Eutrophication and Algal Blooms in Inland Reservoirs: A Case Study from Australia

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ABSTRACT

Toxic Blue-green algal blooms are one of the major environmental problems in Australian inland water ways causing substantial adverse impact on domestic, livestock and recreational use of water resources. Ben Chifley Dam, which provides Bathurst city with drinking water, has a chronic algal blooms since 1993. Levels of up to 450,000 cells/mL of toxic cyanobacteria (mainly *Anabaena* and *Microcystis*) have been recorded in the dam. A conceptual model has been developed to understand and to address the causal factors and processes controlling blue green algae in the dam. An integrated research program is on going to investigate water quality, hydrology, aquatic ecology, catchment characteristics and land management and sediment-nutrient interactions in order to develop a sustainable management plan for the dam. The initial results of the research indicate that the dam is enriched with nutrients (phosphorus and nitrogen) and is on the verge of being eutrophic. The nutrients are derived from both external diffuse sources (upstream catchment) and internal sources where the bioavailable nutrients are released from the bottom sediments to the water column.

INTRODUCTION

Eutrophication is the process whereby water bodies become enriched by nutrients (Phosphorus and Nitrogen) from both external and internal sources. It is considered as one of the most pressing environmental problems in both the developed and the developing countries. [1,2] Eutrophication and excess blue-green algal (cyanobacteria) growth are one of the major water-quality problems in inland waterways of Australia and in water supplies of country towns. In late 1991 the world's largest riverene blue green algal bloom occurred along 1000 km of Australia's Darling-Barwon River. This event prompted New South Wales's government to declare a state of emergency. Economically the state had a loss of $ 9.4 million in tourism industry during 1991-1992.[3]

Elevated nutrient levels in aquatic ecosystems are normally derived from point sources (e.g. municipal and industrial effluent) and non-point (diffuse) source (e.g. agricultural runoff from fertilised top soils and livestock operation). In Australia, this water quality problem is related to land degradation resulting from poor land management practices over the past 200 years.[4] Large agricultural areas in inland Australia are being inappropriately used and many agricultural practices are simply unsustainable.[5] Recent studies have revealed that the phosphorus in some turbid inland waterways are derived from naturally phosphorus rich soil.[6]

Quality deterioration of water resources is increasingly becoming a major concern because it further complicates the problems associated with the scarcity of inland water in Australia. The following case study is presented to provide a context to the above issue. Bangladesh could avail the opportunity to use its surface water for recreation and fisheries through sustainable management plan (e.g., establishing lakes and reservoirs or restoration of existing storage). This study could be helpful for sustainable management of inland lakes and reservoirs (e.g., Kaptai lake) in Bangladesh where these water bodies could be used for recreation, fisheries and shelter for other aquatic birds and animals.

Case Study: Ben Chifley Dam, Bathurst, New South Wales.

Ben Chifley Dam, which was built in 1957 to provide Bathurst town a secure water supply, is located on the Campbells River approximately 20 km south-east of Bathurst (Figure 1). The dam covers an area of 220 ha when full having a storage capacity of 16000 ML. It is the main water supply source for the 30,000 people living in the city of Bathurst. It has a drainage basin (catchment) of 986 km^2, which is drained by Campbells River and its tributaries.

The dam has been experiencing algal problems since 1993 (Figure 2). Levels of up to 450,000 cells/mL of cyanobacteria (mainly *Anabaena* and *Microcystis*) have been recorded in the dam (W. Battey Smith 1997, Pers. Comm.). When the level of blue-green algae in the dam exceeds 25,000 cells/mL the dam is closed to recreational users.[7] Department of Public Works and Services reported that the existing dam storage is on the border of being eutrophic i.e. susceptible to blue green algal growth with associated impacts on water quality.[8] Out break of blue green algae depends on the interaction of a wide range of biophysical processes and socio-economic factors such as nutrients, temperature, light, dissolved oxygen, aquatic ecosystem balance, land use and catchment management.[4] From management point of view, it is essential that we understand the physico-chemical and ecological processes in the dam and its catchment.

