Cyanobacterial Bloom Management
Current and Future Options

Abstracts from the meeting held
12 & 13 August, 2009, Parramatta, NSW

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This National cyanobacterial workshop was hosted by the Office of Water, NSW Department of Environment, Climate Change and Water in association with NSW Health, the Sydney Catchment Authority and Water Quality Research Australia.

Attending the workshop were people involved in the management of public health, water resources and water supplies, and core cyanobacterial research.

The workshop was organised by **Dr Lee Bowling**, Principal Limnologist/State Algal Coordinator Office of Water, NSW Department of Environment, Climate Change and Water,
together with an organising committee comprising:

Dr Bala Vigneswaran - Sydney Catchment Authority
Dr Yoshi Kobayashi - Scientific Services Division, NSW Department of Environment, Climate Change and Water
Mr Sandy Leask - NSW Health
Dr Michele Akeroyd – Water Quality Research Australia

*Cover photographs, of algal blooms on Chaffey, Copeton and Pindari Dams, kindly supplied by **Warwick Mawhinney**, Water Quality Officer, Office of Water, NSW Department of Environment, Climate Change and Water, Tamworth, NSW.*

Book of abstracts edited and designed by Angela Gackle and Steve Papp, WQRA, Adelaide SA.

Foreword

Maintenance of water quality is a key goal of water management agencies and water utilities. It is particularly important across the Murray Darling Basin as a result of the level of irrigation and other intensive agriculture, but all water drainage divisions across Australia experience water quality issues at some point in time.

The occurrence of “blooms” of cyanobacteria (blue green algae for many of us) poses particular concerns given the potential for adverse health effects in both humans and livestock. In New South Wales, recent experiences with major cyanobacterial blooms in the Darling River, Lake Burragorang and most recently the Murray River, have clearly demonstrated that the natural balance of systems can rapidly change. So whilst we expect that cyanobacteria will always be a small but nonetheless important part of any healthy and balanced aquatic ecosystem, human impact — physical changes to flow or nutrient enrichment — can sometimes stimulate massive growth of these organisms.

Water resource managers routinely experience the development of cyanobacterial “blooms” in dams and lakes over the warmer summer periods, but the severity of these “blooms” varies from year to year depending upon climate and other causal factors but we still don’t fully understand the dynamics of these events. The impacts of climate change on “bloom” occurrence and severity is also of concern to managers.

The late summer of 2009 saw 1000 km of the Murray River affected by a mixed bloom of potentially toxic cyanobacteria. Thankfully the results of years of research by the water industry and health sector were available to assist in the management of the bloom. However in the course of managing this event it became obvious that there was a real need for those researchers and water managers dealing with algae, to share their findings for the broader benefits of the water industry and so was born the idea of this national workshop.

I commend the efforts of the organisers of this workshop and welcome the opportunity to publish the current state of play in managing algal blooms and researching the myriad aspects associated with the development, detection, treatment and potential health effects of cyanobacterial “blooms”.

Bruce Cooper,
Manager, Environmental Evaluation and Performance Branch,
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Cyanobacterial Bloom Management - Current and Future Options

The Sebel Hotel, 350 Church St, Parramatta, NSW, 2150

Day 1 – Wednesday 12th August 2009

8:30 – 9:00 Arrival – Check in for Workshop

Session 1 – Opening Session – Chair Lee Bowling

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9:05–9:15	David Harriss	National Cyanobacterial Workshop – Opening address	7
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Morning Tea – 10:00 – 10:30

Session 2 – Regional Reports and Status – Chair Michele Akeroyd

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11:10–11:20	Louisa Davis	State report: blue-green algae management in Victoria	14
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11:30–11:40	Karen Stacey	All hands on deck -a review of a BGA response procedure for water treatment plants.	18
11:40–12:00		Discussion of presentations	

Lunch – 12:00 – 13:00

**Session 3 – Regional Reports and Status (cont), & Issues and Management – ** Chair – Felicity Roddick

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13:55–14:00	Simon Townsend	Cyanobacterial blooms in Northern Territory inland waters	26
14:00–14:15	Ian Stewart	Closure of recreational lakes because of toxic cyanobacteria: risk communication, risk perception, enforcement and economic impacts	28
14:15–14:25	Christine Hill	Determining an economic value for reduced incidence of blue green algal events in the Barwon Darling river system	30
14:25–14:40	Paul Hackney	A review of some methods to manage cyanobacterial blooms in drinking water reservoirs	30
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Afternoon Tea – 15:00 – 15:30

Session 4 – Monitoring & Growth and Fate– Chair – Larelle Fabbro

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15:45–16:00	David Fotheringham	Techniques for in-site measurements using Fluorometry	34
16:00–16:15	Tim Malthus	Quantitative remote sensing for detection and monitoring of cyanobacterial blooms	36
16:15–16:30	Nagur Cherukuru	Monitoring and management of cyanobacterial blooms in estuarine and coastal waters: An earth observation based assimilation approach	38
16:30–16:45	David Waite	Impact of iron species transformations on growth and toxicity of cyanobacterial *Microcystis* species	40
16:40–17:00	Yoshi Kobayashi	Downstream fate of cyanobacteria and other phytoplankton following discharge from a dam	40
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Workshop Dinner – 19:00

Day 2 – Thursday 13th August 2009

Session 5 – Testing for Toxins – Chair – Glen Shaw

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9:10–9:25	Barbara Sendall	Identification, detection and characterisation of cyanobacteria using traditional and DNA-based methods	46
9:25–9:40	Larelle Fabbro	Toxins that may not be readily detected by traditional methods	48
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Morning Tea – 10:00 – 10:30

Session 6 – Water Treatment – Chair – Andrew Humpage

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10:45–11:00	Felicity Roddick	*Microcystis aeruginosa* blooms in wastewater: managing microfiltration performance	52
11:00–11:15	Lionel Ho	Biological degradation of cyanobacterial toxins	54
11:15–11:25	Daniel Hoefel	Biofiltration of cyanobacterial metabolites MIB and geosmin as a viable water treatment option	56
11:25–11:40	Steven Giglio	Isolation and characterisation of the gene associated with geosmin production in cyanobacteria	58
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Lunch – 12:00 – 13:00

Session 7 – Guidelines & Summary Workshop – Chair – Malcolm Robb

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13:00–13:10	Bruce Gray	Revision of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000* and the *Australian Guidelines for Water Quality Monitoring and Reporting 2000*	60
13:10–13:25	Gayle Newcombe	The development of practical guidance manuals for the management of cyanobacteria	62
13:25–13:40	Ian Falconer	Risk and regulation in environmental toxicology, application to cyanobacterial toxins	64
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Afternoon Tea – 15:00 – 15:30

15:30 Workshop Ends

Opening Address

Mr David Harriss
Deputy Director General and NSW Commissioner for Water, Office of Water, NSW Department of Environment, Climate Change and Water

There have been two recent major cyanobacterial bloom problems in NSW - Warragamba (August 2007) and the Murray River (April 2009), but many localised blooms occur all across the state (e.g. in State Water storages, sections of the Darling River, etc) each summer.

