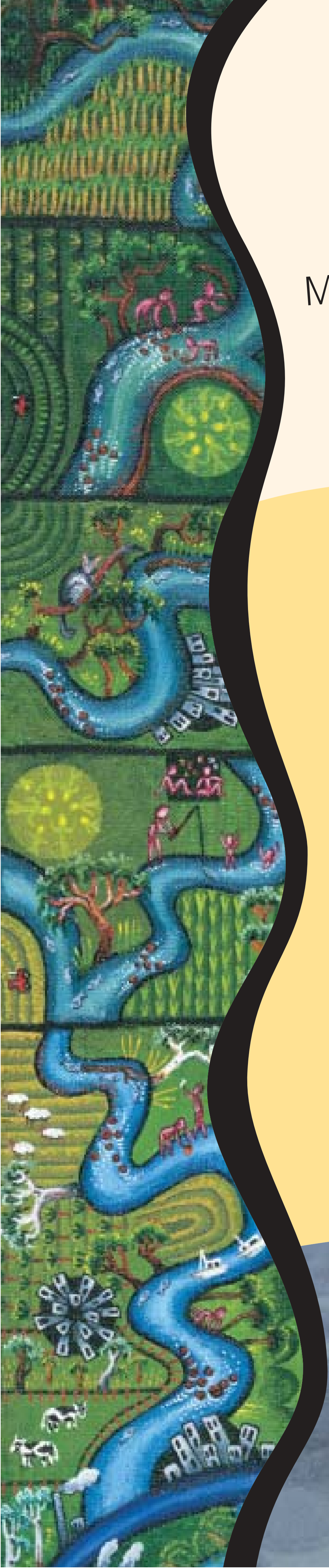

RIVER AND RIPARIAN LAND MANAGEMENT TECHNICAL GUIDELINE UPDATE

NUMBER 2, JULY 2002

2

ISSN 1445-3924

Managing nutrients in floodplain wetlands and shallow lakes

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Summary

~ Submerged water plants (aquatic macrophytes) are a desirable component of shallow lakes and wetlands, and management activities should be directed to ensure their continual presence.

~ Aquatic systems dominated by submerged aquatic plants are resilient to low levels of nutrient enrichment, but higher loadings lower the resistance of shallow lakes to events that can result in the catastrophic and very rapid (< 4 months) loss of these valuable plants.

~ As nutrient loads increase it becomes more likely that submerged water plants (macrophytes) will disappear and be replaced by algae and phytoplankton. These new species can be more problematic (e.g. in producing odour, health and taste problems) than the original species.

~ Management actions should aim to maintain submerged water plants because they protect against algal blooms and:

- provide habitat and refuge for zooplankton which graze on algae;
- reduce light available for algal growth;
- produce compounds which inhibit algal growth; and
- reduce nutrients available for algal growth.

~ Harvesting of submerged macrophytes when nutrients in the water column are high, may increase the likelihood of algal blooms and prevent the re-establishment of submerged aquatic plants.

1 Background

It is well known that nutrient enrichment often leads to frequent and intense algal blooms in shallow lakes. Scientists have been working to find out what causes these sudden changes in the make-up of aquatic vegetation. It is usually expected that ecosystems respond in a gradual way to change, resulting in a slow degradation in ecosystem health. These changes can be caused by a number of factors, for example, a steady increase of nutrients, or slowly rising or falling water levels. Recently, however, it has become evident that ecosystems can also respond suddenly, and without warning, to gradual changes in their aquatic environment.