Conceptual Model of Ben Chifley Dam

A conceptual model (Figure 3) shows the main factors and processes that control the development of blue green algae in the dam. On the basis of this model, several questions/objectives have been set up to be addressed through an integrated and collaborative research project involving the University of Sydney, New South Wales Environment Protection Authority and Bathurst City Council.

The development of such a conceptual model provides a sound foundation for understanding the roots causes of the problems and consequently allows the development of sustainable and cost effective management strategies to control eutrophication and to minimise algal out breaks.

It should be emphasised that environmental problem like eutrophication requires a multidisciplinary investigation to determine the dynamic and complex interactions of the biophysical and socio-economic systems.

This paper present a preliminary assessment based on initial results of three components of the above-described conceptual model namely water quality, algae and sediment-water interaction). The research is still on going to provide the necessary data for other components of the model.

Water Quality

Water quality parameters (physical and chemical) have been monitored fortnightly in headwater (riverine), mid water (transitional) and tail water (lacustrine) sections of the reservoir since 1998 for a period of twelve months. The thermal pattern of the water column on most sampling days displayed a gradual decrease from top to the bottom of the reservoir. However, during spring and early summer a rapid fall in temperature is observed within the top six meters then followed by a gradual change (Figure 4). Oxygen

stratification is more pronounced than the thermal stratification. During spring and summer, the deepest part of the dam (tail water) showed clear oxycline (Figure 4).
As shown in Table 1 nutrient concentrations in the dam do not satisfy the Australian guidelines for the protection of aquatic ecosystem.[10] Nitrate-N and dissolved reactive phosphorus show seasonal and temporal variations in summer, nutrient values in surface water are low but they tend to increase in the hypolimnetic (bottom) water. In autumn, surface water concentration of dissolved reactive phosphorus was comparatively low with an exception in case of nitrate nitrogen (Figure 3).

Blue Green Algae and other Phytoplanktons

Temporal and spatial variability in abundance of blue green algae has been shown in Figure 5. Blooms in the dam have been noticed in mid autumn when surface water nutrients were higher than in summer. A number of studies supported that the bloom might be observed during spring, or fall or even winter.[9] During the bloom period, the population was above the drinking water protection level i.e. 1000-2000 cells/mL of toxic algae.[10] Later on the population declined sharply probably due to the cold water inflow to the dam. In late autumn and winter Diatom (*Meloisira*), Cryptophyta (*Chroomonas*), Chrysophyta (*Synura*) and Dinoflagellate (*Ceratium*) dominate the phytoplankton community respectively.
Chlorophyll -a concentration, which is used as phytoplankton biomass index, reached the peak (36.0 and 33.0 μg/L) in late summer and autumn. Most of the sampling time the values remain within the range (5-25 μg/L) reported in the literature for productive waters.[11] It is recommended that, chlorophyll-a concentrations should be kept below 5 ug/L in reservoirs used for drinking water and below 20 μg/L for recreational lake.[12]

Sediment-Nutrients Interaction

Lake sediments are long term sinks for the nutrients particularly phosphorus but can release significant amount of nutrients particularly when overlain by anaerobic or nearly anaerobic water. Slower release can also occur under aerobic conditions.[13]

An experiment using core incubation technique has been conducted during October 1998 (mid spring) to investigate the source-sink behaviour of the bottom sediments of Ben Chifley Dam. As shown in Table 2, the release of ammonia is more significant than that of oxidised nitrogen. Moreover, the absorption of oxidised nitrogen is more pronounced rather then release. The release of dissolved reactive phosphorus has been found very little. This experiment indicates the potentiality of benthic sediments in the nutrient budget of the lake water column. Therefore, it is essential to determine how the sediments can affect nutrient status of the water column and what are the conditions and the time favourable for nutrient release from the sediments. Further studies are needed to enhance our understanding of the process and factors influencing sediment-nutrient interaction.

CONCLUSIONS

It is commonly accepted that control of nutrient input to water bodies is the most cost-effective tools to manage algal growth. The preliminary findings of this research have indicated that the nutrients in Ben Chifley Dam are derived from both external source (upstream catchment) and internal source (bottom sediment). To ensure that sustainable management of the dam is achieved, two types of management strategies should be adapted:

- Short term practices to alleviate the affect of the problem by water column manipulation using destratifier to prevent water stratification during summer and autumn.
- Long term strategies to reduce sediment and nutrient inputs to the waterways by adapting total catchment management practices in the upstream catchment.