These blooms provide ongoing stimulus to ensure adequate and timely responses to bloom management in NSW, which is undertaken by 9 Regional Algal Coordinating Committees that cover the entire state.

The Murray Regional Algal Coordinating Committee (MRACC) was tasked with the management of the recent bloom in the Murray. NSW government agencies, and in particular the Office of Water, Department of Environment, Climate Change and Water (DWE), were at the forefront in providing sampling, data analysis and management advice to the MRACC and its stakeholders throughout the bloom.

The bloom also fostered considerable cross-border cooperation and management input from Victorian counterpart agencies, and with the Murray Darling Basin Authority.

The bloom highlighted the benefit of open communication between those involved in cyanobacterial bloom management, and those researching the latest bloom management technologies across Australia.

NSW understands that cyanobacterial blooms continue to be a problem in most other Australian states and territories, but unfortunately communication between the various jurisdictions has decreased in recent years as the focus has moved to other water management issues.

There has not been a major meeting at a national scale of those involved in the management of and research into cyanobacterial blooms for a number of years now.

NSW anticipates that there are considerable synergies in bloom management and research across Australia, but often what happens in one state or territory is not widely known outside of that jurisdiction, whereas a wider knowledge of these would be to the benefit all.

Consequently this workshop has been organised to update participants on the current status of cyanobacterial blooms across Australia, the issues arising from these, and the options available for their management both now and in the future.

A major objective of this workshop is to promote better knowledge transfer between people involved in bloom management and research across Australia, establish better avenues for this to occur, and ultimately lead to better management of future problem blooms

I welcome you to Parramatta, to this workshop hosted by the NSW Office of Water, Department of Environment, Climate Change and Water and our co-sponsors, and I trust that this will be an informative and rewarding two days for all of you, and will stimulate continued broader interaction and communication amongst all involved in cyanobacterial monitoring, management and research across Australia.

Quantitative molecular, morphological and analytical assessment of blue-green algae bloom events in water supplies

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In many aquatic ecosystems world-wide, including drinking water supplies, cyanobacteria can proliferate into the so-called “harmful algal blooms”. Members of this bacterial phylum can produce an unparalleled array of bioactive secondary metabolites; some of which are potent toxins. The past ten years has witnessed major advances in our understanding of the genetic basis for toxin production by a number of groups of cyanobacteria. This paper addresses the molecular genetics underlying cyanotoxin production in fresh and brackish water environments that pose a direct threat to public health. Understanding the role of these toxins in the producing microorganisms and the responses of their genes to the environment may suggest the means for controlling toxic bloom events in water supplies and also affords their rapid detection.

It was reported in late August 2008 that a blue-green algal bloom had infested many square kilometres of Warragamba Dam, the major water source for Sydney. Meanwhile, cyanobacterial toxins were also detected in the Wingecaribee River, a tributary of this reservoir. Raw water samples were continuously collected throughout the system and at various depths along the dam wall. Samples were analysed for the presence of the hepatotoxic peptide microcystin. Polymerase chain reaction (PCR) amplification of the 16S rRNA gene and various microcystin synthesis genes (*mcy*) confirmed the predominant cyanobacterial species existing in the raw water to be *Microcystis aeruginosa*, and at least some of which contained the toxin gene. High performance liquid chromatography (HPLC) was also used to detect microcystin content in the water. The aim of this project was to quantify and correlate the amount of cyanobacterial 16S rRNA genes and *mcy* genes from water samples using quantitative real-time PCR (qRT-PCR). The ratio of *mcy* genes to 16S rRNA genes allowed the estimation of the extent of the toxic *M. aeruginosa* population among the entire *M. aeruginosa* community present along spatial and temporal grades. The ratio of cyanobacterial (*Microcystis* sp.) cells with the potential to synthesise toxin in comparison to the whole population was always below 0.5%, while this ratio was significantly higher (up to 8%) in the Wingecaribee River samples.

This study highlighted the importance of genetic testing of harmful algal blooms. The results of this and another recent molecular study of the 2009 Murray River bloom will be presented.

Cyanobacteria bloom in Warragamba Dam in 2007

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A cyanobacteria bloom developed in Warragamba Dam in August 2007, and persisted over three months. This paper describes the nature of the cyanobacteria bloom of 2007, the operational responses undertaken by the Sydney Catchment Authority (SCA) and the preliminary results of the analysis of relevant data.

The cell count of *Microcystis* exceeded 100,000 cells/mL in the first week of September 2007, and reached 700,000 cells/mL near the dam wall in October 2007. A cyanobacteria bloom of this proportion has never occurred before near the dam wall. The strength of the bloom started to decline in December 2007. The SCA managed this event in accordance with its Bulk Raw Water Quality Incident Response Plan. A comprehensive monitoring and surveillance program was developed in consultation with Sydney Water and NSW Health. The incident management actions were continually reviewed. This effective management meant that treated water continued to meet Australian Drinking Water Guidelines (ADWG), and the consumers in Sydney were not impacted in any way.

More than 120 water samples were tested for toxins, and all but four detected no toxins. On the four occasions where toxins were detected, the toxin levels were well below the guideline values, and immediate re-sampling of the same sites detected no toxins. A molecular technique was used to investigate the potential presence of genes in the cell population that might produce Microcystin toxin. *Microcystis* species detected near the dam wall had a very low fraction of cells with a capacity to produce toxin. A fluorometric probe was trialled as a means to study the distribution of cyanobacteria cells with mixed results. Remote imagery was also analysed to investigate its potential value in the monitoring of a bloom.

To better understand the nature and cause of the bloom and therefore the risk of similar events in the future, the SCA undertook a comprehensive analysis of the available data. Before the event the storage volume in the dam had declined to only 681,000 ML, i.e., 34% of the full capacity. The subsequent inflow event in June 2007 delivered an inflow of approximately 489,000ML over a period of six weeks. Therefore the volume of water delivered represented about 72% of the volume of stored water prior to the event. This inflow raised the water level by approximately 9 metres.

