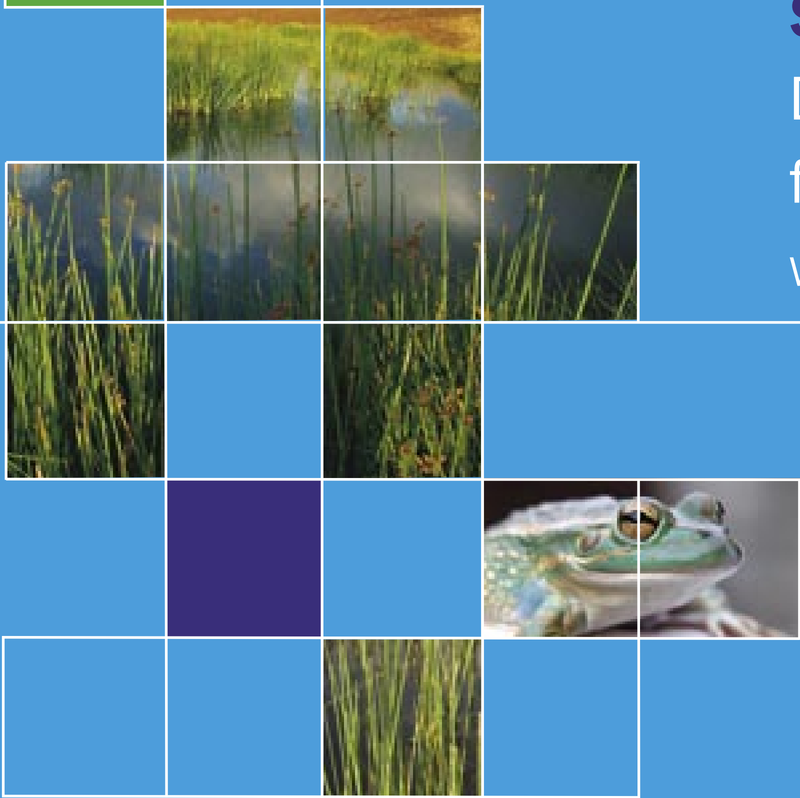

Constructed Shallow Lake Systems

Design Guidelines for Developers

Version 2, November 2005

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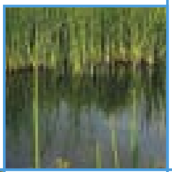
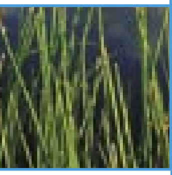




Contents

Acknowledgments

This document is a review of the document published in September 2003. This review has been undertaken to reflect the increasing knowledge and understanding of constructed shallow lake systems. Major contributions by Dr Mike Grace, Water Studies Centre, Monash University were gratefully accepted in the first version of this document.

Introduction

Constructed shallow lake systems within urban developments are normally designed for amenity or recreational purposes. This contrasts with wetland systems designed specifically for stormwater quality treatment. Constructed shallow lakes are generally considered to have a higher probability of algal blooms than wetlands due to the longer residence times of stormwater, lower abundance of rooted macrophytes and an increased likelihood of thermal stratification. The likelihood of algal blooms can however be minimised by appropriate design and management of the waterbody.

Melbourne Water does not have recreation functions as part of its Operating Charter and therefore does not plan or construct water bodies designed primarily for amenity or recreation as opposed to water quality treatment.

Whilst constructed shallow lakes are not encouraged, where they can be demonstrated to be sustainable, are appropriately managed and pose minimal threats to downstream waterways and receiving waterbodies, Melbourne Water does not object to their construction.

When algal blooms do occur, they are in general short lived. Warning notices should be put into place to prevent access to the waterbody. However, if they are frequent and persistent, more substantial actions may be required. Further information can be obtained from The Department of Sustainability and Environment (136 186) and from The Department of Human Services (9616 7777), state-wide coordinators for the management of blue green algae. Melbourne Water acts as a regional coordinator and can be contacted for blooms occurring within Port Phillip and Western Port regions (131 722).

The purpose of this document is to provide a basic description of the function and behaviour of lake systems and highlight the risks and issues that need to be considered in their design and management. This document will help ensure a consistent approach to modelling, designing and constructing shallow lake systems using best practice design. A flow chart summarising the different steps towards a successful approval is given in Appendix 1.

This document should be read in conjunction with:

- Melbourne Water's *Constructed Wetland Systems, Design Guidelines for Developers*, which is available as a download from Melbourne Water's web page: http://www.melbournewater.com.au/content/library/rivers_and_creeks/wetlands/Design_Guidelines_For_Shallow_Lake_Systems.pdf
- WSUD – Engineering Procedures. Stormwater, MWC, 2005.

1. Risk Assessment

The design of the lake should be the result of a thorough analysis of the level of risk of algal blooms (green and blue green algae) and any other issues that may impact on lake sustainability. Overall three main factors are considered to control algal blooms (see conceptual model). The right adequacy of these factors will most likely engender an algal bloom.

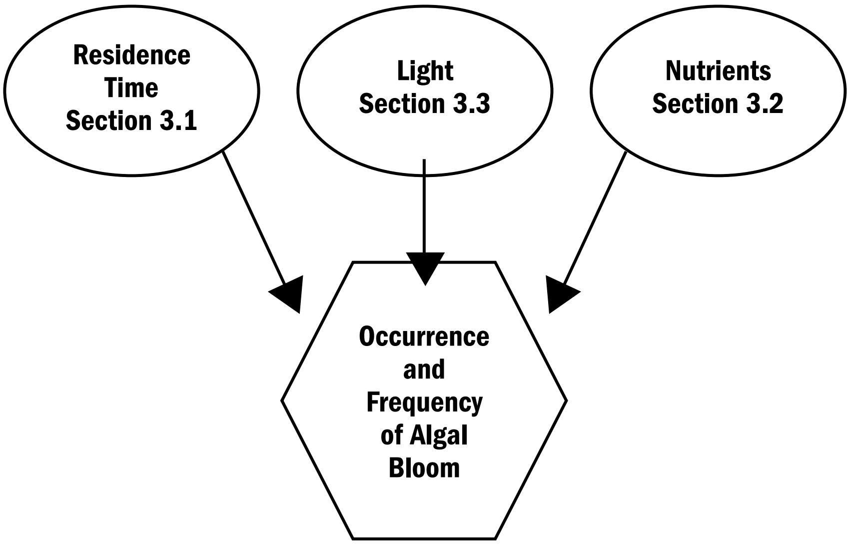


Figure 1. Conceptual model showing the main factors controlling an algal bloom.