The study has also revealed that a complex and dynamic interactions of host of biophysical processes and socio-economic factors influence the algal blooms. It is essential, therefore, that a multi-disciplinary, multi-sectoral and multi-focal approach is adapted to reach the ultimate goal of sustainable management. Towards this end, the development of a conceptual model, such as the one used in this study is paramount to facilitate the multidisciplinary investigations. The model will enhance our understanding of the root causes of the problem and facilitate the development of sustainable management system.

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Table 1. Nutrient status in Ben Chifley Dam

Nutrients (ug/L)	Range	Mean	Median	ANZEC guideline (Nov. 1992)
Total Nitrogen	194-1060	853	798	100-500
Total Phosphorus	16-101	51	51	5-50
Nitrate Nitrogen	6-65	19	15	
Dissolved Reactive Phosphorus	0.4-26	9	8	

Table 2. Flux of oxygen and dissolved nutrients from bottom (8 m) sediments.

Core #	Flux rate (mmol m^{-2} d^{-1})			
	Oxygen	Ammonia (NH3)	Oxidative Nitrogen	Dissolved Reactive Phosphorus
1	-8.5	1.80	0.30	ND
2	-15.2	-0.40	-2.10	ND
3	-18.0	2.00	-1.00	0.10
4	-19.3	3.30	1.40	0.10
5	-12.5	-0.01	-2.20	ND
6	-17.7	5.00	1.60	ND

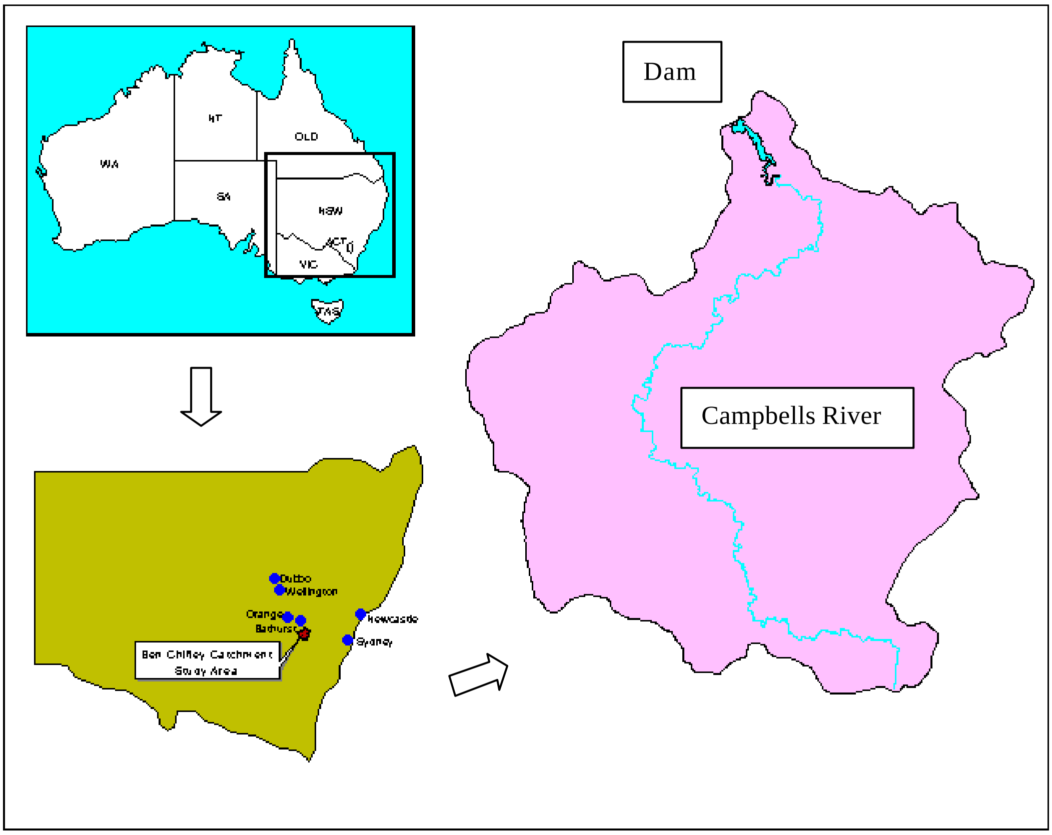


Figure 1. Location of Ben Chifley Dam and its catchment.