It was concluded that the cyanobacteria event was the result of the unprecedented combination of the following factors; (a) a significant inflow, which entered the storage as an underflow, (b) timing of the inflow during the seasonal cooling cycle between April and July, (c) substantial levels of nutrient loading through catchment contributions and remobilisation from the bed deposits within the storage, (d) efficient transport of the nutrient rich waters to the dam wall, (d) low initial storage volume and high inflow volume to storage volume ratio, and (e) the environmental conditions conducive for a cyanobacteria bloom.

The Warragamba Dam blue-green algae action plan

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A cyanobacteria bloom developed in Warragamba Dam in August 2007, and persisted over three months. This paper outlines the response by the Sydney Catchment Authority (SCA), and other NSW agencies, to the bloom, through the implementation of the Warragamba Dam Blue-green Algae Action Plan (WDBGAAP).

The WDBGAAP was implemented in 2008 as a joint initiative of the Sydney Catchment Authority, Sydney Water Corporation and the NSW Office of Water, Department of Environment, Climate Change and Water. The WDBGAAP was designed to build on the successful management of the 2007 algal bloom by both the SCA and Sydney Water in continuing to supply water that met Australian Drinking Water Guidelines.

The WDBGAAP outlines a comprehensive suite of actions designed to:

- minimise the occurrences of excessive algae events in Warragamba and other SCA storages;
- enhance techniques for predicting algae outbreaks so as to maximise the time available to implement planned operational and other responses;
- implement operational response procedures for managing the supply of water to a standard acceptable to customers;
- implement appropriate treatment processes to mitigate any health or taste and odour risks due to the algae; and
- increase the level of scientific investigation to expand the body of current knowledge of algae production, reservoir behaviour, treatment options and preventative measures.

The actions are focussed on the following elements:

- Operational response
- Catchment management programs
- Reservoir management strategies
- Treatment strategies
- Research
- Monitoring
- Communication and consultation.

The research component of the WDBGAAP encompasses a mix of short and medium term initiatives which are discussed in this paper. These include investigations into the causes of the 2007 bloom, as well as research targeted at better understanding of the environmental influences and their potential management such as; consideration of the potential for seeding of algae from the sediments, the potential for biological control of algal blooms, the conditions under which algal populations may become toxic, the fate and management of toxins and taste & odour compounds in reservoirs and the influence of various environmental conditions on blue-green algae.

The Murray River cyanobacterial bloom in autumn 2009 – monitoring results and implications

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In autumn 2009 a cyanobacterial bloom developed in the Murray River, South Eastern Australia, which extended for about 1000 river kilometers at its peak. Results from the monitoring of this bloom are presented in terms of species composition, biovolumes and toxicity testing. The implications of these results for water supply authorities are discussed.

State report: blue-green algae management in Victoria

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The management of Blue-Green Algae (BGA) across Victoria is a cooperative arrangement undertaken by a number of parties. Victoria has ten regional coordinators who oversee the management of local blooms by the local water mangers in their area and coordinate the response to regional blooms. The Department of Human Services provides advice on health matters relating to BGA and administers the *Safe Drinking Water Act 2003*. The Department of Sustainability and Environment is the state-wide coordinator for blooms. The coordination and management of BGA in Victoria is governed by the BGA framework, which has recently been reviewed. The framework adopts the Emergency Manual Victoria's concepts of preparedness, response and recovery in the management of BGA blooms.

In its role as state-wide coordinator, the Department of Sustainability and Environment has kept a database of blooms since 1992. A number of trends emerging from this data base and other sources on the occurrence of BGA across Victoria will be discussed.

The Victorian response to the 2009 Murray River algal bloom

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Victorian water managers are required by the government to monitor their storages for blue green algae (BGA) and prepare incident response plans to enact when algae levels reach certain (human health) triggers. Goulburn-Murray Water (G-MW) has also been nominated to coordinate BGA preparedness and response across the G-MW region of northern Victoria.

The Murray Region Algal Coordinating Committee (MRACC) is the cross-border body that prepares for and coordinates response to algal blooms along the Murray River, from the headwaters to the confluence with the Murrumbidgee River. The MRACC members include representatives from G-MW, MDBA, and water, health and local government agencies from both NSW and Victoria. The Sunraysia RACC performs a similar role from the Murrumbidgee confluence to the South Australia border.

In early March 2009 Lake Hume developed high levels of BGA, leading to public health warnings to avoid contact with the raw water. A week later high BGA levels were confirmed in Lake Mulwala (Yarrawonga Weir) and a public alert was issued by G-MW on 13 March 2009.

In the following weeks high BGA levels were also detected in the Murray River between Lake Hume and Torrumbarry Weir and later downstream as far as Robinvale (Euston Weir). The initial alert for the Murray River was issued on 26 March 2009 after a teleconference of key MRACC members including GMW.

The alert was extended to Tooleybuc, downstream of Swan Hill, on 6 April 2009.

Blue green algae levels started to decline in late April 2009 and by 15 May 2009 had all fallen below high alert.

The MRACC convened via teleconference and the response included monitoring plans, media communication, signage, town supplies, aerial surveillance and toxin testing.

G-MW coordinated the Victorian response. This included contacting local councils and Parks Victoria to advise them of the need for signage at recreational areas and liaison with urban water authorities.

The main method of communicating with the public was media releases and subsequent media interviews combined with signage advising against contact with and use of the water. Media releases were issued weekly. Information was also available via websites and telephone information services in both states.

No reports of adverse health effects due to the bloom have been received despite the continued use of the river and lakes by many people. The three main species of blue green algae detected can be toxic through contact (skin irritation) and ingestion.

All hands on deck - a review of a BGA response procedure for water treatment plants

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Top priority for North East Water, Victoria, is to provide safe drinking water to our customers. Following the latest Blue-green algal bloom along the Murray River, a revision of our Blue-green algae response procedure was undertaken. It covered our training, plant operations, monitoring, algae testing, toxin testing and partnerships. A discussion on what worked and what did not work, to ensure any lessons learned are implemented ready for next season.

Cyanobacterial blooms in Tasmania

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Over the past few years cyanobacterial blooms in Tasmania have become more prevalent. Whilst the state has suffered drought conditions which may have caused an increase in cyanobacterial blooms, there is also now a higher level of awareness in both the general public and government that cyanobacterial blooms do exist and their potential consequences. This has been highlighted by the increase in monitoring which is now taking place compared to several years ago. Toxic species have been found in Tasmania along with some non-toxic but nuisance causing species.

The main species of concern in Tasmania are *Anabaena*, *Microcystis*, *Aphanothece*, *Cylindrospermum* and *Anabaenopsis*.

