Waterbody Management Guideline

Module 1

Waterbodies in Our Landscape

VERSION 1 SEPTEMBER 2013

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Healthy Waterways is a not-for-profit, non-government organisation working to protect and improve waterway health in South East Queensland (SEQ). We facilitate careful planning and coordinated efforts among a network of member organisations from government, industry, research, and the community to achieve our shared vision for healthy waterways.
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1.1 INTRODUCTION

1.1.1 Purpose of module 1

This purpose of this module, *'Waterbodies in Our Landscape'*, is to provide easy and accessible information about how a waterbody functions and where the waterbody sits within the landscape. A waterbody's values are usually linked to the broader catchment and hence understanding this information is essential for choosing and implementing an appropriate management strategy.

1.1.2 How to use module 1

Module 1 is divided into three key sections. Figure 1.1 describes how to use each section.

Figure 1.1 How to use module 1

Section 1.2	
Context of Waterbodies	This section sets the context of waterbodies in the landscape and the pressures they face.
Section 1.3	
Value of Waterbodies	This section identifies and describes the values that a waterbody can have.
Section 1.4	
How a Waterbody Works	This section presents the different components of a waterbody and describes how these components work and interact. This includes outlining impacting factor, the subsequent implications and introducing possible management concepts.

1.2 CONTEXT OF WATERBODIES

Waterbodies are a common feature of the landscape and can be either wetlands in themselves or part of a broader wetland and range from rural farm dams to artificial urban lakes. For example, in the Redlands Catchment of South East Queensland, an area of 537 sq km, there are 108 sq km of wetlands including approximately 2000 waterbodies. Many of the waterbodies in South East Queensland are in poor condition and have adverse downstream impacts (LimnoLogic, 2011). The condition of these waterbodies is set to worsen as the pressures of a growing population, landuse change and climate change take effect. These pressures increase the challenges faced by managers.

1.2.1 Pressures on waterbodies

Pressures affecting waterbodies may be located a long way from the waterbody itself, e.g. land clearing occurring upstream of the waterbody. Although the focus of this guideline is on managing the waterbody itself, it is important to adopt a whole of catchment perspective to help ensure pressures are appropriately addressed.

Population growth and landuse change

Australia's population is estimated to increase from its current size of 23 million to 35.5 million by the year 2056 (Australian Bureau of Statistics, 2006). According to the *South East Queensland Regional Plan 2009-2031*, from 2006 to 2031, 754,000 additional dwellings will be required to cater for population growth in South East Queensland. This will result in expansion of current urban areas and conversion of rural and peri-urban areas into urban areas. This will lead to an increase in direct and indirect pressures exerted on waterbodies (Table 1.1).

Table 1.1 Common pressures that development exerts upon a waterbody

	Pressure	Description
Indirect pressure	Catchment disturbance	Development results in landuse change, including vegetation clearing, which can result in erosion and sediment loading to the waterbody.
	Impacts on the fringing zone	Developing land adjacent to waterbodies creates edge effects such as weed ingress, degrading the waterbody.
	Loss of connectivity of the waterbody to the overall landscape	Developing land can cause fragmentation between habitats.
	Hydrological disturbances	Developing land alters hydrology by modifying catchment characteristics, typically increasing impervious land cover. This increases the magnitude and frequency of runoff events resulting in changes to waterbody inflows and waterbody detention time. This can cause erosion and alter ecological communities by changing the inundation or drying periods for vegetation and animals that live in the waterbody.
Direct pressure	Impacts on waterbody soils	Development can directly cause mechanical disturbance of waterbody soils which can lead to exposure and activation of acid sulfate soils (low pH and metal mobilisation).
	Impacts on waterbody flora and fauna	Development can directly remove habitat and encourage the introduction of pest flora and fauna.
	Impacts on water quality	Development increases stormwater pollution delivered to waterbodies, impacting water quality.

Climate change

Climate change will impact waterbodies via more frequent and intense rainfall events, extended periods of high temperature, more intense drought, rising sea level and higher storm tides. It is critical to consider climate change when planning the future management of catchments and waterbodies. This is particularly true of waterbodies located along the coast owing to sea level rise. The National Climate Change Adaptation Research Facility provides useful tools and resources for adapting to climate change (http://www.nccarf.edu.au/). Understanding the impact that climate change will have on a specific waterbody requires careful, case-by-case consideration of the waterbody, its processes and the pressures it faces. Wetland*Info* outlines a step by step guide to understanding how climate change will impact a waterbody. For more information on this guide visit: http://wetlandinfo.ehp.qld.gov.au/wetlands/management/climate-change/climate-variability.html

1.3 VALUE OF WATERBODIES

Waterbodies have economic, social and environmental values. A high value waterbody can provide:

- a water source for uses such as irrigation, drinking water, stock watering and farm water supply
- biodiversity such as connectivity, habitat provision and drought refuge
- activities such as recreation, tourism, cultural and heritage as well as education
- flood mitigation such as water flow attenuation.

These waterbody values are further described in Table 1.2. These values are referred to throughout the rest of this guideline and are derived from the ecological values in the National Water Quality Management Strategy and Guidelines, Millennium Ecosystem Assessment, 2005, and South East Queensland Ecosystem Services Framework.

Healthy waterbodies can provide opportunities for recreation and tourism. Recreational activities such as fishing can generate considerable income. In Australia it is estimated that over five million Australians take part in recreational fishing as a leisure activity. It is estimated that international tourists spend over $200 million on fishing in Australia each year (Australian Bureau of Statistics, 2002). Our communities receive social and health benefits from interaction and connection with waterways and the environment. One study showed a positive correlation between environmental infrastructure (such as trails, recreation facilities and enjoyable scenery) and physical activity (Brownson *et al.*, 2001). These connections help improve individual health and help strengthen social bonds between families and communities. Community engagement with waterbodies can be enhanced by providing opportunities for people to interact with the ecosystem through the provision of trails, viewing platforms, signage etc. This also creates opportunities to engage the community to protect waterbodies, prevent trampling and pollution, and foster environmental custodianship of waterbodies.