To best understand the severity of the risk, consideration needs to be given to both the consequence of the threat and the probability of the threat occurring. The risk assessment should provide a matrix of consequence and likelihood to help guide the importance of the risk in the lake design and management plans.

Risks should not be discussed in isolation, as they are often interdependent. A risk assessment needs to be integrated with the design intent and must clearly demonstrate that the developer understands the risks.

Nutrient inputs can be managed by installing pre-treatment measures upstream. Treatment of stormwater to protect receiving water bodies is now common practice in Victoria (Urban Storm Water: Best Practice Environmental Management Guidelines, 1999). Targets are to retain 80% of the suspended solid annual load, 45% of total phosphorus and 45% of total nitrogen annual loads.

Light can be managed to a certain extent but some blue green algae are able to regulate their position in the water column and migrate vertically, increasing their exposure to optimum light intensities.

Residence time is also amenable to management action and constitutes a tangible tool to assess the likelihood of potential algal problems within a lake.

Table 1 gives examples of several scenarios for the setting of a lake with their associated risk of developing algal blooms, in particular blue green algal ones. It is assumed in all cases that the macrophyte community is established in at least 50% of the lake area. These examples apply to a water body with a summer water column temperature of 20°C. More detailed information is provided in the WSUD Engineering Procedures: Stormwater (MWC, 2005) document. This table should be read as a guide only and is based on the best information available to date. The guidelines will be redefined as more data becomes available.

Table 1. Risks of lakes developing algal blooms

	Risk of Algal Bloom	Recommended Action
Residence time < 20 days more than 80% of the time **Pretreatment in place** **Macrophyte cover > 50% lake area**	Very low risk	Provide an overview of the lake's function to residents (Appendix 4)
Residence time < 30 days at least 80% of the time **Pretreatment in place** **Macrophyte cover > 50% lake area**	Low risk	Provide an overview of the lake's function to residents (Appendix 4)
Residence time < 30 days at least 80% of the time **No Pretreatment in place** **Macrophyte cover > 50% lake area**	Low to Medium risk	Investigate the feasibility and implementation of pre-treatment structures (Section 5.1)
Residence time >30 days more than 20% of the time **Pretreatment in place** **Macrophyte cover > 50% lake area**	Medium risk	As above and change the design of the lake to minimise the residence time (Section 5.2)
Residence time >30 days more than 20% of the time **No Pretreatment in place** **Macrophyte cover > 50% lake area**	High risk	Construction of the lake not recommended

A report should be provided to the relevant authority demonstrating the identification and understanding (consequence and likelihood) of the risks associated with the proposed waterbody.

2. Shallow Lake Eutrophication

Shallow lakes are dynamic systems that change over time in response to internal and external inputs and processes. The most pervasive system change that can lead to problems is the process of eutrophication, which is the enrichment of the system with inorganic nutrients, either in soluble form or associated with organic matter or silt. In shallow lake systems, this enrichment often leads to the excessive growth of algae, also called algal bloom.

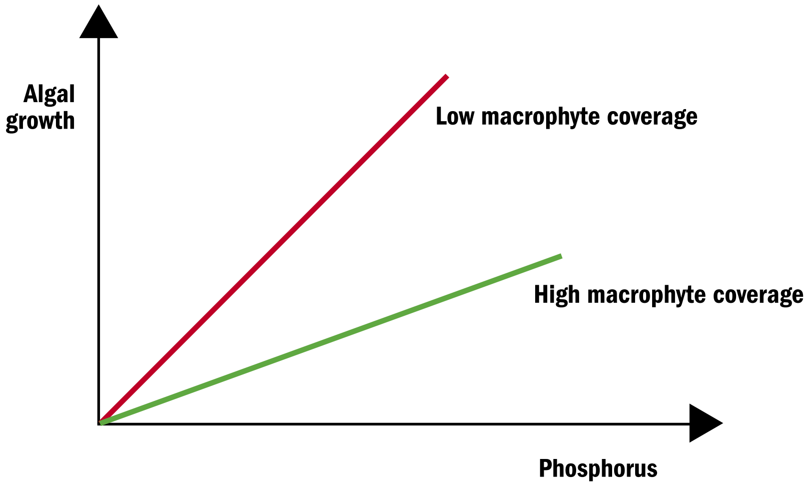
Microscopic and macroscopic forms of algae can produce a bloom. Blue green algae (or cyanobacteria) are often classified as part of the microscopic algal populations, despite the fact that these micro-organisms are bacteria. However, like algae, they rely on sunlight for energy. Nuisance green algal blooms may occur more frequently than cyanobacterial blooms and possibly affect the amenity of the system, particularly in residential areas.

Plants are important to maintenance of both biological processes and water quality. They take up dissolved nutrients for their growth and provide food and shelter for zooplankton, which may graze on algal species. The oxygen released during photosynthesis is important in maintaining oxygen saturation in the water column that is depleted by animal, plant and bacteria respiration and decomposing organic matter. Vegetation also helps stabilise sediments and reduce release of sediment-bound nutrients arising from resuspension processes.

