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.

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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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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]

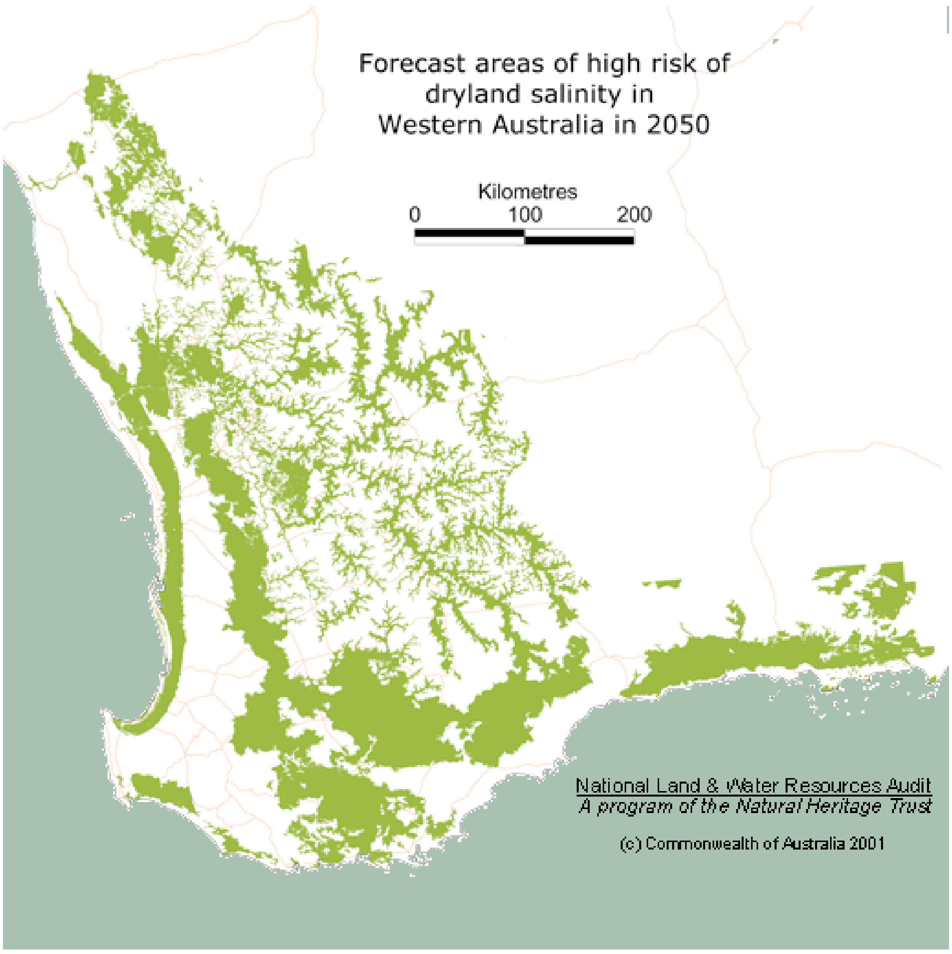


Figure 1. Forecast areas of high risk of salinity in 2050, based on the predicted extent of land at risk of high water tables (from Australian Natural Resources Atlas 2007[6]).

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

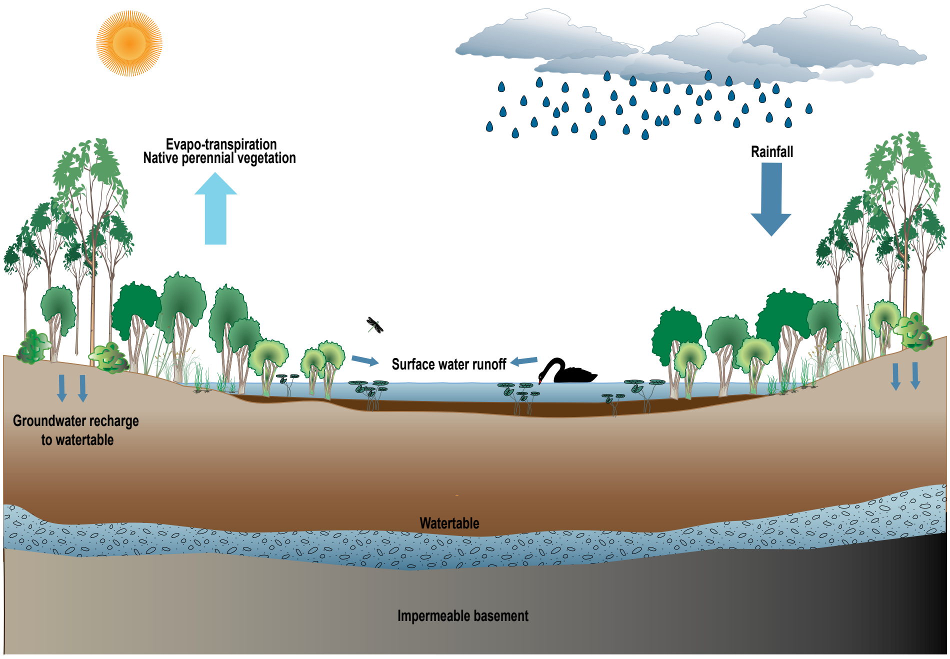
Groundwater table: the upper surface of the groundwater in an unconfined aquifer (top of the saturated zone)

