2. EUTROPHICATION

This chapter should be read by anyone wanting a brief summary of the causes, the impacts and the management of eutrophication.

CHAPTER CONTENTS

2.1 INTRODUCTION

The word ‘eutrophic’ comes from the Greek word *eutrophos* meaning well-fed. A variety of definitions of ‘eutrophication’ exist in the literature, some differing fundamentally from others. One difference is in respect of whether eutrophication is only the process of nutrient enrichment or whether it should include the problems associated with such enrichment. In South Africa, the latter is the generally accepted view. Rast and Thornton (1996) state that “eutrophication is the natural ageing process of lakes”. Others suggest that eutrophication is the *enhancement* of the natural process of biological production caused by nutrient enrichment [Chorus and Bartram, 1999].

A widely quoted definition in South Africa is that “eutrophication is the process of nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes, amongst which increased production of algae and aquatic macrophytes, deterioration of water quality and other symptomatic changes are found to be undesirable and interfere with water uses [OECD, 1982]”.

This definition is somewhat clumsy. It is also not necessary that a complex definition is adopted for the present purposes. In essence, eutrophication is nutrient enrichment that causes problems. Therefore, the following simplified definition is adopted.

Eutrophication is the process of excessive nutrient enrichment of waters that typically results in problems associated with macrophyte, algal or cyanobacterial growth.

While an enormous amount of literature has been published on this topic, a detailed treatment is outside the scope of this report. A recent local review [Walmsley, 2000] provides important perspectives on eutrophication of surface waters with particular emphasis on policy and research needs in South Africa. It contains a very useful list of references which can be consulted for more detailed information.

The causes and effects of eutrophication are complex. This chapter only summarises briefly the current state of knowledge. Internationally, much research work is in progress that aims at furthering our knowledge of the intricate interrelationships involved in eutrophication of water resources. A paper by Rast and Thornton (1996) can be consulted for more information on research trends.

2.2 CAUSES

2.2.1 Introduction

In *natural* lakes a distinction is sometimes made between ‘natural’ and ‘cultural’ (anthropogenic) eutrophication processes (*e.g.* Rast and Thornton (1996)). Natural eutrophication depends only on the local geology and natural features of the catchment. Cultural eutrophication is associated with human activities which accelerate the eutrophication process beyond the rate associated with the natural process (*e.g.* by increasing nutrient loads into aquatic ecosystems). In South Africa where impoundments are man-made, the conceptual difference between ‘natural’ and ‘cultural’ seems less appropriate.

Increased nutrient enrichment can arise from both point and non-point sources external to the impoundment as well as internal sources like the impoundment’s own sediments (that can release phosphate).

The adjacent figure illustrates some of the factors that drive the eutrophication process in an impoundment.