It is important for the community to understand the range of values placed on waterbodies and the beneficial functions performed by a waterbody. Getting the balance right between values of waterbodies and aligning the most appropriate functions are important determining factors for long term management of waterbodies. This understanding will also help communication between local governments and the community about waterbody management and build relationships for working together to maintain and improve waterbody health.

Table 1.2 Waterbody values

Category	Waterbody value	Description
Water use	Drinking water	Waterbody provides suitable raw drinking water for personal supply
	Farm water supply	Waterbody provides a source of water suitable for domestic farm water supply for example for use for laundry and produce preparation
	Irrigation	Waterbody provides a source of water suitable for irrigation
	Stock watering	Waterbody provides a suitable source of water for livestock
Biodiversity	Habitat provision	Waterbody provides habitat that supports diverse ecological communities and species, including biological control of pest species
	Connectivity	Waterbody provides connectivity between important ecological communities including genetic, species and ecosystem connectivity
	Drought refuge	Waterbody provides refuge for species during drought
Activities	Recreation	Waterbody provides recreation including primary (e.g. swimming), secondary (e.g. kayaking, fishing, yabbies) and visual (e.g. walking trails, amenity)
	Cultural and heritage	Waterbody provides historical, cultural or spiritual relevance
	Tourism	Waterbody provides economic benefit through encouraging tourism
	Education	Waterbody provides areas for learning about ecology or conducting research
Flood mitigation	Flood mitigation	Waterbody reduces risk of erosion and flooding by attenuating water flows

1.4 HOW A WATERBODY WORKS

To manage a waterbody, it is important to understand what components are present and how these various components work and interact (the processes). This helps to identify, plan for and manage all those aspects of a waterbody that enables it to deliver values. The components that comprise a waterbody include things such as water type, plants, animals, soil and geology. The processes relate to the interactions between the components.

The health of a waterbody is dependent on the condition and functioning of different components of the system and landscape. This section discusses each of these components and their interacting processes in detail including information on impacting factors, the resulting implications and also introduces some management concepts.

1.4.1 Components

Geology and topography

Geology refers to the structure and composition of the earth and to the material (substrate) comprising a landscape. The topography (shape of an area) and geology influences the location and shape of waterbody and directly influences other components (e.g. water quality, fauna, flora).

Table 1.3 Impacts, implications and management concepts: Geology and topography

Impacts	Implications	Management concepts
Major development, earth works and extractive industries can alter the geology and topography.	Major alterations to geology and topography will impact the shape and functionality of the waterbody by effecting processes such as connectivity and water movement.	It is important to thoughtfully plan any development or earth works to ensure it has minimal negative impacts to the geology and topography.

Soils and acid sulfate soils

Soils directly influence other components (e.g. water quality, fauna, flora) and can be a reflection of the physical processes occurring in the waterbody e.g. water movement, nutrient and carbon cycles. Acid sulfate soils contain highly acidic soil horizons or oxidated iron sulfides. Acid sulfate soils are found predominantly in coastal waterbodies which are rich in organic matter and have available sulfate ions, iron and sulfate reducing bacteria.

Table 1.4 Impacts, implications and management concepts: Soils and acid sulfate soils

Impacts	Implications	Management concepts
Mechanical disturbance can mobilise sediment and can also result in acid sulfate soils.	Mobilised sediment can cause high turbidity in the waterbody. When exposed to air due to drainage or disturbance acid sulfate soils produce sulfuric acid, often releasing toxic quantities of iron, aluminum and heavy metals.	See Table 1.15 for management concepts for high turbidity. The presence of acid sulfate soils within a waterbody requires specific management, particularly if the waterbody is prone to disturbance. Refer to the Queensland Acid Sulfate Soil Technical manual for further information or contact the Queensland Acid Sulfate Soils Investigation Team for advice.

Water depth and bathymetry

The bathymetry of a waterbody refers to the profile of the waterbody's base. In other words bathymetry is the underwater equivalent of topography.

Table 1.5 Impacts, implications and management concepts: Water depth and bathymetry

Impacts	Implications	Management concepts
The design and construction of a waterbody will determine its bathymetry and depth. In the rural landscape, waterbodies that are primarily constructed for water supply vary in depth, but usually slope continuously to the deepest point in the waterbody. In the urban landscape, waterbodies may be as shallow as 2 m, but in some cases deeper than 6-7 m. These urban waterbodies will often have steeply sloping edges (1:2 to 1:4), which grade to a completely flat base.	Waterbodies with depths greater than 3 m and steep edges are vulnerable to stratification and weed infestation. Steep edges also increase safety risks. Shallow waterbodies (<3 m) with gradually sloping edges provide ideal habitat for submerged and emergent vegetation to grow. Shallow systems tend to be more resilient and stable compared with deep systems.	• Infilling backwater • Reconfiguring inlet and outlet structures • Targeted planting • Dredging. For further information on the above management concepts see Module 4 '*Maintenance and Operations*'.

Water type – salinity

Water salinity can be expressed in parts per million (ppm) but most commonly it is measured as electrical conductivity (EC) and expressed in micro Siemens (ųS). EC is the ability of water to conduct an electrical charge, which is primarily dependent upon the concentrations of ions in the water. Those ions are commonly associated with mineral salts, so EC is closely related to salinity. Table 1.6 outlines the typical ųS and ppm values for a range of water types. Waterbodies can be freshwater, marginal, brackish or saline.