Cyanobacteria: their impact on Queensland's water security and aquatic ecosystems

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Blooms of cyanobacteria represent one of the most conspicuous waterborne microbial hazards to human and agricultural water supplies, fisheries production and freshwater and marine ecosystems. This hazard results from the production of harmful cyanotoxins by multiple species, along with BOD and surface water deoxygenation issues associated with seasonally high biomass of micro- and macroalgae and cyanobacteria. This can manifest itself within reservoirs and in downstream receiving water systems during releases, and in estuaries and shallow coastal bays. As the demand on limited water resources grows against a backdrop of increasing climate variability there is an urgent need to quantify water quality security risks. This information is vital for assessing the human and ecological impacts of future water resource management including interbasin transfers and recycled water reuse, and to support the development of regional water supply strategies.

Since 2002 harmful algal blooms (HABs) in Queensland have been managed under a whole of government Harmful Algal Bloom Response Plan which outlines the roles and responsibilites of the various state agencies. The HAB Plan provides a focus for the state's bloom response and assists in addressing the need for ongoing technical capacity to advise and assist local government, water storage operators and the public. Long term data sets from systematic state-wide monitoring programs can now be coupled with climate change scenarios to assess the impact of climate variability on the frequency, duration and magnitude of cyanobacterial blooms. New national water recreation guidelines can also be interpreted against this data to communicate risk-based information to water users. Although considerable progress has been achieved in these areas, the recent identification of cylindrospermopsin and deoxy-cylindrospermopsin production by the benthic cyanobacterium *Lyngbya wollei* from Queensland freshwaters and the occurrence of *Nodularia spumigena* blooms in sub-tropical Queensland highlights that gaps still exist in our knowledge of potential environmental cyanotoxin sources.

Cyanobacteria as blooms in the West

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Western Australia has an extensive history of cyanobacterial blooms manifesting mainly in estuarine waters (*Nodularia* sp) and in freshwater systems associated with these estuaries (*Microcystis*, *Anabaena* and *Anabaenopsis)*. In general these are areas affected by large scale artificial drainage of coastal land and subsequent urban and agricultural development. The best publicised may be the Peel Harvey estuary which underwent total ecosystem collapse and expensive remediation with the Dawesville Cut and in which cyanobacterial and other algal blooms are still annual features in the riverine portions of the estuary. Annual blooms occur in the Vasse Wonnerup and Torbay-Lake Powell systems. Apart from farm dams, local wetlands and urban, and the Harding reservoir in the Pilbara, cyanobacterial blooms in water storages for potable water supply are not a major problem. More recently *Lyngbya* species have made an appearance in coastal and estuarine waters subject to high organic loading. The current status and issues will be outlined.

In managing algal blooms a number of remediation techniques have been trialled; including the development of the Phosphorus binding clay Phoslock™ developed by the CSIRO and the WA Department of Water (DoW), and trials of flocculating clays to settle algae in fresh water. Many of the popularly offered solutions have been evaluated over the years.

Algal blooms including cyanobacteria are addressed through the State Algal Management Strategy which, although not formally funded, promotes a whole of government, joint agency response. The DoW is the lead agency for algal management in natural and recreational waters working with the WA Department of Health (through an MOU) where public health warnings are required.

The DoW through the Water Science Branch maintains the Phytoplankton Ecology Unit which undertakes statewide surveillance of at risk systems and carries out identification of algal samples, with provision of advice on toxicity and management responses.

SA Water's drought monitoring of the River Murray – early detection of potential issues affecting water quality

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As a response to the drought, SA Water has implemented a pre-emptive monitoring strategy for the River Murray through focused surveys along the South Australian reaches of the river. This initiative was implemented in September 2007 and is providing SA Water, as well as key stakeholders, with an immediate on-the-ground assessment, tracking and early warning of potential water quality challenges and risks, in particular focusing on cyanobacterial blooms. It has been designed to complement SA Water's existing routine monitoring program by employing a flexible, responsive approach. While the focus of this project is on the detection and early warning of potential algal blooms, it is also being utilised to investigate other issues likely to affect water quality in the main river channel. Central to the implementation of the project is the deployment of a specialist field team which is able to respond to and assess emerging issues affecting water quality in the river in a timely manner. Key to the success of the field team deployment is the use of *in situ* water quality assessment technology, including state-of-the-art multi-parameter water quality sondes fitted with fluorescence sensors to provide an immediate indication of cyanobacterial biomass and other water quality parameters, as well as rapid field test kits for cyanobacterial toxins. As a further development of the water quality sonde deployment, a fixed installation of a fluorescence sensor linked to wireless telemetry at Lock 1 in the River Murray has been under way for a year and a vertical profiler system including a fluorescence sensor is being trialed in one of SA Water's reservoirs.

Cyanobacterial blooms in Northern Territory inland waters

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The Northern Territory is sparsely populated, with generally low intensities of land use and few point sources of nutrient pollution. The climate in the north is wet/dry tropical, with a predictable seasonal cycle of wet season “floods” followed by dry season “drought” when rivers either cease to flow or are supplied by groundwater. Many rivers feature floodplain billabongs or lakes which become isolated water bodies in the dry season. Apart from small farm dams, there are two large reservoirs in the north. River regulation is generally negligible, though consumptive water use in the Daly River catchment has reduced dry season flow, and hence pool retention times that could provide favourable hydraulic conditions for algal growth.

The climate in the southern part of the Territory is arid and rivers are ephemeral, though there are many perennial water holes. Small farm dams, supplied from groundwater pumped to the surface, are common. The Territory landscape is generally highly weathered with most surface waters having naturally low nutrient concentrations.

The generally low anthropogenic impact on surface waters, both through nutrient enrichment and flow alteration, has not provided conditions that support cyanobacterial blooms. Nutrient concentrations are low below 20 µg/L soluble N and P. There is a history of chlorophyte (*Botryococcus)* blooms in new reservoirs in the north, however cyanobacterial blooms are unknown. Investigations of rare algal blooms in farm dams in arid parts of the Territory have not proved to have been cyanobacteria.

Phytoplankton populations in floodplain billabongs have been assessed for the South Alligator, Mary and Reynolds Rivers floodplains in the north. High cyanobacterial concentrations, or blooms, have been recorded in one billabong. Chlorophyll *a* concentrations approximated 40 µg/L, with *Microcystis* and *Anabaena* the dominant taxa. Despite the seasonal flushing of this billabong, the “bloom” of cyanobacteria occurred annually in the dry season. It is unclear whether the billabong’s cyanobacterial bloom is associated with the adjacent cattle land use or natural.

