechnical investigations need to confirm that the extent of consolidation of wetland sediments is sufficient to support machinery.
- Floating dredges using industrial strength suction pumps have been proposed in the past. These required the establishment of settling ponds to enable dredged sediment to settle, given an extraction ratio of 5 per cent sediment to 95 per cent water followed by the return of the water to the wetland. Previous proposals have also required a minimum water depth of 1 metre to enable the dredge to operate.
- Knowledge of the depth of the sediment that is phosphorus-enriched is needed to inform the proposal.
- Depending on the depth of sediment required to remove the phosphorus-enriched portion, considerable deepening may be a result. Deepening can alter the habitat and water regime, as well as potentially leading to stratification, which can have implications for nutrient management in the future.
- The disposal of the excavated sediment may be regulated. Sediments containing contaminants may be classified as contaminated waste, for which there are specific disposal requirements. For example, it may have high levels of heavy metals.
- Dredging can be expensive, particularly in larger wetlands. An undated estimate of the cost of sediment removal at Bibra Lake a number of years ago was reported to be approximately 30 million dollars.

case study

Case study – toxic algal bloom in Hawker Lake, Rockingham

Hawker Lake, in Rockingham, has had serious water quality problems for many years. These problems culminated in a toxic bloom in the summer of 2007 when water temperatures, sunlight and nutrient levels in the water lead to the development of a toxic bloom (Figure 22). The bloom and sick and dying birds at the wetland prompted an investigation by City of Rockingham staff into the causes of the poor water quality. Samples of water were collected from the wetland by the City's environmental staff for analysis.

Figure 22. Bloom in Hawker Lake, City of Rockingham. Photo – D Mort/City of Rockingham.

Analysis of water samples confirmed the presence of a toxic cyanobacteria as well as the bacterium *Clostridium botulinum*, which can cause the rare but dangerous disease botulism, which poses a serious health risk to humans, pets and wildlife. The wetland was immediately closed as a precaution to protect the surrounding community (Figure 23).

Figure 23. Sign erected at Hawker Lake warning of health risks associated with algal blooms. Photo - J Nichol/DEC.

How did the lake water become toxic?

Staff began their investigation into how the water had become so toxic by looking at the location of the wetland and influences from the surrounding catchment. The wetland lies at the lowest point of the catchment and receives stormwater from surrounding roads, drains and gardens (Figure 24). It was likely that the stormwater contained high loads of nutrients (from fertiliser and animal faeces) and possibly other pollutants such as herbicides, hydrocarbons and pathogens.

Figure 24. This stormwater drain transports nutrient rich water into the lake, contributing to the bloom pictured here. Photo - D Mort/City of Rockingham.

The council also recognised that wetland vegetation around the water's edge had been replaced with grass, which was regularly fertilised (Figure 25). These conditions were most certainly encouraging the development of blooms.

Figure 25. Replacing native vegetation with fertilised grassed areas around the lake contributed to blooms. Photo - D Mort/City of Rockingham.

case study

Case study – toxic algal bloom in Hawker Lake, Rockingham (cont'd)

Remediation of Hawker Lake

Since the bloom in 2007, the council has spent over $70,000 undertaking a number of projects to improve water quality in Hawker Lake. Engaging the community in the 'Yellow Fish' education program was a key strategy in reducing pollutants entering the wetland and improving water quality. The Yellow Fish program encouraged neighbours to consider the impacts of their activities at home, particularly those that result in pollution of stormwater entering the wetland, such as excessive use of fertilisers on lawns and gardens. The community was actively involved in revegetating the wetland and its surrounding area with local native plants (Figure 26). Newly established native vegetation has also provided benefits for local waterbirds, which have returned to the site (Figure 27).

Figure 26. Revegetation of the wetland with native species to reduce nutrients entering the lake. Photo - D Mort/City of Rockingham.

Figure 27. Newly established native vegetation provides habitat suitable for many of the local birds which have returned to the site. Photo - J Nichol/DEC.

Large scale 'bubblers' and water fountains have been installed in the lake to aerate and circulate the water, reducing the release of nutrients stored in the sediments and subsequent growth of algae and toxic bacteria (Figure 28).

Figure 28. Bubbler (foreground) and fountains (rear) aerate the water and prevent anoxic conditions which can increase release of nutrients from the sediment and growth of algae and cyanobacteria.
Photo - J Nichol/DEC.

Staff at the council continue to work with the community to encourage improved catchment management by encouraging local residents to grow native plants and reduce the application of fertiliser, water and herbicide on lawns and gardens. The community are also helping by replacing introduced fish such as Koi, which stir up the sediments, resulting in the release of nutrients, with native fish.

The water quality in the lake has vastly improved since the remediation activities have been implemented. It is hoped these activities will reduce the possibility of future algal and cyanobacteria blooms and botulism outbreaks in Hawker Lake so the community and wildlife can enjoy a more natural wetland environment.

Wetland scale intervention: algae and cyanobacteria control methods

Algae and cyanobacteria control methods are considered a short-term approach because they address the symptoms and not the causes of blooms. When scoping potential control methods it is important to be aware that a number of methods used in reservoirs and drinking water supply waterbodies are not suitable for use in wetlands of conservation value because of their effects on the physical, chemical and biological characteristics of wetlands.

Algaecide: any chemical or biological agent intended to kill algae

Table 12. Wetland-scale algae and cyanobacteria control methods, grouped and colour-coded according to their potential risk of unintended ecological effects.

✓ Typically low risk
Harvesting algae and cyanobacteria
Potentially high risk
Applying algaecides
Adding organic material

Harvesting wetland algae, cyanobacteria

✓ Low risk

Some species of cyanobacteria form surface scums, for example, *Microcystis*, *Anabaena* and *Aphanizomenon*. They possess gas vacuoles that allow them to move up or down in the water column over the course of 24 hours to make the best use of sunlight to photosynthesise in the upper water column as well as to access nutrients present lower in the water column, and to avoid constant UV radiation. In suitable densities, it can be possible to harvest these scums, as well as dislodged, floating clumps of benthic cyanobacterial mats.

Manual harvesting may be carried out using rakes or skimmers. Oil-spill booms and skimmers have been used to remove surface cyanobacteria in wetlands and on the Swan River in Perth where in 2000, more than 900 tonnes of *Microcystis aeroginosa* was removed and safely disposed using sewage treatment facilities.[106]

Considerations

- The personal safety of the people harvesting algae or cyanobacteria is a priority. A full risk assessment should be taken to avoid health issues arising from exposure to toxic algae, cyanobacteria or bacteria (for example, botulism from *Clostridium botulinum*).
- The disposal of the cyanobacteria should be to an appropriate waste disposal facility. This needs to be determined in advance of the harvesting.
- Depending upon the species of cyanobacteria, optimal removal is likely to be in calm conditions in the early morning when cyanobacteria have migrated to the top of the water column.

Applying algaecides

Algaecides (also known as algicides) are a short-term measure (weeks to months) for the management of algal blooms in wetlands because they kill the algae but do not reduce the nutrient levels needed to prevent further algal blooms. Algaecides can be sprayed from a boat. Algaecides are a type of pesticide and their use is regulated by the Health (Pesticides) Regulations 1956.

Considerations

- Algaecides should not be used in natural wetlands, particularly those of conservation value, because they can be toxic to wetland plants and animals, including crustaceans, fish, birds and non-target algae and bacteria that are not in bloom proportions. Similar considerations apply to algistats (any substance or agent that inhibits the growth of algae). Copper, a metal, is the active constituent of many algaecides is a toxic heavy metal in aquatic environments. Copper can accumulate in sediments and be taken up by organisms in this form or released into the water under certain conditions. As outlined in the 'Metals' section later in this topic, aquatic plants are thought to be particularly sensitive to iron, copper and aluminium.[118]
- The death of large amounts of algae provides a food source for bacteria. In decomposing this large energy source, the bacteria consume oxygen, leading to the deoxygenation of the water column and anoxic conditions that can result in odours, fish kills and botulism, and potentially a boom population of midge.
- It is important to be aware that the use of algaecides can cause the mass release of toxins produced by cyanobacteria upon the dissolution of their cells (lysis), and that these toxins may persist long after the cyanobacteria die. This needs to be taken into consideration if native animals or livestock are at risk, for example, if the wetland is being used to water livestock. The toxins are generally very stable compounds that are resistant to chemical breakdown and may remain in natural waters for several months. Under natural conditions, sunlight and bacteria may cause the breakdown of some toxins. It is also a lot more difficult to detect algal toxins than whole algal cells. Once algal cells are killed, the only way to determine whether algal toxins are still present in the water is through toxin testing, which can take up to a week and is far more expensive than testing for algal cells.[109]
- Cyanobacteria resistant to algaecides may flourish following treatment and death of other species of cyanobacteria.[109]
- Algaecides may kill zooplankton that graze on algae, increasing the potential for future algal blooms.

Using algaecides

Any chemical or biological agent intended to kill a living thing, such as a poison, is a pesticide, and an algaecide is a type of pesticide. Extreme care must be taken to ensure that the use of pesticides does not constitute an offence or cause environmental harm. In WA, anyone who uses pesticides is bound by the Health (Pesticides) Regulations 1956. These regulations were developed to provide protection for the applicator, the public and the environment from misuse of pesticides. Pesticide labels are written in accordance with the regulations and therefore any pesticide user has a legal obligation to read and follow instructions on the label. By law and without exception, pesticides cannot be used in any manner contrary to that described on its label without the permission of the Australian Pesticides and Veterinary Medicines Authority. The label provides instructions for use, for the protection of the environment, information about storage and disposal and recommendations for personal protective equipment. Anyone proposing to apply a pesticide to a natural area of conservation value should have appropriate authorisation and should undertake training in the correct preparation, handling, application, transport and storage of pesticides.

Adding organic material

The addition of organic matter has been used with varying levels of success in wetlands in Australia and internationally as an algistat – that is, to prevent new growth. Theories for algistatic effects observed have been put forward including that the decomposition of straw cell walls releases phenolic compounds (such as tannins) that inhibit the cyanobacteria; that the absorption of UV light by the dissolved organic matter produced generates reactive oxygen species which may damage tissues and alter the bioavailability of limiting trace metals; and that the addition of this material stimulates the production of antibiotics by fungi. However, in a review of barley straw, Water Quality Research Australia Limited, a company funded by the Australian water industry, concluded that "The evidence on the efficacy of barley straw from Australia conflicts with overseas studies. Of the two published studies a lab investigation failed to find any inhibitory effects from extracts derived from rotting straw on isolates of *M. aeroginosa* [a cyanobacterium], and a comprehensive field-based trial also found no algicidal or algistatic effects from barley straw over a 6-month period. These contradictory findings and the unknown identity of the phytotoxic compounds in rotting barley straw would indicate that this technique is too poorly understand to recommend for widespread use as an algal control measure, particularly in drinking water supply situations".[66] The potential for the organic matter to increase the biological oxygen demand (BOD) of the wetland needs to be assessed before considering using this technique, as low oxygen levels or anoxia could create a range of problems.

Acidity: the amount of acidity associated with all dissolved ions in a solution, expressed as an amount of pure calcium carbonate needed to neutralise these. Dissolved ions include hydrogen ions and commonly free dissolved metals such as aluminium, iron and manganese.

Ion: an atom that has acquired an electrical charge by the loss or gain of one or more electrons

Alkalinity: a solution's capacity to neutralise an acid, expressed as the amount of hydrochloric acid needed to lower pH of a litre of solution to pH 4.5. The concentration of bicarbonate (HCO_3^-), or when pH is greater than 8.3, the concentration of carbonate (CO_3^{2-}). Sometimes due to dissolved silicate, phosphate or ammonia in relatively high concentrations (tens of milligrams per litre).

Latent: dormant, inactive

Managing acidification

Wetland acidity is a chemical characteristic that, like dissolved nutrients and pesticides in water, can't be seen. However, like nutrients and pesticides, acidity can have significant effects upon a wetland and, when a wetland is very acidic, these are very visible.

Acidification of wetlands: a summary

Causes: rising acidic groundwater, acid sulfate soils, acidification of shallow groundwater

Impacts: reduced biodiversity of plants and animals, oxygen deficiency, metal toxicity

Indicators: wide range of changes in vegetation, soil and water characteristics

Management options: a range of options for preventing acidification, a number of wetland-scale interventions and treatments

What is acidity?

In chemical terms, **acidity** is a high concentration of dissolved hydrogen in water. Hydrogen has the chemical symbol 'H', while the chemical shorthand for the dissolved, **ionic** form of hydrogen that produces acidity is 'H^+'. Waters with a low concentration of dissolved hydrogen are often referred to as alkaline waters, however, the term **alkalinity** specifically refers to a solution's capacity to neutralise an acid.

The presence of hydrogen ions reflects acidity at a point in time. However, it is also important to be aware that wetlands have a **latent,** or stored, form of acidity in the presence of dissolved iron and aluminium in the water. Latent acidity can account for more than 80 per cent of acidity in a wetland.[119,120] Latent acidity can become actual acidity when the wetland water is exposed to air, causing the dissolved metals iron and aluminium to progressively react with oxygen and water and to precipitate as oxyhydroxide minerals. In the process of doing this, more hydrogen ions are released into solution, generating actual acidity.

Why is acidity important?

Acidity and alkalinity are properties of water that directly affect the ability of organisms to function, breed and survive in water. Acidity and alkalinity also have a strong influence on many chemical reactions in water that affect organisms and which help to shape a wetland's ecological character.

There are wetlands in WA that are naturally extremely acidic or alkaline, though most are naturally within a relatively neutral range ('circumneutral'), or mildly to moderately acidic or alkaline. In WA, when human activities cause a change to a wetland's acidity, the effect is typically to increase acidity, and for this reason the focus of this section is upon managing human-induced acidity in WA wetlands. However, human-induced increases in alkalinity can also have serious effects on WA wetlands and where there is a risk of this occurring (for example, when applying chemicals to treat acidic wetlands), specialised monitoring and management is required.

Wetland animals, plants and microbes are adapted to particular ranges of acidity or alkalinity for survival, breeding and normal function.[14] Most WA wetland plants, animals and microbes are adapted to within the range of circumneutral to moderately acidic or alkaline conditions. Some wetlands are naturally acidic, and these wetlands support species that are tolerant of this acidity, and in some cases, may support acid-specialised species known as acidophiles. Organisms are directly affected by the level of acidity or alkalinity, with tolerance depending on the species and factors such as the stage of their life cycle. They can also be affected by secondary effects of acidity or alkalinity, including changes to oxygen levels, toxicity of dissolved metals and turbidity.

How is acidity measured?

Acidity levels can vary in a wetland over time and is influenced by a range of factors. One commonly used measure is the pH scale, which commonly ranges from pH 0 (strongly acidic) to pH 14 (strongly alkaline). pH is a very crude indicator of the acidity of a wetland, as this measurement only indicates the presence of hydrogen ions – in essence, the instantly available acid at a specific moment in time. Importantly, it doesn't measure the acidity present in a latent or stored form in the presence of dissolved iron and aluminium in the water. For this reason, samples of water from two wetlands may have the same pH, but quite different total acidity values, because of their different iron and aluminium concentrations. The pH scale is logarithmic, meaning that a fall of one pH unit represents a ten-fold increase in hydrogen ions.

The best way of assessing wetland acidity is to measure both pH and total titrateable acidity using a field test kit. Commercially produced test kits are available for purchase, or alternatively can be made using items from the supermarket and pharmacy; instructions for making these kits are described in the below text box 'Making simple field test kits to measure the total titratable acidity'.

The unit of measurement for acidity is the weight of calcium carbonate (pure limestone, $CaCO_3$) or the equivalent such as sodium hydroxide (NaOH), needed to neutralise all of the acidity in a litre of water to pH 8.3. In contrast, the unit of measurement for alkalinity in waters with a pH greater than 4.5 is the amount of hydrochloric acid (HCl) needed to lower pH of a litre of the solution to pH 4.5. When acidic waters are neutralised by alkaline materials, dissolved metals like iron and aluminium consume large quantities, while pH consumes comparatively small quantities.

Acidity in the pore waters of sediments has a wider range of reactivity than acidity of water columns. Acidity in sediments may be a combination of soluble (reacts over minutes to hours), exchangeable (minutes to days) and insoluble (hours to decades, sometimes centuries) forms. The acidity stored in soils and sediments can be more than 100 times that held in overlying water.[121]

extra information

Making simple field test kits to measure the total titratable acidity

-by Dr Steven Appleyard, Department of Environment and Conservation

The acidity of a water sample can be determined by a process known as an acid-base titration. This involves adding in a drop-wise fashion a solution of sodium hydroxide of known concentration to a measured volume of the water sample to which has been added a few drops of an acid-base indicator. The drop-wise addition of sodium hydroxide (with swirling of the sample) is continued until the colour of the solution just changes colour (the titration end-point). The volume of sodium hydroxide solution added to the water sample is then measured, and the acidity of the water sample can then be calculated, usually in units of the equivalent mass of calcium carbonate required to fully neutralise the acidity, or milligrams per litre as $CaCO_3$. The total titratable acidity of a water sample is generally measured by titrating the sample to a pH of 8.3, the pH at which the acid-base indicator phenolphthalein changes from colourless to a pink colour.

There are a number of commercially available acidity test kits that can be used to carry out this titration on water samples in the field. However, these kits are generally expensive (of the order of $100 each). It is possible to make kits of an equivalent accuracy to the commercial kits for a small fraction of the cost using only materials that can be readily purchased in a supermarket and a pharmacy and using recycled plastic or glass containers.

Components of the test kit

The components of a test kit include:

- a 50–100 millilitre plastic bottle containing the standard sodium hydroxide solution
- a small syringe or an eyedropper which is graduated in fractions of a millilitre
- a medicine glass or a small plastic container which has marks indicating volumes of 5 millilitre and 25 millilitre
- a small bottle (5–10 millilitre) with a drop dispenser (or use another eyedropper) containing turmeric-based acid-base indicator which changes colour at the same pH as phenolphthalein.
- a plastic lunch-box or a similar container to house components of the test kit.

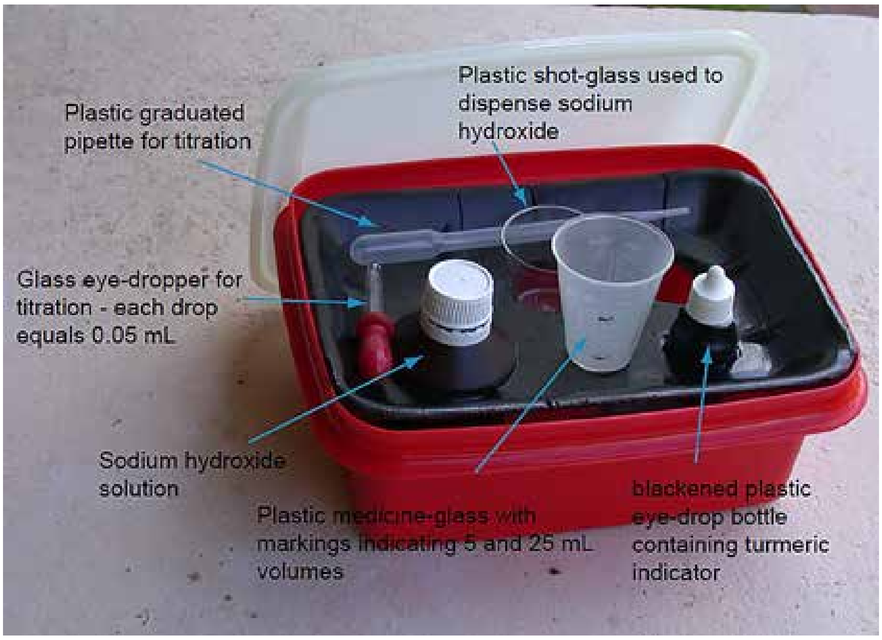


Figure 29. Components of a total acidity test kit housed in a plastic lunch box with an insert made with a foam meat tray to keep containers upright. Photo – courtesy of ASSAY newsletter.

Making the standard sodium hydroxide solution

The sodium hydroxide solution can be made using sodium hydroxide pellets and distilled water that can be obtained cheaply from a supermarket or hardware store (reagent grade materials are not needed). Weigh 8 grams of pellets of sodium hydroxide and add to 1 litre of deionised water (also available cheaply in supermarkets). This solution is further diluted by a factor of 10 with deionised water to make the standard solution (that is, a concentration of 0.02 molar NaOH). This solution can be made using kitchen scales and plastic measuring jugs, so it is not necessary to have access to laboratory equipment. It is recommended that the solution is discarded and replaced at 6-monthly intervals, as the sodium hydroxide progressively reacts with carbon dioxide absorbed from air to form sodium carbonate.

extra information

Making an acid-base indicator with turmeric

If phenolphthalein is not available, an alcoholic extract of powdered turmeric (the spice available in supermarkets) will provide a suitable acid-base indicator. This is made by placing a teaspoon of powdered turmeric in a small, dark-coloured glass or plastic container (turmeric extracts are light-sensitive) and covering the powder with methylated spirits. The active ingredient in the extract is the dye curcumin which changes colour from yellow to bright red at the same pH that phenolphthalein changes from colourless to a pink colour. This solution is used in the same way at phenolphthalein, and only 1–2 drops should be added to the water sample before carrying out a titration.

Using the acidity test kit

The sample to be tested should be collected using a standard method, such as the field sampling protocol published by the Massachusetts Water Watch Partnership: www.umass.edu/tei/mwwp/phalk.html.

A 5 millilitre volume of water is added to the medicine glass and 1–2 drops of the indicator solution is added to the sample. The standard sodium hydroxide solution is added drop-wise with the eyedropper or small syringe while swirling the water sample until the colour of the solution just permanently changes colour from yellow to red. The volume of sodium hydroxide added to the water sample is then determined, and the acidity (in units of milligrams per litre as $CaCO_3$) is determined by multiplying the volume in millilitre by 500. The volume added from an unmarked glass eye-dropper can be determined by counting the drops added as 1 drop is equivalent to a volume of 0.05 millilitre (20 drops are equivalent to a volume of 1 millilitre).

If the calculated total acidity value of the sample is less than 100 milligrams per litre as $CaCO_3$, the precision of the test can be improved by measuring a 25 millilitre volume of the water sample and then repeating the titration as before. The total acidity of this volume of water is determined by multiplying the volume of sodium hydroxide added by a factor of 100.

What determines the natural acidity of a wetland?

As indicated, the range in the natural acidity/alkalinity levels of WA wetlands is very broad. In fact, the area between Hyden and Norseman in the Great Southern/Esperance districts contains some of the most naturally acidic wetlands anywhere on the planet, with pH values as low as 1.5[122] (with the organisms that inhabit these salt lakes being the subject of NASA-sponsored research). The natural level of acidity or alkalinity in wetlands in WA is strongly influenced by natural acids produced, and the natural buffering capacity present. Key factors include:

- The chemical properties of the catchment (the rocks and the aquifer materials) that the surface water and groundwater flows through prior to reaching the wetland, as well as those of sediment.
- Rainwater tends to be naturally slightly acidic, and the chemical properties of the land surface and aquifers it flows through before reaching a wetland, and upon entering the wetland, determines whether it will be altered. Geological substrates and wetland sediments containing calcium carbonate (limestone, $CaCO_3$) tend to be naturally alkaline and are often 'buffered' (stabilised) against rapid changes in acidity.[123] Other sources of potential acid buffering also include clay minerals, aluminosilicate and organic matter.[124] On the other hand water flowing over granite is typically poorly buffered. Wetlands on sandy soils often have very little buffering capacity and are often acidic.
- Wetlands that receive surface water from naturally acidic or alkaline waterways or wetlands, or that have groundwater capture zones that receive water from upgradient acidic or alkaline wetlands, may reflect this acidicity or alkalinity.
- The level of acid produced by decaying plant matter.

- Wetlands can be naturally acidic if their sediments release organic (tannic, humic and fulvic) acids from decomposing vegetation. Wetlands with peat or lots of organic matter tend to be naturally acidic. The pH level attributable to natural organic acidification is generally thought to be as low as 4.5,[125,126,15] though levels as low as 4 have been attributed to this process.[127] Peats can also contain pyrites which, if exposed to air, can lead to acidification. Peats contain up to 15 per cent by weight of oxidiseable sulfur.[128]
- The use of carbon dioxide by primary producers, and the production of carbon dioxide by all organisms.
- Photosynthesising organisms (plants, algae and cyanobacteria) use carbon dioxide (and in the case of plants, also bicarbonate, HCO_3^-). If they use carbon dioxide from the water column or sediment pore waters, there will be a decline in carbon dioxide. This tends to increase the pH of the water. During an algal bloom, pH levels may increase as a result of increased photosynthesis. Because photosynthesis occurs during the day, pH is likely to be higher later in the day due to the cumulative effect of removing carbon dioxide from water. On the other hand, carbon dioxide produced by organisms via the processes of (cellular) respiration and bacterial decay decreases the pH of water. The lowest pH from carbon dioxide production in soil is around 4.6.[129] In very shallow granite rock pools, sometimes referred to as vernal pools, the very small volume of water relative to the high plant biomass and the poorly buffered nature of the water results in large day-night fluctuations in carbon dioxide and pH.[130]
- The degree to which oxidation of iron sulfides naturally occurs.
- Wetlands with iron sulfide minerals in sediment that undergo natural drying or burning events may release acid from the oxidation of iron sulfides. Naturally seasonally drying wetlands do not build up a significant store of iron sulfide minerals and therefore normal levels of drying do not generate significant amounts of acid.[131]

The level of acidity or alkalinity in wetland waters can change as a result of chemical reactions occurring in the water column and wetland sediment. They are affected by the chemical composition of substances in the wetland plus those substances entering and leaving the wetland. They can vary naturally over the course of the day (due to changes in carbon dioxide levels) and over the course of a season (due to multiple factors) as well as over longer timeframes.

➤ For more information on what influences the natural acidity or alkalinity of a wetland, see the topic 'Conditions in wetland waters' in Chapter 2.

What should a wetland's acidity be?

Due to the existence of a wide range of natural levels of acidity in WA wetlands, there is no 'normal' range for wetland acidity or pH. A default trigger value for total acidity is not provided in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC). As stated earlier, pH is only an imprecise measure, but trigger values are available; the ANZECC guidelines indicate that the pH in most natural, freshwater inundated wetlands in WA should not drop below pH 6.0 or exceed pH 8.5 if no negative impact to the ecosystem is to occur[15] (Table 13). There are a number of exceptions, including humic (coloured) wetlands which are often naturally acidic, as outlined in the section 'What determines the natural acidity of a wetland?'). Note that because the pH scale is logarithmic, a fall of one pH unit represents a ten-fold increase in the effective concentration of hydrogen ions.

Information from other studies are presented in Tables 14–16 below, with Tables 15 and 16 relating specifically to Wheatbelt wetlands.

Buffering capacity: a measure of the soil's inherent ability to buffer acidity and resist the lowering of the soil pH

Acid neutralising capacity: a measure of the soil's inherent ability to buffer acidity and resist the lowering of the soil pH

Table 13. Default trigger values for pH for slightly disturbed freshwater wetlands in Western Australia, from the ***Australian and New Zealand Guidelines for Fresh and Marine Water Quality***[14]

Water Quality Parameter	Trigger Value Southwest Australia	Trigger Value Northwest Australia
pH	Greater than 7.0 and less than 8.5	Greater than 6.0 and less than 8.0
Notes	In highly coloured wetlands (gilvin >52 $g_{440}m^{-1}$) pH typically ranges from 4.5 to 6.5	NA

Table 14. Biological threshold for pH for saline aquatic ecosystems in the Wheatbelt (Jones, Francis, Halliday & Leung 2009[118])

Water Quality Parameter	Threshold for Wheatbelt saline aquatic ecosystems
pH	6

Table 15. Reference ranges for pH in various central Wheatbelt wetland types (Jones, Pinder, Sim & Halse 2009[26])

Wetland type	pH range	Notes
Naturally saline basin wetlands subject to inundation	7.8–8.7	Excludes naturally acidic wetlands
Freshwater inundated basin wetlands subject to inundation	6.8–8.1	
Turbid claypans subject to inundation	8.6–8.9	

How sensitive are wetlands to acid generating processes?

When acid is generated in a wetland, the change in acidity levels that occurs depends on the **buffering** or **acid neutralising capacity** of the wetland (or, in groundwater, the aquifer sediments). Materials and processes in the wetland can buffer against large changes in pH. These include the presence of carbonate minerals (shells and other calcareous matter) in the sediment, the process of anaerobic respiration and the presence of alkalinity (bicarbonate ions). Acidification occurs when the rate of acid input or generation exceeds the rate at which acid can be neutralised by these processes.

The United States Environmental Protection Agency (EPA) has classified the sensitivity of lakes and ponds to acidification, based upon their alkalinity, measured as the concentration of calcium carbonate ($CaCO_3$) as shown below.

Table 16. US EPA classification of sensitivity of lakes and ponds to acidity. Source: Massachusetts Acid Rain Monitoring Project[132]

US EPA category	Total alkalinity measured as concentration of $CaCO_3$ in milligrams per litre
Acidified	Less than 1 and pH of less than 5
Critical	Less than 2
Endangered	2–5
Highly sensitive	5–10
Sensitive	10–20
Not sensitive	More than 20

Causes of human-induced acidification

In WA, human-induced acidification of wetlands is primarily caused by:

- the discharge of iron-rich acidic groundwater, such as occurs in the Wheatbelt
- the disturbance or exposure of soils containing sulfidic materials to air, causing localised acidification, as occurs in many coastal areas of south-west WA
- the disturbance or exposure of soils containing sulfidic materials to air, causing acidification of shallow groundwater systems, as has occurred in the shallow groundwater of the Bassendean Dunes.

Additional factors are the deposition of aerial sulfidic material and acid rain due to industrial pollution, although these are more prevalent in the northern hemisphere, and acid mine drainage. Acid mine drainage is an important issue but in terms of impacts to wetlands it is currently not considered to have the widespread scope of other forms of acidification, and is not specifically addressed in this guide. Proposals to mine that may cause acid mine drainage are considered in mining and environmental approval processes.

Acidic waters are generally considered to be very similar regardless of whether they are generated via acidic groundwater, acid mine drainage or acid sulfate soils, with the exception that acidic waters in the Wheatbelt are generally also saline.

Rising naturally acidic groundwater (Wheatbelt)

Acidification associated with iron poses a significant threat to many Wheatbelt wetlands. It is associated with acidic groundwater; the groundwater of the eastern Wheatbelt is generally less than pH 5.5, and there are several areas of acidic groundwater in the Wheatbelt where the pH is between 3.0 and 4.5. It is thought that groundwater acidity was present in many areas prior to clearing and salinisation of the Wheatbelt landscape. While it is generally accepted that oxidation of sulfides is not the cause of this acidity[133] (unlike acid sulfate soils, below), researchers continue to investigate the cause for this groundwater acidity, with the most accepted explanation being that in wetter conditions in the past, waterlogged soils in affected areas were iron-rich and this water percolated to the groundwater over tens of thousands of years. This theory accounts for the fact that alkaline soils (calcareous or carbonate-rich) often overlie areas with acidic groundwater.[134] The iron-rich water is believed to have acidified soils below these carbonate layers, resulting in groundwater that is acidic but still contains some unreacted iron.

A range of human activities have mobilised this acidic groundwater, bringing it into contact with wetlands. Most importantly, the widespread clearing of deep-rooted native vegetation for agriculture has caused groundwater to rise extensively across the Wheatbelt, mobilising salts and bringing acidic and salt laden groundwater up the soil profile, affecting wetlands, waterways, valleys, farming land and infrastructure.[135, 136] The high concentrations of dissolved iron in this groundwater means that, as it rises and moves into more **oxidising** conditions in the formerly unsaturated zone and eventually seeps into wetlands, waterways and other low-lying areas, it has the potential to become even more acidic on exposure to oxygen through a chemical reaction known as iron oxidation/hydrolysis or **ferrolysis**, which can significantly lower pH.[134] While acidity in saline waters is rare on a worldwide scale[120], over a quarter of a million hectares of valley floors in the Wheatbelt are influenced by shallow saline groundwater that has pH of less than 4, to as low as pH 2.8.

The construction of deep (2–3 metres), open drains, or alternatively groundwater pumping, can intercept this saline, acidic groundwater. While acidic before discharge into a drain, the pH of drain waters can fall further due to the reaction of dissolved iron

Oxidation: the removal of electrons from a donor substance

Iron ferrolysis: a process by which anoxic groundwater containing dissolved ferrous ions is exposed to air and ferrous irons are oxidised to ferric ions, which reacts with water to form orange-brown precipitates, gels or crusts of ferric oxyhydroxides, releasing free hydrogen ions in the process with oxygen on exposure of the water to air. Deep drainage can also facilitate other acidifying processes, such as the exposure of sulfidic materials to oxygen (described in the next section). The water in these drains is transported downstream into receiving environments such as wetlands and waterways which can, in turn, be acidified.[137] Estimates in 2002 suggested that, of more than 90,000 kilometres of salinity earthworks constructed in the Wheatbelt, at least 4,000 kilometres are deep, open drains intercepting groundwater.[135] Approximately 1000 kilometres of deep drains are being constructed each year.[138] In the eastern Wheatbelt, more than half the drains sampled were strongly acidic, with an average pH of 3.0.

Wetland sediments can contain significantly more acidity than overlying water columns. For example, an analysis of samples found that some Wheatbelt wetlands contained up to several thousand times more acidity in sediments than in waters at the time of sampling, and shallow soils along wetland margins were found to have higher levels of acidity again.[135]

Given that naturally and human-induced acidic wetlands in the Wheatbelt appear to have similar geochemical properties[135], the extent of wetland acidification caused by human activities is difficult to determine (particularly that caused by groundwater rise and discharge). Studies indicate that acidic lakes may occur across a much larger area of the eastern WA Wheatbelt than previously recognised, with the extent and degree of acidification present unlikely to be attributable to natural causes (for example, Degens et al, 2008[135]). With groundwater rise and increased discharge likely to continue in many areas for coming decades, it is likely that more wetlands may become acidic, compounding the serious effects of secondary salinity; it has been found that acidic saline wetlands have less aquatic diversity than alkaline saline lakes.[139] Acidic groundwater is widespread across all agricultural regions of WA.[135]

extra information

Technical information is available from the following reports:

- *Mapping acidic groundwater in Western Australia's Wheatbelt*[133]
- *Avon catchment acidic groundwater – geochemical risk assessment*[135]

Acid sulfate soils

Acidification in wetlands can also occur when naturally occurring sulfur compounds known as sulfides or pyrites present in rocks, soils or iron-rich groundwater are exposed to air.[137] When exposed to air, sulfides oxidise. They undergo a complex series of oxidation reactions that ultimately produces sulfuric acid. This can result in significant and sometimes persistent acidic conditions.

Sulfidic soils are known as **acid sulfate soils** or **ASS** for short. Left undisturbed and unexposed to air, they are harmless. In this state they are known as **potential acid sulfate soils** or **PASS** for short. When exposed to air, they are known as **active (or actual) acid sulfate soils** (**AASS**). The word 'sulfate' can also be spelt 'sulphate'.

The sulfides in PASS are commonly contained in waterlogged soil layers, often below the groundwater table and at a pH of between 6 and 8. The layers containing PASS materials can be clay, loam, sand, mud, peat or 'coffee rock' (cemented iron and/or organic rich sands), ranging in colour from pale grey to dark grey and black to red-brown and olive greens.[141,142] While they remain waterlogged, the sulfides in the soil are stable and the soil pH is usually circumneutral. Left undisturbed, PASS are harmless and can remain so indefinitely.

Acid sulfate soils: includes all soils in which sulfuric acid is produced, may be produced or has been produced in quantities that can affect the soil properties. Also referred to as acid sulphate soils.

Potential acid sulfate soils: soils that can contain significant sulfidic material, which on oxidation can cause the pH of the soil to fall to very low levels

Active (or actual) acid sulfate soils: soils in which the sulfidic minerals have oxidised and the pH has fallen to very low levels

extra information

The formation of potential acid sulfate soils

Acknowledgement: some text sourced from Department of Sustainability, Environment, Water, Communities and Population.[140]

Potential acid sulfate soils are prevalent in wetlands because they form when there is a source of:

- sulfate, which in the Australian landscape comes mainly from ancient seawater brought inland with rain
- metal ions, some of which can be naturally prevalent
- organic matter, which builds up in many wetlands due to the presence of water/ lack of oxygen
- low or no available oxygen, due to the presence of water.

As shown in Figure 30, acid sulfate soils are formed by bacterial activity in waterlogged conditions when there is no or little available oxygen. Naturally occurring bacteria convert sulfate (dissolved salt) from seawater, groundwater or surface water into sulfide (another type of compound that contains sulfur). This sulfide reacts with metals especially iron in the soil sediments or water column, to produce metal sulfides (the main components of acid sulfate soils). In order to convert the sulfate into sulfide, the bacteria also need a source of energy provided by organic material such as decaying vegetation.

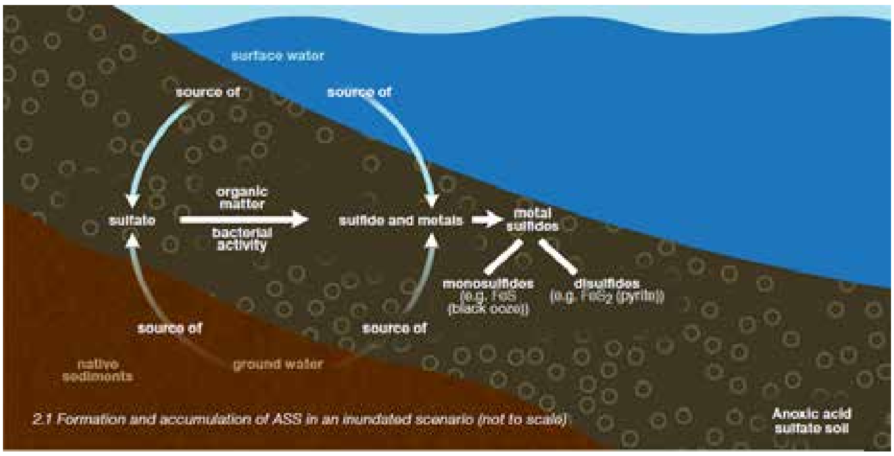


Figure 30. Formation and accumulation of ASS in an inundated scenario (not to scale). Source - *National Guidance for the Management of Acid Sulfate Soils in Inland Aquatic Ecosystems.*[131]

Bassendean Sands: (also known as the Bassendean Dunes) a landform on the Swan Coastal Plain, comprised of heavily leached aeolian sands, located between the Spearwood Dunes to the west and the Pinjarra Plain to the east

The issue of ASS has been recognised as being of national importance. In WA, acid sulfate soils are a critically important management issue, particularly for the groundwater dependent wetlands on the Swan Coastal Plain (Jurien–Dunsborough), the Scott Coastal Plain (Augusta–east of Donnelly River), the Albany–Torbay region, Geraldton, the Pilbara coastline and estuaries in the Kimberley. The extent of inland ASS is largely unknown at this time.[143]

Swan Coastal Plain wetlands that are undergoing ASS, have experienced ASS events or have permanently acidified, include Lake Gnangara (late 1970s), Lake Mariginiup (since at least 2005), Melaleuca Park, Lake Gwelup, Lake Wilgarup and Lake Jandabup (detected since 1997). Importantly, the **Bassendean Dunes** of the Swan Coastal Plain have also been identified as being of high to moderate risk; this area supports many seasonally waterlogged wetlands of high conservation significance, and in particular, many **damplands.** The Bassendean Dunes have been found to have the potential to become very acidic when soils are exposed to air, due to the very poor acid buffering capacity of their soils, which are typically dominated by quartz sands and which contain very little clays or carbonates.[144] The environment around wetlands that have acidified can also been severely affected; for example, acidic groundwater extends 5–10 metres below the watertable in Stirling.[128]

Damplands: seasonally waterlogged basin wetlands

Gnangara groundwater system: the groundwater system formed by the superficial, Leederville and Yarragadee aquifers located in northern Perth, east to Ellen Brook, south to the Swan River, west to the Indian Ocean and north to Gingin Brook

➤ Broad-scale risk maps have been compiled by DEC for several coastal regions of WA where a high or moderate probability of ASS occurrence has been identified. This risk mapping of acid sulfate soils is available via the DEC website: www.dec.wa.gov.au/management-and-protection/land/acid-sulfate-soils/ass-risk-maps.html

Triggers

Exposure of PASS to air occurs when the soils undergo drying or are disturbed.

Factors that can contribute to wetlands drying out include:

- less surface and/or groundwater entering the wetland, due to reduced rainfall, associated with climate change, such that the wetland has shorter periods of inundation and waterlogging and longer periods of drying out than normal, on a much more frequent basis
- lowering of the groundwater table due to over-extraction of groundwater (for example, bore water for irrigation)
- lowering of the groundwater table due to dewatering (for example, draining wetlands for urban development)
- lowering of the groundwater table as a result of deep drainage
- less surface water/lowering of the groundwater due to interception of rainfall by plantations
- compaction of soils, reducing their water-holding capacity.

Activities that disturb PASS include:

- earthworks such as excavating in or around wetlands
- digging drainage channels to manage waterlogging and salinity in agricultural areas
- fire, particularly the burning of peat, which may release significant amounts of stored acidity[126] and which can act as a source of acidification for extended periods of time because it can smoulder for months
- livestock and feral animals (for example, pigs and camels)
- vehicle access
- digging holes (for example, when planting)

Acidification of groundwater systems

The acidification of shallow groundwater that naturally interacts with wetlands has been identified in WA in recent years. An investigation found that groundwater acidification near the water table has occurred on a regional scale in Bassendean Sand in the **Gnangara groundwater system** due to oxidation of iron sulfide minerals.[124] This oxidation process has been triggered by a decline in the groundwater level, exposing iron sulfide minerals to oxygen. The investigation also identified associated impacts including elevated dissolved aluminium levels on a regional scale. This regional scale acidification affects the quality of groundwater for ecosystems and groundwater users. It presents a risk to the ecological value of wetlands on the Gnangara Mound.[102,119,120] For example, elevated levels of dissolved aluminium are flowing towards high conservation value wetlands including Lake Jandabup, Lake Mariginiup, Lake Gnangara, the Lexia wetlands and Egerton Seepage.[124]

A review indicated that acidification was also common on the crest of the Jandakot Mound[145] (located south of the Swan River). The risk to groundwater quality on the Gnangara and Jandakot mounds in Perth and surrounds due to iron sulfide minerals oxidation is predicted to increase, with researchers concluding that "As the depth to the water table increases due to water extraction, evapotranspiration by deep rooted vegetation (e.g. pine trees), development, dewatering and climate change we can anticipate drying of aquic soil profiles with a consequent release of acidity, consequently the above issues should represent priority areas for future research".[146] Wetland managers in areas of risk, such as the Bassendean Sand formation and similarly poorly buffered (non-calcareous) aquifers, can use well designed groundwater monitoring to inform management. Expert advice is typically needed to establish well designed monitoring programs in order to obtain consistent hydrogeochemical monitoring data from groundwater in the capture zones of wetlands.

Impacts of acidification

Acidic waters are generally considered to very similar regardless of whether they are generated via acidic groundwater, acid mine drainage or actual acid sulfate soils, with the exception that acidified waters in the Wheatbelt are also saline. Furthermore, naturally acidic wetlands and acid tolerant biota can suffer harm due to human-induced acidification.[147]

Wetland acidification affects wetland organisms both directly and indirectly. In addition to increased acidity, the key impacts of acidification are deoxygenation, the release of metals and metalloids and increased turbidity and smothering. Changes in bioavailability of nutrients can also occur. Each of these processes can have serious detrimental effects on organisms, and can be compounded when more than one occurs. The overall effect on wetlands is typically to alter their ecological characteristics and to reduce their biological diversity. Fish, crustaceans and molluscs are typically particularly sensitive to the direct and indirect effects of acidification. Changes in pH can also accelerate or retard the degradation of pesticides in wetlands.[14]

The rate and effects of acidification are dependent upon many factors, including the

- acidity generated
- amount of available buffering or acid neutralising capacity within the environment
- duration of acid generation/flows
- regularity of acid production/acid flows
- other factors, such as secondary salinity.

Cycles of decline and recovery in wetland macroinvertebrates have been documented. Sommer and Horwitz[148] documented cycles over 12 years of monitoring in three Gnangara Mound wetlands affected by drought-induced acidification. Acidification did not result in a reduction of the total number of macroinvertebrate families present, however, there were clearly identifiable groups of acid-sensitive taxa and acid-tolerant taxa. The effects of acidification were reversed in the wetland in the study that was artificially supplemented with water, with acid-sensitive taxa reappearing and acid-tolerant taxa decreasing in numbers.

extra information

Studies which consider the effects of acidification on wetland organisms in WA include:

- *The potential effects of groundwater disposal on the biota of wetlands in the Wheatbelt, Western Australia*[118]
- *Aquatic invertebrate assemblages of wetlands and rivers in the Wheatbelt region of Western Australia*[149]
- *Vulnerability of organic acid tolerant wetland biota to the effects of inorganic acidification*[147]
- *Macroinvertebrate cycles of decline and recovery in Swan Coastal Plain (Western Australia) wetlands affected by drought-induced acidification*[148]
- *Diatoms and invertebrates as indicators of pH in wetlands of the south-west of Western Australia.*[150]
- *Diatom and micro-invertebrate communities and environmental determinants in the Western Australian Wheatbelt: a response to salinization*.[151]

Impairment and death due to acidification

Although it can be difficult to separate out the effects of acidity from associated effects including deoxygenation, the release of metals and metalloids and increased turbidity and smothering, acidity of itself can have serious effects upon organisms. Acidity directly affects organisms by affecting the function of cells – specifically, the functions of enzymes and membranes.

Some wetlands are naturally acidic, and these wetlands support species that are tolerant of this acidity, and in some cases, may support acid-specialised species ('acidophiles' such as the brine shrimp *Parartemia contracta*, and the ostracods *Reticypris* sp. and *Diacypris* sp., which appear to be restricted to acidic conditions of pH lower than 5).[118] However the acidification of other wetlands can significantly alter the natural processes in their soils and waters, and affect wetland plants, animals, fungi, algae and bacteria; resulting in the loss of acid-sensitive species (commonly affected species include amphipods and isopods, ostracods, chydorid and daphnid cladocerans, mayflies, oligochaetes, clams and snails), favouring acid-tolerant species (for example, sandfly larvae, macrothricid cladocerans and water boatmen) and reducing biodiversity in wetlands.

Acidification can lead to impaired function, growth and reproduction, disease and death in some groups of wetland organisms. Some invertebrate groups are particularly sensitive to acidic conditions because appendages such as gills (filter-feeders) or calcareous shells tend to be acid-sensitive. Studies have found that crustacean abundance and richness are markedly reduced in acidic conditions due to their calcium needs and as acidic conditions can soften outer calcareous shells. Groups like mayflies and caddisflies, which have more porous bodies and larger membranous surfaces such as gills, also tend to be sensitive. Groups with a lower permeability to water and ions such as beetles are more resistant. Mosquitoes can actually become more prevalent in acidic waters[152] and may lead to an increasing prevalence of acid-tolerant mosquitoes which can carry diseases like Dengue fever and Ross River virus.[140]

Susceptibility of an organism can also depend on which stage of their life-cycle they are at when exposed. For example, acidification of sediments can affect the survival of organisms inhabiting sediment during resting stages.

At the wetland scale, impairment of wetland vegetation and algae can reduce the primary productivity of wetlands, with flow-on effects through trophic levels (herbivores, carnivores and decomposers). Low pH/low buffer capacity can provide poor environmental conditions for microbial growth[153] with most microbes growing within the pH range 4–9[154] and inhibit decomposition processes[42], resulting in less organic matter being cycled back into a form that can be used by plants and animals, ultimately limiting productivity. Death of wetland shrubs and trees can significantly reduce the shading of wetland waters, which can cause additional changes in the wetland, due to increased water/sediment temperature and greater amounts of light penetrating the water column.

Bioaccumulate: process in which tissues of an organism accumulate a chemical because uptake is greater than elimination and breakdown

Biomagnify: an increase in the concentration of a chemical along a food chain

Flocculation: the joining of particles (small objects) into loose masses (floc) in water

Impairment and death due to deoxygenation (loss of oxygen)

Individual wetlands differ in their capacity to buffer against natural changes in pH, particularly in their capacity to neutralise acid. This means that the severity of acidification will depend on the characteristics of each wetland. However, even in those wetlands in which the acid released during an acidification event is neutralised, the oxidation of these soils can consume oxygen, removing the oxygen from the water column. When this happens, organisms in the water column that rely on dissolved oxygen can perish if oxygen concentrations drop too much. Acidic drain waters in the Wheatbelt have also been found to often be poorly oxygenated, and these can lower the oxygen concentration in wetlands they discharge into.[121]

➤ For more information, see the information on oxygen in the topic ‘Conditions in wetland waters’ in Chapter 2.

Impairment and death due to the release of metals and metalloids

Acidification can trigger the release of toxic quantities of metals and metalloids from sediments, such as aluminium, iron, lead, copper, zinc, nickel, uranium, rare earth elements (lanthanum, cerium), cadmium, arsenic and selenium. For example, the solubility of aluminium is significantly increased when pH is less than 4.5. Iron from acid sulfate soils is known to stimulate harmful *Lyngbya* blooms. These metals are present naturally, but in many cases they may be present at elevated levels due to pollution.

These metals and metalloids are released from bound forms into dissolved forms, which are far more toxic to organisms. These metals can have toxic effects on plants, algae, animals, fungi and bacteria, leading to disease and death. Greatly reduced abundance and diversity of some types of organisms, such as macroinvertebrates, may occur. Metals such as cadmium and metalloids such as arsenic and selenium have the potential to be **bioaccumulated** in organisms and **biomagnified** in wetland food chains and cause effects such as genetic damage. Under these conditions, monitoring of organisms may detect declines in species richness, abundance and productivity. It is important to note that some metals and metalloids are as soluble in very alkaline conditions as under acidic conditions.[119] The community structure of wetlands can alter as a result, including the physical structure created by plant communities.

Acidified areas that have above background concentrations of contaminants in soils, sediments and/or waters, and which present or have the potential to present a risk to human health or the environment, may be classified as contaminated sites under the provisions of the *Contaminated Sites Act 2003*.[119]

➤ For more information, see the ‘Managing metals’ section in this topic.

Impairment and death due to turbidity associated with metal flocculation

Acidification can promote **flocculation** in the water column, and the resulting floc can coat the gills of fish, smother plants and benthic organisms and modify habitat, resulting in simplified ecosystems and a loss of biodiversity. For example, iron sludges and precipitates can smother organisms, and sludges are readily resuspended into the water column, repeatedly directly affecting organisms in the water column.

➤ For more information, see the 'Managing turbidity' section in this topic.

Changes in nutrient availability

In wetland soils, acidity can alter the availability of nutrients such as phosphorus, nitrogen, magnesium and calcium. For example:

- Calcium availability tends to be limited in acidic conditions.[155]
- Ammonium (NH_4^+), a form of nitrogen that is used by plants, algae and bacteria, may reach high levels under acidic conditions. Acidic conditions can inhibit nitrification, the process by which ammonium is converted to nitrate (NO_3^-). While both forms of nitrogen are available for plants, algae and bacteria, nitrate is much more easily lost from wetlands via groundwater flow and by the coupled process of denitrification, whereas ammonium is retained in wetlands. Nitrification rates are generally thought to drop steeply below a pH of 4.5.[154]
- Under acidic to neutral and oxygenated conditions, phosphate, a form of phosphorus that is used by plants, algae and bacteria, adsorbs or precipitates to iron and aluminium, particularly in freshwater wetlands. This reduces the availability of phosphorus for primary production. This is thought to be the case at Spoonbill Lake, an acidified wetland in the suburb of Stirling, which is reported to have become ultra-oligotrophic (that is, have very low nutrient levels), and as having a lack of wildlife.[156] However, under acid and anoxic conditions, phosphate can be released into the soil pore water if sulfur is present. This is because the sulfur facilitates the reduction of iron to form FeS.
- Very acidic conditions are not optimal for microbes, with most microbes growing within the pH range 4–9.[154] Decomposition processes are inhibited in poorly buffered waters[42], resulting in less organic matter being cycled back into a form that can be used by plants and animals, ultimately limiting productivity.

The alterations to nutrients compound the direct effects that wetland acidification causes.

➤ For more information on the relationships between nutrient availability and acidity, see the 'Conditions in wetland waters' topic in Chapter 2.

Increased salinity

Acidification typically increases the salinity of water, due to the release of sulfate salts. However, the increases may not be large in some freshwater wetlands.

Indicators of acidity

Indicators of PASS

There are often few visual indications of PASS being present. PASS are widespread in freshwater wetlands and coastal landscapes. They are common in wetlands with dark organic soils and muds, peaty sediments, pale grey sands and coffee rock (cemented iron and/or organic rich sands). DEC has mapped high risk areas for several coastal regions of WA. These provide a broad-scale indication of the area where PASS are most likely to exist in shallow soils (within 3 metres of the ground surface). No distinction is made in the risk maps between whether actual and potential ASS might occur.

➤ Maps showing areas that are at high risk of potential acid sulfate soils are available from the ASS webpages of the DEC website: www.der.wa.gov.au/your-environment/acid-sulfate-soils.

Net acidity: the degree of acidity in water, accounting for dissolved alkalinity (that is, acidity minus alkalinity, measured in units of CaCO3 equivalent per litre)

Identifying the presence of PASS

Confirming that PASS or AASS are present in a wetland can cost thousands of dollars. The Australian Government has adapted a two-stage approach for determining their presence or absence, described in the document, *National guidance for the management of acid sulfate soils in inland aquatic ecosystems*.[131] It entails a rapid assessment, and where this indicates a high likelihood of ASS, it is confirmed by carrying out a detailed assessment.

The rapid assessment uses data sourced from the desktop and a site visit. Desktop data includes:

- water and sediment quality data
- flooding history
- source of water

The site visit requires the collection of data quantifying:

- pH, and where practicable, field measurements of acidity and alkalinity
- conductivity
- sulfate

The purpose of the detailed assessment is to determine the wetland's **net acidity**. In simple terms net acidity can be summarised as acidity minus alkalinity. The below equation is used to calculate net acidity:

> Net acidity = potential sulfidic acidity + actual acidity + retained acidity – acid neutralising capacity

Net acidity accounts for the fact that some water has acidity (due to dissolved metals) and alkalinity (mostly as bicarbonate) at the same time (for reasons, see section 3.2 of Degens, 2009[121]).

Obviously, these investigations are highly technical and it is advisable that they are designed by an appropriately qualified practitioner with ASS experience. For more information, refer to the *National guidance for the management of acid sulfate soils in inland aquatic ecosystems*.[131]

Indicators of acidity (including AASS)

Soil and water characteristics can indicate that acidic conditions are having an effect upon the environment. A brief outline is provided below. Field tests and laboratory analysis provide diagnostic tools. For more information see:

- *Identification and investigation of acid sulfate soils and acidic landscapes*[143]
- Known sites of AASS recorded in the *Contaminated Sites Database*, available from https://secure.dec.wa.gov.au/idelve/css/.

Biological indicators

Visual indicators that a wetland may be acidifying include:

- plants in poor health, stunted or that are dead/dying
- the disappearance of wetland vegetation and the appearance of clear 'beaches' around the water's edge

- decreasing diversity of macroinvertebrates and increasing abundance of acid-tolerant fauna such as water boatmen (*Notonecta glauca*) and mosquito larvae
- an increasing abundance of filamentous algae (algae with long strands visible)

Soil indicators

Soil indicators of acidity including the presence of jarosite, iron staining, iron monosulfides, salt crusts and scalds.

- Jarosite is a good indicator of actual acid sulfate soils as it only forms under acid conditions. AASS are often recognised by the presence of 'flecks' of jarosite in soil profiles, which appears as either a butter-coloured (Figure 31) or mottled orange coloured mineral.

Figure 31. Jarosite is a butter or mottled orange coloured mineral that is a good indicator of actual acid sulfate soils as it only forms under acidic conditions.

- Increased iron staining can form around the water margins in summer months in response to acidification.
- Iron monosulfides are gooey black sediments formed in low oxygen environments. They can form in wetlands and drains. Beneath the water surface, they remain black and gooey. However, if the water is removed, the soil surface turns a bright orangey-red colour as the iron monosulfides are exposed to the air. Iron monosulfides should not be confused with iron floc (particles).
- Salt crusts on the soil surface can be a by-product of AASS and may indicate the need for further investigation. In inland areas, salt crusts are often found where groundwater tables are close to the surface (Figure 32).

Figure 32. White, fluffy salts accumulating on soil surfaces during summer may indicate acid salts: a combination of iron, aluminium, calcium and magnesium based salts. Photo B Degens/Department of Water.

- Spongy sediments, when excavated. They often resemble lava flow.
- Bare areas of land within or around wetlands may be either an acidic or saline 'scald'. Scalds occur when plants die and only bare soil remains (Figure 33). Once bare, the soil water evaporation is accelerated, drawing water containing toxic oxidation products from soil layers beneath the surface. The bare surface layers of the scald accumulate acidity and salinity during dry periods, due to increased soil water evaporation. During wet conditions, the concentrated pollutants can be washed into adjacent areas. Once bare, conditions that produce the scald can quickly develop further and revegetation can be difficult. Scalds can vary in size and are not always permanent features. During wet years, additional water in the soil may encourage salt and acid tolerant vegetation (including some weed species) to grow and the scald may disappear for a short time.

Figure 33. AASS scalding with salt crusting in a seasonally inundated wetland, Ravenswood. Photo – B Degens/Department of Water.

Surface water indicators

Indicators that groundwater is acidifying due to the oxidation of sulfides include:

- a sulfate/chloride (in milligrams per litre) ratio greater than 0.5 in estuarine environments
- an alkalinity/chloride (in milligrams per litre) ratio of less than 5 in freshwater environments
- a pH of less than 5
- a soluble aluminium concentration greater than 1 milligram per litre.[129]

Indicators that a wetland it is acidifying due to the oxidation of sulfides include:

- sudden decreases in pH, generally during summer months (in the south-west). During the early stages of acidification, pH values may moderate during winter[119]
- large diurnal (that is, between day and night) fluctuations in pH, with changes of up to 2 pH units occurring within a 24 hour period[119]
- decreasing alkalinity values[119]
- increasing values of the sulfate/chloride ratio[119]
- increasing concentrations of soluble iron and aluminium[119]

Visually, clear water, and water stained yellow, brown, orange, milky-white or blue-green can be a sign that acidification has occurred. Oily-looking bacterial scums may also be present.

- Milky-white water at pH of 5 to 6 can indicate aluminium particles due to reactions associated with AASS.
- Blue-green water with a pH of 4 to 5 is caused by aluminium floc (fine colloidal particles).
- Clear water isn't necessarily good water. Crystal clear water can indicate a pH level of 3 to 4. High levels of aluminium can cause the soil and sediment particles to drop to the bottom of the wetland, leaving the water clear (Figure 34).

Figure 34. Crystal clear acidic water (pH 3.5) with iron bacteria in a wetland near Mandurah. Photo – B Degens/Department of Water.

- Iron flocs (particles) can appear in the water at pH levels below 4. These flocs are usually coloured a red-brown or brown-yellow and will be present throughout the water (Figure 35). If water recedes, this floc is deposited on the vegetation and soil.

Figure 35. Iron floc in a seasonally inundated wetland, Jarrahwood. Photo – B Degens/Department of Water.

- Water affected by AASS can have high levels of dissolved iron, which colours the water yellow, brown or orange (Figure 36). Iron is soluble (dissolved) at pH levels below 3.8.

Figure 36. Yellow-brown water can be an indicator of iron, which is released from sediments under acidic conditions. Photo - A Lillicrap/Department of Food and Agriculture WA.

Other indicators

Acid can corrode concrete and steel (Figure 37). Noxious odours such as rotten egg smells (hydrogen sulfide) and metallic, burnt gunpowder odours (sulfur dioxide) indicate that acidification may possibly be occurring.

Figure 37. Road culverts that have corroded as a result of acidic drainage. Photo – B Degens/ Department of Water.

Preventing acidification

Preventing acidification associated with iron

Reduce the rate of rising acidic groundwater

Arresting the rise of groundwater in the Wheatbelt is a large scale, long-term endeavour. Effective management of rising groundwater relies on coordinated effort and investment across regions and areas of expertise and can be very costly to implement, with long-term time scales for change. Agronomic change, revegetation and protection of remnant vegetation are all part of the solution. As with secondary salinity, it will not be possible to stop the acidification of all wetlands in the Wheatbelt, and prioritisation processes will be important in determining which wetlands are identified for preventative measures.

➤ More information on approaches to arresting the rise of groundwater in the Wheatbelt are outlined in the topic 'Secondary salinity' in Chapter 3.

Design and management of drainage channels

Proposing new drainage

When proposing drainage into a wetland, an important consideration is the ecological and other values of the wetland. The wetlands receiving drainage water can be so adversely affected that they are often called 'sacrificial' wetlands, because their values have been sacrificed in order to save other values in the landscape.

Because of their potential to create serious environmental impacts, proposals to construct drains or pump groundwater in agricultural regions require assessment via the Soil and Land Conservation Regulations 1992 under the *Soil and Land Conservation Act 1945*. The principles for assessing drainage proposals are outlined in the 2012 Department of Water document, *Policy framework for inland drainage*.[12]

➤ More information on the assessment of new drainage proposals is available from:

- the Department of Agriculture and Food website www.agric.wa.gov.au/PC_93235.html
- the topic 'Legislation and policy' in Chapter 5.

A broadscale assessment of the value of many of the Wheatbelt's wetlands has been conducted by DEC. A methodology for assessing individual wetlands at a finer scale, as is needed to help determine its suitability as a sacrificial wetland, has been developed and published by DEC, for proponents to use in preparing an application to decision making authorities.

➤ For more information on the existing evaluation of Wheatbelt wetlands, and the detailed evaluation methodology for the region's wetlands, see the Wheatbelt wetland mapping page on the DEC website: www.dec.wa.gov.au/management-and-protection/wetlands/wetlands-mapping/wetlands-of-the-wheatbelt-mapping.html.

Treating existing drainage

Treating acidic water of drainage channels prior to discharge into wetlands is an important intervention measure. The Department of Water has developed guidelines for treating acidic drain waters for the Avon catchment, based on trials.[157] These guidelines outline in-drain treatment options, including lime-sand beds, subsoil carbonate beds, in-drain composting beds and diversion wells. The guidelines also discuss end-of-drain treatment options including lime-sand basins, composting 'wetlands' (that is, purpose-built structures), lime-sand reactors and hydrated lime dosing.

The Department of Water has also published a discussion paper[120] on draft proposed interim acidity levels for discharge into Wheatbelt ecosystems, as outlined in Table 17.

Table 17. Draft proposed interim net acidity guideline for discharges into primary and secondary saline ecosystems in the Wheatbelt (DOW 2013[120])

Water quality parameter	Discharge to slightly disturbed ecosystems	Discharge to highly disturbed ecosystems
Net acidity	10 milligrams of calcium carbonate ($CaCo_3$) per litre, provided that the water has had time to react with air, to allow any metals to precipitate and settle as sludge prior to discharge	20 milligrams of calcium carbonate ($CaCo_3$) per litre

Preventing actual acid sulfate soils

Prevent oxidation of potential acid sulfate soils

PASS are benign when left in a waterlogged, undisturbed environment. Where PASS are present, disturbance and drying of the soil should be avoided. To minimise disturbance and drying, the Government of WA has put in place controls on the development of land, drainage alterations and water abstraction, as outlined below.

Controls on the development of land

Land development is subject to many controls to minimise the development of actual acid sulfate soils. These controls are outlined in the following documents:

- *Planning Bulletin 64/2009: Acid sulfate soils*[158], which provides advice and guidance on matters that should be taken into account in the rezoning, subdivision and development of land that contains acid sulfate soils. This planning bulletin introduces a set of revised acid sulfate soils planning guidelines.
- *Acid sulfate soils planning guidelines*[159], which outline the range of matters that need to be addressed at various stages of the planning process to ensure that the subdivision and development of land containing acid sulfate soils is planned and

managed to avoid potential adverse impacts on the natural and built environment.

Drainage associated with urban development needs to be approved via the appropriate land use planning legislation, and typically needs to be consistent with approved water management plans for the area. For more information, see the policy *Better Urban Water Management*.[160]

Controls on dewatering

Dewatering is regulated via groundwater abstraction licences from the Department of Water, except if an exemption applies. If a hydrological impact assessment shows that impacts are likely, dewatering management plans may be required as a condition of licence. The Department of Water must inform the Environmental Protection Authority if a water licence being sought under the *Rights in Water and Irrigation Act 1914* would have a significant effect on the environment. As outlined in the Department of Water's *Western Australian water in mining guideline*[161] and the *Strategic policy 2.09: Use of mine water surplus*[162], water generated by mining dewatering operations must first be used for the mitigation of environmental impacts. This involves ensuring that water is returned to the environment, through injection back into the aquifer or augmenting reduced environmental flows of groundwater-dependent wetlands. This is usually enforced via conditions of the licence.

➤ *Dewatering of soils at construction sites*[163] outlines how the Department of Water assesses impacts of dewatering associated with construction.

DEC also has requirements for proposed dewatering in proximity to wetlands. The document *Treatment and management of soils and water in acid sulfate soil landscapes*[119] (section 5.3.9) states that dewatering must not alter the wetland water level or water quality of valuable wetlands (such as conservation and resource enhancement management category wetlands). Proposals to dewater within 500 metres of a valuable wetland must implement a range of management measures to protect the wetland. These include:

- baseline laboratory analysis of wetland water quality data, capturing seasonal variation
- baseline water level monitoring
- water level and water quality monitoring during dewatering
- a range of monitoring, mitigation and remediation measures in the event of changes in water quality or water level.

There are alternatives to dewatering near wetlands. Driven pile construction, sheet piling and slurry walls can avert the need for dewatering associated with various types of construction. Trenchless technologies for installing or repairing underground cables and pipelines, such as microtunnelling, avoid the need for open trenching or dewatering.

➤ The Australasian Society for Trenchless Technology website (www.astt.com.au) is a source of information on potential alternatives to trenching and dewatering.

Dewatering techniques differ in their potential to affect nearby wetlands. For example, an array of dewatering well-points or spears connected to a common suction pump or vacuum extraction system is a technique that can have a larger radius of influence than sumps with submersible pumps at their base.[119]

Carrying out works when the watertable is lowest in summer can reduce the depth and/or size of the dewatering footprint and rates. Using groundwater recharge trenches to constrain the lateral extent of the cone of depression by creating a hydraulic barrier between the wetland and the cone of depression is another important technique. Examples of this can be found in the Pilbara.[164]

Controls on rural and semi-rural drainage alterations

To minimise the development of acid sulfate soils, rural and semi-rural drainage alterations are governed by the following controls:

- Proposals to construct drain or pump groundwater in agricultural regions require assessment via the Soil and Land Conservation Regulations 1992 under the *Soil and Land Conservation Act 1945*. The principles for assessing drainage proposals are outlined in the 2012 Department of Water document, *Policy framework for inland drainage*.[12]

Controls on water abstraction

Under the *Rights in Water and Irrigation Act 1914* the Department of Water requires applications for a licence to take groundwater to state whether acid sulfate soils been identified at the site, and when present, require an acid sulfate soils management plan to be submitted to the Department of Environment and Conservation.

Controls on activities that disturb wetland sediments

Activities that disturb wetlands are subject to approval under the *Planning and Development Act 2005* and the *Environmental Protection Act 1986*. These include activities such as:

- installing infrastructure, for example, boardwalks, drainage swales and so on
- burning of wetlands
- clearing of wetland vegetation and wetland buffer vegetation, including forms of clearing such as cattle grazing

Reduce the risk and extent of secondary salinity

The discharge of salts, including sulfate, to wetlands increases the potential for the formation of PASS. Therefore reducing the mobilisation of salts in the landscape is key. In agricultural areas, this can be achieved by preventing regional groundwater tables from rising above normal levels, and avoiding discharge of deep drainage into wetlands. Both of these management options tend to require regional-scale works and involve many land managers in the broader community. Arresting the rise of groundwater in the Wheatbelt and other agricultural areas is typically a large scale, long-term endeavour. Effective management of rising groundwater relies on coordinated effort and investment across regions and areas of expertise and can be very costly to implement, with long-term time scales for change. Agronomic change, revegetation and protection of remnant vegetation are all part of the solution. As with secondary salinity, it will not be possible to stop the acidification of all wetlands in the Wheatbelt, and prioritisation processes will be important in determining which wetlands are identified for preventative measures.

➤ For information on the management of secondary salinity, please refer to the topic ‘Secondary salinity’ in Chapter 3.

Maintain natural seasonal drying regime

Wetlands that are naturally wet on a seasonal basis and dry out in the intervening period limit the excessive accumulation of sulfide in sediments. This is because oxygen is used in preference to sulfate by bacteria, minimising the reduction of sulfate to sulfides. Maintaining this natural wetting and drying regime is therefore a cost-effective preventative measure.

extra information

Proactive monitoring by wetland managers

A number of the measures for preventing wetland acidification require decision-making authorities to control land or water use. However, some acidification triggers are not within the scope of these frameworks, for example, drying of wetlands caused by climate change. Wetland managers can play an essential role by identifying valuable wetlands that are at risk of acidification, monitoring them and providing an early warning of possible changes.

Wetland managers should advise DEC if there are signs of acidification or if triggers of acidification are likely (for example, a wetland is progressively holding less water each summer).

Where it is not possible for land managers with numerous wetlands under their management to continually monitor all the wetlands under their management, a prioritisation process for monitoring at-risk wetlands is a strategic way to manage the risk. Such a prioritisation process should take into account risk of acidification and the conservation value of wetlands (for guidance on the conservation value of wetlands, the wetland management category can be used, if available, or if not, guidance can be provided by DEC). To identify a wetland's risk of acidification, two factors should be determined: present and/or future triggers for acidification, as outlined in this topic, and the sensitivity of the wetland to acid generating processes. Table 18 shows a possible prioritisation matrix.

Table 18. Framework for prioritising wetland monitoring

Matrix 1: wetland acidification risk assessment framework

Acidification sensitivity (as per Table 16)	**Potential for drying, disturbance or receiving acid drainage (acidification triggers)**		
	Low potential	**Medium potential**	**High potential**
Not sensitive	Low risk	Low risk	Medium risk
Sensitive	Low risk	Medium-high risk	High risk
Acidified, critical, endangered or highly sensitive	Medium-high risk	High risk	High risk

Matrix 2: wetland monitoring priority framework

Wetland conservation significance	**Risk of acidification determined using matrix 1**		
	Low risk	**Medium risk**	**High risk**
Low (e.g. multiple use management category)	Lowest priority	Lowest priority	High priority
High (e.g. resource enhancement management category)	Lowest priority	High priority	Very high priority
Very high (e.g. conservation management category)	High priority	Very high priority	Very high priority

Treating acidification

Involve experts when dealing with acidification

Managing acidification can be a serious and complex issue. Inappropriate management actions can result in serious environmental harm, with economic and legal implications. Specialists should always be consulted.

Acidification often involves a complex series of chemical reactions which are influenced by the local geochemical conditions. Management of AASS requires a site-specific strategy developed using the findings of a detailed investigation that should only be conducted by practitioners experienced in this field. Once field investigation and testing has been completed, appropriate management actions can be developed. Options that can be considered as part of this planning process are described below.

➤ Key resources include:

- The acid sulfate soils webpage of DEC's website: www.dec.wa.gov.au/pollution-prevention/contaminated-sites/acid-sulfate-soils.html
- *Treatment and management of soils and water in acid sulphate soil landscapes*[119]
- *National guidance for the management of acid sulfate soils in inland aquatic ecosystems*[131]

Despite good intentions, because of the potential to cause environmental harm, a proposal to implement some of the options listed below may trigger referral to the Environmental Protection Authority for assessment under Part IV of the *Environmental Protection Act 1986*.

➤ For information on legislation and policy protecting WA's wetlands, see the topic 'Legislation and policy' in Chapter 5.

The management techniques described below may help to address the chemical, physical and biological changes that have occurred due to acidification, but success is not guaranteed. Trial and error is still common in this area, as highlighted in the below case study. Further trials at sites as well as laboratory studies are likely to provide more insight in future.

case study

Case study – treating the acidification of Spoonbill Lakes, Stirling

Spoonbill Lakes, two seasonally inundated basins in the Perth suburb of Stirling, have undergone acidification due to acid sulfide soils, and widespread acidification of the surrounding groundwater table has occurred. A number of factors contributed to the acidification of groundwater in the area, including a decline in the groundwater table due to low rainfall, the disturbance of sulfidic peat soils through dewatering and excavation for two new residential developments, and excavation of Spoonbill Lakes, with spoil used to create central islands. Groundwater pH measurements as low as 1.9 have been recorded, while the pH of the Spoonbill Lakes has been as low as 2.4.[128] A distinct plume of acidic groundwater stretches many hundreds of metres to the south, affecting domestic bores, and generally extends 5–10 metres below the watertable.[128]

A treatment trial has been carried out at Spoonbill Lakes by researchers at Edith Cowan University in partnership with the City of Stirling. The wetlands have low conservation value, having been seriously degraded by clearing, earthworks, alterations to their water regime and water quality. As a result, they have been identified as a 'multiple use' management category wetland by DEC (in the *Geomorphic Wetlands Swan Coastal Plain* dataset). For this reason, an *in situ* treatment trial was carried out by researchers.

The trial employed a number of techniques in a 'treatment train' sequence. These included neutralisation with sodium hydroxide, followed by settling and removal of iron and aluminium hydroxide sludge. This was followed by treatment using organic matter in two bioreactor tanks, using 10 tons of potatoes and *Eucalyptus* mulch. Following aeration down a concrete riffle, the water was directed through 1 ton of potatoes and mulch on the wetland bank, and 2500 rushes (*Schoenoplectus validus* and *Baumea articulata)* for aerobic polishing. The assessment of the treatment indicates that so far, some aspects of the water quality have improved, but that there have been a number of problematic outcomes that were not anticipated, and that to date the treatment has not improved water quality or increased biodiversity. Some aspects of the treatment are expected to become more important over time, while redesign of other parts of the treatment process have been identified in order to optimise the treatment processes.[165,156]

Neutralisation using chemical additives

Neutralising the acid produced may be a potential option at some wetlands. Some waterways in eastern Australia have been treated with chemicals with a high neutralising capacity. These chemicals are either applied to the water or the sediment to increase the pH buffering capacity. A range of chemicals have been tested, including calcium carbonate, calcium oxide, calcium hydroxide, lime kiln dust, magnesium oxide, sodium carbonate, seawater neutralised red mud, fly ash and biochar. These chemical ameliorants, and their advantages and disadvantages, are discussed in the *National guidance for the management of acid sulfate soils in inland aquatic ecosystems*[131] and *Treatment and management of soils and water in acid sulfate soil landscapes*.[119] Before investing is neutralisation programs, consideration needs to be given to the potential for future acid generation to occur and whether these causes can be addressed, and if not, whether neutralisation can be maintained.

Neutralisation may be a temporary treatment rather than a long-term solution. For example, despite being treated with 5 tonnes of calcium hydroxide, the pH of Spoonbill Lakes had returned to the pre-treatment level after not more than 1 month.[119] At this site, groundwater flow is continuing to transport acidity into the wetlands. Groundwater flow may continue to transport acidity into wetlands for many decades.[119]

It is necessary to consider the potential unanticipated effects of additives. For example, some neutralising agents can increase salinity, particularly those containing sodium (chemical symbol 'Na'). It is also necessary to consider aspects of water quality that can be modified during treatment. These include changes in nutrient concentrations, increases in salinity and changes in ionic composition. Contact of acidified water with a neutralising agent will cause precipitation of metals from solution, and consideration needs to be given to how issues such as flocculation will be managed. The potential to use materials to remove metals and attenuate acidity is likely to continue developing as research continues (for example, Wendling et al 2010[166]).

Neutralisation using chemical additives needs to be carefully planned. Proposals to apply neutralising agents need to be approved by the land owner and relevant authorities, including the relevant state government agencies. In the case of wetlands, this includes DEC. Technical expertise is needed to quantify the acidity in a wetland and determine the appropriate neutralisation agent, effective neutralisation value, application method, rate, volume and purity/contaminants in additives. It is possible to 'overshoot' and create highly alkaline conditions, which can also be extremely harmful to wetland organisms. Similarly, in severely acidified waters, elevation of pH to the acidity at which aluminium is most toxic—between 4.4 and 5.4—should be avoided.

The origin and potential other inadvertent effects of neutralisation materials also warrants attention. Reliance on natural materials that result in degradation of other natural environments is not sustainable (for example, quarrying of limestone from intact ecosystems). Additionally proposals to use alkaline waste materials need to rigorously demonstrate that they do not pose a risk to human health or the environment.