A shallow lake is considered healthy when a balance exists between algal and rooted macrophyte (large plant) populations. Once the environmental conditions are suitable for sustaining an excessive growth of algae (either micro or macroalgae), it will be very difficult to reverse the situation to a healthier system. Maintaining a diverse, extensive and healthy rooted macrophyte population is a critical element in maintaining a system that is appropriate for residential estates.

Figure 2 is conceptual only and illustrates the value of macrophyte establishment. It suggests that in a lake system with poor rooted macrophyte coverage, low levels of phosphorus would result in greater algal growth. Alternatively, in a lake system with extensive macrophyte establishment, the lake may be able to deal with higher levels of phosphorus without increased algal growth.

Figure 2. Conceptual rooted macrophyte benefit on algal growth (freshwater environment).



The shallow lake design should aim to minimise the excessive growth of algae by maximising the growth of rooted macrophytes. Processes that can contribute to the loss of rooted macrophytes and therefore impact on the state of the lake system include:

- Elevated nutrients and associated rapid growth of algae that compete with macrophytes for light and can smother submerged vegetation
- Changes in water depth, colour or turbidity reducing light penetration to submerged vegetation

- Disturbance events such as storms or droughts causing increasing levels of sediment and smothering of submerged vegetation with silt
- High densities of herbivorous fish over grazing submerged vegetation
- High densities of benthivorous fish such as carp that stir up lake sediments and dislodge submerged vegetation.

Residents and managing authorities must be aware that as the lake system ages, it has a greater chance of problem algal growth and algal blooms. The frequency and duration of a green algal bloom or cyanobacterial bloom that would be considered an unattractive appearance to residents or provide a health risk, should reflect community expectations about the appearance and management of the waterbody. It is possible that a lake system may require desilting and a total 'reset' if algal blooms become a recurrent and persistent problem.

3. Main Factors Controlling Algal Blooms

The design of a sustainable shallow lake system should take into account the following issues, identified as the main factors controlling algal blooms:

3.1. Water Residence Time

Water quality problems associated with algal growth, are likely to arise as a consequence of insufficient water inflows to circulate and/or displace the water stored in the lake. Under long residence times, blooms of blue green algae (cyanobacteria) can occur. When the residence time is reduced, the algal biomass becomes regulated by the rate at which it is removed from the shallow lake by flushing. Waterbody residence time analyses are a very useful indicator as to whether the waterbody is at significant risk of algal blooms (see section 6.1).

3.2. Nutrients

Algal blooms in constructed lakes will be driven by phosphorus and nitrogen. It is important that the design process considers both diffuse and point sources of nutrients so that appropriate management strategies or interventions can be planned for.

Diffuse sources of nutrients originate from the catchment and reach the receiving waterbody via rainfall runoff and flooding of the land. Diffuse sources may be generated from forests and rangelands, pasture, enhanced soil erosion, hard surfaces not connected to the local drainage network, groundwater, septic tank or sewage leakage and ground fill leachate.

Point sources are delivered directly to the waterbody via stormwater drains, sewage treatment plants and irrigation drains. The lake sediments themselves constitute a potentially large point source of nutrients. Sediments act as a large reservoir, which, under the appropriate physico-chemical conditions, will release nutrients into the water column.

Thermal stratification is important in potentially making phosphorus available. In the sediment, phosphate is usually bound to iron coatings on the surface of mineral particles and is not available to the biota. However, in the absence of oxygen, bacteria can dissolve the iron coating, which releases the phosphate back into the water column. Thermal stratification facilitates this process by establishing oxygen-free conditions on the sediment surface. Therefore, the design of the lake should ensure that thermal stratification is minimised by orientating the lake to the dominant winds to facilitate mixing of the water column.

No inflows should enter the lake unless adequately treated through a wetland or infiltration system to reduce nutrients as well as organic loads and suspended solids.

3.3. Light

In Australian climatic conditions, surface light is rarely a limiting factor for algal growth. Throughout the water column, turbidity and mixing conditions will determine the light environment that algal populations are exposed to. Some cyanobacterial species can regulate cell buoyancy (capacity to adjust their position in the water column by means of gas vacuoles) and migrate vertically, increasing their exposure to optimum light intensities. The depth of light penetration can be reduced by turbidity and therefore limit algal biomass.

However, the depth of light penetration will also be a limiting factor for submerged aquatic plants. Turbidity should be reduced to maximise the development of the rooted macrophyte community. Therefore, suspended sediment loads should be low enough to allow light penetration to the maximum depth of the lake. This may only be exceeded for extremely short periods of time after a significant storm event.

4. Design Intent

A design intent must be produced for the construction of any waterbody and should clearly articulate the objectives of the lake and consider the surrounding environment.   The design intent should be developed in consultation with relevant authorities and when completed will provide direction to the functional and detailed design.

The design intent should capture the expected recreation use, public safety, amenity and community expectations regarding water quality and associated algal growth.   The design intent should:

- Articulate what is an acceptable frequency and duration of algal blooms and acceptable level of floating surface algae to the local community
- Communicate the performance requirements for all surface hydrology issues, such as surface drainage, flood retardation and flood passage. It should also describe the level of hydraulic and water quality modelling required
- Communicate habitat, environmental and cultural issues, such as desirable fauna, proximity to significant flora and fauna or preservation of cultural sites
- Consider the surrounding topography and geology and its impact and integration into the lake design.

The design intent must be produced during feasibility discussion and communicated to all relevant stakeholders (including Local Government, Melbourne Water and community groups where appropriate).

5. Modelling

As part of the risk assessment, the catchment and lake system should be modelled using an appropriate software package. Modelling shallow urban lakes is essential to predict the likely evolution of water quality. The level of modelling to be undertaken should relate to the risk profile developed from the risk assessment.