The seasonal pattern of river flow in the wet/dry tropics provides for annual flushing of rivers and floodplain lakes, which would disperse any cyanobacterial bloom. The dry season, when there may be no or negligible through-flow water bodies, combined with warm water temperatures and thermal stratification, provides physical conditions favourable to cyanobacterial blooms, though such blooms are rare, based on albeit limited data and anecdotal evidence.

Closure of recreational lakes because of toxic cyanobacteria: risk communication, risk perception, enforcement and economic impacts

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Recreational access to some freshwater lakes is on occasion restricted because of the presence of toxigenic cyanobacteria or cyanotoxins. Formal guidelines to direct management decisions regarding lake closure are either lacking, variable across regulatory agencies or open to interpretation, so such responses are often made initially on subjective grounds. Regardless of the processes by which lake closure decisions are made (the "how"), there should also be a contingent requirement to provide information on the reasons for taking such actions (the "why"). Recent recreational lake closures in Canberra and Logan (south-east Queensland) reveal divergent accounts of risk perception, particularly with regard to mass media coverage from the former locale. Recruitment of the Canberra Water Police to enforce the closure of Lake Burley Griffin because of a cyanobacteria bloom is a new development, and contrasts with management approaches elsewhere in Australia.

Closure of a recreational waterbody on public health grounds may be accompanied by significant economic side-effects and inconvenience. Affected individuals and organisations will express their dissatisfaction if there is a perception that lake closures are conducted in an arbitrary and capricious manner, and claims for compensation may be anticipated. Invoking a public health imperative that prevails over economic and aesthetic considerations may not be sufficient to dispel such disquiet.

Effective communication of the health risks that drive decisions to close a recreational waterbody is needed. Cutaneous exposure to cyanobacteria and water-soluble cyanotoxins may provoke hypersensitivity reactions in a small proportion of the population. Irritant skin reactions may be associated with exposure to the *Lyngbya*-spectrum toxins. Cutaneous exposure to these toxins in recreational settings does not pose a risk of systemic intoxication. Inhalational exposure to cyanotoxins in recreational waters is suspected by some cyanobacteriologists to present a risk of acute systemic poisoning, but the available experimental and epidemiological literature arguably does not support this premise. The natural exposure that unequivocally presents a danger of serious morbidity or death is via the oral route. A community outreach program to present the health risks posed by inadvertently swallowing cyanotoxin-contaminated water during recreational activities is recommended. Such a program could also identify hazardous activities, for example forced immersion during horseplay, and sub-populations at particular risk from oral exposure to cyanotoxins in recreational waters, e.g. toddlers and alcohol or drug-affected leisure seekers.

Determining an economic value for reduced incidence of blue green algal events in the Barwon Darling river system

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Water quality in river systems has been of ongoing public concern. In December 1991 the world's largest recorded blue green algal bloom stretched for 1000 km along the Barwon - Darling River system in the Murray Darling Basin in New South Wales.

Following that bloom, a contingent valuation methodology was applied to establish a value that the public would place on improved water quality in the Darling River.

The results confirmed that the public considered both pollution in general and river pollution in particular to be major environmental issues.

This study supported the application of 'willingness to pay' methodology as a significant input to allocating physical and financial resources for major environmental issues facing governments and policy makers.

A review of some methods to manage cyanobacterial blooms in drinking water reservoirs

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Cyanobacterial blooms in drinking water reservoirs are a worldwide problem, causing aesthetic issues from releases of taste and odours and potential health problems from releases of toxins. Human induced climate change effects such as warmer weather, increased nutrient inflows and increased carbon dioxide levels are likely to make this issue worse in future decades.

With my mind fresh from a major literature review of algal control methods I will review some of the ways in which these blooms have been managed around the world, including methods such as copper sulphate dosing, selective withdrawal, water level draw down and destratification. For each method I will discuss principles, costs and benefits. I will also briefly review the potential of more speculative methods for algal control such as ultrasound, barley straw and mixing of the surface water zone.

Preliminary results of investigations into *in-situ* fluorometry and biovolume as management tools

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With time delays due to sampling, transport and laboratory analysis, obtaining up-to-date cyanobacterial data from rivers and reservoirs in western NSW is sometimes a problem when managing blooms. *In-situ* fluorometry is being evaluated as a means of obtaining data on cyanobacterial presence more rapidly.

A YSI water quality sonde incorporating probes for chlorophyll-a and phycocyanin fluorescence was evaluated along the Murray and lower Darling Rivers in NSW between November 2008 and May 2009. 26 sites were monitored on an approximately weekly basis for 20 weeks. Phycocyanin fluorescence was evaluated against total cyanobacterial biovolume calculated from laboratory identification, cell counts and cell size measurements.

Preliminary results are presented. Raw data shows a skewed distribution of data points towards the lower end of the scale, although some mid-range data were obtained during the Murray River bloom of April 2009. There is considerable scatter of data points especially at the lower end of the scale, and interference from suspended solids was also noted at the more turbid sites, causing a high phycocyanin fluorescence recording even when total cyanobacterial presence was negligible. A general trend of increasing phycocyanin fluorescence with increasing total cyanobacterial biovolume is however apparent.

Analysis of the data on a site by site basis (rather than all data pooled), after log transformation, also reveals this trend at most sites. It may be possible to combine data from a number of adjacent sites along certain sections of the river (eg Albury to Corowa; Barham to Tooleybuc) to obtain a conversion factor to convert phycocyanin fluorescence to an estimate of total cyanobacterial biovolume for these parts of the river. However a single conversion factor for the entire river is probably not possible.

One spin-off from the fluorometry project was that cellular biovolumes for certain taxa of cyanobacteria were noted to vary considerably throughout the course of the study. This variation appeared to be temporal rather than spatial, with cell size decreasing in autumn compared to late spring. Causes could include poor taxonomic resolution (i.e. different species being called the same thing), phenotypic plasticity within one species, and environmental factors influencing the cell size of various species. Further investigations are continuing.

Techniques for *in situ* measurements using fluorometry

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The measurement of algae levels by cell counting or conventional wet laboratory techniques tends to be slow and expensive. As a result there has been a lot of effort to develop techniques such as fluorometry using multiwavelength excitation to enable rapid, onsite or in line measurement of total algae levels, and to discriminate between toxic and other species.

The presentation will describe some of the theory and experimental development behind the use of fluorescence techniques to discriminate algal classes, and an insight into the latest developments to try and quantify toxin release by measuring cell free phycocyanin as an indicator.

After investigating the fluorescence properties of cyanobacteria it is postulated that there is a considerable amount of free phycocyanin (the dominant pigment beside chlorophyll). Free phycocyanin is not bound energetically to chlorophyll and seems to leave the cell in a similar manner to the release of cyanobacterial toxins. Therefore it could serve as an early warning system for toxic effects in a water supply. This is important information e.g. for water treatment plants because extensive treatment (e.g. carbon) needs to be applied to remove them.