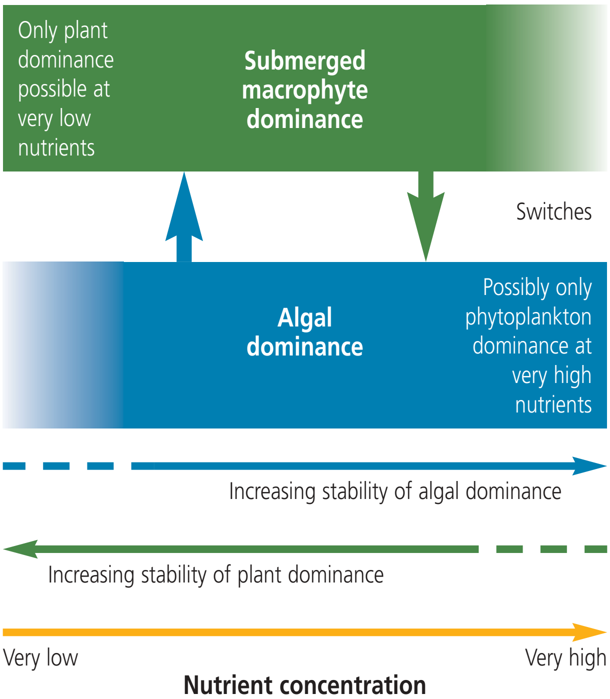
A new concept has been developed to improve our understanding of the ecology of shallow lakes and wetlands, and to explain why ecosystems can change suddenly in the face of gradual changes in their condition. This concept is called *alternative metastable states*.

In this model it is predicted that shallow aquatic systems commonly exist in only one of two states:

1. dominated by aquatic macrophytes (usually flowering plants with submerged or floating leaves); or
2. dominated by phytoplankton (very small photosynthetic organisms, including algae and cyno-bacteria, found in water).

The concept of *alternative metastable states* proposes that submerged aquatic macrophytes maintain themselves in shallow lakes over a wide range of nutrient concentrations because they generate self-regulating mechanisms. These include the ability of macrophytes to compete with phytoplankton for nutrients and light; to produce compounds that inhibit algal growth; to provide habitat for grazing zooplankton that eat the algae; and to stabilise sediments against erosion.

These macrophyte dominated systems can, however, switch over to phytoplankton dominated systems suddenly and unpredictably. This occurrence has been observed across the world, including in Australia. The rapid shift from a macrophyte dominated to phytoplankton dominated system has been linked to nutrient loadings, water level fluctuations, fish introductions and pollution by pesticides. From a management perspective, it is important that we understand why shallow lakes and wetlands often switch from a state characterised by aquatic macrophytes to one dominated by algae as the latter state is of far less amenity and ecological value than a macrophyte-dominated system. Moreover, it is usually very difficult to restore a lake experiencing algal blooms to one with a healthy community of submerged aquatic macrophytes.



Model of alternative metastable states modified from Moss (1989)

Both the submerged macrophyte and algal dominant states can occur across a broad range of nutrient concentrations. As nutrient concentrations increase, the stability of the submerged macrophyte dominant state declines and it becomes more likely that a switch to algal dominance will occur.

2 Recent studies on stable states in aquatic vegetation

A research project funded jointly by Land & Water Australia and Environment Australia investigated ways in which aquatic vegetation could switch across metastable states. The research was conducted in Victoria Park Lake, an ornamental lake near Shepparton in central Victoria, which is currently dominated by dense beds of the submerged flowering plant *Vallisneria americana*. The research aimed to test the hypothesis that the current condition (macrophyte dominance) could be switched to the alternative metastable state (algal dominance) as a result of nutrient enrichment or by plant harvesting.

To test this proposal, large experimental tanks (3000 litre) were established in the lake and treatments applied to the tanks. In the first year, a low level of nutrient enrichment was applied to some tanks for four months over summer. In other tanks the macrophytes were removed to mimic the harvesting that occurs in the lake each year to permit recreational uses. Some tanks were kept as controls and did not receive any treatment. In the second year, a medium and a high nutrient loading were applied to the tanks, which had been relocated to different areas in the lake.

A large number of environmental variables were measured to determine the changes in the lake after these treatments. Phytoplankton and algae were measured in terms of chlorophyll concentrations and species composition. The performance of the *Vallisneria americana* was observed in terms of biomass, growth rates, leaf characteristics and above-ground / below-ground biomass proportioning. Other variables were measured, including nutrients (nitrogen and phosphorus, organic and inorganic, dissolved and particulate), light regimes, and dissolved oxygen concentrations. The ability of sediments to take up and release nitrogen and phosphorus was also addressed, in order to determine the fate of added nutrients.

Above: Victoria Park Lake, showing dominance by submerged macrophytes. Below: Replicate tanks placed in Victoria Park Lake.

3 How shallow lakes respond to nutrient enrichment and plant harvesting — research findings

Low level nutrient enrichment

As predicted by the theory of alternative metastable states the existing beds of *Vallisneria americana* in Victoria Park Lake were resistant to a low level of nutrient enrichment, and there was no sign over the experimental period of any decrease in their vigour. However, phytoplankton biomass increased, resulting in a co-existence of macrophytes and phytoplankton.