5.1. Catchment Modelling

To determine the likely inputs into a receiving waterbody, catchment modelling should be performed through considering catchment uses and any treatment measures that may be constructed upstream. The time step of the model should be appropriate for the size of the catchment and for the range of treatment measures proposed.

A catchment model should be submitted as part of the lake application proposal to simulate pollutant generation loads (gross pollutants, Total Nitrogen, Total Phosphorus & Total Suspended Solids) and the performance of any treatment measures.

5.2. In-lake Modelling

For lakes that have a high risk profile the catchment model should then be linked to an in-lake hydrodynamic and water quality model. Model selection should depend on the nature of the dominant physics/water quality processes of each lake. In general, either a 1-D or 2-D model should be sufficient, depending on whether or not stratification is deemed to be an important consideration. All models must allow extraction of in-lake model results as time series outputs, so that statistical analysis can be performed on the output.

At a minimum, the in-lake water quality model should be capable of simulating:

- Water depth
- Water temperature
- Salinity
- Impacts of catchment derived inflows
- Internal cycling processes including as a minimum
  - Denitrification
  - Sediment nutrient release/uptake
  - Conversion of available and unavailable nutrients via adsorption/desorption and organism uptake
  - Settling of particulate bound nutrients
- Impacts of rainfall
- Impact of tidal exchange or other flushing mechanisms (if appropriate)
- Phytoplankton growth and decay.

An in-lake modelling exercise should be undertaken and be provided to the relevant authority for approval.

6. Design Considerations

6.1. Waterbody Residence Time

Waterbody residence time (or turnover frequency) analysis can be undertaken using probabilistic monthly evaporation and rainfall data or daily historical data. Average residence times are calculated by modelling continuous simulation of flows into and out of the lake. Further details on how to estimate waterbody residence time are provided in "WSUD Engineering Procedures: Stormwater, MWC, 2005".

6.2. Morphology

Lake morphology is important to create a functional ecosystem. Figures 3, 4 and 5 give a schematic illustration of a shallow lake system to provide a general concept only.

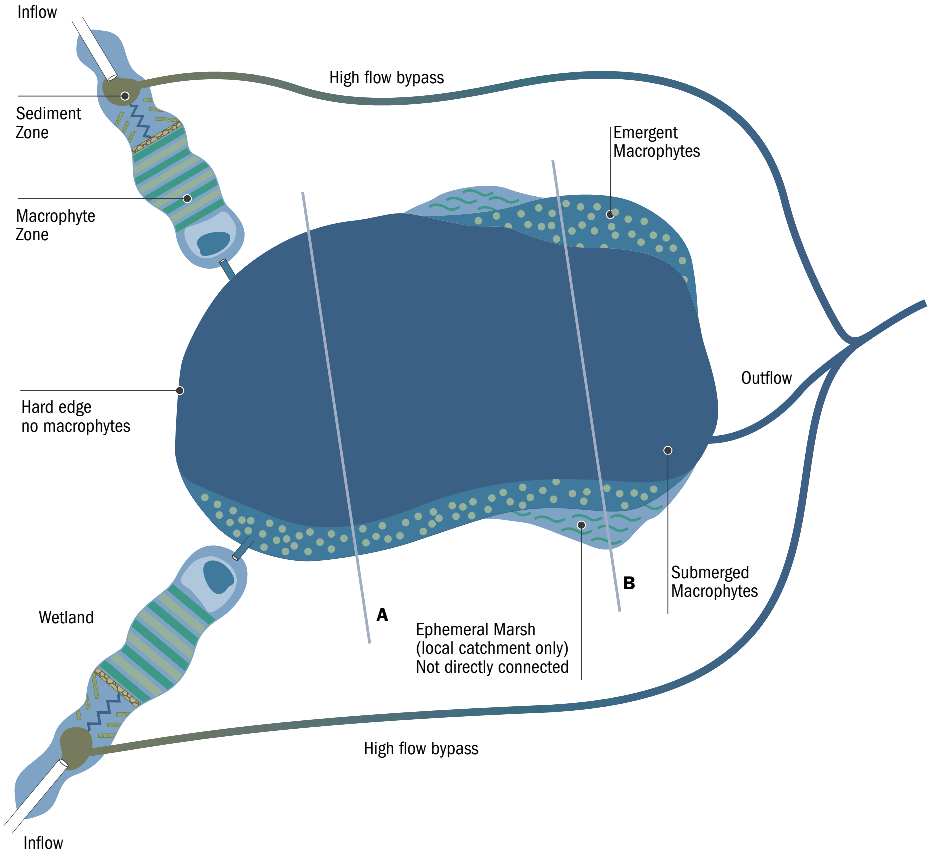


Figure 3. Schematic representation of a constructed shallow lake system.

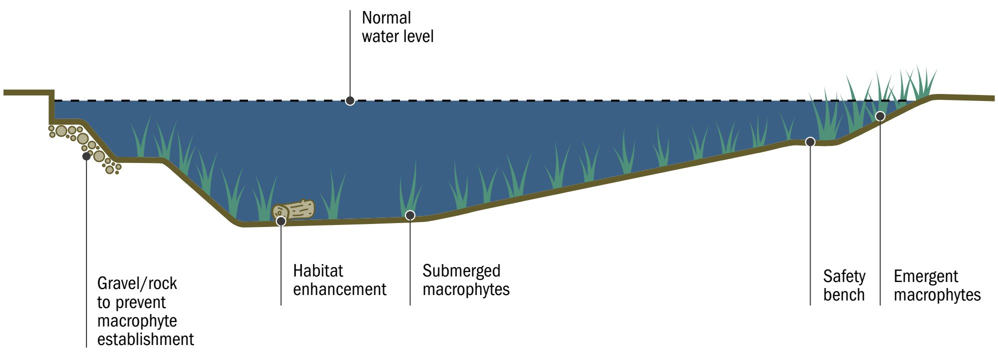


Figure 4. Cross Section A - schematic representation.