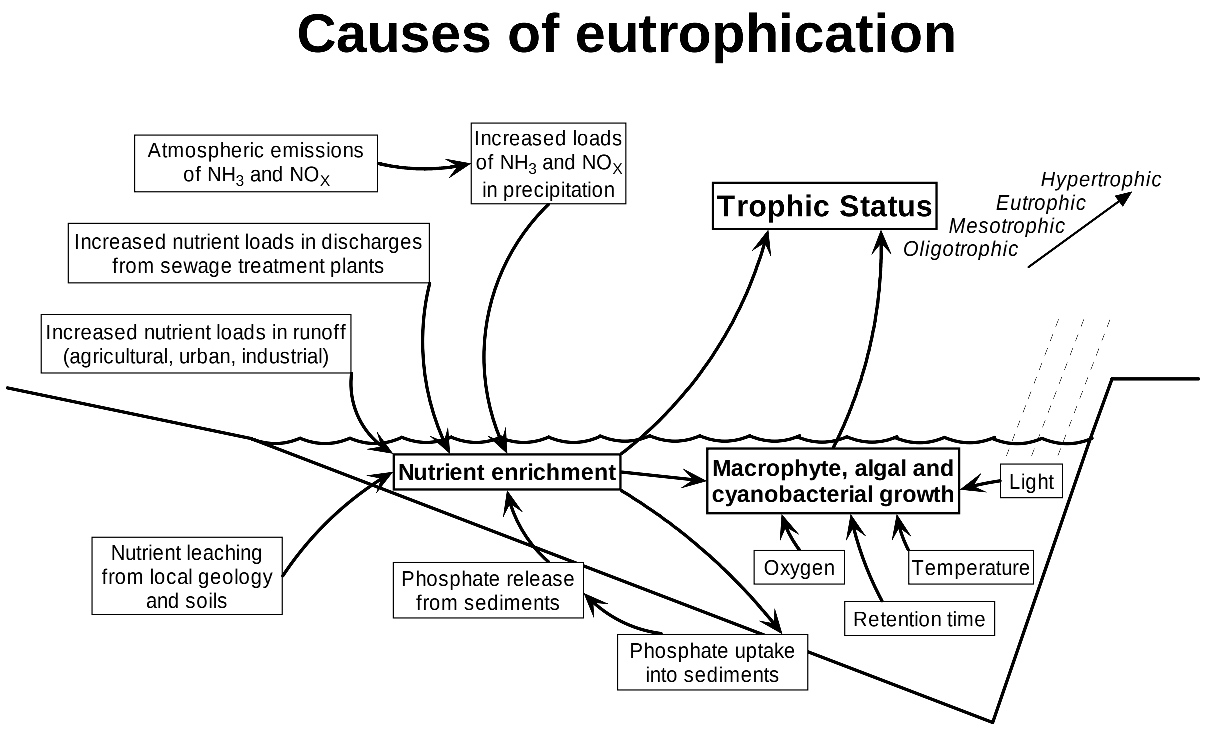
Causes of eutrophication

Figure 2.1. Simplified schematic illustration of the most important factors driving the eutrophication process.

2.2.2 Trophic status

Eutrophication is a process and it is useful to be able to characterise the stage at which this process is at any given time in a particular water body. The 'trophic status' of the water body is used as a description of the water body for this purpose. The following terms are used [Walmsley, 2000].

Oligotrophic - low in nutrients and not productive in terms of aquatic animal and plant life.

Mesotrophic - intermediate levels of nutrients, fairly productive in terms of aquatic animal and plant life and showing emerging signs of water quality problems.

Eutrophic - rich in nutrients, very productive in terms of aquatic animal and plant life and showing increasing signs of water quality problems.

Hypertrophic - very high nutrient concentrations where plant growth is determined by physical factors. Water quality problems are serious and almost continuous.

It is convenient to associate the trophic status in impoundments with total phosphorus and chlorophyll *a* measurements. The following relationships between trophic status and these variables are used. These are essentially those of Van Ginkel *et al.* (2000), which were based on the work of Walmsley and Butty (1980) and Walmsley (1984). These have been shown to be applicable to South African impoundments.

Table 2.1. Relationships between trophic status and monitoring variables.

		Trophic Status			
Variable	**Unit**	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Hypertrophic**
Mean annual chlorophyll *a*	µg/ℓ	$0<x\leq10$	$10<x\leq20$	$20<x\leq30$	>30
% of time chloropyll *a* > 30 µg/ℓ	%	0	$0<x\leq8$	$8<x\leq50$	>50
Mean annual Total Phosphorus	mg/ℓ	$x\leq0.015$	$0.015<x\leq0.047$	$0.047<x\leq0.130$	>0.130

Trophic status is therefore strictly related to one of the nutrients (namely phosphorus) and concentrations of planktonic algae and cyanobacteria (as chlorophyll *a*). (Note that it is not necessarily directly related to concentrations of macrophytes or algae attached to rocks and other surfaces.) It is also possible to have a relatively high nutrient concentration and yet low plant growth (*i.e.* low chlorophyll *a*). For example, this can occur if light availability is reduced because of high levels of suspended solids or if high flushing rates occur.

2.3 IMPACTS

2.3.1 Introduction

Eutrophication is a concern because it has numerous negative impacts. The higher the nutrient loading in an ecosystem the greater the potential ecological impacts. Increased productivity in an aquatic system can sometimes be beneficial. Fish and other desirable species may grow faster, providing a potential food source for humans and other animals (though this is not a common situation in South Africa). However, detrimental ecological impacts can in turn have other adverse impacts which vary from aesthetic and recreational to human health and economic impacts. This is summarised in the following figure.