Table 1.6 Typical salinity measurements

	Rainwater	Freshwater	Marginal	Brackish	Saline	Seawater
Micro Siemens (ųS)	15	< 800	800-2400	2400-8000	> 8000	~ 54,000
Parts per million (ppm)	10	< 520	520-1550	1550-5200	> 1550	~ 35,000

Table 1.7 Impacts, implications and management concepts: Water type – salinity

Impacts	Implications	Management concepts
Freshwater ecosystems are confronted with increasing salinity on a worldwide scale, due to a variety of different processes, including long term droughts, rising seawater levels, agricultural practices or specific water management strategies (Williams, 2001, Nielsen *et al.*, 2003)	Rising salt concentrations are known to affect numerous freshwater plants and animals (Hart *et al.*, 1991, 2003), and may change the composition of ecological communities. Salinity can affect both the community structure and function of freshwater waterbodies. High salinity can influence nutrient cycling, rates of primary production and respiration, and the survival of riparian vegetation and aquatic fauna. Cyanobacteria are found across a wide range of different salinities, including hypersaline waters. Studies have shown that certain freshwater species of cyanobacteria (e.g. *Microcystis aeruginosa*) have high salt tolerance and will have a competitive advantage over species vulnerable to changes in salinity (Tonk *et al.*, 2007).	• Backflow preventing device on the outlet pipe • Trenching along the waterbody batter and placing a clay barrier across the groundwater intrusion site • Raising bund levels to prevent tidal backwatering • Replanting the waterbody with saline or brackish tolerant species. For further information on the above management concepts see Module 4 *'Maintenance and Operations'*.

Water type – pH

The term pH is an abbreviation of potential hydrogen. It is a measure of the concentration of free hydrogen ions which indicate the acidity of water. The pH scale is a measure of hydrogen ions and ranges from 1.0 (highly acidic) through to 7.0 (neutral) to 14 (highly alkaline). Water with a pH of 5.0 has ten times the concentration of free hydrogen ions as water with a pH of 6.0, and 100 times the concentration of water with a neutral pH (7.0). The pH of waterbodies usually varies naturally between catchments due primarily to catchment geology and vegetation. The pH of waterbodies in South East Queensland generally ranges from about 4.5 in the tannin-stained waterbodies near coastal 'wallum' heath to near 9.0 in waterbodies located near headwaters of catchments.

Table 1.8 Impacts, implications and management concepts: Water type – pH

Impacts	Implications	Management concepts
A wide variety of factors may have an effect on the pH of water, including: • rainfall • water temperature • amount of algal or plant growth in the water (photosynthesis and respiration) • geology and soils • disturbance of acid sulfate soils due to agriculture, urban development or mining • atmospheric deposition (acid rain, dry particle deposition) • burning of fossil fuels by cars and factories • salinity.	Although small changes in pH are not likely to have a direct impact on aquatic life, they greatly influence the availability and solubility of all chemical forms in the waterbody (including nutrients and metals) and may aggravate nutrient problems. For example, a lowering of pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long term demand for dissolved oxygen.	• Management of industrial discharge • Acid sulfate soil management plans • Establish and maintain riparian vegetation to buffer inflows. For further information on the above management concepts see Module 4 *'Maintenance and Operations'.*

Biodiversity

Biodiversity is the variety of plant, animal and microbial life within an ecosystem. Biodiversity is essential for our existence, providing the fundamental building blocks which support our economy and lifestyle. A waterbody with high biodiversity reflects a healthy ecosystem that is likely to be more resilient and stable to environmental changes such as nutrient inputs and variations in climate. High biodiversity and stable ecosystems reduce management burdens. The plants in and surrounding waterbodies are an integral part of the ecosystem health, stability and functioning. Waterbody plants can be grouped into five broad categories, namely: free floating, floating attached, submerged, emergent as well as trees and shrubs. Waterbody plants play a number of important roles in waterbody health. Submerged, emergent and riparian waterbody plants improve waterbody health by:

- reducing erosion through reduction of flow rates and stabilising banks
- improving water quality by reducing nutrient concentrations and increasing dissolved oxygen levels
- promoting biodiversity through provision of food and habitat for aquatic fauna
- improving water clarity through trapping and settling suspended sediment
- reducing water temperature through shading.

Even waterbodies which are artificially constructed, such as farm dams, can provide important habitat for native waterplants and fauna and can even provide 'stepping stones' between undisturbed and modified habitats, helping to reduce habitat fragmentation (Brainwood and Burgin, 2009).

There are useful resources on waterbody flora available to managers of waterbodies, including:

- Waterplants in Australia (Sainty and Jacobs, 2003) is a comprehensive field guide for identifying waterplants in Australia
- A Census of Queensland Flora (Bostock and Holland, 2010) also provides a comprehensive list of native vegetation
- Mangroves to Mountains (Leiper, *et al.*, 2009) is a full colour field guide for the plants of South-East Queensland and northern NSW
- Planting Wetlands and Dams (Romanowski, 2009) provides practical advice on planting in constructed dams and wetlands.

Over the last 200 years Australia has suffered the largest documented decline in biodiversity of any continent. The biodiversity of Australia is still in decline, with this decline expected to accelerate as the added threats of climate change and landuse change come into play. Australia has been invaded by multiple introduced plants and animals, some of which have become established as problematic. Allaby's (1998) definition of a weed describes a weed as 'a plant in the wrong place'. A plant that may be considered a weed or pest in one area may be a valued member of the ecological community in another area. When defining and assessing a plant or animal as a pest it is important to consider the impacts, both negative and positive, that organism has on its surrounding environment. In Queensland the *Land Protection (Pest and Stock Route Management) Act 2002* provides the legislative measures to manage pests and address their environmental impacts. This Act declares pest species under one of three classes. A list of declared pest plants and animals within the different classes in Queensland under this Act can be viewed at www.daff.qld.gov.au. Pest plants and animals should be managed in accordance with local government area pest management plans (LGAPMPs).