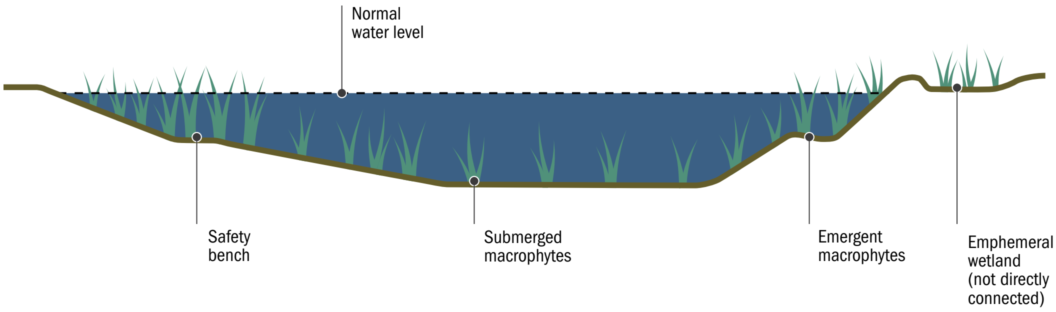


Figure 5. Cross Section B – schematic representation.

The lake should be oriented to the dominant winds to facilitate mixing, particularly for summer and autumn and edge treatments must be designed to minimise wave damage.

The lake depth should be no greater than 3.0 meters to ensure sufficient light penetration to maintain submerged plants and to minimise the likelihood of stratification by allowing wind mixing. It is preferable that the lake is between 1.5 – 2.0 m in depth to maintain the most productive biological system possible. The lake depth should vary to create an opportunity for the most diverse ecological system possible.

6.3. Vegetation

Rooted macrophytes should include a minimum of 50% areal cover and 50% volumetric coverage of the lake. A greater cover is highly recommended.

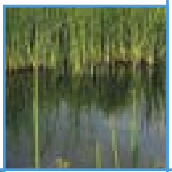
To assist in vegetation establishment, the entire bed of the lake and fringing ephemeral areas must be topsoiled with a minimum of 150mm of locally derived topsoil with a minimum of 5% organic matter.

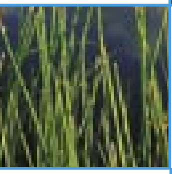
The lake should be filled in three stages; 0.5 m above the lake bottom to allow planting and establishment of the submerged macrophytes, 1.5 m above invert to allow planting of any Deep Marsh species and final filling and planting of any Shallow Marsh species. Two months should be a minimum period between stages to allow establishment.

For a comprehensive list of appropriate species please refer to Melbourne Water document "Constructed Wetland Systems, Design Guidelines for Developers (2005)".

6.4. Organic Matter

The amount of organic matter entering the lake system needs to be minimised as much as possible by diverting high flows around the lake system and adequately treating all low flows through wetland or infiltration systems. Sudden increases of organic matter from large catchment flows or the death of in-lake macrophytes fuels greater bacterial respiration, and can lead to a substantial reduction in dissolved oxygen levels, resulting in fish kills and death of other oxygen requiring organisms.





The lake must include a high flow bypass capable of bypassing all flows that cannot be treated by upstream wetlands or bioretention systems, and the design must demonstrate how the input and internal levels of organic matter have been considered and will be managed.

6.5. Inflow Water Quality

The water entering the lake systems must be pre-treated to reduce sediment, organic load and nutrient levels.

Catchment modelling must demonstrate that as a minimum Best Management Practice (BMP) for nutrient removal is achieved (45% reduction in Phosphorus, 45% reduction in Nitrogen, 80% reduction in Suspended Solids of a typical urban annual load).

It is highly likely that inflow nutrient levels should be treated beyond BMP to background concentrations to achieve the water quality criteria described in Section 6.6.

6.6. In-lake Water Quality

Both phytoplankton and macro algae need to be considered. It is expected that algal counts above 15,000 cells/mL represent a likely phytoplankton bloom where either aesthetics or health impacts may occur. In a water sample, algal abundance can be estimated by measuring the amount of pigment or chlorophyll *a*. It is estimated that 15,000 cells/mL would approximately equate to a chlorophyll *a* concentration in the range of 10.15 µg/L. This figure can be used in modelling to determine the frequency and duration of unacceptable algal growth. Macroalgae can be estimated by measuring their biomass or their area coverage.

It is important to note that blooms of blue green algae can have a significant impact with levels much lower than 15,000 cells/mL because they are able to produce toxins. Alert levels can begin as low as 2,000 cells/mL. An ongoing monitoring program should be used to identify increases in blue-green algae levels.

Figure 6 provides a range of nutrient and chlorophyll *a* concentrations, within which the lake is most likely to have manageable algal growth. The closer to the lower end of the range, the less likelihood of a regular algal bloom and the closer to the higher end the more likely. Detailed biogeochemical cycles for both nutrients are provided in Appendices 2 and 3.

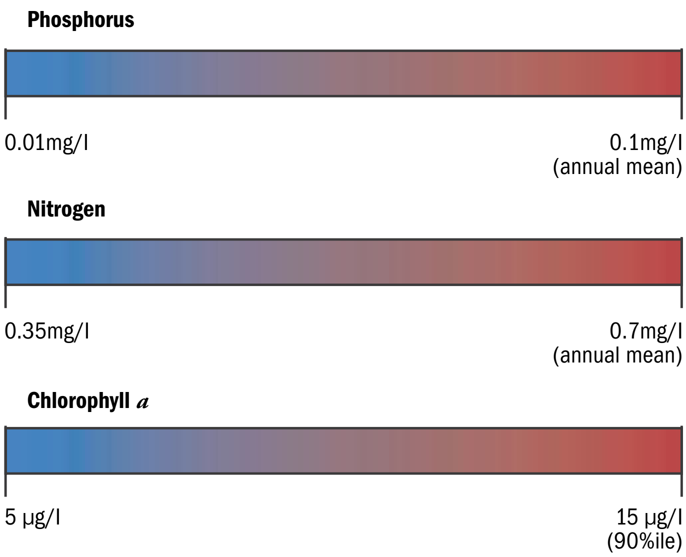


Figure 6. Acceptable range of Phosphorus, Nitrogen and Chlorophyll *a* concentrations for a "manageable" lake.