Neutralisation using organic matter (via microbially-driven increases in alkalinity)

Neutralising the acid produced in a wetland by generating alkalinity in a wetland is a potential option, although there are a number of issues to consider before proceeding. In essence, the addition of carbon sources in the form of plant material enables microbial respiration. This in turn reduces the oxygen levels in the wetland, leading to microbially-mediated sulfate and iron reduction, which initially creates a drop in pH, but ultimately produces alkalinity (that is, sulfate reducing bacteria use sulfate instead of oxygen for respiration, producing bicarbonate as a by-product). Carbon is typically added in the form of wetland plants or mulch of plant material. One of the risks posed by this option is that sulfate reduction produces sulfide – the material that caused the problem in the first place! This option needs to be carefully considered and is generally perceived as a stop-gap measure while longer term measures are being investigated. Microbially-driven neutralisation was employed as part of the treatment of Lake Mealup, as described in the case study below. The *National guidance for the management of acid sulfate soils in inland aquatic ecosystems*[131] outlines the principles of this treatment option, while section 7.3.1 of the *Treatment and management of soils and water in acid sulfate soil landscapes*[119] describes passive treatment systems that employ these principles. Locations where this form of treatment, driven by biological reactions, occurs are sometimes referred to 'bioreactors'.

case study

Case study – treating the acidification of Lake Mealup, West Pinjarra

Declining water levels in Lake Mealup culminated in the annual drying of the wetland each year from 1994 until 2012. This is thought to be due to a combination of reduced rainfall and a reduction in surface water flowing into the wetland, due to the closure of a shallow channel that had previously connected the wetland to the Water Corporation's Mealup Main Drain. Signs of drying and acidification were abundant: the pH dropped from 7 to below 3, algal blooms were common, waterbirds were less common and the invasive introduced bulrush *Typha orientalis* expanded to cover 80 per cent of the wetland. The Lake Mealup Preservation Society worked to secure the involvement and collaboration of many people and organisations in order to halt Lake Mealup's ecological decline. Studies confirmed the presence of actual acid sulfate soils. Approvals and funding were sought and provided to divert drainage flows from the Mealup Main Drain into Lake Mealup by way of a variable height weir on the drain. 43 hectares of *Typha orientalis* was flattened and left in situ to provide a carbon source to promote microbially-driven neutralisation of acid, and control of regrowth was carried out using herbicides. The first diversion of drain water was carried out in June 2012. The pH has stabilised at 7 and the signs of life are reappearing, with frogs and waterbirds evident. A close eye is kept on the wetland's water chemistry, with fortnightly monitoring of pH, oxygen reduction potential and dissolved oxygen. More information on this project is available from the topic 'Roles and responsibilities' in Chapter 5.

Figure 38. The dry sediment in an area of Lake Mealup, showing signs of acidification prior to the diversion of drainage flows into the wetland.
Photo – H Bucktin/DEC.

Figure 39. The crushed introduced bulrush ***Typha orientalis***, left in place to provide a carbon source following inundation. Photo – H Bucktin/DEC.

Figure 40. The adjustable height weir, receiving flows diverted from the Mealup Main Drain.
Photo – H Bucktin/DEC.

Figure 41. Lake Mealup, full in August 2012.
Photo – R Rose.

Reinstatement or artificial replenishment of permanent inundation

Where wetlands have dried out and the exposed acid sulfate soils have oxidised, causing acidification, reinstating permanent inundation or artificial maintenance (replenishment) of water levels can slow down or halt further acidification. By keeping wetland sediments covered with water, acid production can be more effectively managed. This technique has been employed to address acidification of Lake Jandabup, as outlined in the case study below. This technique can however present problems. Maintaining static water levels may alter the ecological integrity of wetland species that are adapted to changing water levels. Furthermore, sourcing the water from groundwater may cause further drawdown of the water table, and exacerbate the problem that led to the wetland drying out in the first place. Groundwater pumping is expensive and may not be suitable for every situation. It also does not address some of the major causes of acidification such as over-use of groundwater supplies and reduced rainfall. It is not a practical or sustainable solution for the vast majority of wetlands in the long term. Diverting surface water may provide a suitable water source for artificial maintenance. It is important that the diversion is not detrimental to receiving environments downstream if they are of equal or higher ecological value than the wetland being treated.

case study

Case study – treating the acidification of Lake Jandabup, Wanneroo

Lake Jandabup, a seasonally inundated wetland 22 kilometres north of Perth, became acidic as a result of increasing extent and duration of summer drawdown of water levels between 1997 and1999. This became apparent from routine monitoring of the water quality conducted by scientists from Edith Cowan University, who noticed that pH readings in surface waters declined from ~6 to 8 to ~4 to 5 over a four year period. Monitoring also indicated that changes in the aquatic macroinvertebrate community structure of the wetland had occurred in this period. Macroinvertebrate species such as small crustaceans, water snails and some types of worms disappeared or declined in number. Increases in acid tolerant species such as sandfly larvae, water boatmen and macrothricid water fleas was also indicated were also observed.

Researchers from Edith Cowan University carried out further research to find out why the wetland had become acidic. It was discovered that due to the prolonged drought conditions over a four year period, wetland sediments had become dry and cracked for longer than they normally would (over summer and autumn periods), leading to oxidation of exposed acid sulfate soils. When the sediments became wet again following subsequent autumn rains, a decline in pH occurred due to the acid released into the water column as a result of oxidation of the sediments.

To reduce the risk of further acidification occurring as a result of excessive drying and oxidation of acid sulfate soils, groundwater has been pumped into the wetland to maintain saturation of wetland sediments. The challenge in artificial maintenance of water levels in Lake Jandabup is that the wetland naturally wets and dries and wetland plants, animals, fungi, algae and bacteria are adapted to seasonal cycles in wetting and drying. As a result, artificial maintenance needed to find a balance between maintaining normal wetland ecological processes as much as possible whilst preventing further oxidation of acid sulfate soils. It was also necessary to consider the amount of groundwater pumped into the wetland, as this action could contribute to excessive drawdown of the water table impacting on other natural areas.

As a result of these management actions, artificial maintenance of water levels in Lake Jandabup has been successful. pH levels have returned to normal and macroinvertebrate species that had disappeared have returned to the lake. However, without other actions being taken, the wetland will revert back to severe drying and acidification if pumping ceases.

Pesticide: any chemical or biological agent intended to kill animals or plants

Revegetating acidified areas

Revegetation of persistent ASS scalds has several benefits. Plants increase the organic matter in the soil; reduce surface evaporation, minimising upward soil-water movement; intercept groundwater, leaving acidic products at depth; and bind up large amounts of soluble iron and aluminium.[167] Revegetating acidified soils involves some approaches not required in standard revegetation. Where ASS scalds persist, digging holes in the soil should be avoided, with planting in windrows consisting of wood mulch or other organic-rich organic material considered to be a suitable alternative. Mulch is considered to be the single most effective treatment[167] as it prevents evaporation, slowing the accumulation of acidity in the root zone; though for optimal results a combination of practices such as fencing, windrows, mulching and neutralisation with a chemical additive may be required. Sedges or other low-water use plants are often more appropriate than trees or shrubs that transpire large volumes of water and in doing so reduce the soil moisture level. These areas should be fenced to exclude cattle and feral animals that may disturb the soil and reduce plant germination, growth and survival.

Managing pesticides

Pesticides include all groups of chemicals used to control undesirable plants and animals, such as insecticides, herbicides and fungicides. They come in various physical forms including liquids/sprays, powders, pellets and baits.

Causes

Pesticides are, at times, deliberately applied directly to wetland areas, for example, for controlling weeds, insects such as midges and mosquitoes, and introduced animals such as exotic fish. Pesticides can also be unintentionally transported into wetlands in a number of ways including:

- careless use or spillage near wetlands, or discarding used containers and drums
- drainage of irrigation water or stormwater following rainfall after pesticide application
- leaching through soil profiles to the water table
- drift of spray to wetlands during application
- accidental application over wetlands during aerial spraying
- erosion and transport of contaminated soil particles and organic matter into wetlands.[168]

Sampling of drains in the Swan and Canning catchments in Perth found that "high concentrations of herbicides in drains that feed the Swan and Canning Rivers commonly appear to be linked to rainfall patterns, as heavy rainfall or overhead irrigation soon after irrigation can wash herbicides from foliage, causing loss with runoff".[23] The sampling also found that occurrences of insecticides in surface waters may be linked closely with heavy rainfall events causing insecticide runoff.

Pesticides are also present in wetlands as a legacy of their historical use. For example, in the 1950s and 60s organochlorines were applied to wetlands to kill midge larvae.[169] With far less regulation in the past, pesticides were often used in very large amounts, with very little management with regard to the natural environment, and a number of the pesticides used are still present wetlands of WA.

Impacts

Pesticide impacts are often considered in terms of toxicity and exposure (concentration and duration of contact). Pesticides can be taken up by wetland organisms through contact with body and respiratory surfaces, by ingestion of water, suspended particles and organic matter or by inhalation of aerosols. Once absorbed into body tissue, they can disrupt function at the cellular level, impair metabolism and result in damage to, or death of the affected organism. Effects of pesticides on wetland organisms and ecosystems as a whole are not well understood, particularly where several pesticides and/or other contaminants may be interacting in combination to produce a chemical 'cocktail'. Furthermore, some chemicals may persist in the soil and water longer than others, which may increase the likelihood of toxic effects in exposed organisms over a longer period. Persistence in the environment depends on the susceptibility of the pesticide to degrading processes such as photodecomposition (due to sunlight), microbial decomposition and chemical degradation.[170]

Some highly toxic pesticides causing **lethal effects** may have low persistence in the environment and conversely, some pesticides with lower toxicity may have a higher persistence in the environment. For example, the group of insecticides known as 'organochlorines' including DDT, dieldrin, aldrin and chlordane are known to persist in the environment for many years and may become 'liberated' from sediments under the right conditions.[168] Although they don't dissolve in water, they dissolve easily in fat, so they can accumulate in fatty tissues in the brain and reproductive organs, for example.[171] DDT was de-registered for agricultural use in Australia in 1987, while the use of chlordane and dieldrin was ceased in Australia in 1994. The importation, manufacture and use of all organochlorine pesticides has been completely banned in Australia since 2004. However, these compounds are still identified in sampling of aquatic ecosystems in WA today. Dieldrin, for example, is known to be particularly persistent in groundwater. **Endocrine** disruption, immune system damage, **carcinogenic**, **mutagenic**[14] and **teratogenic** effects are potential ecological impacts. The degradation products of many of these chemicals are even more toxic than the parent compound. Changes in pH can retard or accelerate the degradation of the chemical. The breakdown rate of the organochlorine pesticide endosulfan, for instance, increases rapidly in acidic waters, and the organophosphorus pesticide profenofos is many orders of magnitude more stable at pH 9 than pH 5.[14] Organophosphates, on the other hand, are thought to be less persistent than organochlorines, but they are water soluble and are far more toxic than organochlorines.[171] All of these factors play a role in the severity and duration of toxic effects on wetland ecosystems.

Known impacts on aquatic organisms from pesticides may range from **acute** to **chronic toxicity**, depending on the concentration of the chemical(s), duration of exposure and individual tolerance limits of exposed organisms. It is likely that the most serious impacts occur as a result of sublethal effects from chronic toxicity, where organisms become less able to tolerate other environmental stresses such as changes in salinity.[31] **Sublethal effects** involving cellular damage can result in impacts ranging from reduced ability of plants and algae to photosynthesise to disruption to fertility, reproduction and growth in animals such as birds, fish and macroinvertebrates. For example, atrazine, which has been found in many of the drains feeding the Swan River[23] is an endocrine disruptor which amongst other effects has been found to induce hermaphroditism in genetically male frogs at levels as low as 0.1 micrograms per litre (as cited by Foulsham et al 2009[23]).

It should be noted that toxicity testing of herbicides often only tests the active compound. Herbicide formulations often contain additional substances such as fillers, wetting agents, solvents or stabilisers. Some of the additives in commercial formulations may have a harmful effect on aquatic life or may modify the toxicity of the herbicide.[172] Glyphosate is an important point in case. It is a broad spectrum, non-selective herbicide. It is the most extensively used herbicide in Australia today. Only some formulations of

Lethal effect: where exposure to an agent such as a toxin results in death

Endocrine system: a complex network of glands and hormones that regulates many of the body's functions, including growth, development and maturation, as well as the way various organs operate

Endocrine disruptor: a synthetic chemical that when absorbed into the body either mimics or blocks hormones and disrupts the body's normal functions

Carcinogenic: cancer-causing

Mutagenic: mutation-causing

Teratogenic: causing malformations of an embryo or foetus

Acute toxicity: sublethal or lethal impacts resulting from a single or multiple exposures to an agent in a short time (usually less than 24 hours)

Chronic toxicity: sublethal or lethal impacts resulting from a single or multiple exposures to an agent over a longer time period (months or years)

Sublethal effect: where exposure to an agent such as a toxin is insufficient to cause death, but may result in other adverse impacts glyphosate are currently approved for use on environmental weeds in or near aquatic ecosystems in WA, in accordance with the off-label permit. This off-label permit, PER13333, has been obtained by the Department of Agriculture and Food from the Australian Pesticides and Veterinary Medicines Authority and is in force until March 2017. The reason why only some glyphosate formulations are permitted for use in or near aquatic ecosystems is that non-target organisms may be harmed. In particular, tadpoles and mature frogs have been found to be extremely sensitive to the **surfactants** (surface active agents, a type of **adjuvant**) used in many glyphosate formulations. They can cause damage to tadpole gills and frog skin, and result in death (e.g. Mann 2000[173]; NRA 1996[174]; DEP 1995[175]). Newer formulations of glyphosate are now available, for example, Roundup Biactive®, which is reported to be one hundred times safer for frogs than the original Roundup® formulation.[176] However people may mistakenly assume that it is safe to combine any adjuvant with a safe formulation. Extreme care needs to be taken to ensure that adjuvants used are permitted for use in or near wetlands.

Surfactant: a substance that helps water or other liquid to spread or penetrate. Also known as a wetting agent or penetrant.

Adjuvant: includes substances such as surfactants, oils, penetrants and wetting agents

Bioaccumulation of pesticides, where pesticides accumulate in organisms over time, may occur in wetlands. This applies to persistent pesticides such as organochlorines, for example, DDT, dieldrin and chlordane. Accumulation can result in consumers that are high in the food chain, such as birds and mammals, suffering toxic effects as a result of eating contaminated fish or crustaceans that have accumulated high levels of chemicals in their tissues.

It is important to remember that wetland organisms can be exposed to pesticides outside of water. For example, reptiles including turtles, frogs, lizards and snakes, and mammals such as quenda can be exposed to pesticides sprayed on wetland vegetation in seasonally waterlogged areas and adjacent dryland areas; and mobile species such as birds can be exposed to pesticides further afield.

Indicators

Visual indicators of pesticide contamination may range from decline in health of individual organisms sensitive to particular toxicants (for example, plant deaths from exposure to herbicides) to mass mortality events (for example, death of fish, frogs, birds etc). Indicators may provide some insight as to whether the contamination is mainly in the form of pesticides that are adsorbed to particles, for example, if filter feeders and detrital feeders are the predominant groups affected (through the ingestion of particles). The time taken for organisms to display visual symptoms of toxic poisoning after initial exposure will vary depending on a range of factors including the nature and concentration of the toxicant(s), sensitivity of individual organism/species and frequency, duration and nature of exposure. External symptoms of toxicity may not be evident and impacts may go unnoticed until longer term effects such as decline in species abundance and diversity becomes apparent due to effects such as decreased fertility and reproduction and increased birth defects.

The presence of pesticides can be more accurately determined through testing of water and sediment or alternatively, testing organisms via tissue samples from affected organisms such as fish, crustaceans and molluscs. Herbicides tend to be more concentrated in surface water, whereas the less soluble insecticides are more likely to be concentrated in sediment (as cited by Foulsham et al 2009[23]). Where contamination is suspected, samples of water and/or sediment should be analysed by chemical laboratories to determine the presence of specific pesticides. The results of testing should then be compared against trigger values for pesticides in Chapter 3.4 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.*[14] There are two important notes about the guideline trigger values: they are for freshwater ecosystems, they have not been developed for application to saline wetlands; and concentrations do not account for the potential of pesticides to bioaccumulate.

Table 19. Default trigger values for pesticides in freshwater wetlands in WA, from the ***Australian and New Zealand Guidelines for Fresh and Marine Water Quality***.[14]

Parameter	Effectively unmodified wetlands, with high conservation/ecological value	Slightly to moderately disturbed freshwater wetlands
Pesticides in water	Chemicals originating from human activities should be undetectable. Naturally occurring toxicants should not exceed background concentrations	Refer to Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
Pesticides in sediment		Refer to Table 3.5.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*

Managing pesticides

Management of pesticides should focus on preventing their entry into wetlands through reducing level of usage at the point source and controlling levels in inflowing groundwater and surface water runoff.

➤ The use of pesticides to control midges and mosquitoes in wetlands can contribute significant amounts of pesticides. The management of pesticides used for this purpose is discussed in the topic 'Nuisance midges and mosquitoes' in Chapter 3 of this guide.

In an emergency

In the event of an accidental spill of pesticides, or adverse effects to wildlife or wetlands occurring, call the Pollution Watch Hotline: 1300 784 782 (24 hours). In the event of a hazardous materials release or life-threatening incident, call 000 and ask for Fire and Rescue).

Research into the treatment of contaminated water is progressing, for example, CSIRO researchers have developed a nanomaterial that can filter herbicides such as paraquat in water. However the widespread application of such technologies for wetland protection is likely to be limited due to their diffuse pollutant sources and cost. Activated carbon and carbonaceous material is identified as a potential amendment material for pesticide-polluted sediments.[177] However, once pesticides enter a wetland, treatment options are very limited at most wetlands. Pesticides decompose in soil and water, but the total decomposition time can range from days to years. Removal of soils contaminated with pesticides requires special permits and involves a highly regulated disposal process. Seek advice from DEC if this is being considered. If pesticides are present in a wetland, minimising their harmful effects is a key strategy. Disturbance of sediments with high levels of pesticides bound to them should be avoided, in order to reduce the potential for resuspension and remobilisation of pesticides into the water column.

All pesticide users are bound by legal requirements, as outlined in the text box below, but the levels of pesticides detected in aquatic systems in WA indicate the need for awareness and behaviour change across the cross-section of pesticide users. All parts of our community, from individuals, non-government organisations, for-profit sector and local and state government, can take actions that will contribute to reduced pesticide pollution of WA's wetlands.

Specific strategies and techniques for preventing and managing pesticide pollution in wetlands include:

- Better managing wetlands so that the need for pesticide application is reduced. Chemical-free methods for preventing and controlling the invasion of weeds, introduced pest animals, and nuisance populations of midge and mosquitoes are outlined in this guide – see the topics 'Introduced and nuisance animals' and 'Wetland weeds' for information. In the future a topic 'Nuisance midges and mosquitoes' may also be available.
- Reducing the use of pesticides in surrounding urban, peri-urban and agricultural areas and replacing chemical control options with chemical-free forms of pest and weed control where feasible.
- Reading and following the guidance in the Materials Safety Data Sheet (MSDS) for each product, available from various websites such as www.msds.com.
- Observing best management practices. Many industry bodies have developed specific codes of practice or guidelines to assist industry practitioners with this. Key resources are presented in Table 20 below.
- Training of pesticide users. Almost all pesticide training carried out in WA is provided by ChemCert WA, an independent, not for profit organisation that provides a range of pesticide training courses delivered either by independent consultant trainers, or through the TAFE colleges. For more information on training, see *A guide to the use of pesticides in Western Australia*.[178]
- Careful timing of pesticide application is important; for example, contamination of wetlands from groundwater leaching and surface runoff is less during dry periods than in wet conditions, and during still periods the risk of spray drift is less than in windy periods.
- Best practice management of stormwater in the catchment. For example, converting piped discharge into wetlands to overland flows through vegetated buffers can help attenuate pesticide levels. Management of sediment entrained in runoff and erosion can reduce the transportation of contaminated sediments and organic matter into wetlands. This may involve use of vegetated buffer strips or swales, creation of artificial wetlands and other structures such as sediment traps and infiltration basins to assist in settling out and removing sediments and suspended particulate matter from water flowing into wetlands. For more information, see the *Stormwater Management Manual for Western Australia.*[30]
- Appropriate storage and disposal of pesticide chemicals and containers. ChemClear® and DrumMuster provide these services.

  ChemClear® (www.chemclear.com.au) provides a reliable and responsible recovery, collection and disposal service is a hazardous waste recovery, collection and disposal service for currently registered obsolete rural chemicals manufactured by association members of Crop Life Australia Limited, Veterinary Manufacturers Association (VMDA) and other participants. This service is offered to users of agricultural and veterinary chemicals.

  DrumMuster (www.drummuster.com.au) is a chemical industry organisation that, in conjunction with cooperating local governments, provides a pesticide container disposal service for empty, clean agvet chemical containers. It collects millions of drums each year totalling thousands of tonnes of waste.

➤ For information on minimising unintended impacts of herbicides in wetlands, see the topic 'Managing weeds' in Chapter 3.

Legal requirements of pesticide users

In Western Australia, anyone who uses pesticides is bound by the Health (Pesticides) Regulations 1956 of the *Health Act 1911*. These regulations were developed to provide protection for the applicator, the public and the environment from misuse of pesticides. Pesticide labels are written in accordance with the regulations and therefore any pesticide user has a legal obligation to read and follow instructions on the label. The label provides instructions for use, for the protection of the environment, information about storage and disposal and recommendations for personal protective equipment. By law and without exception, pesticides cannot be used in any manner contrary to that described on its label without the permission of the Australian Pesticides and Veterinary Medicines Authority. For more information refer to www.apvma.gov.au/publications/fact_sheets/docs/permits.pdf, and to view the minor use and emergency use permits that have been issued, see www.apvma.gov.au/permits/search.php. Anyone proposing to apply a pesticide to a natural area of conservation value should have appropriate authorisation and should undertake training in the correct preparation, handling, application, transport and storage of pesticides. Extreme care must be taken to ensure that the use of pesticides does not constitute an offence or cause environmental harm. Legislation regarding the use of chemicals is under review and in future this may become a legal requirement. *A guide to the use of pesticides in Western Australia*[178] from www.health.wa.gov.au/publications/documents/11627_Pesticides.pdf is recommended reading for pesticide users. Reports of illegal pesticide use within natural wetlands should be reported to DEC.

Table 20. Guidelines on managing pesticides

Application	Guideline
General	*A guide to the use of pesticides in Western Australia*[178]
Local governments	*A guide to the management of pesticides in local government pest control programs in Western Australia*[179]
General	*Contaminant spills – emergency response* WQPN[180]
General	*Toxic and hazardous substances – storage and use* WQPN[181]
General	*Pest control depots* WQPN[181]
General	*Nutrient and irrigation management plans* WQPN[68]
Industry-specific	
Dryland crop industry	*Aerial spraying of crops with pesticides* WQPN[182] *Agriculture - dry land crops near sensitive water resources* WQPN[77]
Floriculture industry	*Floriculture activities near sensitive water resources* WQPN[78]
Horticulture industry	*Best environmental management practices for environmentally sustainable vegetable and potato production in Western Australia: a reference manual*[79] *Code of practice for environmentally sustainable vegetable and potato production in Western Australia*[80]
Orchard industry	*Orchards near sensitive water resources* WQPN[81]
Turf industry	*Environmental guidelines for the establishment and maintenance of turf and grassed areas*[82]
Viticulture industry	*Environmental management guidelines for vineyards*[83] *Wineries and distilleries* WQPN[84]
Aquaculture industry	*Aquaculture* WQPN *85*
Animal industries	*Stockyards* WQPN[86]
Abattoir industry	*Rural abattoirs* WQPN[87]

Application	Guideline
Beef industry	*Guidelines for the environmental management of beef cattle feedlots in Western Australia*[88]
Dairy industry	*Dairy processing plants* WQPN[89]
Horse industry	*Environmental guidelines for horse facilities and activities*[36]
Pastoral rangeland industry	*Pastoral activities within rangelands* WQPN[92]
Pig industry	*Environmental guidelines for new and existing piggeries*[93] *National Environmental Management* *Guidelines for Piggeries*[94]
Poultry industry	*Environmental code of practice for poultry farms in Western Australia*[95]
Associated benefits	
Cost effectiveness, compliance with environmental regulations, corporate citizenship.	
Who to go to for assistance	
Department of Agriculture www.agric.wa.gov.au Department of Water www.water.wa.gov.au Department of Environment and Conservation www.dec.wa.gov.au	
Relevant regulation	
Health (Pesticides) Regulations 1956 of the *Health Act 1911*	Department of Health
Environmental Protection (Unauthorised Discharges) Regulations 2004 of the *Environmental Protection Act 1986*	Department of Environment and Conservation
Approval may be required to establish and operate an intensive animal industry. This may include a works approval, license or registration under the *Environmental Protection Act 1986.*	Department of Environment and Conservation

➤ The following are sources of more information on pesticides:

- The Department of Health's pesticides webpage: www.public.health.wa.gov.au/3/1139/2/pesticide_use.pm
- Section 8.3.7.15 through to section 8.3.7.21 of the *Australian and New Zealand guidelines for fresh and marine water quality. Volume 2. Aquatic ecosystems - Rationale and background information (Chapter 8)*[14]
- The Australian Pesticides and Veterinary Medicines Authority: www.apvma.gov.au
- National Pollutant Inventory: www.npi.gov.au

Managing metals

A number of metals and metalloids (semi-metals) that have been associated with contamination and potential toxicity in aquatic ecosystems include aluminium, lead, cadmium, mercury, arsenic, chromium, copper, iron and zinc. Metals and metalloids are collectively referred to as 'metals' in this topic and can occur in many forms in water, including dissolved or attached to particulates and sediments.

Causes

Metal pollution

Metals can occur naturally in wetlands in low concentrations, sometimes referred to as natural 'background' levels. There is natural variation among wetlands, due to factors such as geological substrate of groundwater. For example, it has been proposed that concentrations of most metals are naturally high in surface waters of salt lakes in the Goldfields, based on evidence of the concentrations of cadmium, cobalt, chromium, copper, lead, nickel and zinc.[40]

Human activities can increase levels of metals in wetlands significantly, beyond the tolerance of wetland organisms. Metal contamination tends to be highest in areas situated in close proximity to mine sites (both active and abandoned), industrial installations and heavily populated areas such as cities. The document *Potentially contaminating activities, industries and landuses*[183] indicates that metals are a very common potential contaminant type, used in such a wide range of industries and land uses. Examples of activities that generate metals as a product or by-product of their operations include pulp mills, coal fired power stations, tanneries, foundries, and plants producing petrochemicals, chlor-alkali, fertilisers, metal plating, glass, cement, textiles, paints and pesticides.

Diatom: a microscopic, single-celled alga with cell walls made of hard silica, freely moving in the open water and forming fossil deposits

Metals can enter wetlands from diffuse sources such as atmospheric deposition, urban and agricultural stormwater, groundwater discharge and leaching; and point sources such as accidental spillages and discharge of metals, products containing metals, and contaminated wastewater from urban, mining, industrial and agricultural land uses. Metals are transported attached to sediments or dissolved in water. As such, most metals in wetlands are found in suspended particles in the water column and within the sediment.[46] Metals in sediment are generally orders of magnitude more than levels in water (in fact, the US Environmental Protection Agency states that sediment solids can hold up to a million times more metal than an equivalent volume of water[184]). Input into wetlands generally occurs as short, intense pulses during flow events, but can also occur as slow, gradual inputs via contaminated groundwater.

Examples of metal pollution in WA wetlands include:

- lead detected in Lake Monger in Perth's northern suburb is thought to originate from landfill, road runoff and aerosols. In 1991 it was estimated that 138 kilograms of lead were entering the lake per year, primarily via stormwater drains.[34] High levels of arsenic, zinc and copper have also been detected.
- the application of superphosphate fertilisers in WA since 1982 has resulted in more than 273 tonnes of cadmium being added to ecosystems.[185] Fifty percent of this is water soluble and therefore eventually leaches into waterbodies and accumulates in the sediments.
- metals in mine dewatering discharge. In salt lakes of the Murchison and Coolgardie bioregions, dewatering discharge has been implicated as a source of arsenic, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel and zinc.[40,186] Salt lakes with high concentrations of metals have been linked to lower **diatom** species richness and often abundance, with strong correlation between the discharge footprint and the effect upon diatoms in larger salt lakes.[40]
- metals including copper sulfate, arsenic and mercury have also been applied directly to wetlands in an effort to control algae.[111] Copper chrome arsenate (CCA) treated wood may have been used in wetland areas.[187]

Metal dissolution, precipitation and suspension in-situ

The chemical form a metal takes in wetland soils or water influences how mobile and available a metal is to organisms – in short, its bioavailability. Understanding bioavailability is essential in assessing the potential toxicity of metals and their compounds. Human-induced changes in water chemistry can alter the mobility and bioavailability of metals and is a major cause of metal toxicity in some wetlands.

The bioavailability of chemical contaminants in the environment depends on the nature of the medium in which they are found (for example: soil, water or organic matter). Soil chemical and microbial processes affecting metal mobility and toxicity are very different in wetland soils compared to dryland soils. A number of metals present in wetlands may be more or less toxic, depending upon the water chemistry, and in particular, the acidity. Water-soluble metals are the most mobile and plant-available form, and together with exchangeable metals (those weakly bound to soil surfaces by cation-exchange processes), are considered to pose the most risk to organisms[188] (see the text box below for more information on different chemical forms metals may take). Where sediments are highly contaminated with metals, bioavailability will be low if the metals are bound very strongly to sediment particles, such as when sediments have a high clay/humic fraction. If conditions change, for example the water becomes more acidic, the bonds between metals and sediments may be broken and metals will be released into the water where they can be taken up by organisms. Dissolved organic matter derived from the partial decomposition of organic materials is also a powerful agent for the binding of metals and therefore also plays an important role in regulating metal toxicity and mobility.[189] This includes fulvic and humic acids, products of the degradation of lignin and cellulose, which can stain the water the colour of tea. Decomposition of dissolved organic matter can release metals.

extra information

Chemical forms metals may take in wetlands

Metals can exist in a range of chemical forms including:

- water-soluble metals
- metals soluble as free ions
- metals soluble as inorganic or organic complexes
- exchangeable metals
- metals precipitated as inorganic compounds including metal oxides, hydroxides and carbonates (strongly controlled by pH)
- metals complexed with large molecular weight humic materials
- metals adsorbed or occluded to hydrous oxides
- metals precipitated as insoluble sulfide
- metals bound within the crystalline lattice structure of primary minerals

Source: Wright and Keddy[188] (undated)

The pH and water hardness are particularly influential; pH is probably the single most important variable that influences the behaviour of metals in the environment; and in sediments, redox potential is also considered to be a controlling factor.[184] If pH becomes moderately to strongly alkaline or acidic, metals may be converted to mobile forms. For example, dissolved aluminium is most toxic to aquatic organisms in freshwater at pH values of 5 to 6.[119] Studies have found fish, amphibians and phytoplankton to be susceptible.[14] Acidification processes, such as acid sulfate soils, and acid mine drainage can result in metal toxicity in wetlands. Acid mine drainage can be a significant source of metals through seepage and stormwater containing acidic water from tailings or spoil heaps into groundwater, natural or artificial waterways and wetlands. Acid wastewater from mining operations may not only contain toxic metals, its acidity can trigger the release of metals stored in sediment of receiving wetlands, rendering them bioavailable. Not all metals are more soluble or toxic with increasing acidity; zinc toxicity, for example, generally decreases with decreasing pH below a pH of 8.[14] Redox potential is also important, with sediment oxygen deficiency altering the chemistry of metals such as iron and manganese, which in turn will affect the behaviour of other heavy metals that were previously bound to oxides of iron and manganese.[14]

The toxicity of many metals decreases with increasing water hardness. This is the case for aluminium, cadmium, copper, lead and zinc for instance.[14]

As more permanently inundated wetlands undergo drying due to climate change and other factors, they are at risk of metal mobilisation. Permanently inundated wetlands tend to accumulate humic materials, which metals have a strong association with. In aerated soils that occur due to drying, decomposition of organic matter is enhanced and metals bound to organic matter are released, leading to enhanced bioavailability of metals. Drying of these wetlands can also result in the dissolution of metal sulfides, mobilising metals and releasing acid.

Impacts

All organisms require certain trace metals (such as manganese, zinc, cobalt and selenium) for normal growth and functioning at low concentrations. These elements occur naturally in soil and water as a result of physical and chemical weathering of rocks over millions of years. Some metals are relatively abundant and have naturally high concentrations, such as aluminium and iron, while others are rare and have naturally low concentrations, such as mercury, cadmium, silver and selenium, which are collectively referred to as 'trace elements'. At low concentrations, many of these metals are referred to as 'micronutrients' that are essential for life (though lead, cadmium and nickel have no known botanical function[188]).

Metals can become toxic when concentrations exceed natural levels and are in a bioavailable form, but it is important to note that the toxicity of metals is species-specific. In addition, the concentration at which any given metal becomes toxic depends on the metal itself and factors such as temperature, pH, water hardness, phosphate concentrations, salinity and interactions with other metals.[46] In general, low pH and high water temperatures increase the bioavailability and toxicity of metals, whilst high salinity and increasing water hardness decrease the toxicity and uptake of trace metals.[14,190,190]

The toxic effects of metals can result in changes in the abundance and diversity of wetland species and the composition of wetland communities. In immediate areas of high concentrations, in certain forms, metals can be highly reactive with algae, plants and animals. Metals enter wetland organisms through body and respiratory surfaces, and by ingestion of water, suspended particles and organic matter. Once absorbed into tissue, they can disrupt function at the cellular level, impair metabolism and result in damage to, or death of the organism. While sediments are the major accumulator of metals in wetlands, wetland plants and macroinvertebrates can also accumulate metals, but generally to a lesser extent.

Plants can absorb and accumulate metals from the sediment, water or air, depending on the degree of inundation and/or emergence out of the water.[191] For example, a study by the Bannister Creek Catchment Group in Perth's south-eastern suburbs found that watercress (*Rorippa nasturtium-aquaticum*) in Bannister Creek contained zinc, manganese, lead, copper, chromium and arsenic. In response to reports of locals harvesting watercress from the creek, the Water Corporation and Department of Health warned people that the continued consumption could be detrimental to people's health and should not be fed to farmed animals like chickens. While local research on the effects of metals on local wetland plants is limited, aquatic plants are thought to be particularly sensitive to iron, copper and aluminium.[118] It has been suggested that sedges have higher tolerances to heavy metals than shrub and tree species (for example, Regeneration Technology 1995[34]).

As reported by Jones et al (2009)[118], an increase in trace metal concentrations in wetland water may result in the loss of sensitive plant species and a reduction in productivity and growth. The specific metal sensitivities of WA wetland plant species are not known.

Wetland plants display a wide range of tolerances to iron. A study of iron toxicity in forty-four British wetland plant species found that iron concentrations greater than 10 milligrams per litre influenced the growth and distribution of wetland plant taxa.[192] Monocotyledonous species tended to have higher tolerance to iron compared to dicotyledonous species. Symptoms of iron toxicity include growth retardation, reduction in leaf size, abnormalities in root growth and discolouration of leaves.

In excess, copper inhibits vegetative growth, induces senescence, reduces photosynthesis and disrupts membrane integrity. Toxicity thresholds vary considerably between plant species. Some species of algae are particularly sensitive to copper.[14]

The tolerance of plants to excessive aluminium varies widely between species and no thresholds are available for WA species. Aluminium toxicity limits growth in acidic conditions. This is generally applicable at a soil pH of less than 5.0, but can occur at around 5.5. Aluminium toxicity in acidic soils has been shown to reduce plant rooting depth by interfering with cell division in plant roots, increase susceptibility to drought by interfering with the uptake, transport and use of water and several elements (calcium, magnesium, phosphorus, potassium) and decrease the use of subsoil nutrients by fixing phosphorus in a less available form in the soil or plant roots. Algae are generally the most sensitive to aluminium.[14]

A range of animals, including fish, birds, frogs, mussels and mammals, can accumulate metals such as lead, cadmium and selenium through direct exposure or by consuming plants and other animals that contain them. Limited information exists on the toxicity of trace metals to Australian invertebrates, but in general terms zinc and lead are thought to be of particular concern.[118] Metals can be taken up by plants or animals over a period of time and passed on through the food chain without immediate noticeable effects. As the level of toxins increase within affected organisms, when symptoms do present, they may occur as skin lesions due to fungal infections in fish, thinning of bird's egg shells and birth deformities. International studies suggest that lead exposure in frogs can result in physical deformities and defects, behavioural changes, reduced reproductive success and death.[193]

Researchers found that cadmium in superphosphate fertiliser easily leaches into stormwater and groundwater, then travelling into wetlands and waterways. Cadmium can then enter the food web through algae and benthic animals and may ultimately be passed to humans. The cadmium levels of the priority 4 species Carter's freshwater mussel (*Westralunio carteri*), endemic to the south-west of WA, have been found to exceed statutory Australia New Zealand Food Authority (ANZFA) guidelines for maximum permissible concentrations (MPCs) with respect to human consumption (these MPCs have now been removed). The cadmium levels bioaccumulate in freshwater mussels elevated with increasing catchment clearing, being highest in degraded catchments.[185]

Some species more tolerant of metal contamination thrive as a result of the decline of species that are sensitive to metals. For example, abundance of cyanobacteria and green algae have been known to increase significantly in wetlands following the loss of algae-grazing organisms as a result of metal poisoning.[46]

Metals may progressively accumulate in sediments or in biological tissues to levels that are much higher than water column concentrations (bioaccumulation). Chronic effects of bioaccumulated toxicants in organisms include deformities, alterations in growth, and reduced reproductive success and competitive abilities. Elevated toxicant concentrations in organisms such as fish and shellfish may also pose health risks to consumers of those organisms, including humans.

Indicators

Visual indicators of dissolved metal contamination may range from decline in health of individual organisms sensitive to particular toxicants, for example, lesions in fish, to mass mortality events such as fish kills. The time taken for organisms to display visual symptoms of toxic poisoning after initial exposure will vary depending on a range of factors including the nature and concentration of the toxicant(s), sensitivity of individual organism/species and frequency, duration and nature of exposure.

Some dissolved metals such as aluminium or iron may be identified through changes in the appearance of the water or sediments. For example, wetlands affected by high levels of acidity containing aluminium may have 'crystal clear' water ranging through to blue green or milky white colour with increasing water pH. Similarly, contamination from iron may result in water appearing a yellow-brown colour, particularly evident in slow flowing water, when there has been no recent rainfall. There may be iron flocs (particles) present which can be a red-brown or brown-yellow colour, again depending on the pH.

The presence of metals can be more accurately determined by testing the water, sediment and organisms (from tissue samples from affected organisms such as fish, crustaceans and molluscs). Where heavy metal contamination is suspected, samples of water, sediment and biota should be analysed by chemical laboratories to determine the presence of specific metals. The results of testing can then be compared against standard guidelines for water quality criteria, for example the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.[14]

Table 21. Default trigger values for metals in freshwater wetlands in WA, from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.[14]

Parameter	Effectively unmodified wetlands, with high conservation/ecological value	Slightly to moderately disturbed freshwater wetlands
Metals in water	Chemicals originating from human activities should be undetectable. Naturally occurring toxicants should not exceed background concentrations	Refer to Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
Metals in sediment		Refer to Table 3.5.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*

Managing metals

Management of metals should focus on preventing their entry into wetlands and/or reducing their impacts once they have entered wetlands. No pollutant trap is successful in removing the majority of heavy metals encountered in stormwater.[194] Strategies and techniques for preventing and managing nutrients are applicable to metals and include:

- regulation of mining, industrial and other activities to reduce generation of metals and acid effluent
- effluent control from point and diffuse sources of pollution (such as reducing water flow through contaminated areas and sealing tailings ponds with impervious materials)
- catchment management practices to reduce erosion and runoff
- construction of settling ponds, sediment traps and artificial wetlands to trap and strip metals

Many of these techniques are discussed in more detail under the heading 'Managing nutrient enrichment'. Specific guidelines for managing metals are outlined in Table 22.

Where metals are present in wetlands, optimising those conditions which promote their immobilisation may be considered. Plants and some charophytes (complex algae described in the 'Wetland ecology' topic in Chapter 2) such as *Nitella congesta* have been found to hyper-accumulate metals[195], but there is the potential to affect animals that consume it. Promoting conditions needed for metal adsorption (binding to soil particles) and precipitation (forming solid compounds) include:

- avoiding disturbing wetland sediments, resulting in re-suspension of metals, rendering them bioavailable
- avoiding disturbing or exposing potential acid sulfate soils to air
- where serious metal contamination is known, monitoring pH levels with the aim of, where appropriate, maintaining neutral pH to limit metal toxicity
- avoiding drying of permanently inundated wetlands.

Table 22. Guidelines on managing metals

Application	Guideline
General	*Toxic and hazardous substances – storage and use* WQPN[181]
General	*Contaminant spills – emergency response* WQPN[180]
Light, general and heavy industry best practice	*Managing waste in the metal manufacturing industry*[196] *Industrial wastewater management and disposal* WQPN[70] *Light industry near sensitive waters* WQPN[71] *General and heavy industry near sensitive waters* WQPN[72] *Stormwater management at industrial sites* WQPN[197] *Mechanical servicing and workshops* WQPN[198] *Mechanical equipment washdown* WQPN[199]
Associated benefits	
Cost effectiveness, compliance with environmental regulations, corporate citizenship.	
Who to go to for assistance	
Department of Environment and Conservation www.dec.wa.gov.au	
Relevant regulation	
Environmental Protection (Metal Coating) Regulations 2001 of the *Environmental Protection Act 1986* Environmental Protection (Unauthorised Discharges) Regulations 2004 of the *Environmental Protection Act 1986*	Department of Environment and Conservation

➤ The following are sources of more information on metals:

- Section 8.3.7.1 of the *Australian and New Zealand guidelines for fresh and marine water quality. Volume 2. Aquatic ecosystems - Rationale and background information (Chapter 8)*[14]
- National Pollutant Inventory: www.npi.gov.au

Managing hydrocarbons

Hydrocarbons—including oil, grease and petroleum products—refer to several hundred chemical compounds that originate from crude oil, polycyclic aromatic hydrocarbons (PAHs) and benzene, toluene, ethylbenzene and xylene (these four compounds are sometimes collectively referred to by the acronym BTEX).

Causes

Hydrocarbons generally enter wetlands via stormwater and groundwater that has received hydrocarbons from urban roads, contaminated runoff from light industrial areas and service stations and deliberate or accidental spillage of chemicals. A wide range of industries, land uses and activities use and emit hydrocarbons, as outlined in the handy reference document *Potentially contaminating activities, industries and landuses*.[183] Under the Environmental Protection (Unauthorised Discharges) Regulations 2004 it is illegal to discharge hydrocarbons to wetlands, groundwater or stormwater.

These manufactured hydrocarbons should not be confused with natural oils produced from the decomposition of plants in the Myrtaceae and other families. Although these can reduce oxygen transmission to the water column, natural oils are a natural part of wetland ecosystems and are not associated with significant detrimental effects in wetlands.

The extent of hydrocarbon pollution in WA's wetlands is not known, due to a lack of survey data. However, in large urban centres of WA, hydrocarbon pollution is considered likely to be a problem. Studies of the Swan and Canning catchments, for example, show that high concentrations of polycyclic aromatic hydrocarbons are entering waterways and will have both chronic and acute effects.[23] They are commonly found in road runoff.[14]

Impacts

Hydrocarbon pollution can have a range of serious environmental impacts. Hydrocarbons can coat animals and plants and other surfaces including sediment and the water surface. Slicks upon the water surface reduce the diffusion of gases between the atmosphere and the water, causing a number of problems. In particular, hydrocarbons can reduce the amount of oxygen that dissolves in water by preventing gas exchange across the air-water interface. As oxygen exists in much lower proportions in water (about 1 per cent) than in air (about 21 per cent), this exchange is critical for aquatic life in wetland waters, as well as driving many chemical processes in the water column and sediments. Hydrocarbons and surfactants also alter the surface tension of the water, which many insects and other invertebrate aquatic animals rely upon in order to survive, because they primarily inhabit the water surface. Oil and surfactants such as household detergents decrease the surface tension, reducing the ability of these 'surface dwellers' such as water striders (Gerridae, Veliidae) to repel water with the hydrophobic hairs on their legs, causing them to sink.[200] Oils can cause damage to the water proofing on birds feathers, and prove toxic to birds which ingest it during preening. The decomposition of oils by bacteria can also consume oxygen, further reducing oxygen levels in the water column and sediments.

Many polycyclic aromatic hydrocarbons are acutely toxic and several are described as endocrine disrupting, mutagenic, carcinogenic and teratogenic (defined in the glossary). Their toxicity has been shown to increase with increased molecular weight, while degradation time has been shown to decrease with increased molecular weight. They have the potential to be bioaccumulated. It is reported that concentrations of PAHs in aquatic ecosystems are generally highest in sediments, intermediate in aquatic biota and lowest in the water column and that a mixed microbial population in sediment water systems may degrade some PAHs, with degradation progressively decreasing with increasing molecular weight.[14]

Indicators

A film on the water or sediment surface is the main visual indicator of hydrocarbon contamination in wetlands. Oily films are sometimes confused with scums. For more guidance on natural oils, from plants and in some cases algal blooms (for example, from *Botryococcus*), see the *Scum book*[60], produced specifically for south-western Australia. Oily-looking bacterial scums may also be present when acidification is occurring, as outlined earlier (see 'Managing acidification').

Bioremediation: the use of microorganisms to break down environmental pollutants

Detecting hydrocarbons and tracing their source is becoming easier with the use of hydrocarbon capture pads in stormwater systems. These are being employed in various areas of Perth, for example, the South East Regional Centre for Urban Landcare (SERCUL) in partnership with the Swan River Trust and the City of Gosnells, has carried out Hydrocarbon Track and Trace project in the Maddington industrial area.

The presence of hydrocarbons can be accurately determined through testing of water and sediment analysed by chemical laboratories to determine the presence of specific hydrocarbons. The results of testing can then be compared against trigger values for hydrocarbons in Chapter 3.4 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[14] (Table 23).

Table 23. Default trigger values for hydrocarbons in freshwater wetlands in WA, from the ***Australian and New Zealand Guidelines for Fresh and Marine Water Quality***.[14]

Parameter	Effectively unmodified wetlands, with high conservation/ecological value	Slightly to moderately disturbed freshwater wetlands
Hydrocarbons in water	Chemicals originating from human activities should be undetectable. Naturally occurring toxicants should not exceed background concentrations	Refer to Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
Hydrocarbons in sediment		Refer to Table 3.5.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*

Managing hydrocarbons

In the event of a spill, rapid and effective containment and removal of the hydrocarbon is critical. The DEC responds to serious pollution incidents, taking action to stop the discharge, minimise environmental harm and direct clean-up works. It maintains a Pollution Response (HAZMAT) Unit (PRU) in Perth that can be deployed quickly around the state in the event of major pollution incidents. DEC Regional Offices also have ability to respond to pollution incidents and can obtain support from PRU as required. Equipment such as oil spill booms and skimmers may be used to contain and remove hydrocarbons effectively.

In an emergency

In the event of an accidental spill of hydrocarbons, call the Pollution Watch Hotline: 1300 784 782 (24 hours). In the event of a hazardous materials release or life-threatening incident, call 000 and ask for Fire and Rescue).

Preventing hydrocarbons from entering wetlands, and water that enters wetlands from drains, should always be the focus of management. The management of runoff and discharges from roads, industrial areas and service stations is particularly important. Table 24 lists guidelines on hydrocarbon management. In some circumstances, **bioremediation** may help to reduce the impacts of hydrocarbon pollution.

Figure 42. DEC's Pollution Response Unit found this site to have a number of environmental hazards including overflowing wash down bays, oil discharges that were leading into a constructed wetland and more than 500 drums of unknown liquid waste stored near stormwater drains. This site has since been cleared of the liquid waste and mineral oil drums, empty drums, packaging, pallets, used tyres and chemical containers. Oil spills and stains have been cleaned up and systems put in place to prevent recurrences. Photo – DEC.

Table 24. Guidelines on managing hydrocarbons

Application	**Guideline**
General	Pollutant control section, Chapter 9, S*tormwater management manual for Western Australia*[30] *Toxic and hazardous substances – storage and use* WQPN[181] *Contaminant spills – emergency response* WQPN[180]
Light, general and heavy industry best practice	*Service stations* WQPN[201] *Mechanical servicing and workshops* WQPN[198] *Mechanical equipment washdown* WQPN[199] *Motor sport facilities near sensitive waters* WQPN[202] *Industrial wastewater management and disposal* WQPN[70] *Light industry near sensitive waters* WQPN[71] *General and heavy industry near sensitive waters* WQPN[72] *Stormwater management at industrial sites* WQPN203
Relevant regulation	
Environmental Protection (Petrol) Regulations 1999 of the *Environmental Protection Act 1986* Environmental Protection (Unauthorised Discharges) Regulations 2004 of the *Environmental Protection Act 1986*	Department of Environment and Conservation

➤ The following are sources of more information on hydrocarbons:

- Section 8.3.7 of the *Australian and New Zealand guidelines for fresh and marine water quality. Volume 2. Aquatic ecosystems - Rationale and background information (Chapter 8)*[14]
- National Pollutant Inventory: www.npi.gov.au

case study

Mitigating the impact of hydrocarbon spills in the catchment

The City of Stirling has installed a hydrocarbon interception system to protect Herdsman Lake from hydrocarbon contamination carried in with stormwater from the surrounding light industrial area. Booms made of specialised toxicant capture material have been installed across stormwater drains. These booms are marketed as being able to capture up to 30 kilograms of oil contaminants; and as still capturing oil contaminants up to 12 months after initial deployment, and are marketed to float even when fully saturated with oil up to one year. Underflow weirs prevent surface flow oil and emulsified oil and water from flowing under the boom, which is reported as causing poor performance in some types of boom systems. The second line of containment employs high floating mats that capture any oils that breach the first line of containment during high flow events. The capture material is marketed as capturing organics from BTEX to oil and greases and heavy metals (as suspended organo-metals) commonly from internal combustion engine wear.

Figure 43. The hydrocarbon interception system installed by the City of Stirling to protect Herdsman Lake from hydrocarbon contamination carried in with stormwater from the surrounding light industrial area. Photo – Oleology.

Managing pathogens

Pathogen: any organism or factor causing disease within a host

Infectious microorganisms such as bacteria, viruses, protozoans, fungi and parasites that can cause disease or illness in humans, animals and plants are **pathogens**. Water can play a significant role in transmitting a wide variety of diseases and illnesses if contaminated with pathogens (for example, amoebic meningitis).

One introduced pathogen, *Phytophthora cinnamomi*, is so pervasive and destructive in wetlands as well as dryland communities in WA, a whole topic is dedicated to it.

➤ The topic ‘Phytophthora dieback’ is also in Chapter 3 of the guide.

Another, *Clostridium botulinum*, causes botulism, and is linked with nutrient enrichment, and is covered in the ‘Nutrients’ section of this topic.

Causes

There is a strong link between the presence of many pathogens and contamination of water by human and/or animal faecal material.[168] Humans can be exposed to pathogens in wetlands from immersion of head and face, wading or swimming and swallowing water Pathogens can enter organisms through the mouth, eyes, ears, nasal cavity, skin (particularly cuts and abrasions) and upper respiratory tract. Infection can also ensue when organisms (such as fish or crustaceans) that are already contaminated with a pathogen are consumed.

Some pathogens occur naturally in wetlands, without causing a problem. Under natural conditions, pathogens can be destroyed by exposure to ultra violet light in open waters, adsorption and predation. However pollution can significantly alter the number or type of pathogens present. The main sources of pathogens in wetland waters include:

- Groundwater leaching and stormwater from urban areas containing animal and human faecal material. Human faecal material carries the pathogenic bacteria *Escherichia coli* and animal faeces can carry the pathogenic protozoans *Cryptosporidium* and *Giardia*, all of which can cause serious illness in humans. Risks to humans from pathogenic organisms are greater in highly populated urban areas with septic tanks and on-site sewage disposal systems or leaking sewage connections.
- Groundwater leaching and stormwater from rural and/or agricultural areas containing animal faeces, including dog kennels and horse keeping areas, and intensive animal industries such as poultry farms, dairies and piggeries.

Concentrations of pathogens in wetlands are likely to be highest during high rainfall events when groundwater leaching and stormwater into wetlands is greatest.

Some pathogens occur naturally in the water column or sediments of wetlands, without causing a problem until conditions change that favour an outbreak, such as changes in water temperature, pH, salinity, light or dissolved oxygen. For example, the bacterium *Clostridium botulinum* (which causes botulism in fauna such as fish and birds) can be present in the sediment without causing a problem. When conditions are favourable, such as during algal blooms and anoxic (low oxygen) conditions, an outbreak can be triggered.

Low pH conditions resulting from acidification of wetlands can cause damage to fish skin and gills and increase their susceptibility to fungal infections, which may have lethal consequences. Activities that disturb sediments, causing re-suspension of pathogens, may also lead to outbreaks of disease or illness in vulnerable organisms.

Impacts

Disease and death of sensitive species from pathogens can result in changes in the abundance and diversity of wetland species and the composition of wetland communities.

For example, bandicoots in urban areas have been found to be infected with strains of the parasite toxoplasma and cases of neurological disease have also been detected. Murdoch University researchers are investigating the effect of closer contact of humans due to urbanisation and clearing, with causes such as people giving them food scraps or exposure via septic systems being considered.

Indicators

The presence of pathogens in wetlands should be suspected if there are signs of illness or disease, or death, in organisms that have been exposed to potentially contaminated water. Symptoms of infection from pathogens in humans range depending on the pathogen involved. For example, symptoms of infection by the amoeba *Naegleria fowleri*, which causes amoebic meningitis in humans, include a severe and persistent headache, sore throat, nausea, vomiting, high fever and sleepiness. Fish exposed to pathogens may display unusual behaviour such as swimming on their sides, or develop skin lesions or ulcers. Birds and other native fauna, pets and livestock may show signs of confusion, respiratory distress and paralysis.

Detecting the presence and type of bacterial and viral pathogens in water can be difficult and where there is potential risk to human health, sampling should only be undertaken by professionals trained in handling biohazardous substances, such as public/environmental health officers from the local shire or the Department of Health. Analysis of water samples should be undertaken by specialist pathology laboratories. Where faecal bacterial densities are being measured, these should be assessed according to the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[14].

Managing pathogens

Management of pathogens in wetlands will depend on the type of pathogen(s) present and the level of existing (or potential) risks posed to humans or other organisms that may be exposed. Where pathogens are entering wetlands from diffuse or point sources of pollution, management strategies will be similar to those already discussed for managing nutrients (see heading 'Managing nutrients' in this topic), as the sources of pathogens are also potential sources of nutrients. Management strategies include:

- Reducing pathogen contamination at the source. For guidelines on source reduction, see the guidelines listed in Table 25.
- If leaking or overflowing septic tanks are the cause, these should be replaced, fixed or removed. Connection to mains sewage may be the best long term solution, if this is a viable option.
- Where pathogens originate from faecal matter from livestock or other animals defecating in or around wetlands, exclusion of these animals may be necessary. For additional information on managing pathogens from livestock in wetlands, see the topic 'Managing livestock' in Chapter 3.
- Where pathogens are naturally present in wetlands, preventing the onset of conditions that can trigger problematic outbreaks (for example, eutrophication and algal blooms, anoxic conditions, disturbing wetland sediments, acidification).

Turbid: the cloudy appearance of water due to suspended material

Table 25. Guidelines on managing pathogens

Maintain best practice industry standards, including:	Guideline
General	*Contaminant spills – emergency response* WQPN[180]
On-site domestic wastewater and sewage disposal	*Wastewater treatment – onsite domestic systems* WQPN[204]
Bridle trails	*Bridle trails near sensitive water resources*[205]
Aquaculture industry	*Aquaculture* WQPN[85]
Animal industries	*Stockyards* WQPN[86]
Abattoir industry	*Rural abattoirs* WQPN[87]
Beef industry	*Guidelines for the environmental management of beef cattle feedlots in Western Australia*[88]
Dairy industry	*Dairy processing plants* WQPN[89] *Effluent management guidelines for dairy sheds*[90] *Effluent management guidelines for dairy processing plants*[91]
Horse industry	*Environmental guidelines for horse facilities and activities*[36]
Pastoral rangeland industry	*Pastoral activities within rangelands* WQPN[92]
Pig industry	*Environmental guidelines for new and existing piggeries*[93] *National Environmental Management Guidelines for Piggeries*[94]
Poultry industry	*Environmental code of practice for poultry farms in Western Australia*[95]

Managing turbidity

The presence of fine, suspended matter in the water column, referred to as particulates and colloidal matter, can significantly influence wetland functions. These particulates may be clay, silt, phytoplankton or detritus and they affect the availability of light in the water by scattering and reflecting it. Wetlands with high levels of these particulates suspended in the water column are said to be **turbid**, and the measure of the extent to which light is scattered and reflected by these particles is the **turbidity**. Although having a similar appearance, highly coloured waters are not considered to be turbid because the effect is due to dissolved substances rather than suspended particles, and they play a different role in wetland ecology.

Causes

Naturally turbid wetlands

Natural levels of turbidity in WA wetlands can vary significantly between wetlands and within individual wetlands on a daily or seasonal basis (Figure 44). Turbidity is generally highest during peak surface inflows, such as during wet season rainfall and after intense rainfall events such as cyclonic rain. Upon reaching wetlands, suspended particulates may settle to the bottom, however they may be re-suspended in the water column if sediments are disturbed by natural phenomena include strong wind and wave action and native fauna movement. Many claypans support naturally high levels of turbidity almost all of the time. These claypans can support fauna that use the turbid conditions to their advantage. For example, turbidity can shelter animals from predators or protect them from harmful ultraviolet radiation. Most wetlands with a deep water column have low turbidity, while those with a shallow water column may have a naturally higher turbidity due to wind-induced re-suspension of sediments. The characteristics of the catchment also plays a key role in natural turbidity levels. Wetlands in catchments with highly erosive clay soils and low vegetation cover may have naturally high turbidity.

Figure 44. A wetland with high natural turbidity. Suspended silt particles give the water a milky appearance. Photo – DEC.

Vegetation clearing and grazing in the catchment

Turbidity is influenced by the general condition of the catchment draining into the wetland. Wetlands in heavily cleared and grazed catchments can be very turbid due to erosion of soils in the catchment.

Mining and industrial processes

Runoff from mining and industrial sites can contain suspended solids if not managed appropriately. The processes being carried out can generate significant levels of suspended solids. Some have a high level of genotoxicity (that is, can cause DNA damage in aquatic organisms). For example, iron-ore mine effluent has been found to affect fish in receiving lakes in Canada.[206]

Sediment re-suspension activities

Many human-induced activities can also cause re-suspension of particles, including waterskiing, increase volumes and intensity of stormwater flows, and clearing and fires that cause erosion in the catchment. In addition, a range of introduced and nuisance species are known to disturb sediments, including midge larvae, introduced fish such as carp, and pigs, horses and cattle.

Impacts

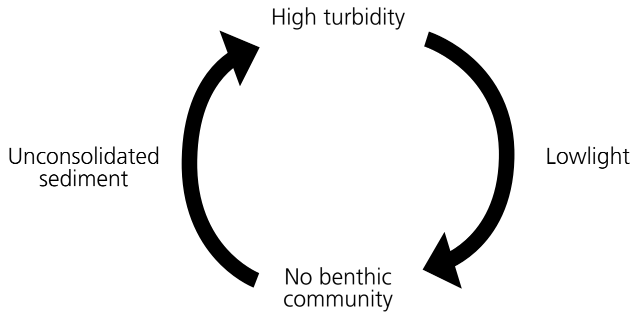
Suspended particulate matter can cause problems in wetlands both when in suspension in the water column and when it settles out in the bottom sediments. While in suspension, particulate matter can reduce light penetration, reducing photosynthesis in algae and submerged plants. It cause damage to fish and other aquatic organisms by clogging, coating or abrading respiratory structures such as gills, and by smothering benthic organisms and altering their habitats.[14] Suspended solids in runoff from some mining and industrial processes can cause cell damage in aquatic organisms. Suspended particulate matter is also important in that if these originate from inflows from the surrounding catchment, the particles can transport contaminants into wetlands such as nutrients, pesticides, bacteria and metals. The latter commonly bind to soil particles in catchments and can be transported via these to wetlands. The introduction of nutrients, pesticides and metals with particulate matter can also have adverse impacts on aquatic organisms (these are discussed under the headings 'Nutrients' and 'Metals' in this topic).

Impacts of increased turbidity on wetland ecosystems can be dramatic, in particular due to the effects on plants and algae, which are primary producers that form the basis of wetland food webs. Secondary effects as a result of increased turbidity, such as eutrophication (due to introduction of nutrients attached to particulate matter) and algal blooms, further exacerbate the problem. These impacts can lead to loss of species, altered communities and ultimately a reduction in wetland biodiversity.

Turbidity affects the amount and quality of light available for photosynthesis. Due to the different photosynthetic adaptations to light and shade of different plant and algal species, high levels of turbidity or shade can change species dominance, especially in phytoplankton. For example, cyanobacteria are quite often moderately shade-tolerant, and are also problem species in algal blooms due to the toxins produced by many species.[31] On the other hand, aquatic plants that grow close to the sediment can be severely disadvantaged by turbid conditions.

The low light conditions caused by high turbidities may prevent the establishment of bottom-dwelling (benthic) communities (for example, submerged wetland vegetation, benthic microbes), or lead to the loss of previously-established communities. This can often lead to 'positive feedback loops' in which sediments are not consolidated by benthic communities, leading to further turbidity and so on (Figure 45). This continual resuspension of inorganic sediments can also lead to elevated water column nutrient levels, since nutrients in the sediments are constantly resuspended, and sequestration (taking up) by rooted plant material does not occur. This feedback process forms part of the mechanism for maintaining a 'turbid, phytoplankton-dominated state'.

Figure 45. Feedback loop promoting turbid conditions in wetlands.



Indicators

Turbidity can be determined in a number of ways including:

- visual observation
- measurement in the field
- measurement in the laboratory using a water sample taken in the field.

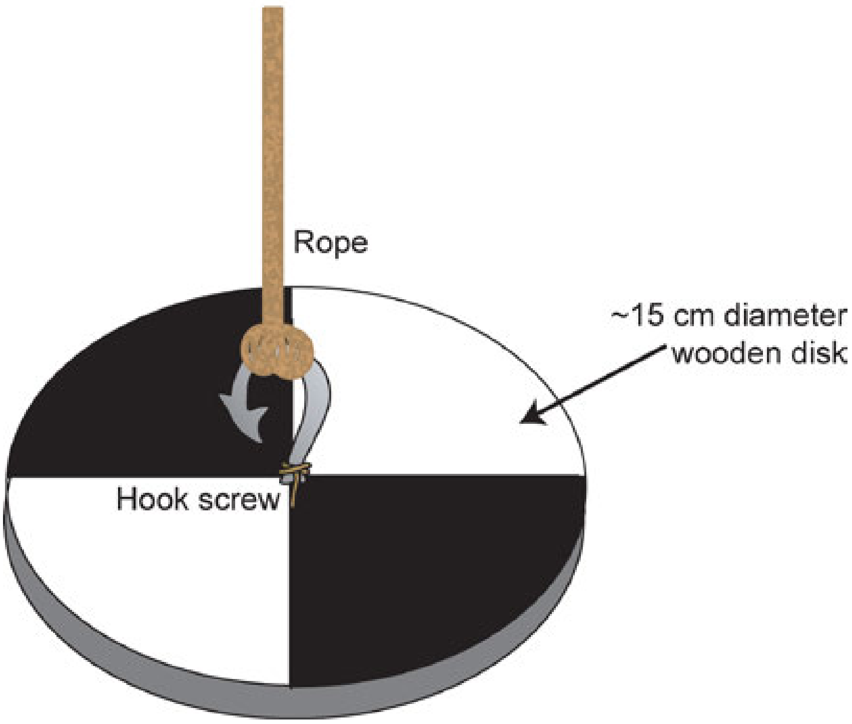
The simplest, but potentially least accurate method of determining increased turbidity, is visual inspection of the water body. If the water looks more 'cloudy' or 'muddy' than normal, increased turbidity is likely. It is more likely to be evident following rainfall when an increase in inflow of water into wetlands via stormwater occurs. Turbidity due to soil erosion from surrounding land may look brownish in colour, depending on the colour of the soil being washed into the wetland. Turbidity from stormwater may not be an obvious colour and the water may just look more 'cloudy' than normal.

Turbidity can be more accurately determined using several different methods:

- Measuring the 'cloudiness' of water using a 'turbidity tube', which is filled with water and small quantities are poured out until a black cross at the bottom of the tube becomes visible (from looking down through the water sample from the top of the tube). The turbidity value (measured in units called NTU, nephelometric turbidity units) is then determined by the measurement on the tube scale that corresponds with the water level.
- Measuring the transparency of the water using a secchi disk (pronounced 'sekki'). A secchi disc is used for measuring water transparency (Figure 46). The secchi depth of a water body is found by lowering the disc into the water until the black and white quadrants are no longer discernable. The depth at which this occurs is the secchi depth and the transparency of the water column is double the secchi depth.

NTU: nephelometric turbidity unit is a measure of the clarity of water. Turbidity in excess of 5 NTUs is just noticeable to most people.

Figure 46. Recommended width, colouration and weighting of a secchi disc.
Image - www.globe.gov.[207]



- Measuring the concentration (by mass) of suspended particulate matter per volume of water (often measured as milligrams per litre (mg/L)). This is undertaken under laboratory conditions.
- Measuring the fraction of light scattered at right angles as it enters the water (the more suspended particulate matter present, the more light is scattered). This is undertaken using a nephelometer under laboratory conditions.

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[14] trigger values for turbidity in northwest and southwest Australian freshwater ecosystems are between 2–200 and 10–100 **NTUs** respectively (Table 26).

ANZECC guidelines under review

The Council of Australian Governments has announced that the ANZECC guidelines are under review. This review includes the revision of sediment water quality guidelines, nitrate trigger values and toxicant trigger values. For more information, see www.environment.gov.au/water/policy-programs/nwqms/index.html#revision.

Table 26. Default trigger values for turbidity for slightly disturbed wetlands in WA, from the ***Australian and New Zealand Guidelines for Fresh and Marine Water Quality.***[14]

Water quality parameter	Trigger value Southwest Australia	Trigger value Northwest Australia
Units of measurement	Nephelometric turbidity units (NTU)	
Turbidity	10-100 [c]	2-200 [c]
Notes c: most deep lakes and reservoirs have low turbidity. However, shallow lakes and reservoirs may have higher turbidity naturally due to wind-induced resuspension of sediments. Lakes and reservoirs in catchments with highly dispersible soils will have high turbidity. Wetlands vary greatly in turbidity depending on the general condition of the catchment or river system draining into the wetland and the water level in the wetland.		

➤ For additional information on monitoring turbidity, see the topic 'Monitoring wetlands' in Chapter 4.

Managing turbidity

In those wetlands where the material in the water causing turbid conditions is either algae or cyanobacteria, managers should determine whether eutrophication is the primary cause. If it is, the previous section on managing eutrophication should be referred to.

In wetlands where the material in the water is primarily abiotic (that is, not living) and the turbid conditions are due to human causes rather than being the wetland's natural state, there are three key measures for managing it:

1. reduce the influx of suspended solids
2. reduce high velocity flows into the wetland
3. reduce re-suspension of solids.

Reducing the influx of suspended solids and high velocity flows

The most effective measure is to determine where sediments are coming from and to implement measures to prevent or reduce sediment loads entering wetlands.

Reducing erosion

Erosion can be considerable on pastoral lands due to grazing and soil disturbance by livestock. Managing stocking rates, and total grazing pressure accounting for feral animals, weather and land conditions, is important.

Erosion rates vary significantly across the state, with the Kimberley and the west Pilbara having the highest average rates of soil loss. Declines in soil stability have been noted in the Gascoyne, Murchison, Pilbara and Kimberley.

➤ The Department of Agriculture and Food has detailed information about local conditions across the state and can calculate the relevant permissible stocking rates on request. The department's Small Landholder Information Service provides advice tailored for small landholders. For more information, see the topic 'Livestock' in Chapter 3.

➤ The *State of the Environment Report 2007*[137] provides information about soil erosion; see www.soe.wa.gov.au.

If the source of sediments is sheet or gully erosion, measures to reduce stormwater flow rates, improve infiltration and stabilise soil surfaces can be very effective.

This can be achieved in a number of ways, for example:

- strategic revegetation of the dryland area around wetlands, to stabilise sediment and intercept sediment in stormwater, and regeneration of wetland vegetation
- constructing sediment traps/settling ponds
- retrofitting stormwater systems to reduce direct discharge of stormwater into wetlands via drains and increase diffuse overland flow of stormwater through vegetated dryland buffers.
- installation of erosion control banks to channel runoff to other areas.

Reducing suspended solid transport from building sites

Tips for building sites include:

- prepare a site management plan that includes evaluation of the site conditions and risks and outlines measures to manage wastes, control erosion and reduce the risk of stormwater pollution
- secure all litter and waste on site before disposing of it thoughtfully
- keep the verge, footpath and gutter free of building materials and wastes
- install an erosion/sediment barrier to catch sand and coarse sediment
- place sand, mulch and gravel stockpiles behind sediment barriers
- contain wash water and wastes from concrete, plaster, paint or brickwork in one area on site
- ensure rainfall runoff from downpipes does not leave the site
- use a shovel and broom to clean up sediments tracked onto roads by vehicles.

➤ For detailed information on how to manage sediments in the catchment, see the *Stormwater management manual for Western Australia.*[30] Managing construction practices are outlined in Chapter 7, Section 2.1.

Reducing suspended solid transport from mining and industrial sites

Guidelines for reducing suspended solid transports generated by mining and industrial sites are listed in Table 27.

Table 27. Guidelines on managing suspended solids in mining and industry

Application	Guideline
General	*Ponds for stabilising organic matter* WQPN[208]
Extractive industries	*Extractive industries near sensitive water resources* WQPN[209]
Mining and mineral processing	*Mining and mineral processing: tailings facilities water quality protection guideline*[210]
Mining and mineral processing	*Mining and mineral processing: liners for waste containment*[211]
Industrial sites	*Stormwater management at industrial sites* WQPN[212]
General and heavy industry	*General and heavy industry near sensitive waters* WQPN[72]
Light industry	*Light industry near sensitive waters* WQPN[71]

Reducing re-suspension of solids in wetlands

Erosion and re-suspension by animals within wetlands is readily addressed, and is described in other topics of this guide.

➤ Controlling introduced animals in wetlands is described in 'Introduced and nuisance animals' in Chapter 3.

➤ Horses, cattle and sheep are covered in 'Livestock' in Chapter 3.

➤ Nuisance midge populations may be covered in a future topic 'Nuisance midge and mosquitoes' in Chapter 3.

Closing wetlands to waterskiing and powerboats is also an effective measure. For example, in May 2012, DEC in co-operation with the Department of Transport closed Lake Jasper in D'Entrecasteaux National Park to powerboats. Approved waterskiing sites are listed at www.transport.wa.gov.au/marine.

Turbidity is generally manageable using catchment prevention and intervention techniques. Where human-induced turbidity presents a serious problem in wetlands of conservation value, removing sediments is not considered a viable solution. This is because:

- Wetland sediment is an extremely important part of a wetland. It helps to form the ecological character of a wetland, being important as habitat and the site of the most important chemical processes in wetlands. It also affects the wetland water regime. Removing wetland sediment can have short, medium and long-term effects on wetland ecology, including potentially irreversible changes to wetlands. Proposals of this nature can have significant ecological impacts and require referral to the Environmental Protection Authority under Part IV of the *Environmental Protection Act 1986*.
- Disturbing the sediments can expose acid sulfate soils and cause acidification of the wetland.
- Disturbing sediments has the potential to mobilise contaminants, such as arsenic and lead, in toxic concentrations if they are present in the sediment.

Considerations

- Wetlands typically do not provide firm ground from which to operate conventional excavating machinery such as front-end loaders or scrapers. Geotechnical investigations need to confirm that the extent of consolidation of wetland sediments is sufficient to support machinery.

- Floating dredges using industrial strength suction pumps have been proposed in the past. These required the establishment of settling ponds to enable dredged sediment to settle, given an extraction ratio of 5 per cent sediment to 95 per cent water followed by the return of the water to the wetland. Previous proposals have also required a minimum water depth of 1 metre to enable the dredge to operate.
- Considerable deepening may be a result. Deepening can alter the habitat and water regime, as well as potentially leading to stratification, which can have implications for nutrient management in the future.
- The disposal of the excavated sediment may be regulated. Sediments containing contaminants may be classified as contaminated waste, for which there are specific disposal requirements. For example, it may have high levels of heavy metals.

Thermal water pollution: the excessive raising or lowering of water temperatures above or below normal seasonal ranges in streams, lakes, estuaries, or oceans as a result of the discharge of hot or cold effluents into such waters

Managing thermal pollution

Thermal pollution of wetlands can occur when wastewater discharged into wetlands is significantly warmer or cooler than the ambient water temperature of the receiving water.

Causes

Heated wastewater may be a by-product of industries such as power generation plants, which use water to cool machinery (cooling water), before being discharged. Urban stormwater (from roads and car parks) and clearing fringing vegetation around wetlands (reducing shading) may also lead to increased water temperature in wetlands.

Another form of thermal pollution, 'coldwater pollution', can occur when very cold irrigation water is released from dams or other storage bodies (for example, for flood irrigation) and enters waterways and wetlands.[31] Both forms of thermal pollution can have serious impacts on aquatic ecosystems, in particular, aquatic fauna such as fish, amphibians and macroinvertebrates.

Impacts

Temperature plays an important role in regulating photosynthesis in plants and algae, and aerobic respiration, metabolism, growth and reproduction in aquatic organisms. Temperature changes of 1 or 2 degrees Celsius may be enough to cause significant damage in sensitive organisms, affecting reproduction and mortality. For example, some species of fish are dependent on specific temperature regimes to trigger development of reproductive organs and spawning.[31] Variations in temperature outside of the tolerance limits of aquatic organisms can result in loss of species and changes in community structure to favour species that are more tolerant of temperature fluctuations.

Water temperature strongly influences physical and chemical parameters that play a role in maintaining healthy functioning of aquatic organisms, such as dissolved oxygen level, pH and conductivity. For example, water is more likely to become anoxic due to decreasing availability of dissolved oxygen as temperature increases and increased bacterial respiration. Temperature also affects arsenic toxicity and aluminium speciation and solubility.[14]

The degree to which aquatic organisms and wetland ecosystems as a whole may be affected by thermal pollution includes:

- Tolerance range (and duration of exposure) of aquatic organisms during different stages of their lifecycle. Aquatic organisms may be more or less sensitive to temperature changes during the various life stages. Juveniles and adults at reproductive stage may be more sensitive than adults generally.

- How growth of primary producers (plants, algae, cyanobacteria) is affected by temperature change. If growth is stimulated by increased temperature, this may lead to nuisance growths such as algal or cyanobacterial blooms.
- Whether or not temperature changes lead to increased abundance of introduced or pest species and decreases in the diversity and abundance of native species.

Indicators

Visual indicators of thermal pollution may not be immediately obvious where temperature changes are not so sudden or great as to produce immediate lethal effects. In instances where temperature changes are localised within a wetland (such as around a drain outlet), fish and other organisms may avoid these areas and congregate in areas where temperatures are within their tolerance range. If a temperature rise results in deoxygenation of water, fish may be seen at the water surface 'gasping' for air. Lethal effects may be noticeable where an abrupt and significant increase or decrease in water temperature occurs and fish and other organisms are killed shortly after exposure (thermal shock).

Thermal pollution can be determined by measuring water temperature and comparing this against known 'ambient' temperatures, or if these have not been previously determined, compared against the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.[14] It should be noted that water temperature may fluctuate naturally during the course of a day due to changes in air temperature, sunlight, shading and local water movement. For example, temperature of surface water varies during the day and tends to be highest in the later afternoon as the sun is setting, and the interpretation of temperature measurements needs to consider these natural variations. Further, some wetlands may be naturally stratified, in which large temperature differences occur between surface and bottom waters. This can occur in deeper wetland bodies such as lakes and in shallow coloured lakes due to heat absorption.

Temperature measurements are usually made with digital instruments or mercury thermometers (with 0.1 degrees Celsius increments). Temperature loggers can also be used to measure and record temperatures at different depths and over specified periods of time.

Long-term monitoring of water temperature provides an indication of natural variations in temperature cycles, as well as temperature anomalies caused by human activities (for example, large changes in temperature).

➤ For additional information on monitoring temperature in wetland waters, see the topic 'Monitoring wetlands' in Chapter 4.

Managing thermal pollution

The most effective strategy for managing thermal pollution is to prevent heated/cooled water from being discharged into wetlands. If this is not possible, a range of techniques may be used to manipulate temperature of inflow water to temperatures that are within normal ranges of receiving wetlands. Temperature manipulation techniques would normally be undertaken at the point source of wastewater generation (for example, industrial operations) and include:

- Cooling ponds – heated wastewater is passed through specially constructed cooling ponds, where water temperatures are reduced by mixing (dilution), evaporation, convection and radiation.
- Cooling towers – heat from wastewater is transferred to the atmosphere by evaporation or heat transfer.

- Aeration – aerators can be used in cooling ponds before wastewater reaches wetland, or within the wetland itself. A well mixed water column prevents stratification from developing (i.e. a layer of warm water developing within the wetland water column), thus buffering the effect of thermal pollution.
- In urban areas, heated stormwater runoff can be diverted to groundwater through infiltration basins or artificial wetlands.

Managing litter and debris

Apart from being unsightly, litter and debris can cause significant problems in wetlands, particularly where these materials contribute to nutrient loads from breakdown of organic matter or the release of toxic materials. Examples of litter and debris that can be introduced into wetlands, affecting water quality include:

- household rubbish such as paper, cardboard, plastic, fishing line, food waste, aluminium cans, animal excreta, bricks, rubble, furniture, mattresses, white goods, clothing, batteries and containers holding toxic substances such as herbicides, insecticides, paint, petrol, oil etc
- garden waste such as street sweepings, prunings, lawn clippings, weeds, leaves, soil and mulch
- larger items such as timber, car bodies, and metal objects (Figure 47).