Table 1.9 Impacts, implications and management concepts: Biodiversity

Impacts	Implications	Management concepts
A variety of factors may have an effect on biodiversity, including: • landuse change – habitat destruction • habitat fragmentation • clearing of native vegetation • introduction of invasive alien species • climate change • overexploitation and overharvesting • pollution, in particular nutrient loading.	Pest flora and fauna can cause the following problems: • out competing and displacing native species • establishing monocultures which lower the biodiversity and hence stability of the system • lowering the recreational, aesthetic, social and cultural value of the system • damaging the economic viability of the system.	Studies have shown that waterbodies have the highest conservation value when they have the following features (Hazell *et al.*, 2001): • high percentage of the water's edge providing emergent vegetation cover • low levels of bare ground in the riparian zone • high percentage of native tree cover in the surrounding 1 km area. For information on the management of pest flora and fauna see Module 4 *'Maintenance and Operations'*

1.4.2 Processes

Connectivity

A waterbody can rarely be considered as an individual, isolated ecosystem. Rather, waterbodies usually sit within a broader wetland and catchment and are connected to this much larger ecosystem. Connectivity looks at the connections between and within waterbodies, taking a whole of catchment approach. When managing a waterbody, it is important for the surrounding catchment to be considered as this can have a major effect on the waterbody. Therefore, always consider the upstream and downstream impacts of management actions. Similarly, when tracking the sources of waterbody issues consider the upstream features of the catchment. It is important to understand how a waterbody functions within its catchment and manage accordingly.

Table 1.10 Impacts, implications and management concepts: Connectivity

Impacts	Implications	Management concepts
Landuse change, habitat fragmentation and changes to water movement within the catchment can all impact connectivity.	Low connectivity can negatively impact the biodiversity and stability of the ecosystem.	• Provide waterbodies with buffer and support zones • Allow environmental flows • Encourage wildlife corridors For further information on understanding the connectivity of waterbodies and associated management, visit http://wetlandinfo.ehp.qld.gov.au/wetlands/ecology/landscape/.

Water movement

Understanding the water movement in a waterbody is key for directing appropriate management. This includes understanding the timing, frequency, duration, extent and depth as well as the variability of the water within the waterbody (Boulton and Brock, 1999). The hydrology and hydraulics of a waterbody are interrelated and influence the functionality of a waterbody.

The hydraulics of a waterbody describes the physical mechanisms by which water moves into, out of and through a waterbody. This includes consideration of the conveyance of water through pipes and channels. These factors influence the amount of time that water spends in the waterbody (known as hydraulic residence time). Inlet and outlet pits, pipes and weirs are common hydraulic features of waterbodies.

The hydrology of a waterbody describes how a waterbody interacts with the surrounding environment, particularly the sources and distribution of a waterbody's water.

Water inflows:	**Water outflows:**
• catchment runoff e.g. stormwater • rainfall onto surface of waterbody • groundwater • flood water • water pumped in for storage • tidal water (in the case of coastal waterbodies).	• evaporation of surface water • evapotranspiration by plants • discharge through hydraulic structures (e.g. pipes, weirs, channels, swales) • seepage to groundwater • water drawn for irrigation, water supply or animal watering.

Table 1.11 Impacts, implications and management concepts: Water movement

Impacts	Implications	Management concepts
The waterbody's location within the catchment, the landuse of the catchment, the amount of water drawn for irrigation, water supply or animal watering as well as the configuration of the hydraulic structures are all factors that influence and impact a waterbody's hydrology.	A waterbody with persistent low flows and high hydraulic residence time is more likely to develop cyanobacterial blooms. Non flowing water allows the cyanobacterial population to grow and develop a bloom. Warm weather coupled with non flowing water causes stratification. Stratification causes low oxygen conditions on the bottom of a waterbody which can result in substantial release of phosphorus from the sediment. Cyanobacteria have competitive advantages over other species, allowing them to become dominant and cause management burdens. The main competitive advantage of cyanobacteria is that they can regulate their buoyancy and move from the upper, light part of the water column during the day, to the deeper, phosphorus-rich layers at night.	• Reconfiguring hydraulic structures such as inlet and outlet pipes • Configuring waterbody to receive flushing flows • Altering water level by diverting catchment runoff into or around the waterbody • Mechanical aeration and recirculation systems. For further information on the above management concepts see Module 4 *'Maintenance and Operations'.*

Nitrogen cycle

Nitrogen is an essential nutrient to flora and fauna in waterbodies. Nitrogen is present in waters in both dissolved and particulate forms. Particulate forms include those bound up in organisms, chiefly as proteins in plant and animal tissues, and those bound to suspended particulate matter such as sediment. Dissolved nitrogen may be either inorganic or organic. Water quality reporting often refers to Dissolved Inorganic Nitrogen (DIN), which represents the total amount of nitrogen present as ammonium, nitrate and nitrite. Nitrogen is also present as soluble, carbon-containing molecules such as urea and amino acids, collectively known as Dissolved Organic Nitrogen (DON). Finally, nitrogen is found in particulate organic form such as phytoplankton and organic detritus known as Particulate Organic Nitrogen (PON). The total nitrogen concentration in water (TN) includes all these forms. Figure 1.2 summarises the different forms of nitrogen.