Figure 2. Blue-green algal scum in the dam in early autumn (April 1999).

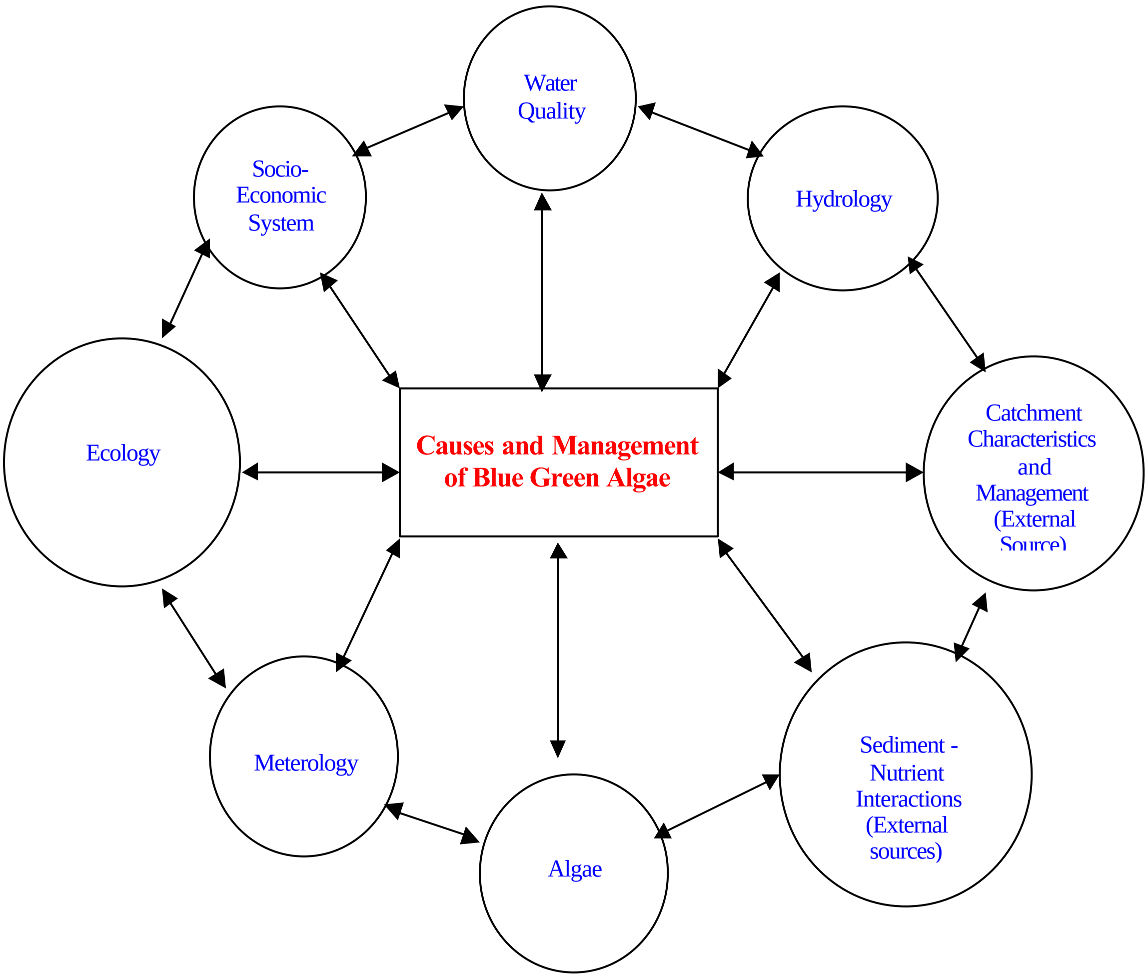


Figure 3. Conceptual Model showing factors and processesncontrolling Blue Green Algae in Ben Chifley Dam