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

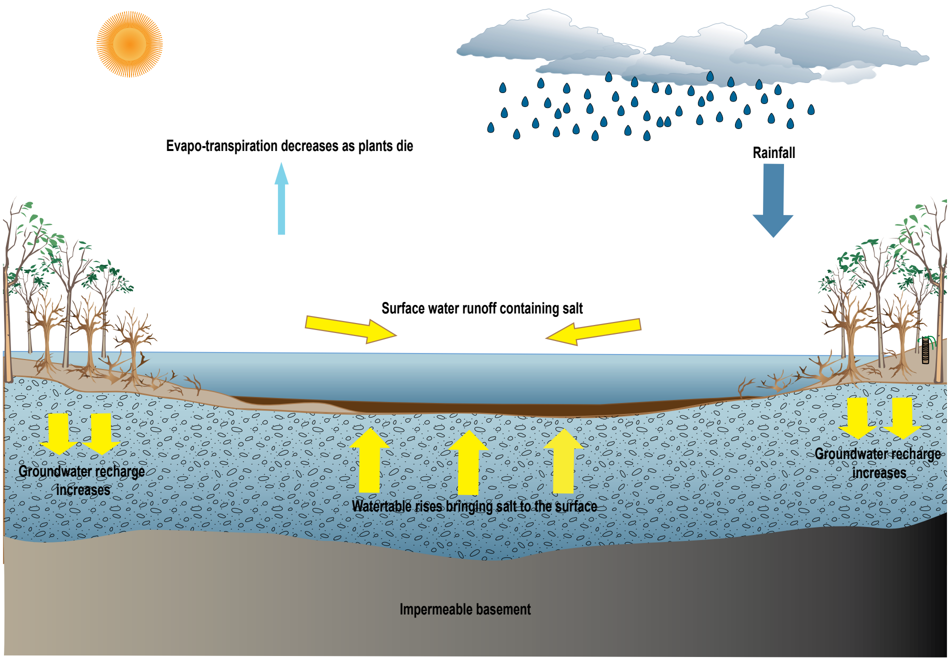
Perched: not connected to groundwater

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.