Figure 47. Dumped car bodies in wetlands are not only unsightly, they can also leak toxic substances into wetlands. This car was dumped in a wetland in Kemerton. Photo – DEC/ Wetlands Section.

Causes

Litter and debris can enter wetlands from stormwater (for example, as overland flow or from urban stormwater and agricultural drains), or they may blown into wetlands or deliberately disposed of by humans.

Impacts

Litter and debris can directly or indirectly affect water quality by introducing weeds, pathogens, nutrients, sediment and suspended particulate matter, metals, pesticides, acids and a range of other chemicals and toxicants. The effects on wetland ecosystems will depend on the type of litter or debris that is introduced, for example, garden waste can introduce pathogens such as *Phytophthora cinnamomi* responsible for phytophthora dieback, weeds and cause nutrients to build up as a result of waste decomposition upon reaching the wetland. Dumping of building materials such as sand and rubble can increase turbidity due to erosion and stormwater mobilising particulates from stockpiles.

➤ These impacts are discussed in more detail in the topics 'Phytophthora dieback' and 'Wetland weeds' in Chapter 3, and within this topic under the headings 'Nutrients', 'Turbidity' and 'Pathogens'. The impacts of pesticides and metals is discussed within this topic under the headings 'Pesticides' and 'Metals'.

Wetland fauna including macroinvertebrates, fish, frogs, reptiles and birds may suffer physical injury or death as a result of ingesting litter/debris (from choking or poisoning), or by becoming entangled, trapped or smothered.

Indicators

The presence of litter and debris such as household rubbish, garden waste, car bodies, used chemical containers is evident as foreign material floating in the water or deposited on soil or vegetation.

Obvious signs may include injury, disease or death of fauna such as fish kills, birds swallowing or becoming entangled in fishing line or death of wetland vegetation due to increased turbidity, smothering, pathogens or physical damage. Not-so-obvious indicators of litter and debris on water quality such as increased turbidity, nutrients and introduction of pathogens, pesticides, metals and other toxic materials are discussed under the relevant section of this topic.

Managing litter and debris

Best practice management by particular industries, such as the building industry, can reduce the disturbance of sediment in the catchment. Stormwater management can reduce litter and debris in the catchment. Litter and debris in stormwater drains can be managed through the installation of structures (for example, 'trash racks') which are designed to trap rubbish before it enters receiving wetlands (Figure 48). These need to be cleared regularly to prevent build up of material, which impedes water flow and can lead to flooding. Where structural control options are not practical, litter and debris may need to be removed manually. This can be undertaken when water levels are lowest, allowing for better access into areas that would otherwise be inundated. Litter and debris can become trapped in native vegetation and therefore care should be taken when removing it in order to minimise damage to native plants. Community litter prevention programs can be very effective in preventing disposal of waste that may otherwise end up in local wetlands.

➤ Keep Australia Beautiful WA provides support and resources for litter prevention. See www.kabc.wa.gov.au for more information.

Figure 48. Structures to prevent litter and debris from entering drains and wetlands need to be cleared regularly. Photo – DEC.

Glossary

Acid neutralising capacity: a measure of the soil's inherent ability to buffer acidity and resist the lowering of the soil pH

Acid sulfate soils: includes all soils in which sulfuric acid is produced, may be produced or has been produced in quantities that can affect the soil properties. Also referred to as acid sulphate soils.

Acidity: the amount of acidity associated with all dissolved ions in a solution, expressed as an amount of pure calcium carbonate needed to neutralise these. Dissolved ions include hydrogen ions and commonly free dissolved metals such as aluminium, iron and manganese.

Active (or actual) acid sulfate soils: soils in which the sulfidic minerals have oxidised and the pH has fallen to very low levels

Acute toxicity: sublethal or lethal impacts resulting from a single or multiple exposures to an agent in a short time (usually less than 24 hours)

Adjuvant: includes substances such as surfactants, oils, penetrants and wetting agents

Adsorption: the adhesion of a substance to the surface of a solid or liquid

Aeration: the addition of oxygen to the water column of a wetland

Aerobic: an oxygenated environment (organisms living or occurring only in the presence of oxygen are aerobes)

Aestivating: being in a state of dormancy that occurs in some animals to survive a period when conditions are hot and dry

Algae: a general term referring to the mostly photosynthetic, unicellular or simply constructed, non-vascular, plant-like organisms that are usually aquatic and reproduce without antheridia and oogonia, that are jacketed by sterile cells derived from the reproductive cell primordium; includes a number of divisions, many of which are only remotely related to each other

Algaecide: any chemical or biological agent intended to kill algae

Alkalinity: a solution's capacity to neutralise an acid, expressed as the amount of hydrochloric acid needed to lower pH of a litre of solution to pH 4.5. The concentration of bicarbonate (HCO_3^-), or when pH is greater than 8.3, the concentration of carbonate (CO_3^{2-}). Sometimes due to dissolved silicate, phosphate or ammonia in relatively high concentrations (tens of milligrams per litre).

Anoxic: deficiency or absence of oxygen

Bassendean Sands: (also known as the Bassendean Dunes) a landform on the Swan Coastal Plain, comprised of heavily leached aeolian sands, located between the Spearwood Dunes to the west and the Pinjarra Plain to the east

Benchmark: a standard or point of reference; a predetermined state (based on the values that are sought to be protected) to be achieved or maintained

Benthic: the lowermost region of a wetland water column; the organisms inhabiting it are known as benthos

Bioaccumulate: process in which tissues of an organism accumulate a chemical because uptake is greater than elimination and breakdown

Bioavailable: in a chemical form that can be used by organisms

Biodiversity: encompasses the whole variety of life forms—the different plants, animals, fungi and microorganisms—the genes they contain, and the ecosystems they form. A contraction of 'biological diversity'.

Biofilm: bacteria, microalgae, fungi and unicellular microorganisms enmeshed in a hydrated mucopolysaccharide secretion that sequesters ions and isolates microorganisms from the water column[101]. May be present on living and non-living surfaces and substrates.

Biological parameters: organisms that inhabit wetlands such as algae, macroinvertebrates, fish

Biomagnify: an increase in the concentration of a chemical along a food chain

Bioremediation: the use of microorganisms to break down environmental pollutants

Bloom: rapid, excessive growth, generally caused by high nutrient levels and favourable conditions

Buffering capacity: a measure of the soil's inherent ability to buffer acidity and resist the lowering of the soil pH

Carcinogenic: cancer-causing

Catchment: an area of land which is bounded by natural features such as hills or mountains from which surface water flows downslope to a particular low point or 'sink' (a place in the landscape where water collects)

Chemical parameters: chemicals found in water such as dissolved oxygen, pH, nutrients and pollutants

Chronic toxicity: sublethal or lethal impacts resulting from a single or multiple exposures to an agent over a longer time period (months or years)

Cyanobacteria: a large and varied group of bacteria which are able to photosynthesise

Damplands: seasonally waterlogged basin wetlands

Decomposition: the *chemical* breakdown of organic material mediated by bacteria and fungi, while 'degradation' refers to its *physical* breakdown. Also known as mineralisation.

Denitrification: the conversion of nitrate (NO_3^-) to elemental nitrogen (N_2) under deoxygenated conditions, facilitated by specialised bacteria

Detritus: organic material originating from living, or once living sources including plants, animals, fungi, algae and bacteria. This includes dead organisms, dead parts of organisms (e.g. leaves), exuded and excreted substances and products of feeding.

Diatom: a microscopic, single-celled alga with cell walls made of hard silica, freely moving in the open water and forming fossil deposits

Dystrophic: a wetland that suppresses increased algal, cyanobacterial and plant growth even at high nutrient levels due to light inhibition

Endemic: naturally occurring only in a restricted geographic area

Endocrine disruptor: a synthetic chemical that when absorbed into the body either mimics or blocks hormones and disrupts the body's normal functions

Endocrine system: a complex network of glands and hormones that regulates many of the body's functions, including growth, development and maturation, as well as the way various organs operate

Eutrophic: nutrient rich waters or soil with high primary productivity (plant/algal/cyanobacterial growth). From the Greek term meaning 'well nourished'.

First flush: the first rainfall for a period of time, resulting in stormwater dislodging and entraining relatively high loads of sediments, particulates and pollutants that have built up in the intervening period between rainfall events, and typically carrying a higher pollutant load than subsequent events

Flocculation: the joining of particles (small objects) into loose masses (floc) in water

Gnangara groundwater system: the groundwater system formed by the superficial, Leederville and Yarragadee aquifers located in northern Perth, east to Ellen Brook, south to the Swan River, west to the Indian Ocean and north to Gingin Brook

Groundwater: water occurring beneath the ground surface in spaces between soil grains and pebbles and in fractures or crevices in rocks

Groundwater capture zones: the area within which any recharge (infiltrating water) eventually flows into the wetland

Groundwater plume: body of polluted water within an aquifer

High water soluble phosphorus fertilisers: products containing greater than 2 per cent total phosphorus and greater than 40 per cent of the total phosphorus as water soluble phosphorus

Impermeable: does not allow water to move through it

Indicators: the specific components and processes of a wetland that are measured in a monitoring program in order to assess changes in the conditions at a site

Internal eutrophication: eutrophication of wetland surface waters as a result of changes in water quality without additional external supply of nutrients[42]

Invertebrate: animal without a backbone

Ion: an atom that has acquired an electrical charge by the loss or gain of one or more electrons

Iron ferrolysis: a process by which anoxic groundwater containing dissolved ferrous ions is exposed to air and ferrous irons are oxidised to ferric ions, which reacts with water to form orange-brown precipitates, gels or crusts of ferric oxyhydroxides, releasing free hydrogen ions in the process

Latent: dormant, inactive

Lethal effect: where exposure to an agent such as a toxin results in death

Limiting nutrient: the nutrient in an ecosystem which limits further growth because it is available at proportionately lower levels with respect to other nutrients needed for primary producers to increase their abundance

Luxury uptake: the process by which some organisms take up more nutrients than they need for current growth, instead storing them for future growth

Macroalgae: algae large enough to be seen with the unaided eye

Microalgae: microscopic algae

Midges: biting and non-biting species of a number of families within the true flies (Diptera) including the Chironomidae and Ceratopogonidae.

Mutagenic: mutation-causing

Net acidity: the degree of acidity in water, accounting for dissolved alkalinity (that is, acidity minus alkalinity, measured in units of $CaCO_3$ equivalent per litre)

Nitrification: the conversion of ammonia (NH_3) or ammonium (NH_4^+) to nitrate (NO_3^-) in freshwater wetlands under oxygenated conditions, facilitated by specialised bacteria, if conditions (pH, temperature, organic carbon availability) are suitable

NTU: nephelometric turbidity unit is a measure of the clarity of water. Turbidity in excess of 5 NTUs is just noticeable to most people.

Organism: any living thing

Oxidation: the removal of electrons from a donor substance

Particulates: in the form of particles (small objects)

Pathogen: any organism or factor causing disease within a host

Pesticide: any chemical or biological agent intended to kill animals or plants

Phenol: complex organic compounds derived from plant materials

Physical parameters: physical characteristics of water such as temperature, turbidity, colour

Potential acid sulfate soils: soils that can contain significant sulfidic material, which on oxidation can cause the pH of the soil to fall to very low levels

Precipitate: cause a substance to be deposited in solid form from a solution

Reference range: a quantitative and transparent benchmark appropriate for the type of wetland

Resilience: capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks

Scum: froth or floating matter on the water surface

Sediment: in general terms, the accumulated layer of mineral and dead organic matter forming the earth surface of a wetland. Used interchangeably in this guide with the terms 'wetland soil' and 'hydric soil', although all three of these terms have more specific meaning in wetland pedology.

Sediment pore waters: water which is present in the spaces between sediment grains at or just below the land surface. Also called interstitial waters.

Setback: a minimum distance between a particular land use and a wetland. A setback does not necessarily preclude other land uses within that setback area, in contrast to a wetland buffer. Land uses associated with a relatively high potential for site contamination, nutrient export or alterations to wetland water regimes (for example, some forms of intensive agriculture, industry, some effluent treatment facilities and groundwater abstraction) may require setbacks greater than the wetland buffer.

Slightly disturbed: ecosystems that have undergone some changes but are not considered so degraded as to be highly disturbed. Aquatic biological diversity may have been affected to some degree but the natural communities are still largely intact and functioning. An increased level of change in physical, chemical and biological aspects of these ecosystems is to be expected.[13]

Species: a group of organisms capable of interbreeding and producing fertile offspring, for example, humans (*Homo sapiens*)

Stormwater: water flowing over ground surfaces, in natural streams and drains as a direct result of rainfall over a catchment. It consists of rainfall runoff and any material (soluble or insoluble) mobilised in its path of flow

Stratification: the division of the water column into distinct layers called the epilimnion (top), the metalimnion (middle) and the hypolimnion (bottom), due to differences in water density between the layers

Sublethal effect: where exposure to an agent such as a toxin is insufficient to cause death, but may result in other adverse impacts

Sulfate-mediated eutrophication: eutrophication of wetland surface waters as a result of changes in water quality associated with sulfate rather than additional external supply of nutrients

Surfactant: a substance that helps water or other liquid to spread or penetrate. Also known as a wetting agent or penetrant.

Swan Coastal Plain: a coastal plain in the south west of Western Australia, extending from Jurien south to Dunsborough, and the Indian Ocean east to the Gingin, Darling and Whicher Scarps

Teratogenic: causing malformations of an embryo or foetus

Thermal water pollution: the excessive raising or lowering of water temperatures above or below normal seasonal ranges in wetlands, waterways, estuaries or oceans as a result of the discharge of hot or cold effluents into such waters

Transpiration: the process in which water is absorbed by the root systems of plants, moves up through the plant, passes through pores (stomata) in the leaves and other plant parts, and then evaporates into the atmosphere as water vapour

Trigger values: quantified limits that, if exceeded, would indicate a potential environmental problem, and so 'trigger' a management response e.g. further investigation

Trophic: from the Greek word for 'feeding', it relates to food and nutrition

Trophic classification: the classification of an ecosystem on the basis of its productivity or nutrient enrichment. The three main trophic classes are oligotrophic, mesotrophic and eutrophic.

Tolerance limits: the upper and lower limit to the range of particular environmental factors (e.g. light, temperature, salinity) within which an organism can survive. Organisms with a wide range of tolerance are usually distributed widely, while those with a narrow range have a more restricted distribution.

Turbid: the cloudy appearance of water due to suspended material

Turbidity: the extent to which light is scattered and reflected by particles suspended or dissolved in the water column

Water hardness: a measure of the concentration of calcium and magnesium ions in water, frequently expressed as milligrams per litre calcium carbonate equivalent

Water quality: the quality of water relative to its natural, undisturbed state

Water regime: the specific pattern of when, where and to what extent water is present in a wetland. The components of water regime are the timing, frequency, duration, extent and depth and variability of water presence.

Wetland buffer: an interface adjoining a wetland that is designated to assist in protecting the wetland's natural values from the threats posed by the surrounding land use(s)

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A guide to managing and restoring wetlands in Western Australia

Secondary salinity

In Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Secondary salinity' topic

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Contents

Case studies

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

Ion: an atom with an electrical charge. Used to refer to dissolved salts such as sodium (Na+) or chloride (Cl-) in solution

Salinisation: the process of accumulation of salts in soils, waters or sediments

Salts: ionic compounds comprised of cations (positively charged ions, such as sodium, Na+) and anions (negative ions, such as chloride, Cl-)

What is secondary salinity?

Salinity is a measure of the concentration of **ions** in waters, soils or sediments.[1] **Salinisation** can be a natural process, originating from sea **salts** that become airborne and are transported inland and which gradually accumulate in inland soils over thousands of years, or from natural salt build-up through contact with saline water near the coast. These processes give rise to naturally saline soil and wetlands. There are many such naturally saline wetlands in Western Australia, and they support a range of ecological values. In contrast, **'secondary' salinisation** is a human-induced degrading process in which the salt load of waters or soils increases at a faster rate than would have occurred naturally, leading to secondary salinity. Secondary salinity can occur in both freshwater and naturally saline wetlands.

➤ For information about naturally saline wetlands, see the topic 'Conditions in wetland waters' in Chapter 2.

There are two main types of secondary salinisation in Australia; dryland salinisation and irrigation salinisation. Dryland salinity occurs on non-irrigated land (including wetlands) and usually results from broadscale clearing of native vegetation and its replacement with crops and pastures that use less water, while irrigation salinity occurs through the addition of irrigation water to a landscape. In both cases, a change to the water balance leads to accelerated land and water salinisation. In Western Australia the predominant form is dryland salinisation, which occurs in the inland agricultural zone of the south-west (Figure 1).

Irrigation salinisation occurs in the Ord Irrigation Area in the north-east of the state and some of the irrigation areas of the south-west[2], with salt scalds evident in some areas of the Harvey River catchment.[3] About 20 per cent of the southern Swan Coastal Plain (i.e. between Gingin to Dunsborough) is considered to be at risk.[4] However irrigation salinity is not nearly as widespread as dryland salinisation[5], and is not discussed further in this topic.

Background to secondary salinity in Western Australia

Secondary salinity is a major threat to **biodiversity** in south-western Australia[7] and poses a serious threat to the biodiversity and **ecosystem processes** occurring in many wetlands in south-west WA.

Even relatively small increases in the levels of water and sediment salinity can dramatically decrease the growth, reproductive capacity and survival of wetland plants and animals, and if salinity ranges cross critical **thresholds** (which vary between species) this may cause irreversible loss of species and communities. In addition, increased salinity is coupled with changes to wetland **water regime**, particularly an increase in water depth and loss of seasonal wetting and drying cycles, and the combined effects of these two stresses on wetland **organisms** are even more severe.

The main area of Western Australia that is affected by secondary salinity is the inland south-west agricultural zone, which extends from north of Geraldton to east of Esperance, and which lies to the east of the Darling Scarp within the 300 and 600 millimetre rainfall zones[9,10] (Figure 1). The western part of the inland agricultural area and the south coast east of Esperance are particularly affected.[9,10]

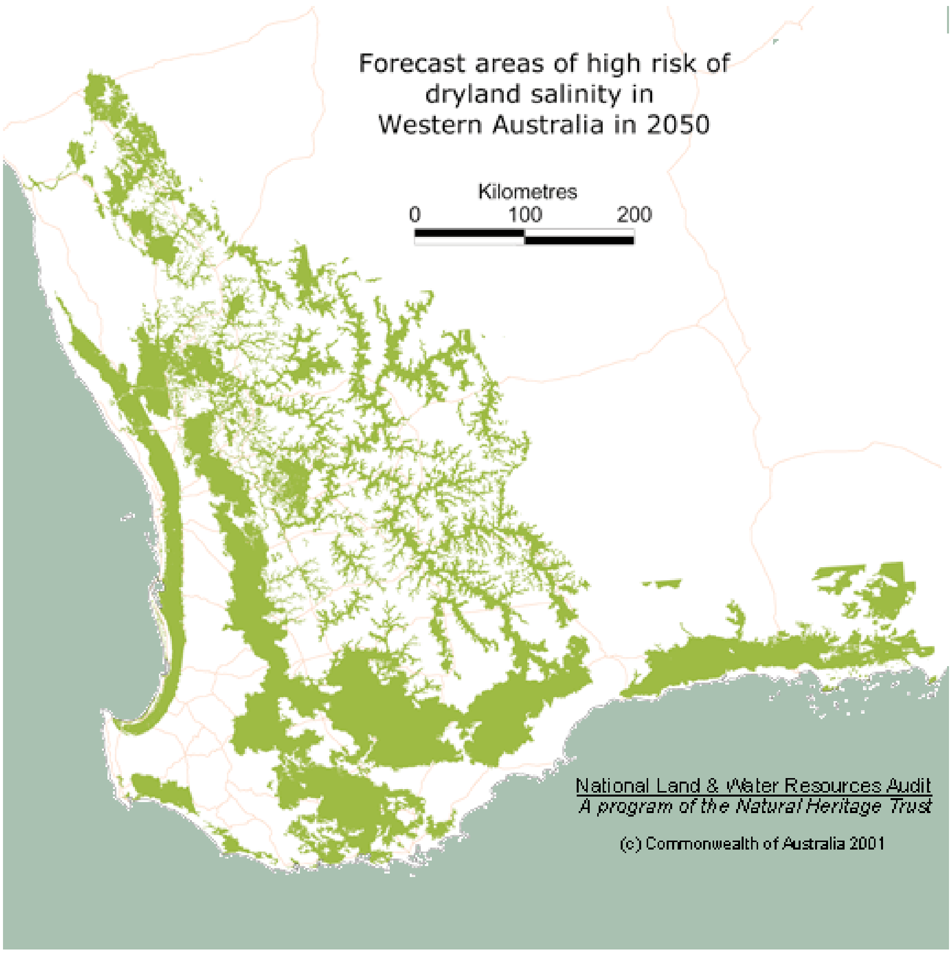


Figure 1. Forecast areas of high risk of salinity in 2050, based on the predicted extent of land at risk of high water tables (from Australian Natural Resources Atlas 2007[6]).

Biodiversity: encompasses the whole variety of life forms—the different plants, animals, fungi and micro-organisms—the genes they contain, and the ecosystems they form. A contraction of 'biological diversity'

Ecosystem: a community of interdependent organisms together with their non-living environment

Ecosystem processes: the complex interactions (events, reactions or operations) among biotic and abiotic elements of ecosystems that lead to a definite result[8]

Thresholds: points at which a marked effect or change occurs

Water regime: (of a wetland) the specific pattern of when, where and to what extent water is present in a wetland, including the timing, duration, frequency, extent and depth and variability of water presence[1]

Organisms: any living things (includes plants, animals, fungi and microbes)

Figure 2. (below) Two south-west Western Australian wetlands affected by secondary salinity. Photos - L Sim.

(a) Lake Mears, near Brookton

(b) Rushy Swamp, near Woodanilling

Dryland salinisation occurs over long time scales (decades to hundreds of years) and over very large areas, making it very challenging to manage. In 2001, the Land Monitor project estimated that the area of the state affected by salinity was about one million hectares and increasing at 14,000 hectares a year, based on 1996 data.[11] In total, 5.4 million hectares of the south-west are estimated to be at risk from dryland salinity.[11]

The number of wetlands potentially at risk is not known, as comprehensive mapping of all wetlands in south-west Western Australia is not complete. The landscape-scale processes driving secondary salinity mean that only limited intervention is usually possible at a wetland scale.

Along with its impacts on the environment, secondary salinity also has major economic implications, including the degradation of agricultural land and infrastructure such as roads and rural towns. This is accompanied by significant social impacts on rural communities, landholders and Aboriginal cultural heritage.[12]

What causes the salinisation of Western Australian wetlands?

Dryland salinisation within the south-west of Western Australia has developed as a result of the widespread clearing of **perennial** native vegetation and its replacement with **annual** crops and pastures which use less water. Most clearing took place between 1900 and 1930, and from 1950 to 1980.[13] Increases in water and land salinities in Western Australia were first noticed in the 1920s, however, the problem only became widely recognised throughout the inland south-west agricultural area several decades later.[13]

The inland south-west agricultural area is dominated by areas of naturally flat **landform**, low annual rainfall and high evaporation. These conditions have promoted the natural accumulation of airborne sea salts in the soils over hundreds of thousands of years.[10] Natural salinisation of many areas of the south-west occurred slowly before the landscape was disturbed by clearing, resulting in the development of naturally saline wetlands. In the Wheatbelt such sites of primary salinisation are estimated to have occupied less than 1 per cent of land area.[14] The rate of salinisation since land clearing and the areas affected by secondary salinity are much greater.[15] In areas of higher rainfall, lower evaporation and hillier landform (such as the tropical north, the Darling Scarp and areas of the south coast of Western Australia) the clearing of native vegetation has not had the same salinising effect.[10]

As described, dryland salinisation is linked to the clearing of native, perennial vegetation (such as trees) and its replacement with annual crop species (such as wheat).[10] This drives large-scale changes in **hydrology** – that is, the distribution and movement of water between the land surface, **groundwater** and atmosphere. Before broadscale land clearing, less than 1 millimetre per year of rainwater used to reach the groundwater in much of the inland south-west agricultural area; the rest was evaporated or **transpired** by vegetation, with the majority of water use in summer.[10] Most of the rainfall, except in large episodic events, infiltrated into the soils locally, with very limited surface flows (Figure 3(a)). The soils were also covered in a thin surface crust (a hard, water-repellent top layer), which prevented water from soaking in easily, and this crust has been disturbed by livestock and tilling for crops.[10] Both the removal of native perennial vegetation (particularly trees) and increased disturbance of the soil surface have resulted in increased amounts of water reaching the **groundwater tables**, causing them to rise (Figure 3(b), (c)). In consequence, both naturally saline groundwater and the salt stored in the soil profile are brought to the surface as the water rises.[10] The result is a significantly increased salt load in surface soils and in the region's fresh and naturally saline wetlands and waterways.[10] Rates of salinisation vary significantly across the region, but at Lake Bryde for example, salinity levels have increased rapidly with researchers identifying a ten-fold increase between 1981 and 1994.[16]

Wetlands often become salinised more quickly than other areas of the landscape because they are predominantly located in low-lying positions in catchments.[17] Saline water may enter wetlands directly from the underlying groundwater (Figure 3(b)). Wetlands that are not intercepted by the saline groundwater table may receive salty surface flows (Figure 3(c)). Many wetlands receive both saline groundwater and surface flows. As a result, most wetland types in the inland agricultural areas are affected by salinisation.

Few wetland types within the inland south-west agricultural area are considered to be at low risk of salinity and altered hydrology. These are typically higher in the catchments, for example, the bentonite wetlands in the Buntine-Marchagee catchment. They may be protected by geological features, for example, **gnammas** located on rocky outcrops and **perched** wetlands in vegetated catchments.[18] These wetlands should be managed as refuges for plants and animals vulnerable to salinisation.

Perennial: a plant that normally lives for two or more growing seasons (from germination to flowering, seed production and death of vegetative parts)

Annual: a plant that completes its life cycle within a single growing season (from germination to flowering, seed production and death of vegetative parts)

Landform: a natural feature of a landscape such as a valley, mountain, basin or plain

Hydrology: the properties of the Earth's water, particularly the distribution and movement of water between the land surface, groundwater and atmosphere

Groundwater: water occurring beneath the ground surface in spaces between soil grains and pebbles and in fractures or crevices in rocks

Transpire (transpiration)**:** the loss of water from plants to the atmosphere through evaporation

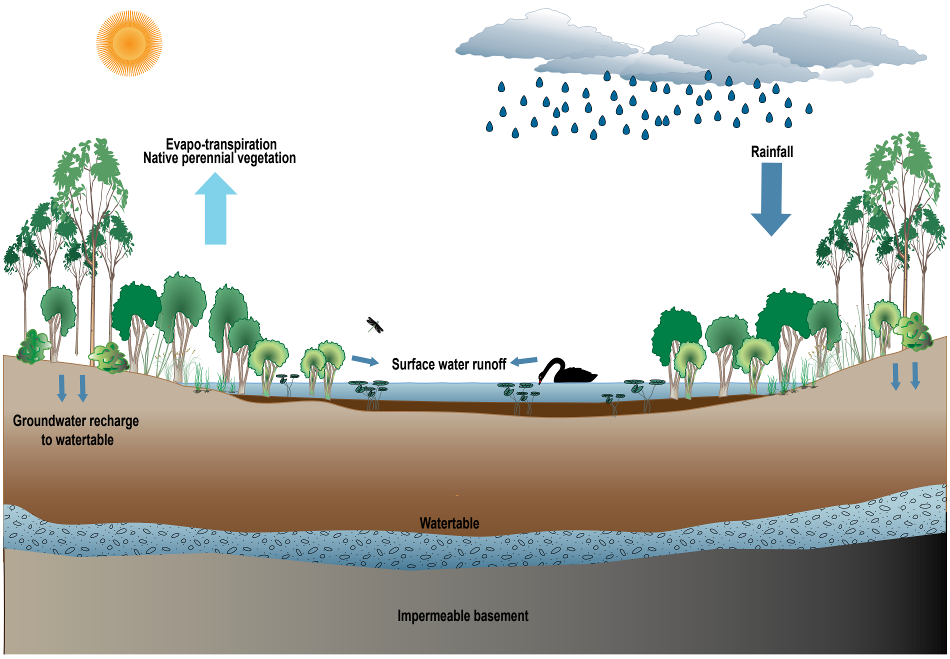
Groundwater table: the upper surface of the groundwater in an unconfined aquifer (top of the saturated zone)

Gnamma: a hole (commonly granite) that collects rainwater, forming a wetland. This word is of Nyoongar origin

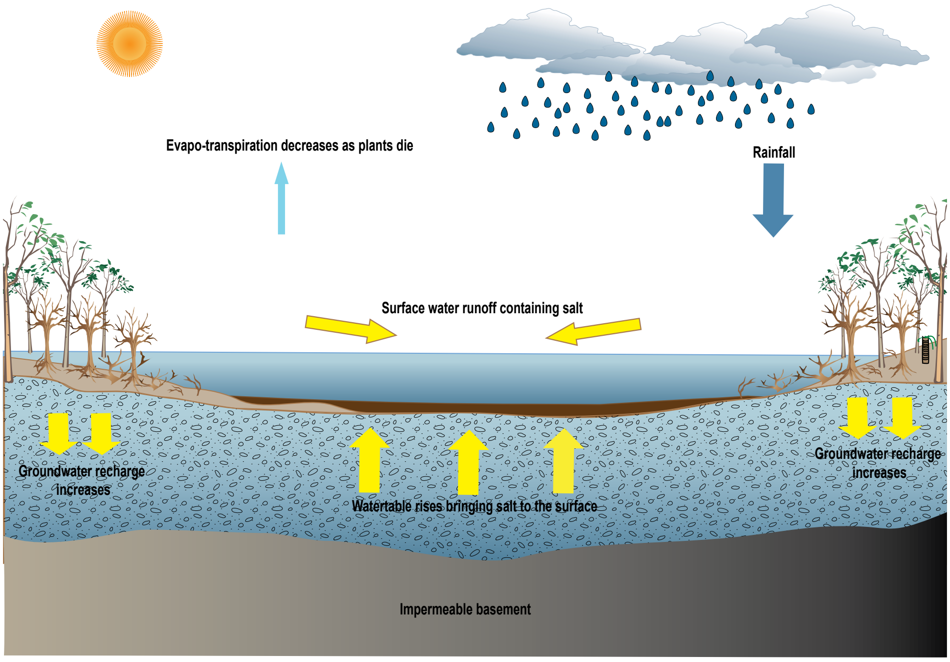
Perched: not connected to groundwater

In some areas that are affected by salinisation, freshwater seeps still exist, and along with wetlands less affected by salinisation, these may allow animals such as waterbirds to survive despite the salinity in the broader area, as they provide a source of fresh water for drinking.

Figure 3. (below) The distribution and movement of water and salt in wetlands of the Western Australian inland south-west agricultural area under (a) natural and (b) and (c) altered conditions after clearing.

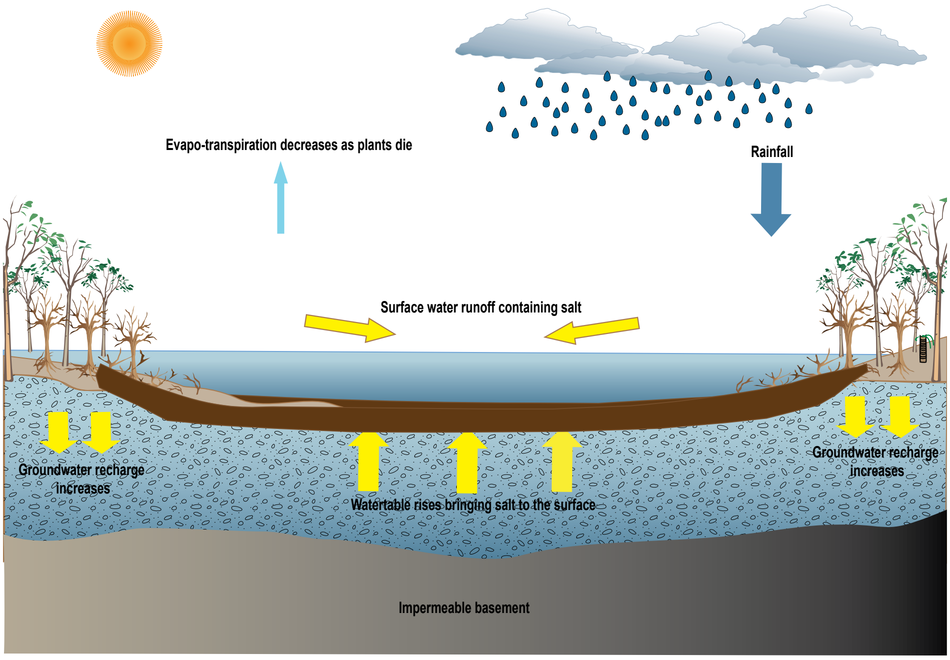


(a) Natural conditions of a wetland prior to clearing, showing low groundwater table, perennial vegetation and high transpiration rates.



(b) Altered conditions in a wetland after clearing, showing high groundwater table and low evapo-transpiration rates. In this scenario, saline groundwater is directly entering the wetland.

Figure 3. (continued)



(c) Altered conditions in a perched wetland after clearing, showing high groundwater table and low evapo-transpiration rates. In this scenario, the saline groundwater is not directly entering the wetland due to the presence of the impermeable clay layer. However it is reaching the soil surface and entering the wetland via surface flows.

Figure 3 depicts the process of secondary salinisation within landscapes that have relatively simple geological and hydrological profiles. In reality, the sub-surface characteristics and groundwater systems of the south-west of WA can be complex. To develop a better understanding of the conditions, specialist investigations including analysis of chemical isotopes and airborne electromagnetic surveying, such as that used in the Lake Warden catchment, may be used. Figure 4 shows more complex conditions present in many areas subject to secondary salinity.

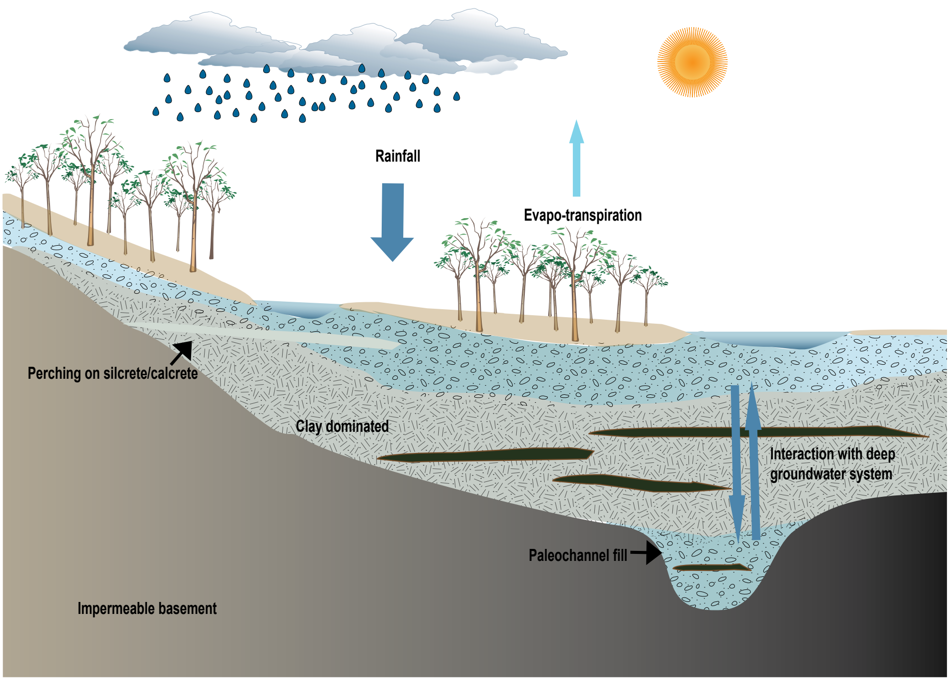


Figure 4. A representation of the complex, altered hydrological conditions present in areas of the agricultural zone within the zone of ancient drainage. Image – adapted from DEC.[19]

The general processes that lead to dryland salinity are similar throughout the inland south-west agricultural area, however, local and landscape variations in climate, landform, **geology** and the natural hydrology mean that the effect of land clearing and change in hydrology differ from place to place.

The trend of rising groundwater continues in high rainfall parts of the Wheatbelt and South Coast.[20] In contrast, the Environmental Protection Authority has reported that there is evidence to suggest that the drying climate in the south-west has lowered local groundwater levels in some places, slowing the rate of salinisation, especially in areas of the central and eastern Wheatbelt.[3] However the drying climate can create further stress on salinising systems, particularly perched wetlands, because the lack of rainfall deprives the plants and animals of the freshwater they require to survive and breed.

Geology: the composition, structure and features of the Earth, at the surface and below the ground

Metabolic functions: the processes occurring within a living organism that are necessary to maintain life

Endemic: naturally occurring only in a restricted geographic area

Microbe: an organism that is too small to be seen with the unaided eye, for example, bacterium, some algae

What effect does secondary salinity have on wetlands?

Dissolved salts occur naturally in fresh and naturally saline wetlands and play an important role in wetland chemical processes and the **metabolic functions** of wetland organisms, even when they are present in very low concentrations.[1,21,22] Furthermore, some species occurring in naturally saline areas are adapted to very high levels of salt. It is when a change in salinity level occurs very rapidly, or when a salinity threshold is reached for a particular species, that adverse effects on ecosystems may occur.[1,21,22]

Secondary salinisation can have significant impacts on the biological, chemical and physical components of both naturally fresh and naturally saline wetlands, and may ultimately cause a decline in biodiversity, the loss of **endemic** species, and changes in ecosystem processes. Naturally saline wetlands are not immune to the effects of secondary salinity, as it can alter the natural levels and ionic composition of salts to which the wetland plants, animals and **microbes** are adapted. The effects of secondary salinisation on wetlands are often particularly severe because they are coupled with significant and widespread changes in hydrology, and because they take place in an agricultural landscape where other pollutants such as nutrients, pesticides, acidic water and heavy metals are often also entering wetlands. Very little is currently known about how the combined effects of two or more threatening processes (for example, salinity and acidity) differ from those of salinity alone, although some work on the interaction between human-induced waterlogging and salinity has been done.[23] It is likely that the impact of multiple stresses on biodiversity and ecological processes is more severe than that of a single factor.

The biological, chemical and physical effects of salinisation are often interrelated, as the following sections describe.

➤ For additional detail on the effect of altered wetland water regime, see the topic 'Managing wetland hydrology' in Chapter 3.

➤ For additional detail on human-induced wetland acidity, see the topic 'Water quality' in Chapter 3.

Biological effects

The salinity ranges within which different species of wetland plants, animals and microbes survive, grow and reproduce are related to the salinities of their native environments. Organisms adapted to either naturally saline or freshwater conditions usually cannot tolerate large changes in the timing, duration, seasonality or range of salinities.[9,24] However, freshwater species are often sensitive to much smaller changes in salinity than salt-adapted species. The change from fresh to saline waters is generally accepted to occur at around 3 grams per litre (g/L) or 3 parts per thousand (ppt) of salinity.[24] This is the point at which marked changes in the types of plants and animals found in wetlands are expected. However, many salt-sensitive freshwater species may be unable to tolerate salinities as low as 1 part per thousand.[24]

Importantly, **juvenile** plants and animals are often much more susceptible to increased salinity levels than adults of the same species[24], therefore in order for a species to persist, salinities must be low enough during their development, as well as during reproductive phases, for **recruitment** to occur.

➤ For additional detail on salinity units, conversion and measurement, see the topic 'Conditions in wetland waters' in Chapter 2.

Vertebrates

The adults of many **vertebrate** species found in Western Australian wetlands are highly mobile, and can tolerate some increases in salinity levels if they can access alternative sources of fresh drinking water.[25,26,27] An example is the Australian shelduck (*Tadorna tadornoides*), which feeds at saline wetlands and is able to rid itself of excess salt it ingests through specially adapted nasal glands.[25] However, when breeding, Australian shelducks are dependent of fresh waters until their young develop an ability to rid their bodies of salt.[25]

Rather than restricting the community to a particular number of waterbird species, salinity appears to constrain the 'maximum potential number' of waterbird species occurring in agricultural zone wetlands, with **species richness** also being influenced by other factors such as water depth and density of emergent vegetation.[18] Even if an animal can tolerate some salinity change, it may still be lost from salinised wetlands due to the effect of the salinity on breeding or feeding habitats.

Another example of a moderately salt-adapted freshwater vertebrate is the oblong tortoise (*Chelodina colliei*), which is known to be able to tolerate estuarine level salinities if it has access to fresh water for breeding and long-term health (J Giles 2009, pers. comm.).[27] It does not possess a salt excretory gland (J Giles 2009, pers. comm.).

Only limited information is available about the tolerances of frogs to salinity in Western Australian wetlands, however, anecdotal information suggests that frog declines are associated with an increase in salinity.[13] The effect of increased salinity on populations of the spotted burrowing frog (*Heleioporus albopunctatus*) has been investigated in the inland south-west agricultural area, and there is some indication that there may be a decline in its numbers correlated with salinisation of its habitats, possibly related to the effect of salinity on eggs and tadpoles.[28] If this is the case, it is likely that other frog species in the region are also affected.

Juvenile: young or immature

Recruitment: addition of new individuals to a population (usually through reproduction)

Vertebrate: an animal with a backbone

Species richness: the total number of species (in a defined area)

Invertebrates

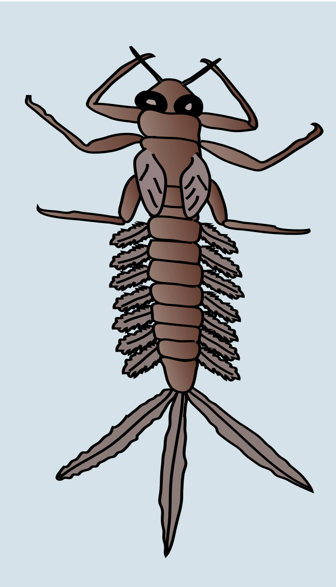
A few freshwater **invertebrate** species in south-western Australia are very salt tolerant, many are tolerant of mild salinity[9,29], but most, especially outside of the inland south-west agricultural zone, are largely restricted to freshwater (A Pinder 2009, pers. comm.). There is also a substantial number of salt-adapted fauna species called **halophiles** (from the Greek term for 'salt-loving') that show a preference for saline waters and many of these species are native to the south-west.[9,10] Many are restricted to naturally saline wetlands. These salt-adapted species are also threatened by salinisation, as salinity rises and hydrological regimes change.[9,30]

Despite some salt tolerance in the invertebrate fauna, the salinity changes occurring with salinisation have been too rapid and too large for freshwater species to adjust. Research[30] suggests that there are several salinity thresholds at which rapid loss of the Wheatbelt region invertebrate fauna occurs (in the higher rainfall areas of the south-west thresholds would be even lower). The most sensitive species are rapidly lost from wetlands with even very mild salinisation, leading to changes in the composition of the invertebrate fauna inhabiting the wetlands to more salt-tolerant species. Species richness (excluding halophiles, species that prefer very saline conditions) starts to decline at about 2.6 parts per thousand.[30] Those species that prefer saline waters decline in richness once salinity reaches above about 30 parts per thousand, though some will tolerate salinities many times that of seawater, which is around 35 parts per thousand. Even invertebrate groups with very high salt tolerances, such as the brine shrimp (*Parartemia* species) are showing declines in the Wheatbelt due to salinisation.[31] An example of a freshwater invertebrate group that contains many species sensitive to salinity increases is the insects (such as mayfly larvae), while groups like the **crustaceans** (such as copepods) tend to include a greater number of tolerant species (Figure 5).

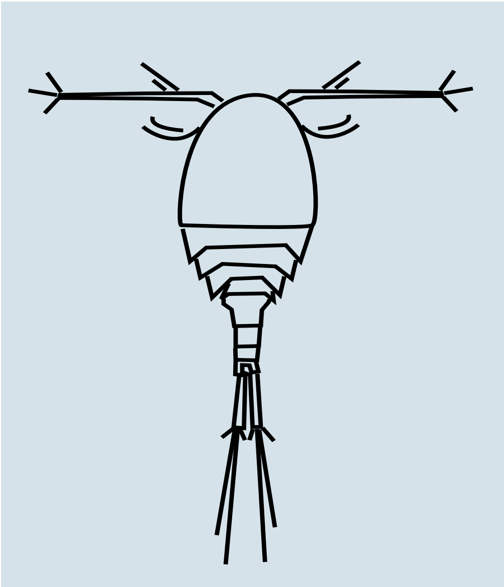
Invertebrate: an animal without a backbone

Halophile: a species that shows a preference for saline habitat such as salt lakes

Crustaceans: a class of animals that have a hard exoskeleton (shell) and usually live in the water, for example, crabs, lobsters, yabbies



(a)



(b)

Figure 5. Examples of (a) salt-sensitive (mayfly larvae) and (b) salt-tolerant (copepod) wetland invertebrate groups.

➤ For more information on invertebrates and the role they play in wetlands, see the topic 'Wetland ecology' in Chapter 2.

Plants

In general, freshwater wetland plant species tend to be sensitive to increases in salinity level and are rapidly replaced by salt-tolerant species as salinity increases.[24] In addition, changes to a wetland's salinity and water regime have different effects on **submerged** and **emergent** wetland vegetation due to their different tolerance ranges for these two factors. Many species of emergent vegetation (such as moonah (*Melaleuca preissiana*) and lake club-rush (*Schoenoplectus validus*), Figure 6) are perennial and feel the full effects of the combined stresses of increased salt and increased duration of waterlogging.[32,24] In contrast, freshwater submerged vegetation may be slightly protected from increased water in the wetland by being fully underwater, and annual submerged species can also persist through summer, when salinities levels are highest, as **dormant** seeds or **vegetative** parts such as **tubers**.[24] Despite this, in salinising wetlands, salinity levels quickly become too high for all freshwater organisms to survive. Even salt-tolerant plants such as species of *Ruppia* (Figure 6), *Lepilaena and Lamprothamnium* are lost when salinity levels exceed their tolerance limits.[33,14] Research[33] into salt-tolerant species of aquatic plants shows that their threshold for germination is 45 grams per litre, while the threshold for their survival is 90 grams per litre. At greater salinities, **phytoplankton** or **benthic microbial communities** (often visible as pink or purple mats formed by cyanobacteria and bacteria) are often the predominant primary producers. In permanently inundated wetlands, benthic microbial communities can dominate even at lower salinities.[14] Invertebrates, amphibians, reptiles and waterbirds reliant on plant-dominated wetland ecosystems may be lost when these changes occur.[14]

➤ For more information about plants and benthic microbial communities and the role they play in wetlands, see the topic 'Wetland ecology' in Chapter 2.

Loss of dryland vegetation surrounding wetlands and loss of emergent wetland vegetation can reduce the amount of protection the wetland has from wind and pollutants from surrounding land (such as nutrients), and can increase the amount of light and heat reaching wetlands. These are all factors that contribute to changes in the ecology of salinising wetlands.

Submerged: a plant that is entirely underneath the surface of the water

Emergent: a plant that is protruding above the surface of the water or, where a water column is not present, above the wetland soils (as distinct from floating or submerged plants)

Dormant: a state of temporary inactivity in which plants are alive but not growing

Vegetative: a stage or structure of a plant that is concerned with feeding, growth or asexual reproduction, rather than sexual reproduction

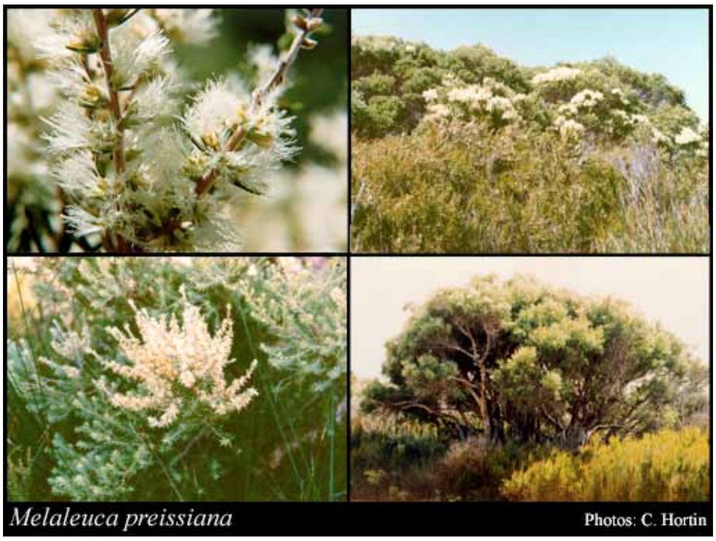
Tubers: specialised fleshy storage organs of the stem that are present in some plant species, usually found underground

Phytoplankton: Plankton (aquatic organisms floating or suspended in the water that drift with water movements, generally having minimal ability to control their location) that are photosynthetic (for example, algae and bacteria)

Benthic microbial communities: bottom-dwelling communities of microbes (living on the wetland sediments)

Figure 6. (below) Examples of salt-sensitive and salt-tolerant wetland plant species. Photos – (a) C Hortin; (b) JF Smith; (c) J Thomas; (d) KA Shepherd; and (e) L Sim. Images (a) – (d) used with the permission from the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright.

Salt-sensitive species



(a) Moonah (*Melaleuca preissiana*) (emergent)

(b) Lake club-rush (*Schoenoplectus validus*) (emergent)

(c) Floating pondweed (*Potamogeton tricarinatus*) (submerged)

Figure 6. (continued)

Salt-tolerant species

(d) *Sarcocornia blackiana* (emergent)

(e) *Ruppia polycarpa* (submerged)

Water column: the water within an inundated wetland that is located above the surface of the wetland soils (as distinct from soil pore waters of inundated and waterlogged wetlands)

Flocculation: the joining of particles (small objects) into loose masses (floc) in water

Particulate: in the form of particles (small objects)

Photosynthesis: the process in which plants and some other organisms such as certain bacteria and algae capture energy from the sun and turn it into chemical energy in the form of carbohydrates. The process uses up carbon dioxide and water and produces oxygen.

Ionic composition: the particular ions making up a solution, usually expressed in terms of the relevant dominances of the major (most abundant) positively charged and negatively charged ions in a solution

Chemical effects

The chemical and physical effects of salinity on wetlands are often closely interrelated and can be difficult to separate. For example, in wetlands with **water columns**, salinity leads to increased **flocculation** of suspended **particulate** matter (including organic material and suspended sediments), and these larger particles then settle on to the wetland sediment.[24] This settling process leads, in turn, to increased light penetration into wetland waters, enabling better visibility and the potential for higher rates of predation of some organisms than under turbid conditions.[34] Increased light can also stimulate **photosynthesis**, leading to accelerated plant and algal growth, and may also increase heating of the water and penetration by ultraviolet rays. Flocculation can also make some important nutrients less available to wetland organisms. In particular, high levels of calcium (a naturally occurring salt) in the water column can affect the availability of the important nutrient phosphorus, as phosphate quickly binds to calcium carbonate and settles out.[35] A lack of biologically available phosphorus can restrict plant and algal growth.

Other chemical characteristics of wetland waters, such as the **ionic composition**, change as wetlands become more saline, and this can alter the relative dominance of different microbially driven processes such as **sulphate reduction** and **methanogenesis**. This changes the way that nutrients are cycled in a wetland, and has flow-on effects for the function of wetland food webs.

➤ For additional detail on the properties of wetland waters, including ionic composition and nutrient cycling, see the topic 'Conditions in wetland waters' in Chapter 2.

➤ For additional detail on wetland food webs, see the topic 'Wetland ecology' in Chapter 2.

Physical effects

The process of dryland salinisation can also lead to significant physical changes in wetlands, many of which are closely linked to chemical changes. Some of these effects are caused by excess water, some by excess salt and some by changes to the light penetration and temperature of the wetland waters.

As described earlier, the loss of vegetation together with changes to the chemical environment in salinised wetlands can increase the amount of light entering wetland waters. Increased light can increase the temperature of wetland waters, which may affect the metabolic processes of plants, animals and microbes. Higher water temperatures may alter the rates at which organisms grow and reproduce, the relative dominance of different organisms (some may be able to tolerate the new conditions better, and may out-compete others), and also have other flow-on effects, since temperature influences the solubility of dissolved gases such as oxygen and carbon dioxide.

Increased salinity in wetland waters may also cause wetlands to **stratify**. Salinity-driven **stratification** can lead to **anoxic** conditions at the bottom of the water column, and may lead to fish deaths and a change in microbial processes. This is because oxygen is much less **soluble** in saline waters than fresh waters, reducing its relative availability to wetland plants and animals.[36]

➤ For additional detail on stratification and on the effects of temperature change, see the topic 'Conditions in wetland waters' in Chapter 2.

In many permanently inundated saline wetlands, a thick mat of benthic microbial communities can develop over the **sediments**, and this layer may reduce or almost stop water exchange between groundwater and surface water.[37] This means that the wetland waters become increasingly saline over time, as the surface water evaporates and is not diluted by an inflow of fresher (although still saline) groundwater.

Another effect of the excess water associated with salinisation is increased flooding frequency and severity across the landscape. This occurs because much of the soil is already saturated with water, reducing its ability to 'soak' up large rainfall events. Instead of soaking into the soils, much of this excess water may become surface flood flows.[9,10]

In some cases, excess salt can lead to a decline in soil/sediment structure. Over time, the chloride ions in salinised soil may be flushed out, leaving high concentrations of sodium ions (sodium and chloride are the two most dominant ions in land and water salinity in Australia). This lead to the development of 'sodic' soils where the sodium ions attach to clay particles in the soil, meaning that when they are wet they can no longer stick together.[38] This makes them prone to **erosion** and collapse, especially if they are drained.

Excess salt may also lead to the creation of salt crusts on the base of wetlands, which can act as a physical layer shielding the sediments from the effects of solar radiation and exposure to air. Benthic microbial communities can survive underneath this layer of salt, and the crust can also prevent the seeds and eggs of wetland plants and animals from germinating or hatching.

➤ For additional detail on the effects of dissolved salts in wetlands, see the topic 'Conditions in wetland waters' in Chapter 2.

Sulphate reduction: the chemical process where sulphate is joined with hydrogen and gains electrons

Methanogenesis: the production of methane by microbes

Stratify: separate the water column into distinct layers

Stratification: the division of the water column into distinct layers called the epilimnion (top), the metalimnion (middle) and the hypolimnion (bottom), due to differences in water density between these layers

Anoxic: deficiency or absence of oxygen

Soluble: able to dissolve

Sediments: in general terms, the accumulated layer of mineral and dead organic matter forming the earth surface of a wetland. Used interchangeably in this guide with the terms 'wetland soil' and 'hydric soil', although all three of these terms have more specific meaning in wetland pedology

Erosion: wearing away and movement of land surface materials (especially rocks, sediments and soils) by the action of water, wind or a glacier

What does wetland salinisation look like in Western Australia?

The first sign of wetland salinisation is usually the death of freshwater wetland vegetation, including emergent and submerged species.[13] A decline in water quality will also be evident if wetland water is used for livestock or domestic purposes. The loss of freshwater vegetation leads to bare areas around and inside wetland boundaries, which may later be colonised by salt-tolerant species, such as **samphires**. Increases in both salinity levels and the extent and duration of soil waterlogging can cause a decline in the health of emergent and dryland vegetation, although the effects may vary between species.[23] When they become more advanced, the effects of salinisation are very visually evident (Figure 7) due to the presence of **salt scalds** on the ground and the widespread death of trees and shrubs, and lumps of salt may even be seen floating in the waters of highly saline wetlands. Common signs of secondary salinity in and around previously freshwater wetlands include:

- dead trees and other woody shrubs (Figure 7(a, b))
- salt scalds on bare ground (Figure 7(c))
- deposits of solid salt in and around wetlands (Figure 7(d))
- disappearance of salt-sensitive plant species (Figure 7(e))
- appearance of salt-tolerant species such as samphires or salt bushes (Figure 7(f)).

Samphire: the common name for a group of succulent sub-shrubs and shrubs including *Tecticornia, Halosarcia, Sarcocornia, Sclerostegia, Tegicornia* and *Pachycornia*, belonging to the family Chenopodiaceae

Salt scald: a bare area of ground caused by secondary salinisation, in which vegetation has died and solid salt is visible

Figure 7. (below) Signs of dryland salinity in and around wetlands. Photos – (a), (c)–(f) L Sim, (b) M Cundy/DEC.

(a) Death of trees and other woody vegetation at Lake Mears, near Brookton

(b) Tree death in the Buntine-Marchagee Natural Diversity Recovery Catchment

Figure 7. (continued)

(c) Salt scald, Arthur River flats near Highbury

(d) Deposited solid salt at the Yenyening Lakes, near Brookton

(e) Loss of rushes/sedges around 'Rushy' Swamp, near Woodanilling

Figure 7. (continued)

(f) Samphires around Lake Mears, near Brookton

The effects and appearance of salinity may also change from year to year with the influence of variable rainfall on wetland water levels, salt loads and sediment/soil salinity. The most reliable way of assessing whether wetland waters or surrounds are affected by salinisation is to measure the water or soil salinity levels.

➤ For additional detail on salinity measurement, see the topic 'Conditions in wetland waters' in Chapter 2, and for monitoring methods, see the topic 'Monitoring wetlands' in Chapter 4.

➤ The salinity of a number of Western Australian wetlands has been monitored by DEC's and its predecessor agencies. See the *South west wetlands monitoring program report 1997–2010*[39] and *WetlandBase*[40] for more information.

At a much broader scale, remote sensing can be used to predict whether a wetland may be saline. A method for predicting whether a wetland is either 'fresh-subsaline' or 'saline' using remote sensing methods has been developed for use in the Avon natural resource management region.[41]

Managing and restoring salinising wetlands

Landscape-scale approaches

Landscape-scale salinity management focuses on the reduction of excess water in the landscape. The landscape-scale nature of the processes underlying dryland salinisation make it necessary to approach salinity management from a catchment perspective if it is to have a lasting effect on the conditions on ground. As a result, effective salinity management is often the result of coordinated effort across different regions and areas of expertise and can be very costly to implement.

A variety of complementary measures are typically required, that is, an 'integrated water management' approach. This calls for a sound understanding of the hydrological conditions and typically involves a range of studies including catchment and finer-scale surface water assessments, groundwater investigations, groundwater numerical models, soil mapping and the installation and maintenance of a bore network.

Table 1 summarises the broad approaches used to manage dryland salinisation at the catchment-scale in the inland south-west agricultural zone.

Table 1: Water management in the inland south-west agricultural zone - problems, causes and solutions. Reproduced with permission from K Wallace/DEC.

Water problems		
Surface water	**Groundwater**	**Water-borne**
• Waterlogging • Erosion (soil, drainage line, stream banks) • Increased recharge • Flooding, inundation and associated damage	• Groundwater rise, and all associated salinity problems • Increased surface flows from saline soils	• Siltation • Nutrient loading • Eutrophication • Spread of weeds • Pesticides • Water quality decline

Causal factors				
Biophysical changes (non-structural)	**Cultural structures**	**Natural structures**	**Episodic events**	**Interaction between causal factors**
• Replacement of natural veg. with annual crops and pastures • Changes in soil properties as a result of agriculture • Loss of storage and discharge function of natural wetlands • Degradation of nutrient sink function of wetlands	• Damage to roads, tracks • Damage to railway lines • Drainage works • Cultivation of drainage lines • Paving and other enhanced drainage in towns and urban areas	Topography, landform, soils, geology, and salts stored in soil profile will all have a range of impacts such as: • dykes impeding groundwater flow • natural surface barriers • sand bars • extensive flats and areas of low relief.	• High volume, high intensity rainfall events, particularly summer cyclones • High volume, long duration events; high volume and prolonged wet seasons • Wildfires and associated loss of vegetation cover • Extended periods with little or no rainfall	All the preceding factors interact. How they interact at a particular site, or within a particular sub-catchment or basin, will vary.

Solutions				
Engineering	**Revegetation and high water-use plants**	**Agronomic change**	**Enhanced storage**	**Protection of remnant native vegetation**
• Diversion structures (e.g. grade banks, diversion banks, levees) • Drainage structures (e.g. seepage interceptors, deep drains, w-drains) • Storage structures (see column dealing with enhanced storage) • Groundwater pumping	• Perennial woody vegetation • Perennial grasses and legumes • Stabilisation of stream banks • Nutrient stripping	• Contour farming • Continuous cropping • Phase cropping • Complete change of land use in prone areas, e.g., adopt productive saline systems and aquaculture • Salt land agronomy	• Increase dams up-slope and associated water harvesting • Increase valley storage • Evaporation basins • Regulation of flow to wetlands	For example: • fence remnant vegetation • control herbivores and omnivores • manage weeds.

Salinity management programs

One of the major programs for landscape-scale salinity management in WA that focuses on wetlands is the 'Natural Diversity Recovery Catchments' program developed under the State Salinity Strategy, which is aimed at protecting areas with high natural diversity that are threatened by rising water tables and salinisation, and focusing especially on wetlands. So far, six Natural Diversity Recovery Catchments exist:

- Buntine-Marchagee
- Drummond
- Lake Bryde complex
- Lake Muir-Unicup
- Lake Warden
- Toolibin Lake.

This program has been instrumental in pioneering many techniques for managing dryland salinity in WA. A central aim of salinity and landscape-scale water management in these catchments is to achieve integration between nature conservation and sustainable agricultural practices[19] (Figure 8).

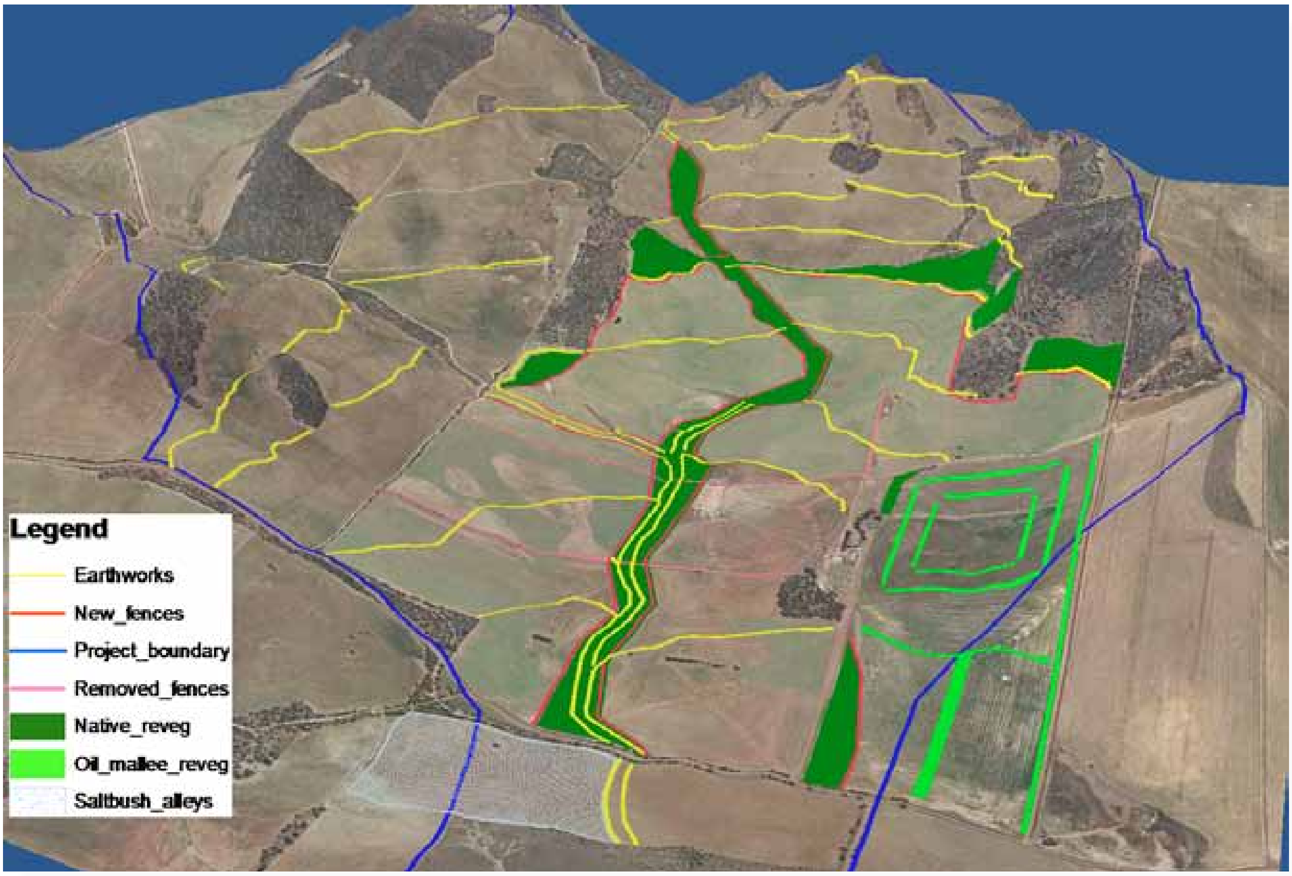


Figure 8. Integrated water management at the landscape scale has a positive effect on reducing salt, nutrient and sediment export to downstream wetlands. Engineering and biological options are integrated to optimise gains in water management (surface and groundwater) and agricultural productivity in this 800-hectare demonstration area in the Buntine-Marchagee. Note the elevations are exaggerated. Image – R Dawson/DEC.

➤ Information on DEC's Natural Diversity Recovery Catchments can be found at DEC's website.[42]

Another major state government program, which focuses on landscape-scale salinity management more broadly, is the Engineering Evaluation Initiative led by the Department of Water. It examines a range of potential mitigation options including deep drains, groundwater pumping and surface water management, safe saline water disposal and regional drainage planning.

➤ More information on the Engineering Evaluation Initiative is available from the Department of Water website.[43]

Intervention measures for wetlands

The management and restoration of salinising wetlands is complex and requires a detailed understanding of site hydrology and ecology. In cases where resources are more limited, such as when managing wetlands on private land in areas outside of large catchment-scale restoration projects, it may be more realistic to aim to assist the wetland ecosystem to adapt in the face of a threat that is unlikely to lessen, or to maintain current conditions if possible. This approach is described in the case study in this topic entitled 'Meeking Lake – wetland management at a local scale'.

The reality is that even within managed catchments, it is likely that it will not be possible to tackle secondary salinity at every wetland. Prioritisation is typically required to decide which wetlands should receive intervention measures and which will miss out.

The majority of wetlands affected by secondary salinity within the inland south-west agricultural area are already significantly altered and, as such, relatively unchanged wetlands are rare. Wetlands that have been salinised for several decades have arguably now become a 'new' type of ecosystem, and may resemble naturally saline wetlands more than naturally fresh wetlands, although there are also likely to be differences between naturally and secondary saline systems. However, although salinised wetlands are degraded in terms of their original values, they may still provide important services in the landscape, such as nutrient cycling, water retention, and drought refuge.

Importantly, there is evidence to suggest that further salinity increases could actually have significant detrimental effects on many salinising wetlands if they lead to the loss of the (salt-tolerant) submerged plant communities that dominate these systems.[14] These plants provide habitat for invertebrates, food for vertebrates such as waterbirds, and store nutrients, which would otherwise be free to feed algal blooms. Therefore, a critical goal is to stop salinities from exceeding the threshold level at which these submerged plants are lost from the system. The concept of 'alternative stable states' suggests that re-establishing these submerged vegetation communities may not be as simple as lowering the salinity level again, making it even more important not to cross the threshold in the first place.[44,45]

➤ Funding, training and other resources are available for landholders and wetland managers tackling secondary salinity and altered hydrology. For more information see the topic 'Funding, training and resources' in Chapter 1.

➤ A detailed example of an integrated approach to the management of a catchment with multiple valuable wetlands can be found in the *Buntine-Marchagee Natural Diversity Recovery Catchment Recovery Plan: 2007–2027*.[19]

Intervention techniques at the wetland scale

Key water management and restoration techniques for use in and around salinising wetlands include:

- retaining and restoring remnant vegetation
- revegetating
- controlling surface water inflows
- flushing
- dewatering
- pumping
- drainage
- creation of evaporation basins and sacrificial wetlands.

These are outlined in Table 2.

Expert advice is required to design and carry out management interventions, particularly those that relate to altered hydrology. Ideally, any salinity management activities should be undertaken as part of a comprehensive wetland management plan, which also addresses other management issues or degrading processes and their associated management activities. It is strongly encouraged that a management plan is prepared, when managing any wetland, however basic it may be.

➤ For additional detail on preparing a wetland management plan see the topic 'Planning for wetland management' in Chapter 1.

Legal requirements associated with draining and pumping water

It is very important to be aware of the legal requirements associated with draining and pumping water for salinity control purposes. These activities are primarily regulated under the *Soil and Land Conservation Act 1945*. The environmental harm provisions of the *Environmental Protection Act 1986* also apply. Further regulations may apply, for example, within proclaimed surface water areas and waterway conservation areas. For additional detail on legal requirements associated with the control or modification of ground and surface water for salinity control purposes see the topic 'Legislation and policy' in Chapter 5.

Table 2. Key water management techniques for use in and around salinising wetlands

Action	Purpose	How it is achieved	Figure	Considerations	Case studies/key resources
Retaining and restoring remnant wetland and dryland vegetation	Maintain existing water use	Fencing off remnant vegetation from livestock; covenanting of remnant vegetation	Figure 9	• A cost-effective salinity management tool • Provides the dual function of maintaining biodiversity and ecosystem function	Example: fencing of remnant vegetation in the integrated water management demonstration catchment, Buntine-Marchagee[46] Resource: 'Managing wetland vegetation' topic, Chapter 3
Revegetating areas around wetlands	Increase water use	Planting and maintaining perennial woody vegetation e.g. endemic natives, perennial pastures, saltbush, oil mallees	Figure 10	• Yields short to long-term changes on water table and salinity levels. Can prevent further concentration of salts in the short-medium term, and reduce water levels in the longer term (e.g. a decade or more) • Critical to select suitable revegetation sites and vegetation. Site selection factors include geology, soil, size and part of the landscape • Preferable to use species local to the area that also meet the landowner's agricultural land use objectives	Example: revegetation in the integrated water management demonstration catchment, Buntine-Marchagee[46] Resource: Revegetation guidelines on DEC website.[47] Includes case studies of numerous revegetation projects Resource: 'Managing wetland vegetation' topic, Chapter 3
Controlling surface water inflows	Prevent saline water entering wetland	Installing and managing structures to bypass or divert salty water	Figure 11	• Often reduces total amount of inflows. This can cause environmental impacts to the wetland, which can be exacerbated by periods of sustained drought or sustained reduced rainfall due to climate change • May have significant downstream impacts (see evaporation basins and sacrificial wetlands, below) • Requires environmental approval to ensure that no significant environmental impacts occur	Example: Toolibin Lake surface water diversion channel and separator gate
Wetland flushing	Remove some accumulated salts from wetland	Using fresher water, making use of an inflow and outflow		• Less common technique in WA as wetlands are not as commonly connected to permanently flowing river systems as in eastern Australia	Example: Toolibin Lake outlet control system

Table 2. Key water management techniques for use in and around salinising wetlands

Action	Purpose	How it is achieved	Figure	Considerations	Case studies/key resources
Wetland dewatering	Lower wetland water levels	Pumping wetland water out of wetland	Figure 12	• Requires environmental approval to ensure that no significant environmental impacts occur • May have significant downstream impacts (see evaporation basins and sacrificial wetlands, below)	Example: Lake Wheatfield dewatering, Lake Warden Wetland System, Esperance
Groundwater pumping	Lower groundwater table	Pumping groundwater from the site and disposing elsewhere	Figure 13	• Feasibility needs to be assessed by an experienced hydrologist • Very expensive to establish and run; requires power • Buys time; can be feasible in combination with longer-term techniques such as revegetation • May have significant downstream impacts (see evaporation basins and sacrificial wetlands, below) • Requires environmental approval to ensure that no significant environmental impacts occur	Example: Toolibin Lake groundwater pumping
Landscape drainage	Remove excess surface water or shallow groundwater from landscape	Constructing and maintaining earthen drains and waterways	Figure 14	• Works need to be designed by an experienced hydrologist • Suitability of site is dependent of the geology and hydrology of the area • Groundwater drains involve a higher level of intervention, cost and maintenance than surface water drains • May have significant downstream impacts (see evaporation basins and sacrificial wetlands, below) • Requires environmental approval to ensure that no significant environmental impacts occur	Example: constructed grassed waterway, integrated water management demonstration catchment, Buntine-Marchagee[46] Example: Toolibin Lake, Dulbining constructed waterway
Creation of evaporation basins, selection of sacrificial wetlands	Dispose saline water generated via pumping, drainage etc	Constructing/ selecting a site for evaporation and development of saline crust or brine	Figure 15	• The location of the basin/wetland must be optimal to minimise transportation required, while ensuring that plumes do not reach the wetland being managed • Requires environmental approval to ensure that no significant environmental impacts occur	Example: Toolibin Lake, Taarblin Lake saline groundwater disposal

Figure 9. Fencing to help protect remnant vegetation. Retaining existing native vegetation is a cost-effective measure for salinity management. Photo – G Mullan/DEC.

Figure 10. (below) Revegetation with native species to help manage altered hydrology in the Buntine-Marchagee catchment (a) using oil mallee eucalypts as a prospective commercial crop (b) using *Atriplex amnicola* (river saltbush), a stock fodder, in groundwater discharge areas and (c) using mixed shrubs and trees chosen for their resilience, structural diversity and genetic integrity in areas of low agricultural productivity. Photos – G Mullan/DEC.

(a)

(b)

Figure 10. (continued)

(c)

Figure 11. Controlling surface water flows into Toolibin Lake using a separator gate. It captures and diverts low volume, high salinity flows, preventing them from entering the wetland. Photo – L Mudgway/DEC.

Figure 12. (below) Dewatering of Lake Wheatfield (a) pipeline entry point at Lake Wheatfield (during installation, prior to being submerged); (b) pipeline exit point at Bandy Creek. Photos – (a) K Oswald/DEC; (b) J Lizamore/DEC.

(a)

Figure 12. (continued)

(b)

Figure 13. (below) (a) Pump and (b) tank to pump groundwater at Toolibin Lake. Photos – R McKnight/DEC.

(a)

(b)

Figure 14. A landholder inspects a constructed grassed waterway in full flow in the Buntine-Marchagee catchment – a part of the landscape-scale integrated water management approach. Photo – K Stone.

Figure 15. (below) (a) Lake Taarblin, which receives saline discharge from Toolibin Lake (b) a saline discharge point at Lake Taarblin. Photos – M Lee/DEC.

(a)

(b)

case study

Toolibin Lake – wetland restoration at a catchment scale

Toolibin Lake is a large (493-hectare), tree-dominated, brackish-freshwater wetland located 40 kilometres east of Narrogin in the central inland south-west agricultural area[48] (Figure 16). It is located at the top of a chain of nine wetlands that form part of the Northern Arthur River drainage system within the Upper Blackwood River catchment.[49] It is the only major wetland in the chain not to have salinised.[50] The wetland is located within a system of 'A' class nature reserves managed by the DEC, but the wider catchment has been extensively cleared for agriculture, and is affected by dryland salinisation.[48]

Figure 16. Aerial view of Toolibin Lake, June 2008. Photo – DEC.

Toolibin Lake is recognised as a wetland of international significance, being listed under the Ramsar Convention on the basis of it being the last, large wetland dominated by *Casuarina obesa* and *Melaleuca strobophylla*, and due to its important waterbird habitat, particularly the significant number of breeding waterbird species it can support when full or close to full.[51,52] It is also listed as an (endangered) threatened ecological community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and is also identified by DEC as a critically endangered community.[48] The wetland is recognised as the best remaining representative of a 'Perched wetland of the Wheatbelt region with extensive stands of living sheoak and paperbark across the lake floor' that still retains a significant proportion of living trees[48] (Figure 17).

(a) (b)

Figure 17. (a) *Casuarina obesa* and (b) *Melaleuca strobophylla* stands at Toolibin Lake. Photos – R McKnight/DEC.

case study

Prior to salinisation, this was a common wetland type in the region, but increased salinity has impacted heavily on these wetlands. The absence of water in recent years has significantly impacted on waterbird use of the wetland.[48] In recognition of its high natural diversity values and the threat posed by secondary salinity, Toolibin Lake was listed in 1996 as one of the first 'Natural Diversity Recovery Catchments' under the State Salinity Action Plan.[49]

Toolibin Lake was historically a perched freshwater wetland, with the groundwater table located 15 metres below the wetland bed. It is filled through surface flows in years of above-average rainfall, or when there are significant summer rainfall events. Depending on rainfall, the wetland may not fill for a number of years, but after a large rainfall event, it may remain full for several years. When Toolibin Lake is full, it can reach a maximum depth of 2 metres, after which it overflows into other wetlands downstream.[49] Since overflowing in 1996, it has only partially filled once, in summer 2006. This is due to very low rainfall over the past decade and the installation of a diversion gate to divert saline surface water flows, which reduces the amount of water entering the lake.[19]

Salinity in the wetland has increased over the past decades as a result of catchment clearing, due to increasingly saline surface water inflows from surrounding land and a rise in the saline groundwater level almost to the level of the wetland bed.[49] The wetland appears to have some protection from salinisation from direct groundwater intrusion due to the presence of an unconsolidated clay layer under the wetland, however the wetland vegetation is still vulnerable to the combined effects of salinity and increased waterlogging.[23]

Recovery actions

A detailed recovery plan was developed for Toolibin Lake in 1994[53] and a review of this plan is underway. A range of key recovery works have been carried out since 1994, as outlined below.