Demonstrating that the in-lake water quality is within this range and utilising all best management options in the design, it is predicted that the lake will not have excessive management issues relating to the growth of phytoplankton and macro algae.

If the in-lake model produces results above this range, it is likely the lake will not satisfy the expected lake performance that would be acceptable to residents.

6.7. Surrounding Open Space

Surrounding open space should be designed to incorporate low or preferably zero fertilizer requirements.

Adjacent lawn areas that require fertiliser inputs should be discouraged or appropriate treatment measures should be installed (e.g. vegetated swales as buffer strips). Grassed areas should ensure that surface flow does not discharge directly into the lake system.

Any irrigation of grassed areas surrounding the lake must have a scheduling system advanced enough to reduce the amount of surface flow in a rain event and minimise infiltration to groundwater.

6.8. Make Up Water

The lake system should be designed with consideration to the yield of treated stormwater from the catchment and should not rely on make-up water from other sources. The use of potable water to maintain water levels is not acceptable. Only where groundwater can clearly meet yield and quality criteria should it be considered as a source of top up water. The long-term impact on the lake ecology and impact on the groundwater resource must be considered.

6.9. Groundwater Interaction

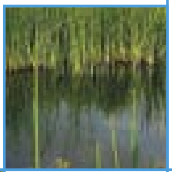
Lake systems have a high potential to interact with groundwater. They can become sources of groundwater recharge and impact on surrounding areas lower in the landscape. Alternatively, groundwater may discharge directly into the lake impacting on its water quality.

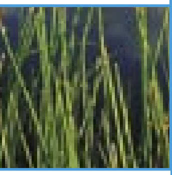
A geotechnical investigation is normally required to determine groundwater depth and quality (including nitrate, dissolved metals and organic contaminants), and the likelihood of the lake either acting as a recharge or discharge area. Clay lining may be required to control groundwater interaction.

6.10. Safety

Melbourne Water is not responsible for managing any waterbodies that are constructed for recreation or amenity and advises that qualified professionals should conduct an adequate safety audit on the design.

Please refer to "The Royal Life Saving Society Australia, Guidelines for Water Safety in Urban Water Developments (2004)" for detailed information on safety issues.





7. Management of flora and fauna

Residents should be made aware of the primary objectives of the lake and be given an overview of the lake's biology to assist them in developing realistic expectations (Appendix 4). They should be aware that waterbodies tend to be variable in condition and at times water quality may be temporarily poor (such as during a drought or immediately following a storm), and should contribute to protecting the health of the waterbody through responsible household practices.

The lake should provide a robust, resilient and diverse biological system that can buffer against any inflow storm events or prolonged dry conditions. Habitat requirements for all plants and animals should be considered early in the conceptual design. Consideration needs to be given to all levels of life ranging from zooplankton through to fish and bird life.

The lake system should only include indigenous species. Non-indigenous fauna species such as carp or trout and exotic flora species must never be introduced to the lake and if established should be removed.

Introduced species such as carp pose a significant risk to a lake system and it is essential that an appropriate management plan is created. Stocking of native species may be a component of the lake management[1]. Fish introduction should only occur when the lake is established (i.e. adequate habitat and food). Not all species may breed in lakes, therefore on-going stocking may be required.

A list of possible species based on geographical drainage basins and salt content of the waterbody is provided in Table 2. Advice should be sought from The Department of Primary Industries and The Department of Human Services regarding suitability of introducing sporting species. It is important to note that there may be issues associated with obtaining certain stock species.

Table 2. Potential fish species suitable for stocking in shallow lake systems.

Species	Stocking Region/Catchment	Brackish /Freshwater
Southern pygmy perch	All	Fresh
Dwarf galaxiasa	Dandenong, Western Port	Fresh
River blackfish	Dandenong, Western Port, Yarra	Fresh
Australian smelt	Western Port, Yarra, Maribyrnong, Werribee	Both
Shortfinned eel	All	Boths
Flathead gudgeon	Dandenong, Yarra, Maribyrnong, Werribee	Both
Estuary perch	All	Brackish
Australian bass	Dandenong, Western Port	Brackish
Smallmouthed hardyhead	All	Brackish
Blue-spot goby	All	Brackish
Black bream	All	Brackish

A fish management plan must be prepared for the control of carp. If fish introduction and manipulation is considered, this plan should be prepared by an appropriately qualified professional. Under no circumstances will stocking with carp, trout or other non-indigenous species be acceptable.

[1]A permit from the Department of Sustainability and Environment will be required for any stocking with native species.

8. Maintenance and Operation

Poor maintenance and operation will invariably lead to poor water quality and it is expected that the lake system is designed to minimise future maintenance requirements. Lake systems can require operational inputs to maintain acceptable performance, such as recirculation systems or dredging activity. These maintenance activities should be carefully examined, particularly in regard with their impact on the lake biota.

All maintenance and operation issues should be identified and fully costed and it is essential all stakeholders clearly understand their roles, responsibilities and liabilities before any works begin. A detailed management plan should be written for the responsible authority to implement. The maintenance schedule should be flexible enough to be guided by the results of monitoring. It is worth considering that some lakes may require a total reset if algal problems are persistent.