Quantitative remote sensing for detection and monitoring of cyanobacterial blooms

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Regular monitoring of water bodies is necessary to have timely warnings of cyanobacterial blooms. Whilst conventional *in situ* sampling is useful, remote sensing approaches have the potential to provide both spatial and temporal coverage of inland and coastal water quality parameters. Quantifying cyanobacterial concentrations and perhaps identifying key species is only feasible using robust physically driven analytical algorithms. Whilst the presence of phytoplankton is detected via pigment absorption features (i.e. chlorophyll *a*), cyanobacterial dominated waters can also be identified by the effects of phycoerythrin and phycocyanin pigments absorbing in the specific wavelength regions of 565 nm and 624 nm where optical remote sensors have their highest sensitivity (Dekker et al. 1991, Simis, 2008).

Knowledge of the underlying optical properties of the key parameters driving optical water quality is required to both develop and apply analytical algorithms for the detection of cyanobacterial blooms. To identify the current status of the proposed method and determine research priorities, this paper outlines the relevant optical water quality parameters, and their influence on optical properties, with particular focus on cyanobacteria dominated systems. A review of the current algorithms for remote detection of blooms will be presented, drawing on examples from Dutch lakes and earlier Australian studies over Lake Mokoan and Hawkesbury River. Examples will highlight the application of airborne sensing techniques as a precursor to using high spectral and spatial resolution earth observing satellites. Recent developments in research in Europe will also be highlighted (e.g. the EU funded RECONCYLE project).

Monitoring and management of cyanobacterial blooms in estuarine and coastal waters: an earth observation based data assimilation approach

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For adaptive management of estuarine and coastal ecosystems, knowledge about the transformation and transportation of biogeochemical components, including nutrient loads and phytoplankton biomass is critical. This is motivated by the need to monitor the response of an ecosystem due to changes induced both by natural and anthropogenic influences, to be able to predict harmful algal blooms and to preserve the biogeochemical status of the ecosystem. Environmental models that are capable of representing estuarine and coastal ocean circulation, sediment transport and biogeochemical processes now exist. However, such environmental models will always be simplified representations of natural processes.

Observations contain important information about the true state of the system under investigation. Advancement in spaceborne optical remote sensing technology has provided a unique source of high resolution spectral observations. Data from optical remote sensing has suitable spectral, spatial and temporal resolution to investigate estuarine and coastal processes. The objective of estimation of the true state of the aquatic system is best achieved following an assimilation based approach which optimally extracts and merges information contained in the dynamic model and in the high resolution remote sensing based observations. In this presentation we discuss the potential of earth observation data in improving the predictive capability of aquatic environmental models.

Impact of iron species transformations on growth and toxicity of cyanobacterial *Microcystis* species

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It has been purported that the growth and toxicity of some cyanobacterial species is influenced by the bioavailability of the trace nutrient iron. Previous work supporting this proposal is reviewed and new evidence based on batch culture studies with toxic and non-toxic strains of *Microcystis aeruginosa* is presented which provides insight into the role of iron in growth and toxin production by this organism. Results show that the presence of natural organic matter (NOM) and light has a dramatic influence on iron bioavailability and kinetics of iron uptake by *Microcystis aeruginosa*. The implications of the effect of NOM and light on both iron and phosphorus supply to cyanobacterial growth (and potentially toxicity) will be examined in this presentation.

Downstream fate of cyanobacteria and other phytoplankton following discharge from a dam

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The population densities (cells ml^{-1}) of cyanobacteria and other phytoplankton were investigated at multiple sites in the Cudgegong River downstream of the Windamere Reservoir, NSW. The study aimed to investigate the spatial variation in phytoplankton cell densities following discharge from the dam. Approximate travel times of water were estimated and phytoplankton samples of the same water masses were collected at five fixed sites covering a longitudinal distance of 25 km in a downstream direction. This was achieved by adjusting sampling times. The cell densities of cyanobacteria and other populations decreased exponentially with respect to the distance downstream in this high-land river. Comparison of results with data from other rivers downstream of major reservoirs suggest that the patterns of longitudinal population dissipations following discharge differ between high- and low-land rivers.

Assessment of rapid assays for cyanotoxins

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The initial driver for this project was the fact that current analytical methods for saxitoxins (aka Paralytic Shellfish Poisons or PSPs) are too slow to be operationally useful because it can take up to 5 days to get a confirmed result. Rapid (few minutes to hours) field-based and laboratory-based tests are commercially available for detection of these toxins in shellfish, and so it was proposed that they be tested for their usefulness for detecting these toxins when produced by cyanobacteria in our drinking source waters. This might then provide forewarning to operational staff that a bloom is toxic, and so preparations can be made while waiting for the analytical results. During the project new rapid tests also became available for microcystin and cylindrospermopsin, so these were included in the assessment.

It is known that this type of assay can be subject to matrix affects and that they do not detect all the different structural variants or analogues of a particular toxin that have been reported worldwide (the manufacturers make this clear in their product information), and so the aim of this study was to assess the reliability and accurancy of the assays for detection of the particular toxin analogues known to occur in Australia when spiked into various Murray River waters.

Results will be presented and recommendations made for how they might be usefully included in our arsenal of assays.

Multiplex quantitative-PCR determination of toxic cyanobacteria in environmental samples

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Cyanobacterial blooms in water bodies are potentially health hazardous due to their production of toxins. Major cyanotoxins detected in water bodies are hepatotoxins and neurotoxins. A sensitive method is needed to reliably detect toxic cyanobacterial species that are potentially responsible for these cyanotoxins. Multiplex quantitative-PCR was developed based on design of novel oligonucleotide primers and fluorescent TaqMan probes. The primers and TaqMan probes were designed from conserved regions within specific toxins genes in strains that were selected as representatives of the global population of toxic cyanobacteria. The method determines major cyanotoxins in environment and lab culture samples based on the copy number of saxitoxin, microcystin, nodularin, cylindrospermopsin genes in single tube. This is the first time these cyanotoxins genes have been amplified in multiplex quantitative-PCR from globally isolated cyanobacterial strains. Additionally this method is able to infer potential toxigenicity of the samples. Following optimisation on isolated cyanobacterial strains the multiplex qPCR method was applied to water samples collected from different positions along 800 km of Australian Murray River. Concentration of cyanotoxins correlated positively with individual cyanotoxin gene copy numbers, indicating that the latter can be used as a measure of potential toxigenicity in cyanobacterial blooms.