To reduce groundwater recharge:

- protection and revegetation of remnant vegetation in the catchment
- changes to agricultural practices, including the introduction of contour farming (tillage across slopes that follows the topographic contour, or close to it) and sustainable, high-water use crops such as woody perennials.

To manage surface water:

- reductions in agricultural waterlogging, particularly via the installation of surface water drains
- diversion of highly saline inflows around Toolibin Lake via a separator gate and diversion channel
- increased salt export out of the wetland, by constructing an outlet control system to manage outflows
- construction of Dulbining waterway to reduce the impact of increasing surface flows, waterlogging and inundation, and to reduce salt storage in the catchment.

To increase groundwater discharge from the wetland:

- groundwater pumping to lower the water table beneath the wetland.

Regular monitoring of biological and physical parameters is carried out at Toolibin Lake to assess the success of these management actions against a range of key criteria. In 2002, it was estimated that an 80 per cent reduction in salt load entering the lake had been achieved.[54] Furthermore, a depth to groundwater of greater than 1.5 metres has been achieved. Yet while there has been a positive effect of actions designed to lower the watertable under the wetland, many of the biological and water quality criteria have been made difficult to assess due to the lack of rainfall to fill the wetland since the early 1990s.[55] To date, the overall condition of mature vegetation has either stabilised or continued to decline in areas, with limited regeneration (Figure 19). A range of studies and an adaptive management approach is being carried out.

➤ For more information about Toolibin Lake, please contact the Conservation Officer (Toolibin Lake), Narrogin District Office, DEC. Telephone: (08) 9881 9200.

case study

Figure 18. (below) Examples of management actions being implemented in the Toolibin Lake NDRC (a) Toolibin Lake showing diversion channel on western side, (b) view of 'Chadwick's Block', which was purchased by DEC and revegetated, (c) waterway from Dulbining Lake to Toolibin Road North to improve water conveyance through to Toolibin, (d) catchment revegetation works. Photos – DEC.

(a) **(b)**

(c) **(d)**

Figure 19. Recruitment of *Melaleuca strobophylla* at Toolibin Lake. Photo – J Higbid/DEC.

case study

Meeking Lake – wetland management at a local scale

Meeking Lake is a 25-hectare seasonally inundated wetland situated on private land north of Darkan in the central inland south-west agricultural area. It is thought that it is gradually becoming more saline. The property is not located within a catchment with a dedicated integrated catchment-scale restoration program.

By fencing out livestock and revegetating the wetland, the landowners have reduced the threats to it and improved its condition. While these actions will not reduce the rate of salinisation, they may assist the wetland ecosystem to adapt to the changing conditions.

A narrow fringe of wetland vegetation surrounds the water on all sides. The landholders have fenced and revegetated the northern and eastern sides of the wetland. A road lies to the west, while there is paddock to the north and woodland to the east and south. Meeking Lake was historically fresh however over the past twenty years it has experienced increased water salinities (M Steddy 2004, pers. comm.), accompanied by tree deaths and the recruitment of salt-tolerant species including *Ruppia polycarpa* and *Melaleuca viminea*.

Figure 20. Meeking Lake. Photo – L Sim.

Impacts of catchment-scale clearing

It appears likely that Meeking Lake has salinised both via groundwater intrusion at its edges (although not through the main bed of the wetland), and via overland flow of surface water from nearby salinised land (T Mathwin 2004, pers. comm.). Water salinities measured at the wetland between 2002 and 2004 usually ranged from 7 to 30 parts per thousand.[56] Without intervention, the wetland is likely to continue to become more saline (T Mathwin 2004, pers. comm.). It is not known how quickly it has become salinised, however the persistence of turtles and frogs (D Steddy 2004, pers. comm.), and the health of the wetland vegetation suggest that the change has been gradual, and that a critical threshold for the loss of these species has not yet been reached.

case study

Retained wetland values

Despite the change from fresh to saline water, Meeking Lake still supports a diversity of healthy wetland vegetation including *Melaleuca viminea*, *M. lateritia*, *Baumea articulata* and *Typha* species, and a relatively diverse fauna including resident breeding oblong tortoises (*Chelodina colliei*, Figure 21), gilgies (*Cherax quinquecarinatus*) and small fish. When the wetland is inundated, it is covered in a dense bed of submerged plants, dominated by *Ruppia polycarpa, Lamprothamnium macropogon* and *Lepilaena preissii.*[56]

Figure 21. Juvenile oblong tortoise (*Chelodina colliei*) at Meeking Lake. Photo – C Mykytiuk.

Topic summary

- Secondary salinity is a major threat to wetland and terrestrial biodiversity within the south-west agricultural zone, and it operates over very large scales. The main area of WA that is affected by secondary salinity is the south-west agricultural area, which extends from north of Geraldton to east of Esperance, within the 300 and 600 millimetre rainfall zones.
- The removal of native perennial vegetation and its replacement with annual crop species has led to a rise in groundwater levels. Rising groundwater brings salt stored in the soil profile to the surface, salinising lands and waters.
- The large-scale causes of salinity make management of wetland salinisation and the restoration of salinising wetlands very difficult.
- When the concentrations of dissolved salts get much higher or change very quickly, significant impacts on biological, chemical and physical components of wetlands can result. The effects of increased salinity are heightened by the accompanying changes to wetland hydrology.
- Most wetland types in the inland south-west agricultural area are affected by salinisation unless they are protected by special geographic or geological features, for example, perched wetlands in vegetated catchments and on rocky outcrops.
- Common signs of salinity include:
  - death of trees and other woody vegetation
  - salt scalds on bare ground
  - precipitated salt in and around wetlands
  - loss of salt sensitive species
  - appearance of salt-tolerant species (for example, samphires or salt bushes)
  - changes to wetland vegetation (species)
  - water or soil salinity testing (most reliable).
- The management and restoration of salinising wetlands is often complex and costly, and is most effective if approached as part of integrated catchment management. If resources are limited, it may be more feasible to focus management actions on the maintenance of existing wetland conditions or adaptation to a new state, rather than aiming for restoration.
- Intervention at wetlands may include:
  - retaining and restoring remnant vegetation
  - revegetating
  - controlling surface water inflows
  - flushing
  - dewatering
  - pumping
  - drainage
  - creation of evaporation basins and sacrificial wetlands.

  Authorisation is necessary to undertake the majority of these measures.

Sources of more information on understanding and managing secondary salinity in wetlands

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Glossary

Annual: a plant that completes its life cycle within a single growing season (from germination to flowering, seed production and death of vegetative parts)

Anoxic: deficiency or absence of oxygen

Benthic microbial communities: bottom dwelling communities of microbes (living on the wetland sediments)

Biodiversity: encompasses the whole variety of life forms–-the different plants, animals, fungi and microorganisms–-the genes they contain, and the ecosystems they form. A contraction of 'biological diversity'

Crustaceans: a class of animals that have a hard exoskeleton (shell) and usually live in the water, for example, crabs, lobsters, yabbies

Dormant: a state of temporary inactivity in which plants are alive but not growing

Ecosystem: a community of interdependent organisms together with their non-living environment

Ecosystem processes: the complex interactions (events, reactions or operations) among biotic (living) and abiotic (non-living) elements of ecosystems that lead to a definite result[8]

Emergent: a plant that is protruding above the surface of the water or, where a water column is not present, above the wetland soils (as distinct from floating or submerged plants)

Endemic: naturally occurring only in a restricted geographic area

Erosion: wearing away and movement of land surface materials (especially rocks, sediments and soils) by the action of water, wind or a glacier

Flocculation: the joining of particles (small objects) into loose masses (floc) in water

Geology: the composition, structure and features of the Earth, at the surface and below the ground

Gnamma: a hole (commonly granite) that collects rainwater, forming a wetland. This word is of Nyoongar origin

Groundwater: water occurring beneath the ground surface in spaces between soil grains and pebbles and in fractures or crevices in rocks

Groundwater table: the upper surface of the groundwater in an unconfined aquifer (top of the saturated zone)

Halophile: a species that shows a preference for saline habitat such as salt lakes

Hydrology: the properties of the Earth's water, particularly the distribution and movement of water between the land surface, groundwater and atmosphere

Invertebrate: an animal without a backbone

Ion: an atom with an electrical charge. Used to refer to dissolved salts such as sodium (Na+) or chloride (Cl-) in solution

Ionic composition: the particular ions making up a solution, usually expressed in terms of the relevant dominances of the major (most abundant) positively charged and negatively charged ions in a solution

Juvenile: young or immature

Landform: a natural feature of a landscape such as a valley, mountain, basin or plain

Metabolic functions: the processes occurring within a living organism that are necessary to maintain life

Methanogenesis: the production of methane by microbes

Microbe: an organism that is too small to be seen with the unaided eye, for example, bacterium, some algae

Organisms: any living things (includes plants, animals, fungi and microbes)

Particulate: in the form of particles (small objects)

Perched: not connected to groundwater

Perennial: a plant that normally lives for two or more growing seasons (from germination to flowering, seed production and death of vegetative parts)

Photosynthesis: the process in which plants and some other organisms such as certain bacteria and algae capture energy from the sun and turn it into chemical energy in the form of carbohydrates. The process uses up carbon dioxide and water and produces oxygen.

Phytoplankton: plankton (aquatic organisms floating or suspended in the water that drift with water movements, generally having minimal ability to control their location) that are photosynthetic (algae and bacteria)

Recruitment: addition of new individuals to a population (usually through reproduction)

Salinisation: the process of accumulation of salts in soils, waters or sediments

Salinity: a measure of the concentration of ions in waters, soils or sediments

Salt scald: a bare area of ground caused by secondary salinisation, in which vegetation has died and solid salt is visible

Secondary salinisation: a human-induced process in which the salt load of soils, waters or sediments increases at a faster rate than would have occurred naturally

Sediment: in general terms, the accumulated layer of mineral and dead organic matter forming the earth surface of a wetland. Used interchangeably in this guide with the terms 'wetland soil' and 'hydric soil', although all three of these terms have more specific meaning in wetland pedology

Soluble: able to dissolve

Species richness: the total number of species (in a defined area)

Stratify: separate the water column into distinct layers

Stratification: the division of the water column into distinct layers called the epilimnion (top), the metalimnion (middle) and the hypolimnion (bottom), due to differences in water density between these layers

Submerged: a plant that is entirely underneath the surface of the water

Sulphate reduction: the chemical process where sulphate is joined with hydrogen and gains electrons

Thresholds: points at which a marked effect or change occurs

Transpire (transpiration)**:** the loss of water from plants to the atmosphere through evaporation

Tubers: specialised fleshy storage organs of the stem that are present in some plant species, usually found underground

Vegetative: a stage or structure of a plant that is concerned with feeding, growth or asexual reproduction, rather than sexual reproduction

Vertebrate: an animal with a backbone

Water column: the water within an inundated wetland that is located above the surface of the wetland soils (as distinct from sediment pore waters of inundated and waterlogged wetlands)

Water regime: (of a wetland) the specific pattern of when, where and to what extent water is present in a wetland, including the timing, duration, frequency, extent, depth and variability of water presence[1]

Personal communications

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A guide to managing and restoring wetlands in Western Australia

Phytophthora dieback

In Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Phytophthora dieback' topic

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Contents

Case studies

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

Phytophthora dieback: the introduced plant disease caused by ***Phytophthora cinnamomi,*** which results in the decline or death of susceptible plants

***Phytophthora cinnamomi*:** an introduced water mould that attacks the roots of susceptible plant species, resulting in the decline or death of the plant

Pathogen: any organism or factor causing disease within a host

Introduction

Phytophthora dieback refers to the introduced plant disease caused by ***Phytophthora cinnamomi*** (pronounced fy-tof-thora – meaning plant destroyer in Greek). The impacts of Phytophthora dieback were first detected in Western Australian forests in the 1920s. The **pathogen** itself, a water mould, *P. cinnamomi*, was identified in the mid 1960s and since then management procedures have been introduced to combat the disease and minimise its spread.

The arrival and spread of *P. cinnamomi* in WA has been catastrophic for the plants and animals of many south-western ecosystems, including wetlands (Figure 1). As many as 2,300 of the estimated 5,700 native plant species in the south-west are susceptible to, and often killed, by the pathogen. Phytophthora dieback has been recognised as a key threatening process under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. It is now considered to be a bigger threat to Western Australia's natural ecosystems than salinity and is estimated to cost the Australian economy $160 million each year.[1] In addition, *P. cinnamomi* has caused major problems for road construction, timber harvesting, mining and other industries since researchers realised that the movement of soil is the most likely method of spread of the pathogen.

There are several other species of *Phytophthora* present in native vegetation in the south-west of WA, including *P. cryptogea, P. multivora* and *P. nicotianae*, but their extent and impact on native vegetation is unclear.

Figure 1. The effects of Phytophthora dieback in a seasonally waterlogged wetland near Busselton in the south-west of WA. Photo – C Mykytiuk/DEC.

Dieback: the progressive dying-back of a plant as a result of disease or unfavourable conditions

Historically, Phytophthora dieback has also been known as 'dieback' and 'jarrah dieback'. The use of these names has contributed to the confusion about the disease. For example, the term '**dieback**' is used in other parts of Australia to refer to tree decline caused by factors such as salinity, drought and insect damage. Furthermore, *P. cinnamomi* affects a large number of native and introduced plant species in addition to jarrah (*Eucalyptus marginata*). To overcome this confusion the term 'Phytophthora dieback' is now used.[2]

What is Phytophthora dieback?

As previously mentioned, Phytophthora dieback refers to the plant disease caused by the introduced pathogen *P. cinnamomi*. *Phytophthora cinnamomi* is a microscopic soil-borne organism belonging to the **Oomycetes** or 'water moulds'. As the name suggests, the organism depends on moist conditions that favours its survival, reproduction and dispersal.

Phytophthora cinnamomi lives in both soil and plant tissue. It invades the roots of plants from the surrounding soil to obtain nutrients and moisture for growth and reproduction. It grows as microscopic-sized filaments, **mycelium**, on the surface of plant roots.[3] The pathogen extends these microscopic filaments into the major roots of susceptible species causing cell breakdown and the formation of lesions (areas that appear dead or rotten – see Figure 2). This reduces the ability of a plant to take up and transport water and nutrients and usually results in plant death.[3] In very susceptible species, such as banksias, death may occur within weeks, while in moderately susceptible species such as jarrah (*Eucalyptus marginata*), the tree may not die until a year or more after infection. Moderately susceptible and resistant species such as flooded gum (*E. rudis*) have the ability to 'wall off' the infection to prevent further spread of the mycelia, with varying degrees of success.[4]

Phytophthora cinnamomi mycelia need environmental conditions to be favourable to grow within a plant root. For instance, there is little growth when the water content of the plant tissue is below 80 per cent. The pathogen is able to survive within dead plant roots and dry soils, by producing tough long-lived spores known as chlamydospores. These allow the pathogen to persist more easily during the dry summer months of south-west WA.

Oomycetes: the group of fungae-like organisms known as the water moulds

Mycelium: the vegetative part of a fungus, consisting of microscopic threadlike filaments known as hyphae

Figure 2. A *Phytophthora cinnamomi* lesion in a sheoak (*Allocasuarina*) trunk with the bark removed. Photo – Dieback Working Group.

extra information

Phytophthora cinnamomi life cycle

Phytophthora cinnamomi feeds on living plant roots and stems. It invades the roots of plants to get the nutrients it needs. This invasion and growth within the plant reduces the plant's ability to transport water and nutrients, often resulting in death of the host plant.

Phytophthora cinnamomi is able to reproduce through the production of microscopic fruiting bodies which release spores. Four types of spores are produced—sporangia, zoospores, chlamydospores and oospores (Figure 3 and described below).

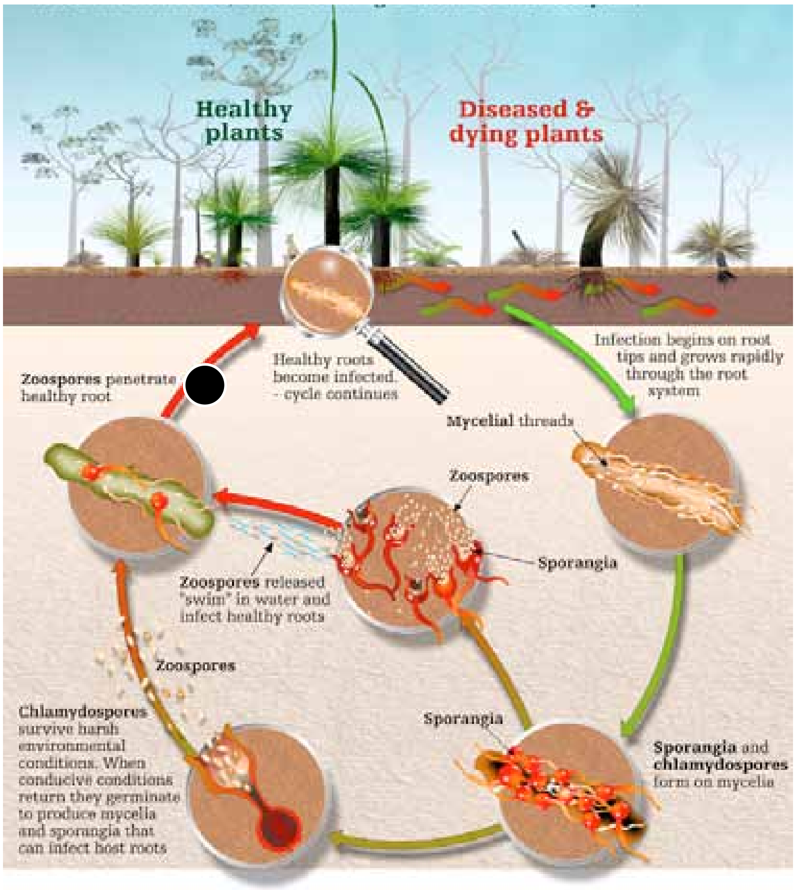

Figure 3. Life cycle of *Phytophthora cinnamomi.* © Dieback Working Group.[5]

Sporangia

Sporangia are the largest of all the spores and are produced under favourable temperature and soil moisture conditions. Zoospores are produced internally in sporangia and are released into soil once the sporangia reach maturity.

Zoospores

Zoospores are short-lived and fragile, but are produced in large numbers under moist soil conditions and are probably the cause of most new infections. Produced by sporangia, zoospores have flagella (tails), which allow them to swim very short distances (25–35 millimetres) in standing water or in films of water in soil pores. They can also be carried along in moving water over large distances. As they move through the soil, zoospores are attracted to the tips of plant roots, where they lodge, and then **germinate** (begin to grow, usually after a period of dormancy) to produce germ tubes which penetrate roots. Once inside the plant, the germ tube develops into mycelia which grow within the roots of susceptible plants, and may grow from plant-to-plant via root contact points. This root-to-root growth is the main cause of spread of a Phytophthora infestation in an upslope direction.

Chlamydospores

These are much larger than zoospores and are tough and long-lived (within dead plants and the soil). They are produced within plant roots in response to drying conditions, and are the 'resting' phase of the water mould. Chlamydospores are resistant to drying-out and are one of the mechanisms the pathogen has developed to help it survive adverse conditions. They may be transported in root fragments or soil and then germinate to cause a new infection when they encounter warm, moist conditions. Germinated chlamydospores may produce sporangia, more chlamydospores, or mycelia which directly infect roots.

Oospores

Oospores are produced through the sexual recombination of two different forms of the pathogen (A1 and A2 mating types). The sexually produced oospores are round and thick-walled, and are considered highly resistant to degradation. In some Phytophthora species, oospores are an important mechanism of surviving harsh environmental conditions. Although both mating types do occur together in some infested sites in WA, there is limited evidence of sexual recombination, and thus oospore production, occurring in the natural environment in this state.

What causes the spread of Phytophthora dieback in Western Australian wetlands?

Phytophthora cinnamomi is transported by two main mechanisms. The first is the movement of its spores through free water (including groundwater in coarse-textured soils and water-filled root channels), or by root-to-root contact between plants.[6] The second is through the movement of infected soil or plant material around the landscape. It is the movement of infected soil and plant material that has caused the large-scale spread and devastating impacts of Phytophthora dieback in the south-west of WA.

Phytophthora dieback is able to spread quickly down slopes and cover long distances if infected water is able to move freely. Its movement is much slower up slope and on flat ground (around one metre per year) as movement is generally restricted to root-to-root contact. Any action or process, including water movement, which transports soil in the landscape can also potentially transport the pathogen to a new site. Wetlands that are located in the lowest points in the landscape, and receive water from throughout the catchment, are at a high risk of being infested by *Phytophthora cinnamomi*.

The main cause of the spread of infected soil and plant material is transport by humans and some animals. *Phytophthora cinnamomi* can be carried by animals such as horses and wild pigs, often in soil attached to hooves and fur. It is transported by: humans on boots, in the muddy tyres of vehicles travelling along infested tracks, in plant pots, through earth moving and some vegetation clearing activities, and road construction.[2]

Warm, moist soil provides ideal conditions for the spread of *P. cinnamomi*. These conditions enable the pathogen to produce millions of zoospores. The zoospores are then attracted to plant roots as they seek out moisture and nutrients, swimming through soil water.[2]

High risk activities for transporting *Phytophthora cinnamomi*

Activities with a high risk of transporting *Phytophthora cinnamomi* include:

- removal of groundwater and surface water from wetlands potentially contaminated with *P. cinnamomi* for activities such as dewatering, irrigation and fire fighting
- transport of soil to and from wetlands potentially containing the pathogen
- fire break construction, which can result in the movement of soil around a property and between properties[1]
- revegetation activities that may potentially introduce *P. cinnamomi* to an area if the potting mix or soils used are contaminated with the pathogen
- movement of equipment and vehicles for a range of purposes, including the construction and maintenance of linear corridors such as roads, railways, gas pipelines and powerlines.

What effect does Phytophthora dieback have on wetlands?

Effects on vegetation

Over 40 per cent of the native plants in south-west WA are susceptible to Phytophthora dieback.[7] In field studies of south-western plant communities the families with the highest proportion of susceptible species were: Proteaceae – banksia family (92 per cent); Epacridaceae – heath family (80 per cent); Papilionaceae – pea family (57 per cent); and Myrtaceae – myrtle family (16 per cent) (Table 1).

Very little research has been undertaken on the effects of Phytophthora dieback on wetlands. Many common wetland plant species in the south-west such as flooded gum (*Eucalyptus rudis*), moonah (*Melaleuca preissiana*) and white myrtle (*Hypocalymma angustifolium*) are resistant to Phytophthora dieback (see Figure 4). Yet common species such as swamp peppermint (*Taxandria linearifolia*), swamp banksia (*Banksia littoralis*) and swamp teatree (*Pericalymma ellipticum*) have been identified as being susceptible (see Figure 5). Field observations have suggested that many wetland species are resistant to the disease (C Dunne 2008, pers. comm.), hence wetland plant communities often don't exhibit signs of Phytophthora dieback. Although many wetland species may be resistant to Phytophthora dieback, they may still act as resistant hosts for the pathogen (C Dunne 2008, pers. comm.).

Table 1. Examples of wetland species susceptible to Phytophthora dieback in the south-west by plant family

Family	Species – scientific name	Species – common name
Proteaceae	*Adenanthos obovatus*	Basket flower
	Banksia littoralis	Swamp banksia
Epacridaceae	*Sphenotoma gracilis*	Swamp paper-heath
Papilionaceae	*Jacksonia horrida*	-
Myrtaceae	*Melaleuca thymoides*	-
	Verticordia densiflora	Compacted featherflower

Garden species susceptible to Phytophthora dieback

A number of garden and horticultural plants are susceptible to *Phytophthora cinnamomi* including:

- apple, peach, apricot and avocado trees
- roses
- camellias
- azaleas
- proteas
- rhododendrons[8,9]

Figure 4. (below) Common south-west wetland species resistant to Phytophthora dieback. Photos – (a) ND Burrows and SD Hopper; (b) C Horton; (c) M Seale and J Stevens. Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 4/2/2009.

(a) Flooded gum (*Eucalyptus rudis*)

(b) Moonah (*Melaleuca preissiana*)

(c) White myrtle (*Hypocalymma angustifolium*)

Figure 5. (below) Common south-west wetland species susceptible to Phytophthora dieback. Photos – (a) BA Fuhrer, M Hancock, A Ireland and E Wajon; (b) I and M Greeve, C Hortin and T Tapper; (c) A Ireland and M Hislop. Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright, accessed 4/2/2009.

(a) Swamp peppermint (*Taxandria linearifolia*)

(b) Swamp banksia (*Banksia littoralis*)

(c) Swamp teatree (*Pericalymma ellipticum*)

case study

Critically endangered wetlands threatened by Phytophthora dieback

The following information has been taken from the then Department of Conservation and Land Management (CALM) (2005).[10]

The 'Shrublands on southern Swan Coastal Plain ironstones' (Busselton ironstone community) is a species-rich plant community of seasonally inundated wetlands with ironstone and heavy clay soils on the Swan Coastal Plain near Busselton (Figure 6). The community is recognised as being critically endangered on the list of threatened ecological communities endorsed by the Western Australian Minister for Environment. In 1995 there were only thirteen known occurrences of the Busselton ironstone community totalling 90 hectares. As a result of further surveys, the area of these occurrences has been found to be bigger than first thought and two additional occurrences have been identified bringing the total area of the community to almost 140 hectares.

The ironstone soils on which the Busselton ironstone community occurs are extremely restricted in distribution on the Swan Coastal Plain. They occur only on the eastern side of the Swan Coastal Plain along the base of the Whicher Scarp near Busselton. The heavy soils of this area are particularly useful for agricultural purposes. It has been estimated that around 97 per cent of vegetation on the eastern side of the Swan Coastal Plain has been cleared.

Much of the species diversity of the Busselton ironstone community is made up of annuals and **geophytes** (land plants that survive unfavourable periods by means of underground food storage organs, for example, rhizomes, tubers and bulbs). Typical and common native species are the shrubs *Kunzea* aff. *micrantha, Pericalymma ellipticum, Hakea oldfieldii, Hemiandra pungens* and *Viminaria juncea,* and the herbs *Aphelia cyperoides* and *Centrolepis aristata*. The community contains a number of taxa that are listed as priority or declared rare flora (DRF) by the Western Australian Government and are either totally confined or largely confined to these areas.[10]

Major threats to the community include Phytophthora dieback, clearing, too frequent fires, weed invasion, hydrological changes, and possibly salinisation. A number of plant species that occur in the community are very susceptible to Phytophthora dieback, including *Banksia nivea* subsp. *uliginosa* (Figure 7). All but one of the fifteen occurrences of the plant community are thought to be infected with the disease.[10] As such, Phytophthora dieback has the potential to seriously impact the 'Shrublands on southern Swan Coastal Plain ironstones'.

Figure 6. Busselton ironstone community. Photo – C Mykytiuk/DEC.

Figure 7. Death of *Banksia nivea* subsp. *uliginosa* (in the foreground) from Phytophthora dieback in an occurrence of the Busselton ironstone community. Photo – A Webb/DEC.

When *P. cinnamomi* invades communities dominated by species from the Proteaceae family, such as banksias and grevilleas, substantial changes in plant abundance and floristic structure may be observed. However, the effect of Phytophthora dieback on a plant community can vary greatly, depending both on the species composition of a particular community, and on the prevailing environmental conditions. It has been found that within the portion of the south-west land division that receives more than 800 millimetres mean annual rainfall, plant communities respond to Phytophthora dieback in one of four distinct ways:

1. No apparent disease at all (Figure 8).
2. An extremely destructive epidemic of root rot.
3. A variable epidemic within the dominant tree component of the jarrah forest, characterised by:
    a. irregular and often prolonged death of trees ranging from early localised mass collapse, through delayed and patchy deaths, to no apparent effect on the health of the jarrah overstorey
    b. high sensitivity to subtle differences in soil characteristics particularly those affecting drainage.
4. Replacement of forest with open woodland.[11]

The loss of native vegetation as a result of Phytophthora dieback (both within and surrounding a wetland) can have a number of detrimental impacts including:

- increased erosion and sedimentation
- reduced water quality
- loss of biodiversity, both directly and through loss of habitat and food for native fauna.

➤ For additional detail on the impacts of vegetation loss, see the topic 'Managing wetland vegetation' in Chapter 3.

Figure 8. Wetland vegetation infested with *Phytophthora cinnamomi* but showing no signs of the disease. Photo – R Lynch/DEC.

Effects on native animals

Changes in plant community composition and structure caused by *P. cinnamomi* may adversely affect associated groups of animals and soil biota by altering the availability of food resources and habitat (Table 2). Large herbivores such as western grey kangaroo (*Macropus fuliginosus*) and western brush wallaby (*M. irma*) may become more common, while smaller animals such as bandicoots and frogs may suffer from loss of refuge, with the more open vegetation giving them less protection from predators.

Pollinators reliant on susceptible plant species as key nectar sources, such as western pygmy-possum (*Cercartetus concinnus*) and honey possum (*Tarsipes rostratus*) may become rare or extinct in areas which have lost many species as a result of being infested for a long time. Insect pollinators may also be adversely affected by a reduction in nectar-producing plants, which in turn may affect the reproductive success of surviving plants dependant on the pollinators.

Table 2. Potential effects on fauna due to vegetation loss from Phytophthora dieback (based on Wilson, 1994[12])

Effects on vegetation	Effects on fauna
Loss of susceptible plants in the understorey and midstorey	Direct loss of food sources such as seeds, nectar and pollen
	Indirect loss of food sources such as invertebrates
Decline in plant species richness and diversity	Loss of food for species that prefer floristically rich vegetation
	Loss of seasonal food
Decrease in plant cover, increase in bare ground, erosion	Loss of habitat for species dependant on thick ground cover
	Increased predation risk
	Changes to microclimate
Decrease in canopy cover	Loss of food for tree-dwelling species
Decrease in litter fall	Decline in litter invertebrates
	Decline in invertebrate food sources for insectivores
Post-infection increase in frequency of resistant species	Changes in food webs

What types of Western Australian wetlands are commonly affected by Phytophthora dieback?

Phytophthora dieback is now widespread throughout the south-west of WA (Figure 9). In general, *Phytophthora cinnamomi* is restricted to areas in the south-west of the state receiving at least 400 millimetres of average annual rainfall; between Eneabba in the north and Cape Arid near Esperance in the east. It may, however, exist in slightly drier regions in water retaining sites such as wetlands and waterways. The pathogen causes the greatest impact in areas that receive more than 600 millimetres of annual rainfall. *Phytophthora cinnamomi* does not establish on coastal limestone soils of high pH (although other species of Phytophthora may) suggesting that wetlands on this substrate are unlikely to be infected.[13]

The degree to which plant communities are infested by *P. cinnamomi* is dependant on several factors, including the length of time the disease has been present, the history of land use, species susceptibility and landscape and soil factors. The location of many wetlands low in the landscape means that they have a high likelihood of being infested if *P. cinnamomi* is located within their catchments, particularly if infested waterways or other drainage lines direct surface water into them. If food and oxygen are available, and temperature, chemistry and microflora are not inhibitory, *P. cinnamomi* is also able to survive in groundwater.[14] Other than the jarrah forest, little is known of the movement of *P. cinnamomi* in groundwater. Although *P. cinnamomi* can be transported via groundwater for more than a couple of metres in the jarrah forest, the same movement may not occur elsewhere and the spread of the pathogen from one infested wetland to another wetland via groundwater may not occur (B Shearer 2009, pers. comm.). There are three basic requirements for the rapid, long-distance, lateral (sideways) dispersal of *P. cinnamomi* through groundwater:

1. the soil structure must be porous enough (full of holes) to allow spores to move through[15]
2. groundwater flow must largely be lateral (sideways)[16]
3. the connections between larger groundwater pores must be unbroken over significant distances.[17]

Figure 9. Distribution of Phytophthora dieback in the south-west of WA. © Dieback Working Group.

Extent of infestation

According to conservative estimates, 15–20 per cent of the jarrah (*Eucalyptus marginata*) forest has been infested by *P. cinnamomi,* with the proportion considerably higher in the wetter, north-western part of the forest.[13] Around 60 per cent of the montane shrublands and banksia and mallee woodlands of the 116,000-hectare Stirling Range National Park are infested, as are perhaps 70 per cent of the seasonally inundated banksia woodlands in the Shannon and D'Entrecasteaux national parks.[13] In contrast, largely because of restricted vehicular access, less than 0.1 per cent of the 328,000-hectare Fitzgerald River National Park is infested with *P. cinnamomi,* even though a large part of it receives more than 400 millimetres annual average rainfall.[13] There are a number of wetlands in the south-west that have been identified as being impacted by Phytophthora dieback. These include: Lake Logue near Eneabba; Lake Warden in Esperance; numerous wetlands on the southern Swan Coastal Plain ironstone (Busselton area); and wetlands within Jandakot Regional Park and Lightning Swamp bushland in the Perth metropolitan area.

Recognising the symptoms of Phytophthora dieback

The first step in the management of Phytophthora dieback is determining whether it is present or absent, and if it is present, identifying which parts of a site are infested.

Indicator species

The first indication that *P. cinnamomi* has spread into a new area is the death of 'indicator species' (Figure 10). An indicator species is a plant species which is reliably susceptible to *P. cinnamomi* (i.e. the disease usually kills that species). Common indicator species in wetlands include the swamp peppermint (*Taxandria linearifolia*), swamp banksia (*Banksia littoralis*), and swamp teatree (*Pericalymma ellipticum*). The distribution and composition of indicator species will vary from place to place according to vegetation type.

➤ Lists of Western Australian native species both susceptible and resistant to Phytophthora dieback are available on the Centre for Phytophthora Science and Management website. This list includes both dryland and wetland species. www.cpsm.murdoch.edu.au[18]

Figure 10. Deaths of oak-leaved banksia (*Banksia quercifolia*) in a seasonally waterlogged wetland within D'Entrecasteaux National Park on the south coast of WA.
Photo – Dieback Working Group.

Epicormic: (of a shoot or branch) growing from a previously dormant bud on the trunk or limb of a tree

Other causes of plant decline or death

Plant decline and death may be caused by factors other than Phytophthora dieback. When assessing a site for the presence of Phytophthora dieback using indicator species, it is important to be able to discount other causes of plant death or decline such as:

- insect attack
- changes to surface water or groundwater levels
- poor soil or water quality (including nutrient enrichment, acid sulfate soils and secondary salinity)
- the honey fungus *Armillaria luteobubalina*
- fire
- nutrient deficiencies.

If Phytophthora dieback 'resistant species' such as flooded gum (*Eucalyptus rudis*), moonah (*Melaleuca preissiana*) and white myrtle (*Hypocalymma angustifolium*) are dying, then it is likely that the cause is something other than *P. cinnamomi*.

When affected by Phytophthora dieback, moderately susceptible plant species such as jarrah (*Eucalyptus marginata*) may show symptoms of crown decline including the yellowing of leaves and death of primary leaf-bearing branches.[19] **Epicormic** buds may shoot, forming new branches along existing branches, with the leaves on these tending to be smaller than on the primary branches. Over time, epicormic branches will decline, resulting in an overall thinning of the crown.[19] Trees showing symptoms of crown decline may take a number of years to die. In some cases, apparently healthy trees (in groups or individually) can suddenly collapse and die.

Interpreters

The personnel who carry out the tasks of detection, diagnosis and mapping of Phytophthora dieback are known as 'interpreters' because they interpret disease symptoms to draw conclusions about the health of the vegetation. By recognising disease symptoms and observing the pattern of indicator species deaths, interpreters can build up a picture of the history and future progress of the disease at a particular site. As the pathogen spreads through an area, some or all susceptible plants become infected and die. Consequently, there will be a spread of ages in the plants that have succumbed to Phytophthora dieback, ranging from more recent deaths with yellowing or brown leaves, through to older leafless stags, and finally to remnant stumps in the ground.

Apart from a knowledge of common indicator species, interpreters need to be able to assess the influence of landscape position, soils and drainage on the development of the disease and to be able to distinguish the effects of Phytophthora dieback from those of drought and other diseases of native vegetation such as *Armillaria*.

Aerial photography

Since 1986, 230-millimetre (1:4,500) colour aerial photographs have been used for mapping the position of *P. cinnamomi* disease boundaries in WA. Given sufficient disease expression (dead and dying plants) at the time of photography, an interpreter can make decisions about the disease status of an area (that is, whether *P. cinnamomi* has caused the deaths). Field visits to view the symptoms and sampling of recently dead plants are used to verify the interpretation of aerial photographs.

GPS: global positioning system, an accurate worldwide navigational and surveying facility based on the reception of signals from an array of orbiting satellites

Ground stripping

Ground stripping involves interpreters walking an array of parallel lines through the bush to determine whether disease caused by *P. cinnamomi* is present and to record its position. It is used in areas which are not suitable for interpretation using 230-millimetre aerial photography or when such photography is not available. Field maps and **GPS** units are used to record the position of infected plants and the boundaries of infested areas. Boundaries are demarcated with painted yellow tree blazes or 'dayglo' orange flagging tape (Figure 11).

Figure 11. Sample being taken from a dead tree for laboratory testing to determine the presence of *Phytophthora cinnamomi.* Photo – M Pez/DEC.

Sampling to determine the presence of *Phytophthora cinnamomi*

To confirm the accuracy of the interpretation of disease symptoms, samples of root and lower stem material as well as adjacent soil can be taken from recently dead plants (Figure 12). Long-dead plants are unlikely to return positive results from sampling even if *P. cinnamomi* killed the plant. Collected material can then be sent to an analytical laboratory for testing. Laboratories offering this service can provide detailed instructions on how to take a sample, store and transport the collected materials to them.

Laboratories are able to determine the presence of *P. cinnamomi* using either the baiting or direct plating method. 'Baiting' involves mixing soil from the sample bag with distilled water in a container and then floating cotyledons (imillimetresature leaves) of *Eucalyptus sieberi* (which have purple undersides) on the water. If after five to ten days the cotyledons have lost their purple colour the sample is presumed to be infected with *P. cinnamomi*. 'Plating' is then carried out by placing the cotyledons on antibiotic **agar** in a **petri dish**. Plated baits are left for a maximum of three days and if *P. cinnamomi* is not evident after this time, the plates are discarded, and the samples are recorded as negative.

It is important to note that a negative result from a sample does not mean that the site is free of pathogen. A negative result only means that the pathogen was not captured in the sample. Multiple samples of a site may be required before a positive result can be obtained.

Agar: a gelatinous substance obtained from any of various kinds of red seaweed and used to grow cultures of fungi and other microorganisms

Petri dish: a shallow covered dish used for the culture of fungi and other microorganisms

Figure 12. A DEC interpreter marking the boundary of an area infested with *Phytophthora cinnamomi* with yellow tree blazes and orange flagging tape. Photo – Dieback Working Group.

Mapping Phytophthora dieback

Interpreters generally produce two main types of maps, a *P. cinnamomi* occurrence map and a *P. cinnamomi* protectable areas map, both of which are accompanied by a written report. The *P. cinnamomi* occurrence map shows disease distribution, and is used as a basis for the *P. cinnamomi* protectable areas map and a *P. cinnamomi* hygiene management map. Three categories are shown on a *P. cinnamomi* occurrence map: uninfested, uninterpretable and infested (Table 3).

A *P. cinnamomi* protectable areas map shows areas which are disease free, and which are considered to be able to be protected from the establishment of new centres of infestation (arising from the activities of humans) through the implementation of hygienic management practices (Figure 13). The *P. cinnamomi* hygiene management map is jointly prepared with the land manager as part of the protectable areas *P. cinnamomi* hygiene planning process, and forms part of the *P. cinnamomi* hygiene plan. The frequency at which these maps need to be produced will be influenced by the circumstances at a particular wetland.

Table 3. *Phytophthora cinnamomi* occurrence categories used in maps

Unmappable Areas that are sufficiently disturbed so that *Phytophthora cinnamomi* occurrence mapping is not possible at the time of inspection	Further categorisation may be possible after variable regeneration periods for different types of disturbance	
Mappable Natural undisturbed vegetation. *Phytophthora cinnamomi* occurrence mapping is possible	**Infested**	Area that a qualified person had determined to have plant disease symptoms consistent with the presence of *Phytophthora cinnamomi*
	Uninfested	Area that a qualified person had determined to be free of plant disease symptoms that indicate the presence of P*hytophthora cinnamomi*
	Uninterpretable	Area where indicator species are absent or too few to determine the presence or absence of *Phytophthora cinnamomi*

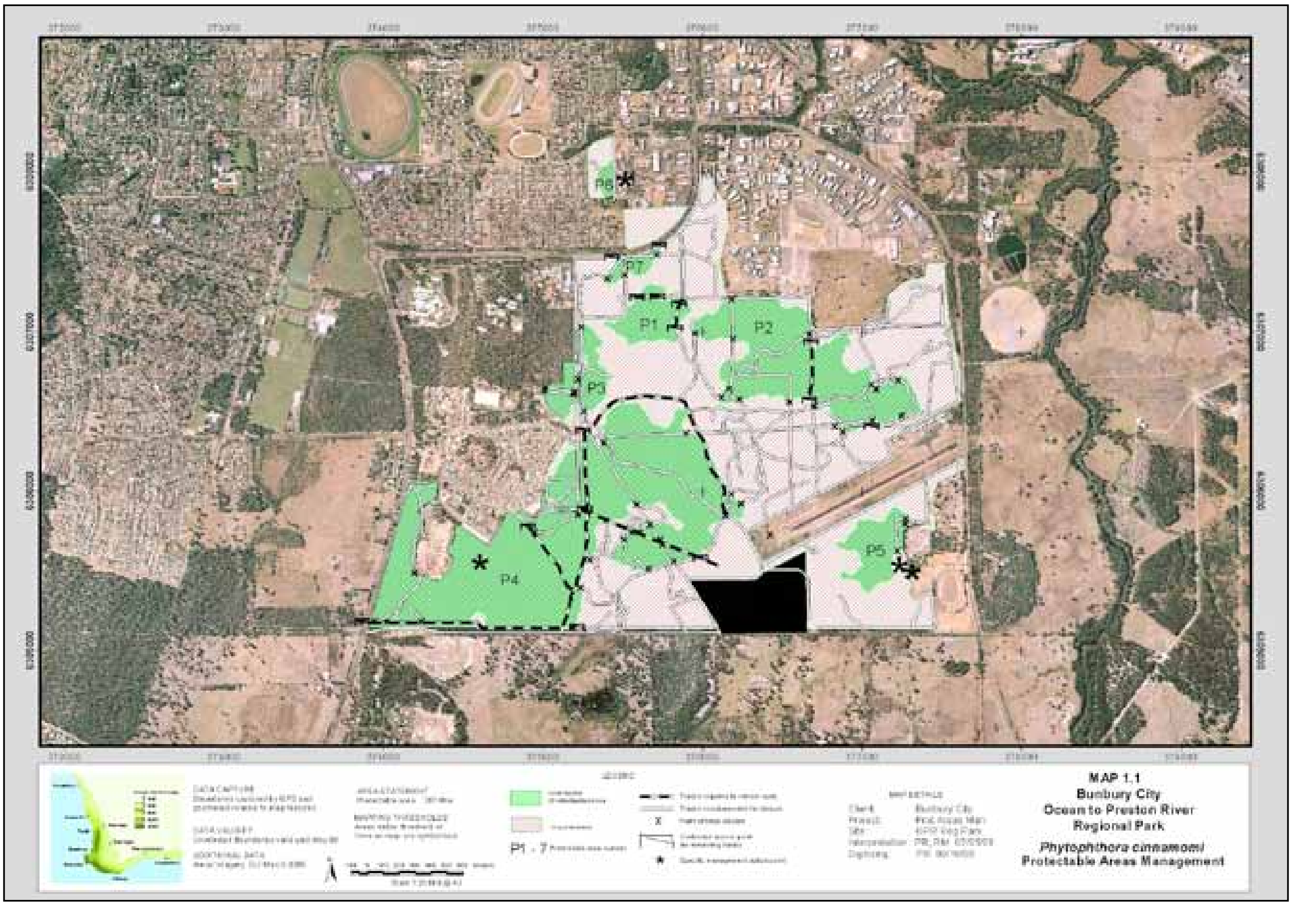

Figure 13. A protectable areas map produced for Manea Park in Bunbury. Map produced by Glevan Consulting for the City of Bunbury.

Key management techniques for tackling Phytophthora dieback in wetlands

Phosphite: an aqueous solution of mono- and di-potassium phosphite used to protect plants against Phytophthora dieback

The management of Phytophthora dieback in wetlands can be summarised into three steps:

1. Assess the site and map Phytophthora dieback occurrence
2. Prepare and implement management procedures
3. Treat plants with **phosphite**.

Assessing a wetland for Phytophthora dieback

As described above, there are a number of ways of assessing a wetland for the presence of Phytophthora dieback, which include field assessment, analysis of aerial photography and laboratory testing of plant and soil samples. A key component of an assessment is determining the distribution of Phytophthora dieback at a site and recording this information in a *P. cinnamomi* occurrence map.

As a number of common wetland species are resistant to Phytophthora dieback and may not show symptoms of the disease, many wetlands may be considered to be 'uninterpretable' with regard to detecting the presence of *P. cinnamomi.* It may therefore be necessary to test plant and soil samples in a laboratory to confirm the presence or absence of *P. cinnamomi* at wetland sites. If a wetland is located low in the landscape and Phytophthora dieback has already been positively identified within the catchment, it can be assumed with reasonable confidence it already is or soon will be infested. In such cases it may be considered unnecessary to have wetland plant and soils samples tested in the laboratory.

More information on assessing a wetland for the presence of Phytophthora dieback is available in the sections: 'Recognising the symptoms of Phytophthora dieback' and 'Sources of more information on managing Phytophthora dieback in wetlands' within this topic.

Preparing and implementing management procedures

Once present, *P. cinnamomi* cannot be eradicated from an area. As such, the management of Phytophthora dieback is focused on minimising the spread of the pathogen. How Phytophthora dieback is managed at a wetland depends largely on knowing if it is present and having an understanding of its distribution. Whether Phytophthora dieback is present at the site or not, or is spread throughout an entire site or located in an isolated section, all management procedures are based on minimising the movement of soil, plant material and water (hygiene management), and on protecting plants by treating them with phosphite.

➤ Excellent examples of how to manage Phytophthora dieback in different scenarios are provided in: Dieback Working Group (2008). *Managing Phytophthora dieback in bushland: A guide for landholders and community conservation groups.*[2]

The basic steps in preparing and implementing Phytophthora dieback management procedures include:

- Identifying areas which are free of Phytophthora dieback and have a high likelihood of being maintained as such ('protectable areas') and focusing hygiene management on them
- Implementing hygiene protocols to minimise the spread of Phytophthora dieback including signage, boot-cleaning stations, vehicle and equipment washdowns (see Figure 14)
- Setting a timeframe for re-assessing areas for the presence of Phytophthora dieback and preparing up-to-date occurrence maps
- Utilising up-to-date occurrence maps to review the effectiveness of management procedures.

A number of guidelines for the best practice management of Phytophthora dieback have been produced for a variety of land managers including landholders and community groups, local government and state government agencies. A list of the best practice guidelines that have been produced for each of these groups is included in this section. Please note that the documents listed may be of use to land managers beyond the targeted group.

It is also worth noting that the guidelines listed below have been written with dryland bushland rather than wetlands in mind. When relating management guidelines to wetlands it is important to keep the following points in mind:

- If Phytophthora dieback is present in a catchment area, wetlands located low in the landscape within that catchment have a high likelihood of being infested.
- When preparing management guidelines which deal with restricting the movement of water, it is important to consider the implications of restricting water movement on the wetland water regime.

➤ For additional detail on wetland water regime see the topic 'Wetland hydrology' in Chapter 2.

(a) **(b)**

Figure 14. Phytophthora dieback hygiene management activities: (a) signage; and (b) boot-cleaning station. Photos – Dieback Working Group.

Guidelines for the best practice management of Phytophthora dieback

For landholders and community groups:

Dieback Working Group (2008). *Managing Phytophthora dieback in bushland: A guide for landholders and community conservation groups.*[2]

For local government:

Dieback Working Group (2000). *Managing Phytophthora dieback: Guidelines for local government.*[20]

For state government and other agencies:

Department of Conservation and Land Management (2003). Phytophthora cinnamomi *and disease caused by it: Volume I Management guidelines.*[3]

Department of Conservation and Land Management (2004). *Best practice guidelines for the management of* Phytophthora cinnamomi *(Draft).*[11]

Treating plants with phosphite

Phosphite, an aqueous solution containing phosphorus, has shown great promise in the battle to preserve rare and endangered Western Australian native plants under threat from *P. cinnamomi*. Depending on how it is applied, phosphite can provide protection for vulnerable plant species against the disease for up to ten years. Phosphite is an environmentally safe, inexpensive chemical that is systemically transmitted throughout treated plants and has a very low toxicity to animals.

Fungicide: a substance that kills fungi

Fungistat: a substance that inhibits the growth and reproduction of fungi without destroying them

How it works

The mode of action of phosphite is not fully understood. At high enough concentrations, phosphite will act directly on *P. cinnamomi* as a **fungicide** or **fungistat** to either kill or halt its growth. This direct effect appears to occur within the *P. cinnamomi* organism, but it also appears that the progress of infection by *P. cinnamomi* is halted when it comes into contact with phosphite in plant tissue. This may be because high phosphite concentrations interfere with the way that phosphorus is used by the pathogen for survival. The application of phosphite may also trigger the plant's self-defence mechanism, causing it to wall-off and isolate the invaded root cells. Plants in poor health which are treated in time have been shown to fully recover and remain healthy for a number of years.

History of use

Previously called phosphonate, phosphite has been used to protect avocado, pineapple and cocoa crops against Phytophthora disease since the 1970s. In the late 1980s Department of Conservation and Land Management research staff began investigating whether the fungicide provided any protection to Western Australian native plant species. Phosphite solution was injected into jarrah (*Eucalyptus marginata*) and several banksia species, and the treatments showed considerable promise; slowing and stopping the growth of the pathogen within the plants under attack.[21]

Research efforts continued over the next decade and included field trials in locations ranging from the northern sandplains near Eneabba to Fitzgerald River National Park east of Albany. Aerial application of phosphite to native plant communities was tested for the first time in 1993 in several reserves near Albany and proved a success. Aircraft allow for relatively cheap and rapid treatment of entire plant communities containing rare plant species, and are suitable for areas where the ruggedness of the terrain would make ground application prohibitively expensive.

How it is applied

Phosphite is applied via stem injection (to trees with a diameter at chest height of 10–14 centimetres or greater[22]), or as a spray by aerial or ground application (Figure 15). One drawback with aerially applied phosphite is that protection normally only lasts for about two years, whereas stem injection may provide protection for up to ten years. There are two main strategies for its application. Firstly, phosphite can be applied in an already infested area to protect susceptible plants that have not yet been infected or help already infected plants to recover.[23] Secondly, phosphite can be used strategically for effective protection ahead of an advancing 'front' of *P. cinnamomi*. A 30–40-metre-wide swathe of phosphite can be applied in front of an advancing *P. cinnamomi* infestation to prevent root-to-root transfer of the pathogen across the barrier.[22] If the infested area is upslope of the area to be protected the protective swathe would need to be wider than if it is downslope. This is because of the possibility of overland or subsurface transport of *P. cinnamomi* zoospores for considerable distances downslope following rainfall. In contrast, movement of an infestation upslope is generally slower, being mainly caused by root-to-root contact between plants.

Figure 15. (below) Application of phosphite via (a) spraying; and (b) stem injection. Photos – Dieback Working Group.

(a)

(b)

Applying phosphite in wetlands

If applying phosphite, or any other chemical, in wetlands or other natural environments it is important to minimise any off-target impacts such as the unwanted decline or death of plants or animals. It is also important to be aware that when phosphite is applied as a spray, by aerial or ground application, it is mixed with a wetting agent to help droplets hold onto leaf surfaces until they are absorbed. There are significant risks associated with the use of wetting agents in wetlands and other aquatic environments including toxic effects on tadpoles.[24,25] As such, it is essential that any off-target impacts of wetting agents are also minimised.

➤ For more information on reducing the off-target impacts of the application of chemicals see the topic 'Wetland weeds' in Chapter 3.

The off-target impacts of chemicals (including wetting agents) can be reduced and the effectiveness of application increased by:

- selecting the correct application method (which will depend on the type and size of plants being targeted, for example, using stem injection where possible)
- applying the chemical under ideal environmental conditions (for example, dry, still wind conditions to minimise spray drift and timing the application while susceptible fauna aren't in a critical life phase such a reproduction)
- carefully following the manufacturer's instructions.

Wetting agent: a substance that helps water or other liquid, to spread or penetrate (also known as a surfactant or penetrant)

The future

Research into phosphite and its application is continuing. Among the areas requiring additional investigation is the refinement of application rates, times and frequencies for different vegetation types. Phosphite cannot eradicate *P. cinnamomi* from an area once it has established. However, by boosting the ability of plants to ward off infection, it does provide some ability to protect endangered plants that might otherwise become extinct in the wild within a few years. Nevertheless, the major strategy for limiting the environmental damage caused by the pathogen remains the prevention of the transport of infested soil into uninfested areas, by means of quarantine and the maintenance of high standards of hygiene.

Monitoring the success of management and restoration techniques

Monitoring is a key component of wetland management and restoration. The information collected through monitoring can be used to assess if management is successful, and if not, to adapt or modify the management (adaptive management).

In order to monitor the success of Phytophthora dieback management techniques it is recommended that up-to-date Phytophthora dieback occurrence maps are prepared. The frequency at which these maps need to be produced will be influenced by the circumstances at a particular wetland. Specialist advice should be sought from an interpreter or other specialist for more information. As Phytophthora dieback impacts wetland vegetation, it is recommended that vegetation also be monitored to assess the effectiveness of management activities.

➤ Additional detail on monitoring wetland vegetation is provided in the topic 'Monitoring wetlands' in Chapter 4.

case study

Manea Park – a collaborative approach to Phytophthora dieback management

Manea Park is approximately 500 hectares in size and is managed by the City of Bunbury for conservation purposes. The reserve contains more than 150 hectares of wetlands including damplands, palusplains and sumplands. The reserve also contains two threatened ecological communities, which are both listed as vulnerable. Both of these communities are wetlands (Figure 16).

Much of the flora of Manea Park is highly susceptible to Phytophthora dieback and, as such, an investigation into its distribution within the park was conducted by the then Department of Conservation and Land Management in 2001. This survey found that up to half of Manea Park was infested with the disease, including many of the wetland areas and some heavily degraded dryland areas. In 2007, the City of Bunbury secured funding from Project Dieback to have Manea Park reassessed and mapped by a consultant. The results from the survey undertaken by Glevan Consulting in 2008 strongly mirrored the results of the 2001 assessment and show that Phytophthora dieback has spread very little since the original mapping exercise in 2001.

The survey undertaken in 2008 found that the vegetation in around 36 per cent of the survey area was sufficiently disturbed (by factors such as clearing and grazing) that *P. cinnamomi* mapping was not possible at the time of inspection, and was otherwise referred to as 'unmappable'. This 36 per cent included many of the wetlands within the reserve. Of the area that was able to be mapped, approximately 22 per cent was found to be infested with *P. cinnamomi.*[26] The survey also found that it was predominately low-lying wetlands in the north-west of the park that were infested. Although many wetland plant species are resistant to Phytophthora dieback, impacts of the disease have been observed in a number of the wetlands in Manea Park, including those recognised as threatened ecological communities, with deaths of swishbush (*Viminaria juncea*), swamp banksia (*Banksia littoralis*) and swamp teatree (*Pericalymma ellipticum*) recorded (Figure 17).

In mid-2008 the City of Bunbury decided to take the next step in protecting Manea Park from Phytophthora dieback by developing management strategies for dieback-free areas or 'protectable areas' in the reserve. Limited areas of wetland were included within the identified protectable areas, as most of the wetland areas within the reserve were identified as either being infested with *P. cinnamomi* or unmappable.

Management strategies for protectable areas were developed at a workshop with key stakeholders including the Department of Environment and Conservation, Department for Planning and Infrastructure, Project Dieback, the Friends of Manea Park and the City of Bunbury's consultant. It was agreed that track closure and the control of track access were the most effective strategies available. To complement these strategies it was also agreed to erect interpretive signage at strategic points throughout the park to explain the current *P. cinnamomi* infestation status and the management strategies implemented to control its spread.

To manage those areas already infested by *P. cinnamomi*, phosphite treatment will be undertaken in a number of places, including the wetland areas. This treatment will assist in reducing the loss of plant species in these high conservation value areas.

For further information contact the City of Bunbury Environmental Officer.

Figure 16. One of the threatened ecological communities in Manea Park near Bunbury. Photo – C Mykytiuk/DEC.

Figure 17. Deaths of swamp banksia (*Banksia littoralis*) in one of the threatened ecological communities in Manea Park. Photo – C Mykytiuk/DEC.

Whether or not to manage Phytophthora dieback in a wetland

When deciding whether or not to manage Phytophthora dieback at a wetland, there are a number of factors that should be considered, which will help focus the decision-making process. These include:

- **What are the values under threat from Phytophthora dieback?**

  Example: Which plants species are susceptible to Phytophthora dieback? What will be the impact of the loss of these species?

  If the values under threat from Phytophthora dieback are significant, managing dieback will be a higher priority.

- **How practical and effective will management (hygiene management and treatment with phosphite) be?**

  Example: Does Phytophthora dieback already occur throughout the site? Is the wetland located low in the landscape within a catchment already infected with Phytophthora dieback?

  If management actions are unlikely to be effective in controlling and/or reducing the impact of Phytophthora dieback at the site, it may not be a good use of resources to implement these actions.

- **Will management protect the values under threat?**

  Example: Are the values under threat from Phytophthora dieback, already threatened by a potentially more significant degrading process such as altered hydrology? Is the wetland already so significantly impacted by Phytophthora dieback that management will not achieve improvements?

  If managing Phytophthora dieback is not going to be sufficient to protect the values under threat because they're threatened by something else, or because the site is already severely impacted by Phytophthora dieback, it may not be a good use of resources to implement these actions and instead resources may be better directed towards managing another degrading process.

- **How urgent is the need for action – at what rate is Phytophthora dieback diminishing wetland values?**

  Example: Is Phytophthora dieback causing a rapid and significant loss of plants? Is the loss of plants from Phytophthora dieback relatively slow over time?

  Threats that are having a rapid impact would generally be a higher priority for management than threats that act very slowly.

- **What are the financial and other costs (such as time and labour) of carrying out management activities?**

  Example: How do financial and other costs of Phytophthora dieback mapping and hygiene management weigh up against the values under threat? How do the financial and other costs of phosphite treatment weigh up against the values under threat?

  Management will be most cost effective and beneficial if the site has high values, and the cost of management actions is relatively low.

- **Taking into account the management of other threats or degrading processes – what is the most logical sequence for undertaking management actions?**

  Example: If it is planned to close tracks or paths as part of a hygiene management plan, it should be determined whether the paths are needed for other management activities, such as providing access to remove car bodies or other rubbish?

  All threats and degrading processes need to be documented for the site, and any possible links between these identified prior to planning on-ground management.

In some situations, it may be necessary to make decisions regarding the management of Phytophthora dieback across multiple wetlands within one landscape or management area. In these situations, the questions listed above will still be a useful guide to decision-making. Often it is most effective to focus resources on those wetlands that are minimally degraded and still have high values, as intervention is likely to be most successful, and have most conservation value at these sites.[21]

In an ideal situation, any management activities should be undertaken as part of a comprehensive wetland management plan which would address other management issues or degrading processes and their associated management activities. It is strongly encouraged that a management plan is prepared, however basic it may be.

➤ For additional detail on preparing a wetland management plan see the topic 'Planning for wetland management' in Chapter 1.

Topic summary

- Phytophthora dieback refers to the introduced plant disease caused by the microscopic soil-borne organism *Phytophthora cinnamomi*.
- *P. cinnamomi* invades the roots of plants, killing cells, reducing the ability of a plant to take up and transport water and nutrients, often resulting in the death of the plant.
- Many common wetland species are susceptible to Phytophthora dieback, however field observations have suggested that a large number of wetland species are resistant to *P. cinnamomi*, hence wetland plant communities often don't exhibit signs of Phytophthora dieback disease.
- The loss of native vegetation as a result of Phytophthora dieback can have a number of detrimental impacts on wetlands including increasing the risk of erosion and sedimentation, reducing water quality, loss of biodiversity, loss of habitat and food for native fauna and a subsequent decline in native fauna.
- The fact that most wetlands are located low in the landscape means that they have a highly likelihood of being infested if Phytophthora dieback is located within their catchments.
- Once present, *P. cinnamomi* cannot be eradicated from an area. As such, the management of Phytophthora dieback is focused on minimising the spread of the pathogen to disease-free areas.
- The management of Phytophthora dieback is based on minimising the movement of soil, plant material and water, and protecting plants by treating them with phosphite.
- The management of Phytophthora dieback in wetlands can be summarised into three steps:
    1. assess the site and map Phytophthora dieback occurrence
    2. prepare and implement management guidelines
    3. treat plants with phosphite.
- When deciding whether or not to manage Phytophthora dieback at a wetland, there are a number of factors that should be considered including the values under threat, how practical and effective will management be, and the financial and other costs (such as time and labour) of carrying out management activities.

Sources of more information on managing Phytophthora dieback in wetlands

Websites

Dieback.org.au
www.dieback.org.au
Information on the impacts of Phytophthora dieback and its management. Designed to be a one-stop shop for information on how to manage Phytophthora dieback.

Dieback Working Group
www.dwg.org.au
Information on the impacts of Phytophthora dieback and its management.

Project Dieback
www.dieback.net.au
Information on the impacts of Phytophthora dieback, maps of its distribution within the south-west, and lists of susceptible and resistant species in the South Coast NRM region.

Centre for Phytophthora Science and Management
www.cpsm.murdoch.edu.au
Information on Phytophthora dieback research, links to national best practice guidelines, and list of susceptible and resistant species.

Department of Environment and Conservation
www.dec.wa.gov.au (search for 'Phytophthora')
Information on the impacts of Phytophthora dieback and its management, state government Phytophthora dieback policy, Phytophthora dieback Atlas.

Department of Sustainability, Environment, Water, Population and Communities
www.environment.gov.au (search for 'Phytophthora')
Information on Phytophthora dieback management and threat abatement.

Publications

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Glossary

Agar: a gelatinous substance obtained from any of various kinds of red seaweed and used to grow cultures of fungi and other microorganisms

Dieback: the progressive dying back of a plant as a result of disease or unfavourable conditions

Epicormic: (of a shoot or branch) growing from a previously dormant bud on the trunk or limb of a tree

Fungicide: a substance that kills fungi

Fungistat: a substance that inhibits the growth and reproduction of fungi without destroying them

Germinate: begin to grow, usually following a period of dormancy (resting phase)

Geophytes: land plants that survive unfavourable periods by means of underground food-storage organs, for example rhizomes, tubers and bulbs

GPS: global positioning system, an accurate worldwide navigational and surveying facility based on the reception of signals from an array of orbiting satellites

Mycelium: the vegetative part of a fungus, consisting of microscopic thread-like filaments known as hyphae

Oomycetes: the group of fungae-like organisms known as the water moulds

Pathogen: any organism or factor causing disease within a host

***Phytophthora cinnamomi*:** an introduced water mould that attacks the roots of susceptible plant species, resulting in the decline or death of the plant

Phytophthora dieback: the introduced plant disease caused by *Phytophthora cinnamomi*, which results in the decline or death of susceptible plants

Petri dish: a shallow covered dish used for the culture of fungi and other microorganisms

Phosphite: an aqueous solution of mono- and di-potassium phosphite used to protect plants against Phytophthora dieback

Wetting agent: a substance that helps water or other liquid, to spread or penetrate (also known as a surfactant or penetrant)

Personal communications

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Chris Dunne	26/09/2008	Senior Research Scientist	Department of Environment and Conservation, Western Australia
Dr Bryan Shearer	21/01/2009	Principal Research Scientist	Department of Environment and Conservation, Western Australia

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2009185-1011-PDF

A guide to managing and restoring wetlands in Western Australia

Managing wetland vegetation

In Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

‘Managing wetland vegetation’ topic

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Recommended reference

When referring to the guide in its entirety, the recommended reference is: Department of Environment and Conservation (2012). *A guide to managing and restoring wetlands in Western Australia*. Department of Environment and Conservation, Perth, Western Australia.

When specific reference is made to this topic, the recommended reference is: Department of Environment and Conservation (2012). ‘Managing wetland vegetation’, in *A guide to managing and restoring wetlands in Western Australia*, Prepared by J Nichol, Department of Environment and Conservation, Perth, Western Australia.

Contents

Case studies

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

INTRODUCTION

Wetland plants are an important part of the state's biological diversity. It is estimated that wetland **taxa** form more than 20 per cent, or 3,000 of Western Australia's approximate 12,500 flora.[1]

The **vegetation** also constitutes part of the wetland **ecosystem**, playing a key role in many physical, biological and chemical **wetland processes**, helping to maintain a stable ecosystem and defining a wetland's **ecological character**. As such, vegetation change can significantly influence the long-term health and values of a wetland.

WA's wetlands can be degraded by a range of threatening processes that impact upon wetland flora and vegetation. This is telling in the number of wetland **ecological communities** that are threatened: thirty-three of WA's sixty-nine threatened ecological communities are wetland communities defined or reliant on (vascular) plant taxa.[1] Weeds are usually prevalent in wetlands that have been subject to disturbance.

Vegetation changes can either occur naturally or because of human influences. This topic focuses on managing human-caused vegetation change in natural wetlands. Most human-caused vegetation changes are detrimental and can lead to further degradation of a wetland ecosystem. This topic outlines the steps wetland managers can take to manage native wetland vegetation in order to maintain a wetland's natural values. The information in this topic applies to the management of vegetation that is currently degraded, or that is in good condition or within acceptable limits of change, so as to prevent the vegetation becoming degraded.

Specifically, this topic is designed to assist wetland managers to:

- identify the three main types of vegetation change that occur within a wetland and determine the type and extent of these changes in a given wetland
- determine an appropriate level of intervention
- plan management actions.

Requirements for revegetating or rehabilitating wetlands as a condition of development approval, an offset, or a vegetation conservation notice under the *Environmental Protection Act 1986* or relevant planning legislation are not addressed in this topic. These mechanisms may have specific requirements, such as completion criteria and specific timeframes.

➤ For guidance on these matters, see:

- *Rehabilitation of terrestrial ecosystems*[2]
- *Guidelines checklist for preparing a wetland management plan*[3]
- Chapter B4 of *Environmental guidance for planning and development*[4]

Taxa: a taxonomic group (the singular being taxon). Depending on the context, this may be a species or their subdivisions (subspecies, varieties etc), genus or higher group.[6]

Vegetation: combinations of plant species within a given area, and the nature and extent of each area

Ecosystem: a community of interdependent organisms together with their non-living environment.

Wetland processes: the dynamic physical, chemical and biological forces within a wetland, including interactions that occur between wetland organisms, within the physical/chemical environment, and interactions of these

Ecological character: the sum of a wetland's biotic and abiotic components, functions, drivers and processes, as well as the threatening processes occurring in the wetland, catchment and region

Ecological community: naturally occurring biological assemblages that occur in a particular type of habitat

There is no substitute for maintaining the natural characteristics of wetland vegetation. Regeneration and revegetation activities may never completely re-establish natural wetland processes.[5] Prevention, and maintaining or improving the **resilience** of the vegetation, are key strategies. In the absence of vegetation changes, wetland managers can manage wetland vegetation by:

- keeping a watch for vegetation change, particularly weeds
- managing the dryland surrounding the wetland (sometimes designated as a **wetland buffer**) to help protect the wetland from potential impacts from surrounding land uses and to help maintain its natural processes
- retaining, or where possible, reinstating **ecological linkages**
- where warranted, surveying the wetland vegetation and considering contingencies such as seed storage that can be used in the event of significant vegetation change.

➤ Programs providing funding, labour, training and technical guidance for wetland vegetation management are outlined in the topic 'Funding, training and resources' in Chapter 1.

It is strongly recommended that anyone intending to carry out regeneration or revegetation activities consider doing so within the framework of a wetland management plan. A wetland management plan provides a structured way of deciding on priorities and tasks to make the process as effective, efficient and successful as possible. For large, complex or significant wetlands it is invaluable.

➤ Further guidance in provided in the topic 'Wetland management planning' in Chapter 1.

Resilience: capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks

Wetland buffer: an interface adjoining a wetland that is designated to assist in protecting the wetland's natural values from the threats posed by the surrounding land use(s)

Ecological linkage: a network of native vegetation that maintains some ecological functions of natural areas and counters the effects of habitat fragmentation[6]; a series of (both contiguous and non-contiguous) patches of native vegetation which, by virtue of their proximity to each other, act as stepping stones of habitat which facilitate the maintenance of ecological processes and the movement of organisms within, and across, a landscape[7]

extra information

WA's wetland vegetation: background information

WA's wetland plants are remarkable and important for many reasons. Wetland flora contributes to the incredible biodiversity and endemism found in WA, in parts of the Kimberley, Pilbara and Goldfields regions, and in the south-west, which is a centre of exceptionally high species richness and endemism and is one of the world's 25 biodiversity hotpots.[2]

For more information on WA's wetland vegetation and flora refer to:

- the topic 'Wetland vegetation and flora' in Chapter 2, which documents the remarkable vegetation and flora of WA's wetlands
- the topic 'Wetland ecology' in Chapter 2, which provides information on the ecological role played by wetland vegetation.

In seeking to provide guidance on managing the vegetation of WA wetlands, there are many limitations to how specific or detailed the information can be. The vegetation in WA's wetlands ranges from forests to tiny moss pillows, extremely diverse to fairly limited, and relatively well-documented to those containing flora not yet documented by science.

Useful contacts and resources for additional information include:

- *Restoring Natural Areas in Australia* (Buchanan 2009)[8]
- Florabank's Native Vegetation Management Tool: www.florabank.org.au
- The Australian Association of Bush Regenerators www.aabr.org.au

extra information

WA's wetland vegetation: background information (cont'd)

- Revegetation Industry Association of WA www.riawa.com.au
- Wildflower Society of Western Australia http://members.ozemail.com.au/~wildflowers/policies.htm
- Greening Australia[9] http://live.greeningaustralia.org.au/nativevegetation/pages/page116.html
- *Restoring Perth's Banksia woodlands* (BGPA, in preparation)

WHAT ARE THE MAIN TYPES OF VEGETATION CHANGE IN WA WETLANDS?

Changes to natural wetland vegetation can be categorised into three main types:

- composition
- structure
- density.

These are defined below.

Composition

A 'composition' change is any change to the assemblage of individual plant species within a plant community or group of communities (see Figure 1 and Figure 4). Examples of a 'composition' change include:

- a plant species is lost from the community
- a new plant species enters the community
- a plant species is replaced in the community with another plant not found in the original community

A possible result of a 'composition' change is the establishment of a new assemblage of plants, so the community itself has been altered.

Figure 1. Impacts to this wetland have resulted in a change in composition, with weeds replacing native species in the understorey. Photo – C Mykytiuk.

Structure

A 'structure' change is any change to the configuration or arrangement of a plant species within a community. A community consists of a suite of species, and one or more of those species may become more dominant over others, but the same suite of species remains (as opposed to a change in 'composition') (see Figure 4).

For example, a wetland may became more saline over time, allowing one species already found in the plant assemblage to become more dominant because it is more tolerant of the more saline environment. For example, samphires may already be present in the community but may become more dominant with increasing salinisation.

Similarly, if abstraction of groundwater causes the death of a significant proportion of trees of a particular species in a forested wetland (that is, supporting canopy with greater than 70 per cent cover), the change in structure from a forest to a woodland (which supports less than 70 per cent cover) would constitute a change in structure. In addition to trees, other life forms in WA wetlands are shrubs, herbs, grasses, sedges and climbers; and layers in WA wetlands include shrubland, herbland, grassland, sedgeland and combinations of these.

Structural change can also be natural, with relative species dominance changing over time as a community 'matures' following a disturbance, such as a flooding event or fire. This is known as succession in a plant community. It is important to understand the cause of structural changes in a community, and determine if this is natural or not, and if management intervention is required, or not.

It is important to keep in mind that many wetlands naturally do not have a stereotypical zonation from an inundated central area vegetated with aquatic plants and extending out to sedges, shrubs and trees (as shown in Figure 17). Particularly in waterlogged wetlands, there is often a mix of these types of plants throughout, with plant patterning reflecting smaller-scale habitats within these wetlands (Figure 2 and Figure 3).

Figure 2. Wetland vegetation of a seasonally waterlogged wetland.

Biomass: the total mass of biological material (living or dead), usually expressed as live or dry weight per unit area or volume

Senescence: the natural aging and subsequent death of an organism

Figure 3. Wetland vegetation of a seasonally waterlogged wetland.

Density

A 'density' change is any change to the total amount of plant material or **biomass** in a wetland. Examples of a density change include a reduction in density due to the removal of plants through clearing or **senescence**, or an increase in the density due to re-growth following a fire.

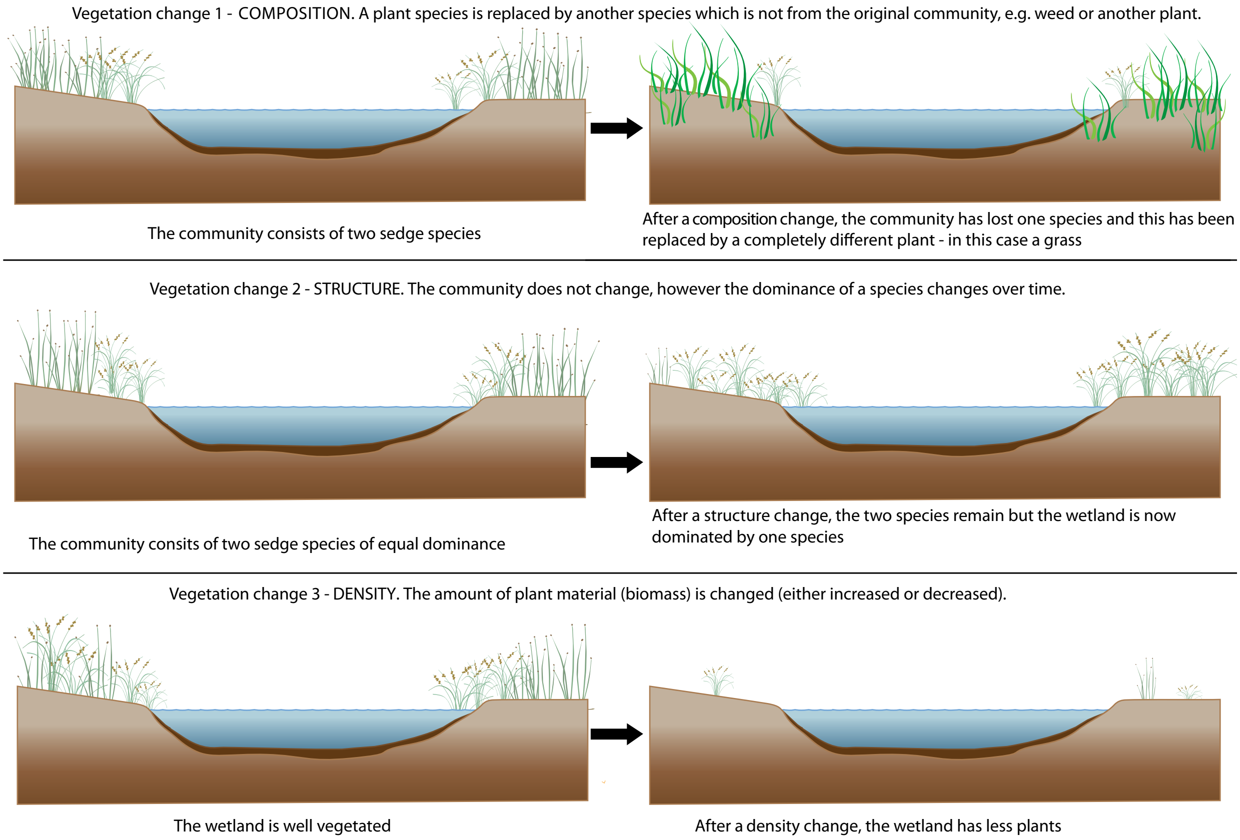

Figure 4. Schematic representation of the three main types of vegetation change in wetlands.

The reasons for vegetation change are often complex and vegetation change itself may result in the generation of other threats developing over time, which may then lead to further vegetation change occurring. For example, clearing resulting in a 'density' change to wetland vegetation, may allow the introduction of weeds leading to 'composition' and 'structure' changes. Figure 5 schematically represents clearing as a vegetation change and how this event may lead to other vegetation change events occurring over time.