Moderate and high level nutrient enrichment

In contrast to the findings with low-level nutrient enrichment, there were massive effects of the medium and high nutrient loading on the lake. It was predicted that these higher levels of nutrient enrichment would increase phytoplankton and epiphytes (plants that are attached to and grow on other plants) covering the submerged macrophytes, shading them out and causing them to die. Dense algal blooms should then have developed as the macrophytes were lost, and the lake should have "switched" over to the other metastable state.

Vallisneria americana.

Azolla.

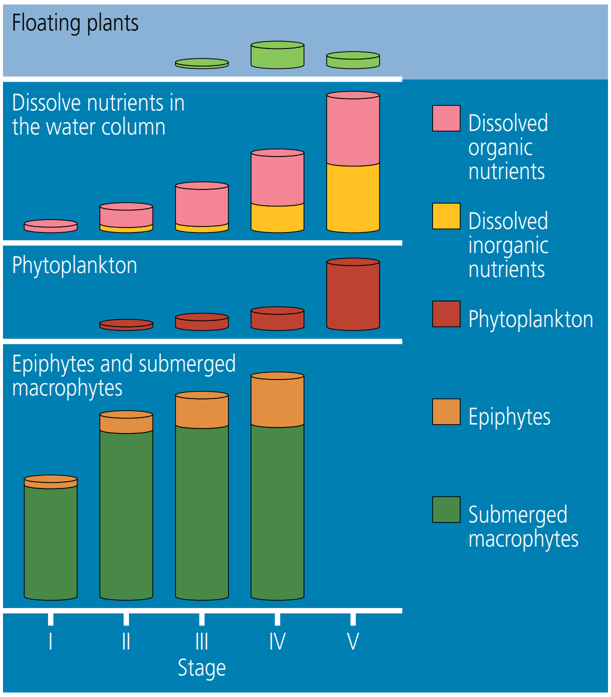
This pattern was not observed. Instead, nutrient enrichment caused the prolific growth of the floating fern, *Azolla*, and/or thick mats of algal scums on the water surface. These surface plants resulted in severe decreases in light penetration and the complete de-oxygenation of the water column. The existing beds of *Vallisneria americana* were all dead within four months of fertilisation, probably due more to the oxygen depletion than the decrease in light availability.

From these findings and those of others, a conceptual model was developed for changes in aquatic vegetation after moderate and high levels of nutrient enrichment (see schematic diagram at right).

Plant harvesting

The effects of plant harvesting were interesting but somewhat equivocal. Harvesting plants increased light penetration down the water column, and resulted in changes to the patterns of temperature stratification in the water column. Somewhat unexpectedly, plant harvesting did not immediately result in the creation of an algal bloom. The macrophytes rapidly regrew, but with a different taxonomic composition to that which had occurred prior to harvesting. Charophytes (large, plant-like algae attached to the sediment) previously absent, suddenly appeared.

Algal scum.



Schematic diagram of changes in aquatic plants and nutrient concentrations in the water column following moderate to high levels of nutrient enrichment.

Stage I. Pre-enrichment condition

Under historical conditions with low nutrient input, the wetland would be dominated by submerged macrophytes covered with a thin film of epiphytes and few phytoplankton in the water column. The sediments are the major pool of nutrients, and what nutrients occur in the water column are found in the organic form.

Stage II. Onset of eutrophication

As the catchment becomes degraded, nutrient loads into wetlands increase. Initially, the sediments take up almost all of the nutrients. The submerged macrophytes respond by growing quickly and their biomass increases.

Stage III. Increased productivity

After a prolonged period of enrichment, the sediments are still capable of taking up nutrients but submerged macrophytes no longer increase in biomass. There are continuous increases in epiphytes and phytoplankton that can form floating algal mats. Floating plants also begin to cover the water surface. Total nutrients in the water column increase and continue to be dominated by organic forms.

Stage IV. Blanketing of the water surface

The sediments can no longer take up any additional nutrients. For the fist time, there are significant amounts of dissolved inorganic N and P in the water column. Epiphytes, phytoplankton and floating plants respond positively to the increased availability of nutrients.