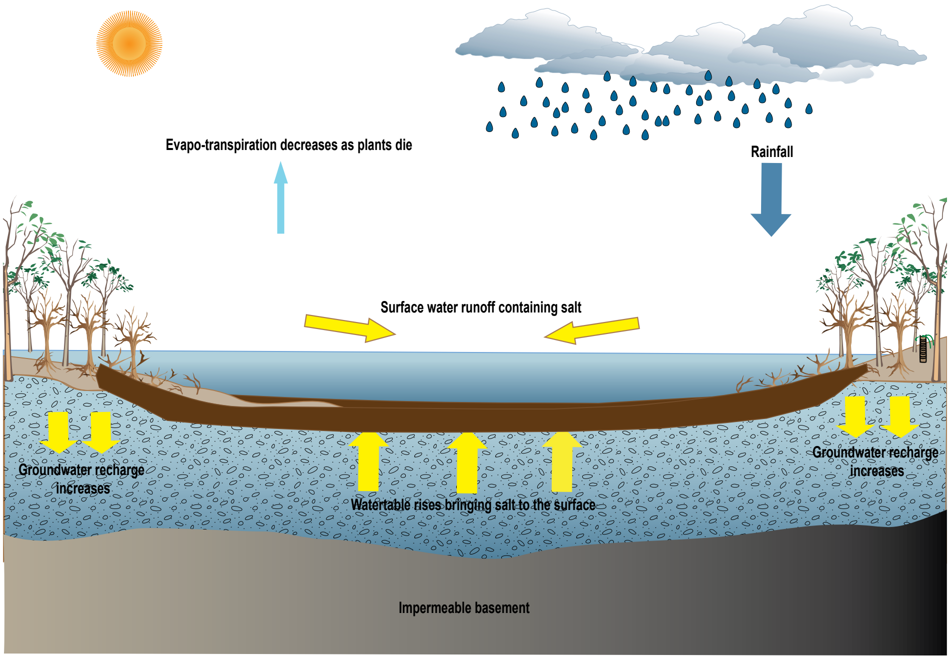


(a) Natural conditions of a wetland prior to clearing, showing low groundwater table, perennial vegetation and high transpiration rates.



(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.

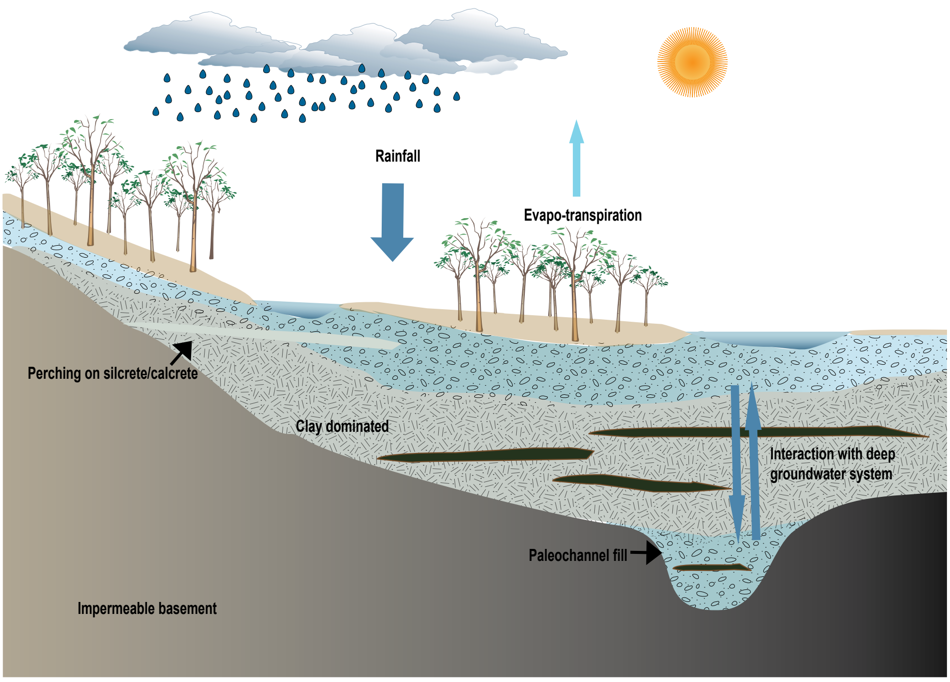


Figure 4. A representation of the complex, altered hydrological conditions present in areas of the agricultural zone within the zone of ancient drainage. Image – adapted from DEC.[19]

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.

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.

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

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

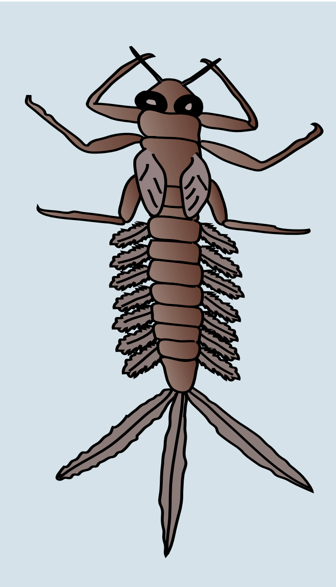
A few freshwater **invertebrate** species in south-western Australia are very salt tolerant, many are tolerant of mild salinity[9,29], but most, especially outside of the inland south-west agricultural zone, are largely restricted to freshwater (A Pinder 2009, pers. comm.). There is also a substantial 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]