Figure 1.2 The different forms of nitrogen present in a waterbody

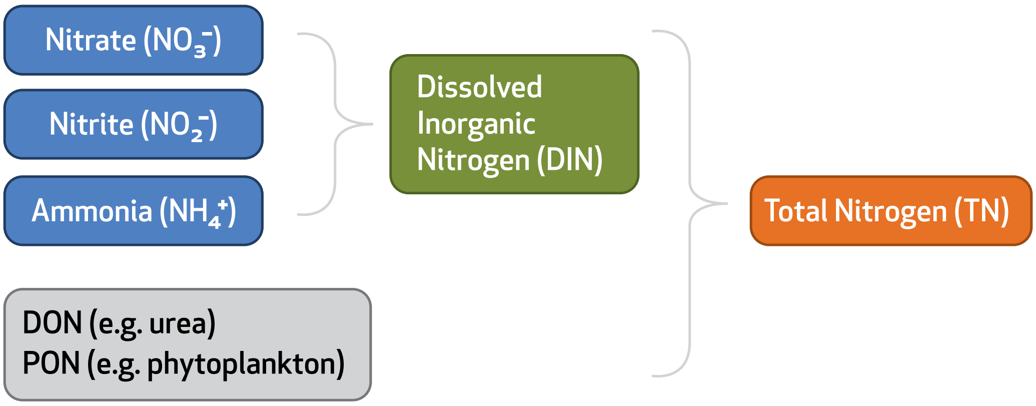
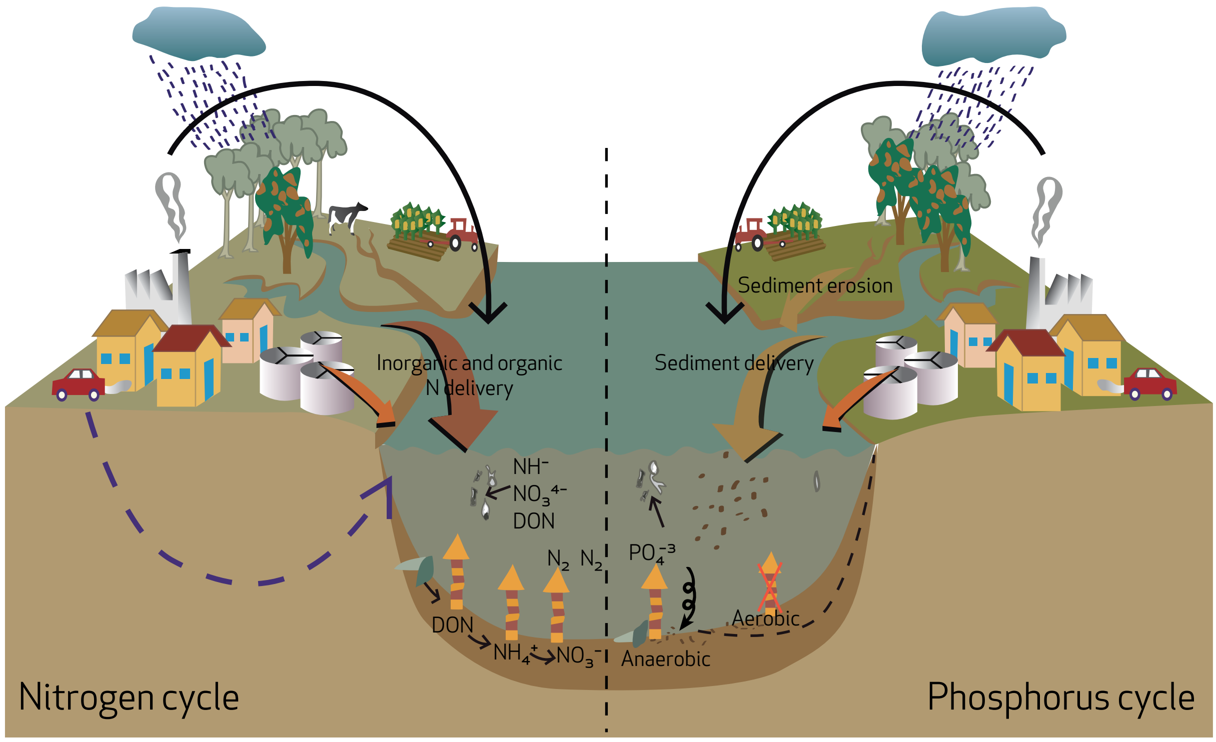


Table 1.12 Impacts, implications and management concepts: Nitrogen cycle

Impacts	Implications	Management concepts
The major nitrogen reservoir is the atmosphere which is comprised of 78% nitrogen gas (N_2). Nitrogen enters waterbodies through the atmosphere. External sources of nitrogen to a waterbody impact the nitrogen cycle. Sources of nitrogen to a waterbody include: • animal wastes (faeces and urine) • fertilisers • stormwater runoff • decomposing plant and animal matter (e.g. grass clippings) • leaking septic or sewerage systems. Certain species of cyanobacteria (e.g. *Anabaena, Nodularia*) can be a source of nitrogen to the waterbody by fixing N_2 directly from the atmosphere. This increases the nitrogen levels of the waterbody and gives these species a competitive advantage making them difficult to eradicate. Figure 1.3 presents the sources and influencing factors on nitrogen in a waterbody.	High nitrogen concentrations encourage the growth of problematic aquatic weeds such as *Salvinia molesta, Eichornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) as well as increasing the occurrence of algal and cyanobacteria blooms. When these blooms and weeds start to die and decay they lower water quality by consuming oxygen from the water column. As decaying blooms are broken down by organisms, the increase in respiration to achieve this breakdown will exert a significant demand on the dissolved oxygen supply of the water. This can lower dissolved oxygen levels to the point where fish kills may occur. Fish kills bring a range of problems such as lowered biodiversity, public complaints and disposal issues.	• Stormwater treatment system in the upstream catchment • Floating wetlands • Recirculation systems • Animal waste management • Agriculture runoff management • Establishment and protection of riparian revegetation • Manage point sources such as on-site sewage treatment systems • Appropriate fertiliser application on surrounding land. For further information on the above management concepts see Module 4 *'Maintenance and Operations'*.