Identification, detection and characterisation of cyanobacteria using traditional and DNA-based methods

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Queensland Health Forensic and Scientific Services (FSS) have a long and successful history of identification, enumeration and characterisation of cyanobacteria using traditional methodologies such as microscopy for enumeration, and LC/MS and HPLC for toxin analysis/quantitation. Since the focus of the organisation is public health, our aim is to assist water storage body managers and public health officials in decision-making with respect to management of potentially toxic cyanobacteria and algal blooms, through the dissemination of analytical data and the provision of information and advice.

The main organisms of concern in Queensland water storages are *Cylindrospermopsis raciborskii* and *Aphanizomenon ovalisporum,* both of which produce the cyanotoxin cylindrospermopsin (CYN); *Microcystis aeruginosa* which produces microcystins (mainly MCLR); and to a lesser extent, *Anabaena circinalis* which produces saxitoxins (STX). Additionally, the nodularin (NOD)-producing cyanobacteria *Nodularia spumigena* has recently emerged as a minor problem in brackish recreational lakes in southeast Queensland.

In the past few years, alternative methods have been sought to augment and improve our ability to identify cyanobacteria and to differentiate between toxic and non-toxic strains of cyanobacteria as taxonomic features are not always definitive. DNA-based methods have been shown to assist in both the identification of cyanobacteria and in characterisation of the biosynthetic pathways that lead to toxin production. In 2007, a Culture Facility was commissioned by the Phycology Unit at FSS with the aim of developing and maintaining a reference collection of cyanobacteria for taxonomic purposes and for the development of DNA-based methodology.

Polymerase chain reaction (PCR) assays (targeted to genes in the biochemical pathways that lead to toxin analysis) have been used successfully at FSS to detect cyanobacteria that produce the cyanotoxins CYN, STX, MCLR and NOD. Real time PCR (RT-PCR) technology has been applied to water samples also to detect as little as a single cyanobacterial cell that contains the target gene. RT-PCR has so far been applied to the detection of CYN- and microcystin-biosynthesis genes with the aim of extending this technology to detect cyanobacteria that produce SXT. Therefore, FSS has the capability to confirm the presence of potentially toxin-producing cyanobacteria in water samples, alerting water managers to the risk of toxin production in the event of a bloom.

Toxins that may not be readily detected by traditional methods

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Cyanobacterial identification and enumeration are the traditional methods of assessing risks associated with toxin-producing cyanobacteria. More recently, primary risk assessment has been enhanced by the use of a combination of chemical, morphological and genetic techniques. However, detailed testing in an Australian Coal Industry Research Programme funded collaborative study between AWQC and CQU also incorporating toxin screens has detected toxin in the absence of cells of known toxin producing species.

Testing of samples found that up to 70 µg L^{-1} of microcystin could be present in the absence of cells. In the same project, initial studies of water samples used by industry in the Central Queensland region demonstrated the presence of cylindrospermopsin in the absence of species known to produce this toxin. The difficulty in associating specific cell concentrations with toxin concentrations and relative human health risk is evident from the data. Whereas a general approximation of 10,000 cells mL^{-1} of *Cylindrospermopsis* were present in samples containing 1 µg L^{-1} of CYN plus deoxy-CYN, this concentration of toxin was also recorded in relation to individual cell counts as low as 835 cells mL^{-1} or zero. Possible explanations considered were: (i) destruction of cells as a result of pipeline transport of water, (ii) stratification and separation of toxin and cells within the water column resulting in withdrawal from depths where toxin only is present and (iii) presence of new cylindrospermopsin producers.

The latter hypothesis was investigated and further genetic testing showed the presence of various morphotypes of *Aphanizomenon/Anabaena* associated with the production of cylindrospermopsin. Fine filamentous algae associated with a novel toxic response were also detected.

Zeta potential: a tool for the successful control of coagulation and removal of *Microcystis aeruginosa* in water treatment plants

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Microcystis aeruginosa blooms in surface water utilised for the production of drinking water represent a significant challenge for plant operators, who are required to ensure removal of these cyanobacteria while meeting the Australian Drinking Water Quality Guidelines. Successful coagulation is a key component in ensuring cell removal in conventional treatment systems. Poor coagulation results in carry over of cells, dissolved organic matter, and chemical coagulant to downstream treatment processes. Conventionally, coagulation is optimised by jar tests which are undertaken in the lab as required. However, rapid changes in cyanobacteria concentrations, pH and the character of the associated algogenic organic matter make it difficult to successfully administer the correct coagulant dose and a more efficient coagulation control protocol is required.

Coagulation control using zeta potential has previously been demonstrated to be effective for natural organic matter and kaolin. Zeta potential (ζ), also termed the electrokinetic potential, is a measure of the potential difference between the fluid that remains associated with the surface of a colloid or particle and the surrounding solution. This study demonstrates how zeta potential monitoring is a useful tool for controlling the coagulation of cyanobacteria, such as *Microcystis aeruginosa*, and indeed many algae species. Zeta potential analysis is currently conducted via an off-line technique that takes approximately ~1 minute per sample. There is the potential to make this an on-line technique and thus process control using zeta potential is a viable tool for controlling cyanobacteria removal.

Microcystis aeruginosa blooms in wastewater: managing microfiltration performance

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Microcystis aeruginosa is a frequent cause of periodic blooms in Australian wastewater treatment plants. Such blooms can impact severely on the performance of microfiltration (MF) and ultrafiltration units upstream of reverse osmosis (RO) units used for the desalination of secondary effluent. The effect of the algal organic matter may be due to the algal cells, extracellular organic matter or intracellular organic matter.

The EOM of *M. aeruginosa* forms a thick mucilaginous layered structure surrounding the cell. The EOM can cement algal cells and particles of natural organic matter from the treated effluent on the filtration membrane surface causing an increase in resistance to filtration. Furthermore, as the bloom collapses it releases intracellular organic matter and toxins to the surrounding water. This phenomenon further impacts on the fouling of the MF membrane and the filtration efficiency.

Minimisation of the impact of algae by effective pre-treatment is the initial line of defence in controlling membrane fouling and assuring successful RO operation. In this study we investigated the impact of *M. aeruginosa* at various stages of its life cycle on MF performance. The alga was grown in treated effluent from a municipal biological sewage treatment plant and sampled in different phases of the life cycle. MF performance and the efficacy of pre-treatment with alum and aluminium chlorohydrate for mitigation of fouling was determined for each phase. Membrane performance was examined in terms of flux profiles, permeate volume collected, removal of algogenic and effluent organic matter, and the reduction of irreversible fouling.