Stage V. Catastrophic ecosystem change

This stage is characterised by the catastrophic elimination of submerged macrophytes. This was mediated by the dramatic decline in light and dissolved oxygen caused by the blanketing effects of the plants on the water surface. Phytoplankton are now dominant and it is likely that there will be massive algal blooms. Concentrations of nutrients are extremely high, exacerbated by the release from decaying plants.

4 Management implications of nutrient enrichment of floodplain wetlands and shallow lakes

This research generated a number of discoveries that are highly relevant to the improved management of shallow lakes and wetlands. These have been grouped according to the responses of macrophytes and algae to varying levels of nutrient enrichment, the dynamics of nutrients when added to shallow lakes and wetland systems, and some general management implications.

Responses of macrophytes and algae to nutrient enrichment

When designing management strategies for shallow lakes and wetlands, it is important to consider what changes may result from changing nutrient concentrations.

1. Aquatic systems dominated by submerged aquatic plants are resilient to low levels of nutrient enrichment, but higher loadings can result in the catastrophic and very rapid (< 4 months) loss of these valuable plants.
2. When nutrient concentrations are very low in the water column, submerged macrophytes will dominate the aquatic vegetation and it is unlikely that serious algal blooms will occur.
3. As the nutrient load increases, the growth of submerged macrophytes may or may not be stimulated, depending on other environmental conditions, especially light availability and sediment characteristics. It is not always possible to predict in advance what the result of large increases in nutrients will be, although the risk of a sudden and detrimental change is increased.
4. It is important to protect submerged aquatic macrophytes because they provide protection against algal blooms by:
   - providing habitat and refuge for zooplankton which graze on algae;
   - reducing the light available for algal growth;
   - producing compounds which inhibit algal growth;
   - reducing nutrients available for algal growth; and
   - changing the chemical conditions that favour phosphorus retention by the sediment and nitrogen loss to the atmosphere.

Algal bloom sign at urban lake.

Dynamics of nutrients added to shallow lakes and wetlands

An understanding of what happens to nutrients when they are added to wetlands and shallow lakes can help managers interpret the changes that they observe and develop appropriate management strategies.

1. Nutrients added to wetlands and shallow lakes are often rapidly removed from the water column by *abiological and biological* processes, that is they are taken up by sediments or plants. The concentration of inorganic nutrients in the water column will only increase once these processes have been saturated. It is important not to jump to the conclusion that a wetland isn't suffering from nutrient enrichment on the basis of low concentrations of inorganic nutrients in the water column. The sediments act as a powerful buffering mechanism until their ability to take-up additional nutrients can become saturated. Once saturated changes can quickly occur.
2. Phosphorus dynamics in shallow lakes and wetlands are dominated by the binding of inorganic phosphorus by oxidised sediments and by the release of this phosphorus under

Aquatic macrophytes, *Triglochin procerum* (common name Water Ribbons) and *Ranunculus* sp.

Inset: Harvesting of macrophytes.

anoxic (low oxygen concentration) conditions. Phosphorus binding by sediments will eventually become saturated. The external phosphorus load will then show up as an increase in phosphorus concentration in the water column.

3. Nitrogen dynamics are dominated by biological processes. Under the right conditions, bacteria in the sediment and water column can convert inorganic nitrogen into N_2 gas that is then lost to the atmosphere. This represents a net and permanent loss of nitrogen from the system, but this process can be easily overloaded.
4. Sediments are a major pathway for removal of nitrogen and phosphorus from the water column. Thus, they probably function as nutrient sinks and 'protect' submerged plants. However, sediments cannot act as sinks indefinitely, and when they are saturated with nutrients, inorganic nitrogen and phosphorus appear in the water column. The loss of valuable submerged macrophytes is then made far more likely.