Figure 1.3 Nitrogen and phosphorus cycle



Nutrients (nitrogen and phosphorus) are transferred to waterways via a number of mechanisms including, diffuse loads, point source loads, atmospheric deposition, and groundwater flow

Diffuse sources of nitrogen enter waterways as dissolved inorganic and dissolved or particulate organic form

Decomposition of organic matter releases Dissolved Organic Nitrogen (DON)

Ammonification converts DON into ammonium (NH_4^+) which may be released into the water column if not converted further

Nitrification converts NH_4^+ into nitrate (NO_3^-) which is generally denitrified to nitrogen gas (N_2) and released

Dissolved nitrogen is available for uptake

Diffuse sources of phosphorus predominantly enters waterways attached to sediment particles

Phosphorus is deposited with sediments

Phosphorus release is prevented when sediments are aerobic

P release occurs when sediments are anaerobic

Dissolved P is available for uptake

Phosphorus cycle

Phosphorus is an essential nutrient for ecosystems. Phosphorus is present in water in both dissolved and particulate forms. Orthophosphate is the major form of biologically available phosphorus found in water. Particulate forms include those incorporated into plant and animal matter, and those bound to suspended matter such as sediment. Figure 1.3 presents the sources and influencing factors on phosphorus in a waterbody.

Table 1.13 Impacts, implications and management concepts: Phosphorus cycle

Impacts	Implications	Management concepts
Phosphorus availability is highly dependent upon the pH of the water and the oxygen levels in the hypolimnion (bottom layer of the water column when waterbodies are stratified). The less oxygen in the hypolimnion, and the lower the pH, the more bioavailable phosphorus will exist in the water column. Most of the phosphorus entering a waterbody is attached to sediment particles. Therefore, if the waterbody experiences stratification coupled with high sediment loads, particularly if phosphorus fertilisers are applied to the surrounding land, then it is likely that the waterbody will have high phosphorus concentrations. Figure 1.3 presents the sources and influencing factors on phosphorus in a waterbody.	Although sediments have some capacity to absorb and recycle phosphorus inputs, if the waterbody suffers from high inputs of organic matter and nutrients then this capacity may be exceeded. This will lead to the sediment providing the waterbody with bioavailable forms of phosphorus and exerting a demand on the dissolved oxygen supply, a phenomenon known as 'internal loading' (Pettersson, K., 1998). Internal loading typically results in eutrophication. In particulate form phosphorus is not bioavailable, however, phosphorus is continually recycled and can become remobilised from sediments under anaerobic conditions (i.e. when the waterbody is stratified).	• Stormwater treatment system in the upstream catchment • Floating wetlands • Recirculation and aeration systems • Animal waste management • Agriculture runoff management • Establishment and protection of riparian revegetation • Manage point sources such as on-site sewage treatment systems • Appropriate fertiliser application on surrounding land. For further information on the above management concepts see Module 4 *'Maintenance and Operations'.*

Carbon cycle

All living things are made of carbon. Carbon can be found in gas, solid and liquid forms. The total amount of carbon on earth is fixed and always remains the same. Carbon is mobile and continuously cycled through the earth's systems. Carbon can be stored or 'sequestered' as organic matter in reservoirs such as soil or plant matter.

Table 1.14 Impacts, implications and management concepts: Carbon cycle

Impacts	Implications	Management concepts
Sequestered carbon can be released back to the atmosphere via soil disturbance, land clearing, plant and animal respiration and burning of fossil fuels. Taking water out of a waterbody means oxygen can reach previously inundated organic matter. This results in large emissions of carbon dioxide as the organic matter oxidises. This is an important consideration for waterbody management.	Carbon emissions are a major driver of the greenhouse effect and climate change.	• Minimise land clearing and vegetation removal • Minimise disturbance of soil and sediments.

Turbidity and sedimentation

Turbidity is a measure of the cloudiness of water and is dependent on the concentration of suspended solids within the water column. As rain falls and flows over a catchment, sediment and organic matter are picked up and deposited into the waterbody. Depending on the size of the particles and other conditions in the waterbody, sediment either stays in the water column, or settles onto the bottom of the waterbody. Not all turbid waters are an indication of poor water quality. Some inland waterbodies are naturally very turbid and the animals and plants that grow in them have adapted to live in these conditions (Wetland*Info*, 2013). It is important to find out whether the waterbody is naturally turbid or clear before implementing any management actions.

Table 1.15 Impacts, implications and management concepts: Turbidity and sedimentation

Impacts	Implications	Management concepts
Erosion of surrounding soil is a significant source of sediment to waterbodies. Various types of erosion can occur within a catchment which can pollute waterbodies with sediment, these include: • upstream gully erosion • hoof erosion both upstream and around the waterbody • sheet erosion from exposed soil on surrounding land including construction sites or cleared paddocks • erosion of the waterbody's banks through trampling or exposed soil. Another source of turbidity is waste discharges from sewage systems, mining sites or factories. Resuspension of sediment from the bottom of a waterbody can also cause turbidity issues. Resuspension can occur for a number of reasons for example rain events, windy conditions or aquatic animals which feed from the bottom sediments of a waterbody (e.g. Carp).	High turbidity levels affect the health of the flora and fauna of the waterbody by clogging fish gills and by reducing penetration of light which inhibits the photosynthetic ability of submerged aquatic plants. High turbidity levels give cyanobacteria a competitive advantage over other algae species. Cyanobacteria contain gas vesicles which allow them to float to less turbid surface layers where they can avail of the sunlight. When turbidity levels are high the submerged vegetation will die and the health of the waterbody will decline.	• Establishing and maintaining healthy submerged and emergent macrophytes within the waterbody • Establishing and maintaining healthy riparian vegetation on waterbody margins • Repairing areas of bank erosion (e.g. lining with geofabric) and revegetating using endemic species • Stormwater treatment within the upstream catchment • Installation of floating wetlands within the waterbody • Managing runoff from construction and agriculture sites. For further information on the above management concepts see Module 4 '*Maintenance and Operations*'.