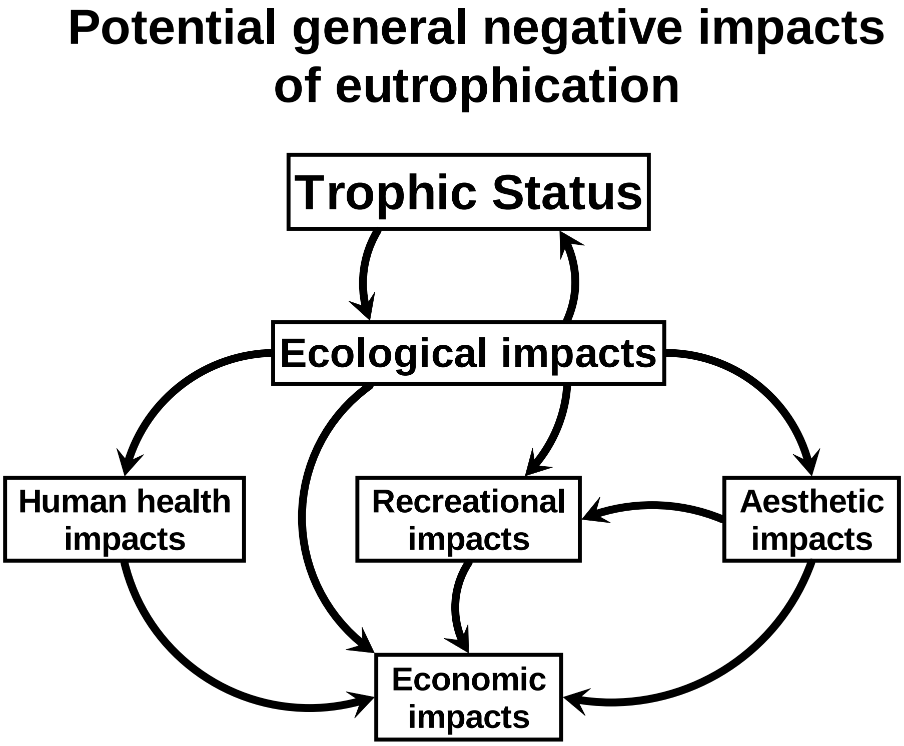
Potential general negative impacts of eutrophication

Figure 2.2. Summary of potential general negative impacts of a high trophic status.

The more detailed impacts of eutrophication are complex and interrelated. The excessive growth of aquatic plants and cyanobacteria has a multitude of impacts on an ecosystem. The specific impacts depend on what plants are stimulated to grow.