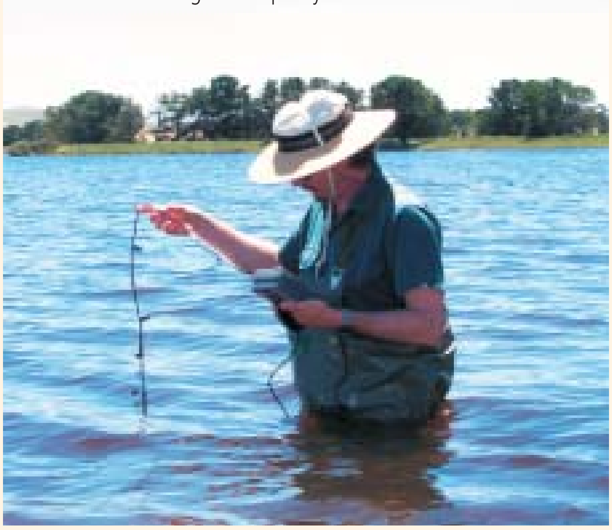
General management advice for shallow lakes and wetlands

From this and related research, some general management advice for shallow lakes and wetlands can be provided.

1. Submerged aquatic macrophytes are a desirable component of shallow lakes and wetlands, and management activities should be directed to ensure their continual presence.
2. Harvesting of submerged macrophytes when nutrients levels in the water column are high, increases the likelihood of algal blooms and may prevent the re-establishment of submerged aquatic plants.
3. Harvesting of submerged macrophytes may result in the establishment of other aquatic plant species not present earlier. These new species could potentially be more problematic (e.g. in producing taste and odour problems) than the original species.
4. Dense mats of floating plants or algae growing on the water surface, in response to nutrient enrichment, can cause de-oxygenation of the water column and the catastrophic loss of submerged macrophytes.

5. Managers who are constructing artificial wetlands need to be aware that there is a limit to the potential use of wetlands to treat nutrient-enriched waters. This is because the buffering capacity of the sediments will become saturated.

Paul Boon monitoring water quality in a rural lake.



6. Current monitoring programs that address only blue-green algae could easily miss significant algal blooms caused by other types of phytoplankton. Diatoms, green algae and dinoflagellates bloom in response to nutrient enrichment and cause a decrease in water quality.

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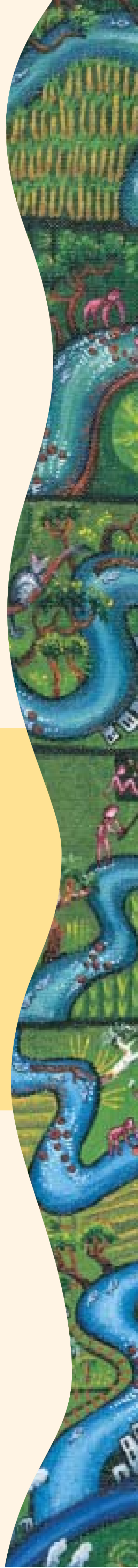
~ Submerged water plants are a desirable component of shallow lakes and wetlands, and management activities should be directed to ensure their continual presence.

~ Aquatic systems dominated by submerged aquatic plants are resilient to low levels of nutrient enrichment, but higher loadings lower the resistance of shallow lakes to events that can result in the catastrophic and very rapid loss of these valuable plants.

~ As nutrient loads increase it becomes more likely that submerged water plants will disappear and be replaced by phytoplankton. This may lead to severe and recurrent algal blooms.

~ Harvesting of submerged macrophytes when nutrients in the water column are high may increase the likelihood of algal blooms and prevent the re-establishment of submerged aquatic plants.

~ Even if the submerged aquatic plants re-establish, new species can appear which may be more problematic than the original vegetation.



River and Riparian Land Management, Technical Guideline Update No. 2. Managing nutrients in floodplain wetlands and shallow lakes. Edited by Brendan Edgar and Siwan Lovett.

Published by Land & Water Australia
GPO Box 2182 Tel: 02 6263 6000 E-mail: public@lwa.gov.au
Canberra ACT 2601 Fax: 02 6263 6099 Website: www.lwa.gov.au
www.rivers.gov.au

July 2002, reprinted August 2004

ISSN 1445-3924 ISBN Print 0 642 76080 2 Web 0 642 76081 0
Product code number PR020251

Australian Government
Land & Water Australia

Publication data
Bailey, P., Boon, P. & Morris, K., 2002, 'Managing nutrients in floodplain wetlands and shallow lakes'. River Management Technical Update No. 2, Land & Water Australia. Canberra.

Cover illustration 'River Landscapes' painting by Annie Franklin.
Cover photograph Paul Boon, internal images Kay Morris, unless credited.

Design by Angel Ink, Canberra. Printed by Goanna Print, Canberra.