Invertebrate: an animal without a backbone

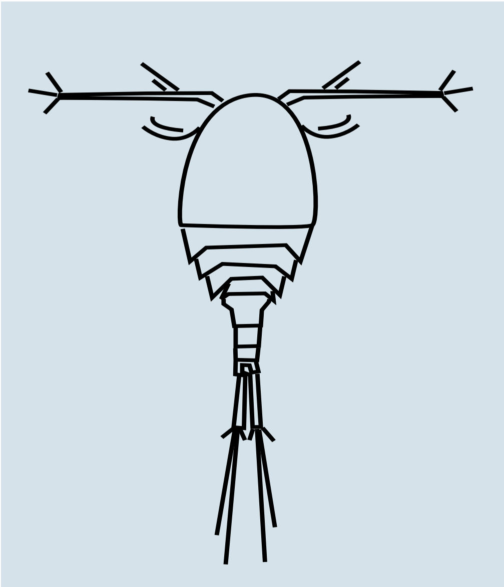
Halophile: a species that shows a preference for saline habitat such as salt lakes

Crustaceans: a class of animals that have a hard exoskeleton (shell) and usually live in the water, for example, crabs, lobsters, yabbies

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).



(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

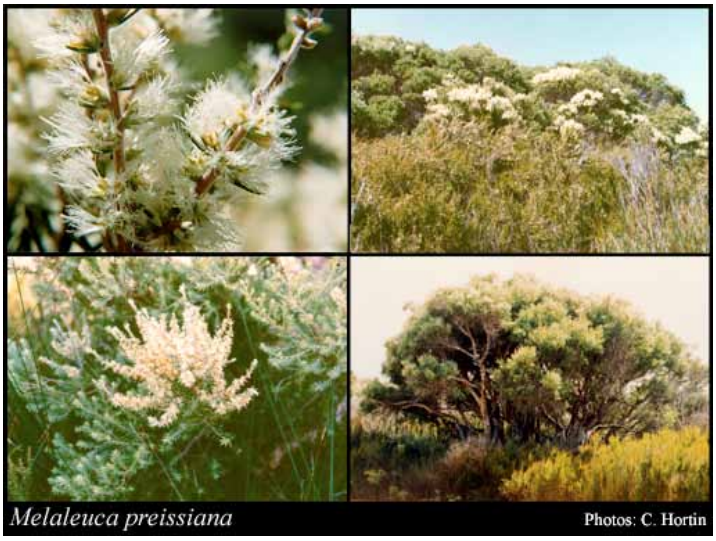
Tubers: specialised fleshy storage organs of the stem that are present in some plant species, usually found underground

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)

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

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 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).