Potential negative impacts of eutrophication

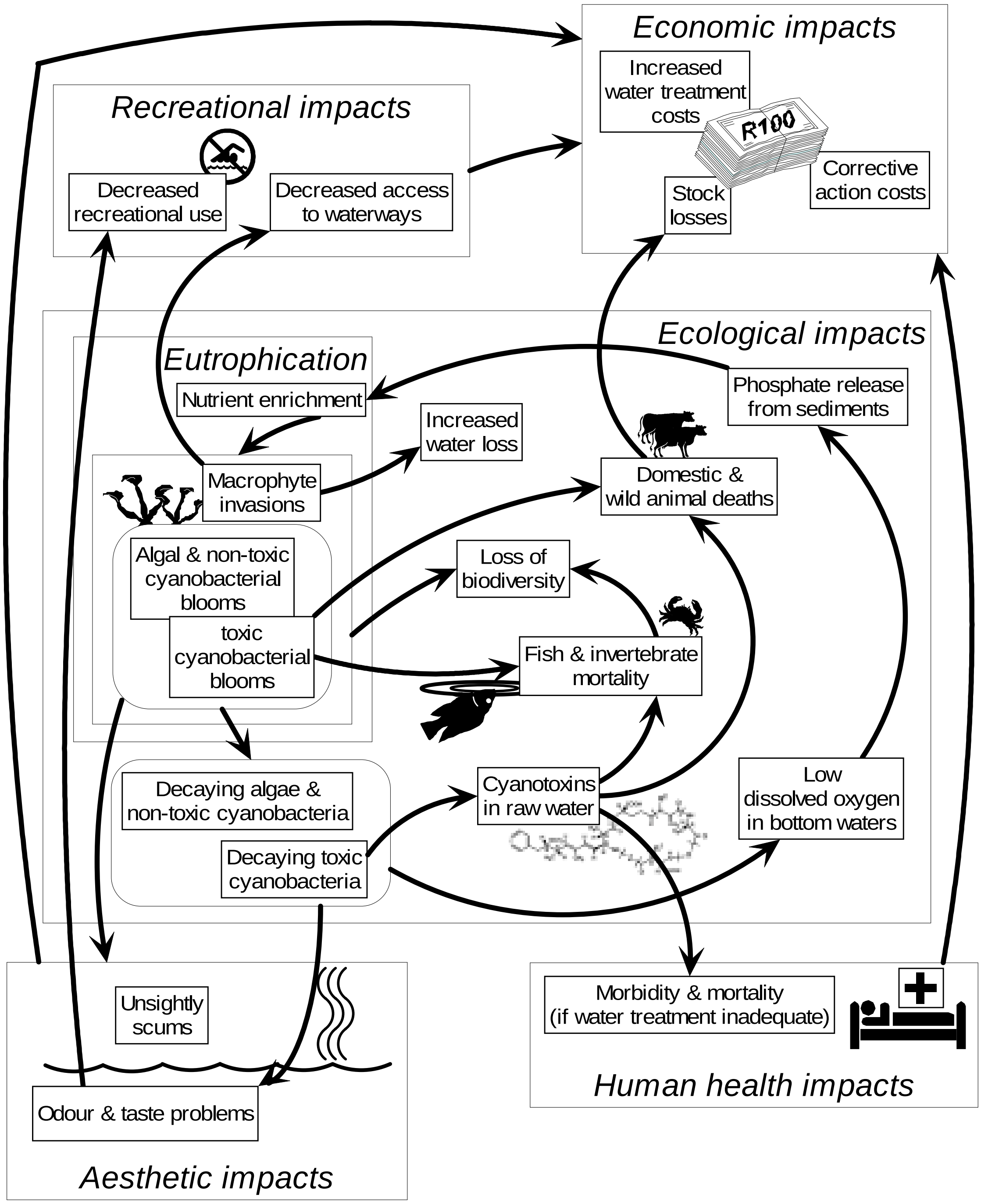

Figure 2.3. Schematic illustration of some specific impacts of eutrophication.

2.3.2 Ecological impacts

Macrophyte invasions and algal and cyanobacterial (blue-green) blooms are themselves direct impacts on an ecosystem. However, their presence causes a number of other ecological impacts.

Of critical concern is the impact of eutrophication on biodiversity. Macrophyte invasions impede or prevent the growth of other aquatic plants. Similarly, algal and cyanobacterial blooms consist of species that have out-competed other species for the available nutrients and light.

Their impact on animal biodiversity is also of concern. By generally lowering the ecological integrity of an ecosystem, only the more tolerant animal species can survive.

Cyanobacteria (also known as blue-green algae) and algae require water, carbon dioxide, inorganic substances and light for their life processes [Chorus and Bartram, 1999]. Cyanobacteria are found widely in nature and flourish in water that is salty, brackish or fresh, in cold and hot springs and in environments in which no other algae can exist. The basic forms and structure include unicellular, colonial and multicellular filamentous forms. The growth rate of cyanobacteria is usually much lower than that of many algal species. The following table shows comparative growth rates for some organisms (in number of days to double the biomass).

Table 2.2. Comparative growth rates for some organisms at 20°C and light saturation [Chorus and Bartram, 1999].

Organism	Growth rate range (days per doubling)
Most common planktonic cyanobacteria	0.7 - 3.3
Diatoms	0.5 - 1.3
Single-celled green algae	0.4 - 0.8

Cyanobacteria can maintain a relatively higher growth rate compared to other phytoplankton organisms when light intensities are low. They will therefore have a competitive advantage in waters that are turbid due to dense growths of other phytoplankton. Maximum growth rates are attained by most cyanobacteria at temperatures above 25°C. These optimum temperatures are higher than for green algae and diatoms [Chorus and Bartram, 1999].

Cyanobacteria can form floating scums (like *Microcystis*), be distributed homogeneously throughout the epilimnion (like *Oscillatoria*) or grow on submerged surfaces. Cyanobacteria are particularly problematic because when their cells are ruptured (*e.g.* by decay or by algicides) they release toxic substances (cyanotoxins) into the water, though passive release can also occur. These cyanotoxins fall into three broad groups of chemical structure: cyclic peptides, alkaloids and lipopolysaccharides. Globally, the most commonly found cyanotoxins in blooms from fresh and brackish waters are the cyclic peptides of the microcystin and nodularin family [Chorus and Bartram, 1999].

Cyanotoxins are recognised to have caused the deaths of wild animals, farm livestock, pets, fish and birds in many countries [Holdsworth, 1991]. The primary target organ of most cyanotoxins in mammals is the liver (*i.e.* they are hepatotoxic). Some cyanotoxins are neurotoxic (target the nervous system) and others dermatotoxic (target the skin). Ecological impacts include various water quality impacts like increased cyanotoxin levels and lowering of oxygen levels (due to decay of algae and cyanobacteria). Decreased oxygen levels can have a number of other secondary water quality impacts. Anaerobic conditions allow reduced chemical species (like ammonia and sulfide) to exist. These chemicals can be particularly toxic to animals and plants.

2.3.3 Aesthetic impacts

Algal and cyanobacterial blooms, and particularly surface scums that might form, are unsightly and can have unpleasant odours. This is often a problem in urban impoundments where people live close to the affected water body.