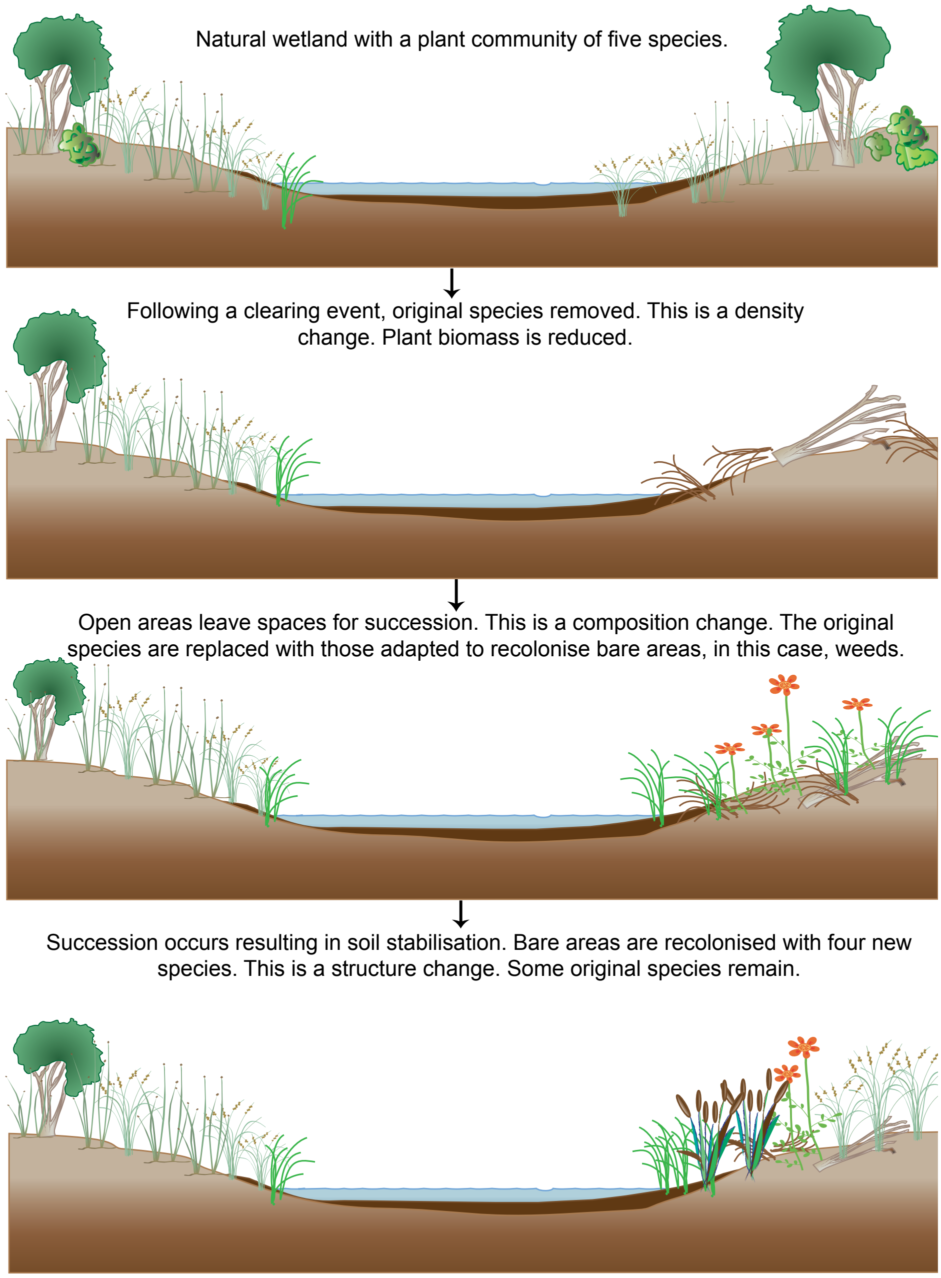

Figure 5. Vegetation clearing leading to other vegetation changes.

Natural responses to change: colonisation and succession

Succession is defined as progressive change in species composition and/or structure that occurs following disturbance of a site.[10] It can be caused by a natural or human-induced event such as fire, clearing or grazing. Following the disturbance event, the changed physical environment is colonised by a series of plant communities until the vegetation reaches a final 'equilibrium state'. Initially, colonising plants (or 'pioneers' or 'disturbance opportunists') grow, develop and modify the environment so that other plants can successively join or replace the initial colonisers, until the maximum number of species exist in that environment.[11] Initial colonising plants are those that are adapted to respond rapidly to opportunities for growth and survival in highly disturbed environments.

Colonising plants in WA wetlands include species such as wattles (*Acacia*), stinkwoods (*Jacksonia*) and spearwood (*Kunzea*) species which are mid-storey plants that produce large volumes of seed (Figure 6 and Figure 7). These seeds remain viable for long periods in readiness to germinate in response to an environmental change such as fire or sudden exposure to light that is significant enough to trigger germination, and start the process of succession. These plants can grow very rapidly and prolifically in order to take advantage of the good growing conditions and lack of competition from other native plants and weeds (Figure 8). Many succession species also have relatively short life spans, for example, many *Acacia* species and stinkwood (*Jacksonia sternbergiana*) live approximately 14–20 years, as opposed to some long lived slow growing species such as jarrah (E*ucalyptus marginata*) which can live up to 400 or more years.[12] When colonisers die off, conditions are often suitable for other species to regenerate. Coloniser species may also enhance the site conditions for later species – for example the legumes (*Acacia* species and pea plants such as *Jacksonia*) are able to 'fix' atmospheric nitrogen, increasing the nitrogen available in the soil for other species.

Figure 6. Panjang (*Acacia lasiocarpa*) is a common succession species in areas of the south west of WA. Photos – M Hislop (main) M Hancock (close up). Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright.

Figure 7. Stinkwood (*Jacksonia sternbergiana*) is a common succession species in areas of the south west of WA. Photos – K C Richardson (main), R Davis (inset). Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright.

However, dense, very old stands of some coloniser species and an absence of other species may indicate that the seed bank of other species is likely to be exhausted. It isn't uncommon for landowners to express a desire to 'get rid of' these species in the belief that they are preventing other plants from establishing. However, such dense stands may be natural and part of the structural arrangement of vegetation in specific habitat types within or surrounding a wetland. These colonising plants play an important role and should not be prematurely removed for aesthetic reasons if the natural wetland vegetation is to be retained. For example, following establishment, acacias and stinkwood stabilise the soil, develop soil nutrients, and provide shade and habitat for a period of time before other more long-lived wetland understorey and overstorey species such as flooded gum (*Eucalyptus rudis*) can establish and gradually out-compete the succession species.

Figure 8. Prolific growth of *Kunzea* sp. has occurred in the older area (left hand side) of a firebreak within a seasonally waterlogged wetland, in the southern Perth suburb of Forrestdale. Photo – J Higbid/DEC.

IDENTIFYING VEGETATION CHANGE

Monitoring will allow vegetation change events to be identified and may help to determine the cause of the change and effects of the change.

Identifying change of wetland vegetation through visual observations over time can provide considerable information on the nature and extent of vegetation changes. Examination of aerial maps and photographs from monitoring points over time are other simple methods of identifying change.

- Google Earth www.google.com/earth supplies a free software program that provides online access to aerial photography covering WA. Some areas have many years of aerial photography (time series), which can assist with identifying vegetation change.
- Aerial photography can be viewed and purchased from Landgate's Map Viewer www.landgate.wa.gov.au/bmvf/app/mapviewer/ and NearMap www.nearmap.com.

To determine wetland vegetation change accurately, the following characteristics of wetland vegetation can be monitored regularly to determine the degree and rate of the change:

- extent
- species composition
- structure (height class and dominance); and
- vegetation density (percentage cover)[13]

These observations will provide information on how rapidly the changes are occurring. This information is important in decision-making for undertaking intervention projects which are discussed in detail later in this topic.

If time or money is not available for monitoring vegetation and other wetland parameters, photo points may be useful in determining if changes are occurring. Photo points are simple, fast and relatively cheap to establish. The drawback of photos is that they only provide an indication that a change is occurring or has occurred and may not enable that change to be quantified. Photos such as those in Figure 9 showing weeds being controlled in a wetland are useful as monitoring points for noticing changes over time. Small, incremental changes may be difficult to detect in monitoring photos, and it may take a number of years before change is noticeable.

Figure 9. Photo monitoring is an effective way of capturing information at a point in time. This photo series shows the extent of *Watsonia meriana* var. *bulbillifera* within Brixton St wetland in response to weed management over a period of six years. Photos - K Brown/DEC.

➤ For a guide to photo points for monitoring purposes, see the Land for Wildlife program's Wildlife Note No. 9 *Photographic monitoring of vegetation*.[14]

➤ For additional detail on monitoring wetland vegetation and other parameters please see the topic 'Monitoring wetlands' in Chapter 4.

Technology now offers opportunities to monitor vegetation in new ways, making use of aerial photography and high-resolution digital airborne imagery to detect indications of canopy change, water use and plant health. These techniques may be suitable for large, complex wetlands or those in remote or inaccessible areas.

➤ For more information, see CSIRO (www.csiro.au/Organisation-Structure/Divisions/Land-and-Water/Environmental-Earth-Observation.aspx)

Where monitoring has not taken place and the vegetation prior to change was not documented, it is likely that it will need to be inferred. Photographs and aerial photographs can provide insight; if this information isn't available it may be useful to examine a suitable benchmark or **reference wetland** that shares the same characteristics as the wetland in question. Alternatively it can be very useful to gain historical insight from people familiar with the wetland in the past, who may be able to identify changes that have occurred and their causes.

Reference wetland: a wetland used to provide a model for planning a management project

Dynamic: a process or system which is characterised by constant change or activity

WHAT ARE THE EFFECTS OF VEGETATION CHANGE ON WETLANDS?

Vegetation change can significantly impact on the physical, biological or chemical processes existing within a wetland. Detrimental changes to vegetation in a wetland can occur at different rates, be subtle or substantial, involve different plant species, and will have a varied impact on wetland condition and functionality.[5] The effects of vegetation change may include:

- changes to habitat for native animals, fungi, algae and bacteria
- changes to the overall level of primary production by plants, resulting in changes to food webs that provide native animals, fungi and bacteria with food/energy
- changes to the chemical characteristics of the water. For example, a change in the amount of tannins in the water, and in the uptake of nutrients in the wetland with resulting changes to the types and density of algae
- changes in the physical structure of the wetland. For example, rates of erosion and sedimentation determined by vegetation can affect the bathymetry of a basin
- localised extinctions of plant species and vegetation communities

➤ For more information on the ecological role played by wetland vegetation, see the topic 'Wetland ecology' in Chapter 2.

WHAT CAUSES VEGETATION CHANGE IN WA WETLANDS?

Plants respond to a range of factors, such as water regime, soil wetness, salinity, pH, temperature, light, nutrients and competition.[15] These factors fluctuate within wetlands because of a variety of natural or human-induced events.

Natural causes

Due to the **dynamic** nature of wetlands in WA, managers should expect some natural vegetation change and allow for subtle changes over time.[16] Natural vegetation changes occur in wetlands in response to events such as drought, floods, cyclones, boom and bust animal populations, and fire caused by lightning strikes. These affect vegetation germination, growth and survival and can result in natural short, medium or long-term changes to composition, structure and density of vegetation. For example, a detailed study of the Becher wetlands in Rockingham found that fluctuations in structure and density of populations of the annual groundcover gota kola (*Centella asiatica*, Figure 10), occurred regularly over five years as local climatic and flooding conditions varied.[17]

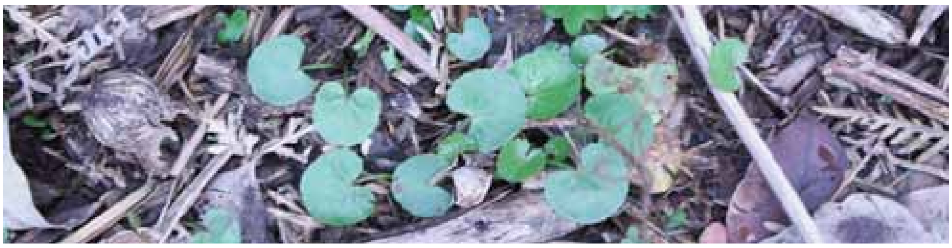

Figure 10. *Centella asiatica* density and structure was shown to fluctuate naturally over time in the Becher wetlands. Photo - J Nichol/DEC.

Human causes

Some of the most common human-induced causes of vegetation change are:

- weed infestations
- grazing by livestock or other introduced or nuisance animals
- manual clearing
- fire
- disease
- altered hydrology
- salinity
- other changes to water quality including **eutrophication** and acidification.

It is not uncommon for a wetland to have been subject to more than one cause of vegetation change over time or at the same time. For example, in urban areas, many wetlands were historically grazed, causing altered hydrology and water quality, and weed invasion. Once urbanised, altered fire, hydrology, water quality and weeds continue to cause vegetation change.

Table 1 below summarises how these **threatening processes** can affect vegetation. Many of these causes of vegetation change are covered in detail in other topics of this guide.

Eutrophication: the nutrient enrichment of a water body, which can trigger prolific growth of plant material (phytoplankton, macrophytes or both). May occur naturally over geological time or may be human-induced.

Threatening processes: processes that threaten the survival, abundance or evolutionary development of a native species or ecological community

Table 1. Common threats to wetlands and examples of their effect on wetland vegetation.

Activity or threat to wetland	Type of change to vegetation	Example	More information
Clearing - manual	Density	Plants are manually removed via a machine, so extent of vegetation altered	
	Structure	Clearing removes the understorey species and changes the arrangement	
	Composition	Clearing activity transports weeds into the community which then outcompete native species	
Livestock and feral animals	Density	High nutrient levels cause algae to proliferate, out-competing native plants and reducing total plant biomass in the wetland.	See the topic 'Livestock' and 'Introduced and nuisance animals' in Chapter 3
	Structure	Areas of the wetland are preferentially spot grazed by horses, while droppings are left in another area	
	Composition	Palatable species that are selectively grazed are lost from the wetland. Weeds are introduced in faeces.	
Weeds	Density	Typha (*Typha orientalis*) invades a population of bare twigrush (*Baumea juncea*) which is much slower growing. The typha spreads and vegetation density in the community alters as the typha is much denser (has a higher biomass).	See the topic 'Weeds' in Chapter 3.
	Structure	Typha (*Typha orientalis*) invades a population of bare twigrush (*Baumea juncea*) which is much slower growing. The typha spreads and vegetation structure changes- the *Baumea* dies off because it has been taken over and only a small remnant remains	
	Composition	Typha (*Typha orientalis*) invades a population of bare twigrush (*Baumea juncea*) and the baumea cannot compete for sunlight and dies. It is completely replaced in the community by the typha	
Phytophthora dieback	Density	Potentially greater biomass due to severe weed invasion post-infection	See the topic 'Phytophthora dieback' in Chapter 3
	Structure	Increased dominance of resistant native and weed species	
	Composition	Loss of susceptible plant species from the wetland	

Activity or threat to wetland	Type of change to vegetation	Example	More information
Secondary salinity	Density	Salinity of water increases causing some wetland plants which are not tolerant to die, reducing overall cover	See the topic 'Secondary Salinity' in Chapter 3.
	Structure	Where saline water is highest; many plants of non-tolerant species are dying and more tolerant species are taking over and dominating, changing the vegetation structure	
	Composition	More saline tolerant weed species move into areas where plants have died.	
Eutrophication (increased nutrients)	Density	Quality of water changes causing some wetland plants which are not tolerant to die reducing overall cover	See the topic 'Managing Water Quality' in Chapter 3.
	Structure	More tolerant species or ones which thrive in high nutrient environments then take over and dominate, changing the vegetation structure	
	Composition	Weeds, which have more tolerance for high nutrient levels, move into the plant community	
Altered hydrology	Density	Reduced water depth means some plants die reducing overall cover of vegetation leaving bare areas	See the topic 'Managing hydrology' in Chapter 3
	Structure	More tolerant species spread and take over from other species	
	Composition	Dryland species from different plant assemblage or weed species spread into drier zones.	
Altered fire regime	Density	Fire can kill individual plants, decreasing density. Plants may germinate in response to fire, increasing density. Either way, vegetation density is altered by fire events	
	Structure	Fire may favour burning particular species in a community over others, thereby altering the dominance of some species over time. Relative species presence will change over time with succession.	
	Composition	Fire tends to favour fire-tolerant species and disadvantage fire-sensitive species. Fire events kill vegetation allowing areas to be opened up for plants potentially not from the local community to invade. Some weedy plant species thrive in fire environments.	

Clearing of native vegetation

Clearing is regulated under the *Environmental Protection Act 1986.* Under section 51A of the Act, clearing is defined as:

(a) the killing or destruction of; or

(b) the removal of; or

(c) the severing or ringbarking of trunks or stems of; or

(d) the doing of any other substantial damage to,

some or all of the native vegetation in an area, and includes the draining or flooding of land, the burning of vegetation, the grazing of stock, or any other act or activity, that causes —

(e) the killing or destruction of; or

(f) the severing of trunks or stems of; or

Clearing of native vegetation (cont'd)

(g) any other substantial damage to,

some or all of the native vegetation in an area.

The Act establishes it to be an offence to cause or allow clearing of native vegetation unless it is done in accordance with a clearing permit, or is exempt. The Environmental Protection (Clearing of Native Vegetation) Regulations 2004 describe the administration of permits.

The regulations apply to all native vegetation including native aquatic or terrestrial vegetation, but not vegetation in a plantation or which was intentionally sown, planted or propagated unless that vegetation was sown, planted or propagated as required under law.

The taking of flora, including seeds, flowers, stems and all other parts of native plants, is regulated under the *Wildlife Conservation Act 1950*. On Crown land, taking of flora for any purpose requires a licence. On private property, the taking of flora requires the land owner's permission, and a licence is required for the sale of any flora that is taken. For further information on flora licences, contact DEC. Clearing that is done in accordance with a licence issued by DEC under the *Wildlife Conservation Act 1950* does not require a clearing permit.

For information on legislation relating to native vegetation clearing, please see the topic 'Legislation and policy' in Chapter 5.

MANAGING DETRIMENTAL VEGETATION CHANGE

There are two main phases when managing detrimental vegetation change:

1. addressing the causes of the vegetation change
2. managing the vegetation

Addressing the causes of detrimental vegetation change

The first step of managing detrimental vegetation change is addressing the cause of the change. This entails identifying the cause and then deciding whether to:

- stop or minimise the cause
- prevent the cause from re-occurring
- take no action at all

Even when the outcome of this step is to take no action at all, it is an essential step which determines how to proceed. If this is not taken into consideration, efforts at regeneration and revegetation may fail, be more expensive, less efficient and even detrimental to a wetland environment.

Many wetland managers in the Wheatbelt face the issue of vegetation change caused by secondary salinity. Secondary salinity is a complex, landscape-scale issue and its management typically involves change in land use across landscapes and a range of expensive intervention measures that are beyond the scope of many wetland managers. If the catchment is not identified as being a priority for biodiversity recovery by regional or state organisations, it is highly unlikely that there will be potential to achieve the vegetation composition, structure and density that existed prior to secondary salinisation. In this scenario, establishing that secondary salinisation of the wetland cannot be halted is the first step in determining the way forward. Wetland managers can then establish whether natural colonisation of native salt-tolerant species is likely to occur and if so, they can prioritise activities to reduce threats to regeneration, such as salt-tolerant weeds and livestock grazing, so that **adaptation** to changing conditions occurs without being compromised by threats that can be managed.

Table 3 cross-references the relevant topics of this guide which provide guidance on addressing the causes of vegetation change.

Table 2. Information on how to manage the cause of vegetation change

Threat to vegetation	Information on how to manage this threat
Weeds	'Wetland weeds' topic, Chapter 3.
Grazing by livestock	'Livestock' topic, Chapter 3
Damage by introduced and nuisance animals	'Introduced and nuisance animals' topic, Chapter 3
Altered hydrology	'Managing hydrology' topic, Chapter 3
Phytophthora dieback	'Phytophthora dieback' topic, Chapter 3
Secondary salinity	'Secondary Salinity' topic, Chapter 3
Eutrophication (increased nutrients)	'Water quality' topic, Chapter 3
Acid sulfate soils	'Water quality' topic, Chapter 3

Weeds require a special mention, because as well as being a cause of vegetation change, weed invasion is also an outcome of every other type of vegetation change listed above. The planning of weed management should be coupled with planning of native vegetation management. The location, size of the area, amount of weeds to be controlled and rate of control should be dictated by the resources available and the rate at which natural regeneration or revegetation is expected to occur following the removal of weeds. The **Bradley method**[16] is effective, that is, working from more intact areas of vegetation towards more degraded areas. This allows natural regenerative processes within the environment to assist with regeneration and revegetation.

Managing vegetation

Deciding whether to actively manage the vegetation

Once the cause of vegetation change has been addressed (identified, stopped, reduced, prevented in future or not acted upon), the wetland manager can aspire to either:

1. **restore** the wetland vegetation composition, structure and density as much as possible, or

2. **rehabilitate** the wetland to create a new, self-sustaining native plant community that can survive in the altered environmental conditions, while still being as close to the original community as possible.

Alternatively, following an examination of these options, it may be determined that the scope for restoration and rehabilitation is too limited and the costs too high to proceed with either option. A decision may then be made to manage the wetland to limit further loss of wetland values. Ultimately, it is necessary for wetland managers to ensure that they are directing limited resources to those sites that achieve the best possible nature conservation outcomes.

Adaptation: the process by which an organism becomes fitted to its environment

Bradley method: working from the most intact parts of a bushland area out towards more degraded areas, to allow natural regeneration to occur, for example, when weeding

Restoration: returning an ecological community to its pre-disturbance or natural state in terms of abiotic conditions, community structure and species composition

Rehabilitation: the re-establishment of ecological attributes in a damaged ecological community although the community will remain modified

Thresholds: points at which a marked effect or change occurs

Revegetation: return vegetation (indigenous or otherwise) to an area

Private landowners may decide it is a priority to rehabilitate their wetland. Public land managers with responsibility for large areas of land (multiple wetlands), and other organisations involved in regional land management activities, typically need to prioritise sites to be managed. Some basic principles include prioritising:

- wetlands that are of high conservation value
- wetlands that are in better condition before those in worse condition
- wetlands that are improving by themselves rather than deteriorating
- those that will take less work to get back to a more natural state.[18]

The decision to restore, rehabilitate or to take a minimalist approach (including not to act at all) needs to be made early on in the management process in order to manage expectations and to set realistic objectives for the long-term management of the vegetation change event. It is also important to note that the required level of intervention may alter over time and will require frequent re-evaluation.[16]

From a nature conservation perspective, restoration is always most desirable, but it is often not feasible. It will depend on whether it is possible to address the cause of the vegetation change and how significant changes to the wetland and its vegetation are. The development of a management plan that describes the objectives for the wetland is a good way to work logically through this decision-making process.

➤ A process for wetland management planning is described in the topic 'Wetland management planning' in Chapter 1.

The rate at which a vegetation change event occurs can be a strong indicator of whether an intervention response is the most appropriate action. Rapid vegetation changes often signify that a critical **threshold** has been reached.

A rapid rate of vegetation change is also likely to allow for opportunities for other threatening processes to occur which may exacerbate the vegetation change event or degrade the wetland further.

The more that vegetation changes, the more challenging it may be to instigate meaningful intervention, the greater the effort required and therefore potentially the higher the management costs.[19,10] Early detection and evaluation of change is vital for preserving existing vegetation and values.[16,20]

The cumulative effect of allowing wetlands with small vegetation change events to continue to degrade is likely to result in additional management costs in the future.

Managing vegetation: choosing regeneration or revegetation

If a wetland manager has determined that either restoration or rehabilitation is feasible, they can usually choose one or more of the following three strategies:

1. where possible, allow for the natural processes such as regrowth and recruitment within the wetland to repair the vegetation; known as 'regeneration'
2. carry out activities to optimise natural regeneration processes that repair the vegetation; known as 'assisted regeneration', including fire, smoke and smoked water
3. where necessary, introduce plants/seeds to the wetland that are adapted to the new conditions following the vegetation change event; known as **revegetation**.

Wherever regeneration potential exists, it should always be the default option. Regeneration provides much greater potential for achieving self-sustaining wetland ecosystems and a far greater chance of approximating the natural diversity of a wetland. Natural and assisted regeneration techniques are natural and non-invasive/minimally invasive respectively. They are also cost-effective.

Figure 11. A wetland near Yanchep, north of Perth, where following a fire, the potential for natural regeneration is likely to be high, unless actual acid sulfate soil generation has occurred. Photo – T Calvert/DoE.

Endemic: naturally occurring only in a restricted geographic area

Propagate: grow plant specimens from parent material

Revegetation is usually required only when a wetland will continue to degrade or will remain in a degraded state without human intervention. Revegetation tends to require significantly more resources and time. Being an invasive technique, it also poses risks that regeneration does not. There are also significant limits to our ability to achieve natural diversity through revegetation. For example, in the area encompassing Perth and surrounds (Moore River to Dunsborough), 74 per cent of the 1,187 native wetland plant taxa are **endemic** to WA.[1] Many of these taxa have not yet been successfully **propagated** (bred) and so are not able to be used in planting programs.

Assessing the potential for natural regeneration

The wetland manager plays no active role in natural regeneration, other than monitoring, and where necessary, working to reduce threatening processes. Natural regeneration is the least invasive, and potentially cheapest way to reverse detrimental vegetation change.

Regeneration uses the natural processes such as regrowth and recruitment to repair the vegetation. Understanding the potential for regeneration of wetland vegetation involves assessing the resilience and reproductive capacity of the wetland vegetation following a vegetation change event.

Natural regeneration is more likely to occur when the cause of vegetation change is a natural process, such as fire, and where this process is not compounded by other impacts. Where fire has occurred, for example, the best approach is to carry out regular inspections to ensure that the area is not being invaded by weeds, and that the fire has not resulted in the generation of actual acid sulfate soils (Figure 11).

Regeneration may or may not result in similar composition, structure and density of wetland vegetation compared to its original state. The vegetation change event may have changed the conditions required for one of these aspects to be achieved. For example, *Phytophthora cinnamomi* can kill individuals of species that are susceptible to the pathogen, changing the vegetation composition; similarly the export of nutrients in ash following a fire may limit the density of regrowth.

This principle does not always apply when altered hydrology has caused the death of mature plants in a tree population. These mature species may be adapted to the existing water regime and may be lost as a result of changes to hydrology, if changes are too fast or too extreme for them to adapt. However, their progeny may develop root morphologies suitable to the new water regime, allowing a plant population to survive even if individuals are lost.

It is important to take into account the timeframes required for regeneration processes, for example, the season in which plants germinate, vegetatively reproduce or re-grow.

As described earlier, colonisation and succession are natural processes of recovery.

Regeneration is reliant upon:

- a source of healthy seed or **propagules**
- a receptive seed bed
- suitable climatic conditions
- suitable water regimes
- protection from grazing/impacts of animals
- low competition from weeds or other native plants
- the absence of harmful pathogens or other disease organisms

Regeneration occurs via:

- the release of seed during/after the event
  For example, modong (*Melaleuca preissiana*) are prolific seed producers and produce a seed rain each season. The seeds are very small and can germinate in large numbers in response to episodic events such as heavy rainfall and fire, where these provide opportunities for germinants to establish. The majority of wetland shrubs and trees in WA are long-lived and experience episodic **recruitment** events under the right conditions. Assessing seed production and viability will help establish the likelihood of germination of seed-setting species.
- suitable conditions for remaining individuals to produce seed after the event
- suitable conditions for re-growth of existing individuals via **epicormic** buds (Figure 12), **lignotubers** etc.
- suitable conditions for vegetative growth to occur via **rhizomes** or **stolons**
- This is particularly relevant for many **sedges**.
- suitable conditions for re-growth of existing individuals via **underground storage organs** such as bulbs, tubers and corms.
- Underground storage organs such as bulbs, tubers and corms allow plants to renew. These organs allow plants to enter a state of dormancy where conditions are extreme, such as during drought and fire. The underground storage organs of some species can remain dormant in the soil for years and still remain viable, and for some, sprouting is stimulated by fire. Twenty-two percent of wetland flora in the southern Swan Coastal Plain (the Perth metropolitan region and surrounds from Moore River to Dunsborough) renew from underground storage organs.[1] If these remain unaffected by detrimental change, a significant amount of regeneration can occur.
- the soil seed bank being intact and viable
- The **soil seed bank** is more likely to be intact if the soil hasn't been disturbed. This factor will affect the degree to which species will germinate from soil seed banks (Figure 13).

Propagule (plant): any part of a plant from which a new plant can grow, including seeds, bulbs and rootstocks

Recruitment: addition of new individuals to a population (usually through reproduction)

Epicormic buds: dormant vegetative buds that are embedded beneath the bark, which have a regenerative function after crown destruction

Lignotuber: a large woody swelling of the plant stem that occurs at and below the soil surface. Regrowth from lignotubers can occur following fire, drought and grazing.[22]

Rhizomes: stems that are buried underground

Stolons: stems that usually run horizontally along the soil surface

Sedge: tufted or spreading plant from the families Cyperaceae, Centrolepidaceae, Hydatellaceae, Juncaginaceae, Restionaceae, Juncaceae, Typhaceae and Xyridaceae. In these plants the leaf sheath is generally not split, there is usually no ligule, the leaf is not always flat and there is an extended internode below inflorescence. Some sedges are also known as rushes.

Underground storage organs: specialised fleshy organs such as corms, bulbs and tubers that allow plants to flourish in nutrient deficient soils or to die back and enter a state of dormancy when conditions are extreme, such as during fire or drought[23]

Soil seed bank: the natural storage of seeds, often dormant, within the soil

Seed dispersal mechanisms: the means by which plants distribute their seeds, for example via wind, water, birds and insects

Figure 12. Epicormic growth of a fallen *Melaleuca rhaphiophylla* at Maramanup Pool, Baldivis, south of Perth. Photo – J Higbid/DEC.

Figure 13. The degree to which the soil has been disturbed will have an effect on how viable the soil seed bank is. Photo – L Perera.

➤ *Are there seeds in your wetland*?[21] describes how to assess the seed bank in a wetland's sediment. This can be used to help determine which species' seeds are present and their viability.

- suitable **seed dispersal mechanisms** occurring to enable seeds to reach the area Many wetland plants disperse seeds using wind, water and animal vectors. Some have a wide distribution in many areas of WA and beyond. For example, the sedge *Juncus kraussii* subsp. *australiensis* occurs along the coast from east of Esperance to north of Shark Bay. Its seed is small and easily distributed by wetland birds that travel long distances. Long distance dispersal creates disjunct populations of the sedge in wetlands in what are effectively 'islands' of suitable habitat surrounded by a much drier landscape.[1]

  Other species rely on water to transport their seeds. For example, *Aponogeton hexatepalus* seeds germinate in the season they form and when water is present they can float to new locations[1] in a wetland or possibly to a different wetland. If the wetland is connected to 'upstream' wetlands, waterways or even drains, some influx of propagules is possible.

Understanding which of the wetland's species use these dispersal mechanisms can provide an understanding of the potential opportunities and timeframes for natural dispersal to occur.

Fire-responsive: plants which have seed pods that open, seeds that germinate, or epicormic buds or lignotubers that resprout in response to a fire event. Some of these responses are triggered by the chemicals produced in smoke during the fire event.

Carrying out assisted regeneration

The two main types of assisted regeneration are:

- managed fire to produce a mosaic of burnt and unburnt areas over time
- smoke and smoked water.

Managed fire

In some instances, fire could be used to promote conditions suitable for regeneration of native plants. Fire can potentially stimulate seed germination, reduce the impacts of weeds (if managed)[24] and encourage the regeneration of mixed age vegetation.[25] Using fire as an assisted regeneration technique for vegetation change events is complex, and must take into account factors such as frequency, season, intensity, pattern and post-fire environmental conditions, as well as legality. Its use can be controversial as it may cause as many problems as it can potentially address, including further damaging existing vegetation as well as destroying seed banks and encouraging more weeds.

Burning is a form of clearing (see 'Clearing of native vegetation' earlier in this topic for the definition of clearing). Where vegetation is proposed to be burnt and the purpose is not exempt, a clearing permit under the *Environmental Protection Act 1986* is required.

➤ For more information, see *A guide to burning under the native vegetation clearing provisions.*[26]

Smoke and smoked water

An alternative to fire is applying smoke or smoked water to the wetland environment to promote plant germination. Using smoke on wetland areas is a relatively non-invasive technique which can be applied fairly cheaply to areas with **fire-responsive** vegetation. Fire-responsive plants are species which have seed pods that open in response to the heat and drying effect of a fire, and/or seeds that have enhanced germination in response to the chemicals produced in smoke during a fire event.[27,28] The chemicals that encourage seed germination are encapsulated in smoke or contained within a water medium and applied directly to the vegetation or soil, avoiding the need for fire. Smoke and smoked water can greatly assist in the germination success of many native seeds, and if the technique is applied correctly can result in regeneration events.[27] Sites to be planted or direct seeded can also be prepared before planting with smoke or smoked water so that seedlings planted can benefit from smoke germination chemicals. Site preparation is described in more detail in the revegetation section of this topic.

➤ The Botanic Gardens and Parks Authority of Western Australia has pioneered much of the research into the application of the chemical in smoke responsible for seed germination. A range of scientific journal articles on the subject are listed on the website: www.bgpa.wa.gov.au.

➤ For further information on using smoked water see:

- Geographe Community Landcare Nursery website[29]
- Greening Australia's *Seed germination data sheet*[30]

Carrying out revegetation

There are three key revegetation techniques:

- brushing
- direct seeding
- planting.

Revegetation is a broad topic. Many techniques are in use, and much has been written about it. When reading such literature, remember that revegetation occurs across many different ecosystems for many different reasons. The following is a very quick overview of key considerations for the purposes stated in this topic.

Brushing

Brushing involves harvesting seed-bearing branches of local plants (either during seeding season, or at any time for plants that hold their seed within their canopy in woody fruits) and laying these branches in chosen regeneration areas. When branches from shrubs and trees from genera such as *Melaleuca, Eucalyptus*, *Casuarina*, *Agonis*, *Astartea*, *Pericalymma* and *Banksia* are laid out, they drop seeds when the branch dries out, increasing the number of seeds present, and the woody material and leaf litter from the branches suppress emergent weeds and protect the regenerating seedlings from other degrading processes such as erosion or strong winds. Brushing is often applied in bare areas where weed control or slashing has occurred and the site requires protection while the brushed species have a chance to regenerate over time when conditions are most suitable.

Plant materials, such as stems, can harbour the pathogen *Phytophthora*, which causes the devastating Phytophthora dieback. It is essential that all brushing materials be carefully selected to avoid spreading Phytophthora dieback. A site assessment by a professional dieback assessor may be appropriate.

It is also important to ensure that the sourcing of brushing material be done carefully and sensitively, so as to minimise environmental impact. The taking of flora, including seeds, flowers, stems and all other parts of native plants, is regulated under the *Wildlife Conservation Act 1950*. On Crown land, taking of flora for any purpose requires a licence. On private property, the taking of flora needs to be authorised by the land owner, and a licence under that Act is only required if the flora is taken for sale. For further information on flora licences, contact DEC.

Clearing of native vegetation is regulated under the *Environmental Protection Act 1986*. Clearing that is done in accordance with a licence issued by DEC under the *Wildlife Conservation Act 1950* does not require a clearing permit.[31] Furthermore, the definition of 'clearing' under the *Environmental Protection Act 1986* does not include the taking of plant material where it does not cause any substantial damage to the plant. Thus, the careful and selective cutting of brush material (or the collecting of seed) should not require a clearing permit under the *Environmental Protection Act 1986*. Making use of plant material cleared for firebreaks or access tracks is also a good way to minimise impacts.

➤ For more information, see the following information sources:

- disease hygiene standards: the topic 'Phytophthora dieback' in Chapter 3
- regulations: see the text box 'Clearing of native vegetation' earlier in this topic

Direct seeding

Direct seeding involves placing viable seeds into a wetland and promoting their germination. The success of direct seeding relies upon appropriate seed collection, storage and preparation to maximise viability and germination success[32], site preparation and sowing. These last two factors are discussed in greater detail in the 'Revegetation' section of this topic.

Seed may be applied directly as cleaned seed that has been tested and, if appropriate, treated to achieve a pre-determined germination rate for the establishment of defined vegetation species composition and density. Alternatively, seed may be applied through indirect means, such as brushing (see above), or through the spreading of weed-free topsoil (applicable in dryland environments, such as areas surrounding wetlands).

Direct seeding can be suitable in weed-free areas of wetlands, although not on steep slopes if erosion is a risk. However, although direct seeding may be significantly cheaper than planting seedlings, it has had a mixed success rate in WA and in particular on the Swan Coastal Plain (the coastal area from Jurien – Dunsborough), due to a variety of reasons, including unsuitable approaches and site preparation.[33] Direct seeding success stories overwhelmingly involve adequate site preparation and post-seeding site management such as weed control, to allow the seedlings to germinate in the absence of other threats.[34] In many instances, although the process appears cheap, the outcomes are too poor to warrant the effort or resources invested. This is most often due to a lack of understanding about WA growing conditions in individual wetland environments, such as challenging soils and weather conditions. Other challenges include low seed viability and seed predation by birds, ants and other animals.[5] Because many of these factors cannot be controlled, wetland managers should compare opportunities for seeding activities with other methods of revegetation prior to commencement.

Seeding may also be used in conjunction with planting, to provide the opportunity for greater species diversity and natural plant establishment outcomes, while not relying only on effective seed germination and establishment for revegetation success. It is also important to note that seed sown may remain dormant for a number of years before germinating, achieving positive revegetation outcomes over a longer time frame.

Where it is important to determine the likelihood of success prior to proceeding with large-scale direct seeding, one possible approach is to trial the use of direct-seeding on a smaller scale.

➤ Many, but not all, native plants have successfully been direct seeded. For further information about direct seeding and types of species which can be direct seeded, refer to:

- the *Seed Notes for Western Australia*[35], which provide information on individual species as well as licensing and storage www.dec.wa.gov.au/content/view/3303/1808/
- *Florabank*, www.florabank.org.au, an information internet portal providing knowledge from research and practice in native species seed management for native seed suppliers, buyers, landholders and other NRM stakeholders

There are different ways to sow seed, including hand planting, niche seeding, broadcasting, machine planting and hydromulching. Many of these will not be appropriate in relatively intact wetland areas. Pre-seeded matting is excellent for steep embankments, providing both erosion control and seeds together. Seeds are spread onto an appropriate fibremulch and germinated. The seeding can occur in a nursery or on-site. If done at a nursery, it is only suitable for seeding of sedges and other monocots because the matting needs to be rolled up to transport (like roll-on lawn) to the site.[18]

Treating seeds prior to or following sowing can be very beneficial. The seeds of different species respond to different treatments, including smoke and smoke products, acid, cold stratification and heat. Seed suppliers often provide these treatment services.

➤ The range of direct seeding methods and seed treatments are outlined in Florabank, along with references for more details. See www.florabank.org.au> Seed Knowledge> Native Vegetation Management Tool> Direct seeding.

Planting

Planting techniques include:

- planting seedlings grown in seedling trays or tube stock
- strip or mat planting, useful in highly erosive sites and where there is the potential for waterbirds to pull plants out of the ground
- long-stem planting, where seedlings are grown to a height of 1 metre or more, and three quarters of the length of the plant is buried. (www.environment.nsw.gov.au/resources/grants/Longstemguide.pdf)

Preparing or pre-ordering stock from an accredited supplier in due time is essential. Collecting, treating and sowing seed of local provenance is a lengthy process which needs to be factored in to the works schedule. As a guide, standard tubestock of trees and shrubs should be no more than 7–8 months old, while sedges should be 10 months old.[18] At this age, tubestock should develop extensive root systems when planted and sedges will be engaged in lateral spread rather than vertical extension only, enabling rapid coverage of planted areas.[18]

Hand planting equipment includes trowels, spades, tree spades, mattocks, powered augers, pottiputkis, Hamilton treeplanters and Hamjam borers.[8] A range of mechanical equipment has been developed and is commercially available, but these are often not suitable for use in sensitive wetland sites.

Poor planting techniques by untrained volunteers can lead to poor establishment and higher mortality rates in seedlings. A short demonstration prior to the commencement of planting at volunteer days can put everyone at ease and reduce this potential problem.

Waterbirds such as ducks, coots, swans and occasionally herons can uproot sedges and consume submerged plants before they have established, quickly undoing lots of painstaking work. A trial exercise may help to determine whether it is likely to pose a problem at a site. Strip or mat planting can help reduce waterbird damage by weighting plants down. Bird netting may be warranted for large sites where waterbird damage is a known problem. For small-scale plantings, wire enclosures can be used for the first few months until plant roots are well established.[18] In both cases, the materials need to selected and installed with great care to ensure that there is no inadvertent injury or death to animals or humans.

➤ For more information on planting techniques, see:

- Florabank: www.florabank.org.au> Seed Knowledge> Native Vegetation Management Tool> Tubestock planting.
- *Revegetation techniques: a guide for establishing native vegetation in Victoria*[36] at: http://live.greeningaustralia.org.au/nativevegetation/pages/pdf/Authors%20C/13_Corr.pdf

Common problems

Some of the most common problems encountered by people revegetating wetlands include:

- not reducing the weed load before planting and not being prepared for follow-up weeding over long timeframes
- not factoring in enough time to get seeds/seedlings ready in time for planting
- planting at the wrong time of the year, or there being unpredictable weather
- underestimating the mortality rate of plantings, and overestimating the success rate of direct seeding
- seedlings being planted badly because people planting are unfamiliar with the procedure
- waterbirds such as ducks, coots, swans and occasionally herons uprooting sedges and consuming submerged plants
- vandalism, often by children

Some tips on these problems are outlined in the sections below.

Revegetation: key considerations

There are a number of details to consider when revegetating, including species choice, diversity and provenance. Timing of replanting activities, costs and post-planting maintenance are also key considerations.

When seeking to emulate the pre-vegetation change environment, the main considerations are:

- site preparation
- hygiene practices to avoid introducing weeds and diseases
- avoiding impacts to animals
- choosing the most suitable species
- aiming for original species diversity and density
- planting in the most appropriate locations
- deciding on the planting density
- minimising excessive damage to existing wetland values;
- using additives to soils during planting or seeding
- post-planting or seeding maintenance.

Site preparation

Preparing an area for replanting or direct seeding is an important step in ensuring revegetation success. Prior to both seeding and planting, the site should be cleared of weeds, as weed species will compete with natives for space and light.[37] The location, size of the area, amount of weeds to be controlled and rate of control should be dictated by the resources available and the rate at which revegetation is expected to occur following the removal of weeds. The Bradley method[16] is effective, that is, working from more

Figure 14. Arum lily (Zan*tedeschia aethiopica*) has taken over this area following the removal of bracken (Pteridium *esculentum*). Photo - J Nichol/DEC.

intact areas of vegetation towards more degraded areas. This allows natural regenerative processes within the environment to assist with regeneration and revegetation. Doing the job right to begin with saves considerable time and resources; managing weeds amongst seedlings can be time consuming and difficult.

If there is a diverse assemblage of weeds on site, or persistent weed vectors, it may take a number of years to eradicate or control them to levels suitable to undertake planting. Just as there is natural succession in native species, the same can be true of weeds. Removing one suite of weeds may just result in suitable conditions for another (Figure 14). It may take a number of years to eradicate or control weeds to levels suitable to undertake planting. Post-seeding and planting weed control is also critical.

➤ Weed control techniques for WA wetlands are described in the topic 'Wetland weeds' in Chapter 3.

Preparing the ground is an aspect of site preparation where particular care needs to be taken in relation to wetlands. Many techniques, such as deep ripping, furrowing and mounding are appropriate for paddocks being rehabilitated and in farm forestry sites, but are generally not appropriate in wetlands due to their impact on wetland soil.

Revegetation hygiene practices: weed and disease free seeds, plants and propagules, vehicles and equipment

It is critical to take steps to avoid introducing pathogens that cause disease and weeds. For example, Phytophthora dieback, which is caused by *Phytophthora* species, can have devastating effects on the vegetation of wetlands and surrounding dryland. *Phytophthora cinnamomi*, for example, can be brought into a site in infected soil, water and plant materials (including dead plant material such as bark and mulch).

It is essential that hygiene standards be observed in all aspects of revegetation programs to minimise the spread of weeds and Phytophthora dieback.

➤ For more information, see the topic 'Phytophthora dieback' in Chapter 3.

Avoiding impacts to animals

Planting disturbs the soil. It is important to consider that animals, or their eggs, may be present in the soil, including burrowing crayfish, frogs (Figure 15), turtles, and a wide range of small invertebrates. It is also important to consider the impact that soil disturbance may have on water quality, and how this may affect species that are sensitive to turbid conditions or to being covered in sediment. For example, fine particulate matter suspended in water can affect many aquatic species, including fish, by clogging, coating or abrading respiratory structures such as gills.

➤ For more information on wetland animals, see the topic 'Wetland ecology' in Chapter 2.

Figure 15. The burrow of a white-bellied frog (*Geocrinia alba*), a critically endangered frog, is susceptible to soil disturbance. Photo - K Williams/DEC.

Species diversity

When seeking to emulate the vegetation that was present prior to a vegetation change, species diversity will be an important consideration. Unless the wetland had a low diversity or the vegetation was well documented, determining the diversity prior to vegetation change event can be a difficult task. Photographs and aerial photographs can provide insight; if this information isn't available it may be useful to examine a nearby wetland of the same or similar type.

Some wetlands naturally support a low diversity of native vegetation. For example:

- some primary saline wetlands
- some wetlands with an overstorey that has a closed canopy and a dense leaf litter
- permanently inundated areas with deep water
- those where benthic microbial communities are prevalent

In situations where the original species will no longer survive, it is necessary to choose an alternative suite of species. This may be necessary when a wetland:

- has become more saline, such that plants with a greater salt-tolerance are necessary. Freshwater wetlands generally have a higher diversity of species than those of saline wetlands.[1]
- is infected with a pathogen such as *Phytophthora cinnamomi*, such that Phytophthora dieback resistant plants are necessary. As over 40 per cent of native plants in south-west WA are susceptible[39], this is likely to limit species diversity.
- has a significantly altered hydrology, such that plants with different water requirements are necessary. This is less likely to alter species diversity.

Figure 16. A simple planting regime with low diversity of species may be justifiable in some circumstances, particularly where it is intended to continue the rehabilitation over time. Photo – DEC.

Provenance: the place of origin[42]

- the water quality is significantly altered, such that tolerant plants are necessary. Some plant species are known for having greater tolerance to higher nutrient levels or for their ability to remove excess nutrients, such as lake club-rush (*Schoenoplectus validus*), salt rush (*Juncus kraussii* subsp. *australiensis*) and tall spikerush (*Eleocharis sphacelata*).[16]

When considering the introduction of locally native species that were not present in the wetland prior to the vegetation change, it is important to ensure that the benefits of their introduction are greater than potential disadvantages (e.g. weediness).

Another important consideration is that not all wetland plants can be supplied for use in revegetation projects, because many have not yet been successfully propagated (bred).

Other circumstances may also constrain the ability to achieve the original species diversity. In particular, the condition of a site may mean that the resources required to prepare the site, manage weeds and achieve the desired species diversity is beyond those available. In some highly degraded sites that have been determined to be a priority for revegetation, it may be necessary to begin with a simple planting regime (Figure 16) to initiate the rehabilitation of the site, within the scope of the available resources.

Plant choice: provenance and ecotype

When seeking to emulate the vegetation that was present prior to a vegetation change, wetland managers will be sourcing seeds or seedlings of the species that were present. However, it is important to take this a step further by sourcing seeds and other propagules (seeds, seed inundated mud or sediments, plant cuttings, plant roots or rhizomes[19,40]) of local **provenance**, that is, local origin. A species' genetic variation over a geographic range can reflect the ecological conditions in which the species has evolved. A compelling reason for ensuring local provenance of propagules is that in WA the genetic variation within plant species can change over short distances, meaning that the wetland itself is the best choice to source propagules, followed by wetlands as geographically close to it as possible.[41] Recent research indicates there are some circumstances when it may be beneficial to broaden the provenance for revegetation activities, for example, when there is a need to build in greater tolerance in the vegetation to cope with environmental changes; these should be considered on a case-by-case basis. For more information, see www.florabank.org.au> Seed Knowledge> Native Vegetation Management Tool> Design – Species and provenance selection.

Many wetland plants have closely related species that inhabit dryland. Furthermore, many taxa have distinctive wetland and dryland **ecotypes**, and a number of these ecotypes are proving to be valid discrete taxa. Correct ecotype is an important consideration.[2]

Care should be taken during collection of genetic materials from local intact wetlands to not cause further damage to these wetlands by taking too much.[19] To prevent damage, seed collection and harvesting of plant genetic material is regulated in WA. Collections must be made in a manner that protects existing plants, with only limited materials being taken. The taking of smaller quantities of propagating material from a greater number of plants also increases the genetic diversity of material being used for revegetation, thereby increasing the health and diversity of the vegetation being established.

Revegetation practitioners must also have permission to collect plant material from land managers prior to any site visit, and should ensure that all collection sites are protected from damage caused by collecting activities.[32,40] Particular care needs to be taken to prevent spread of plant diseases and incidental destruction of vegetation by vehicular movement.

The laws governing flora conservation are contained within the *Wildlife Conservation Act 1950* and Regulations. These are administered by DEC. Flora is protected and may or may not be able to be harvested under particular conditions relating to the level of protection required. Licenses are required for collection on Crown land and the commercial use of flora, and different licenses exist depending on the purposes for collection. Permission is also required from the land manager, including for private property.

➤ For specific information on the details for licensing and laws surrounding flora collection, please go to the flora licensing webpage[43] on DEC's website: www.dec.wa.gov.au/management-and-protection/plants/flora-licensing.html

➤ The Revegetation Industry Association of WA (Inc)[44] has information on seed collection: www.riawa.com.au

It is estimated that tens of thousands of sedges have been used in revegetation projects in wetlands in the Perth region that have been propagated by tissue culture, often used without reference to provenance and with extremely narrow genetic diversity due to using a small number of clones.[45] However, it has been demonstrated that it is possible and relatively easy to produce large numbers of some WA sedges from seed and in doing so maintaining genetic diversity.[45]

Planting and seeding in the right spot

Plant germination and survival depends upon a range of factors, such as **water regime**, soil wetness, salinity, pH, temperature, light, nutrients and competition.[15] These factors vary over time and space. That is, they change with seasons and shorter and longer term drivers; and they change over a geographic area.

Identifying the optimal establishment zone of a plant should take into account the most important factors. Water regime is particularly variable within a wetland and this factor is a strong determinant of where a plant would naturally germinate. If the water regime is intact, planting replacement vegetation becomes more straightforward as seeds or plants can be located where they were previously found.

This approach accounts for the water requirements of species. Even a basic understanding of a plant's **water requirements** will help. Knowing whether a plant is always, sometimes or never submerged under water is a good start. If it is sometimes submerged, knowing the minimum and maximum inundation it can tolerate is important. If it is never submerged, knowing its tolerance to waterlogging and completely dry soil is critical.

Ecotype: a genetically distinct geographic variety, population or race within a species which is adapted to specific environmental conditions. Typically ecotypes exhibit differences in morphology or physiology stemming from this adaptation, but are still capable of breeding with adjacent ecotypes without loss of fertility or vigour.

Water regime: the pattern of when, where and to what extent water is present in a wetland. The components of water regime are the timing, duration, frequency, extent and depth, and variability of water presence

Water requirements: the water required by a species, in terms of when, where and how much water it needs, including timing, duration, frequency, extent, depth and variability of water presence

Figure 17 below provides an example of the vegetation of a wetland that is permanently inundated, showing a classic series of plant types from the centre of the basin to the outer extent of the seasonally waterlogged area of the wetland. The series of plant types, from submerged to emergent plants, occur in zones. This diagram is an example only; there are many patterns of diversity and structure of vegetation in wetlands, including many which do not support classic zonation, for example, as shown in Figure 2 and Figure 3. For example, a seasonally inundated basin wetland may have less aquatic plants and more fringing vegetation than a wetland with standing permanent water such as a lake. The vegetation patterning will therefore vary depending on the type of wetland, its water regime and historical impacts.

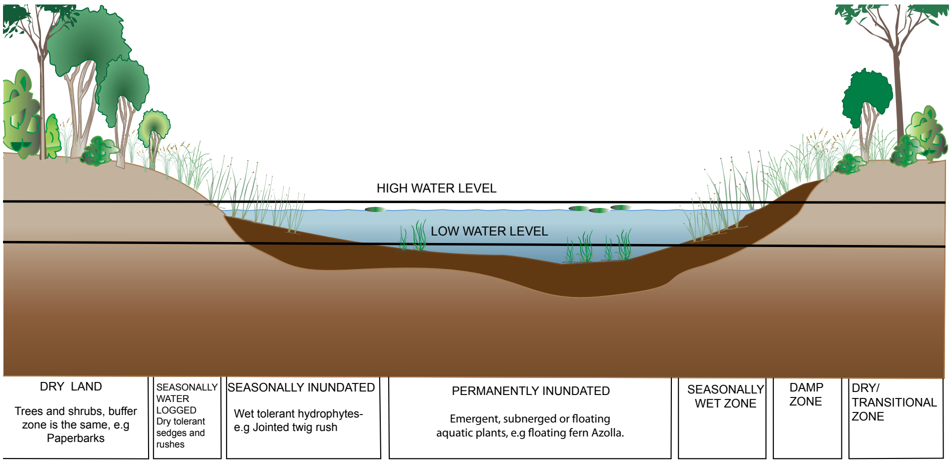

Figure 17. Zonation of plants in a permanently inundated wetland. Adapted from work by Denise Crosbie, Cockburn Wetlands Education Centre (2006).

In 2000, a study was carried out on the water levels and duration of inundation or waterlogging being experienced by sixty wetland species at wetlands on the Swan Coastal Plain.[46] The results of this study have been used to inform the management of a number of wetlands in the greater Perth area. For example, the common wetland tree *Melaleuca rhaphiophylla* was found, on average, to exist at a maximum water depth of 0.006 metres above the ground and minimum water depths of 2.14 metres below the ground. However, the maximum water depth at which the tree was found during the study was 1.03 metres, while the minimum water level at which it was found was 4.49 metres below the ground. It was found to live in wetlands that are inundated on average 2.15 months of every year, but the longest period was 9.4 months of every year. This information is useful in that it provides wetland managers with a coarse indication of the maximum and minimum thresholds for the species' survival. Of equal importance, it shows that there is a great deal of variation amongst a species. However, identifying the water regime that supports a species is not as simple as defining the extreme measures (maximum and minimum). Simply maintaining the water level between a maximum and minimum height is a simplistic approach, because variability in water level is important for plant reproduction and other aspects that determine the ecological character of the site. Since this study, further studies have been undertaken across the broader south-west, resulting in updates to this water range data. Studies have also been undertaken in other areas of the state, as listed below.

➤ Information on water requirements for planting include:

- *A guide to emergent wetland plants of south-western Australia*[47] is an excellent resource, providing a guide to the habitat location, optimum and maximum water depth and mean annual water level tolerated by thirteen native sedges, as well as their seasonal flooding range.

- *Water regime for wetland and floodplain plants: a source book for the Murray-Darling Basin*[48] is, as the name suggests, focused on eastern states species, but does describe the germination requirements of *Eucalyptus camaldulensis* in detail, as well as those of *Muehlenbeckia florulenta*, *Eragrostis australasica*, *Eleocharis acuta* and *E. sphacelata*, *Typha domingensis* and *Cyperus gymnocaulos*.
- Although more technical in nature, a range of water requirement studies of wetland plants may also be useful. In WA, research into the water requirements of wetland organisms has focused on the Gnangara and Jandakot groundwater mounds in the greater Perth region[46,49,50], the Blackwood and Scott Coastal Plain groundwater areas[51], and Ramsar wetlands. Riparian studies that include wetland species in the Pilbara and Kimberley have also been the subject of a number of studies (for example, Loomes[52,53,54]).
- *Establishing samphires in the Avon catchment*[55]

Even when optimally planted, the best efforts of a wetland manager can be confounded if exceptionally wet or dry conditions occur during the growing season – some death of plants is to be expected, although contingencies such as watering may assist in minimising plant losses.

Deciding on planting and seeding density

Replicating the original density can be informed by examining part of the site which has not experienced a vegetation change or by examining a nearby similar, intact wetland, often referred to as a 'benchmark' site.

Planting should attempt to mimic the natural environment as much as possible, but managers should be aware that planting in densities greater than 10 plants per square metre can be very costly and time consuming.

The natural density of wetland vegetation varies widely between wetlands, even those with similar characteristics or in close proximity to each other. This makes it difficult to provide even rules of thumb about appropriate planting densities. Denser is not always better, for example, bare patches between areas of vegetation are often important habitat for a range of reptiles.

Published rules of thumb/actual densities include:

- 2-3 seedlings per square metre in poor and very poor sites
- a rough guide of 500:50:5 herbs or sedges:shrubs:trees for each 100 square metres for riparian vegetation (that is, vegetation associated with waterways) in south-west WA[56,18]
- where only sedges and rushes are being used, a rate of 6-9 tubes or cells per square metre. More sedges/rushes per square metre can be used to achieve dense stands faster, if budgets allow. For a larger stock size, such as blocks or strips of sedges/rushes, densities are normally determined by site characteristics and budget constraints. The closer the blocks and strips are planted, the quicker they will grow to meet each other and create dense stands.
- for direct seeding, determine the seed viability, allow 50 per cent mortality of seedlings, and calculate the required seed lots accordingly (this service is available from some commercial seed operators).[18]

In the south-west of the state, as a rule of thumb, an average loss of up to 80 per cent of all germinants of direct-seeded trees and shrubs can be expected after two years, therefore seed should be sown at a rate of twenty germinable seeds per square metre.[18] The average mortality rate of planted trees and shrubs is estimated to be 30–50 per cent.[18] Over-seeding and over-planting (also known as saturation planting) is often used in anticipation that a certain percentage of the seeds or plants will not survive in the short to medium term. This technique has the added benefit of reducing the area available for weed establishment during the seedling establishment phase.

Timing of seeding and planting

Seeding

As a rule of thumb, seeding should occur prior to the main rains[56]) to give establishing plants the greatest period before drought stress occurs. This is roughly late summer/ early autumn in the south-west of WA, but can differ yearly. The wetland environment can hold water for longer periods than dryland areas, giving new plants a longer establishment period. However, in wetland environments it is important to be aware that surface water flows may wash away seeds. More intense rainfall events can also lead to inundation and poor seedling survival.

Planting

The optimal planting time can depend on the type of plant and whether it is to be planted into an area subject to inundation or waterlogging.

As a rule of thumb, in the tropical climate of northern WA, it is appropriate to plant at the start of the rains, in summer, when rainfall events are common and the soils are moist and yet still warm.

In the south-west of WA, the Mediterranean climate means that most plantings are ideally undertaken in late autumn, at the beginning of the rainfall season, when the soil is moist and still warm and more rain is to be expected. However, winter planting of waterlogged soils and the edges of inundated zones, and early summer planting of zones where inundation is giving way to waterlogging, has been found to work at some sites (for an example, see the case study 'Challenges in wetland rehabilitation at Bibra Lake' at the end of this topic). In inundated wetlands in the south-west of WA, many wetland sedges are planted in spring/summer when water levels are receding (if in the water column) Sedges may be dormant over winter and as a result their roots may not establish as well. This means they can be susceptible to damage by high-energy winter storm events that cause waves and erosion. Similarly they may not be tall enough to avoid being submerged, leading to death.

To water or not to water?

There are many opinions about whether or not to water seedlings in the dry seasons following their germination/planting. As outlined above, planting in the optimal establishment zone of a plant should minimise the need for watering. Over and above this, whether or not it is appropriate in a given situation depends on many factors including:

- seasonal rainfall variations
- soil conditions
- species chosen

Watering can influence the root development of a plant. If, as a seedling, the plant is watered often, it is less likely to establish deep roots to find water. When watering ceases, the plant will have less ability to find water for itself, and will lose vigour and may die unless it can develop a suitable root system.

Wetland managers may consider a limited period of watering, for example, over the first one or two summers, to encourage establishment and minimise potential plant death. In seasons with lower than normal rainfall watering is likely to be required to achieve acceptable plant establishment rates. Optimal watering is infrequent, deep watering, to encourage deep root systems, and watering the base of plants (the root zone) rather than its leaves or branches. Watering can be logistically challenging and expensive.

Soil improvers, fertilisers and plant guards

As a general rule, soil improvers and fertilisers should not be used in wetlands. Native plants have adapted over thousands of years to local soils, hydrology and climatic conditions. Many improvers and fertilisers contain nutrients in much higher amounts than can be tolerated by native species.

The application of gypsum, or dihydrous calcium sulphate ($CaSO_4 2H_2O$), is often suggested for clay or sodic soils to improve soil structure, such as sites subject to secondary salinity, which causes the soil structure to become compacted, and the growing environment for the local plants is changed. Gypsum addition will replace the sodium (Na) ions with calcium (Ca) ions which help to open the soil structure and improve soil permeability. However, this will only be effective in the longer term where the source of the salinity has been addressed and no further sodium is entering the wetland system. If this is not feasible, then the short term benefit and cost of gypsum addition is hard to justify.

The wetland origins of many soil conditioners

Gypsum, or dihydrous calcium sulphate ($CaSO_4 2H_2O$), is a natural product of many wetlands in WA, particularly in the Wheatbelt, the south-west and Goldfields region. Gypsum deposits in wetlands and in the dunes on the southern and south-eastern shores over time; it is estimated that deposits have been forming up to 35,000 years ago in some WA wetlands.[38] In WA it has been mined since 1921 using methods such as excavators (dry excavation) and sub-aqueous dredges. As well as being mined for use as soil conditioners, gypsum is mined for a multitude of uses, including drywalls, plasters, and fertilisers. Similarly, bentonite clay is mined from WA wetlands for use as a soil wetter as well as a range of other industrial and domestic applications.

Plant guards, such as those shown in Figure 18, can reduce grazing by animals such as rabbits, kangaroos and uprooting by waterfowl such as purple swamphens (*Porphyrio porphyrio*).[25] Guards can be costly and time consuming to install, and have limited benefit if not well maintained. Their use comes with the understanding that they will need to be manually removed, when plants are big enough, and if plastic like the ones shown below, generally prior to summer to prevent killing plants by overheating them (the use of mesh plant guards may minimise this issue).

Figure 18. a) plant guards can help to protect plants from people and other animals;
b) unmanaged plant guards may stifle plants or result in over-heating. Photos - J Nichol/DEC.

Timeframes

In natural wetland environments, plants interact with other physical, biological and chemical factors such as climate, soils and hydrology to grow, establish and undertake ecological function over long periods. How long it may take to revegetate a wetland and re-establish these processes is therefore a matter for consideration for wetland managers to manage projects and balance resource allocations.

Another factor to take into account when considering timeframes is the predicted numbers of plants surviving to adulthood following a revegetation project, based on natural attrition and the recognition that revegetation is an artificial process and plants will not always survive. Whilst detrimental vegetation change may occur in wetlands over short periods of time (1–5 years), it is widely recognised that ecological processes will not be reinstated within similar timeframes.

Symbiosis: a condition in which two organisms live in a mutually beneficial partnership

Mycorrhiza: a symbiotic association between a fungus and the roots of a plant, from which both fungus and plant usually benefit

The role of fungi and lichen

Fungi are multi-celled organisms that are neither plants nor animals (fungi is the plural, fungus singular). Fungi include an extremely wide range of organisms including macrofungi such as mushrooms, toadstools, puffballs, coral fungi, earthstars and truffles, and an even broader range of microfungi.

Fungi occur in most environments, however, some fungi species are much more prevalent in wetlands than other areas, such as certain species of macrofungi that fruit most abundantly on paperbark (*Melaleuca*) trees, and the predominantly microscopic aquatic fungi, which rely on free water for some part of their life cycle.

Studies worldwide show that a large number of wetland plants are partnered with mycorrhizal fungi[57,58] and WA is no exception—including but not limited to *Melaleuca, Astartea, Isoetes, Cotula, Viminaria, Myriophyllum, Nymphoides, Nymphaea, Pericalymma, Livistona, Pandanus, Ruppia* and *Eucalyptus*.[59] In recent decades there has been developments in the understanding of mycorrhizal associations with sedges, and the major role they play in phosphorus dynamics.[58]

Many fungi form a close association with plants in which both parties benefit (**symbiosis**) from an exchange of nutrients and sugars. This relationship is known as **mycorrhiza** and the roots of the associated plants are referred to as mycorrhizal roots. These mycorrhizal roots are connected to networks of microscopic thread-like structures developed by the fungi known as hyphae or mycelia, which explore and exploit a far greater area of the soil than uncolonised roots alone. These networks take up nutrients, such as phosphorus, and transport the nutrients back to the plant. Two main types of mycorrhiza occur: endomycorrhiza, where the fungi penetrate the plant's cell wall, and ectomycorrhiza, where the fungi are external to the plant cells. Endomycorrhiza are formed mainly by microfungi and can be present in permanently flooded soils, while ectomycorrhiza are formed by many macrofungi and appear to be sensitive to inundation.[60]

The significance of these beneficial plant-fungi partnerships needs to be considered when planning wetland revegetation. Research has found that healthy natural woodlands have a greater diversity of native fungi than degraded woodlands or revegetated agricultural lands, and that most native fungi are not self re-establishing in degraded or cultivated land, at least in the short to medium term.[61] Mycorrhizal fungi suitable for some plant species is now being made available by commercial suppliers. These fungi are mostly applicable to a range of non-woody plants. Inoculum specifically for use in revegetation for many natural Australian ecosystems with woody plants is not available. Inoculum obtained from similar vegetation in the local area is considered likely to be the most suitable. For more information, see the fungi information in the topic 'Wetland ecology' in Chapter 2, which provides a list of sources of additional information.

Lichen, cyanobacteria, bryophytes, mosses and liverworts form biological soil crusts. These crusts can help to reduce erosion, control water flow through soils, enhance soil nutrition and provide niches for plant seedlings and invertebrates.[62]

Inappropriate management techniques

Care should be taken when undertaking revegetation activities to ensure that the act of revegetation itself does not adversely impact on the condition of the wetland.

Some potential adverse impacts of wetland vegetation management include:

- planting or seeding when natural regeneration is possible. Trampling, weed spread, plant loss, soil compaction and introduction or spread of disease are all risks brought to bear unnecessarily.
- removing dead trees, logs and leaf litter, as these still function as habitat for native plants, animals, fungi, lichen and bacteria. Over time they are broken down and their nutrients are recycled.

case study

Restoring vegetation: the importance of weed control over the long term

John Lombardo was resigned to weeds and dying plants on his private property of 3 hectares in Wandi, thirty-two kilometres south of Perth. Over fifteen years, John had observed the wetland becoming increasingly infested with weeds such as arum lily (*Zantedeschia aethiopica*), perennial veldt grass (*Erharta calycina*) and Sydney golden wattle (*Acacia longifolia*). These weeds were causing composition changes in the wetland, displacing native plants.

In 2005, WWF agreed to fund some work on the property over a three year period, via its 'Wetland Watch' program. The project included the preparation and implementation of a management plan. Implementation included funding for controlling weeds, undertaking minor revegetation and controlling rabbits to allow regenerating plants to establish.

Management strategies - weed, plant and weed again

For the next four years, John undertook a number of weed control and assisted regeneration activities to improve the condition of the wetland vegetation. Specific wetland weeds were targeted for reduction or eradication. The herbicide Fluazifop-p-butyl (the active ingredient in 'Fusilade'), was sprayed over the entire site for several years to target non-native grasses without damaging the existing sedges, rushes and other natives. This controlled the veldt grass and paspalum (*Paspalum dilatatum*). Arum lilies on the property were also treated using other targeted herbicides and woody weeds such as the Sydney golden wattle were hand-removed.

Rabbits were controlled on site by baiting with Pindone. The baiting control was successful for several years in reducing the rabbit populations. However, the rabbits did return, so plant guards were placed around all new planted seedlings. Over time and with perseverance, the wetland began to naturally regenerate, with rushes and sedges growing from existing areas and seedlings of *Kunzea* and *Astartea* springing up once the areas were cleared of weeds (Figure 19, Figure 20).

Ongoing weed monitoring and management

The wetland now has more diversity of wetland species, which John regularly monitors when making his daily walk around the paths (Figure 21). During these walks, John observes any emergent woody weeds such as the Sydney golden wattle and removes the seedlings on the spot. Frequent, short visits to see changes and notice if weeds are spreading is a good technique to ensure work is achieved with limited time allocated. This method is labour intensive, however, John considers the success of the regeneration is well worth the ongoing management.

case study

Figure 19. Natural regeneration of *Casuarina* sp. following consistent weed control and other assisted regeneration activities. Photo - J Nichol/DEC.

Figure 20. Natural regeneration of sedges following consistent weed control and other assisted regeneration activities. Photo - J Nichol/DEC.

John also uses his daily walks in summer to assess whether or not he should water some of the revegetation sites he is working in. John calls his watering frequency "summer rain", in that he only puts around 20 millimetres of water on the wetland areas infrequently, no more than once a month, so as not to cause weeds to germinate or increase the spread of plant disease. John has noticed the plants in these areas do survive the hot summer conditions better.

Ongoing maintenance and monitoring

John's wetland continues to slowly regenerate, following his regime of controlling grasses two to three times per year, annual arum lily control and ongoing woody weed management. He has turned areas from old tracks to stands of *Melaleuca*, *Kunzea* and *Astartea*. Whilst the work is labour intensive the site is small enough to be managed with John and his wife undertaking limited tasks once or twice a week, breaking down the workload into manageable amounts and areas. John hopes to carry out more weed control and management in the future, and looks forward to the return of more native flora and fauna, such as blue wrens (*Malurus cyaneus*), at his property.

Figure 21. Mr John Lombardo showing regeneration on his property in Wandi. Photo - J Nichol/DEC.

PLANNING VEGETATION MANAGEMENT

Planning for vegetation management can be logistically challenging. It often involves long timeframes, overlapping tasks, and substantial resources. A schedule of works is a good way to structure tasks and understand timeframes, and should take into account all of the below factors.

Climatic variations, inferior seeds, incorrect planting methods, storm events, flooding, drought, weeds or varied water quality parameters are just some of the unpredictable influences which will affect the outcomes of a revegetation activity, yet many revegetation projects do not account for these factors. For example, in natural wetlands, native plant seeds may lay dormant within the sediment for years or even decades before the right combination of physical and chemical conditions for germination occur. Yet many projects are planned with the expectation that an entire area will be revegetated in only a few years, without any allowances for the unpredictability of nature. Planning for a project, and measuring its success, needs a timeframe of several years rather than months.

Wetland managers should therefore recognise the complexity of such a task during goal and objective setting, and resource allocation, in order to more accurately predict how long a revegetation project may take, and what will constitute a 'success'.

Planning should account for plant deaths through natural attrition and other causes. Undertaking strategic management activities like overplanting or using several techniques at once, such as direct seeding and revegetation may help reduce the potential for setting unrealistic expectations. Managers should always remember that revegetation is merely a tool used for managing wetlands which are too degraded to regenerate naturally and that success may need to be measured after a long period of time to measure if wetland processes have been restored as a result of the revegetation.

Ideally, wetland management should form part of an overall wetland management plan. A plan can identify priority wetland management actions and where, when and how these should be undertaken.

➤ A process for wetland management planning is described in the topic 'Wetland management planning' in Chapter 1.

Contingency planning

The planning process may identify collecting and storing seeds or other plant propagules as a suitable contingency action, particularly if there is a high risk to the wetland vegetation, or if individual species are rare or difficult to harvest. Seed storage facilities are provided by revegetation businesses companies and a number of non-government conservation organisations.

case study

Challenges in wetland rehabilitation at Bibra Lake

Adapted from a case study prepared by Denise Crosbie (Cockburn Wetlands Education Centre) and Norm Godfrey (Wetlands Conservation Society)

Bibra Lake is a permanently inundated wetland in Perth's southern suburbs. Extensive weeding and planting has been carried out in Bibra Lake.

Getting started

The inundated area of Bibra Lake fluctuates from season to season and year to year. Different wetland plants and weeds are associated with different zones in the wetland, and this has implications for rehabilitation activities. Maps were prepared to gain a better understanding of the site conditions including water levels, topography, type and extent of existing native vegetation and weeds. Weed control was then planned and implemented and planting initiated.

Trials and tribulations

During the early days of rehabilitation at Bibra Lake the following problems were encountered:

- timing of grants restricted the ability to order seedlings early and thus limited species availability
- chemically treated weeds did not mulch down in time for planting
- numerous seedlings needed replanting because they were established in the slashed weed biomass instead of the soil
- late plantings (September) required summer watering of the seasonally waterlogged zone
- secondary weed invasion was extensive
- planted sedges were predated by waterbirds.

Although wetland trees and tall shrubs were able to be established in weedy environments (though they grow more slowly), the object was to re-introduce understorey and attain a reasonably 'self-sustaining system' through dedicated weed control efforts.

Revegetation

Due to the dynamic nature of wetlands, many native plants may be growing outside of their optimal establishment zone. Be careful! Look at historical water data for the wetland, and at other wetland sites prior to planting. It is also difficult to predict future water levels, and during some years plants may lost – this is part of the challenge.

Wetlands plants grow rapidly and are much quicker to reward you than their slower bushland counterparts. The planting efforts at Bibra Lake included:

- saturation planting to out-compete the weeds
- planting transitional, waterlogged and upper seasonally inundated zones during winter months
- staging planting of the lower seasonally inundated zones following a fall in water level (approximately November onwards)
- organising planting days after the maximum water levels
- removing tree guards the following winter to avoid summer predation by rabbits
- propagating locally sourced seed and establishing a wetland seed production area for future supplies

case study

Figure 22. The site post-spraying, being prepared for planting. Photo – D Crosbie/Cockburn Wetlands Education Centre.

Figure 23. Seedlings were planted with tree guards and weed mats to combat weed regrowth. Photo – D Crosbie/ Cockburn Wetlands Education Centre.

case study

Figure 24. Secondary weed growth – weed regrowth was less where mulch had been applied. Photo – D Crosbie/ Cockburn Wetlands Education Centre.

Figure 25. The site two years later following planting. Photo – D Crosbie/Cockburn Wetlands Education Centre.

case study

So, can we really bring back the understorey?

Unfortunately there are no quick solutions when it comes to rehabilitation activities. The understorey is looking fantastic, bandicoot diggings are evident, and the frogs and birds are breeding. Bushy starwort, spear thistle, nutgrass and lotus invade bare areas where saturation planting has not been achieved. Our knowledge is growing and we need to continue long-term monitoring and evaluation to determine the true outcomes of our trials.

Established in 1993, the Cockburn Wetlands Education Centre is an independent, not-for-profit community organisation dedicated to wetlands, restoration activities, environmental education, youth services and facility hire. Numerous volunteers implement the centre's activities along with the assistance of a small band of dedicated staff. The centre lies in the suburb of Bibra Lake, 15 kilometres south of Perth. It provides the gateway to Beeliar Regional Park which contains twenty-seven wetlands within two parallel wetland chains.

GLOSSARY

Adaptation: the process by which an organism becomes fitted to its environment

Biomass: the total mass of biological material (living or dead), usually expressed as live or dry weight per unit area or volume

Bradley method: working from the most intact parts of a bushland area out towards more degraded areas, to allow natural regeneration to occur, for example, when weeding

Clearing: any act that kills, removes or substantial damages native vegetation in an area. This includes severing or ringbarking of trunks or stems, draining or flooding of land, burning of vegetation and grazing of stock or any other act or activity that causes damage to some or all of the native vegetation in an area

Community: a general term applied to any grouping of populations of different organisms found living together in a particular environment

Dynamic: a process or system which is characterised by constant change or activity

Ecological community: naturally occurring biological assemblages that occur in a particular type of habitat

Ecological character: the sum of a wetland's biotic and abiotic components, functions, drivers and processes, as well as the threatening processes occurring in the wetland, catchment and region

Ecological linkage: a network of native vegetation that maintains some ecological functions of natural areas and counters the effects of habitat fragmentation[oo]; a series of (both contiguous and non-contiguous) patches of native vegetation which, by virtue of their proximity to each other, act as stepping stones of habitat which facilitate the maintenance of ecological processes and the movement of organisms within, and across, a landscape[7]

Ecosystem: a community of interdependent organisms together with their non-living environment

Ecotype: a genetically distinct geographic variety, population or race within a species which is adapted to specific environmental conditions. Typically ecotypes exhibit differences in morphology or physiology stemming from this adaptation, but are still capable of breeding with adjacent ecotypes without loss of fertility or vigour.

Endemic: naturally occurring only in a restricted geographic area

Eutrophication: the nutrient enrichment of a water body, which can trigger prolific growth of plant material (phytoplankton, macrophytes or both). May occur naturally over geological time or may be human-induced.

Fire-responsive: plants which have seed pods that open, seeds that germinate, or epicormic buds or lignotubers that resprout in response to a fire event. Some of these responses are triggered by the chemicals produced in smoke during the fire event.

Functioning ecosystem: a community of interdependent organisms together with their non-living environment. A functioning ecosystem is one which has a full suite of these normal resources and functions successfully, interacting within an ecosystem all of the time to maintain a stable sustainable system over time.