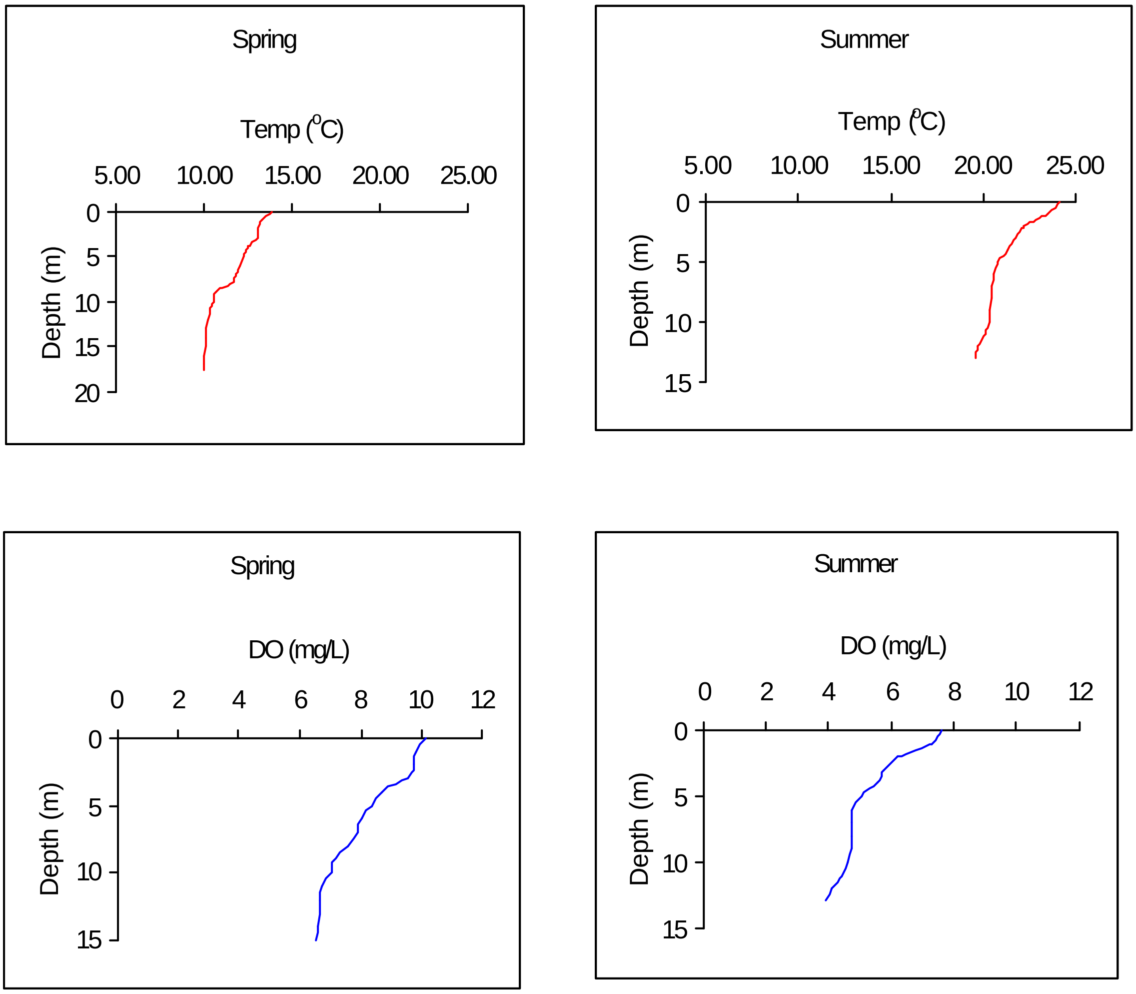


Figure 4. Temperature and dissolved oxygen (DO) profile during spring and summer in Lacustrine water