Stratification

The warming of the surface layer of a waterbody results in thermal stratification. Thermal stratification divides a waterbody as follows:

- epilimnion – upper oxygenated layer
- hypolimnion – lower stagnant, deoxygenated layer
- metalimnion (or thermocline) – middle layer between the epilimnion and hypolimnion.

Under these conditions, downward mixing is greatly restricted because of the difference in density between warm surface water and cooler bottom water (Figure 1.4).

Figure 1.4 Thermal stratification

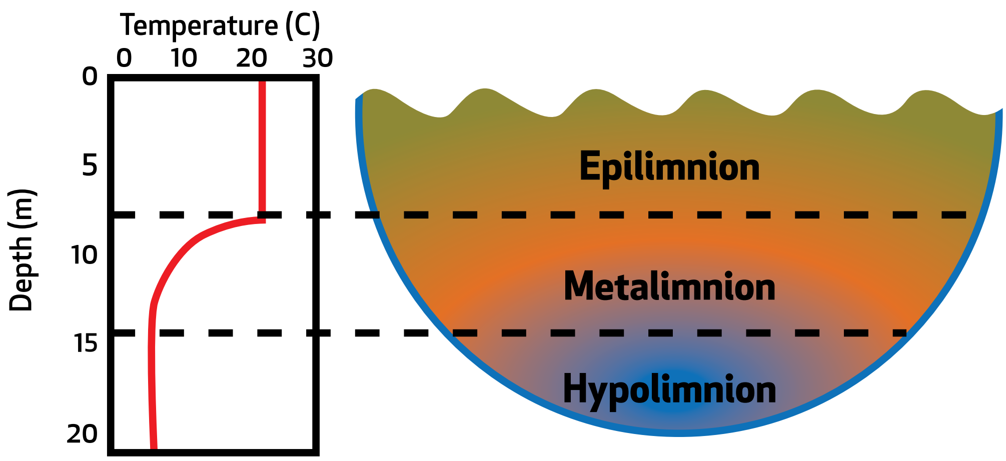


Table 1.16 Impacts, implications and management concepts: Stratification

Impacts	Implications	Management concepts
Waterbodies which experience low water flows are particularly susceptible to stratification especially when weather conditions are warm with little wind. Waterbodies which have little or no riparian vegetation have little shade and therefore minimal protection from the sun heating the surface water.	Stratification has a major influence on the water quality and functioning of the waterbody. During stratification the hypolimnion is denied gas exchange with the atmosphere. This can lead to low dissolved oxygen conditions if the waterbody is susceptible to high input of oxygen demanding substances (i.e. organic matter). This in turn can lead to mobilisation of phosphorus from the sediments resulting in high nutrient concentrations in the hypolimnion. Stratification also gives cyanobacteria a competitive advantage over other algae species. Most algae will permanently sink from the warm upper epilimnion layer to the cooler lower hypolimnion layer. Cyanobacteria on the other hand can remain buoyant and float and accumulate at or near the surface in the epilimnion layer. In the epilimnion layer they receive the light they need to grow and in the absence of other algae species have little competition for the essential dissolved nutrients.	• Recirculation and aeration systems • Modification of waterbody bathymetry to increase hydraulic efficiency and wind forced mixing • Plant tall riparian vegetation to promote shading of waterbody • Installation of floating wetlands to reduce surface water temperatures • Reduce depth of waterbody. For further information on the above management concepts see Module 4 *'Maintenance and Operations'.*

Ecosystem states

A waterbody can be described as having different ecosystem states. Certain triggers can cause switches between these different states. A waterbody is considered to be in a healthy and stable ecosystem state when it has clear water and an established submerged and emergent waterplant community, also known as a macrophyte community. If a waterbody has persistent high turbidity then the submerged macrophyte community will die off due to lack of light penetration and the ecosystem will switch to a less stable floating macrophyte state. If the high turbidity is coupled with high nutrients then the ecosystem state will decline further to an algal dominated state. If there is no intervention and the high sediment and nutrient loads persist then the system will eventually decline to a cyanobacterial dominated state. The process of switches between ecosystem states is summarised in Figure 1.5. It is very difficult to return a waterbody from an algal or cyanobacterial dominated state to a macrophyte dominated state. It is preferable to retain the macrophyte dominated state if at all possible. For more information on alternative states in waterbodies, refer to the Urban Lakes Discussion Paper (Water by Design, 2012) and Scheffer *et al.*, (2001, 2007).