A maintenance agreement with the developer, council or other relevant authority must be established prior to any earthworks. In-lake, ephemeral and terrestrial areas in and surrounding the waterbody should be clearly marked on a site plan to identify maintenance responsibilities. The site plan and an associated legally binding agreement must be signed off by all stakeholders.

9. Signage

Please refer to the signage requirements documented in the Melbourne Water document "Constructed Wetland Systems – Design Guidelines for Developers (2005)".

10. Monitoring

Monitoring is an essential component to managing a shallow lake system and will allow the manager to understand the behaviour of the lake and better predict potential algal problems.

Monitoring must be performed on a routine basis and should consider the 'Water's of Victoria' policy released by the EPA Victoria and seek guidance from the AS/NZS 5667 standard. Monitoring must include a range of biological, physical and chemical parameters.

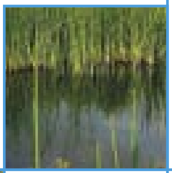
It is expected that the monitoring program will include pH, electrical conductivity, water temperature, turbidity, dissolved oxygen concentration, algae and cyanobacterial counts and chlorophyll *a* concentrations, macrophyte coverage and phosphorus and nitrogen concentrations.

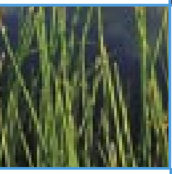
Two measures of phosphorus concentration are frequently performed in water quality monitoring. They are Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP). DRP is synonymous with SRP (soluble reactive phosphorus) and FRP (filterable reactive phosphorus). It is DRP that is considered to be the most readily bioavailable, that is, algae can consume this form of phosphorus but cannot easily consume other forms.

Likewise, the most commonly measured forms of nitrogen are:

- Total Nitrogen (TN)
- Ammonium (NH_4^+) concentration
- Combined nitrate (NO_3^-) and nitrite (NO_2^-), expressed as (NO_x) concentration
- Total Kjeldahl Nitrogen (TKN).

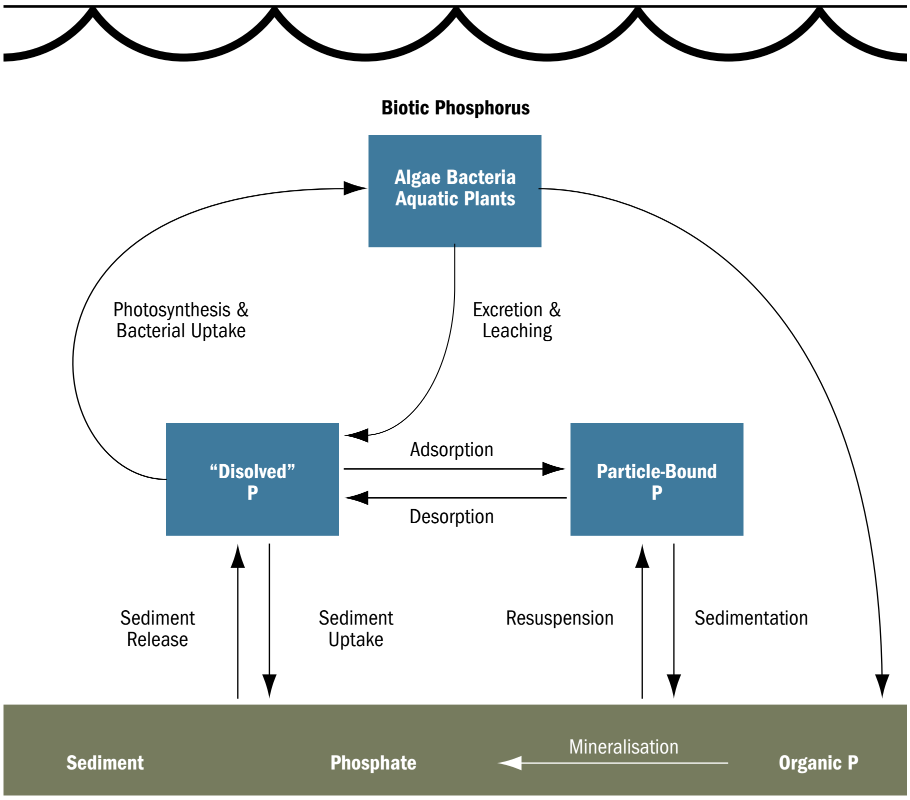
A monitoring program must be developed that details the parameters to be sampled and the frequency of sampling. This monitoring program must be approved by the relevant authority. It will help build a better understanding of the constructed lake behaviour and potentially be used to refine the lake management.