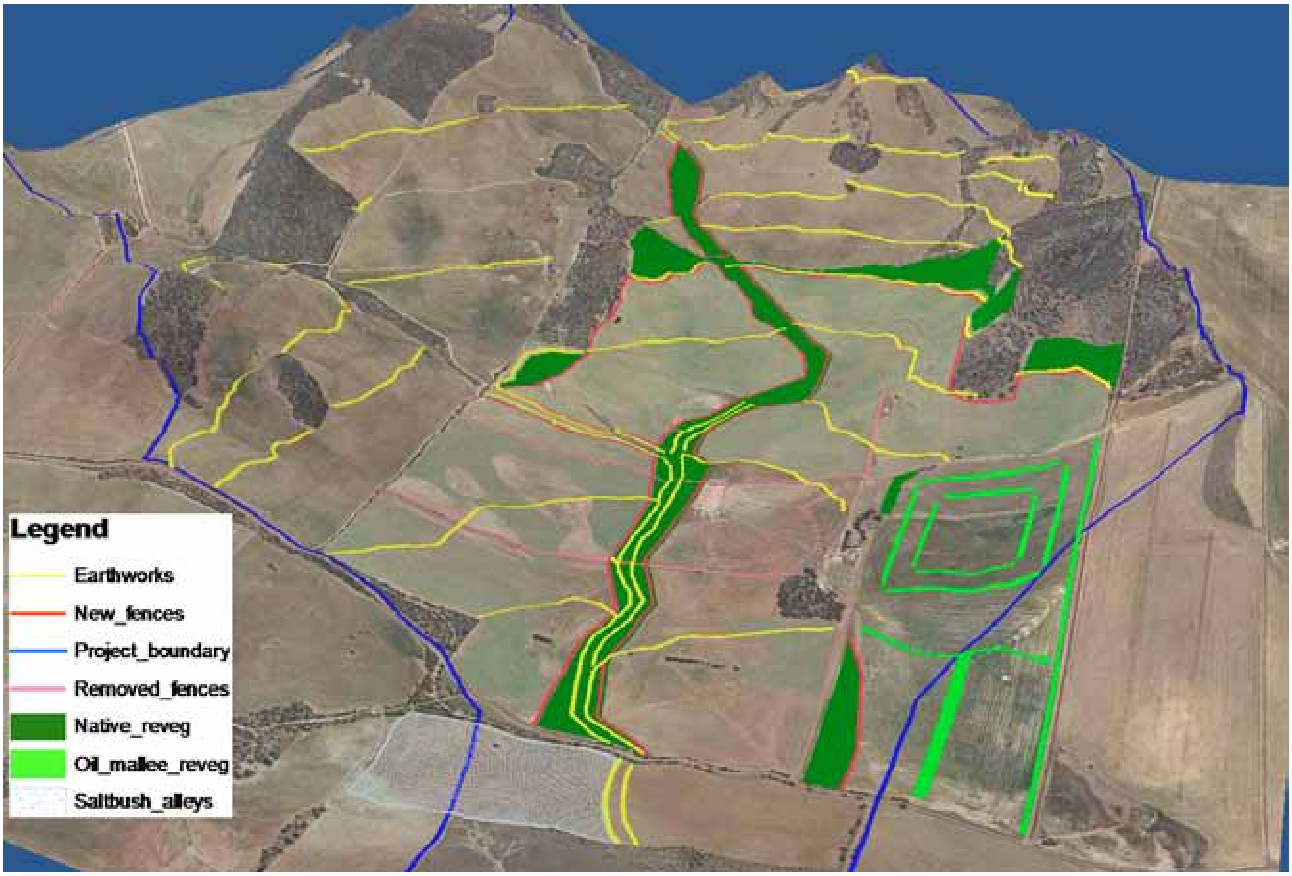


Figure 8. Integrated water management at the landscape scale has a positive effect on reducing salt, nutrient and sediment export to downstream wetlands. Engineering and biological options are integrated to optimise gains in water management (surface and groundwater) and agricultural productivity in 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

Environmental Protection Authority (2007). *State of the Environment Report: Western Australia 2007*. Department of Environment and Conservation, Perth, Western Australia. www.soe.wa.gov.au.

Clarke, CJ, George, RJ, Bell, RW, and Hatton, TJ (2002). 'Dryland salinity in south-western Australia: its origins, remedies and future research directions', *Australian Journal of Soil Research*, vol. 40, pp. 93–113.

Davis, J, McGuire, M, Halse, S, Hamilton, D, Horwitz, P, McComb, A, Froend, R, Lyons, M, and Sim, L (2003). 'What happens when you add salt: Predicting impacts of secondary salinisation on shallow aquatic ecosystems using an alternative states model', *Australian Journal of Botany*, vol. 51, pp. 715–724.

Department of Environment (2005). *Stream salinity status and trends in south-west Western Australia: Salinity and land use impacts series.* Natural Resource Management & Salinity Division, Department of Environment, Perth, Western Australia.

Halse, SA, Ruprecht, JK, and Pinder, AM (2003). 'Salinisation and prospects for biodiversity in rivers and wetlands of south-west Western Australia', *Australian Journal of Botany,* vol. 51, pp. 673–688.

Hart, BT, Bailey, P, Edwards, R, Hortle, K, James, K, McMahon, A, Meredith, C, and Swadling, K (1991). 'A review of the salt sensitivity of the Australian freshwater biota', *Hydrobiologia*, vol. 210, pp. 105–144.

National Dryland Salinity Research Development & Extension Program (1998). *Assessing the causes, impacts, costs and management of dryland salinity.* Econnect Pty Ltd for the National Dryland Salinity Program.

Nielsen, DL, Brock, MA, Rees, GN, and Baldwin, DS (2003). 'Effects of increasing salinity on freshwater ecosystems in Australia', *Australian Journal of Botany,* vol. 51, pp. 655–665.