Figure 1.5 The alternative states observed in shallow waterbodies

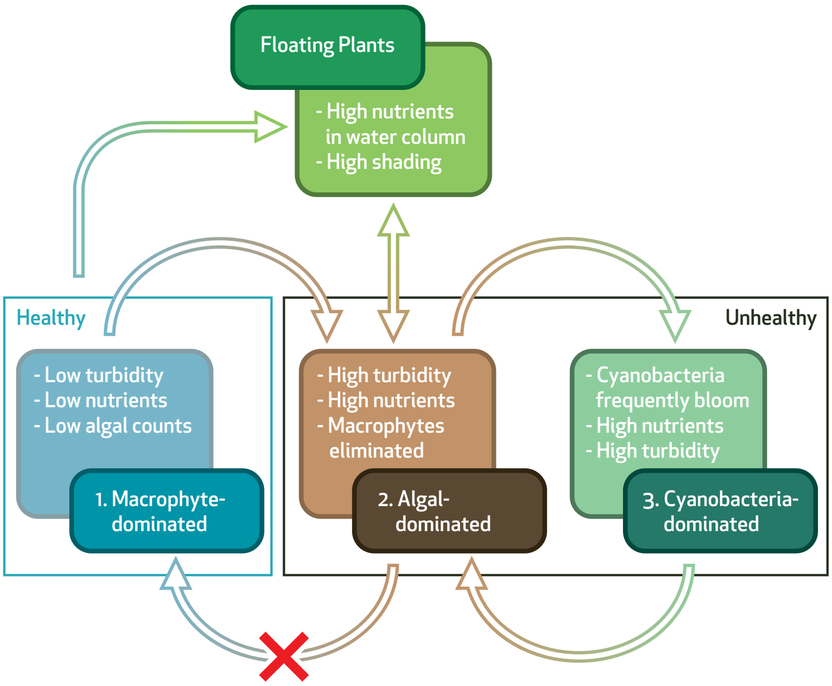


Table 1.17 Impacts, implications and management concepts: Ecosystem states

Impacts	Implications	Management concepts
A number of factors can impact ecosystem states, including: • high sediment loads • high nutrient loads • removal of macrophytes.	If the ecosystem state declines to cyanobacteria-dominated state then the resulting cyanobacterial blooms will cause a range of aesthetic, health and safety as well as biodiversity issues.	• Installation of stormwater treatment system in the upstream catchment to remove pollutants prior to entering the waterbody • Removal of the waterbody sediments • Resetting part or all of the waterbody system as a wetland • Installing water recirculation system (e.g. wetland, sand filter) to deplete algal biomass and nutrient loading within the waterbody • Configuring waterbody to receive flushing flows • Installing floating wetlands to manage nutrients and turbidity • Planting the waterbody with emergent and submerged vegetation. For further information on the above management concepts see Module 4 *'Maintenance and Operations'.*

1.5 REFERENCES

Allaby, M. (1998). *Oxford Dictionary of Ecology*. New York, NY: Oxford University Press.

Australian Bureau of Statistics, Year Book Australia, (2002). http://www.abs.gov.au

Australian Bureau of Statistics Population Projections, Australia, (2006). 2006 to 2101, 3222.0.

Bostock, P. D., and Holland, A. E., (2010). *Census of Queensland Flora,* Queensland Herbarium Biodiversity and Ecosystem Sciences, Department of Environment and Resource Management.

Brainwood, M. and Burgin, S., (2009). H*otspots of biodiversity or homogeneous landscapes? Farm dams as biodiversity reserves in Australia*. Biodiversity Conservation 18, 3040-3052.

Boulton, AJ & Brock, MA (1999), *Australian freshwater ecology: Processes and management*, Gleneagles publishing, Glen Osmond, South Australia.

Brownson, R.C., *et al*., (2001). *Environmental and policy determinants of physical activity in the United States*. American Journal of Public Health, 91:12, 1995-2003.

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

Hart, B.T., Lake, P.S., Webb, J.A., Grace, M.R., (2003). *Ecological risks to aquatic systems from salinity increases*. Australian Journal Botany 51:689–702.

Hazell, D., *et al*., (2001). *Use of farm dams as frog habitat in an Australian agricultural landscape: factors affecting species richness and distribution*. Biological Conservation 102, 155-169.

Land Protection (Pest and Stock Route Management) Act 2002.

Leiper, G., *et al*., Mangroves to Mountains (2009) Society for Growing Australian Plants

LimnoLogic, (2011). *Downstream water quality impacts associated with artificial lakes and farm dams – final outcomes and management options*.

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

National Water Quality Management Strategy and Guidelines http://www.environment.gov.au/water/policy-programs/nwqms/

Nielsen, D.L., Brock, M.A., Rees, G.N., Baldwin, D.S., (2003) *Effects of increasing salinity on freshwater ecosystems in Australia*. Australian Journal Botany 51:655–665.

Pettersson, K. (1998) *Mechanisms for internal loading of phosphorus in lakes*. Hydrobiologia 373/4: 21-25

Romanowski, N., (2009) *Planting Wetlands and Dams: A Practical Guide to Wetland Design, Construction and Propagation,* CSIRO Publishing.

Sainty, G. R. and Jacobs, S. W., (2004). *Waterplants in Australia,* Sainty Books.

Scheffer, M., Carpenter, S., Foley, J. A., Folks, C., Walker, B., (2001) *Catastrophic shifts in ecosystems*. Nature 413: 591-596.

Scheffer, M. and van Nes, E., H., (2007) *Shallow lakes theory revisited: various alternative regimes driven by climate, nutrients, depth and lake size*. Hydrobiologia 584: 455-466.

The South East Queensland Regional Plan 2009–2031.

South East Queensland Ecosystem Services Framework, http://www.ecosystemservicesseq.com.au/index.html

Tonk, L., Bosch, K., Visser, P. M., Huisman, J., (2007). *Salt tolerance of the harmful cyanobacterium Microcystis aeruginosa*., Aquatic Microbial Ecology., Vol. 46: 117–123.

Water by Design, (2012). *Urban Lakes Discussion Paper – Managing the Risks of Cyanobacterial Blooms*. Healthy Waterways Limited.

Williams, W.D., (2001). *Anthropogenic salinisation of inland waters*. Hydrobiologia 466:329–337.