Mycorrhiza: a symbiotic association between a fungus and the roots of a plant, from which both fungus and plant usually benefit

Propagate: grow plant specimens from parent material

Propagule (plant): any part of a plant from which a new plant can grow, including seeds, bulbs and rootstocks

Provenance: the place of origin[42]

Recruitment: addition of new individuals to a population (usually through reproduction)

Reference wetland: a wetland used to provide a model for planning a management project

Rehabilitation: the re-establishment of ecological attributes in a damaged ecological community although the community will remain modified

Resilience: capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks

Restoration: returning an ecological community to its pre-disturbance or natural state in terms of abiotic conditions, community structure and species composition

Revegetation: return vegetation (indigenous or otherwise) to an area

Senescence: the natural aging and subsequent death of an organism

Succession: progressive change in species composition and/or structure that occurs following disturbance of a site

Symbiosis: a condition in which two organisms live in a mutually beneficial partnership

Taxa: a taxonomic group (the singular being taxon). Depending on the context, this may be a species or their subdivisions (subspecies, varieties etc), genus or higher group

Threatening process: processes that threaten the survival, abundance or evolutionary development of a native species or ecological community

Thresholds: points at which a marked effect or change occurs

Turbid: the cloudy appearance of water due to suspended material

Vegetation: combinations of plant species within a given area, and the nature and extent of each area

Water regime: the pattern of when, where and to what extent water is present in a wetland. The components of water regime are the timing, duration, frequency, extent and depth, and variability of water presence

Water requirements: the water required by a species, in terms of when, where and how much water it needs, including timing, duration, frequency, extent, depth and variability of water presence

Wetland buffer: an interface adjoining a wetland that is designated to assist in protecting the wetland's natural values from the threats posed by the surrounding land use(s)

Wetland processes: the dynamic physical, chemical and biological forces within a wetland, including interactions that occur between wetland organisms, within the physical/chemical environment, and interactions of these

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A guide to managing and restoring wetlands in Western Australia

Introduced and nuisance animals

In Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Introduced and nuisance animals' topic

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Contents

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Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'.

Introduction

A wide variety of fauna (animals) may use a particular wetland or be wetland-dependent, including mammals, reptiles, fish, birds, frogs, and **aquatic invertebrates** (such as insects, snails and crayfish). Protecting, maintaining and encouraging native fauna populations at a wetland involves managing the wetland in such a way as to provide suitable habitat (an area or environment where conditions are suitable for the survival of an organism, taxon or community) for such fauna. Managing a wetland to maintain its natural state (in general terms: good water quality, healthy vegetation and unaltered hydrology) will help to maintain suitable habitat for the wetland's natural suite of fauna (Figure 1).

Figure 1. A wetland in Forrestdale which provides habitat to its natural suite of fauna due to good water quality, healthy vegetation and unaltered hydrology. Photo – C Mykytiuk/WWF.

Maintaining or improving habitat for the natural suite of native fauna often involves preventing or controlling introduced and nuisance animals. These will be predators and/or competitors of native fauna and will also degrade the habitat available for native fauna.

There are many species of introduced animals found throughout Western Australia. In fact, introduced animals may be found in almost every area of the state, with wetlands being no exception. Introduced animals may threaten **biodiversity**, degrade habitats and may have severe economic and social impacts. Some species of native fauna can seriously impact wetlands and surrounding land when in unnatural numbers, and in these circumstances may be considered 'nuisance fauna'. This topic briefly describes the introduced and nuisance species that may be present at a wetland, including **feral livestock**, the impacts these may have, and the management strategies available to address these animals.

Aquatic invertebrates: those animals without a backbone (such as insects, worms, snails, molluscs, water mites and larger crustacean such as shrimps and crayfish) that live in or on water for at least one phase in their lifecycle

Biodiversity: a contraction of the words 'biological' and 'diversity', encompassing the whole variety of life forms—the different plants, animals, fungi and microorganisms—the genes they contain, and the ecosystems they form

Feral animals: introduced animals that have escaped, or have been released, from domestication and returned, partly or wholly, to their wild state

Livestock: introduced domestic ungulate (or hoofed) animals

What are nuisance fauna?

Nuisance fauna are native animals that naturally occur at a site, but which have reached a population size that is causing harm to the environment or humans. Examples include kangaroos, Australian white ibis and midges, which can all reach unnatural numbers as a result of human alterations to the environment. Mosquitoes are also labelled nuisance insects, but they are an exception: the population of many species of mosquitoes can grow rapidly and disperse far from wetlands under the right natural conditions.

➤ For guidance on managing nuisance midges and mosquitoes, see the topic 'Nuisance midges and mosquitoes' in Chapter 3.

What are introduced animals?

The term 'introduced animals' refers to those animal species that have been intentionally or unintentionally brought into a region where they do not historically occur, usually facilitated by humans. In the Australian context, this definition includes both non-Australian animals as well as animals that are native to Australia but have been introduced from one area within the country or state to another. For example, common yabbies *(Cherax destructor albidus)* have been introduced to dams in WA from the eastern states. Some introduced animals may also be considered invasive animals, which are rapidly spreading introduced animals that out-compete native fauna for habitat.

Introduced animals are a problem because they are able to rapidly increase in numbers without natural predators or diseases to keep the population in check. Many of the introduced animals in Australia are large animals such as pigs (*Sus scrofa*) or camels (*Camelus dromedarius*). The wild ancestors of these domestic animals evolved among large predators such as the big cats, bears and wolves. In Australia, where these predators do not occur, introduced animals were able to easily establish themselves. The only natural control of most introduced animals in Australia is drought. Introduced animals numbers increase during good seasons and decline rapidly during dry times. During dry times in particular, terrestrial introduced animals seeking water are more likely to congregate around wetlands. Australia's extended evolutionary and biogeographic isolation has resulted in its native fauna being naïve and vulnerable to introduced animals, particularly predators.[1]

Since European settlement (if not before), humans have facilitated the spread of introduced animals to Australia. In a twenty-year period spanning 1860–80 more than sixty vertebrate animal species were released in Australia.[2] Many of these introductions were deliberate, in an attempt to make the European settlers feel more at home by bringing European animals to the country.[3] There were even acclimatisation societies set up solely for the purpose of spreading animals such as rabbits (*Oryctolagus cuniculus*), birds and deer for the 'benefit' of the country.[3] Animals such as rabbits and red foxes (*Vulpes vulpes*) were often released for recreational hunting while European carp (*Cyprinus carpio*) were introduced for ornamental display in garden ponds. Many other animals such as house mice (*Mus musculus*) and rats (*Rattus* spp.) were introduced into Australia accidentally on settlers' ships, while domestic animals such as cats (*Felis catus*), horses (*Equus caballus*) and camels were released from captivity into the wild.

Since the realisation that introduced animals can be harmful to Australia's environment and native fauna, introductions have mostly been accidental, although some intentional introductions (for example for hunting and fishing) still occur. Many animals kept as pets or livestock have become feral animals after straying from the properties they were kept on or after being deliberately abandoned. Animals may also be introduced to new areas by travelling unnoticed with tourists and vehicles transporting food and other products, or even by hitching a ride on debris in waterways: cane toads (*Bufo marinus*) have been reported to be 'surfing' down the Ord River by as much as 20 kilometres a night.[4]

Many of the aquatic introduced animals that occur in wetlands in WA were probably introduced as a result of aquarium and aquaculture ventures. For example, blackworm (*Lumbriculus variegatus*), commonly sold as live fish feed, and aquarium snails are commonly found in wetlands in metropolitan areas. Yabbies and brine shrimp (*Artemia* spp.) are commonly used in the aquaculture industry to feed juvenile fish in hatcheries.

Most introduced fish populations result from intentional releases, for example, of domestic aquarium fish that have been 'set free', or fish released by recreational fishers to enhance recreational fishing. Notably, eastern gambusia (*Gambusia holbrooki*) were deliberately introduced into Australian wetlands and waterways as a **biological control** agent for the control of mosquitoes in the 1920s.[5] They may now be found in most drainage channels and many wetlands along the south-western coast of WA, particularly in metropolitan areas. They were referred to as 'mosquito fish' but unfortunately they are thought to have actually benefited mosquito populations by eating the native insects which would otherwise prey on mosquito larvae. So it appears that they are quite aptly named – their genus name *Gambusia* is derived from the Cuban Spanish term *gambusino*, meaning 'useless'. Eastern gambusia also out-compete native fish for food and attack competitors including tadpoles and fish by damaging their fins.

Biological control: the control of an introduced plant or animal by the introduction of a natural predator or pathogen, usually bacteria, viruses or insects, or by biological products such as hormones

Amphibians: the class of animals to which frogs, toads and salamanders belong. They live on land but develop by a larval phase (tadpoles) in water.

Another notable deliberate introduction is the cane toad. Cane toads were introduced to northern Queensland from Hawaii in 1935 in an unsuccessful attempt to control cane beetles, a pest of the sugar cane industry. Having no natural enemies, the toads spread west into the Northern Territory and south into New South Wales. Cane toads have since crossed the Western Australian border in the northern part of the state. The poisonous toads are considered a threat to Western Australian native frogs and other fauna through predation, competition and lethal ingestion.

Finally, some introduced species have slipped in to Australian wetlands undetected by catching a ride on other introduced species. This is the most likely mode of entry for a European ostracod (*Physocypria* sp.), which was discovered in Lake Jolimont, Perth in 2010. It is thought that the ostracod was introduced when pet goldfish were released into the lake.[5]

Which introduced animals can occur at a wetland?

Table 1 provides a list of introduced animals that are known to occur at wetlands in WA. Which of these species actually occur at a wetland will depend on a number of factors, including the location of the wetland within WA and the available habitat at the wetland.

When assessing the risk of an introduced species inhabiting a particular wetland, it is important to keep in mind that factors such as climate change may alter that risk in the future. For example, some feral fish species may expand in range if wetlands and waterways become warmer or more saline in the future as a result of climate change.

Table 1 groups the introduced animals according to those that are, and are not, dependent on wetlands for their survival. 'Wetland dependent' introduced animals are those that are restricted to or dependent on wetlands for their existence. This category is dominated by aquatic species and **amphibians**. Those introduced animals that are 'not wetland dependent' are visitors to wetlands.

Table 1. Introduced animals that are known to occur at wetlands in Western Australia

Common name		Latin name	Known distribution in WA	Identification guide	Reporting
Wetland dependent					
Birds					
	Mute swan	*Cygnus olor*	Avon River, Northam	Field guide to Australian birds[7]	-
	Domestic waterfowl	*Various*	Metropolitan areas	Field guide to Australian birds[7]	-
Amphibians					
	Cane toad	*Bufo marinus*	Kununurra	DEC pamphlet Is it a cane toad?[8]	Cane Toad Hotline 1800 084 881 Kimberley residents: DEC's Kununurra Office (08) 9168 4200
Reptiles					
	Red-eared slider turtle	*Trachemys scripta elegans*	Perth. Known occurrences have been removed.	Red-eared slider: Animal pest alert No 6/20099	Department of Agriculture and Food 1800 084 881 Or DEC on 9334 0292.
Fish					
	Eastern gambusia	*Gambusia holbrooki*	South-west (widespread)	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	One-spot live bearer	*Phalloceros caudimaculatus*	Perth metropolitan area	Field guide to the freshwater fishes of Australia[5]	FISHWATCH service 1800 815 507
	Tilapia	*Oreochromis mossambicus*	Gascoyne-Lyons river system	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	Pearl cichlid	*Geophagus brasiliensis*	Perth metropolitan area (primarily Bennett Brook and Altone Park)	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	Goldfish	*Carassius auratus*	South-west	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	Swordtail	*Xiphophorus hellerii*	Irwin River, south-east of Geraldton	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	Guppy	*Poecilia reticulata*	Northern Western Australia	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	Redfin perch	*Perca fluviatilis*	South-west	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	European carp	*Cyprinus carpio*	South-west	Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
	Brown trout	*Salmo trutta*	South-west	Field guide to the freshwater fishes of Australia[5]	FISHWATCH service 1800 815 507
	Rainbow trout	*Oncorhynchus mykiss*	South-west	Field guide to the freshwater fishes of Australia[5]	FISHWATCH service 1800 815 507
Invertebrates					
Crayfish	Common yabbie	*Cherax destructor albidus*	South-west, Hutt and Bowes Rivers (north of Geraldton). Native to eastern states	Identifying freshwater crayfish in the south west of WA[11] Aquatic invaders publication[10]	FISHWATCH service 1800 815 507
Crayfish	Smooth marron	*Cherax cainii* (previously known as *Cherax tenuimanus*)	Hutt River, Esperance, Kalgoorlie (human-aided range extensions). Native to south-west. Considered a threat in particular areas of the Margaret River only, where it is a threat to the hairy marron	A field guide to freshwater fishes, crayfishes and mussels of south-western Australia[161]	FISHWATCH service 1800 815 507
Crayfish	Redclaw	*Cherax quadricarinatus*	Kimberley. Native in Northern Territory and Queensland	A field guide to freshwater fishes, crayfishes and mussels of south-western Australia[161]	FISHWATCH service 1800 815 507

	Common name	Latin name	Known distribution in WA	Identification guide	Reporting
• *Snails*	Tadpole snail	*Physa acuta*	South-west	-	FISHWATCH service 1800 815 507
	Great pond snail	*Lymnaea stagnalis*	South-west coastal	-	FISHWATCH service 1800 815 507
	Brine shrimp	*Artemia franciscana* and *A. parthenogenetica*	South-west and coastal WA	-	FISHWATCH service 1800 815 507
	Blackworm	*Lumbriculus variegatus*	Metropolitan areas		FISHWATCH service 1800 815 507
	Some naidid worms	Some species within the Naididae family of worms including *Branchiura sowerbyi*	Metropolitan areas	-	FISHWATCH service 1800 815 507
	Physocypria (ostracod)	*Physocypria sp.*	Lake Jolimont	-	FISHWATCH service 1800 815 507
Not wetland dependent					
Mammals					
	Cat	*Felis catus*	All of WA	-	-
	Red fox	*Vulpes vulpes*	Southern half of state and Pilbara coast	-	-
	Domestic dog	*Canis lupus familiaris*	Pastoral areas	-	-
	Fallow deer and red deer	*Dama dama* and *Cervus elephus*	South-west	Rusa deer: Animal pest alert[12]	Department of Agriculture and Food 1800 084 881
	Camel	*Camelus dromedarius*	Inland/arid areas	-	-
	Horse	*Equus caballus*	Arid rangelands and Kimberley	-	-
	Donkey	*Equus asinus*	Inland, Pilbara and Kimberley	-	-
	Goat	*Capra hircus*	Semi-arid to arid pastoral areas (Midwest and Goldfields)	-	-
	Pig	*Sus scrofa*	South-west, Kimberley and some in Midwest and Pilbara	-	Department of Agriculture and Food 1800 084 881
	Rabbit	*Oryctolagus cuniculus*	All of WA other than Kimberley	-	If present on offshore islands report to DEC Wildcare Hotline 9474 9055
Rodents	Black rat	*Rattus rattus*	South-west and along north-west coast	-	If present on offshore islands report to DEC Wildcare Hotline 9474 9055
	Brown rat	*Rattus norvegicus*	Coastal cities of south-west	-	If present on offshore islands report to DEC Wildcare Hotline 9474 9055
	House mouse	*Mus musculus*	All of WA	-	If present on offshore islands report to DEC Wildcare Hotline 9474 9055

Detecting introduced animals

Introduced animals may be difficult to see at a wetland, but they will usually leave some signs of their presence. Signs of introduced mammals may include grazed vegetation, trampled vegetation in the form of 'runways' which they may regularly use, scats, burrows, tracks (footprints), eroded banks, diggings and signs of wallowing in mud or water. Scats and tracks are particularly useful as they may be used to identify the type of animal that is present more accurately than by using other signs (Figure 2).

➤ The book *Tracks, scats and other traces: A field guide to Australian mammals*[13] is useful for identifying which introduced mammals are present at a wetland.

➤ The Wildlife Note *Sand Pads – using tracks to monitor fauna*[14] describes how to create a sand pad for monitoring purposes.

Figure 2. (a) Tracks preserved in clay at Shirley Balla Swamp in Banjup. Photo – J Lawn/DEC. (b) Fox den at Lake Joondalup. Photo – N Hamilton/DEC.

(a)

(b)

Introduced aquatic species can be harder to detect through observation alone. At least twenty-two species of introduced fish are known to occur in Australia's fresh waters.[5] Of these, at least ten species are found in Western Australian wetlands (see Table 1).

Sophisticated techniques are also being employed to detect some animals and monitor their movements. For example, global positioning system (GPS) collars are being used to monitor foxes and feral cats in Leschenault Peninsula Conservation Park. Sniffer dogs are being used to detect cane toad fronts (Figure 3). Genetic testing of feral pig populations is being used to identify populations that have been transported to new areas by humans for hunting.

Figure 3. Nifty the cane toad detector dog works with DEC State Cane Toad Initiative technical officer Sandy Fleisher to seek out the invading fronts of cane toads in the Kimberley. Photo – M Andrews.

Threatening process: a process that threatens, or may threaten, the survival, abundance or evolutionary development of a native species or ecological community

What effect do introduced and nuisance animals have on wetlands?

There are many reasons for controlling introduced animals. Certain species have devastating impacts on the Australia environment. The effects of introduced species on populations of native fauna has been recognised in the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* with the inclusion of rabbits, feral goats, foxes, feral cats, feral pigs and cane toads on the list of key **threatening processes** in Australia. From a range of serious environmental issues, the Environmental Protection Authority has assigned introduced species the highest priority ranking for policy development, management action and investment in the *State of the Environment Report: Western Australia 2007*.[15]

extra information

Socio-economic impacts of introduced animals

While this topic is focused on the management introduced animals for wetland conservation, managing introduced animals can also maintain or improve the economic, social, aesthetic or recreational values of a wetland. The impacts of introduced animals include reduced water quality, vegetation loss, soil disturbance and a loss of biodiversity, which may indirectly contribute to a wetland becoming less attractive for tourism and recreation, and in turn lead to a reduction in economic assets.

Introduced animals using, or living in, a wetland can also impact on surrounding land uses. Camels can seriously damage pastoral and community infrastructure. The great pond snail (*Lymnaea stagnalis*) is a host for liver fluke (*Fasciola* spp.), which is an internal parasite that affects humans and many herbivorous mammals including sheep and cattle. The disease caused by liver fluke, fasciolosis, occurs in humans in some parts of the world. It can also cause severe agricultural production losses and death in livestock. These are but a few of the wide-ranging effects of introduced animals on land uses surrounding wetlands.

Introduced animals may impact a wetland primarily in two ways: by affecting other animals within the wetland, and by affecting the wetland environment itself.

Herbivores: animals that chiefly eat plants

Omnivorous: feeding on both plants and animals

Effects on native fauna

Introduced predators can have devastating effects on the fauna found at a wetland. Introduced animals may directly affect native fauna in a number of ways, the most obvious of these being predation of native fauna. Other impacts include aggressive and competitive behaviour towards native fauna, the spread of diseases, causing behavioural changes in native animals, and hybridising with native fauna. Each of these effects is discussed below in more detail.

Predation

Feral cats and foxes prey on native birds, mammals and reptiles. Feral cats alone have been implicated in the elimination of twenty-three native animal species in Australia.[16] Foxes have also been responsible for the disappearance of many native fauna species and are affecting the survival of many other species of mammals, reptiles and birds.[1,17,18,19,20] In Perth's urban wetlands, foxes have been implicated in the lack of and reduced recruitment of oblong turtles (*Chelodina colliei*) (also known as long-necked or snake-necked turtles) in some urban wetlands. They are known to dig up and eat turtle eggs. Feral cats and foxes are attracted to wetlands by the large numbers of fauna in these areas, particularly when waterbirds are breeding.

The presence of introduced **herbivores** at a wetland may indirectly affect its native fauna. For example, large populations of rabbits and rodents may attract cats and foxes to the wetland, putting native species at risk. Rabbits and rodents are a major component of the diet for both feral cats and foxes.[21,22,23,24]

Pigs are **omnivorous** and consume a wide range of flora as well as fauna.[25] Feral pigs are active predators of native birds, reptiles (including their eggs), frogs and invertebrates within the soil such as earthworms. Other introduced predators include rodents which may prey on eggs, small reptiles and even juvenile birds.[26,27] Eastern gambusia eat insects that prey on mosquito larvae, and so change the composition of the aquatic invertebrate community within a wetland. Eastern gambusia also eat the eggs of native fish. Carp rarely eat other adult fish but do eat fish eggs or larvae. In a laboratory study yabbies were found to prey on and show strongly aggressive behaviour towards tortoise hatchlings.[28] These results suggest yabbies could be harmful to juvenile tortoises and have the potential to pose a serious threat to some tortoise populations and species.

Juvenile and adult cane toads feed on a broad variety of small prey, predominantly ground-dwelling invertebrates. The bulk of the diet is usually ants, beetles and termites, although they can eat anything that fits in their mouth, including a wide variety of insects, frogs, small reptiles, mammals and birds.[29] Cane toads are thought to consume approximately 200 food items per night, far more prey than most native frogs ingest in the same period.

Competition

Introduced animals may compete with native fauna for food, shelter or breeding habitat (Figure 4). They are also often more aggressive and so displace native fauna. Yabbies (*Cherax destructor albidus*) are known to compete with the native marron (*Cherax cainii*) and gilgies (*Cherax quinquecarinatus* and *C. crassimanus*) for shelter in clay substrates. Access to these clay substrates is important for marron as it provides protection from predators and cannibalism.[30,31] Yabbies have been shown to directly compete with *C. cainii* for food resources and are also expected to outcompete native crayfish when present.

Figure 4. Introduced ducks chasing a native pacific black duck (*Anas superciliosa*), affecting the native duck's choice of habitat and access to potential mates. Photo – A Nowicki/DEC.

Some native fauna, such as bilbies (*Macrotis lagotis*), require a constant supply of carbohydrate-rich seeds and roots.[32] If these are all consumed by introduced herbivores then the native fauna are at risk. Feral pigs eat fungal fruit-bodies, which are also eaten by several small mammal species[33,34], including the Gilbert's potoroo (*Potorous gilbertii*) and southern brown bandicoot (*Isoodon obesulus*). In the eastern states, such competition is a particular threat to the endangered long-footed potoroo (*Potorous longipes*), the diet of which is more than 80 per cent fungal fruit-bodies.[34] Introduced fish often compete with native fish. For example, carp compete strongly with other fish and aquatic invertebrates for food and habitat, affecting the diversity and abundance of these fauna in the water.[30]

Competition among animals may involve very aggressive behaviour, resulting in injury or even death. For example, eastern gambusia and tilapia are very aggressive fish and will nip the fins and eyes of native fish. Even if they do not kill the victim, the injuries sustained by native fish may eventually prove fatal due to their weakened state and susceptibility to infection which may affect their ability to find food or avoid predators.

Cane toads are unique as they have a lethal defence mechanism. All stages of the cane toad's life cycle—eggs, tadpoles, toadlets and adult toads—are poisonous.[29] Cane toads have venom-secreting poison glands (known as parotoid glands) or swellings on each shoulder from which poison is released when the toads are threatened.[29] Native predators are not used to frogs being poisonous as no species of native frog in WA has this defence mechanism. Because of this naivety among native fauna, cane toads could devastate the native fauna populations of a wetland.

The red-eared slider (*Trachemys scripta elegans*) is one of the top 100 'World's Worst' invaders as determined by the International Union for the Conservation of Nature and is considered a major threat to biodiversity (Figure 5). It is native to the United States and Central America and is a popular turtle in the pet industry in some countries. Red-eared sliders were brought to Australia in the 1960s and 1970s.[35] Many were released into the wild after owners discovered their aggressive nature and tendency to bite and they are now an invasive pest in several states. In Australia, owning red-eared sliders is banned because of the threat the turtle poses to wildlife. In Australia, they compete with native turtles for food, nesting areas and basking sites; and by eating hatchlings and carrying diseases that can infect native turtles, while in England they have been reported to damage waterbird nests when using them as basking sites.[9] Even at low numbers they have the potential to create large populations; females can live for forty years, laying up to seventy eggs annually.[36] It is likely that red-eared sliders are still being kept illegally as individuals have been found and removed in the Perth region, including at Tomato Lake and Hyde Park, on three occasions in recent times.[37]

Figure 5. The red-eared slider turtle (*Trachemys scripta elegans*) is a serious threat to native fauna in Western Australian wetlands. Photo – P Lambert/DEC.

Disease

Introduced animals may carry diseases, parasites or pathogens to which native fauna are very susceptible. The following examples are just some of the many diseases that may be transmitted by introduced animals.

Cats are known hosts of the parasite *Toxoplasma gondii* which is responsible for the disease toxoplasmosis.[38] Symptoms of toxoplasmosis have been found in more than twenty species of mammals and the disease has been speculated to be a cause of decline of carnivorous marsupials.[39] Toxoplasmosis can also be transmitted to humans. Symptoms include lethargy, poor coordination, blindness and possible death.[40]

Feral cats and foxes are carriers of *Spirometra erinacei*, which causes muscular haemorrhage, damage to soft tissue and may cause death in native fauna.[41] Feral cats are also carriers for the disease sarcosporidiosis which may be transferred to native fauna, livestock and humans.[18] Pigs are potential carriers for many diseases that are transferable to livestock, native fauna and humans, including foot and mouth disease and tuberculosis[25] and hydatids, which has spread to the local western grey kangaroo (*Macropus fuliginosus*) population at Glen Eagles Forest.

Fish that are translocated from other bioregions, states or countries are potentially carriers of diseases and parasites. Some of the more serious fish diseases include epizootic ulcerative syndrome (red spot disease), irodovirus, goldfish ulcer disease, epizootic haematopoietic necrosis (redfin virus or EHNV), viral encephalopathy and retinopathy (nodavirus or VER), and infectious hypodermal and haematopoietic necrosis (in crustaceans). EHNV is a type of iridovirus which has the potential to affect fish, reptiles and amphibians. Fish such as redfin perch, rainbow trout, silver perch, and eastern gambusia are known to be susceptible to EHNV, and it is thought that most native Australian fish are also susceptible. Signs of disease or significant numbers of dead fish in wetlands should be reported to the Department of Fisheries WA, by calling FISHWATCH on 1800 815 507.

Yabbies are also known to carry many diseases and parasites, the most serious and widespread of which is the parasite *Thelohania parastoci*, which causes disease in native crayfish.[40,41,42] Infection by this parasite causes destruction of muscle tissue and reduced movement. This can lead to mortality by reducing the ability of infected crayfish to compete with healthy crayfish and increasing their risk of predation.

Feral animals can also spread disease to domesticated animals. For example, feral horses can carry exotic diseases such as equine influenza and African horse sickness, which are serious threats to domestic horses. They can also carry tick fever, which can infect domestic horses and cattle.[42] The management of feral populations can be of benefit to both conservation and agriculture.

Hybrids: the results of interbreeding between two animals or plants of different species

Grazing: feeding on grasses and other low-growing herbaceous vegetation

Browsing: feeding on leaves, twigs or bark from non-herbaceous (woody) plants, such as trees and shrubs

Behavioural changes

Just the presence of some introduced animals, particularly predators, at a wetland may influence the well-being of native fauna by changing their behaviour. Activities such as foraging for food or seeking mates generally make an animal more prone to predation or aggression from other species. If native fauna can detect (for example, through smell) their predators such as feral cats or foxes, they might change where and how often they eat, what time of the day they are active, or with whom they choose to mate.[62,63,64,65] Such changes to an animal's behaviour can mean that it doesn't get the optimal food or habitat and that it uses too much energy which, ultimately, can affect its health, reproductive success and chances of survival.

Hybridisation

Some introduced animals are able to interbreed with native animals to produce **hybrids**. Large-scale hybridisation reduces the genetic integrity of the species being hybridised and may eventually result in the pure form of the species becoming extinct.

This may one day be the fate of dingoes (*Canis lupus dingo*), which are relatively rare in their pure form, as most have hybridised with domestic dogs. Predation and hybridisation by wild dogs has been listed as a key threatening process in New South Wales.[43] Domestic waterfowl may also breed with native waterfowl. For example, introduced mallard ducks (*Anas platyrhynchos*) can interbreed with native pacific black ducks to produce fertile hybrid offspring, which can go on to produce more hybrids.[44]

Effects on the environment

Changes to the environment will often indirectly affect the fauna that live at, or visit, a wetland by changing the habitat available or limiting food resources.

Vegetation loss

Many introduced animals are herbivores that remove plants, including below-ground plant parts. Herbivores remove the leaves from plants and sometimes uproot the whole plant. Continual **grazing** or **browsing** can reduce native plant diversity, structural complexity of vegetation and degrade wetland habitats. Camels, for example, are voracious herbivores; they can browse 80 per cent of arid land plant species (Figure 6).

Figure 6. Camels at a wetland in the Rudall River area of the Pilbara. Camels have serious detrimental effects to wetlands in arid to semi-arid areas of Western Australia. Photo – B Ward/DEC.

As introduced animals often prefer to eat fresh growth, continual grazing and browsing can limit the growth and spread of new plants. Introduced animals may also trample plants in and around wetlands causing damage to, or removal of, the plants. In droughts, large herds of over one hundred camels may congregate on available water. This causes overgrazing, trampling, pugging and fouling of wetlands. Feral livestock may also strip bark off trees or rub up against trees, causing tree death by ringbarking. This is true of male feral deer, which can severely damage trees when rutting. In the eastern states, deer have had major impacts on endangered freshwater wetland communities.

The removal of plants by heavy grazing or browsing can mean that there is less food, shelter and reproductive habitat available for native animals. The loss of native vegetation may also allow weeds to establish, reduce biodiversity, and may lead to soil **erosion** and water quality problems through increased run-off.

Erosion: the gradual wearing away and movement of land surface materials (especially rocks, sediments, and soils) by the action of water, wind, or a glacier

Propagule: any part of a plant from which a new plant can grow, including seeds, bulbs and rootstocks

Pugging: depressions, hoof prints or 'pug' marks made in wet soil by trampling animals

Turbid: the cloudy appearance of water due to suspended material

Sedimentation: the process by which soil particles (sand, clay, silt, pebbles and organic materials) suspended in water are deposited or settle to the bottom of a water column.

Turbidity: the extent to which light is scattered and reflected by particles suspended or dissolved in the water column.

Weed dispersal

Introduced animals are often highly mobile and may bring weed **propagules** to a wetland. Disturbance of habitats caused by introduced animals may also facilitate the invasion and spread of weeds.[34] The introduction and spread of weeds at a wetland can affect the composition of plant communities, thereby reducing the available habitat for native fauna. Weeds can also increase the threat of fire at a wetland by increasing the fuel load.

➤ For additional detail on the impacts and management of weeds, see the topic 'Wetland weeds' in Chapter 3.

Spread of pathogens and viruses

As well as weeds, introduced animals may spread pathogens such as *Phytophthora cinnamomi*, a microscopic soil-borne organism belonging to the water moulds. This introduced organism is responsible for the decline and death of native vegetation, known as Phytophthora dieback. For example, there is evidence that feral pigs can carry *P. cinnamomi* on their hooves[45], and that the spread of the pathogen can be associated with soil disturbance and reduction of litter cover by pigs.[46] Furthermore, chewing and other damage to tree trunks may facilitate infection of vegetation by the fungus and other diseases.[34] The typically omnivorous diet of pigs also leads to the passage of *P. cinnamomi* infected plant material through their digestive system, providing an additional means of spreading the pathogen among native vegetation.[47]

➤ For additional detail, see the topic 'Phytophthora dieback' in Chapter 3.

It is thought that introduced aphids are the source of an introduced virus, the bean yellow mosaic virus, which is decimating an aquatic herb species in the Swan River in Perth. Water ribbon (*Triglochin* sp.) was once common along the river foreshore and played an important ecological role by filtering nitrates and phosphates from the river. It is now restricted to a few isolated pockets near Guildford.[48]

Soil disturbance

Introduced animals may cause land degradation by disturbing the soil at a wetland. Soil compaction or erosion is often a consequence of overgrazing by introduced animals or direct damage from **pugging**, rooting, digging, burrowing or wallowing. These actions can have major impacts on flora and leaf litter, particularly after rain when the ground is softer.[34]

Soil disturbing activities are particularly a problem at wetlands. Feral pigs wallow in mud during hot weather, causing significant damage to wetlands. Such actions can create **turbid** conditions and/or **sedimentation** of the water.[34] Muddy water with a high **turbidity** allows less light to penetrate the water to plants and algae, which causes reduced plant growth or plant death. As sediments begin to settle, they smother animals living on the bottom by clogging their gills and causing problems for filter-feeders; coat organic deposits and algae upon which aquatic animals depend for food and cover; and fill in aquatic habitats.[49,50]

Eutrophication: the nutrient enrichment of a water body, which can trigger prolific growth of plant material (phytoplankton, macrophytes or both). May occur naturally over geologic time or may be human-induced

Water quality decline

As mentioned above, introduced animals can affect the water quality of a wetland by impacting on wetland soils and vegetation. In addition to this, introduced animals affect the water quality of a wetland by defecating and urinating in or near the wetland.[34] Even animals that mostly live terrestrially and only visit wetlands, such as cats, foxes or pigs, will congregate around water points and are likely to foul the water with their wastes. Such activities may have a number of flow-on effects such as changed nutrient levels, leading to **eutrophication** of the wetland and algal blooms.

Eutrophication of a water body may lead to nuisance midge and mosquito problems. The management of these nuisance fauna may further affect the water quality of a wetland. For example, some poisons used at wetlands as a method of controlling nuisance mosquitoes and midges have the potential to pollute to the water and cause harm to other fauna.

➤ For additional detail on management of mosquitoes and midges see topic ‘Nuisance midges and mosquitoes’ in Chapter 3.

The presence of introduced animals at a wetland may lead to soil disturbance that may lead to an increase in the turbidity of the water in a wetland. Carp and goldfish vigorously stir up sediment while feeding, which can change the suitability of the wetland for other species as well as potentially releasing phosphorus locked in the sediments.[51]

➤ For additional detail on the impacts of poor water quality and its management see the topic ‘Water quality’ in Chapter 3.

Goldfish (*Carassius auratus*) have also been found to stimulate the growth of some toxic cyanobacteria species that pass through their gut, such as *Microcystis aeruginosa*.[52] Under the right conditions species such as *Microcystis* can form blooms which can cause significant ecological impacts in wetlands. An increase in cyanobacteria can in turn provide goldfish with an abundant food source, creating the potential for an ongoing cycle of ecological impacts. Researchers found this to be an issue of significant concern for the Vasse River in the south-west of WA.[53]

Who is repsonsible for managing introduced and nuisance animals?

At the private property level, landowners and/or managers are responsible for introduced animal damage control (that is, damage to agricultural products such as crops, and to infrastructure such as fences and water points). If declared pests of agriculture are present on private property, landowners are compelled to control the species under the *Agriculture and Related Resources Protection Act 1976*. There are some exceptions to this, which relate to the control of native fauna species. Native fauna species can only be controlled if DEC approves control via a licence, an open season or declares a species’ status to be ‘unprotected’ (Table 2 provides more information about this).

While individual landowners have this responsibility, animals generally do not restrict their movements to property boundaries and so effective management of introduced animals usually involves cooperation between landholders, community groups, councils and regional management authorities.

Landowner assistance

Private landholders can receive assistance with introduced animal management activities from a range of government and non-government programs.

For example, DEC's *Healthy Wetland Habitats* program: eligible landowners on the Swan Coastal Plain can receive funding to manage introduced species. For more information telephone the *Healthy Wetland Habitats* program coordinator on (08) 9334 0333.

➤ For more information on various programs that provide landowners with assistance, see the topic 'Funding, training and resources' in Chapter 1.

Community initiatives

The community is at the forefront of a range of on-ground management initiatives. The 'Red Card for the Red Fox' program is one such initiative that was started in 2003 by two community landcare groups working together, but has steadily developed into a statewide program and attracted funding and technical support from regional natural resource management organisations and government. In 2009, 5,000 foxes, 2,500 rabbits and 230 feral cats were shot as part of this program.[54]

Another successful community-initiated program, the Lake Muir/Denbarker Community Feral Pig Eradication Group, is the subject of a case study entitled 'Fighting feral pigs on the South Coast' presented later in this topic.

State government programs

Various Western Australian government agencies coordinate and participate in on-ground control, regulation, research and monitoring of introduced species.

The WA Department of Agriculture and Food (DAFWA) coordinates the management, control and prevention of introduced species; the prohibition and regulation of the introduction, spread and keeping of certain plants and animals for the protection of agriculture and related resources generally. DAFWA coordinates surveillance and research into vertebrate animal pests and regulates the introduction and spread of introduced species via the *Biosecurity and Agriculture Management Act 2007*. It operates the Pest and Diseases Information Service, which provides information on pests and diseases that affect community and industry well-being in WA, and provides advice on options for control of introduced species. It can provide information on when a licence is required, procedures to follow to obtain licences and the conditions that need to be adhered to when undertaking control activities.

The Department of Fisheries is responsible for controlling the introduction and spread of introduced fish and crayfish, and regulating fishing and fish stocking of state water bodies. It maintains the noxious fish species list and operates the FISHWATCH Service, which is responsible for receiving reports of sightings of freshwater pest species, including introduced freshwater crustaceans. It should be used to notify the Department of Fisheries of mass fill kills as well as reporting illegal fishing activity.

DEC protects and regulates interactions with Western Australian fauna, including fauna surveys and control of nuisance populations of native fauna under the *Wildlife Conservation Act 1950*. DEC manages the *Western Shield* program, which is the world's largest introduced predator control and biodiversity conservation program. *Western Shield* involves 1080 baiting of about 3.5 million hectares in the south-west of WA, allowing native fauna to be reintroduced to their former range. So far, the program has been successful in bringing at least thirteen native species back from the brink of extinction.[15] The State Cane Toad Initiative is also run by the department.

There is limited strategic monitoring of invasive species by state government departments across the state's large geographic area. DAFWA has recently published a monitoring framework for ecologically significant invasive species for natural resource management groups in WA.[55]

Although the control of introduced animals is not currently coordinated nationally, a number of national programs are in place.[56] Two of the national organisations dealing with pest animal control are the Vertebrate Pests Committee and the National Introduced Animal Control Program. The Invasive Animals Cooperative Research Centre was also formed in 2005 and combines the collective knowledge of forty-three research, industry, environmental, commercial and government organisations.

What are the legal requirements for managing introduced and nuisance animals?

Ethical treatment of animals

All introduced and nuisance animal control programs in WA must consider the ethical treatment of animals. Their treatment is governed by the *Animal Welfare Act 2002*, which prohibits cruelty to, and other inhumane or improper treatment of animals. Control and euthanasia are to be conducted humanely and legally, be target specific, and cause no suffering to target or non-target fauna. In order to achieve this, the people undertaking these activities must be competent and, where necessary, licensed to do so.

Industry best practice standards

Adhering to codes of conduct and standard operating procedures ensures that activities are humane, legal and in accordance with best practice standards.

Codes of conduct and standard operating procedures

Code of practice for the capture and marketing of feral animals in Western Australia, Department of Local Government and Regional Development (2003).[57]

A large number of codes of conduct and standard operating procedures for the humane capture, handling or destruction of introduced animals in Australia are available from Department of Sustainability, Environment, Water, Population and Communities website (www.environment.gov.au).[58]

DEC's standard operating procedures for monitoring (which includes trapping that may be extended to control operations) are available from the DEC website (www.dec.wa.gov.au).[59]

Permits, licences and laws relevant to animal control

Most introduced and nuisance animal management activities require authorisation, generally in the form of a permit, licence or exemption. Table 2 below provides a guide to the most common permits and licences. Table 3 lists other relevant laws which must be observed when undertaking animal management activities.

Table 2. A guide to some of the permits and licences required for a range of introduced and nuisance animal management activities

Note 1: in addition to the below, individuals must be authorised to enter any property at which activities are to be conducted.

Note 2: this information may change over time. It is important to keep up to date with legal requirements associated with introduced animal management activities.

Activity	Permit/license/approval required	Regulating authority	Legislation	For more information
Native fauna licence surveys (including macroinvertebrates)	A licence is required under Regulation 17, 'Licence to take fauna for scientific purposes'. It is referred to as a 'Regulation 17' licence.	Department of Environment and Conservation	*Wildlife Conservation Act 1950*	Application for licence to take fauna for scientific purposes[60]
	A 'Scientific exemption' permit is required under Regulation 178 to take some freshwater species including fish and crayfish for scientific purposes.	Department of Fisheries	*Fish Resources Management Act 1994*; Fish Resources Management Regulations 1995	Contact the Department of Fisheries
Culling of native species for conservation purposes (e.g. kangaroos, Australian white ibis)	A licence is required under Regulation 15, 'Licence to take fauna for educational or public purposes'. It is referred to as a 'Regulation 15' licence. This licence is not required when a species is unprotected by virtue of an open season or restricted open season notice.	Department of Environment and Conservation	*Wildlife Conservation Act 1950*; Wildlife Conservation Regulations 1970	Application for a Regulation 15 licence – to take fauna for education or public purposes (fauna relocations and/or education)[60]
Use of traps for land-based non-native species	A permit is required to use any type of trap or snare in some metropolitan and outer metropolitan areas. The permit is requested via an 'Application to Trap Declared Animals'. Individual local government authorities may also have requirements.	Department of Agriculture and Food	*Agriculture and Related Resources Act 1976*; Agriculture and Related Resources Protection (Traps) Regulations 1982	Contact the Department of Agriculture and Food
Use of bird traps	A licence is required under Regulation 11, 'Licence to take avian fauna for sale'. It is referred to as a 'Regulation 11' licence.	Department of Environment and Conservation	*Wildlife Conservation Act 1950*; Wildlife Conservation Regulations 1970	Refer to the Fauna licensing page of DEC's website[60]
Use of firearm	A licence from the Western Australian Police is required to possess, carry and lawfully use a firearm.	Western Australia Police	*Firearms Act 1973*	www.police.wa.gov.au[61]

Activity	Permit/license/approval required	Regulating authority	Legislation	For more information
Use of pesticides (including 1080, fumigants and rotenone)	All instructions on the label of the pesticide container regarding the safe use, storage and disposal of registered products must be followed.	Department of Health	*Health Act 1911*; Health (Pesticides) Regulations 1956	
	A 'Minor Use' or 'Emergency' Permit is required to use a pesticide on a species not identified on the label or in situations not stated on the label.	Australian Pesticides and Veterinary Medicines Authority	*Agricultural and Veterinary Chemicals Code Act 1994*	www.apvma.gov.au/publications /fact_sheets/docs/permits.pdf www.apvma.gov.au/permits
	1080: Trained landholders and land managers can purchase bait products containing 1080 once baiting approval has been obtained through a formal process from the. Only trained and licensed personnel can prepare and mix baits.	Department of Agriculture and Food	*Agriculture and Related Resources Act 1976*	Landholder information for the safe use and management of 1080[62]
Removal of introduced freshwater species of fish and crustaceans from wetlands	An exemption, approval or authority for the purpose of 'fish stock depletion or enhancement' is required under Section 7 of the Act. Alternatively, the department may deem that a recreational fishing licence is required. It is a contravention of the Act to be in possession of most fishing equipment at wetlands in the state without an exemption from the CEO of the Department of Fisheries. Section 104 of the Act specifies that noxious fish listed in Schedule 5 of the Regulations must not be kept in a person's possession or be allowed to remain alive.	Department of Fisheries	*Fish Resources Management Act 1994*; Fish Resources Management Regulations 1995	Contact the Department of Fisheries Recreational fishing: refer to the most current recreational fishing guide on freshwater angling for the bioregion from www.fish.wa.gov.au
Relocation, introduction or reintroduction of freshwater species of fish and crayfish	An exemption is required under Section 7 of the Act for scientific research, fish stock depletion or enhancement; or the collection, keeping, breeding, hatching or culturing of rare and endangered fish. Written authority is required under regulation 176 of the Regulations to bring into the state, or a particular area of the state (i.e. translocate from another area or bioregion), a live fish of a species not endemic to the state or area of the state.	Department of Fisheries	*Fish Resources Management Act 1994*; Fish Resources Management Regulations 1995	
	A 'Regulation 15' licence is needed to move native species.	Department of Environment and Conservation	*Wildlife Conservation Act 1950*	
Shockwaves	A valid Shotfiring permit is required to employ shockwaves. Only fully trained, accredited and licensed operators can carry out this procedure. It is the responsibility of the shotfirer to ensure that all operations undertaken are compliant.	Department of Minerals and Petroleum Resources	*Explosives and Dangerous Goods Act 1961*; Western Australian Explosives Regulations 1963	Department of Minerals and Petroleum Resources

Table 3. General requirements when undertaking animal management activities

Activity	Requirement	Regulating authority	Legislation
All animal management activities	Humane and proper treatment of animals.	Department of Local Government and Regional Development	*Animal Welfare Act 2002*
All activities being undertaken by an employee	Requires employers to identify potential hazards and to develop strategies to minimise the risk of injury or disease. Requires employees to ensure their own safety by following instructions and correctly using any safety equipment provided.	Department of Consumer and Employment Protection, WorkSafe	*Occupational Safety and Health Act 1984*; Occupational Safety and Health Regulations 1996
Activities which, if implemented, are likely to have a significant effect on the environment	Referral of thse proposals to the Environmental Protection Authority.	Environmental Protection Authority	*Environmental Protection Act 1986*
Noise due to shooting	Noise associated with the use of firearms.	Department of Environment and Conservation	Environmental Protection (Noise) Regulations 1997
Removal of non-native species from DEC-managed land	Authority from DEC is required under Regulation 18.	Department of Environment and Conservation	Conservation and Land Management Regulations 2002

How to manage introduced and nuisance animals

There are two main strategies for the management of introduced animals in wetlands:

1. prevention, typically using barriers such as fences, screens and nets to prevent access to a wetland
2. control, using one or more methods, to either reduce the population size or eradicate the population.

As with any threat to a wetland, the best management strategy is to avoid it in the first place. However, if introduced animals become established at a wetland, the best thing to do is to remove those animals. Complete removal of a population of a particular introduced animal may not always be feasible. In this case, population control may still be an option to reduce the introduced animal population to low numbers. Both activities need to be complemented with prevention methods to prevent new or additional individuals from reaching the wetland.

Prevention strategies are particularly relevant for introduced animals for which there are currently no approved control methods available. Introduced aquatic snails, brine shrimp, blackworm and naidid worms cannot be removed from a wetland once established (C Francis 2009, pers. comm.). However, the impact of these species on wetlands is generally limited and so removal of these introduced animals may not be the highest priority.

The decision to undertake management at a wetland should only be made after a management planning process has been completed and a management plan prepared, however basic it may be. Undertaking a management planning process will involve examining all of the threats at a site and assessing which of these is a priority for management. For example, if altered hydrology and introduced animals such as cats are issues at a wetland, it may be determined that managing altered hydrology is a high priority issue and until this is addressed no action will be taken to manage the introduced animals.

➤ For guidance on wetland management planning, see the topic 'Wetland management planning' in Chapter 1.

Any management of introduced animals at a wetland, be it prevention or control, requires an integrated approach. Animals generally do not restrict their movements to property boundaries and so effective management of introduced animals will often involve cooperation between landholders, community groups, councils and regional management authorities.

Considerations when selecting management techniques

When choosing a method to control a population of introduced animals, some key requirements should be considered. It must be:

- Legal: relevant legal approvals, licences and permits should be obtained and conditions of the licence or approvals understood before any management action is undertaken.
- Informed: make sure that the target species is not, in fact, a similar-looking native species.
- Without, or at an acceptable level, of adverse side effects: the environment and native animals should not be adversely affected.
- Feasible in the long term: that is, it will actually stabilise or reduce numbers over long periods. It is common for people to discover that the required frequency and duration of the control activity (for example, baiting or trapping) is often much greater than anticipated.
- Part of the bigger picture: working to control a species at a site is often futile if they are not being controlled in adjacent areas. Coordinated action at a broad scale is usually most effective.
- Undertaken with an awareness of consequences: it is common for the removal of one introduced species to cause another introduced species to increase in numbers (for example, numbers of cats often increase when fox numbers are controlled). A well-planned strategy will address this.
- Cost-effective: management should be economical in terms of the values or benefits gained in return for the money spent.
- Humane: the animals themselves should not suffer and violence should be avoided.
- Internationally acceptable: that is, the management method adopted should not affect the same or similar species in other countries. This is especially true of any immunocontraceptive (sterilisation-causing) organism that is spread by a carrier.

Quick guide to the prevention and control options by animal

Table 4. Summary of key management options by animal

Note 1: preventative actions such as wetland restoration, community education, awareness and legal avenues are applicable to all introduced animals and as such are not addressed in the table.

Note 2: as there are no approved/effective control measures available for introduced aquatic snails, brine shrimp, blackworm and naidid worms, these are not addressed in the table.

	Prevention	**Control**						
Animal	**Barriers (page 24)**	**Trapping (page 26)**	**Shooting (page 36)**	**Poisoning (page 37)**	**Fumigating (page 40)**	**Shockwaves, electrofishing (page 41)**	**Manipulating habitat and food (page 42)**	**Removing manually (page 44)**
Domestic waterfowl		•	•					
Australian white ibis			•				•	
Cane toad		•						•
Red-eared slider turtle		•	•					•
Introduced fish	•	•		•		•	•	•
Introduced crayfish		•					•	
Cat	•	•	•	•				
Red fox	•	•	•	•	•		•	
Domestic dog	•	•	•	•				
Kangaroo	•		•					
Deer	•		•					
Camel	•	•	•					
Horse	•	•	•					
Donkey	•	•	•					
Goat	•	•	•					
Pig	•	•	•	•				
Rabbit	•	•	•	•	•		•	
Rodents		•		•				

Prevention

Prevention is the most important and effective strategy in managing introduced animals, as controlling introduced species is often difficult, if at all possible. Prevention of the establishment of introduced animals at a wetland includes:

- maintaining or restoring wetlands
- community awareness and education
- legislation
- physical barriers.

These preventative measures should be combined with surveillance activities. Depending on the risk of introduced species and the threats they pose to the wetland, the level of surveillance may range from casual observation to comprehensive surveys.

➤ For guidance on wetland monitoring, see the topic 'Wetland monitoring' in Chapter 4.

Maintaining and restoring wetlands

The conditions within modified and degraded wetlands can favour the establishment and domination of some introduced species. For example, some degraded wetland habitats can be more favourable for introduced fish such as the eastern gambusia (*Gambusia holbrooki)* than native species.[63] Maintaining or restoring the natural ecosystem may help prevent such species from establishing or out-competing the native species.

Community awareness and education

Many of Australia's introduced animals were introduced by humans, either directly or indirectly through domestic or livestock 'escapes'. Community awareness and education provide valuable tools for the prevention of further introductions. Education and awareness-raising programs may be aimed at preventing new introductions or encouraging community members to monitor for new invasions. The public may be informed not to release pets (particularly aquarium fish or rabbits) and to ensure pet cats and dogs are sterilised, kept on a lead at all times while outdoors and don't roam freely through wetlands. The public should also be aware of the impacts of deliberately releasing animals such as pigs or fish for hunting and recreational purposes.

There are many tools available to raise the level of community awareness and education. The print, broadcast and internet media can be powerful allies in educating the public on environmental matters. Awareness-raising campaigns are often most successful when they are targeted at specific groups because information can be tailored to the activities, needs and challenges of the group. A good example of an online resource targeted at educating young people is 'Aquatic Invaders', developed by the Queensland Fisheries Service as an education module available online[64] for teachers of upper primary and lower secondary students.

There is much scope for involvement of children and youth in introduced animal monitoring and management. Young people comprise nearly 30 per cent of the global population and will be the decision-makers of the future.[65] Their way of thinking about the environment is already shaping the world of tomorrow and, just as importantly, can shape the views of their parents. Therefore, it is important that community education and awareness of managing introduced animals at wetlands is inclusive of a range of age groups and is extended to all demographic groups. A good example of a hands-on education campaign targeted at high school students is presented in the case study 'Restocking native fish in Masons Gardens Lake, Dalkeith' at the end of this topic.

Activities aimed at raising community awareness may be as simple as installing signs at a wetland informing the public of the impacts of introduced animals. Alternatively, printed material with information on the effects of released and abandoned pets on the environment could be provided to local pet shops for distribution to customers. Collaboration could also be gained from pet shop owners by asking them to commit to accept any unwanted pets as an alternative to 'releasing' them. The Perth Cichlid Society (www.perthcichlid.com.au) offers to take care of any unwanted fish and provides a list of local fish stores that have agreed to accept unwanted fish.

Raising awareness of the issues and management methods relating to introduced animals in wetlands can encourage greater community participation in management actions as well as prevention. Involving organisations and communities in introduced animal management can create a sense of stewardship towards the wetland, ease hardship through collaboration, and provide a forum for new ideas and greater participation.

Communities can be involved in all aspects of managing introduced animals within a wetland. For example, eastern gambusia were discovered by Waterwatch volunteers in Ilparpa Swamp south of Alice Springs in 2000. This discovery allowed the volunteers to quickly remove the eastern gambusia from the wetland before they became a problem.[66]

Endemic: naturally occurring only in a restricted geographic area

Since then, Waterwatch has been educating the community about the impacts of releasing pet fish into waterways and wetlands. The local community continues to be vigilant for new incursions of eastern gambusia. This example shows the importance of ensuring members of the public are capable of correctly identifying introduced animals, even if they have not occurred in the area previously. It also reiterates the value of creating a sense of 'ownership' of a wetland.

Legislation

There are a number of legal avenues available to prevent introduced animals from becoming established at a wetland. These range from legislation at the state government level, through to local government authority laws, and privately enforced regulations within residential developments.

State legislation

At present the key legislation for preventing the introduction and spread of certain animal species is the *Agriculture and Related Resources Act 1976* (ARRP Act), which is administered by DAFWA. The Act provides for the management, control and prevention of certain animals, for the protection of agriculture and related resources generally. In particular, it categorises a range of introduced animals, known as 'declared animals', into one of six possible categories, each with a corresponding requirement of management, control or prevention.

➤ The list of declared animals is available on DAFWA's website (www.agric.wa.gov.au).[67]

The AARP Act is one of seventeen existing Acts that will be replaced by the *Biosecurity and Agriculture Management Act 2007* (BAM Act). While the BAM Act has been enacted, its regulations and other subsidiary regulatory instruments are not yet in place. One of the main purposes of the BAM Act is to prevent new animal and plant pests and diseases from entering WA, and to manage the impact and limit the spread of those already present in the state. The application of the BAM Act covers biosecurity threats to agricultural activities, as well as threats to the environment, to public safety and amenity, to fishing and pearling activities, and to commercial activities related to agriculture, fishing and pearling.

Controls on the introduction and spread of introduced fish and crayfish are governed by the Fish Resources Management Regulations 1995, which is administered by the Department of Fisheries. Under Regulation 176 of the regulations it is illegal to introduce any fish into a site where the species is not **endemic** without the written authority of the Chief Executive Officer of the Department of Fisheries. Translocation of non-endemic fish without written authority may incur a significant penalty. Fish listed as noxious must not be kept in a person's possession and cannot be released, relocated or kept alive. If caught they must be destroyed.

➤ The list of fish species that are restricted for importation and spread (the 'noxious fish' list) is available from the Department of Fisheries website (www.fish.wa.gov.au).[68]

In 2009, the state government proposed the introduction of statewide cat control legislation to assist in reducing the number of unwanted cats in WA. In mid-2010 the Department of Local Government initiated public consultation on a domestic cat act.[69] This follows on from the disallowance of the City of Joondalup's *Cats Local Law 2008* by the Legislative Council in 2009 on the basis that some of the law's provisions should be applied on a statewide level rather than be isolated to a single local government area, notably in relation to the compulsory sterilisation of cats.[70]

Local government controls

At the local government level, some legal restrictions can be placed on domestic animal owners to register and identify their pets (using tags or microchips), limit the number of certain animals per household, prevent the release of these animals and reduce the impacts of straying animals.

Local governments can use one or more mechanisms at their disposal to place restrictions on domestic animals near environmentally sensitive areas. Local laws can be instated. For example, 'cat prohibited areas' are designated under the *Keeping and Control of Cats Local Law 1999* within the City of Stirling. Wetlands identified as cat prohibited areas include Star Swamp, Carine Swamp, Lake Gwelup, Herdsman Lake and Jackadder Lake (Figure 7).

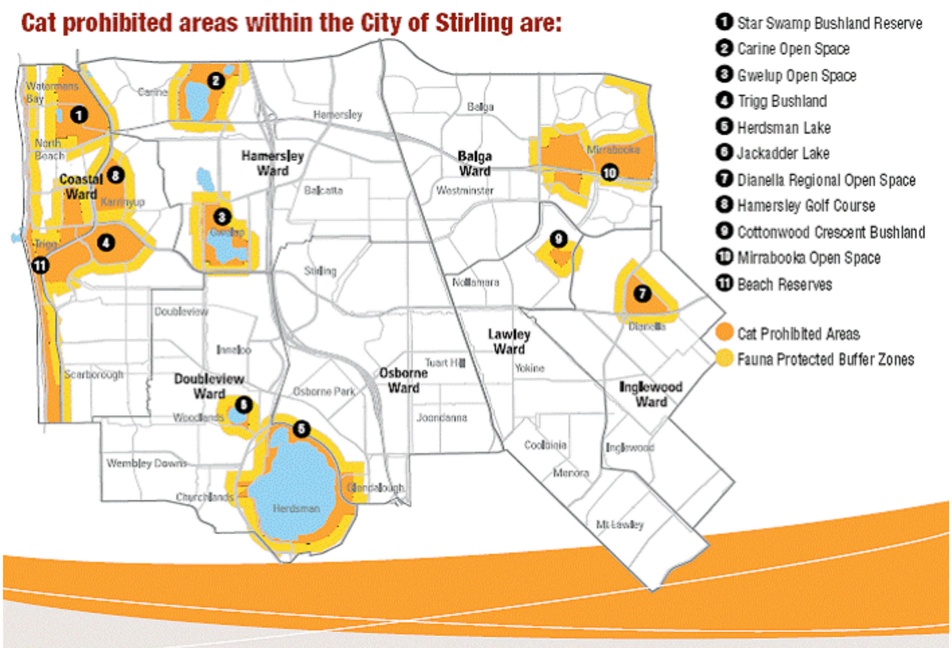

Figure 7. Cat prohibited areas in the City of Stirling.[71] Image courtesy of the City of Stirling.

Alternatively, controls within local planning schemes may be used. For example, a number of areas within the City of Albany are zoned as 'conservation zone' in the City of Albany *Town Planning Scheme No. 3*. Cats and rabbits may not be kept within these areas on the basis that they pose a threat to native flora and fauna.

Many local councils currently encourage voluntary sterilisation of pet cats and dogs by offering subsidies for the procedure.

Private residential developers may place a restrictive covenant on their land that places restrictions on keeping animals. Churchman Book Estate, within the City of Armadale, has prohibited the keeping of cats on the land. This covenant has been put in place to prevent pet cats from roaming and hunting wildlife in the nearby Armadale Settlers Common, an environmentally sensitive area. However, restrictive covenants generally have an 'expiration date' after which time the restrictions lapse.

While creating and implementing legislation may be beyond the scope of wetland managers, they may lobby local and state government for the establishment of laws regulating key problem species. Introduced animals may be controlled by limiting their movement, restricting ownership and by requiring sterilisation.

Physical barriers

An effective way to prevent introduced animals from damaging a wetland is to prevent them from entering altogether. Constructing physical barriers is often the simplest and most effective way to combat introduced animals. Of course, barriers are only effective if they serve to keep introduced animals out, not in. If breached, barriers may actually increase the risk of vulnerability of endangered fauna species by preventing their escape from the predator. If introduced animals are found within the confines of a barrier, it may be necessary to remove them using the methods discussed later in this topic. Continual monitoring for new incursions is essential.

A range of barriers is available, including fencing, screens and netting, depending on the animal being targeted. Fencing is the most commonly utilised type of barrier.

Fencing

There is a myriad of fence designs available for use in excluding introduced animals. The type of fence chosen will depend on the type of animal to be excluded. It is generally understood that no fence will be 100 per cent effective all of the time. Electric wires may be used to improve the effectiveness of this barrier but are rarely a successful deterrent on their own. Fences may be damaged by large animals or by falling vegetation and so monitoring, maintenance and repair of the fencing will be required. The base and corners of a fence, as well as gates and waterway crossings, are often the weak points of a fence that will be exploited by introduced animals. Special attention should be paid to ensure these features are maintained and are functional. The high costs of establishing and maintaining some types of exclusion fencing, such as feral cat-proof enclosures, generally limit their use to the management of threatened or endangered species, such as the protection of the endangered western swamp tortoises (*Pseudemydura umbrina*) at Twin Swamps and Ellen Brook nature reserves in Bullsbrook and Upper Swan respectively.

➤ For more information on the types of fencing that can be used to exclude foxes and feral cats, rabbits, goats, pigs and wild dogs, see the *Catalogue of fence designs* available on the Department of Sustainability, Environment, Water, Population and Communities website.[72]

➤ For more information on fencing suitable for camels, see *Camel control using alternative fencing* available on the Northern Territory government website.[73]

A fence should provide an effective physical barrier to the targeted introduced animals while minimising detrimental effects on the native fauna of the area. Generally the fence should be placed at a distance from the wetland. This will allow native fauna to use both the wetland and adjacent dryland if required. For example, female oblong turtles (*Chelodina colliei*) can lay their eggs at some distance from wetlands (the distance varies). If the fence is placed too close to the wetland, they may die from dehydration or predation while persisting in their efforts to get past the fence to their intended nesting site.[74] Similarly, if fences are too close to the wetlands, they may be within the flight path of large birds, increasing their risk of entanglement.

Fencing can alter or restrict the movement of native fauna in and out of a wetland, alter their dispersion and foraging patterns, and cause entanglement and electrocution. It can also create a significant hazard to wildlife in the event of a bushfire.[75] Mesh, barbed, plain and electric wire fences have caused injuries and deaths of bats, kangaroos, wallabies, small mammals, waterbirds, birds of prey and owls. Wetland fences can pose a higher risk of entanglement or injury when they are new, where they cross animal flight paths and tracks into a wetland and where they are less visible at the boundary between low pasture and taller native vegetation. The top and bottom wires are where animals most often come in contact with the fence, with small animals such as echidnas and snakes being killed by electrified wires close to the ground. These problems can be minimised by choosing a fence type and location that increases fence visibility and by installing native animal access ways, such as gates. In areas where entanglement is a problem, fence visibility can be increased by attaching metal tags, old CDs, tin cans or aluminium pie dishes to the top two wires.

➤ For more information on ways to reduce the impact of fences on native species, see *Wildlife Friendly Fencing Guidelines*[76] and DEC Fauna Note 32 *Fencing and gates to reduce kangaroo damage.*[77]

Screens and nets

Where a waterway (such as a creek, stream or river) or drain flows into a wetland, barriers in the form of large screens or mosquito nets may be fitted to prevent the movement of introduced fish. Screens and netting may also not be effective for juveniles or eggs as these will still pass through the barrier. Sometimes, such barriers may be teamed with traps to remove introduced fish from a waterway (see the section 'Fish traps' for more information). A number of screens are currently available such as vertical travelling screens that remove debris whilst preventing passage of a range of fish sizes. These options are currently being assessed to control downstream colonisation of the pearl cichlid from wetlands on Bennett Brook and Ellen Brook (S. Beatty pers. comm.).

Control

It is very difficult to completely prevent introduced animals from entering a wetland, particularly if they are terrestrial or highly mobile. In some situations, the most feasible option may be to carefully monitor the wetland and promptly remove any new intruders before the introduced animals have a chance to start reproducing and to become established. Therefore, a key component in preventing the establishment of introduced animals at a wetland is appropriate surveillance. Wetlands should be observed for signs of newly occurring introduced animals as often as possible, whether it be on a casual or opportunistic basis, or as part of a dedicated monitoring program.

➤ For information on designing a monitoring program, see the topic 'Monitoring wetlands' in Chapter 4.

Once an introduced animal has become established at a wetland, and is having an impact either on the wetland itself or on the native animals that reside there, the best course of action is to remove the animal in question from the wetland. Introduced animals may be controlled by:

- trapping
- shooting
- poisoning
- fumigating
- using shockwaves
- electrofishing
- manipulating habitat or food
- removing the animals manually
- using fertility control.

The choice of the best method of removal will depend on the animal itself as well as factors such as the environment in which they are found (for example, open or closed vegetation) or population size. In some cases, such as the control of rabbits, a combination of removal methods may be necessary. The eradication or removal of introduced animals may not always be possible; for example, there is no approved method of removing introduced aquatic invertebrates such as brine shrimp. This reaffirms the importance of prevention when managing wetlands for introduced animals.

In some scenarios, the control options available may be more environmentally damaging than the introduced species being controlled. This can be the case where non-target impacts of the control method are high even when carried out by a professional, for example, the use of some pesticides, the creation of shockwaves at some wetlands and the removal of some habitats. A proposed control activity which, if implemented, is likely to have a significant impact on the environment, requires referral to the Environmental Protection Authority, in accordance with the *Environmental Protection Act 1986*. A careful risk analysis should always be undertaken, considering the following:

- What are the values under threat from the introduced species?
- What are the potential off-target impacts to the wetland of each relevant form of control? How can the potential off-target impacts be minimised?
- Do the potential off-target impacts outweigh the benefits of control of the introduced species?

Many of the control options also require forethought regarding the handling and disposal of carcasses. Carcasses should never be buried within or close to wetlands, other aquatic environments or drinking water catchments due to the risk of contaminating the water, nor close to roads due to the road safety risks posed.

Nocturnal: primarily active during the night

Trapping

Trapping may be used to control most introduced animals but can be time consuming and labour intensive and is therefore best suited for control of small populations or individuals. The success of trapping will depend on the species being targeted and the design of the trapping program. The choice of appropriate traps and trap sites will maximise the chance of capture and also minimise the distress caused to any animal caught, be it target or non-target. The use of some types of traps requires authorisation; see Table 2 for more information on the authorisations required.

Traps should be set in a place where the targeted animals are most likely to encounter the trap. Attractants such as edible bait, odours or sounds may be used to lure the introduced animals into the trap. The type of bait used will depend on the diet of the introduced animals. Meat baits such as chicken wings are appropriate for carnivores and most other mammals will be attracted to 'universal bait' (a mixture of rolled oats, peanut butter, honey and sometimes sardines).

Traps will need to be checked often (at least in the morning and late afternoon) to prevent suffering from heat, thirst, starvation, exposure or shock. The trapped animal will be stressed and may injure itself while trying to escape. Frequent checking is particularly important where non-target fauna may be caught (which is likely in most cases). To minimise non-target fauna being caught, traps should be opened to correspond with the time of day the target animals are active. For example, if **nocturnal** animals are being targeted, traps should be opened shortly before sunset and checked as soon as possible after sunrise.

Once caught, the animal may be humanely euthanased. Traps may potentially cause significant suffering or even death and so care should always be taken to ensure the welfare of the trapped animal. This is particularly important to ensure non-target native animals are released unharmed. Traps should always be placed to avoid exposure to the elements, particularly heat or direct sunlight, flooding and predation (including predation by ants). Shade cloth or hessian can be wrapped around wire cages and aluminium folding traps to provide shelter. Some bedding material can also be provided in traps to provide protection from cold weather. The location of all traps should be accurately recorded and marked, and the information readily available in case the trapper is unable to check the traps. It is also important to check each trap every time it is set to ensure it is functioning properly.

There are several different types of traps available. The trap should be selected based on how suitable it is for the species being targeted and the trapping location, as well as logistical factors. Table 5 identifies which traps are suitable by species.

Table 5. The types of traps most suitable for capture of introduced animals affecting wetlands

Introduced animal	Trap yards	Wire/steel cage traps	Aluminium folding traps	Jawed traps	Fish traps	Nets	Basking turtle traps	Cane toad traps
Domestic waterfowl						•		
Cane toad								•
Red-eared slider turtle						•	•	
Introduced fish					•	•		
Introduced crayfish						•		
Cat		•						
Red fox		•		•				
Domestic dog				•				
Camel	•							
Horse	•							
Donkey	•							
Goat	•							
Pig		•						
Rabbit		•		•				
Rodents			•					

Euthanasia of trapped animals must be conducted humanely and legally and cause no suffering to the animal. In order to achieve this, the people undertaking these activities must be competent and, where necessary, licensed to do so.

➤ See *Methods of euthanasia*[78] for suitable techniques for euthanasia of trapped introduced fauna.

Holding yards

Holding yards are used for capturing and holding very large animals such as camels, horses, donkeys and goats for short periods. Holding yards may be fixed or portable. Mobs and herds of animals can be mustered (herded) to holding yards. Additionally various attractants, such as food or water, can be used to entice the animals into trap yards, a form of holding yard. Once in a trap yard, the animals can be trapped by using 'spears' or a trip wire to close the gate. Spears made of steel pipes or timber saplings are held up by wires at the gate. The spears point inwards into the yard. Animals may push their way through the spears which will move sideways slightly, but when they try to leave the yard the spears will point against them.

➤ Standard operating procedures for mustering and trapping feral horses and goats are available from the Department of Sustainability, Environment, Water, Population and Communities website.[58]

➤ A model code of practice for the destruction, capture, handling and marketing of feral livestock is available online from CSIRO.[79]

Wire or steel cage traps

Wire or steel mesh cage traps are available in a variety of sizes, from traps suitable for rats or rabbits (although these are unlikely to enter a trap) to those large enough for pigs. For example, a dog-sized cage is 120 x 60 x 60 centimetres and is made of 2.5-millimetre welded wire with a mesh size of 50 millimetres. There are two types of cage traps: treadle-activated and hook-activated. Treadle-activated traps have a metal plate at the base of the cage which is connected to the cage door. When an animal steps on the treadle, either a hinged swing-style or a drop down guillotine-style door will close shut. The other type involves the bait being placed on a hook. When the animal pulls on the hook, it triggers the door to close behind the animal.

Foxes, feral cats and wild dogs are very wary of entering cage traps. However, the use of cages to trap feral pigs has been found to be quite successful. DAFWA identifies panel, box and silo traps (Figure 8) used with vertical, side-hinged and funnel gates as suitable for use in trapping feral pigs.

➤ For DEC's standard operating procedures for cage traps, see *Standard Operating Procedure 9.2 Cage traps for live capture of terrestrial vertebrates*.[80]

➤ For information on traps suitable for feral pigs, see DAFWA's Farmnote No. 36 *Feral pig control by trapping*.[81]

Figure 8. Pigs trapped in a silo trap with a funnel gate (also referred to as a 'figure 6 trap') in a wetland in the Lake Muir – Denbarker area of Western Australia. Photo - Lake Muir/Denbarker Community Feral Pig Eradication Group.

case study

Fighting feral pigs on the south coast

Feral pigs (*Sus scrofa*) are found in many parts of WA, particularly in the south west and the Kimberley. They favour a wide range of habitats in medium to high rainfall areas and require thick vegetation cover and access to water[82], so are often found in and around wetlands.

Feral pigs cause considerable damage to natural environments such as wetlands through rooting and trampling, which causes physical damage and erosion, and destroys soil fauna (Figure 9). Rooting also reduces ground cover and can cause vegetation change and open areas for weed invasion. Feral pigs consume plants, prey on native fauna (such as frogs, small mammals, reptiles, insects, worms and birds), destroy their habitat and out-compete them for habitat and food. They wallow in wet areas, churning up sediment and fouling the water with faeces and urine. Recent studies also suggest feral pigs can facilitate the spread of the *Phytophthora cinnamomi* pathogen responsible for Phytophthora dieback, as well as other pathogens and diseases.[82]

Figure 9. Evidence of pig damage at a wetland in Pingrup. Pigs cause wetland soil erosion and compaction, providing suitable conditions for introduced weeds to invade. Photo – M Barley/DEC.

Plants that have tuberous roots and which grow in wetlands, such as sundews (*Drosera* spp.) (Figure 10) and orchids (such as *Caladenia* spp.), are often impacted by feral pigs.[83] Large pigs will dig furrows up to 20 centimetres wide throughout feeding sites to dig for tubers and roots. Such behaviour causes erosion and soil compaction, forms trails and destroys wetland vegetation. It appears feral pigs are particularly attracted to sensitive areas of a wetland located around surface water following germination of spring flora species.[84]

Figure 10. *Drosera huegelii*, a species of sundew from the south-west of WA, is eaten by feral pigs. Photos – C Hortin and E Wajon. Image used with the permission of the Western Australian Herbarium, DEC (http://florabase.dec.wa.gov.au/help/copyright), accessed 12/05/2010.

Wetland fauna are threatened by feral pig invasion. Pigs destroy the habitat of species such as quokkas and bandicoots that require dense vegetation for protective habitat. Frog species, such as the sunset frog (*Spicospina flammocaerulea*) found in isolated peat wetlands in the Warren Region north of Walpole and Denmark (Figure 11), are at risk from habitat destruction and being eaten by pigs.

Figure 11. The sunset frog (*Spircospina flammocaerulea*), which is threatened by feral pigs. Photo – K Bain/DEC.

case study

Community action

In 2001, a number of local landholders in the Lake Muir and Denbarker area recognised the growing threat of feral pigs to the south-west and decided to undertake a pilot eradication project in the area, which supports natural areas of high conservation value including the Frankland River and the Ramsar-listed Lake Muir.

The success of the trapping program during the five-month pilot demonstrated the benefit of the project and the Lake Muir/Denbarker Community Feral Pig Eradication Group was formed.

Collaborative action has been a cornerstone of the group's success. A range of project partners and stakeholders have been involved, including local landholders; DAFWA and DEC; South Coast NRM Inc; Green Skills Inc; the shires of Denmark, Plantagenet, Manjimup and Cranbrook; Great Southern Limited; ITC Limited; Walpole-Nornalup National Parks Association and the Wilson Inlet Catchment Committee Inc.

This integrated stakeholder approach has been highly successful in identifying and eradicating feral pig populations, because it combines resources and provides opportunities for coordinated management across property boundaries.[83]

The group's committee has found that trapping is the most appropriate method for the Lake Muir/Denbarker area (Figure 12) and that trapping is most efficient in late summer to early autumn, when water and feed supplies are low. A 'figure 6' silo trap is generally most effective at catching a group of pigs at a time, complemented by traps with a drop gate for pigs too large to enter the figure 6 traps. To maximise trapping success, pre-feeding is employed to encourage pigs to become accustomed to traps prior to trapping. The experience of the group is that inadequately controlled shooting and hunting poses a risk of scattering pigs and training them to avoid humans. The group reports that shooting by organisations such Sporting Shooters' Association of Australia complements trapping, however, communication between organisations has been vital to minimise duplication of effort and disturbance to each other's programs.

Figure 12. Feral pigs trapped by the group. Photo – Lake Muir/Denbarker Community Feral Pig Eradication Group.

The coordinated trapping approach is contributing significantly to the reduction of feral pigs in the area. In the 2007 and 2008 seasons, 225 pigs (including sows carrying a total of 165 unborn pigs) were dispatched.[84] In 2009, 169 pigs were dispatched. This high number reflects refinements in tracking and trapping techniques as well as the addition of new areas under trapping (M Muir 2010, pers. comm.). In autumn of 2010, 139 pigs (including sows carrying 75 unborn pigs) were dispatched.

Despite successful control of local populations of feral pigs, re-invasion is a constant threat because illegal dumping still occurs and because feral pigs can travel significant distances. The group therefore maintains a long-term perspective, with ongoing monitoring and treatment of areas remaining a priority.

The group has seen many advances in the fight against feral pigs since its formation in 2001. A number of groups have formed to fight feral pigs in other areas, and the Southern Feral Pig Advisory Group has recently been formed as an 'umbrella group' for these groups. In addition, a pilot nationally recognised training course has been developed to provide accreditation for feral pig trappers. These initiatives support the ongoing fight to control feral pigs in WA.

For more information on the Lake Muir/Denbarker Community Feral Pig Eradication Group, go to www.feralpig.southcoastwa.org.au.

Note: this case has been prepared in consultation with the Lake Muir/Denbarker Community Feral Pig Eradication Group.

Aluminium folding traps

Aluminium folding traps, often called Elliott traps after the manufacturer, are small metal boxes that are easily folded up when not in use (Figure 13). Aluminium folding traps operate on a treadle mechanism. The hinged door folds inwards to allow the animal to walk over it and onto the treadle. The door then springs shut, trapping the animal. Aluminium folding traps are small and come in two sizes: A and B. These traps are mainly used for capturing small mammals such as house mice.

Figure 13. A typical set-up of an Elliott aluminium folding trap covered hessian. The trap is placed in a shady position under vegetation cover. Photo – A Nowicki/DEC.

➤ For DEC's standard operating procedures for Elliot traps, see Standard Operating Procedure 9.1 *Elliott traps for live capture of terrestrial vertebrates*.[85]

Jawed traps

Jawed traps can be used to trap foxes, rabbits and wild dogs. Foxes and wild dogs are very wary of entering cage traps, and so the use of jawed traps may achieve a higher success rate than cage traps. Even so, jawed traps are generally considered to be an ineffective tool for general population control of foxes, rabbits and wild dogs; they are generally used to control small, isolated populations, hard-to-catch individuals or following a baiting program.[86,87,88,89] Furthermore, as with most traps, jawed traps are not target-specific and can catch animals such as birds, kangaroos, wallabies, echidnas, goannas, wombats, possums, bandicoots, quolls and sheep[88]; as well as humans, therefore the decision to use jawed traps should take this into account.

The main benefit of jawed traps is that the animal is unaware of the trap until it is caught. The traps are buried into the ground in the set position. They operate by snapping two 'jaws' shut when an animal steps on the treadle plate or 'pan'. The pan is usually adjustable to suit the animal being targeted.

Jawed traps come in two main types: leg-hold and foot-hold (often called 'soft-catch'). The difference between leg-hold and foot-hold traps is that leg-hold traps are much larger and often catch the animal higher up on the leg, which can cause major trauma. Foot-hold traps seize the animal across the tougher padded area of the foot and are therefore preferred.