If the water is being used for water treatment purposes, various taste and odour problems can occur. These lower the perceived quality of the treated water, although do not cause human health problems.

2.3.4 Human health impacts

An infestation of water hyacinth (*Eichhornia crassipes*) can be a health hazard. It can provide an ideal breeding habitat for mosquito larvae and it can protect the snail vector of bilharzia [Scott *et al.*, 1979].

Of all the cyanotoxins currently known, the cyclic peptides represent the greatest concern to human health, although this may be because so little is known about the other cyanotoxins [Chorus and Bartram, 1999]. The concern exists primarily because of the potential risk of long term exposure to comparatively low concentrations of the toxins in drinking water supplies. Acute exposure to high doses may cause death from liver haemorrhage or liver failure. Other short term effects on humans include gastrointestinal and hepatic illnesses. A number of adverse consequences have been documented for swimmers exposed to cyanobacterial blooms. Chronic exposure to low doses may promote the growth of liver and other tumours. Nevertheless, many cyanobacterial blooms are apparently not hazardous to animals [Carmichael, 1992].

It is also possible that people exposed to odours from waterways contaminated with decaying algae of cyanobacteria may suffer chronic ill-health effects.

2.3.5 Recreational impacts

The existence of large areas of macrophytes can inhibit or prevent access to waterways. This decreases the fitness for use of the water for water sports such as skiing, yachting and fishing. The presence of unsightly and smelling scums also makes any recreational use of the water body unpleasant.

2.3.6 Economic impacts

Nearly all of the above mentioned impacts have direct or indirect economic impacts. Algal or cyanobacterial scums increase the costs of water treatment in order to avoid taste, odour and cyanotoxin problems in the treated water. Excessive blooms can clog filters and increase maintenance costs.

Human and domestic and wild animal health impacts due to cyanotoxins in water have obvious direct economic impacts.

Once significant eutrophication has occurred, the costs of corrective action can be enormous. Macrophytes may need to be sprayed or brought under control by biological or other costly treatment processes.

2.4 MANAGEMENT

The basis of eutrophication management is often the ‘limiting nutrient concept’ [Walmsley, 2000]. The rate and extent of aquatic plant growth is dependent on the concentration and ratios of nutrients present in the water. Plant growth is generally limited by the concentration of that nutrient that is present in the least quantity relative to the growth needs of the plant. Minimisation of eutrophication-related impacts therefore tends to be focussed on efforts to reduce nutrient (particularly phosphorus) inputs. This approach therefore deals directly with the primary cause of eutrophication (namely, nutrient enrichment).

Typically, limiting nutrients entering an impoundment exhibiting a high degree of eutrophication will first focus on point sources. These are easier to quantify, simpler to manage and often contribute the highest nutrient load. Following this, non-point sources are managed and then internal (“in-lake”) management options can be implemented.

Readers are referred to Walmsley (2000) for a recent review of local and international eutrophication management perspectives. He notes that successful eutrophication management depends on the acceptance of certain perspectives. These include the following.

1. Cultural eutrophication is reversible.
2. There is no quick fix. Long term approaches are required to solve the problem.

3. Collaboration is required between government, business and communities. However, government must play the lead facilitation role.
4. The problem cannot be solved by a single technical intervention. It requires a suite of social, economic and technical actions.
5. Transparent research and monitoring activities are prerequisites to the decision-making that is required.

The excellent work by Chorus and Bartram (1999) on toxic cyanobacteria in water contains much detailed management information. Although primarily focussed on the cyanobacteria, many of the principles are likely to be appropriate in other eutrophication contexts. A report on management of urban impoundments in South Africa is also available which provides an overview of current practice (though not only focussed on eutrophication) which has applicability beyond just urban impoundments [Wiechers *et al.*, 1996]. Publications on the biological control of some aquatic macrophytes in South Africa are also available [Hill and Cilliers, 1999; Cilliers, 1999].

Other management approaches such as harvesting of macrophytes (like the cattail, *Typha capensis*) and biological control (of, for example, water hyacinth, *Eichhornia crassipes*) are, by their very nature, focussed on the symptoms of the eutrophication problem. However, macrophyte harvesting does little to remove nutrients (that would move into the aerial and rhizome biomass).

A drinking water supply safe from cyanotoxins should either be free of cyanotoxins, or have treatment in place that will remove cyanobacterial cells (without rupturing them) and released cyanotoxins [Chorus and Bartram, 1999]. From a recreational point of view, similar measures of resource protection apply as for drinking water. However, a series of guidelines have been proposed associated with incremental severity and probability of adverse effects [Chorus and Bartram, 1999].