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

Name	Date	Position	Organisation
Dr Jacqueline Giles	3/05/2009	Wetland ecologist	Department for Environment and Heritage, South Australia
Tim Mathwin	2004	Hydrologist	Department of Agriculture and Food, Western Australia
Adrian Pinder	2009	Senior Research Scientist	Department of Environment and Conservation, Western Australia
Dana Steddy	2004, 2009	Landholder, Meeking Lake	
Murray Steddy	2004, 2009	Landholder, Meeking Lake	

References

1. Boulton, AJ and Brock, MA (1999). *Australian freshwater ecology: Processes and management*. Gleneagles Publishing, Glen Osmond, South Australia.
2. Agriculture Western Australia (2006). *Salinity: A situation statement for Western Australia: A report to the Minister for Primary Industry, Minister for the Environment*. Prepared by the Chief Executive Officers of Agriculture Western Australia, Department of Conservation and Land Management, Department of Environmental Protection, Water and Rivers Commission. Agriculture Western Australia, South Perth, Western Australia.
3. Environmental Protection Authority (2007). *State of the Environment Report: Western Australia 2007*. Department of Environment and Conservation, Perth, Western Australia. www.soe.wa.gov.au.
4. Government of Western Australia (2000). *The Salinity Strategy: Natural resource management in Western Australia*. Western Australian State Salinity Council, Perth, Western Australia.
5. Australian Bureau of Statistics (2003). *Salinity and land management on Western Australian farms*. www.abs.gov.au/ausstats/ABS@.nsf/7d12b0f6763c78caca257061001cc588/f59529c371a21f55ca256db800783a4f!OpenDocument.
6. Australian Natural Resources Atlas (2007). *Salinity: Risk and hazard: Western Australia*. Australian Natural Resources Atlas, Department of the Environment, Water, Heritage and the Arts, Canberra, Australian Capital Territory. www.anra.gov.au/topics/salinity/risk-hazard/wa.html.
7. Halse, SA and Massenbauer, T (2005). 'Incorporating research results into wetland management: Lessons from recovery catchments in saline landscapes', *Hydrobiolgia*, vol. 552, issue 1, pp. 33–44.
8. Wallace, K J (2007). *Classification of ecosystem services: Problems and solutions*. Elsevier Ltd, Perth, Western Australia.
9. Halse, SA, Ruprecht, JK, and Pinder, AM (2003). 'Salinisation and prospects for biodiversity in rivers and wetlands of south-west Western Australia', *Australian Journal of Botany*, vol. 51, pp. 673–688.
10. Hatton, TJ, Ruprecht, J, and George, RJ (2003). 'Preclearing hydrology of the Western Australia wheatbelt: Target for the future?', *Plant and Soil*, vol. 257, pp. 341–356.
11. McFarlane, DJ, George, RJ, and Caccettta, P (2004). 'The extent and potential area of salt-affected land in Western Australia estimated using remote sensing and digital terrain models'1st National Salinity Engineering Conference, Perth, Western Australia, 9/11/2004–12/11/2004. http://www.cmis.csiro.au/rsm/research/pdf/Land%20Monitor%20Salinity%20Engineering.pdf.