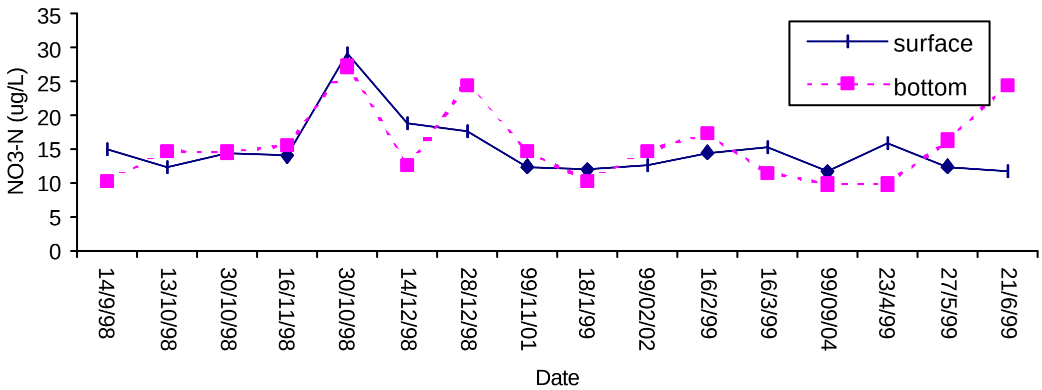
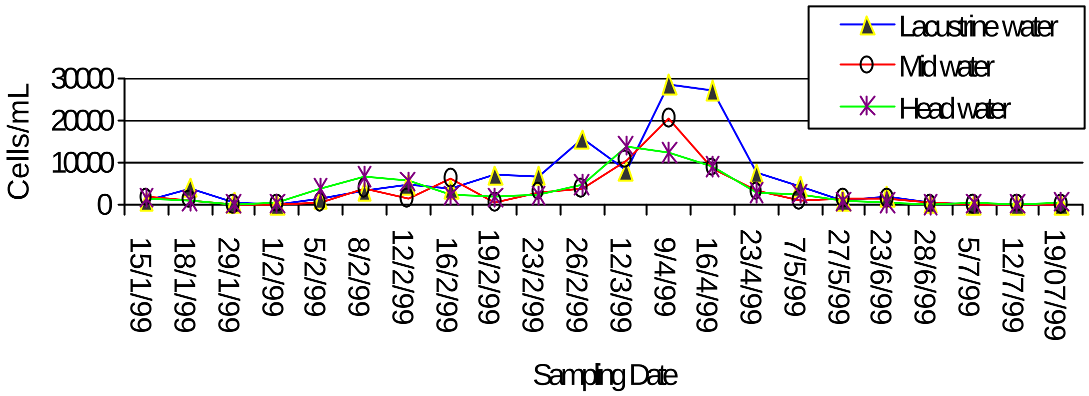


Figure 5. Temporal variability of Nitrate-N and Dissolved Reactive Phosphorus (DRP) in lacustrine water.



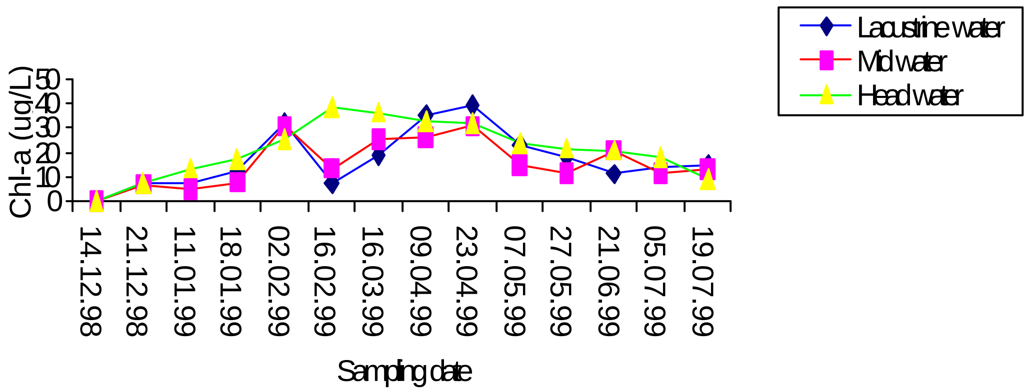


Figure 6. Seasonal (summer, autumn and winter) and spatial (lacustrine-, mid-and head water) pattern of blue green algae and chlorophyll-a in Ben Chifley Dam