Jawed traps have evolved substantially since the early steel-jawed models. The traps in use today have padded, offset and/or laminated jaws. Offset jaws have been altered to leave a gap between the trap jaws, allowing greater blood flow to the animal's foot. Laminating traps expands the thickness of the trap which increases the surface area of the jaw on the animal's foot. Doing so reduces the injury caused to the trapped animal and also increases holding efficiency. Only padded-jaw traps can be used for fox and rabbit control.[88,87,86] For trapping of wild dogs, traps that cannot be serviced daily must be wrapped in hessian that is impregnated with strychnine crystals to prevent prolonged suffering.[89]

➤ Standard operating procedures for trapping of foxes, rabbits and wild dogs using jawed traps are available from the Department of Sustainability, Environment, Water, Population and Communities website.[58]

Fish traps

It is important to seek advice from the Department of Fisheries before attempting to use any equipment, including traps, to catch introduced fish or crustaceans within Western Australian wetlands. An exemption from the department is required for trapping activities.

Generally, fish traps and nets are considered to be relatively ineffective for eradicating introduced fish and crustaceans. This is because the biology of most introduced species makes the containment of such organisms, especially their reproductive material, extremely difficult (B Bardsley 2010, pers. comm.).

However, traps may be used to significantly reduce introduced fish populations. Box-mesh traps, like the one shown in Figure 14, can be used in wetlands to trap introduced fish such as eastern gambusia (*Gambusia holbrooki*). These were used by students of Shenton College to trap and remove eastern gambusia in Dalkeith (for more information, see the case study 'Restocking native fish in Masons Gardens Lake, Dalkeith' at the end of this topic).

Figure 14. A box mesh trap used to capture eastern gambusia. Photo – C Lawrence/Department of Fisheries.

Both the design and placement of fish traps can help reduce the entrapment of non-target species. For example, it is important to ensure that the trap opening is small enough to exclude turtles from entering.

Traps such as carp separation cages can be used to catch introduced fish in waterways or drains feeding into wetlands. The carp separation cage encourages European carp (*Cyprinus carpio*) to jump over a wall into a separate trap with a hinged lid, preventing escape. Recent laboratory trials of a 'finger style' carp push trap in South Australia have shown promise as a carp management option.[90] Cages and barriers may be used together to improve introduced fish management (see 'Barriers' for more information).

Nets

There are three main types of nets that can be used to catch introduced animals within wetlands: hand-held nets, mist-nets (for birds) and netted traps (for water-dwelling animals). Hand nets consist of conical netting attached to a hoop on the end of a rigid handle. The use of a hand-held net is fairly labour-intensive and so a netted trap or mist-net may be preferred.

Mist nets and netted traps are stationery. Steps should always be taken to ensure that these traps can easily be located. For underwater traps, this may be achieved by attaching a buoy to the trap. Careful consideration of non-target animals is required when using netted traps.

Mist net traps are fine nylon or polyester nets which are suspended between two upright poles. The grid size of the mesh netting varies according to the size of targeted birds. The net is practically invisible to birds, which fly into the net and remain caught until released. Birds will entangle themselves in the net and so continual monitoring and expert handling of caught birds is required. Mist nets have a high likelihood of non-target capture, further emphasising the need for frequent surveillance.

Netted traps come in a variety of designs including drop nets, hoop nets, yabbies pots or turtle traps. All designs consist of a rigid frame covered in mesh netting. The traps may be baited. Care should be taken when hauling a trap out of water to avoid disturbing the wetland sediment. Drop nets are constructed from two hoops joined by a cylindrical or cone-shaped net bag. Introduced crayfish are generally trapped with drop nets. Hoop nets are similar to drop nets but only have one hoop with a conical-shaped net attached to it. Yabbie pots are constructed from rigid wire and netting and have two fixed entrance funnels. They come in two shapes: rectangular and 'opera house', which is a semi-circular design. Opera house traps must be used with extreme care, as they can entrap rakali, also known as native water rats (*Hydromys chrysogaster*), which drown if caught. It is important to seek advice from the Department of Fisheries before attempting to use any equipment, including nets, to catch introduced fish or crustaceans within Western Australian wetlands. An exemption from the department is required for trapping activities. In 2007 the Minister for Fisheries granted an exemption for the use of fish traps within Lake Kununurra to allow commercially available 'opera house' style traps, specially modified to target redclaw, to be used to trap the introduced freshwater crayfish redclaw (*Cherax quadricarinatus*).[91]

Turtle nets are similar to yabbie pots but have been modified to allow turtles to reach the surface of the water to breathe air. Turtle nets are collapsible with a rectangular frame, two entrance funnels, and netting.[92] The netting forms a cylindrical shape and extends upwards by about 2 metres. The upper end of the cylindrical netting is tied with a cord to a tree branch or a stake above the water surface, allowing the trapped turtles to swim for air while remaining trapped.

Basking turtle traps

As well as the netted trap design outlined above, there are several basking trap designs and most consist of a floating basking platform with a net or wire basket attached underneath.[93] Turtles climb up the sides of the trap to bask on the platform and are captured in the net after leaving the platform. The sides of the trap are sloped inward to facilitate entry and prevent escape.

Cane toad traps

Cane toads may be removed at all stages of their life cycle. While eggs can only be removed by hand, cane toad tadpoles and adults can be trapped.

Tadpoles of any frog species can be trapped using funnel traps placed under water. These come in a myriad of designs, including cylindrical or box traps constructed from mesh galvanised wire, traps made from plastic beverage bottles, collapsible nylon mesh traps, and traps made with acrylic plastic sheet.[94,95,96,97,98] All of these designs operate by allowing tadpoles to enter the trap through one or two funnels, but not allowing the tadpoles to escape.

A variety of traps have been developed for capturing adult cane toads. These are generally cage traps, traps made of solid metal walls, or traps that are a combination of cage and solid walls. Kununurra and Wyndham residents can currently obtain cane toad traps from the Shire of Wyndham/East Kimberley depot for a small deposit for use on their properties.

Although extensive trapping of adult cane toads has been undertaken in the Kimberley, a number of issues have been identified with this method. These include maintenance and service of traps in remote areas; damage by fire, theft, vandalism, livestock and wildlife; capture of non-target species; and the need to position traps very close to or in water. DEC recognises that cane toad traps may play a role as a surveillance tool at and ahead of the main front and may be required by community members as a tool to keep toads out of backyards. To maximise their effectiveness, a combination of lights, baits and acoustics (that is, playing toad calls in order to attract others) is recommended to attract cane toads to the traps.

The use of fences may also improve the effectiveness of cane toad traps. Deflection fencing, which involves a barrier set up to direct toads towards traps, has been trialled for the control of cane toads (Figure 15). While the specific fence design and application are still being developed, temporary barrier fencing may also play a role in the exclusion of cane toads from strategic sites that are of special significance such as mound springs.

➤ For more information on the control of cane toads, see the DEC website at www.dec.wa.gov.au/canetoads.

Figure 15. Deflection fencing in use during the Stop the Toad Foundation's 2009 'Great Toad Muster'. Photo – A Shanahan.

Shooting

Nuisance kangaroos and larger introduced animals, such as camels, goats, horses, pigs, foxes, cats, rabbits and even red-eared slider turtles may be shot. In most cases, this will be lethal to the animal. Tranquiliser guns may be used if the aim is to translocate the animals, which may be an option for nuisance kangaroos. This can be expensive, with prices around $1,000 per kangaroo quoted in the metropolitan area of Perth. Shooting may be conducted on the ground. Aerial shooting is best suited for large-scale population control, particularly in remote and/or inaccessible areas. A team is required for aerial shooting, including a shooter, a pilot and a spotter/counter who locates the animals and records the number of animals shot.

Shooting can be a humane method of introduced animal control when it is carried out by experienced and skilled shooters (and pilots in the case of aerial shooting). Introduced animals should only be shot when they can be clearly seen and are within range, and using the correct calibre firearm and ammunition. Correct shot placement (aiming for the brain or heart) is very important and wounded animals should be promptly located and killed.

➤ Standard operating procedures on how to humanely shoot introduced animals species are available from the Department of Sustainability, Environment, Water, Population and Communities website.[58]

If carried out correctly, shooting can be the most humane method of removing introduced animals. It is also one of the most cost-effective methods available, particularly when population densities are high. However, shooting is often only a short-term solution and may have to be combined with other management methods such as exclusion fencing.

case study

Managing the nuisance kangaroo population at Thomsons Lake Nature Reserve

Kangaroos are prolific breeders and, due to a reduction in predation and a greater availability of food on cleared land, are able to quickly increase in population size until they can no longer be supported by the habitat.[99] Kangaroos form nuisance populations at golf courses, ovals and on farmland but generally they are not a major issue at wetlands. Large populations of kangaroos can readily form when they are unable to disperse due to fencing or insufficient corridors of native vegetation. In recent years, this has occurred at Thomsons Lake Nature Reserve in southern metropolitan Perth, which is fenced to protect waterbirds from predation by foxes and cats. Following the installation of the vermin-proof fencing in 1993, the population of western grey kangaroos (*Macropus fuliginosus*) within the reserve increased from twenty to thirty individuals to approximately 1,100 kangaroos by 2006. The kangaroos were causing extreme harm by overgrazing the understorey of the wetland and dryland vegetation. Kangaroos were culled (shot) in 2006 in accordance with the kangaroo management program for the reserve[100] and with the approval of the Conservation Commission of Western Australia and the support of the community-based Beeliar Regional Park Community Advisory Committee.[101] Translocation of the kangaroos was considered but rejected on the basis that it was not a feasible or practical option because of the unacceptable level of stress it would place on the animals, as well as causing unnatural pressures on any areas to which they could be relocated.

Poisoning

Poison may be applied within and around wetlands in two forms. The poison may be applied either directly, a method mainly used for controlling introduced fish and aquatic invertebrates; or through bait delivery, a method mainly used for terrestrial mammals.

When using poisons

Any chemical or biological agent intended to kill animals, such as a poison, is a **pesticide**. Extreme care must be taken to ensure that the use of pesticides does not constitute an offence or cause environmental harm. In WA, anyone who uses pesticides is bound by the Health (Pesticides) Regulations 1956. These regulations were developed to provide protection for the applicator, the public and the environment from misuse of pesticides. Pesticide labels are written in accordance with the Regulations and therefore any pesticide user has a legal obligation to read and follow instructions on the label. By law and without exception, pesticides cannot be used in any manner contrary to that described on its label without the permission of the Australian Pesticides and Veterinary Medicines Authority.[102] The label provides instructions for use, for the protection of the environment, information about storage and disposal and recommendations for personal protective equipment. Anyone proposing to apply a pesticide to a natural area of conservation value should have appropriate authorisation and should undertake training in the correct preparation, handling, application, transport and storage of pesticides. Legislation regarding the use of chemicals is under review and in future this may become a legal requirement.

Direct application

Rotenone

The most common poison used to control introduced fish is rotenone. Rotenone is an odourless chemical which occurs naturally in the roots and stems of several plants such as the jicama vine plant.[103] Commercial products containing the extract are used to poison fish, which are then easily collected because they swim to the surface of the water seeking oxygen.

Rotenone is primarily used for the control of introduced fish. However, it is a broad-spectrum pesticide, that is, it is toxic to many species including a number of aquatic fauna, such as tadpoles and a range of aquatic invertebrates. Rotenone is mildly toxic to humans and other mammals. This higher toxicity in fish and insects is because rotenone is easily taken up through the gills or trachea, but not as easily through the skin or through the gastrointestinal tract. The compound breaks down when exposed to sunlight. Rotenone persistence in natural waters is reported to vary from a few days to several weeks, depending on the season.[104] Rotenone is widely considered to have only minor and transient environmental side-effects and is considered by many researchers and institutions to be the most environmentally friendly fish poison.[104]

At this time, most methods of introduced fish control are unable to exclusively target a single species. As such, native fish will be at risk when controlling introduced fish. There has been some research into developing rotenone in bait form, which could then be targeted at individual species such as carp.[105] However, this method still requires further development.

Piscicide: a chemical substance which is poisonous to fish

In Australia, rotenone can only be used as a **piscicide** if permission to do so is granted by the Australian Pesticides and Veterinary Medicines Authority in the form of a 'minor use' permit (see Table 2 for more information). In the United States of America, where rotenone has been in use for many years, the American Fisheries Society has recently published standard operating procedures for the use of rotenone.[106] The New Zealand Department of Conservation has published a review of rotenone which includes a recommended protocol when considering its use as a piscicide.[104]

A proposal to use rotenone requires an environmental assessment as to whether it is acceptable at a particular wetland. As with any pesticide, the risk to all fauna needs to be identified and considered as part of this assessment. Important risk factors include whether the wetland is open or closed (that is, there is no overland flow into or out of the wetland); whether native fish and other susceptible native species may be present; and timing of the application to reduce impacts on native fauna present (for example, rotenone is known to be more toxic to tadpoles than adult frogs).[107] Another option to minimise the impacts on native fauna is to ensure that native species are removed from the control area for later restocking, or that there are nearby breeding populations which can naturally repopulate the area.[108]

➤ The use of pesticides and the removal and reintroduction of freshwater species is subject to regulation. For more information, see Table 2 and the section of this topic entitled 'How to manage the impacts of introduced animals'.

Among other methods, rotenone was successfully used in the control (but not eradication) of pearl cichlids (*Geophagus brasiliensis*) in the Perth metropolitan area. The cichlids were first discovered in March of 2006 and steps were taken to limit their spread in a range of water bodies at Altone Park, the Altone Park Golf Course irrigation ponds, drainage systems and natural streams such as Bennett Brook.[109,110] Rotenone has also been successfully used to control and eradicate populations of goldfish from billabongs near the Warren River and the Margaret River (S. Beatty pers. comm.).

Baiting

Baiting is an option often favoured for the control of foxes and rabbits. Baits may also be used for the control of introduced mice and rats. Baiting techniques for feral cats have improved rapidly in the last decade, however the use of Eradicat® in WA is currently limited to an experimental permit by DEC.

The primary method of control of foxes is by spreading baits containing the compound 1080 (sodium monofluoroacetate). There are two types of 1080 baits: dried meat baits and sausage baits. Meat baits are made by injecting 1080 into various meats (usually kangaroo or horse meat) which are left to sun-dry until at least a hard crust forms. Sausage baits are semi-dry meat baits whereas the traditional dried meat baits are fully dried. Spreading 1080 baits for fox control can be done by manually laying out the baits along set transects or by mass aerial dispersal. Baiting is an effective way of controlling foxes as they readily scavenge and frequently take up baits.[115,38,116] There has been substantial research in improving the effectiveness and safety of 1080 baiting in Australia including assessing the attractiveness and palatability of various types of baits.[116,117,118]

One of the main concerns when applying any lethal control methods is the impact on non-target species, particularly pets and native species. Native south-west Australian fauna are least at risk of fatalities associated with 1080 bait consumption. Monofluoroacetic acid, from which 1080 baits are derived, occurs naturally in the legume genus Gastrolobium. Over the millennia fauna of the area have co-evolved with the plants to develop a very high tolerance to the compound.[111,112] However, native carnivores and scavengers such as dingoes, quolls, goannas and some birds are at risk of consuming 1080 baits.[113] Some strategies can be employed to reduce the risk of bait uptake by non-target species, for example, by burying the baits to prevent birds from picking up the baits.[113,114,115] It must be noted that quolls readily dig up baits just as foxes do.[115,116]

➤ The use of baits containing 1080 is regulated. An excellent guide to the use of 1080 is *Landholder information for the safe use and management of 1080.*[62]

Baiting is now recognised as the most effective method for controlling feral cats when there is no risk posed to non-target species.[117] Historically baiting programs for feral cats were ineffective, principally because the baits used were for other introduced predators such as foxes and wild dogs and were unattractive to cats. In response, DEC researchers conducted an extensive series of trials which have led to the development of the feral cat bait known as 'Eradicat®'.[129,130]

Baiting campaigns using Eradicat® have proven to be an effective method in reducing feral cat numbers and it is now used by DEC as a control tool for feral cat management at a number of mainland sites in arid and semi-arid regions.[118] A recent project has gone a long way to demonstrating that the sustained control of introduced predators (both feral cats and foxes) in the southern rangelands can also be achieved using this bait.[119]

Baiting may also be used to control rabbit and rodent populations. The bait material used is either oats or carrots. Poison is then applied to the baits, usually 1080 or Pindone. Pindone is a registered rabbit poison that was originally developed for rodent control and is available in two forms: powder or liquid.[120] Pindone bait is preferred for use in urban and urban/rural areas as it has an antidote, vitamin K1, and is generally safer to use than 1080 where non-target domestic animals are at risk.[121,120,122] However, Pindone poses a greater risk to wildlife than 1080.[120] Therefore, choice of poison will depend on where the introduced animal control is being conducted. Only 1080 should be used where non-target wildlife are likely to be exposed to the bait, or considered to be at risk.

extra information

Baiting for rabbits

Baiting is generally only the first step in rabbit control and should be carried out in conjunction with warren ripping and/or fumigation.

Rabbit baiting is most effective in the late summer/early autumn. This is when natural causes and deliberately introduced viruses used as biological controls (such as myxomatosis or rabbit calicivirus disease) will have reduced the population, food availability is at a minimum, young rabbits are old enough to emerge from their warrens, and the breeding season is over so rabbits will range over greater distances.[121,120] The best area to lay baits for rabbits is close to their warren, however, they do feed up to 400 metres from their warren. The results of a rabbit control program can be greatly improved by laying unpoisoned baits, known as free feeding, once or twice before laying poison baits. Free feeding allows the rabbits to acquire a taste for the baits and encourages them to feed on a new food source.[121,120] Following baiting, all uneaten bait and rabbit carcasses should be collected (for up to 8–12 days following baiting) to make sure non-target animals aren't harmed by ingestion of either the bait or poisoned carcasses.

Fumigation

Fumigation may be used for the control of rabbits either following or as an alternative to warren ripping, which is undertaken after poisoning. Burrows dug out by foxes as shelter for their cubs (natal dens) may also be fumigated. Fumigation is considered to be less humane than poisoning with 1080. Therefore, it is desirable to fumigate only after a poisoning program has been completed, when the density of rabbits or foxes is low.[123]

Fumigation involves the introduction of toxic fumes into a burrow where it is inhaled by the inhabitants, leading to their death. There are two types of fumigation: pressure fumigation, in which the fumigant gases or vapours are generated outside the burrow and are forced into the burrow under pressure, usually from a pump or fan; and diffusion (or static) fumigation, where tablets are placed in active burrows and the gas generated is allowed to diffuse through the burrow.[124,125,123] Toxins used for fumigation include chloropicrin, carbon monoxide, carbon dioxide, calcium cyanide and phosphine.[124]

Phosphine has been widely used for diffusion fumigation and remains the preferred toxin for fumigation of rabbits. Phosphine is a gas which is released from aluminium phosphide tablets when they react with moisture.[125] Damp soil conditions give the best results when using this method of fumigation.[126]

Fumigation with carbon monoxide has been developed as a humane alternative to phosphine.[127] Carbon monoxide gas causes unconsciousness and rapid death without pain or discomfort. Carbon monoxide fumigant cartridges, such as DEN-CO-FUME®, are now registered for use in controlling foxes in natal dens. The cartridges contain carbon and sodium nitrate, which combust to produce carbon monoxide once the cartridge is ignited. Carbon monoxide has a similar density to air and quickly disperses throughout the available space and is not readily adsorbed by soil. DEN-CO-FUME® is widely used to control foxes in natal dens across Australia, but is not yet registered for use in rabbit warrens. Using car exhaust fumes is not an acceptable method of producing carbon monoxide as adequate gas concentrations cannot be achieved and exhaust contaminants cause severe irritation before death. The exhaust gases produced may also be unacceptably hot.[128,123,123]

Diffusion fumigation is preferred over pressure fumigation. Chloropicrin, used for pressure fumigation, is considered to be highly inhumane and its use is not recommended. It causes intense irritation of the respiratory tract and profuse watering of the eyes for a considerable period before death. Additionally, the process of pressure fumigation is slow and cumbersome, and only suitable for small areas.[129]

When fumigating, it is important that rabbits or foxes are inside the burrow and the burrow is sealed to prevent the gas from escaping. Rabbits will have multiple entrances to their warrens and so each of these will need to be located and sealed. The fumigants used are highly toxic to humans and great care should be taken at all times. Furthermore, care should be taken to ensure that the inhabitants of the burrow are, in fact, rabbits as recent research by the Bandicoot Refuge Project has found that quenda take refuge in rabbit burrows to avoid predators.

➤ Fumigation is the application of a gaseous pesticide; see the information under ‘Poisoning’ in this topic for more information about the legal requirements associated with pesticide use.

➤ Standard operating procedures for fumigating fox dens and rabbit warrens are available from the Department of Sustainability, Environment, Water, Population and Communities website.[58]

Shockwaves

Underwater explosions may be used to reduce the number of introduced fish in wetlands.[108] These explosions, caused by very small charges from detonating cords, create shockwaves in the water which kill fish by rupturing their internal swim bladders. Shockwaves were used in combination with other methods to reduce the number of pearl cichlids (*Geophagus brasiliensis*) in the Swan River system in 2006.[109]

This method is relatively inefficient for eradicating introduced fish, and its use should be restricted to environments where other methods are not viable, or where a combination of methods is required for successful eradication.

This method may affect other aquatic fauna in the wetland, including native fish, aquatic mammals, amphibians, and reptiles. Therefore the proposed use of shockwaves is subject to regulation and may trigger the *Environmental Protection Act 1986*.

The use of shockwaves must only be undertaken by a suitably qualified and licensed practitioner.

➤ The removal of freshwater fish species and the use of shockwaves are subject to regulation. For more information, see Table 2 of this topic.

Electrofishing

Electrofishing (also called electric fishing) is a method used to stun fish in the water to allow for easy collection. Electrofishing uses an electric current, delivered into the water by two electrodes (an anode and a cathode), to attract and immobilise fish.[130] There are three types of electrofishers: backpack models, towed barge models and boat mounted models (sometimes called stunboats). Electrofishing is only effective in water shallower than approximately 2.5 metres and in water with a conductivity range of between 10 and 5,000 microsiemens per centimetre (µS/cm); (for comparison, seawater is around 50,000 microsiemens per centimetre).[131]

➤ For more information on conductivity, refer to the topic 'Conditions in wetland waters' in Chapter 2.

When fish encounter the electric current, galvantotaxis occurs, which is an uncontrolled muscular convulsion that makes the fish swim toward the anode. When performed correctly, electrofishing results in no permanent harm to fish, which return to their natural state in as little as two minutes after being stunned. However, great skill is required by the operator to avoid harming fish. Electrofishing can cause harmful effects on fish that are often not externally obvious or fatal, such as spinal injuries and haemorrhages.[132] Because it requires the use of high voltage electricity in and around water, electrofishing equipment is highly specialised and relatively expensive.[130] The risk of injury to both operators and observers is such that an *Australian code of electrofishing practice* has been established. This prescribes the required standards in operator training and certification, equipment and operational practices.

➤ For guidance on electrofishing activities, see the *Australian code of electrofishing practice*.[133] For information on regulations governing the removal of freshwater fish, see Table 2 of this topic.

The annual control program of the goldfish population in the Vasse River involves boat electrofishing. More than 1,200 goldfish have been removed with no native fish deaths recorded in follow-up surveys.

Manipulating habitat and food

Rabbits, foxes and fish can be controlled by manipulating their habitat. Limiting the Australian white ibis' access to unnatural food sources, such as rubbish dumps and rubbish bins, can help ensure that the size of populations dependent on these food sources at wetlands are controlled.

In the case of rabbits and foxes, habitat manipulation refers only to the specific 'habitat' the animals have created, namely their burrows. Rabbit warrens and fox natal dens may be ripped or destroyed with small explosives. This is often used as part of a control program that includes baiting and possibly fumigation. Destroying burrows discourages rabbits and foxes from returning to the area.

➤ Standard operating procedures for rabbit warren destruction by ripping or explosives are available from the Department of Sustainability, Environment, Water, Population and Communities website.[58]

Draining a wetland of water may remove introduced fish. This is an option that must be considered a last resort only and must only be undertaken if legal. It requires an environmental assessment to determine whether it will have a significant environmental impact, taking into account all aspects of the wetland's hydrology, ecology (particularly native aquatic fauna) and chemistry (particularly acid sulfate soils), and may trigger the *Environmental Protection Act 1986*.

While draining a wetland for two to three days may be effective at removing many species of introduced fish, it is likely to kill most if not all native fish and other aquatic fauna within the wetland. There is not a lot of published data on the effectiveness of this method; however anecdotal reports are that a number of attempts at natural wetlands have proven ineffective. It was used to successfully eradicate eastern gambusia (*Gambusia holbrooki*) from the significantly modified wetland, Ilparpa Swamp, in the Northern Territory. After the eastern gambusia were discovered by Waterwatch volunteers, the swamp was pumped dry and was refilled to capacity by rains two weeks later.[66] This method may also be used for carp when they are present in isolated wetlands.

Draining a wetland will not eradicate yabbies. Extreme manual removal (with an excavator) or the use of chemicals may work[134], but these techniques obviously have the potential to create a significant environmental impact.

➤ There are legal requirements regarding the alteration of drainage into or out of wetlands and the alteration of wetland water regimes. For further information, see the topic 'Legislation and policy' in Chapter 5.

case study

Managing nuisance ibis populations

Australian white ibis (*Threskiornis molucca*) are a native species with the potential to form nuisance populations in some areas of WA (Figure 16).

Figure 16. An Australian white ibis (*Threskiornis molucca*). Photo – T Chapman/DEC.

As a scavenging species with a generalised diet, they have adapted well to urban environments.[135] Large numbers of the Australian white ibis can cause damage to wetlands and out-compete native species for food and nesting resources. Booragoon Lake, in southern metropolitan Perth, provides habitat for a large number of waterbirds and is one of the few urban breeding sites for pied cormorants (*Phalacrocorax melanoleucos*). Australian white ibis are also abundant at the lake and are considered nuisance fauna as their large numbers are out-competing pied cormorants for habitat. The nesting habits of the ibis are also damaging wetland vegetation, in particular, the *Melaleuca teretifolia.*[74] The local population of ibis has grown to nuisance size due to an abundant food source in the form of a nearby rubbish dump.[74]

A range of methods have been employed to control nuisance populations of Australian white ibis in Australia. Limiting access to unnatural food sources, such as rubbish tips and bins, is a key measure. Various methods of exclusion from these food sources are available including the use of netting (Figure 17), barriers, ibis-proof litter bins and preventing people from feeding them. These can be combined with complementary measures including limiting water sources and loafing sites, scaring and spotlighting them, shooting them and oiling eggs. There has also been research into a contraceptive pill to be implanted under the skin of captured birds.

➤ For more information on management options for nuisance populations of the Australian white ibis, as well as associated legal requirements, see *Prevention and control of damage by animals in WA: Australian white ibis* Threskiornis molucca.[135]

Figure 17. Ballina landfill in NSW, where netting has been shown to reduce local Australian white ibis populations significantly. Photo – K Patrick/Ecosure.[136]

Manual removal

Manual removal of introduced animals is generally considered to be the most environmentally sensitive method of removal, with few unwanted side effects. As the name suggests, it involves directly removing introduced animals from a wetland. While this can be a labour-intensive process, it may also be the most feasible method available in sensitive environments. It may also be the simplest method of removal in small wetlands or when only a few individuals of the introduced species are present.

One such method of manual removal is the use of dip nets to remove introduced fish from a wetland. This is generally a labour-intensive process and often less efficient than traps (at one site it was found that traps caught five times more fish than hand nets[137]). Care should be taken to ensure that only introduced fish are removed from the wetland and that any native fish that are caught are returned unharmed. Even if it appears that all adults have been removed, repeated fishing attempts may be required, as some individuals may have remained in the form of eggs or juveniles. Populations of warm-water species are smaller[138] and many species are not in reproductive mode in cooler months. However, this advantage is counteracted by the fact that activity and therefore 'catchability' is also diminished. In the dry season water levels are reduced and the concentration of introduced fish is increased. As such, timing should be assessed depending on the habitat and target species. The only known successful eradication of eastern gambusia from a natural aquatic system in WA was achieved by intensive dip netting in a pool in the upper Margaret River catchment that prevented its colonisation into the high conservation value upper reaches when winter flows resumed (S. Beatty pers. comm.). However, dipping is usually far less effective than use of larger nets (such as seine nets) or trapping in larger systems.

All noxious fish species must be destroyed on site. For other species, the Perth Cichlid Society (www.perthcichlid.com.au) offers to accept unwanted fish and provides a list of local fish stores that have agreed to accept unwanted fish. Alternatively, introduced species of fish that are not listed as noxious species may be disposed of humanely by refrigerating them in water until they stop moving, and then moving the container to the freezer overnight. This method has been endorsed by the RSPCA WA Inc.[10]

Experience has shown the most efficient and effective way to remove cane toads is to simply pick them up.[139] Cane toad 'musters' with high levels of community participation have been effective in reducing the number of cane toads present in WA (Figure 18) and was used to successfully eradicate the local population of cane toads in Port Macquarie, New South Wales. The use of deflection fencing may help to make hand collection more efficient.[140] The timing of hand collection is also an important factor as cane toads concentrate around water points during the dry season, making collection easier. Cane toads exude poison from the glands at their shoulders and so care should be taken when handling the toads. Gloves should be worn and care should be taken to avoid the poison getting into eyes, nose or mouth and pets should be removed from the area.

Figure 18. Volunteers counting and sorting cane toads manually collected during the Stop the Toad Foundation's 2009 'Great Toad Muster' in the Kimberley.
Photo – M Andrews.

Once collected, cane toads may be taken to an allocated disposal facility (usually a DEC office or veterinary clinic) or euthanased. It is essential that members of the public are completely certain of the identification of the animal they have captured prior to euthanasing it, as up to two-thirds of suspected cane toads turn out to be harmless native frogs.[8] Cane toad carcasses are still toxic so they should be disposed of carefully—either by burial in a location where it cannot be dug up by other animals, especially pets; or by incineration.

➤ For more information on the control of cane toads, see the DEC website at www.dec.wa.gov.au/canetoads.

Fertility control

Fertility control options may be considered as a means of maintaining low numbers of introduced animals. Immunocontraception is one method of fertility control where the animal's immune system is made to mount an attack against a part of their own reproductive system such that they become infertile. This could be against eggs, sperm or a hormone necessary for successful reproduction.[141]

Trials of immunocontraception, though promising, have shown limited success. This method requires multiple injections to be made to the animals, either directly or by using dart guns. This makes immunocontraception impractical and raises the issue of costs versus benefit. Orally delivered (using baits) immunocontraception is being investigated, particularly for foxes and feral cats. The high uptake rate of 1080 bait by foxes indicates that this form of control has potential.[142]

For immunocontraception to cause rapid population decline, a large proportion of breeding females need to be sterilised.[143] Some animals which have undergone contraception or vaccination have been found to reproduce, which implies that genetic selection for animals which do not respond to the vaccine is possible.[141] These are the issues that must still be resolved before any form of fertility control for introduced species can be used widely in Australia.

How to manage the impacts of introduced animals

Reintroduction: the deliberate release of a species in an area which is part of its natural historical range but in which it no longer occurs

As previously mentioned, introduced animals can have a number of detrimental impacts on wetlands, including:

- predation and competition with native fauna
- spread of diseases, plant pathogens and weeds
- degradation of native vegetation
- soil disturbance
- reduced water quality.

After introduced animals have been 'controlled' (numbers reduced or completely eliminated), a wetland may require additional management to address the impacts of the introduced animals. If a wetland is in good condition, it may be able to recover naturally. If a wetland has been severely degraded and natural recovery is unlikely, active management may be required. In these circumstances, management of both the wetland vegetation and fauna is likely to be required.

If significant vegetation loss or the complete loss of a particular plant species has occurred at a wetland and recruitment is not occurring naturally, revegetation may be considered.

➤ For additional detail on managing wetland vegetation see the topic 'Managing wetland vegetation' in Chapter 3.

If fauna have disappeared from a wetland because of the impacts of introduced animals and they do not return to the wetland after the introduced animals have been removed, **reintroduction** of the native fauna may be possible. Reintroductions should only be attempted after all threats (not just introduced animals) to the animal in question have been removed from the wetland and when it is unlikely that these threats will return.

Reintroduction programs are often stressful and dangerous to the fauna being moved, may result in the inadvertent spread of harmful diseases and pathogens, and may result in the loss of genetic integrity of an existing population. As such, reintroduction is an option that should only be considered in collaboration with the relevant authorities, typically DEC and/or the Department of Fisheries. The reintroduction, relocation (translocation) and introduction of animals into new areas are subject to regulations administered by these departments (see Table 2 for more information).

case study

Restocking native fish in masons gardens Lake, Dalkeith

A proactive partnership between a school and local and state government has achieved a significant reduction in the numbers of introduced fish in Masons Gardens Lake in Dalkeith.

In 2009 enthusiastic representatives from the City of Nedlands, Department of Fisheries and Shenton College developed an innovative project to remove introduced fish and address nuisance mosquito problems and algal blooms in the wetland, while providing the students of Shenton College with a living classroom in which to develop a range of skills and gain hands-on experience (Figure 19).

As part of an investigation into the ecology of the lake, seventy students used fish traps, scoop nets and drop nets to conduct a baseline survey of the fish population. During this survey they found the introduced eastern gambusia (*Gambusia holbrooki*) (Figure 20) co-inhabiting the wetland with native pygmy perch (*Edelia vittata*) and Swan River goby (*Pseudogobius olorum*) that were stocked by Murdoch University's Freshwater Fish Group in 2004 for the City of Nedlands.

Based on the information gained from the baseline surveys, the project partners opted to remove the eastern gambusia using traps because traps have a relatively low impact on the native fish population and wetland and are safe for use by students, unlike poison, shockwaves and electrofishing. They decided to manage the excess mosquitoes and algae in the wetland using biological remediation techniques rather than using pesticides and herbicides, which at best address the symptoms rather than the causes, and often create a range of other problems in wetlands.

The students conducted an intensive trapping regime over a three-month period using box-mesh traps to remove as many eastern gambusia as possible. It is estimated that the students removed 80 per cent of the eastern gambusia from the wetland, and at the end of trapping the ratio of eastern gambusia to native fish had fallen from 156:1 to 30:1. In comparing the efficiency of methods of capturing eastern gambusia, students found that traps caught five times more fish than hand nets. The students were able to raise awareness in the local community about the project and their findings via the local paper and a student podcast.

It is anticipated that the reduction in eastern gambusia will enable the native fish population

Figure 19. Dr Craig Lawrence from the Department of Fisheries with Shenton College students and (background) City of Nedlands staff Rob Burton and Vicki Shannon, at Masons Gardens Lake. Photo – W. Russell/courtesy of the Community Newspaper Group.

case study

Figure 20. The introduced eastern gambusia, *Gambusia holbrooki*. Photo – C Lawrence/Department of Fisheries.

in the wetland to increase. To assist the recovery of the native fish population in Masons Gardens Lake, species including pygmy perch (*Edelia vittata*), western minnow (*Galaxias occidentalis*) and smooth marron (*Cherax cainii*) were stocked into the wetland using carefully selected genetic stocks bred at the Aquaculture and Native Fish Breeding Laboratory at The University of Western Australia. These species were chosen on the basis that they are endemic to the catchment and could be supplied from the laboratory. The breeding program was an extensive and highly technical process designed to ensure that the genetic vigour of the fish was maintained. Following breeding, the individuals were carefully acclimatised to temperature and water quality of Masons Gardens Lake, and the conditions in which they were transported to the wetland (such as oxygen levels in the water) were carefully managed to maximise their survival rate in the wetland. It is proposed that Shenton College students continue ongoing monitoring of the recovery of the native fish population and trapping of introduced species to ensure their rehabilitation efforts have a long-term effect in their adopted wetland. As the eastern gambusia is a prolific breeder, it is very important that ongoing control continues.

It is hoped that by increasing the number of native fish in the wetland, nuisance mosquito problems can also be reduced, because native fish consume mosquitoes and their larvae. It is also hoped that the native fish species will consume algae, thereby contributing to the reduction of algal blooms; this is currently being evaluated.

Furthermore, the reduction in the numbers of eastern gambusia should indirectly lead to a reduction in algal blooms. This is because eastern gambusia prey on water fleas (*Daphnia carinata*), an aquatic macroinvertebrate that feeds primarily on algae. The loss of water fleas from the wetland can lead to algal blooms, which in turn provides an abundant food source for mosquitoes and midges, which can stimulate population booms.

In these ways, it is hoped that the biological remediation program improves the condition of the wetland while reducing the need to resort to the application of pesticides and herbicides in the wetland in the future.

This project, which is improving the habitat of the native fish population and the condition of the wetland using low-impact management techniques with the participation of local students, is an inspiring model for future wetland management initiatives.

Note: this case study has been compiled from information in a report by Shenton College students[137] and personal communication with Dr Craig Lawrence. The methods employed in this project were undertaken in compliance with regulations governing the management of freshwater fish and crustaceans; see Table 2 for more information.

Sources of more information on managing nuisance and introduced animals

General

Department of Agriculture and Food Western Australia
www.agric.wa.gov.au
Information on introduced animals considered pests to agriculture and the environment, including a list of declared pest species and information on management options, is provided on the Department of Agriculture and Food website.[144]

Feral.org.au
www.feral.org.au
Website and database containing information on vertebrate pest animal species in Australia and New Zealand.

Invasive Animal Cooperative Research Centre
www.invasiveanimals.com
Australia's largest integrated invasive animal research program.

Codes of conduct and standard operating procedures

Department of Local Government and Regional Development (2003) *Code of practice for the capture and marketing of feral animals in Western Australia*[57]

Various codes of conduct and standard operating procedures for the humane capture, handling or destruction of introduced animals in Australia published by the Department of Sustainability, Environment, Water, Population and Communities[58]

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www.dec.wa.gov.au/canetoads

Kimberley Toad Busters
www.canetoads.com.au

Northern Australian Frogs Database System
www.frogwatch.org.au

Stop the Toad Foundation
www.stopthetoad.org.au

Cats, feral

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Donkeys, feral

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Horses, feral

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Kangaroos

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Livestock, feral

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Pigs, feral

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Rabbits, feral

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Turtles, introduced

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Monitoring

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Reporting introduced animal sightings

Pest and Disease Information Service: 1800 084 881

FISHWATCH service, Department of Fisheries: 1800 815 507

Glossary

Aquatic invertebrates: those animals without a backbone (such as insects, worms, snails, molluscs, water mites and larger crustacean such as shrimps and crayfish) that live in or on water for at least one phase in their life cycle

Amphibians: the class of animals to which frogs, toads and salamanders belong. They live on land but develop by a larval phase (tadpoles) in water.

Biodiversity: a contraction of the words ‘biological’ and ‘diversity’, encompassing the whole variety of life forms—the different plants, animals, fungi and microorganisms—the genes they contain, and the ecosystems they form

Biological control: the control of an introduced plant or animals by the introduction of a natural predator or pathogen, usually bacteria, viruses or insects, or by biological products such as hormones

Browsing: feeding on leaves, twigs or bark from non-herbaceous (woody) plants, such as trees and shrubs

Endemic: naturally occurring only in a restricted geographic area

Erosion: the gradual wearing away and movement of land surface materials (especially rocks, sediments, and soils) by the action of water, wind, or a glacier

Eutrophication: the nutrient enrichment of a water body, which can trigger prolific growth of plant material (phytoplankton, macrophytes or both). May occur naturally over geologic time or may be human-induced

Feral animals: introduced animals that have escaped, or have been released, from domestication and returned, partly or wholly, to their wild state

Grazing: feeding on grasses and other low-growing herbaceous vegetation

Habitat: an area or environment where conditions are suitable for the survival of an organism, taxon or community

Herbivores: animals that chiefly eat plants

Hybrids: the results of interbreeding between two animals or plants of different species

Introduced animals: species of animals that have been intentionally or unintentionally brought into a region where they did not historically occur, usually facilitated by humans

Livestock: introduced domestic ungulate (or hoofed) animals

Nuisance fauna: native animals that naturally occur at a site, but which have reached a population size that is causing harm to the environment or humans

Nocturnal: primarily active during the night

Omnivorous: feeding on both plants and animals

Pesticide: any chemical or biological agent intended to kill animals or plants

Piscicide: a chemical substance which is poisonous to fish

Propagule: any part of a plant from which a new plant can grow, including seeds, bulbs and rootstocks

Pugging: depressions, hoof prints or 'pug' marks made in wet soil by trampling animals

Reintroduction: the deliberate release of a species in an area which is part of its natural historical range but in which it no longer occurs

Sedimentation: the process by which soil particles (sand, clay, silt, pebbles and organic materials) suspended in water are deposited or settle to the bottom of a water column

Threatening process: a process that threatens, or may threaten, the survival, abundance or evolutionary development of a native species or ecological community

Turbid: the cloudy appearance of water due to suspended material

Turbidity: the extent to which light is scattered and reflected by particles suspended or dissolved in the water column

Personal communications

Name	Date	Position	Organisation
Bill Bardsley	18/06/2010	Senior Biosecurity Officer	Department of Fisheries, Western Australia
Cara Francis	23/07/2009	Technical Officer	Department of Environment and Conservation, Western Australia

Dr Craig Lawrence	04/2010	Principal Research Scientist; Adjunct Associate Professor	Department of Fisheries, Western Australia; The University of Western Australia
Mark Muir	27/07/2010	Chairman	Lake Muir Denbarker Community Feral Pig Eradication Group
Dr Stephen Beatty	08/05/2012	Research Fellow	Murdoch University

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A guide to managing and restoring wetlands in Western Australia

Livestock

In Chapter 3: **Managing wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Livestock' topic

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Contents

Case studies

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'. In particular, note that grazing constitutes clearing under the provisions of the Environmental Protection (Clearing of Native Vegetation) Regulations 2004 and you may require a permit to graze livestock. For additional detail, see the section of this topic entitled 'Legal considerations'.

Livestock: for the purposes of this topic, the term livestock refers to introduced domestic ungulate (or hoofed) animals. While the focus is on sheep, cattle and horses as these are commonly farmed at or near wetlands, general principles introduced in this topic will also apply to other introduced ungulates such as goats, donkeys, deer, llamas, alpacas and camels. Management of feral populations of these animals is discussed in the topic 'Introduced and nuisance animals' in Chapter 3.

Introduction

The **livestock** industry was one of the first to be established in WA, and it remains extremely important to the state's economy. Since pastoralism first expanded across the state, wetlands have been valued as watering points and areas of good grazing for livestock. As farms became established, many wetlands in agricultural areas were cleared for pasture.

Wetlands contain valuable resources for livestock, including water for drinking and cooling off, trees for shade and shelter and plants that are highly palatable. As a result, wetlands are often used more intensively by livestock than other areas of the landscape, especially when it is dry and during drought. Many factors influence the degree to which livestock may impact upon a wetland, but in many cases, livestock grazing has resulted in significant degradation of wetlands.

Fortunately, livestock management systems better suited to Western Australian conditions are now available and becoming more popular. With livestock grazing forming the main land use across more than 40 per cent of the state, livestock management practices have the potential to affect many of WA's wetlands (Figure1). Sound management of wetlands on grazing land can have benefits for landholders and their livestock, the local community and future generations, because well managed wetlands can provide a range of services valuable to society. Livestock owners can use the management and restoration practices outlined in this topic to minimise the impacts of livestock, improve the condition of their wetlands and, in many cases, improve the health of their animals.

Figure 1. (below) (a) A fenced well-managed wetland in good condition on a horse property near Serpentine. Photo – C Prideaux/DEC. (b) A wetland near Gingin degraded by continuous cattle access. Water is contaminated by sediment, nutrients and faeces, vegetation has been damaged and removed and soils are pugged and exposed. The landowner is currently undertaking fencing to exclude livestock. Photo – R Lynch/DEC.

(a)

(b)

Ten good reasons to keep livestock out of wetlands

Allowing livestock to access wetlands is not only damaging to wetlands, it can also compromise livestock health, reduce productivity and create management problems. Sound livestock management will have benefits for wetlands and positive effects on livestock health and productivity.

1. Livestock contaminate wetland water with urine and faeces, disease-causing organisms and sediments. The poor water quality may cause livestock to reduce their water consumption or refuse to drink from the wetland. Providing alternatives to direct watering from wetlands improves water quality and some studies have found it improves livestock health and productivity.[1]
2. When water levels are low, livestock with no alternative water sources may be forced to wade through mud to drink. Weak or sick animals can become trapped and die.
3. Nutrients from livestock urine and faeces can accumulate in wetland waters and cause excessive algal growth. Blue-green algal blooms caused by excess nutrients in the water can be toxic to livestock.
4. Midges and mosquitoes can be more abundant in wetlands and, in particular, wetlands with poor water quality can be predisposed to nuisance midge populations. Livestock, especially horses, can suffer irritation and allergic reactions to these insects. In some areas, livestock may also be at greater risk of mosquito-borne disease.
5. Livestock kept in waterlogged or muddy paddocks are prone to bacterial and fungal infections. Cattle can experience problems caused by wet mud-covered udders and hooves.[1] Horses can suffer from infections of the hooves and legs such as 'mud fever', 'greasy heel', thrush[2] and sheep from foot rot and fly strike.[3]
6. Parasites such as Barber's pole worm, a serious roundworm parasite of sheep and goats in coastal and high rainfall areas of WA, can survive where pasture remains green over summer.[4] Allowing uncontrolled livestock access to wetlands can exacerbate worm problems and counteract worm control programs.
7. While some wetlands contain palatable native plants, most native vegetation is of low to very low nutritional value. Livestock that spend substantial time grazing coastal wetlands may develop deficiencies in trace elements such as copper and cobalt and require supplementation (R Butler 2009, pers. comm.). Sheep, cattle and horses which graze on stringy and fibrous native vegetation may develop fibrous masses called 'phytobezoars' in various parts of their gut[5] (Figure 2). These can cause obstructions, peritonitis and, occasionally, death (R Butler 2009, pers. comm.).

Figure 2. Phytobezoars inside a sheep gut, formed after grazing on native vegetation. Photo – R Butler/ Department of Agriculture and Food.

8. Mustering and moving livestock can be more difficult when they have access to wooded wetlands, where they can hide.
9. Allowing livestock to access wetlands can spread weeds, which can reduce biodiversity, increase the threat of fire and result in the need for costly weed management.
10. A degraded wetland filled with green, foul-smelling water, blue-green algae which are toxic to humans and livestock, and clouds of nuisance insects, is a management problem, a hazard and an eyesore. In contrast, many people will find a well-managed wetland visually appealing, enjoy the fact that it provides recreational opportunities and attracts native animals such as birds and frogs (Figure 3). A wetland in good condition can be an asset which demonstrates good land management practices and may add value when selling a property or diversifying into farm-based tourism.

How do livestock affect wetlands?

Before European settlement, Western Australian wetlands were grazed by native animals such as kangaroos, wallabies, emus and waterbirds. Native plants have adapted to **grazing** by native animals at natural densities[6] and it is thought that this natural process may be important in maintaining species and structural diversity in some wetlands.[3] However, heavy grazing by any animal will damage native vegetation, regardless of whether it is domestic or commercial livestock, feral animals, native fauna, rabbits or insects.[6]

Livestock access can cause severe degradation of wetlands. Livestock activities can compact and erode the soil, increase runoff and levels of sediments, nutrients and contaminants in wetlands, change the vegetation and degrade the habitats of native animals (Figure 3). These changes can cause serious damage to wetland **ecosystems** (Figure 4). Impacts can be compounded by certain management activities such as clearing of native vegetation for pastures, leaching of farm chemicals, fertilisers and other treatments into water supplies. Other poorly planned activities like carcass burial and inappropriate placement of infrastructure can impact on wetland condition.[7] Well-placed stockyards, waste ponds, roads and storage facilities can improve efficiency and reduce environmental impacts.

Grazing: feeding on grasses and other low-growing herbaceous vegetation

Ecosystem: a community of interdependent organisms together with their non-living environment. Natural ecosystems provide a range of benefits and services to humans such as clean water, nutrient cycling, climate regulation, waste decomposition and crop pollination

Figure 3. Sheep have contaminated this seasonally inundated wetland with faeces and urine, pugged the soils and removed most of the vegetation. Photo – R Lynch/DEC.

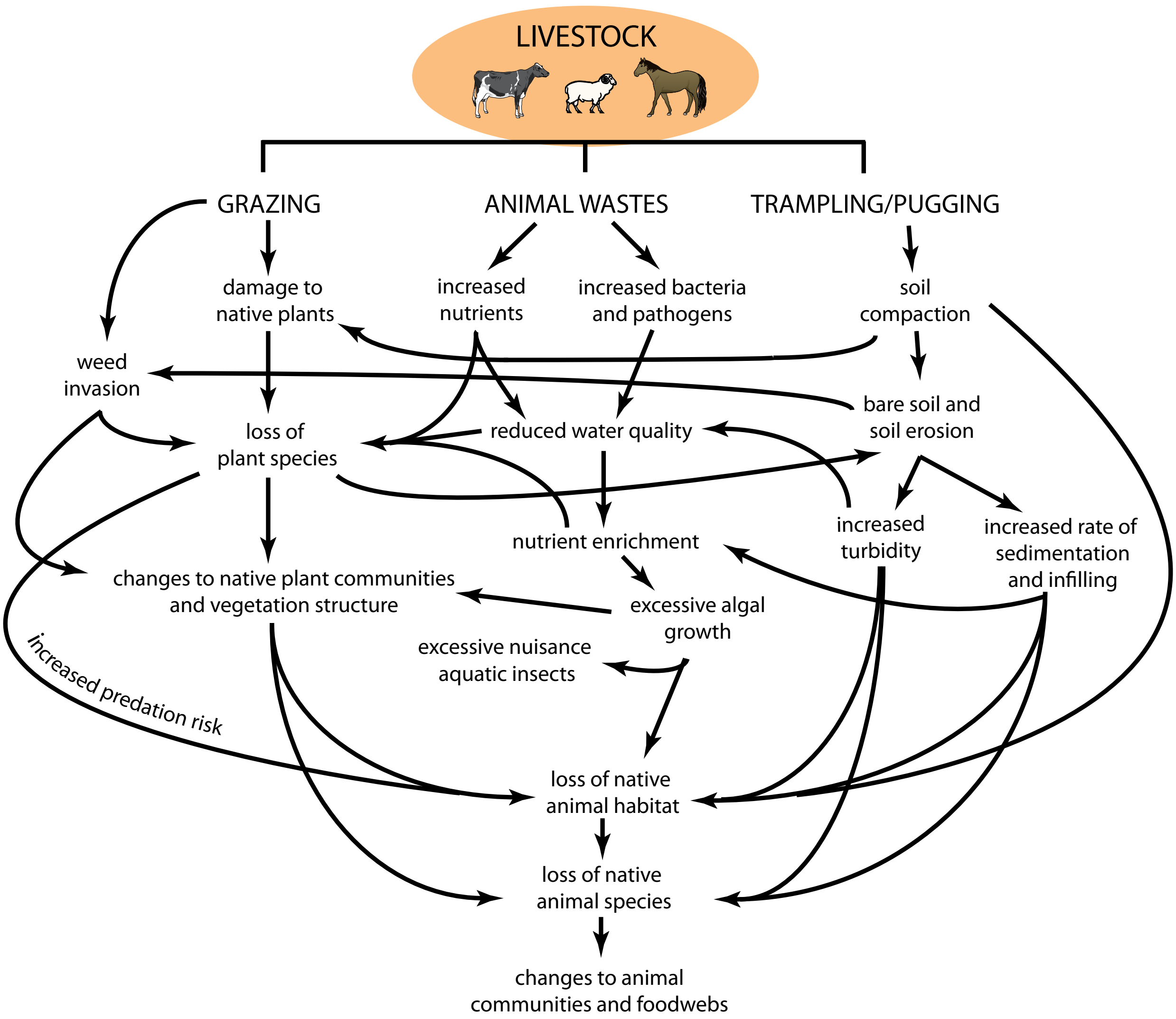


Figure 4. Some impacts of livestock on wetlands.

Effect of wetland type and season

Wetlands differ in attractiveness to livestock depending on the resources present and the time of year. Wetlands with permanent fresh water may be used for drinking by livestock all year round, especially if there are no alternative water sources. This can result in severe impacts on soils, vegetation and water quality (Figure 5). During hot, dry periods of the year and during drought, impacts may be intense as livestock will loiter in wetlands that are shady and cool even when alternative drinking water is available.

Figure 5. This permanent spring near Gingin has been severely degraded by continuous cattle access. Photo – C Mykytiuk/WWF Australia.

Wetlands that are dry at some times of the year may have less livestock activity when they are completely dry. However, this is not always the case, as these wetlands often support a wide variety of very palatable plants both when they are drying out and when dry, and they may be favoured by livestock for grazing at these times (Figure 6).

Figure 6. (below) Large areas of flat, (a) seasonally inundated and (b) seasonally waterlogged wetlands on the Swan Coastal Plain, like these near Dunsborough, were historically cleared for agriculture as they are highly productive. Photos – R Lynch/DEC.

(a)

(b)

Impacts on wetland vegetation

Livestock do not affect all species of plants in the same way, but the overall effect of uncontrolled livestock grazing is to degrade wetland vegetation. The impact of livestock on wetland vegetation depends on many factors. These include the plant species present, the age and size of individual plants, the type of livestock, the stocking rate, the timing of grazing and environmental conditions such as rainfall.

Browse: to feed on leaves, twigs or bark from non-herbaceous (woody) plants, such as trees and shrubs

Unmanaged, livestock will reduce native plant diversity, reduce the structural complexity of vegetation and degrade wetland habitats. These impacts can be compounded by other impacts such as plant diseases, drought, weeds, fire and changes to the natural water regime.[3]

Impacts of different types of livestock

Livestock affect native plants in different ways, due to their physical differences in height, their grazing preferences and the way in which they are able to use their lips and tongues[8] (Table 1). The behaviour of livestock also varies with factors such as herd size, breed and climatic conditions.[9]

Cattle are unable to graze as close to the soil as other species, so the survival of herbaceous species (herbs) is always higher with cattle grazing than sheep.[10] The mobile lips of sheep and the way they use their tongues allow them to feed very selectively. They can easily choose individual leaves over others on the same plant and graze plants very close to the ground.

Goats are similar to sheep in their ability to selectively graze, but prefer a wider range of plants in their diet. They are quite adaptable to different food types and **browse** by climbing high into vegetation to feed. Up to 80 per cent of their diet can be from small trees and shrubs.[8] Goats should always be excluded from wetlands as they cause enormous damage to wetland vegetation.[11]

Table 1. Feeding preferences of cattle, horses and sheep[12,8,3]

Cattle	Horses	Sheep
Are least selective	More selective than cattle	Most selective grazers
Cannot graze as close to the ground as sheep	Tend to be spot grazers, grazing one area close to the ground and leaving other areas for droppings	Can crop vegetation very close to the ground
Prefer plants 10–30 cm in height	Like short grasses and avoid grazing woody plants	Prefer drier vegetation and are more likely to graze on woody seedlings; prefer to graze plants in the following order: herbs, broadleaved grasses, fine-leaved grasses, sedges, and dwarf shrubs
Can reach higher to browse upper stems of shrubs and lower tree branches	Can kill paddock trees by defoliating and bark stripping	Cannot browse shrubs and trees as high as cattle
Will readily enter water to feed on emergent wetland vegetation and can remove whole stands	Will enter water	Do not like to enter water

Physical damage to plants

Livestock grazing damages plants and plants differ in their ability to withstand this impact.

Grazing livestock remove the leaves or foliage from plants (called defoliation) and sometimes uproot the whole plant. This removes nutrients which must then be re-acquired from the soil. Plants may not recover well when nutrient availability is low as defoliation can reduce a plant's ability to take up nutrients when they are in low supply.[13]

Plant species respond to livestock grazing in different ways[14] and differ widely in their ability to withstand the impact of defoliation.[10] For example, a study in which plants were clipped to simulate grazing found that the clipped plants responded in one of three ways. In some species, amount of plant material and reproduction increased, in some the amount and reproduction decreased, and in others the amount decreased while reproduction increased.[15] For some plant species, grazing at low intensity stimulates greater growth, but in general plant performance decreases as grazing intensity increases.[12]

Many wetland plants are sensitive to grazing when they are seedlings and when they are flowering or setting seed. Grazing may impair reproduction by reducing flowering and seed production which results in fewer new plants being produced.[9,10] **Annual** species are usually more tolerant of disturbance because they grow fast and produce lots of seed early. Palatable **perennial** species of **herbs**, shrubs and trees are more vulnerable, because they are comparatively slow-growing and usually require several years to reach reproductive maturity.[16] Seedlings can also be more vulnerable to grazing as their root systems are not fully established.

Livestock graze selectively, choosing the ground layer plants and seedlings they prefer first, along with **palatable** shrub and tree foliage within reach[6] (Figure 7). Grazing animals often prefer new plant growth and revisit grazed patches to feed on regrowth[12], so individual plants can be repeatedly defoliated. Over time, continuous grazing may reduce the capacity of plants to survive, grow and reproduce.

Annual: a plant that normally completes its life cycle (from germination to flowering, seed production and death of vegetative parts) within a single growing season

Perennial: a plant that normally completes its life cycle (from germination to flowering, seed production and death of vegetative parts) in two or more growing seasons

Herb: a small non-woody, seed-bearing plant in which all the above-ground parts die back at the end of each growing season

Palatable: pleasant-tasting

Figure 7. Cattle have grazed and trampled the understorey and created a 'browse line' by eating the low foliage from these paperbark trees in a wetland near Muchea. The cattle have not eaten the less palatable *Astartea* spp. shrubs (on the left).
Photo – C Mykytiuk/WWF Australia.

Livestock also damage plants by trampling, rubbing and ring-barking.Trampling and tracking–can damage and kill **understorey** plants (Figure 8). Rams, bulls and stags like to butt and rub against trees and shrubs, damaging branches and causing death by ringbarking. Horses, which are more active that other livestock, are also notorious for killing isolated paddock trees by stripping bark and foliage, often out of boredom[6] (Figure 9). Other types of livestock will also strip bark, for example, sheep will chew bark and ringbark trees, often in autumn when there is little fibre in paddock feed.[6]

Understorey: the layer of vegetation beneath the main canopy

(a) (b)

Figure 8. Effects of livestock trampling on wetlands. (a) Cattle tracking has damaged a samphire (*Sarcocornia* spp.) wetland community in Capel. Photo – S Priddle/NGH Environmental. (b) Horses have trampled wetland vegetation along a fence line within a paddock near Australind. Photo – R Lynch/DEC.

(a) (b)

Figure 9. Bark-stripping by livestock. (a) Horses have stripped the bark of a tree in a seasonally waterlogged wetland near Capel. Photo – K Wenziker/DEC. (b) Cattle have stripped bark from a paperbark (*Melaleuca* spp.) tree in a wetland on the Swan Coastal Plain. Photo – M Rogers/DEC.

Some wetland plants and plant communities are more sensitive to livestock impacts than others. The following case study profiles the effect of livestock on samphires.

case study

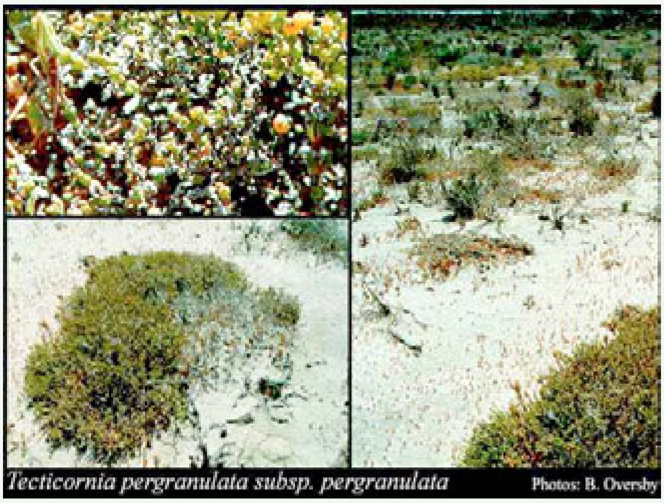
Samphires – grazing-sensitive wetland plants

The name samphire refers to a group of delicate perennial low succulent shrubs including *Sarcocornia, Halosarcia* and *Tecticornia* species. Many saline wetlands in Western Australia support samphires, such as salt lakes, salt pans, salt marshes, coastal flats and saline drainage lines. Many samphire species have evolved to grow in specific areas, under certain conditions in harsh environments and are quite fragile and susceptible to change.[17] Samphires grow actively only during wet periods. Samphires in general produce large quantities of seeds that are held in spongy or woody parts of the plant to be released when conditions are suitable for germination.[17] They germinate after rain when the soil is wet with relatively fresh water.

In general, samphires are high in salt and have low feed value for livestock[18], but sheep will eat samphires if there is fresh water for them to drink and access to supplementary dry food such as crop stubble[17] (Figure 10). Samphires are brittle plants and are particularly sensitive to trampling by hoofed animals. Where grazing and trampling is indiscriminate, samphire plants may be unable to regenerate or re-establish and they can die out.[19]

Where samphire areas are to be grazed, it is best to fence them and only allow sheep to graze for a short period when it is dry and other feed is exhausted. To maximise their recovery, they should be protected from livestock for the rest of the year.[17]

➤ For more information about samphires, see *Samphires in Western Australia*.[17]



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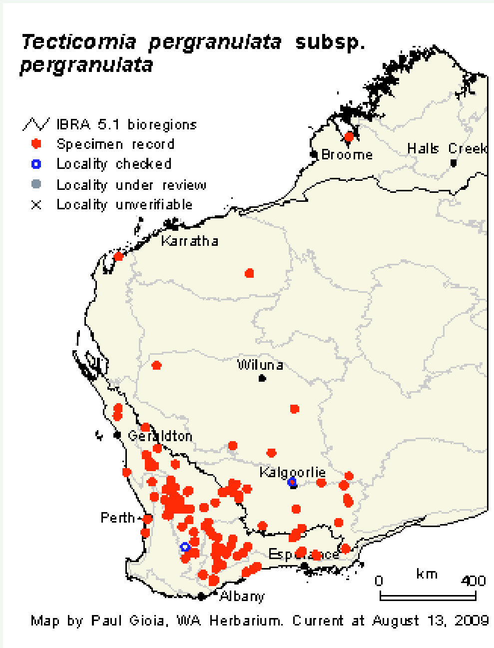


(b)

Figure 10. (a) Blackseed samphire (*Tecticornia pergranulata*) is commonly used as animal feed.[17] Photo – B Oversby; (b) Distribution of blackseed samphire in WA. Image – P Gioia/DEC. Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright.

case study

Mound springs in the WA rangelands – wetlands especially vulnerable to livestock grazing

Mound springs are an uncommon wetland type which occurs around permanent groundwater springs. Most of WA's mound spring types occur either in a restricted geographic area or there are a few isolated occurrences.

In the rangelands of WA, existing mound springs are known from the Kimberley region and in and on the edge of the Great Sandy Desert. They occur singularly or in clusters of up to around twenty separated by several metres to tens of kilometres.[20] These wetlands contain 'mounds' formed from peaty organic soil which can rise up to two metres above the surrounding landscape and be up to several hundred metres across.[20] Research at two mound springs in the Great Sandy Desert has shown that organic sediments have accumulated continuously over the past 6,000 years.[21] The mound is often surrounded by a moat of fresh or low salinity water.[20] Mound spring vegetation can range from sedgelands to paperbark (*Melaleuca*) forests to *Sesbania* woodlands to monsoon vine thickets.[20] The plant and invertebrate communities of mound springs are often diverse or unusual and sometimes contain rare plant species which were more widely distributed in the past when the climate was wetter.[20] As well as having significant ecological values, many mound springs have cultural values for local Aboriginal people.

The presence of permanent water, dense vegetation and sometimes shade can make mound spring communities particularly attractive to cattle as well as feral camels and pigs. Mound springs are particularly vulnerable to livestock activity as it damages the vegetation, causes erosion of the fragile peat soils, can promote weed invasion and contamination of the groundwater source. Several mound spring community types have been listed as threatened ecological communities (TECs).

Springs and mound springs can be best protected by fencing them to keep livestock out (Figure 11, see also Figure 31).

Figure 11. Two plant communities within Saunders Spring, an organic mound spring, in the Shire of Broome. Photos – G Daniel/DEC.

Loss of leaf litter

Livestock reduce leaf litter. **Leaf litter** performs several important ecological functions: it breaks down to return nutrients to the soil, it creates habitat for invertebrates and other small animals and it protects the soil surface from the sun. Loss of leaf litter can affect plants by changing the microclimate around them, allowing heat to damage their roots, increasing water loss and reducing their growth.[6] Grazing livestock remove much of the foliage that would become leaf litter and some livestock, such as sheep, even consume leaf litter when other food sources are in short supply.

Leaf litter: dead plant matter including leaves, flowers, nuts, sticks and bark which accumulates on the ground

Diversity: a measure of the number of species of a particular type and their abundance in a community, area or ecosystem. It can refer to a particular group of organisms, such as native plant diversity or frog diversity. The broader term **biodiversity** is used to encompass the whole variety of life forms–the different plants, animals, fungi and microorganisms–the genes they contain, and the ecosystems they form

Figure 12. Leaf litter around shrubs in a wetland. Photo – K Wenziker/DEC.

Weed invasion

Livestock can promote weed invasion of wetlands. There are many wetland weeds that pose serious threats to the condition of WA wetlands. Many weeds also greatly reduce the grazing value of wetlands. Weed seeds may be carried into wetlands in the coats, hooves or faeces of livestock as well as by wind and water.[22] Nutrients in livestock urine and faeces and bare patches of ground created by overgrazing or trampling increase opportunities for weeds to grow.[22]

Many weed species are well adapted to coping with grazing, as they originate from regions of the world where hoofed animals are part of the natural environment. Weeds tend to be good at either growing back quickly or withstanding damage from trampling and grazing. In general, weeds are fast growing and reach reproductive maturity more rapidly than native plants, so livestock grazing often doesn’t disrupt reproduction to the degree that it does for native plants.

Weeds have a detrimental effect on native vegetation by competing with and inhibiting growth of established plants, inhibiting native plant regeneration, altering nutrient cycling and reducing native plant **diversity**.[6]

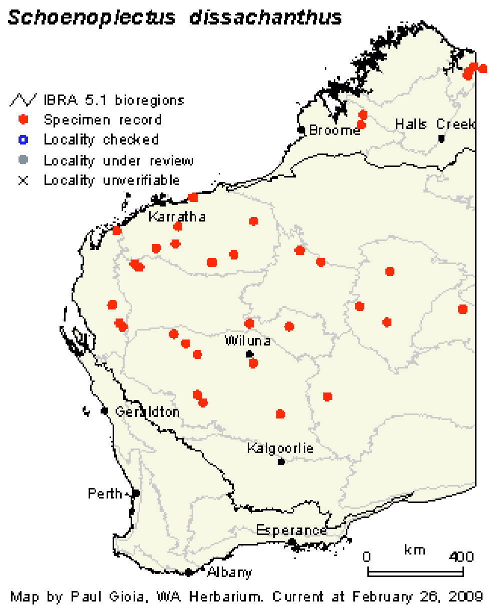
➤ For additional detail, see the topic ‘Wetland weeds’ in Chapter 3.

Reduction in plant diversity and complexity

Some plant species decline in numbers under continuous livestock grazing while other species increase. Over time this leads to loss of native plant diversity. Livestock activity can cause changes to the abundance and diversity of plant species in a wetland. There is often a decrease in the palatable, grazing-sensitive species (called 'decreasers') and an increase in the number and distribution of unpalatable and grazing-resistant species (or 'increasers').[10] For example, pale spikerush (*Eleocharis pallens*), a perennial sedge found in central Western Australian wetlands, and *Schoenoplectus dissachanthus* (Figure 13), an annual sedge found in central WA and Kimberley wetlands, both decrease under persistent grazing. Bluerod (*Stemodia florulenta*), an erect faintly scented perennial shrub, is a wetland 'increaser'.[18] Many weed species are 'increaser' species.

Figure 13. (below) (a) *Schoenoplectus dissachanthus*, a wetland decreaser. Photo – CP Campbell. (b) *Schoenoplectus dissachanthus* distribution in WA. Image – P Gioia/DEC. Images used with the permission of the Western Australian Herbarium, Department of Environment and Conservation http://florabase.dec.wa.gov.au/help/copyright.

(a)



(b)

Loss of 'decreaser' species and greater dominance of 'increaser' species results in plant communities with lower native plant diversity. Such changes in abundance of native plant species are often a sign of declining land condition.[18]

Over time, uncontrolled livestock activity reduces the vegetation structure of wetland plant communities. Livestock grazing on native shrub and tree seedlings can prevent them from reaching maturity and reproducing. As mature trees age and die naturally, they are not replaced and the **vegetation structure** may change from a wetland with trees to a more open community (Figure 14).

Vegetation structure: the three-dimensional distribution of plant material. It includes the horizontal spacing of plants and the vertical heights or layers

Figure 14. (below) (a) A wetland near Bunbury in good condition showing diversity of plant species and vegetation structure (layers). Photo – R Lynch/DEC. (b) A wetland in the Shire of Serpentine-Jarrahdale degraded by continuous heavy cattle grazing. Ground layer plants have been removed, the soil is compacted, mature trees have aged and died and there are no seedlings to replace them. The bare soil is more susceptible to erosion and colonisation by annual weeds. Photo – E Davies Ward/DEC.

(a)

(b)

Soil damage

Livestock trampling can damage the soil, increase erosion and reduce soil spaces, and decrease water infiltration, nutrient cycling, germination and plant growth. **Pugging** is a highly visible form of soil damage caused by livestock activity in and around wetlands (Figure 15). It occurs as their hooves sink into wet soil, leaving depressions and compacting and damaging the soil surface and microstructure, and leaving it more vulnerable to erosion.[23] Compacted soil contains fewer spaces, known as **macropores**, within the soil. Macropores are important for soil aeration and the activity of microbes and other soil fauna, which play an important role in cycling nutrients and maintaining the condition of the soil. When there are fewer spaces between soil particles, less water can soak into the soil. As a result less moisture reaches plant roots[24] reducing plant growth and vigour. Soil compaction may also damage native seeds stored in the soil, reduce their germination, and reduce the chance of germinating seeds reaching the soil surface. Small pools of water that form in the depressions left by pugging can increase the period of time that plants stay wet, causing poor performance or favouring other species more tolerant of the altered conditions. Soils are at greatest risk of compaction when they are wet and heavily grazed.[23]

Pugging: depressions, hoof prints or 'pug' marks made in wet soil by trampling animals

Macropores: spaces in the soil (usually less than 2 millimetres diameter) that include channels created by cracking, old plant roots and soil fauna (such as earthworms). Macropores indicate good soil structure

Wetland hydrology: the movement of water in and out of, and within, a wetland

(a) (b)

Figure 15. (a) Soil pugging by cattle in a seasonally inundated wetland near Gingin. Photo – C Mykytiuk/WWF Australia. (b) Soil pugging by horses in a seasonally waterlogged wetland. Photo – M Rogers/DEC.

Changes to wetland hydrology

Livestock tracks and farm infrastructure can degrade wetland ecosystems by changing the natural pattern of water flow to and from wetlands. 'Critical control points' are natural landscape features that act as dams or levees, causing surface water flows to slow, spread and pool, creating wetlands. They range from rock bars across rivers to low ridges of sand which trap water in small intermittently inundated wetlands.[25] Trails made by livestock and tracks for farm vehicles can act as shallow channels which breach (cut through) critical control points. Instead of slowing and pooling in the wetland, water flow is faster and concentrates along these pathways of bare compacted soil. This increases soil erosion and creates problems such as gullies. Depending on the circumstances, these incisions may channel more water and contaminants into wetlands or divert water away from wetlands. In some cases, this process has caused the intrusion of salt water into freshwater wetlands.[26] Altering drainage patterns can affect **wetland hydrology**, which may have major implications for wetland plants and animals and physical and ecological processes.

➤ For additional detail, see the topic 'Wetland hydrology' in Chapter 2.

For example, in the Murchison River catchment and tropical floodplain grasslands of northern Australia, cattle trails to river pools often breach critical control points on grassy floodplains (seasonally inundated wetlands). The water that formerly spread out across the floodplain becomes channelled along the cattle trails, forming erosion gullies which cut back into the floodplain. The changed drainage pattern has negative impacts on ecology and production in the rangelands. Instead of capturing water which can soak into the soil, the floodplains are drained rapidly and less palatable dryland shrubs begin to replace the native grassland community.[26]

Erosion: the gradual wearing away and movement of land surface materials (especially rocks, sediments and soils) by the action of water, wind, or a glacier

➤ For an example of pastoralists working together to reverse the problem discussed above, see the case study about Wooleen Lake in the Murchison River catchment in *Pastoral management options for central Australian wetlands – Fat cows and happy greenies*[18] (p.61).

Why wetlands shouldn't be dug out

Many farmers dig out natural wetlands to increase the depth or permanency of water for livestock use or other reasons. There are several reasons why this should not be done.

- Using heavy machinery to excavate wetlands causes soil compaction and damage to the soil surface and vegetation.
- Disturbing wetland soils in acid sulphate risk areas can cause acidification of soils and water.
- Changing the topography (landscape shape) alters the wetland's hydrology and habitats. This may change the types of plants and animals that can occur there.

It is better to find alternative sources of water, leave these valuable habitats undisturbed and appreciate them for their natural values, such as the wildlife that occur there.

➤ For additional detail about the impact of acid sulphate soils in wetlands, see the topic 'Water quality' in Chapter 3. For additional detail about wetland hydrology, see the topic 'Managing hydrology' in Chapter 3.

Soil erosion, turbidity and sedimentation

Livestock activity can cause soil erosion which degrades wetland habitats. The movement or **erosion** of soil by rain and flooding is a natural process, but this process can be greatly accelerated by livestock. When soil becomes compacted by livestock trampling, less rainfall infiltrates into the soil and more flows over the soil surface. This is compounded by the loss of groundcover to slow the water down and by the presence of livestock trails which channel the water (Figure 16). When more water flows more rapidly across the soil surface, it can remove more topsoil and create fissures and gullies in the ground (Figure 17).

➤ For additional detail about the effects of erosion on wetland water quality, refer to the topic 'Water quality' in Chapter 3.

Turbid: the cloudy appearance of water due to suspended material

Figure 16. Livestock trails through the vegetation have created new pathways for the movement of surface water and contaminants into the wetland. Photo – C Mykytiuk/WWF Australia.

Figure 17. Erosion and gullying caused by cattle grazing. Photo – R George/Department of Agriculture and Food Western Australia.

Soil erosion in a wetland's catchment results in increased quantities of sediment entering the wetland during rain and floods. Fine particles may remain suspended in the water, causing **turbid** conditions. In this 'muddy' state, less light is available to water plants and algae for photosynthesis, which causes reduced plant growth or death. As sediments begin to settle, they smother animals living on the bottom by clogging their gills and causing problems for filter-feeders; coat organic deposits and algae upon which aquatic animals depend for food and cover; and fill in aquatic habitats.[27, 28] Over time, increased erosion and sedimentation can gradually fill in wetland basins.[27]

Erosion is a serious environmental problem, particularly in arid lands managed for pastoral production.[29] The most important factor in reducing erosion is managing total grazing pressure. **Total grazing pressure** describes the combined impact of all grazing animals—domestic, wild, native and feral—on the vegetation, soil and water resources of a particular area.[30] When too many animals are grazing an area, **groundcover** will be reduced by grazing and trampling and the soil will become exposed and vulnerable to erosion.

Groundcover: the percentage of ground covered by plant materials (alive or dead) and leaf litter

Erosion is influenced by other factors including the body weight and type of grazing animal, slope steepness and the ability of the soil type to withstand trampling under wet conditions.[23] Livestock access to steep slopes, particularly by cattle (which are heavier than other species), can result in substantial damage such as collapse or slumping of banks and gullying.[9,14] Some types of livestock, although lighter in body weight, can cause extensive soil damage and promote erosion when allowed access to wetlands, because of their specific behaviours. For example, red deer deliberately create muddy wallows during the mating season, cake mud onto their hides to assist in scratching off their winter coats, and use mud to protect themselves from biting insects at other times of the year.[23] Pigs rapidly damage areas of wetland because they dig, turn over the soil and uproot vegetation while foraging for roots, tubers and invertebrates.

Nutrient enrichment

Livestock faeces and urine entering wetlands can cause nutrient enrichment, algal blooms and nuisance insect problems. Livestock faeces and urine are highly concentrated sources of nutrients, particularly nitrogen and phosphorous. Most Western Australian soils have naturally low levels of nutrients and native plants are adapted to cope with this. Livestock faeces and urine can be detrimental to the survival of some native plants, such as banksias[6], which cannot tolerate high levels of phosphorus.

Livestock faeces and urine are deposited directly in wetlands when livestock are allowed to graze in them. Excess nutrients from livestock faeces and urine, fertilisers and eroded sediments also enter wetlands from surrounding pastures in surface water runoff or by leaching into groundwater that flows into the wetland. Increased nutrients in wetlands (especially nitrogen and phosphorous) can result in excessive growth of water plants and algal blooms (Figure 18). Algal blooms may include blue-green algae, some of which are toxic to humans, pets, livestock and wildlife. They can also can cause taste, odour and aesthetic problems (they look like a green paint-like scum on the water).[27]

Figure 18. An algal bloom in a nutrient-enriched wetland on a cattle property near Muchea. Photo – C Mykytiuk/WWF Australia.