12. Beresford, Q, Bekle, H, Phillips, H, and Mulcock, J (2001). *The salinity crisis. Landscapes, communities and politics*. University of Western Australia Press, Crawley, Western Australia.
13. Sanders, A (1991). *Oral histories documenting changes in Wheatbelt wetlands. Occasional paper 2/91*. Department of Conservation and Land Management, Perth, Western Australia.
14. Department of Environment (2005). Water Notes 33: *The ecology of wheatbelt lakes*. Prepared by J Davis, Murdoch University and M Braimbridge, Department of Environment for the Department of Environment, Perth, Western Australia. www.water.wa.gov.au/Managing+our+water/Managing+our+rivers+and+estuaries/Restoring/Water+notes/default.aspx.
15. George, R, Clarke, J, and English P (2008). 'Modern and palaeogeographic trends in the salinisation of the Western Australian Wheatbelt: A review.', *Australian Journal of Soil Research,* vol. December 2008.
16. Halse, S A, Pearson, G B, and Patrick, S (1993). Technical report no. 30: *Vegetation of depth gauged wetlands in nature reserves of south-west Western Australia.* Department of Conservation and Land Management, Perth, Western Australia.
17. Davis, J, McGuire, M, Halse, S, Hamilton, D, Horwitz, P, McComb, A, Froend, R, Lyons, M, and Sim, L (2003). 'What happens when you add salt: Predicting impacts of secondary salinisation on shallow aquatic ecosystems using an alternative states model', *Australian Journal of Botany*, vol. 51, pp. 715–724.
18. Cale, DJ, Halse, SA, and Walker, CD (2004). 'Wetland monitoring in the Wheatbelt of south-west Western Australia: Site descriptions, waterbird, aquatic invertebrate and groundwater data', *Conservation Science Western Australia*, vol. 5, issue 1, pp. 20–135.
19. Department of Environment and Conservation (2008). *Buntine-Marchagee Natural Diversity Recovery Catchment: Recovery Plan 2007–2027* www.dec.wa.gov.au/content/view/449/949/.
20. Indian Ocean Climate Initiative (2005). Climate note: *How salinity has changed. Climate note no. 11/05*. IOCI, Perth, Western Australia.
21. Dorit, RL, Walker, WF, and Barnes, RD (1991). *Zoology*. Saunders College Publishing, Orlando, Florida, USA.
22. Moore, R, Clark, WD, Stern, KR, and Vodopich, D (1995). *Botany*. Wm. C. Brown Publishers, Dubuque, IA, USA.
23. Froend, RH, Heddle, EM, Bell, DT, and McComb, AJ (1987). 'Effects of salinity and waterlogging on the vegetation of Lake Toolibin, Western Australia', *Australian Journal of Ecology*, vol. 12, pp. 281–298.
24. Nielsen, DL, Brock, MA, Rees, GN, and Baldwin, DS (2003). 'Effects of increasing salinity on freshwater ecosystems in Australia', *Australian Journal of Botany*, vol. 51, pp. 655–665.
25. Goodsell, JT (1990). 'Distribution of waterbird broods relative to wetland salinity and pH in south-western Australia', *Australian Wildlife Research*, vol. 17, pp. 219–229.
26. Halse, SA, Williams, MR, Jaensch, RP, and Lane, JAK (1993). 'Wetland characteristics and waterbird use of wetlands in south-western Australia', *Wildlife Research*, vol. 20, pp. 103–126.
27. Hussey, BMJ and Wallace, KJ (1993). *Managing your bushland*. Department of Conservation and Land Management, Perth, Western Australia.
28. Roberts, J D (2006). *Excerpt from the newsletter of the ACT herpetological association:Heleioporus albopunctatus and salinity in the WA wheatbelt*. Department of Zoology, University of Western Australia, Nedlands. www.jcu.edu.au/school/tbiol/zoology/herp/decline/uwa.shtml.
29. Kay, W, Halse, SA, Scanlon, MD, and Smith, MJ (2001). 'Distribution and environmental tolerances of aquatic macroinvertebrate families in the agricultural zone of southwestern Australia', *Journal of the North American Benthological Society*, vol. 20, issue 2, pp. 182–199.
30. Pinder, AM, Halse, SA, McRae, JM, and Shiel, RJ (2005). 'Occurrence of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity', *Hydrobiologia*, vol. 543, pp. 1–24.