APPENDIX 1 - Flow Chart of Approval Process

APPENDIX 2 - Phosphorus Cycling in the Aquatic Environment

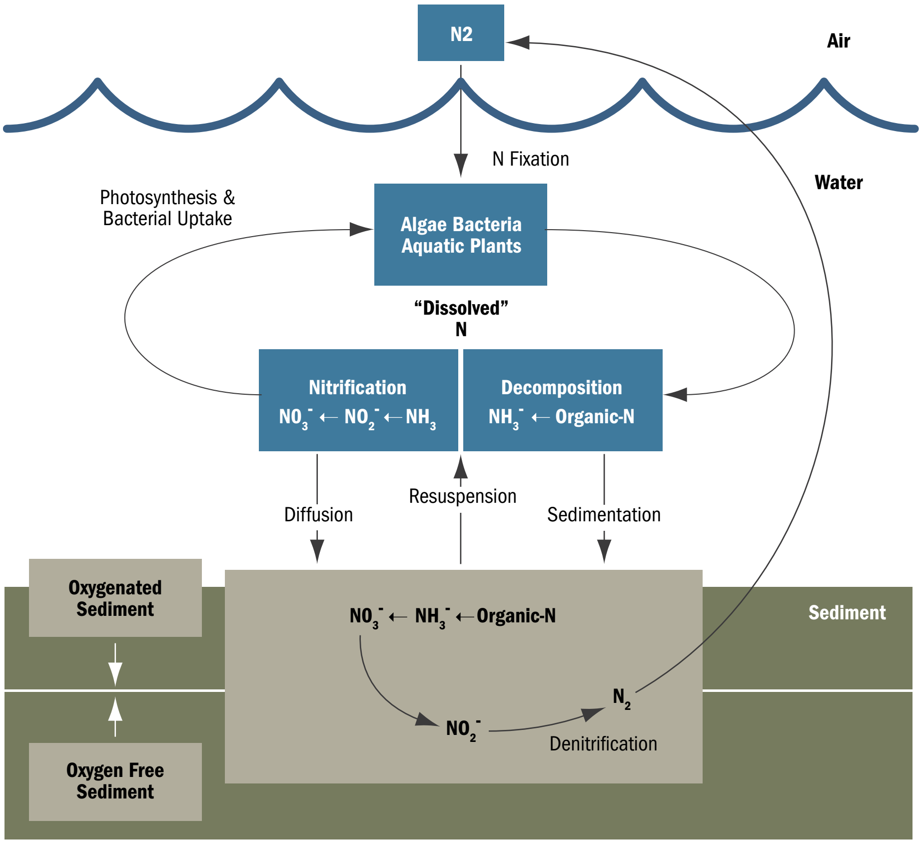


In the aquatic environment, phosphorus undergoes cycling where it is taken up by living organisms and ultimately excreted or remineralized upon the death of the biota. Phosphorus can also be either adsorbed or desorbed from suspended particles and/or the sediment.

Higher trophic levels (e.g. zooplankton, invertebrates and fish) have been omitted from the diagram for clarity but are important in the cycling process. It is also important to note that the time scale of various parts of this cycle may vary enormously – from hours in cycling through water column bacteria up to years for release from sediments.

In freshwater lakes, phosphorus is typically the limiting nutrient, meaning that algae deplete all available phosphorus before depleting other nutrients. Therefore, phosphorus levels often regulate the abundance of algae. In saline and brackish systems, nitrogen however is more likely to be the limiting nutrient.

APPENDIX 3 - Nitrogen Cycling in the Aquatic Environment



Nitrogen can be removed from the aquatic ecosystem as a totally inert product, nitrogen gas (N_2). This removal is carried out by bacteria and is called denitrification. Denitrification is the only true sink for nitrogen as the gas is lost to the atmosphere.

As illustrated in this figure, ammonia arising from the decomposition of organic matter is converted to nitrate (NO_3^-) during the multi-step nitrification process. Nitrification, also carried out by bacteria, requires the presence of oxygen and hence occurs primarily in the water column and at the interface between the water and sediments where bacterial populations are generally high. However, the conversion of nitrate to nitrogen gas (denitrification) requires the absence of oxygen, and occurs predominantly in the subsurface sediments.

The forms of nitrogen most readily taken up by biota (bioavailable) are the dissolved inorganic species NO_x (NO_3^- + NO_2^-) and ammonia.

Higher trophic levels have been omitted from the diagram for clarity purpose.

APPENDIX 4 - Basic Lake Ecology

This section helps to explain some of the basic ecological principles that should be considered in the lake design.

Lake biology can be broadly divided based on the organism's biological function within the water body:

- **Primary Producers (Algae and Rooted Macrophytes)**

  Primary producers form the lowest order in the food chain. Their growth is largely controlled by the amount of sunlight and available nutrients in the water column.

  Microscopic forms of algae that float in water are called phytoplankton. Blue green algae (or cyanobacteria) are often classified as part of the phytoplankton despite the fact that these micro-organisms are bacteria. However, like algae, they rely on sunlight for energy. Algae that occur in larger forms are called macro-algae. Macro-algae can be free floating moving with wind and currents similar to phytoplankton or attached to any substrate in the lake. Rooted macrophytes are large aquatic plants, either emergent or submerged.

- **Consumers**

  Primary consumers such as zooplankton graze on algae, bacteria, detritus (partially decayed organic material) or predate on other zooplankton. Secondary consumers, such as planktivorous fish or predaceous invertebrates, predate on zooplankton and tertiary consumers that prey on smaller fish include larger fish and other carnivorous animals.

- **Decomposers**

  Decomposers include fungi, bacteria and other organisms that feed on the remains of aquatic organisms and decaying organic matter. The decomposition process does contribute to oxygen depletion, and in extreme cases can lead to anoxic conditions.

Organisms in a lake can be broadly classified according to their mobility:

- **Organisms that are highly mobile**

  This includes fish, amphibians, turtles, larger zooplankton and insects. These organisms will move to utilise preferred habitat areas in the lake.

- **Organisms that drift with water currents and wind**

  This includes bacteria, micro and macro algae and zooplankton. These organisms tend to move with the water currents and impacts from water reticulation systems will need to be considered.

- **Organisms that live on (or in) the lake bottom**

  This includes bacteria, fungi, submerged plants and invertebrates (such as worms and molluscs).

Who we are

Melbourne Water is owned by the Victorian Government. We manage Melbourne's water supply catchments, remove and treat most of Melbourne's sewage, and manage rivers, creeks and major drainage systems in the Melbourne region.

We are a significant business, managing $8.1 billion of natural and built assets.

An independent Board of Directors is responsible for the governance of Melbourne Water. The responsible Minister is the Minister for Water.

Our people have diverse skills and expertise and we place a high priority on building strong partnerships and relationships with the community and all our other stakeholders. Our customers include the metropolitan retail water businesses, other water authorities, local councils and the land development industry.

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For information on Melbourne's water resources in languages other than English, call 131 722 or visit www.melbournewater.com.au and click on the Community Languages link.