Changes in plant growth can alter the type and quantity of food and habitat available to wetland organisms, affecting food web structure and function, as well as favouring some species over others. Algal blooms deplete the oxygen supply which can result in death of aquatic animals (such as fish kills).[27] Nuisance midge numbers are often higher in nutrient enriched wetlands.

➤ For additional detail, see the topic 'Water quality' in Chapter 3.

extra information

How much faeces and urine?

Horses and cattle produce large amounts of faeces and urine. A standard light horse (450 kilograms) produces approximately 5.5 tonnes of wet faeces and 5.5 kilolitres of urine each year. This volume of waste contains 62 kilograms of nitrogen (N) and 5.5 kilograms of phosphorus (P).[31] If poorly managed, livestock faeces and urine can contaminate both groundwater and surface water[31] (Figure 19).

Figure 19. Grazing horses have removed most of the native vegetation in this seasonally inundated wetland in Kenwick. Horse manure accumulating on the degraded pasture will be washed into the water during heavy rainfall as there is little vegetation to trap it. Photo – M Rogers/DEC.

Contamination by pathogens

Livestock faeces are a source of bacteria, viruses and parasites which can pose serious health risks to humans, livestock and wildlife. Bacteria, such as *Salmonella*, and other harmful disease-causing organisms can enter wetland waters from livestock faeces and urine. Infection can lead to scouring (diarrhoea) and death of livestock. Research has shown that young livestock (particularly foals and dairy calves) have higher rates of infection by the parasites *Cryptosporidium* and *Giardia* and excrete large amounts of infective oocytes or cysts[32,33] which can contaminate water supplies. Some strains cause diarrhoea, and sometimes death, in young or weakened humans, livestock and other animals.

Faecal contamination is likely to be higher when livestock are allowed free access to wetland waters; no alternative drinking water is provided; stocking rates are high; the livestock are deer or cattle (these species are more likely to defecate in the water); or there is no alternative shade available in hot weather.[23] Contamination can also occur when livestock become trapped and die in wetlands or groundwater sources become contaminated by buried carcasses.

Chemical contamination

Unless carefully managed, agricultural chemicals such as herbicides, veterinary chemicals, fuel, oil or solvents can leak or drain into surface water or leach into groundwater. The active ingredients of some worm drenches are toxic to invertebrates (of which many are beneficial to soil health); these toxic drenches can enter the water when they leach out of faeces and urine.[31] Unless carefully managed, spraying herbicides, pesticides or fertilisers onto pastures next to wetlands can cause death of native plants and animals and contaminate wetland waters through run-off and spray drift.

Impacts on native animals

Livestock can impact native animals by trampling them or their nests and degrading the habitats and resources they require. Wetlands in good condition provide a wide variety of habitats and resources such as food, shelter, roosts and breeding sites and are important to a wide range of native animals. When these resources are degraded, some species may not be able to survive or breed (Figure 20). In particular, animal species that breed, shelter or feed on the ground, under leaf litter or in low vegetation may be more affected by loss of food sources, at greater risk of injury or nest damage by livestock trampling or be more exposed to predation due to loss of protective vegetation cover.[3] For example, on floodplains in south-eastern Australia, frog and bird communities varied with livestock grazing intensity.[34] Frog diversity, the numbers of some species of tadpoles and frogs and the numbers of small insect-eating birds (which depend on insects found in understorey vegetation, fallen logs and leaf litter) were lower where grazing intensity was higher because of impacts of grazing on wetland vegetation.[34,35]

Figure 20. Cattle have damaged this wetland near Harvey and degraded the resources used by wetland animals. The soil is trampled and exposed. The water is muddy and contaminated with wastes. Most native understorey vegetation has been grazed and trampled, except the unpalatable species in the foreground. Photo – R Lynch/DEC.

Aestivating: being in a state of dormancy that occurs in some animals to survive a period when conditions are hot and dry

Trampling also closes spaces and cracks in the ground, collapses burrows and may crush soil-dwelling invertebrates, frogs, tortoises and small mammals.[36] For many intermittently inundated wetlands in semi-arid and arid pastoral lands, the top layer of soil is extremely important when the wetlands are dry, as it contains the dormant stages of aquatic invertebrates, **aestivating** burrowing frogs, seeds and carbon stores until the next time the wetlands are inundated.[37] Trampling can compact and disturb this soil layer and its plant and animal life, and grazing removes the vegetation, exposing the soil to wind erosion.[37]

Grazing livestock also compete for food with native grazers. Livestock grazing may reduce the abundance of important food plants or seeds eaten by certain animals. Native animals often take refuge in wetlands during droughts. As introduced livestock and feral animals also use wetland areas more intensively at these times, native vegetation may become severely overgrazed.

case study

Endangered burrowing crayfish – wetland animals threatened by livestock

The Dunsborough burrowing crayfish (*Engaewa reducta*) is found in seasonally inundated freshwater wetlands between Dunsborough and Margaret River in the south-west of WA.[38,39] The crayfish are small (up to 5 centimetres in length) with large claws that are usually vivid purple or cobalt blue[38] (Figure 21a). They are found in a variety of wetland habitats with moist sandy or loamy soils, including vegetated seeps, swampy plains and swamp headwaters of streams. They construct a complex burrow system that can be several metres deep. At wetter times of the year burrows are marked by conspicuous chimneys of soil pellets (Figure 21b). Their burrows enhance the flow of oxygen, water and nutrients through wetland soils and provide shelter and retreats for other organisms, especially when their habitats dry.

The Dunsborough burrowing crayfish is listed as a critically endangered species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The main threats to the crayfish are land clearing, farm dam construction and cattle grazing.[39] Cattle activity leads to soil compaction and erosion, reduces the water-absorbing and water-holding capacity of soils and trampling of burrows. Farm dam construction alters surface and groundwater flows, increases sedimentation and leads to waterlogging or flooding of suitable habitats.

Two very similar species of *Engaewa* crayfish – the Margaret River burrowing crayfish (*E. pseudoreducta*) and the Walpole burrowing crayfish (*E. walpolea*) – are listed as threatened species under Western Australian legislation.[38] Protecting critical habitat with livestock-proof fencing is a key conservation measure for all of these species of crayfish.[38]

Figure 21. (below) (a) The endangered Dunsborough burrowing crayfish (*Engaewa reducta*). Photo – K Rogerson/DEC. (b) A 'chimney' of soil pellets at the entrance of a crayfish burrow. Photo – J Jackson/DEC.

(a)

(b)

Managing livestock in and around wetlands

Sustainable agriculture is defined as profitable agricultural systems that conserve the environment while contributing to the economic and social wellbeing of rural WA.[40] The challenge for landowners and managers is to manage livestock and properties to be both profitable and ecologically sustainable in the long term. In the past, society and markets have not valued wetlands, but this is now changing and landholders whom manage wetlands are expected to ensure they are in good condition. The good news is that sustainable land management has positive outcomes for landowners and their livestock and that there is assistance, such as technical and financial assistance, available to enable landowners to manage wetlands.

There are four main strategies for managing livestock in and around wetlands (Figure 22):

1. Permanently exclude livestock from the wetland – this is the best option for wetlands.
2. Keep the wetland in reserve for special or emergency use only – this is the best of the options for grazing wetlands.
3. Graze the wetland for a short time period as part of a controlled grazing system – a better option than continuous grazing but this needs to be carefully managed.
4. Continuous wetland grazing – this option has the most impact on wetlands.

Livestock properties are very diverse. They range from a single paddock with a few horses for recreational purposes to extensive sheep and cattle enterprises in the WA rangelands. In considering which strategy is most suitable at a site, many factors relating to the property, the landowner's aims, and the nature of the wetlands need to be taken into account. Note that these options refer to livestock grazing systems and not to intensive livestock-keeping such as feedlots.

Four strategies for managing livestock in and around wetlands

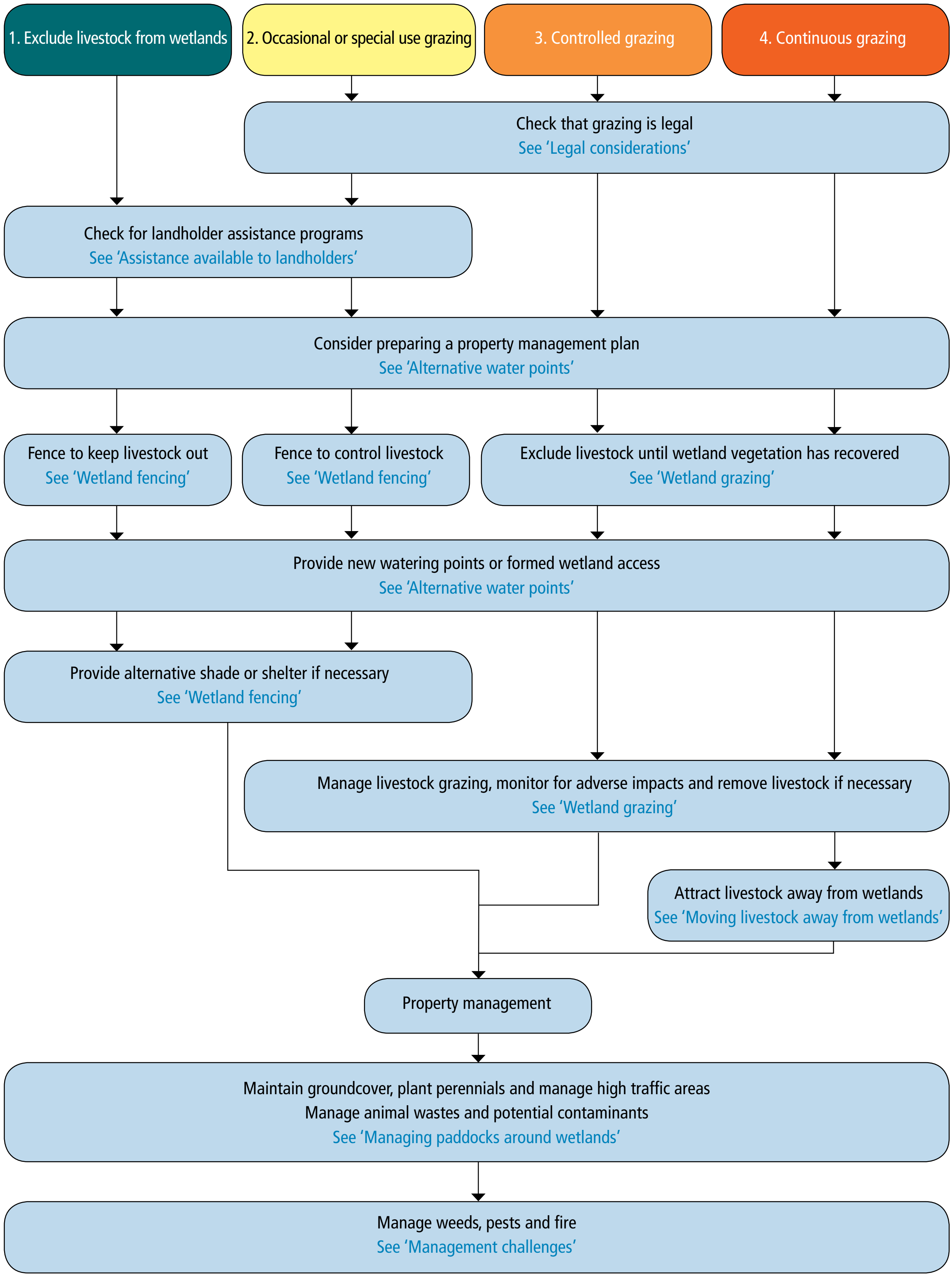


Figure 22. Four strategies for managing livestock in and around wetlands

Assistance available to landowners

Nature conservation assistance programs

There can be significant costs in effectively managing wetlands on livestock properties. Government and non-government organisations recognise that ecologically sound livestock management practices can contribute to the preservation of Western Australia's environment. As it benefits the wider community, a number of organisations have established programs to assist landowners to make positive changes.

➤ Wetland conservation assistance programs are listed in the topic, 'Funding, training and resources' in Chapter 1.

Tax deductions for landcare operations

Landholders or lessees may be able to claim a tax deduction in the year they incur capital expenditure on a 'landcare operation' for land in Australia. Landcare operations cover what were previously known as 'land degradation measures'. Landcare operations include the following activities: erecting fences to keep animals out of areas affected by land degradation, to prevent or limit further damage and help reclaim the areas; erecting fences to separate different land classes in accordance with an approved land management plan; eradicating, exterminating or destroying plant growth detrimental to the land; eradicating or exterminating animal pests from the land; and preventing or combating land degradation other than by the use of fences.

➤ For more information see *Landcare operations tax concessions*[42] from the Australian Taxation Office website (www.ato.gov.au).

Legal considerations

The *Environmental Protection Act 1986* (EP Act) contains provisions for the protection of native vegetation in WA while allowing for approved clearing activities. The native vegetation clearing provisions of the EP Act and the Environmental Protection (Clearing of Native Vegetation) Regulations 2004 came into effect on 8 July 2004 and are administered by DEC. These regulations govern all forms of land clearing. Livestock grazing is clearly identified as a type of clearing, because of its impact on native vegetation. Activities such as increasing the stocking rate on native pastures or grazing regenerated areas will require a permit if an exemption does not apply.

➤ The EP Act and the Environmental Protection (Clearing of Native Vegetation) Regulations 2004[43] can be viewed online at the State Law Publisher's website at www.slp.wa.gov.au. Fact sheets outlining the clearing provisions are available from DEC's website at www.dec.wa.gov.au/nvc.

Farming activities, such as land-use change or intensification, can have the potential to impact upon environmental assets including threatened species and ecological communities, migratory birds, wetlands of international importance, World Heritage properties and national heritage places. Activities which have the potential to impact on these assets need approval under the Australian Government *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The *Environmental Reporting Tool*[44] can provide an indication of whether a particular property is likely to contain any matters of national environmental significance under the EPBC Act.

➤ For more information see *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and *Farming and the national environment law: EPBC Act* fact sheets at www.environment.gov.au/epbc. Other fact sheets are available from the National Farmer's Federation (NFF) (www.nff.org.au/policy/nrm.html). Free advice on how the EPBC Act applies to particular properties is available from the Environment Liaison Officer at the NFF (email: environment@nff.org.au).

Property management planning

Livestock owners can employ a number of strategies to reduce the impacts of livestock on wetlands. A property management plan is a useful way to identify, plan and integrate new strategies into a farming operation. A **property management plan** or whole farm plan is a working plan for the design and management of a property based on its natural resources, the activities undertaken (such as horse breeding or beef production), the manager's goals and financial considerations.[45] A well thought-out and achievable plan can have many benefits including meeting personal and lifestyle goals; maximising the productivity, profitability and sustainability of a property by designing the most effective layout for paddocks, roads, watering points and other infrastructure; and managing and protecting natural resources such as wetlands. Many land managers have taken the steps involved in a property management plan but may not have recorded them in a plan or kept it up to date. A written property management plan is a valuable management tool that maintains a record of information and decisions and can also help with obtaining approvals, funding and tax concessions by demonstrating a duty of care to the environment and natural resources.[45]

➤ See *How to develop a property plan*, available at www.agric.wa.gov.au. HorsesLandWater *Management Guidelines*[45] also provide information about property management planning for horse-keepers. For assistance with property management planning, landholders with small properties (up to 100 hectares) can contact the Small Landholder Information Service (SLIS) at the Department of Agriculture and Food Western Australia or visit www.agric.wa.gov.au. In the rangelands, the Ecologically Sustainable Rangeland Management Program (ESRM) based within the Department of Agriculture and Food can help with property plans. For more information, see www.esrm.com.au.

Some land managers may wish to develop a more detailed plan of management for their wetland. A wetland management plan can also help with obtaining approvals, funding and tax concessions. Various organisations can assist with property planning and wetland management advice. For guidelines on wetland management planning see the topic 'Wetland management planning' in Chapter 1.

Figure 23. Pastoralists engaged in a property planning workshop as part of the Ecologically Sustainable Rangelands Program (ESRM). Photo – L Bayley/Department of Agriculture and Food.

Section 1: Wetland fencing

Fencing is the best tool for reducing the impact of livestock on wetlands. Keeping livestock out of wetlands can reduce erosion and promote livestock safety, protect or improve water quality, regeneration of native vegetation and habitats for native animals. Where it is not feasible to exclude livestock from wetlands, managers can use fencing to control livestock access.

As fencing is often a significant investment it is worth doing well the first time, by planning carefully, choosing good quality materials and using sound construction, as wetland fences often come under extra pressure compared to dryland fences. Issues to consider include the type of livestock, fence location, costs and maintenance requirements. Good access gates may be needed to carry out fire, weed and pest management, and for recreational use and livestock access, if grazing is to be permitted. Where livestock are excluded from wetlands, it is necessary to ensure that they have alternative sources of water, food and shelter.

Fence placement

To protect the whole of a wetland by fencing it involves identifying the whole area of the wetland. For example, a wetland that has surface water for all of the year will have one or more areas that are always under water, as well as areas that are only under water for part of the year. There will also be areas that are waterlogged after the wet season or after cyclonic rain but that eventually dry. As a rule of thumb for fencing purposes, the outer edge of the seasonally waterlogged area following successive wet seasons is the edge of the wetland.

➤ For additional detail on different types of wetlands and determining a wetland boundary, see the topic 'Wetlands in Western Australia' in Chapter 2.

It is best to position fences well above the highest known flood limits. Wetlands are very dynamic environments—that is, they vary over time—and during very wet years, they may cover a much larger area than in dry periods. Placing the fence too close to the edge of the open water can result in flood damage or loss of fences. If possible, locate fence lines where there is low erosion hazard to minimise damage from fence line tracking by livestock.[18]

➤ Determining a wetland boundary can be difficult. For advice about determining an appropriate place to put wetland fencing, contact your local regional DEC office, landcare organisation or NRM wetlands officer.

Fencing an area of dry land between the wetland and the adjacent paddocks helps to buffer wetlands from livestock impacts. Another way to maintain and improve biodiversity is to link wetlands with other areas of remnant vegetation on the property using corridors.

extra information

Wetland buffers and corridors

A buffer is an area of dryland around a wetland that can help to protect the wetland from the impacts of livestock and farm activities, such as chemical and fertiliser drift, wind erosion, nutrient enrichment and weed invasion.

Natural regeneration or replanting a wetland buffer can have other benefits, such as providing a windbreak or shade for livestock outside the fenced area, habitat for native animals and by using water, which may help protect the area from salinity caused by rising groundwater.

For some landholders, allowing for a wetland buffer will be a sacrifice of productive pasture on the wetland margin. However, wetland buffers can be used creatively to provide economic benefits as well as wetland protection. Maintaining or planting the buffer with local native bushland species could be a source of native seed for other local revegetation projects, provide timber, carbon or firewood. Examples which provide future economic benefits include native tree species for timber, carbon or firewood collection, sandalwood (with its host jam trees) or oil mallee for their specific products. It is best to choose species which do not require fertilising or irrigation as these activities will compromise the purpose of the buffer. In each of these cases, harvesting needs to be carefully planned and managed so that it doesn't reduce the function of the buffer or damage the wetland.

➤ For advice about determining an appropriate buffer width, contact your local regional DEC office. For more information about bushland buffers on farms, see the Department of Agriculture and Food publication *Vegetation buffer zones*[46] (www.agric.wa.gov.au).

Wildlife corridors (also known as ecological linkages) are a good way to maintain and improve biodiversity in rural landscapes. Doug and Eva Russell, cattle farmers in Manypeaks, have fenced wetlands and remnant vegetation on their farm (Figure 24). Seventy-three hectares of remnant vegetation and wetlands have been covenanted with the National Trust and their property is registered with DEC's *Land for Wildlife* program. The Russells have used fencing, direct seeding and planting to create vegetated corridors through the cleared farmland which now connect the wetlands and dryland remnants.

(a)

(b)

Figure 24. (a) Doug Russell at a lake on his Manypeaks farm which he has fenced off from cattle. Photo – B Schur/Green Skills Inc. (b) An aerial photo showing (in red) two corridors that have been revegetated to connect fenced wetlands and remnant vegetation. The corridor on the left is along a creek (that flows out of the lake in the foreground) and, in this photo, it had been recently planted. Photo – K Hopkinson/Green Skills Inc.

Fencing for flood-prone areas

When choosing fencing to use near wetlands, it is also important to consider the frequency and extent of flooding that occurs at the site. Fences in wet areas may deteriorate very quickly so putting in expensive fences may be a waste of resources. Instead, portable fencing that can be contracted or expanded to prevent damage to the fence and injury to livestock may be an option where frequent flooding occurs. In wetlands which flow during floods, prefabricated mesh fencing may trap debris like a net and collapse. Plain wire fencing with strainer assemblies either side of the floodway is one option to minimise damage. If it fails, only the section between the strainers will be lost (Tim Saggers 2009, pers. comm.). Lay-down fencing and drop-down fencing are other options for flood-prone areas.[47]

➤ For flood-proof fencing designs see the Department of Water's Water Notes 19 *Flood-proof fencing for waterways.*[47]

Types of fencing

There are many fence designs available to suit different situations. Table 2 compares the advantages and disadvantages of fences commonly used around wetlands. Fences around wetlands can come under extra pressure from livestock (Figure 25) when there is a feed shortage in their paddocks or where there is intensive grazing, so it is essential that they are well constructed. Local knowledge is usually a good guide to local best practice.[48]

➤ Good sources of information on fence types and costs are fencing manufacturers and suppliers (many have informative websites) and local fencing contractors.

Figure 25. Cattle from the paddock on the right have pushed their way through this barbed wire and star picket fence protecting Saunders Spring, a mound spring in the Kimberley, to access the regenerating pasture and wetland vegetation on the left. Photo – G Daniel/DEC.

Table 2. Advantages and disadvantages of common fence types used to exclude livestock from wetlands

Fence type	Advantages	Disadvantages
Plain wire high-tensile fencing High-tensile fencing consists of up to seven tensioned strands of wire usually supported by wooden posts or steel star pickets.	• lower construction costs compared to prefabricated mesh fences • suitable for covering long distances • strong • simple to maintain • longest lasting (up to thirty years) • plain wire (rather than barbed) is less prone to flood damage[49] • less damage to kangaroos (and the fence) compared to mesh fencing	• may deteriorate rapidly if inundated • plain wire is less effective in controlling livestock[49] • can be damaged by livestock and may require electrifying or use of barbed wire for two strands[50] • cheaper for straight sections, more expensive to follow contours[48,51] • plain wires have low visibility and horses in particular have been known to sustain leg injuries from entanglement. Plastic-coated 'sighter' top wires can be used to improve visibility.
Prefabricated mesh fencing These consist of strong 'ready-made' mesh such as Ringlock, Stocklock® and Griplock® suspended between droppers and end posts, often supplemented with one or two plain or barbed top wires. Mesh is manufactured in a range of horizontal wire spacings suited to different types of livestock.	• excellent control for cattle, sheep, lambs and vermin • requires fewer droppers, because the intermediate support is in-built • copes well with minor damage as snapped wires are supported by surrounding mesh	• more expensive than other types of fencing • can be damaged by flooding as it tends to collect more debris than plain wire • may create a barrier for native animals • difficult to repair where many wires have snapped • more damaging to livestock and native fauna (e.g. kangaroos) when they get legs tangled in the mesh
Electric fencing An electric fence consists of a power source/ energiser, an earth/insulation system and a post/ wire arrangement. Construction can be as simple as electrified tape on insulated poles which can be put in by hand. Alternatively, electric wires can be incorporated into traditional permanent wire fences or added as an outrigger to existing or deteriorated fences. The design of the fence and the shock the animals receive should be matched to the type of livestock and livestock need to be trained or educated to electric fences before they can be relied on.[52] Mains power is the most reliable and least expensive option but is not available in all areas. Solar powered battery energisers are another option.	• cheap to establish[52] • quick and easy to erect and move[52] • low risk of injury or damage to livestock • can follow the contours of the area to be protected, resulting in the need for fewer materials[52] • if inundation is a problem, electric wires can be removed and coiled for storage • cattle will generally require only one well-placed electrified wire	• sheep require three or more electric wires with close spacings between wires • regular inspection and maintenance is important as a short circuit can render a large section of a fence ineffective • native animals and feral goats can cause frequent shorting and high maintenance[51] • need to be kept clear of grass and weed growth, falling branches and debris • not suitable where overgrowth of vegetation is likely • poor earthing and lightning strikes are common problems • not a physical barrier and may not stop aggressive animals • electric fences and energisers can pose a danger to people, especially children, and if people can access the fence warning signs are mandatory • small native animals, such as echidnas and bandicoots, may be killed by electrified wires close to the ground[53]

Native animals and wetland fencing

Wetland fencing may unintentionally exclude or trap native animals. Mesh, barbed, plain and electric wire fences have caused injuries and deaths of bats, kangaroos, wallabies, small mammals, waterbirds (Figure 26), birds of prey and owls.[54] Wetland fences can pose a higher risk of entanglement or injury when they are new, where they cross animal flight paths and tracks into a wetland and where they are less visible at the boundary between low pasture and taller native vegetation.[54] The top and bottom wires are where animals most often come in contact with the fence, with small animals such as echidnas and snakes being killed by electrified wires close to the ground.[53]

Figure 26. Straw-necked ibis (*Threskiornis spinicollis*) are commonly seen in wetlands. This individual died after it became entangled in barbed wire fencing. Photo – A Johnson/Tolga Bat Hospital.

These problems can be minimised by choosing a fence type and location that increases fence visibility and by installing native animal access ways, such as gates. The use of four or five strands of plain wire fencing is considered safer for native animals than barbed wire or mesh and is usually effective for livestock control where stocking rates are not high. Barbed wire fencing can be modified to reduce wildlife injuries by replacing the top two wires with plain wire or covering barbs with tubing such as longitudinally split poly pipe. In areas where entanglement is a problem, fence visibility can be increased by attaching metal tags, old CDs, tin cans or aluminium pie dishes to the top two wires. Other options include solid high-tension nylon sighter wire which glows in the dark and is used mainly for horse fencing.

As well as being injured, kangaroos and emus can cause damage to fences (Figure 27). Allowing them to pass through safely reduces fence damage, repair costs and time spent locating escaped livestock. Kangaroos and wallabies generally cross fences by crawling through lower wires or by digging underneath; generally their least preferred option is to jump over. Prefabricated mesh fencing can be dangerous to kangaroos and wallabies, but even plain wires can cause entanglement if they attempt to jump over or through while being chased. Emus usually try to roll between the wires. Solutions can be relatively simple. A cattle producer in the Murchison found that stringing the bottom wire one foot above the ground let native animals move underneath and reduced damage by kangaroos and emus.[51] Placing the bottom wire 15–20 centimetres from the ground will allow kangaroos to go under, but it should be noted that lambs will also be able to get under (Tim Saggers 2009, pers. comm.). Owners of a cattle property in Queensland found positioning two end posts separated by a gap too narrow for cattle, allowed animals to move through the high-tensile fence without injury or causing damage.[53] Livestock-proof kangaroo access gates can be installed where kangaroos have dug under a fence along a well-used kangaroo track (Figure 28).

➤ For more information, see *Wildlife Friendly Fencing Guidelines*[53] at www.wildlifefriendlyfencing.com and DEC Fauna Note 32 *Fencing and gates to reduce kangaroo damage.*[55]

Figure 27. Kangaroos have damaged this mesh fence in order to access the wetland. Photo – E Davies Ward/DEC.

Figure 28. A livestock-proof kangaroo gate in a fence around Lake Mealup in the Shire of Murray. Photo – P Wilmot/Lake Mealup Preservation Society.

extra information

Barbed wire fences around wetlands – a problem for brolgas

Barbed wire fences around wetlands can be especially hazardous to large waterbirds.[56] For example, brolga (*Grus rubicunda*) which occur in northern WA, have large wingspans of 2 metres or more, require space for a 'run-up' to gain momentum for take-off and their long legs hang down for both landing and take-off. Fences, especially barbed wire, placed close to wetlands and in flight paths can entangle these and other large waterbirds such as black-necked storks (*Ephippiorhynchus asiaticus*).[56] Young birds and those not familiar with fences are the most vulnerable. Fencing around wetlands can also prevent young flightless brolgas from following their parents between pastures where they feed and roosting and breeding areas in wetlands.

➤ For more information about this issue and alternative fence designs, see the *Australian Crane Network*[56] at ozcranes.net.

Providing alternative shade or shelter

On some farms, wetland vegetation is important for livestock welfare, as it provides shade and shelter for livestock such as newly shorn sheep or ewes with lambs.[57] For this reason landholders can be reluctant to exclude livestock from wetland vegetation, or may choose to place fences very close to the vegetation, so that livestock can shelter.[57] However, in the long term, this approach can cause erosion and jeopardise wetland condition, because livestock will browse the wetland vegetation through the fence. Horses and sheep tend to 'track' along fence lines often causing excessive damage to vegetation and soil in these areas.[45] Alternative shade and shelter can reduce livestock dependency on wetland areas. Constructed shelters may fulfil the requirement for shelter in the short term, with strategically placed, fenced clumps of fast growing native shade trees or perennial shrubs providing a long-term alternative.

➤ Local Department of Agriculture and Food offices can provide advice on appropriate local plant species suitable for livestock shelter.

Natural regeneration or revegetation

If natural processes of the wetland are still functioning (that is, sources of native plant seed are present as soil seed banks or there is native vegetation nearby) and growing conditions are good, wetland plants will regenerate naturally (Figure 29). If the land has been cleared for a long time and native species and seed banks are depleted, revegetation may be a better option.

➤ For additional detail, see the topic 'Managing wetland vegetation' in Chapter 3.

Figure 29. Sandy Lyon, a cattle farmer with a property south of Stirling Range National Park, has fenced off flat-topped yate (*Eucalyptus occidentalis*) wetlands and associated remnant vegetation on his property. There has been prolific regeneration of flat-topped yate and paperbark (*Melaleuca* sp.) trees in some wetlands, rushes and sedges in others. Photo – B Schur/Green Skills Inc.

Section 2: Alternative watering points

When livestock are excluded from a wetland previously used for livestock watering, it will be necessary to provide alternative watering points. Even without the use of fencing, careful siting of alternative watering points can attract livestock away from wetlands, reducing grazing pressure in these sensitive areas and distributing grazing more evenly through dryland pastures. This needs to be planned carefully though as horses and cattle, in particular, like to cool off by standing in water or under trees during hot weather and may enter the wetland despite that fact that alternative water points are available.

Some benefits of providing an alternative watering system include:

- cleaner water, which can promote healthier livestock, less disease, increased growth rates and better wool, milk and meat production
- better capacity to match needs of livestock (for example pregnant or lactating) to the available pasture
- better control of grazing patterns and improved feed utilisation
- reduction in livestock losses due to floods or bogging
- reduced mustering times
- improved wetland condition.[51]

Providing a watering system for livestock can be relatively simple for small properties which have another readily available water source and few livestock. For extensive landholdings with large numbers of livestock that require a lot of water, installing a watering system can be expensive and time-consuming to establish and may involve ongoing maintenance and operating expenses, though the effort can be offset by the many advantages. Careful planning and consideration should be given to the best system for a given property, purpose and paddock layout.[51] The choice of watering system will depend on several factors including:

- the available water source/s
- the amount of water required
- the paddock layout
- the distance between the water supply and watering point and between watering points
- the height difference between the water supply and the watering point/s[51]
- the availability, type and quantity of feed.

➤ Case studies of watering systems used successfully by farmers in different parts of Australia are provided in *Stock and waterways: a manager's guide*.[51]

Water sources

In WA, the Department of Water regulates the use of water from many sources and a permit or licence may be required to take water from a natural surface water source, build a dam or weir, collect water in a dam or drill an artesian bore. Local government approvals may also be required.

➤ More information about farm water supply, licensing and permits can be obtained from regional Department of Water offices or from the Department of Water's Rural Water Planning Team. A range of Department of Water *Water Facts* publications are available at www.water.wa.gov.au.

Also, bear in mind that taking water from the environment, whether it is surface water or groundwater, may adversely affect the wetland you are trying to protect.

➤ For additional detail, see the topic 'Managing hydrology' in Chapter 3.

The quality of alternative water sources needs to be determined before establishing alternative watering points. The quality of the water required by livestock is determined mainly by the total soluble salts (the salinity) it contains. All livestock require access to clean, fairly fresh water, but different livestock have different tolerances to salt levels, and tolerance also varies with circumstances and conditions.[58]

➤ For more information, see the Department of Agriculture and Food's *Water quality for farm domestic and livestock use.*[58]

Water troughs are a common way to provide water to livestock and protect wetlands from trampling and fouling (Figure 30). Livestock prefer to drink from troughs rather than natural water bodies because they don't have to stretch their heads below their feet to drink, which they don't like to do due to their poor depth perception and behaviour adapted for predator avoidance.[59] Troughs need to be cleaned and checked regularly to ensure they provide a continuous supply of clean fresh water, especially in the dry season. Portable and permanent troughs may be manually or automatically filled by water pumped or piped from surface water, rainwater, groundwater or scheme water.

Figure 30. Water troughs provide clean drinking water for livestock excluded from fenced wetlands. Photo – P Maloney/Department of Agriculture and Food.

Surface water

Landholders with legal access to natural surface water may be able to pipe or pump it to other parts of their property (Figure 31). Taking water from or near wetlands needs to be managed carefully to minimise impacts associated with altering the natural water regime of the wetland.

➤ The importance of wetland water regime is discussed in the topic 'Wetland hydrology' in Chapter 2.

Figure 31. This dam has been constructed to reduce the impact of livestock on Saunders Spring, a mound spring wetland in the Shire of Broome. Cattle can access water which is gravity-fed to the dam from the continuously flowing spring, but the wetland (in the background) is protected by fencing. Photo – G Daniel/DEC.

Dams

On larger properties which contain a suitable site, a dam that captures surface run-off can be an effective and environmentally sound option for watering livestock. In general, the soil needs to contain more than 25 per cent clay and should not be strongly structured, friable or self-mulching for dam construction. Dams need to be carefully designed with adequate natural catchment and volume to supply the number of livestock to be watered.

The viability of dams as a water source will depend on factors such as the average annual rainfall, its reliability and the evaporation rate. Evaporation rates across much of WA are very high. For example, typical evaporative water losses from farm dams in the Wheatbelt range from 1 metre per annum in the south-west to 2.5 metres per annum in the north-east.[60] 'Roaded' catchments which direct water flow into dams can be used to increase collection.[61]

Unfenced dams may be subject to the same water quality issues as wetlands where livestock have direct access to the water, so fencing and piping or pumping to nearby troughs may be a good option.

➤ For more information, see *Farm dams in Western Australia.*[62] *Dam design for pastoral stock water supplies*[63] and *Dam construction and operation in rural areas.*[64] In arid areas, see the *WaterSmart pastoralism handbook*.[65]

Groundwater

Abstracting groundwater via a bore may provide a more reliable water source, though bores can be expensive to construct and equip. The availability and quality of groundwater varies from site to site. The cost of groundwater bores will vary according to soil type and the level of the water table.[51]

Domestic water supply

Water from household supplies, such as rainwater tanks or government-provided scheme water, may be an option for small properties with very few livestock.

➤ For more information on water supply issues affecting farms, please contact the Department of Water's Rural Water Planning Team or email ruralwater@water.wa.gov.au.

Water requirements

Water requirements should be determined according to the maximum number of livestock to be watered in each paddock. When planning water requirements, allow for losses by evaporation, and consumption by native and feral animals.[67] Water requirements of livestock vary depending on the type of livestock, environmental conditions (such as temperature and humidity levels), the type of feed they are eating, physiological condition (such as pregnancy or lactation) and the quality of the water. For example, while young cattle require 25–50 litres per head per day, lactating cows feeding on grassland or saltbush require 40–100 or 70–140 litres per head per day respectively. The quantities in Table 3 are a guide to the daily water requirements of some livestock.

➤ To calculate water requirements see *The Pastoral Stock Water Workbook*[66] at www.agric.wa.gov.au. The Department of Agriculture and Food can help landholders estimate costs of maintaining livestock water and make informed decisions about existing and proposed water points.

Table 3. Daily water requirements of livestock in summer[62,69]

Type of livestock	Sheep	Beef cattle	Dairy cows	Bulls	Horses
Litres/animal/day	7	30–45	50–70	Up to 90	45

Paddock layout and water point placement

The installation of a watering system is often a trigger to implement a more efficient paddock layout.[51] Property planning can assist in this process, since paddocks and fence locations can be altered to take advantage of existing water sources or landforms which provide elevation for water storages. In some cases, it may be more practical to establish a new water supply than to pump or pipe it over long distances.

If wetlands are not being fenced to restrict livestock access, water troughs are best installed well away from wetlands to encourage livestock to move away from these areas.[52] Allowing for additional water points at the time of installation will provide backups in the event of problems and builds flexibility into the watering system. Creating a system where watering points can be shut or closed off adds the potential to move livestock around to even up grazing or spell degraded areas by shutting down a particular water point.[51] As a general guide, permanent water points should be placed:

- no more than 3 kilometres apart for effective grazing and animal production, although healthy animals can travel further[51]
- at least 50 metres from waterways, wetlands and drainage channels which feed into them
- away from boggy, fragile or degraded areas, depressions and steep slopes to minimise erosion caused by livestock tracks
- along a fence line (for easy maintenance), rather than the interior of the paddock[52]
- in the shade, to keep algal growth to a minimum.[52]

Pumps and water delivery systems

The location of the water source relative to distribution points will determine the type of watering system that can be installed. Research has shown that the flow rate to a trough is a more important factor for effective livestock watering than the capacity of the trough[52], so this should be taken into account when designing a watering system.

Pumps can be selected based on the pressure and volume of water required. The operating requirements will determine the power required to drive the pump. The main types of pump power are electric, wind, diesel/petrol and solar. Solar pump systems are generally more expensive to install, but are reliable and require little maintenance.[65] They are gaining in popularity in the rangelands as they perform well in summer and are well-suited for water points at remote sites.

➤ A good overview of the different types of pumps and power sources including their applications, advantages and disadvantages is presented in The Kondinin Group's research report *Watering stock from natural sources*[67] and New South Wales Department of Primary Industries' publication *Farm Water.*[68] In the arid rangelands, see the *WaterSmart Pastoralism Handbook.*[65]

Telemetry is a technology that allows remote monitoring of infrastructure. Data is gathered, recorded and transmitted from measuring devices (such as a flow meter at a water point) using radio or cellular phone technology without a person having to be at the location. Telemetry systems are capable of switching pumps on or off, monitoring tank or dam levels, recording rainfall, starting and monitoring generators and medicating water. This allows monitoring when access is restricted (for example during the wet season) and offers substantial savings in terms of travel costs, time, labour and vehicle wear and tear.

➤ For more information, see *Telemetry systems for remote water monitoring control systems.*[69]

Formed wetland access for livestock watering and crossings

If access to the wetland area for livestock watering or crossing is unavoidable (and legal), strategically located formed access points can reduce the impacts of livestock. A fenced compacted rocky laneway that extends down into the water (to the low water mark) is a good method for allowing strategic access (Figure 32). The following guidelines should be considered:

- Choose an area that is relatively flat – this will reduce the risk of erosion as well as being easier and safer for livestock to access.
- The area provided should be the minimum required for the number of livestock that will be using the area.
- Ensure adequate fencing around the area so that livestock are not able to access other sections of the wetland.
- Reinforce the area's surface with gravel or a similar material to reduce the erosion risk. The use of coarse rocky material to create a rough variable surface (that is uncomfortable, but not dangerous, for livestock to walk on) will minimise the time they spend at the water's edge.[70]
- Avoid areas that are well sheltered as this is will increase the likelihood of livestock loitering in the area for longer than is necessary.

Restricted access points limit trampling and grazing of wetland vegetation and may reduce, but do not prevent, faeces and urine and the associated nutrients and contaminants from entering the water. Erosion can occur at the access point if care is not taken with its location, construction and maintenance.[70]

➤ For more information about constructing livestock crossings, see *Livestock management: construction of livestock crossings.*[71]

Figure 32. A fenced laneway with a compacted rocky ramp allows cattle to access and cross a waterway, but minimises damage at the site and protects the rest of the waterway.
Photo – R Thorpe/Chittering Landcare Centre.

Section 3: Wetland grazing

General principles for wetland grazing

Allowing livestock access to wetlands is not recommended, because livestock degrade wetlands. Where grazing wetlands is proposed or is to continue, consider the following points.

Determine whether grazing is legally permitted in the wetland

A permit may be required to start or alter grazing practices in wetlands under the Government of Western Australia's Environmental Protection (Clearing of Native Vegetation) Regulations 2004. Be aware that there may be land use restrictions (including the exclusion of livestock grazing) which apply to wetland and bushland areas protected or restored with grants or funding for soil, water or biodiversity conservation. Local government legislation may also restrict livestock access to wetlands and regulate the type of livestock or stocking rate.

➤ For additional detail, see the previous section in this topic entitled 'Legal considerations'.

Exclude livestock until native vegetation has recovered

It may be important initially to 'spell' a wetland paddock. Spelling involves removing livestock for a period of time so that wetland and buffer vegetation can regenerate either naturally or through plantings. Some additional vegetation management, such as weed control or seeding, may be necessary to get good regeneration results. A good groundcover of native plants is desirable and livestock should be excluded until young trees have gained sufficient height to survive grazing when livestock are re-introduced.[72]

➤ For additional detail, see the topic 'Managing wetland vegetation' in Chapter 3.

Avoid grazing after flood, fire or drought

Grazing after flood events, fire or drought can result in pugging and accelerate erosion of exposed soils. At these times, wetland plant communities are stressed and at their most vulnerable. When rain returns after a drought, livestock should be excluded until plants have had the opportunity to recover. Floods and fires may also stimulate regeneration of native wetland plants and excluding grazing after these events is a great opportunity for native seedlings to establish.

If possible, choose livestock which will cause the least damage

Consider the type of livestock allowed access near wetlands, as some will impact less on wetlands than others. For instance, sheep don't tend to enter water but are more likely to graze low woody vegetation, so might have lower impact on water quality but higher impact on regenerating tree seedlings. Pigs and goats are highly destructive foragers and should never be given access to wetlands.[3]

Monitor the effects of grazing on wetlands

Check wetlands frequently once grazing is in progress, so that problems can be managed. It is important to manage grazing so that there is sufficient vegetation growth and post-grazing stubble to protect soils from erosion and act as a filter strip for sediment and nutrients when it rains. Look for evidence of:

- browsing on shrubs and trees rather than grasses
- bark stripping or other structural damage to trees
- uprooting of wetland plants
- increased water turbidity
- pugged soils
- damage to banks.

These are signs that livestock should be moved out of the area.

Riparian: the habitats adjacent to waterways and estuaries

➤ For additional detail on monitoring the condition of wetlands, see the topic 'Monitoring wetlands' in Chapter 4.

Build flexibility into the grazing management strategy

If possible, have a range of options available to move livestock to another paddock or de-stock, if it becomes necessary. Be willing to change the grazing strategy to achieve the best outcomes. A study of a range of riparian grazing strategies in the United States of America has shown that the commitment of the livestock manager was more important to achieving good land management than the grazing strategy they chose.[59]

Controlled grazing

Livestock exclusion is the best option for maintaining and improving a wetland's nature conservation values. However, if livestock grazing is to occur in and near wetlands, controlled grazing is more likely to minimise damage to these fragile areas than continuous grazing. Under controlled grazing systems, livestock managers may manipulate the paddock size, stocking rate, grazing time and livestock classes or species mix to achieve more even grazing, faster pasture recovery after grazing, persistence of more desirable plant species and maintain pasture productivity for longer.[8] The aim is to support more livestock and produce more meat, milk or wool per unit of land while effectively reducing the environmental impacts of grazing and increasing sustainability of pastures.

A range of controlled grazing strategies have been used successfully for riparian areas[59] which, like wetlands, are vulnerable to overgrazing. Management strategies will differ depending on whether they are being applied to a fenced wetland pasture or to a larger grazing unit which includes unfenced wetlands.

➤ For more information about grazing management options for wetlands in arid and semi-arid areas, see *Pastoral management options for Central Australian wetlands – Fat cows and happy greenies*.[18]

Special use grazing

One of the better options for grazing wetlands is to fence them and keep them as a 'special use' or reserve paddock to be used only for a short period at a particular time of year or for a special purpose such sheltering sheep during severe weather or lambing. In times of a feed shortage or drought, some farmers have opened their fenced wetlands to hungry livestock. It is important to be aware that this usually results in severe damage to wetland vegetation, which may take years to recover.

Rotational grazing

Rotational grazing is one type of controlled grazing system. It involves subdividing larger paddocks into several smaller pastures. Livestock graze a particular paddock for a certain period, and are moved to another paddock to spell the previous pasture.[8] A relatively high stocking rate relative to the size of the paddock forces livestock to be less selective in their grazing and to graze the paddock more evenly, but they are removed before they start to graze plant regrowth and this allows the vegetation to recover.[8] An example of a simple time-controlled rotational grazing strategy rotates livestock between four paddocks in a general program of two weeks grazing and six weeks rest.[73] More complex forms of rotational grazing, such as strip grazing and cell grazing, involve higher grazing intensities, many smaller paddocks and short rotation times (such as 1–3 days) based on the height of remaining plant cover.

When carefully planned, rotational grazing can benefit wetland vegetation by giving it a rest period during which it can regenerate. However, rotational grazing often involves higher stocking rates which can result in rapid degradation of wetlands (see the case study 'The Collards protect wetlands on their cattle property near Gingin' at the end of this topic). Rotational grazing can also benefit wetlands from which livestock are excluded, because it minimises erosion of paddocks adjoining wetlands by maintaining higher pasture cover and reducing the build-up of livestock wastes.

➤ Meat and Livestock Australia (www.mla.com.au) provide a range of fact sheets on rotational grazing.[73] See also *Towards a better understanding of rotational grazing* in Pastoral Memo: Southern Rangelands[74]

Dormancy: a state of temporary inactivity when plants are alive but not growing, i.e. they are **dormant**

When to graze wetlands

The following recommendations can be used to determine the time of year that controlled grazing will have the least negative impacts on wetlands. The recommendations may be contradictory, because grazing will have some impact on wetlands at any time of the year. While it may not be possible to satisfy all of the recommendations all of the time, by monitoring the effects, livestock owners can adapt and improve the controlled grazing strategy used for a wetland over successive grazing periods.

Keep livestock out when soils are wet or drying out

Grazing should be restricted during and after the period of maximum rainfall. This will help to maintain good groundcover during the period when the potential for water erosion and soil loss is greatest.[22] Also keep livestock out of wetlands when they are drying out as this is a time when damage by trampling can be severe.

Avoid grazing when native animals are breeding on the ground or in low vegetation

Disturbance to vulnerable animals such as waterbirds and migratory waders at key times may induce stress, reduce breeding success and cause breeding animals to relocate.

extra information

What are waders?

Wading birds, commonly called waders, are birds that feed on aquatic invertebrates found in shallow wetlands and tidal flats. Some species live in Australia all year round, but some species breed in the northern hemisphere and migrate to Australia for summer period from September to April. Some species are protected under international agreements and the Australian Government *Environment Protection and Biodiversity Conservation Act 1999*. For more information about waders, see the topic 'Wetland ecology' in Chapter 2.

➤ For information about local native wetland plants and animals, contact your regional NRM office, regional DEC office, *Land for Wildlife*, local landcare or bushcare group.

Avoid grazing when plants are germinating, actively growing, flowering and seeding

Grazing is likely to be most damaging to palatable native plants when they are actively growing, germinating, flowering and seeding.[14] Many wetland plants can reproduce from bulbs and tubers under the ground (called **vegetative reproduction**) without producing seed. These species are more vulnerable to grazing when they are actively growing.

Grazing is likely to be least damaging when most of the plants are **dormant**.[14] Different plant species move in and out of **dormancy** at different times and the period of dormancy also varies between regions and according to weather patterns.[14] For example, in south-west WA, the native perennial wetland grass swamp wallaby grass (*Amphibromus nervosus*) grows in winter and flowers from June to November, but matgrass (*Hemarthria uncinata*) grows actively in summer and flowers from December to April.[75]

Many wetland species germinate and seed in response to dry wetland soils being re-wetted. Livestock should be removed after wetting and not be re-introduced until these species have matured and re-seeded.[18]

As there are often many species of native plants within a wetland plant community, it may be difficult to determine the least damaging time to graze because a portion of the plant species in the wetland may be growing, flowering or seeding at all times. Reducing impacts may be a matter of controlling the grazing pressure, duration of grazing and grazing at different times or in different seasons in subsequent years.

➤ Seek advice about your wetland plant community from your regional NRM office, local landcare or bushcare groups to guide decisions about timing wetland grazing.

case study

Using controlled grazing to manage habitat – a trial at Lake McLarty in the Shire of Murray

In Eastern Australia, controlled livestock grazing has been used to achieve specific wetland management goals, such as weed control and fire management.[76] Livestock grazing in wetlands has also been used to maintain habitat suitable for migratory wading birds. Timing, duration and intensity of grazing have been manipulated to slow the spread of invasive aquatic emergent plants, maintain or create patchy vegetation or reduce emergent plant cover and maintain open water.[3]

Under the *Conservation and Land Management Act 1984* and Regulations, grazing is not usually permitted in nature reserves, as it is rarely compatible with nature conservation goals. However, restricted, regulated cattle grazing is planned at Lake McLarty Nature Reserve for the purpose of habitat management.[77] Lake McLarty, which lies south-west of Pinjarra, is a highly modified wetland that has been grazed by cattle since the 1880s, yet provides valuable habitat for many native species, including wading birds. Controlled grazing is to be reinstated on a trial basis, in order to control the growth of introduced pasture grasses and the invasive introduced bulrush (*Typha orientalis*) which threaten to colonise the open water and mudflat habitats favoured by the wading birds. Department of Environment and Conservation scientists will use this opportunity to closely monitor and assess the impacts and benefits of cattle grazing together with the impacts of other habitat management practices, such as regular slashing and use of herbicides.

Figure 33. Lake McLarty, showing introduced bulrush (*Typha orientalis*) growing along the lake edge. Photo – J Jackson/DEC.

Continuous grazing

The capability of any property to support grazing livestock without becoming degraded is determined by a range of factors such as soil type, slope, drainage and rainfall.[45,78] For example, steep land with clay soil that gets soft when wet is more vulnerable to erosion than flat, well-drained land. Land with different capabilities requires different management in relation to livestock.[49] Matching grazing management to land capability reduces the potential for land degradation. For example, creating paddocks on land with good capability and protecting land with low capability such as waterways, steep slopes and wetlands. Mapping land capability classes on a property is a one of the main steps in preparing a property management plan.

The main disadvantage of continuous grazing systems is that uneven animal distribution can lead to overgrazing in certain parts of even lightly stocked paddocks.[79] In paddocks with different land types, livestock will graze some areas in preference to others. To prevent land degradation, grazing management is then constrained by having to lower **stocking rates** to protect the most susceptible parts of a paddock.[79] Wetlands are usually the most susceptible part of a paddock with the lowest land capability, and may also be most favoured by livestock. Having unfenced wetlands in a paddock (i.e. a paddock with mixed land capabilities) can limit the stocking rate for the whole paddock, and will still risk degradation of the wetland and livestock safety. This is a good reason to separate wetlands from other land types using fencing.

extra information

Stocking rate

Stocking rate is the number of animals of a specified class per unit area of land, usually over a specified period of time. Stocking rates are expressed in units of 'dry sheep equivalent' (or DSE) which is the amount of feed required by a 2-year-old 45-kilogram Merino wether to maintain its weight. This is the standard used to express feed requirements of other classes of livestock (Table 4). For example, emus can be stocked at higher rates than sheep or cattle, but horses should be stocked at lower rates than cattle. If feral or native grazing animals are present, they may need to be accounted for in calculating suitable stocking rates. The recommended stocking rate (or **carrying capacity**) is the number of livestock that can consistently be kept on an area of pasture all year round with minor additional feed and without causing environmental degradation.[80]

Table 4. Livestock stocking rate comparisons expressed as Dry Sheep Equivalents (DSE)[81]

Animal to be stocked	DSE equivalent
One pony	8 DSE
One large horse	10 DSE
One breeding ewe	1.5 DSE
One large wether	1 DSE
One heifer	8 DSE
One alpaca (60–70 kg)	0.8 DSE
One large emu	0.7 DSE

It is unlikely that the condition of a wetland that has been degraded by livestock will improve under continuous stocking. To promote regeneration of wetland vegetation, the best strategy is to remove livestock for up to several years, then resume grazing at a lower stocking rate and use other methods discussed in other this topic to achieve a better distribution of livestock.

The capability of a land type will be influenced by its location within WA due to the affect of climatic conditions on plant productivity. As a guide, wetlands, whether inundated or waterlogged seasonally or intermittently, should be stocked at lower rates than the surrounding dryland. In many areas of the south-west, the recommended stocking rates for wetlands will be less than one animal per hectare when stocking animals other than sheep, and will limit the stocking rate for the whole paddock.[80] Meat and Livestock Australia advise not to 'set and forget'.[82] Varying a set stocking strategy between seasons can assist in managing grazing pressure effectively and improve pasture and animal production.

➤ The Department of Agriculture and Food has detailed information about local conditions across the state and can calculate the relevant permissible stocking rates on request. The Department of Agriculture and Food's Small Landholder Information Service provides advice tailored for small landholders. *The stocking rate guidelines for small rural holdings*[80] provides stocking rate guidelines for the Swan Coastal Plain and Darling Scarp areas.

Wetland management in the rangelands

Fencing wetlands

Pastoral enterprises in the rangelands typically graze low densities of sheep or cattle on native vegetation in extensive paddocks that incorporate many different land types. Often livestock are not actively managed beyond annual mustering. Native and feral animals frequently contribute considerably to the total grazing pressure which can lead to overgrazing and erosion.

➤ For more information see *Management of total grazing pressure: managing for biodiversity in the rangelands.*[83]

Managing grazing pressure at unfenced wetlands is rarely achievable. The most effective management for smaller discrete wetlands (such as springs) is to fence them to keep livestock (and other grazers out) and provide alternative water.

Over much of the rangelands the landscape has low relief, and extensive areas of floodplain (often associated with rivers) become intermittently inundated (Figure 34). These areas provide valuable grazing, but are often vulnerable land types. Fencing these land types to control grazing may be a costly improvement, but can improve livestock management, increase ground cover and vegetation condition, reduce erosion and improve water quality.

➤ For more information, read the case study *On the ground: What a difference a fence makes* by the Fitzroy Basin Association www.fba.org.au.

Figure 34. The inundated floodplain of the Lyndon River near Lake MacLeod in April 1998. Photo – L Bayley/Department of Agriculture and Food.

Trap yards

Trap yards, such as total grazing management (TGM) yards, are proving useful to livestock managers in the rangelands. These yards are self-mustering as livestock must enter them to access water points. They trap feral livestock (such as horses, donkeys and goats) and native grazers (kangaroos and emus) as well as livestock, allowing management of total grazing pressure.

➤ For more information, see *Total grazing management yards: A cornerstone for improved station profitability.*[84]

Conservative stocking

In the rangelands, it is common to stock more heavily during optimal weather conditions (such as the growing season following summer cyclonic rains), but these times are often followed by drought. Heavy stocking prior to drought or re-stocking soon after drought (before a pasture has recovered) can lead to degradation of both the vegetation and land.

More conservative stocking during optimal conditions can yield pasture that is better able to sustain grazing during times of drought when it is most needed. Monitoring the condition and productivity of paddocks and wetlands means that management actions can be taken before degradation occurs. If signs of degradation are evident, it is essential to move livestock to prevent further damage. It may be possible to agist livestock to locations outside of rangeland regions during times of drought and until vegetation has recovered.

➤ For more information about managing wetlands in the rangelands, see *Pastoral Management options for central Australian wetlands: Fat cows and happy greenies*[18] and HorsesLandWater's *Management Guidelines – Arid zone.*[85]

Figure 35. Wetlands in the rangelands can provide valuable grazing for livestock if they are fenced, livestock access is carefully timed, total grazing pressure is managed and livestock are removed at the first signs of degradation. Photo – L Bayley/Department of Agriculture and Food.

Section 4: Moving livestock away from unfenced wetlands

Alternative feed points

When given the opportunity, livestock tend to spend much of their time near water.[9] Fencing is the primary method of excluding or controlling livestock access to wetlands, but in some cases fencing is not a practical option. In these situations, it may be possible to attract livestock away from wetlands or discourage them from loitering there. In addition to locating watering points away from a wetland, supplementary hand-feeding or dietary supplements (such as mineral licks, low-moisture energy or protein blocks) can be sited away from wetlands to achieve better grazing distribution.[51] Locations should be chosen using the same guidelines for siting water points.

Behavioural methods of livestock management

Knowledge of livestock behaviour can be used to encourage use of dryland pasture areas.

Seasonal habitat preferences

Livestock have seasonal preferences for using wetland habitats. For example, cattle may move to dryland areas in spring when these have new plant growth, but favour wetlands from summer to autumn for better pasture, a cooler microclimate and shade. Wetlands may be avoided in winter if they are inundated, boggy or colder than the surrounds or may be favoured if they offer shelter from winter winds. Observing seasonal preferences and only permitting grazing in wetland pastures at times when animals are likely to prefer dryland areas can help to protect wetlands from over use.

Turn out locations

A **turn out location** is the site at which livestock are released into a fresh pasture. In large pastures that contain adequate water for livestock, choosing turn out locations well away from overused areas can influence the timing, duration and amount of use by livestock.[59] This technique has been used successfully to reduce pressure on riparian areas and therefore is considered likely to be useful for managing grazing pressure on wetlands. It may be beneficial to change turn out locations each year to vary behaviour patterns.

Low-stress herding

Low-stress livestock handling is a method of herding livestock with prompts rather than force. It involves trained livestock handlers using herding techniques that exploit the natural traits of livestock, encouraging them to stay together and bed down where they are placed.[59] Well-handled livestock prefer to stay together rather than scattering or hiding. This technique is gaining popularity in the United States of America as a tool to control livestock distribution in rangeland areas. Trials have demonstrated that a combination of low-stress herding techniques and strategically placed mineral supplements can be successful in reducing cattle use of riparian areas.[86] Low-stress herding techniques have been used to successfully train cattle to move from riparian areas to dryland areas after drinking.[59] These techniques also have economic and other benefits for livestock and producers.

➤ For more information about low-stress livestock handling in Australia, visit www.lss.net.au.

Section 5: Managing paddocks around wetlands

Manage paddocks to maintain permanent groundcover

Bare patches in paddocks are vulnerable to soil erosion by water or wind. Bare soil in paddocks can increase the risk of horses getting sand colic, and dust can cause respiratory tract infections.[85] Maintaining a healthy groundcover across paddocks all year round will retain topsoil, reduce dust and maintain wetland water quality. Meat and Livestock Australia's sustainable grazing program found that a minimum of 70 per cent groundcover is needed in late summer-early autumn to reduce erosion risk in the temperate high rainfall zones in south-western Australia.[87] The organisation HorsesLandWater recommend all grazing areas have plants at least 3 centimetres high with groundcover of 70 per cent (for soil susceptible to water erosion) or 50 per cent (for soil susceptible to wind erosion).[85]

➤ For information on how to calculate groundcover, see HorsesLandWater *Management Guidelines.*[85]

Perennial pastures

One way to maintain permanent groundcover is to improve pastures by planting deep-rooted perennial plant species. Perennial plants can prevent erosion and reduce nutrient run-off as well as provide a year-round food source for livestock. Perennial pasture grasses are best grazed in a rotation grazing system. They remain green later in spring than annual grasses, allowing longer grazing rotation times, and they are particularly useful in areas that experience medium to low rainfalls.

Introduced perennial pasture species should be selected with caution. Some species have caused seasonal toxicity problems in livestock. For example, signal and panic grasses that are growing rapidly or stressed can become toxic to young sheep.[88] Other perennial species, such as kikuyu (*Pennisetum clandestinum*) and tagasaste (*Chamaecytisus palmensis*), have the potential to become serious weeds in wetlands.

WA has many native species of grass that can be used as alternatives to introduced pasture fodders. Perennial species should be selected with professional advice and evaluated on a trial basis.

➤ For more information on perennial pasture species, contact the Department of Agriculture and Food. Good references include *Perennial pastures in Western Australia*[89] and *Evaluating perennial pastures – a case by case study of perennial pasture use in the south coast region of WA.*[90]

Figure 36. Pastures improved with a mix of perennial species on the margin of a fenced wetland near Gingin. Photo – K Angell/Small Farm Landcare Consultancy.

Figure 37. Kikuyu (*Pennisetum clandestinum*), a perennial pasture grass widely used on horse properties, can become a serious weed in wetlands. Here, kikuyu is spreading from a horse yard into a seasonally waterlogged wetland in Forrestdale. Photo – R Lynch/DEC.

Manage high traffic areas

Any area where livestock congregate, particularly around watering points, but also hand feeding areas, gateways, laneways, shelters and 'stock camps' can experience damage to pasture cover from intense trampling and be at risk of erosion.[45] Horses, which are more active that other types of livestock, tend to loiter at gates and walk along paddock fence lines (especially if they are left in a paddock on their own, but with other horses in the next paddock). Serious damage can be caused in a short time by a stressed horse left behind while companion horses are taken out for a ride.[45] Infrastructure which attracts livestock should be sited on stable ground, avoiding wetlands, paddock corners, clay and sand soils and steep areas.[45] High traffic areas can be permanently surfaced to make them more stable, or a moveable protective pad such as conveyor belt matting can be used to provide temporary surface protection.[45] Regularly moving portable troughs and feed locations is a good option for smaller properties. Temporary electric fencing can be erected to protect damaged groundcover while it recovers.

Manage potential contaminants

Animal faeces and urine

Restricting livestock access to wetlands will minimise direct inputs of animal wastes into wetlands. Well-vegetated dryland buffers between pastures and wetlands will also help by slowing run-off and reducing the volume of sediments, nutrients and faeces reaching wetlands. However, the accumulation of animal faeces and urine on other parts of a property can still cause wetland water quality problems.

While some well-distributed manure will act as a natural fertiliser for pasture plants, too much deposited in one area can enter wetlands through run-off or by leaching into groundwater. Faeces should be regularly collected from areas where it tends to accumulate, such as stables, animal sheds, yards and small paddocks.

Manure composting piles should be sited on hard stand containers, at least 200 metres from waterways and wetlands and well away from drainage lines.[45]

➤ For more information about manure management on horse properties, see *Horse poo – what to do?* at www.horsesa.asn.au.

Animal carcasses can also cause contamination. Livestock carcasses should be buried at least 100 metres from wetlands and not in places where the water table is less than 1.5 metres from the surface.[7] If possible, each carcass should be buried in separate pit and the pits distributed over a wide area.

Chemical contaminants

To avoid contamination of wetlands, agricultural chemicals (including fertilisers, herbicides, veterinary chemicals, fuel, oil and solvents) should be used, stored and handled in accordance with best practice guidelines and regulatory requirements and supplier's directions.

➤ The Department of Water produces Water Quality Protection Notes and guidelines for a range of activities that affect water resources. See *WQPN 35: Pastoral activities in rangelands*[7], *WQPN 33: Nutrient and irrigation management plans*, *WQPN 80: Stockyards* at www.water.wa.gov.au (search in 'Publications') for more information.

Some key points include:

- Livestock drenching and jetting should not be undertaken within 100 metres of a wetland or near waterways.
- Livestock should be kept away from wetlands for at least two days after worm drenching to minimise leaching of drench chemicals from animal faeces and urine.[31]
- Plunge or dipping pools for parasite control are not recommended, but if necessary this should not be undertaken within 200 metres of a wetland and any spills should be immediately contained and disposed of safely.[7]
- Herbicide, pesticide and fertiliser use near wetlands can contaminate them through overspray and spray drift. These chemicals should be used appropriately and with caution. Some herbicides that do not harm aquatic animals are approved for use over water, but may still harm native vegetation in the wetland and its buffer.

  ➤ For additional detail refer to the topic 'Wetland weeds' in Chapter 3.

- If possible, split fertiliser applications into several smaller applications. Using the smallest effective amount, applied at times of enhanced plant uptake, will reduce leaching.[49] Avoid applying fertilisers prior to storms and flooding or to soggy, waterlogged paddocks, as highly soluble forms of nitrogen and phosphorus are flushed by rain into wetlands and waterways.[49]

Section 6: Management challenges

Excluding or controlling livestock access to wetlands can result in significant improvements in wetland appearance and condition and provide benefits to property owners, especially over the long term. As with any change in management practice, it can also create new challenges. Management issues associated with excluding livestock from wetlands include weeds, pest animals and the potential fire risk from increased amounts of vegetation.[51] Accordingly, a variety of nature conservation programs offer financial, technical or labour assistance to eligible landholders.

➤ Refer to the topic 'Funding, training and resources' in Chapter 1 for more information.

Weeds

Many landowners express concern about excluding livestock from wetlands because grazing livestock will no longer keep weeds under control, allowing weeds to flourish and further degrade the wetland. In addition, a common concern is that increased weed and native vegetation regeneration can often make fenced areas difficult to access for spraying and slashing. These are valid concerns, and the exclusion of livestock from wetlands that contain invasive weeds requires planning and ongoing action. In the first few years following the exclusion of livestock, weed control will require a consistent effort. It is difficult for weeds to establish in areas where the native plant cover is intact, so as natural regeneration progresses, weed management is likely to be less time-consuming.[51]

➤ Methods of weed control suitable for use in wetlands are discussed in the topic 'Wetland weeds' in Chapter 3.

Grazing has been used to control highly invasive weeds in some wetlands, such as para grass (*Brachiaria mutica*) in Queensland.[91] If grazing is to be used to control weeds in a wetland, the targeted weed species must not only be palatable, but preferred by the livestock to the native vegetation. Ideally livestock should only be allowed access when soil moisture levels are low enough to avoid pugging. Allow livestock to graze weeds before they set seed, but aim for minimal damage to native vegetation and withdraw livestock as soon as the first signs of this occur. To reduce the spread of weed seeds in manure, livestock can be locked up for a day prior to grazing wetland areas.[51] They will excrete many of the seeds in their faeces while locked up, so fewer weeds are transported into wetlands. Excluding sheep until after shearing will also reduce the weeds transported in their fleece.

Fire hazard reduction

As wetland vegetation regenerates, fire hazard management may be necessary. The use of livestock grazing to reduce potential fire hazard is not recommended as it depends on livestock eating plants which create fuel loads, which is often not the case, and also requires heavy grazing, which is damaging to wetland habitats and vegetation.[3]

Pest animal control

As wetlands regenerate, understorey vegetation becomes denser and may be colonised by more native animals, such as bandicoots. This is a good sign that the wetland is providing good habitat for native animals. However, introduced animals may also use wetland habitats. These, and sometimes native animals, can become a problem if they destroy native vegetation, cause erosion, damage fences, spread diseases or kill livestock. Grazing by rabbits, goats, pigs, kangaroos and native wetland birds can destroy regenerating vegetation and hinder wetland restoration efforts by eating or uprooting plants. Cats and foxes using wetland vegetation as a refuge may also need to be controlled.

➤ Methods of controlling introduced and problem native animals are discussed in the topic 'Introduced and nuisance animals' in Chapter 3.

case study

The Collards manage wetlands on their cattle property near Gingin

In 1973, Ross and Tracy Collard bought a 400-hectare property near Gingin, which they named 'Caladenia Lake Estates', after one of the eight natural wetlands. They cleared much of the property for beef production, but retained areas of wetland vegetation (mainly low open paperbark woodland). They currently run more than 220 head of Red Angus breeder cattle between 'Caladenia' and their nearby property, 'Poverty Nook', which is 160 hectares and also has a wetland.

An intensive rotational grazing system

In 1998, Ross began using a rotational grazing strategy based on a registered system. He subdivided the four original paddocks at Caladenia into thirty-five smaller ones. Under this system, each paddock is intensively grazed by a mob of forty to fifty cattle for no longer than 3 days. The paddock is spelled until the pasture has regrown to a specific stage, which can take between 12 and 30 days, and then grazed again for up to 3 days. Ross found that this system worked well in terms of both livestock and pasture management – there was more feed, stronger plants and better groundcover.

Unintended impacts on the wetlands

Under the old four-paddock system, the margins of the wetlands had provided valuable grazing for the cattle. However, in the new rotational system, the cattle grazed more intensively and ate a wider variety of vegetation, including the wetland plants. It became clear to Ross that the wetlands were rapidly becoming degraded as a result. The cattle "were hammering the wetland … smashing up the tea trees … and the water was disgusting".

Ross was most concerned about the impact on the wetland vegetation and the water quality, as his cattle used the wetlands for drinking. The unfenced wetlands also provided hiding places for the cattle, which made moving them between paddocks more difficult.

Wetland fencing, funding and more fencing …

Ross began fencing some of the wetlands with his own resources, then applied for and received funding from the former Gingin Land Conservation District Committee for fencing to protect more wetlands from livestock. Cattle were excluded (with the exception of the occasional calf) by installing plain wire fences using substantial pine strainer posts with galvanised steel pickets at 10-metre intervals (to provide a visual barrier) and a single electric wire (an earth wire was not necessary).[92] At Poverty Nook, where fires are more frequent, Ross used steel strainer posts around the wetland.

To compensate for fencing the wetlands, Ross then put into practice a pasture improvement program based on a range of perennial species. This yielded a significant increase in the feed available to livestock. In 2007, the Collards applied to World Wide Fund for Nature (WWF) Australia's 'Balancing agricultural production and conservation – wetlands' program. They received wetland management advice as part of a whole farm plan and assessment and monitoring for wetlands and vegetation. With in-kind funding, Ross was able to fence more wetlands and a corridor of remnant vegetation, install a bore, water pump and solar panels, tank, trough and gates and sow 4 hectares of perennials in adjacent pastures.[93]

Figure 38. Red Angus cattle in perennial pastures on the edge of a fenced wetland at the Collard's 'Caladenia' property. The productivity of the perennials has compensated for fencing off wetland areas. Photo – K Angell/Small Farm Landcare Consultancy.

case study

Next, Ross is planning to put in a new bore and upgrade the water pump for an existing bore at Poverty Nook, in order to provide his cattle with alternative water when he completes fencing off a spring-fed wetland. Ross also hopes that using alternative water sources will help to maintain the natural water regime in the wetlands; he is concerned that groundwater abstraction for other nearby land uses is causing the wetlands to dry out earlier than in previous years.

Few problems with weeds and same old pests

Many landowners have concerns that excluding livestock from wetlands will allow weeds to flourish, but this has not occurred at the wetlands at Caladenia. Ross has ongoing problems controlling rats, mice and foxes, but pest numbers did not increase after fencing the wetlands. Feral pigs occasionally move through the property, causing damage to the wetlands. Ross finds he needs to control kangaroos as they compete with his cattle by consuming a lot of vegetation and sometimes short out the electric fences.

Wetlands for the future

Since fencing the wetlands, the Collards have observed that the water is now clear, rather than clouded with sediment; there has been rapid natural regeneration of wetland trees, shrubs and rushes; growth in three different types of water plants; more frogs; and wild ducks.[92] The Collard family value the wetlands as scenic areas for quiet recreation and for their native plants and animals[92] which includes swans, pelicans, spoonbills, ducks, wading birds, bush birds, owls and frogs. Ross has always thought of their property as their 'grandchildren's farm' and is pleased to be protecting the beautiful wetlands so they can be enjoyed by future generations of his family. He says the wetlands "are just nice places to be".

Figure 39. South Ridge Swamp, a wetland on the Collard's property, is protected from livestock impacts by fencing and total cattle exclusion. Photo – K Angell/Small Farm Landcare Consultancy.

Topic summary

Letting livestock into wetlands can be harmful to livestock as well as destructive to wetlands. Livestock and associated farm activities can degrade wetlands by causing damage to soils, erosion, water contamination, damage to native vegetation, harm to native animals and loss of biodiversity.

Wetlands in good condition can provide valuable services for landowners, their livestock and the wider community. There are a range of incentives to help landholders protect wetlands.

Options for reducing livestock impacts on wetlands include:

- fencing wetlands to keep livestock out
- providing alternative watering points located away from the wetland
- creating formed water access points or livestock crossings
- keeping wetlands for occasional grazing, as 'special use' or reserve paddocks
- grazing wetlands for short periods as part of a controlled grazing system (for example rotational grazing)
- if allowing continuous grazing, spelling paddocks initially to allow vegetation regeneration, reduce stocking rates and de-stock, if necessary
- using other methods to reduce wetland grazing such as supplementary feed points, seasonal preferences, turnout locations and herding.

Management of surrounding paddocks can also reduce impacts on wetlands. Best practice is to:

- maintain permanent groundcover
- consider planting perennial pasture species
- manage high traffic areas
- manage animal wastes and other potential contaminants near wetlands.

It may be necessary to plan strategies to manage weeds, pests and fire.

Sources of more information on managing livestock in and around wetlands

Websites

Small Landholder Information Service (SLIS), Department of Agriculture and Food Western Australia
www.agric.wa.gov.au/content/FM/SMALL/PER_SUMM.HTM
A wide range of advice on managing landholdings up to 100 hectares

Ecologically Sustainable Rangelands Management Service (ESRM), Department of Agriculture and Food Western Australia
www.esrm.com.au
Land management and property planning advice for landholders in the WA rangelands

Horses Land Water community of practice
www.horseslandwater.com
Property management and other advice for horse owners including guidelines for horse-keeping in temperate, tropical and arid areas

Rural water planning program, Department of Water, Western Australia
www.water.wa.gov.au/ (click on 'Doing business with us' then 'Farm and pastoral assistance')
Offers technical advice and publications designed to assist with on-farm water supply issues

Other publications

Department of Agriculture and Food in partnership with Geographe Catchment Council and Western Dairy (2006) *DairyCatch – environmental best practice guidelines.*[94]

NSW Department of Environment and Conservation (2000) *Horse properties on the rural urban fringe: Best practice management guide for keeping horses.*[95]

Glossary

Aestivating: being in a state of dormancy that occurs in some animals to survive a period when conditions are hot and dry

Annual: a plant that normally completes its life cycle (from germination to flowering, seed production and death of vegetative parts) within a single growing season

Biodiversity: the whole variety of life forms–the different plants, animals, fungi and microorganisms–the genes they contain, and the ecosystems they form

Browse: to feed on leaves, twigs or bark from non-herbaceous (woody) plants, such as trees and shrubs

Diversity: a measure of the number of species of a particular type and their abundance in a community, area or ecosystem. It can refer to a particular group of organisms, such as native plant diversity or frog diversity. The broader term biodiversity is used to encompass the whole variety of life forms–the different plants, animals and microorganisms–the genes they contain, and the ecosystems they form

Dormancy: a state of temporary inactivity when plants are alive but not growing, i.e. they are **dormant**

Ecosystem: a community of interdependent organisms together with their non-living environment. Natural ecosystems provide a range of benefits and services to humans such as clean water, nutrient cycling, climate regulation, waste decomposition and crop pollination

Erosion: the gradual wearing away and movement of land surface materials (especially rocks, sediments, and soils) by the action of water, wind, or a glacier

Grazing: feeding on grasses and other low-growing herbaceous vegetation

Groundcover: the percentage of ground covered by plant materials (alive or dead) and leaf litter

Herbs: plants with non-woody stems that are not grasses or sedges. Generally under half a metre tall. Most herbs monocots are herbs.

Land capability: the ability of land to be used for a particular purpose or managed in a particular way without becoming degraded

Leaf litter: dead plant matter including leaves, flowers, nuts, sticks and bark which accumulates on the ground

Livestock: introduced domestic ungulate (or hoofed) animals

Low-stress livestock handling: a method of herding livestock with prompts rather than force

Macropores: spaces in the soil (usually less than 2 millimetres in diameter) that include channels created by cracking, old plant roots and soil fauna (such as earthworms). Macropores indicate good soil structure.

Palatable: pleasant-tasting

Perennial: a plant that normally completes its life cycle (from germination to flowering, seed production and death of vegetative parts) in two or more growing seasons

Property management plan: also called a whole farm plan; a working plan for the design and management of a property based on its natural resources, the activities undertaken (such as horse breeding or beef production), the manager's goals and financial considerations

Pugging: depressions, hoof prints or 'pug' marks made in wet soil by trampling animals

Riparian: the habitats adjacent to waterways and estuaries

Rotational grazing: a type of controlled grazing system. Paddocks are usually subdivided into smaller pastures and grazed at higher intensities for shorter periods (to achieve more even grazing), then spelled (or rested).

Sedimentation: the process by which soil particles (sand, clay, silt, pebbles and organic materials) suspended in water, are deposited or settle to the bottom of a water column

Spelling: of a paddock or pasture, involves removing livestock grazing pressure for a period of time so that vegetation can regenerate

Stocking rate: the number of livestock that can consistently be kept on an area of pasture all year round with minor additional feed and without causing environmental degradation

Total grazing pressure: describes the combined impact of all grazing animals–domestic, wild, native and feral–on the vegetation, soil and water resources of a particular area

Turbid: the cloudy appearance of water due to suspended material

Turn out location: the site at which livestock are released into a fresh pasture

Understorey: the layer of vegetation beneath the main canopy

Vegetation structure: the three-dimensional distribution of plant material. It includes the horizontal spacing of plants and the vertical heights or layers

Vegetative reproduction: a type of asexual reproduction found in plants. Also called vegetative propagation or vegetative multiplication

Wetland hydrology: the movement of water in, out of, and within a wetland

Personal communications

Name	Date	Position	Organisation
AR (Roy) Butler	11/05/2009	District Veterinary Officer, Merredin	Department of Agriculture and Food
Tim Saggers	26/05/2009		Kendenup Fencing Contractors

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