31. Timms, B V, Pinder, A M, and Campagna, V (2009). *The biogeography and conservation status of the Australian endemic brine shrimp Parartemia (Anostraca, Parartemiidae)*. Conservation Science Western Australia
32. Cramer, VA and Hobbs, RJ (2002). 'Ecological consequences of altered hydrological regimes in fragmented ecosystems in southern Australia: Impacts and possible management responses', *Austral Ecology*, vol. 27, pp. 546–564.
33. Sim, LL, Chambers, JM, and Davis, JA (2006). 'Ecological regime shifts in salinised wetland systems: I: Salinity thresholds for the loss of submerged macrophytes', *Hydrobiologia*, vol. 573, pp. 89–107.
34. Jones, S, Francis, C, Leung, A, and Pinder, A (2009). *Aquatic invertebrates and waterbirds of wetlands in the Avon region.* Department of Environment and Conservation, Perth, Western Australia.
35. Siong, K, Asaeda, T, Fujino, T, and Redden, A (2006). 'Difference characteristics of phosphorus in Chara and two submerged angiosperm species: Implications for phosphorus nutrient cycling in an aquatic ecosystem', *Wetlands Ecology & Management*, vol. 14, issue 6, pp. 505–510.
36. Water on the Web (2004). *Water on the Web: Monitoring Minnesota lakes on the internet and training water science technicians for the future, a national on-line curriculum using advanced technologies and real-time data*. www.WaterOntheWeb.org.
37. Burke, CM (1990). *Interactions of benthic microbial communities with overlying waters in saline lakes of Yalgorup National Park*. University of Western Australia, Department of Zoology.
38. Nova: science in the news (2006). Sodicity: *A dirty word in Australia*. www.science.org.au/nova/035/035print.htm.
39. Lane, J A K, Clarke, A G, and Winchcombe, Y C (2011). *South west wetlands monitoring program report 1977-2010*. Department of Environment and Conservation, Perth, Western Australia.
40. Department of Environment and Conservation (2010). *WetlandBase: The Western Australian Wetlands Database*. Department of Environment and Conservation, Perth, Western Australia. www.dec.wa.gov.au/index.php?option=com_content&Itemid=2108&id=3574&lang=en&limit=1&limitstart=2&task=view.
41. Jones, S M, Pinder, A M, Sim, L L, and Halse, S A (2008). *Evaluating the conservation significance of basin and granite outcrop wetlands in the Avon natural resource management region: Stage One Assessment Method*. Prepared for the Avon Catchment Council by the Department of Environment and Conservation
42. Department of Environment and Conservation (2011). *DEC Natural Diversity Recovery Catchments webpage*. www.dec.wa.gov.au/content/view/449/1620/.
43. Department of Water (2011). *DOW Engineering Evaluation Initiative webpage*. www.water.wa.gov.au/Understanding+our+water/Understanding+salinity/Engineering+evaluation+initiative/default.aspx.
44. Department of Environment (2005). Water Notes 33: *The ecology of wheatbelt lakes*. Prepared by J Davis, Murdoch University and M Braimbridge, Department of Environment for the Department of Environment, Perth, Western Australia. http://portal.water.wa.gov.au/portal/page/portal/WaterQuality/Publications/WaterNotes.
45. Sim L, Davis JA, and Chambers JM (2008). '17: Development of Conceptual models for Ecological Regime Change in Temporary Australian Wetlands.', in Hobbes RJ and Suding KN (Eds), *New Models for Ecosystem Dynamics and Restoration*. Island Press, Washington DC.
46. Department of Environment and Conservation *Restoring ecological function and structure to the Buntine-Marchagee Natural Diversity Recovery Catchment in the Western Australian wheatbelt.* Department of Environment and Conservation, Perth, Western Australia. www.dec.wa.gov.au/content/view/449/949/.
47. Department of Environment and Conservation (2011). *DEC revegetation webpage*. Department of Environment and Conservation, Perth, Western Australia. www.dec.wa.gov.au/content/view/446/1734/1/1/.

48. Ecosystem Solutions Pty Ltd (2006). *Ecological character description of Toolibin Lake, Western Australia*. Prepared by G. McMahon, Ecosystem Solutions Pty Ltd for the Department of Conservation and Land Management, Perth, Western Australia.
49. Government of Western Australia (1996). *Western Australian salinity action plan*. Department of Agriculture WA, Department of Conservation and Land Management, Department of Environmental Protection, and Water and Rivers Commission for the Government of Western Australia, Western Australia.
50. Smith, A and Wallace, K J (1998). *Major project review Toolibin Lake Recovery Plan*. Department of Conservation and Land Management, Perth, Western Australia. www.dec.wa.gov.au/pdf/projects/salinity/toolibin/major_product_review.pdf.
51. Froend, RH, Halse, SA, and Storey, AW (1997). 'Planning for the recovery of Lake Toolibin, Western Australia', *Wetlands Ecology & Management*, vol. 5, pp. 73–85.
52. Jaensch, R P, Vervest, R M, and Hewish, M J (1988). *Waterbirds in nature reserves of south-western Australia 1981-1985*: Reserve accounts. Royal Australasian Ornithologists Union, Canning Bridge, Western Australia.
53. Toolibin Lake Recovery Team and Toolibin Lake Technical Advisory Group (1994). *Toolibin Lake recovery plan*. Department of Conservation and Land Management, Perth, Western Australia.
54. Wallace, K J C (2002). *Salinity management at Toolibin Lake, Western Australia: Innovative and practical engineering solutions', Australia National Salinity Prize submission to the Institution of Engineers*. Toolibin Lake Recovery Team & Toolibin Lake Technical Advisory Group, Narrogin, Western Australia. www.dec.wa.gov.au/pdf/projects/salinity/toolibin/iae_salinity_prize_app.pdf.
55. Department of Environment and Conservation (2009). *Toolibin Lake*. Department of Environment and Conservation, Perth, Western Australia. www.dec.wa.gov.au/content/view/451/950/.
56. Sim, LL (2006). *Transitions between ecological regimes in salinising wetlands*. Murdoch University, School of Environmental Science.

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