The relationship between algal concentration and alum dosage required for effective membrane cleaning by hydraulic means was investigated. The results were backed up by ESEM images of the membrane surface after cleaning. Residual aluminium concentration in the permeate was also measured.

Biological degradation of cyanobacterial toxins

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The prevalence of cyanobacteria in drinking water supplies is a concern for water authorities as these organisms can cause numerous problems. Of major concern are the secondary metabolites they produce, in particular, cyanobacterial toxins (cyanotoxins) which have the potential to severely compromise human health. With climate change and drought having a profound impact on Australian water resources, it is evident that such conditions are favourable for the increased proliferation of cyanobacteria which, in turn, increases the risks of cyanotoxins contaminating drinking water supplies.

Effective management options to control cyanobacterial blooms in drinking water sources are paramount; however, it is becoming increasingly important to adopt risk-based approaches to ensure that there are multiple barriers in the entire water cycle to guarantee that these organisms and the cyanotoxins they produce do not reach the customer tap. Within water treatment plants (WTPs), there exist some barriers which can be optimised to disrupt the safe passage of the cyanotoxins. In most Australian WTPs, the major barriers for the removal of cyanotoxins are the addition of powdered activated carbon and chlorination. However, these processes are not entirely efficient due to the presence of natural organic matter (NOM). NOM can compete with cyanotoxins for adsorption sites on the activated carbon surface, reducing adsorption; NOM can also impart a chlorine demand, rendering chlorine to be ineffective for the oxidation of cyanotoxins.

In recent times, biological degradation processes have been shown to be a potential treatment option for the removal of cyanotoxins. Biological processes are advantageous as they are natural, require little infrastructure and capital costs and are potentially attractive options in regional or rural communities where technology may not be as advanced. Recently completed research projects, undertaken through the Cooperative Research Centre for Water Quality & Treatment, were focussed on the biological degradation of cyanobacterial metabolites. The key findings from these research projects will be presented at this forum; in particular, biological processes which were implemented to effectively degrade the cyanotoxins, cylindrospermopsin and microcystin. Advancements in genetic technologies allowed for the identification and characterisation of microcystin-degrading bacteria and the associated genes responsible for its degradation within biologically-active WTP sand filters. If biological filtration can be optimised for the removal of cyanotoxins, then this will result in an additional treatment barrier, which aligns with the multi-barrier approach within the “Framework for the Management of Drinking Water Quality” under the Australian Drinking Water Guidelines. Moreover, as most WTPs employ filtration of some kind, the costs for this treatment technology are substantially lower compared with more advanced treatment options.

Biofiltration of cyanobacterial metabolites MIB and geosmin as a viable water treatment option

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MIB and geosmin are cyanobacterial metabolites that impart an earthy/musty taste and odour on drinking water at levels as low as 2-4 ng/L. These compounds are of particular concern to the water industry due to their recalcitrance to conventional water treatment, and require more advanced treatment options for their removal from source waters. Biofiltration of MIB and geosmin, using biologically active sand filters, has been demonstrated as an alternative barrier for the treatment of the taste and odour compounds. This process is favoured by water utilities because the process is generally low technology, requires little maintenance and often has already established infrastructure. However, much work is still required to understand and fully optimise the biofiltration processes for MIB and geosmin.

This short presentation will provide an overview of the research that has recently been conducted at the Australian Water Quality Centre (SA Water) in regard to the biofiltration of the cyanobacterial metabolites MIB and geosmin.

Work that will be presented includes:

- Data regarding the biofiltration of MIB and geosmin through extensive laboratory scale sand filters and degradation in batch experiments. Such experiments have revealed that the processes occur via a pseudo-first-order degradation mechanism and that the rate of biofiltration increases following re-exposure of the biofilm to the taste and odour compounds

- The isolation of biofilm associated bacteria that can degrade geosmin. These include a single species of *Sphingopyxis* which has been shown to degrade geosmin individually, and a consortium *Sphingopyxis*, *Sphingomonas* and *Pseudomonas* that degrade geosmin via a cooperative mechanism.

- Enhancing the biofiltration process by artificially seeding geosmin-degrading bacteria onto laboratory scale sand filters, where removal of the cyanobacterial metabolite was shown to be increased by approximately 40% following the process.

- A full scale study of the Morgan WTP in South Australia, where the inadvertent backwashing of the biologically active sand filters with monochloramine resulted in the inactivation of the biofilm and the subsequent breakthrough of geosmin. However, following cessation of the backwashing the biofilm re-established and the biofiltration of geosmin recommenced

Isolation and characterisation of the gene associated with geosmin production in cyanobacteria

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The biosynthetic mystery of geosmin production has continued to trouble researchers for many years. Several pathways have been postulated, but only recently has the puzzle been solved in the model organism *Streptomyces coelicolor* A3(2). The conversion of the sesquiterpene precursor farnesyl diphosphate (FPP) to geosmin is catalysed by a single bi-functional enzyme (SCO6073), a germacradienol-geosmin synthase, thus dispelling earlier assumptions that several enzymes were needed in somewhat complex pathways.

We have investigated the model cyanobacterium *Nostoc punctiforme* ATCC 29133, a known geosmin producer, for an enzyme similar to SCO6073. Using bioinformatics, a partial similarity to SCO6073 was found within the *Nostoc punctiforme* deposited genome sequence and investigated. The reported gene *npun020003620* was cloned into a protein expression vector, the protein purified, and functional enzymatic assays performed. *npun020003620* did not have geosmin synthase activity, but did possess germacradienol synthase activity.

Following close scrutiny of the *Nostoc* genome sequence, a vital sequencing error was subsequently discovered in the deposited *Nostoc* sequence. This hypothesized sequencing error, which resulted in an erroneous stop codon and subsequent truncation of the gene and repressed activity of the protein, was confirmed by additional DNA sequencing. Using the modified gene and resultant protein product, geosmin synthase activity was confirmed in this organism, and homologous genes were also found in several other cyanobacteria, thus dispelling earlier hypotheses that geosmin synthase activity may be different in different organisms. The detection of geosmin synthase genes in cyanobacterial isolates or natural waters may become a valuable addition to the current “toolbox” for managing taste and odour episodes.

Revision of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000* and the *Australian Guidelines for Water Quality Monitoring and Reporting 2000*

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The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000a), and the *Australian Guidelines for Water Quality Monitoring and Reporting 2000* (ANZECC and ARMCANZ 2000b), are key source documents for managing water quality and protecting aquatic ecosystems in both Australia and New Zealand. These Guidelines form part of the National Water Quality Management Strategy (NWQMS) (http://environment.gov.au/water/policy-programs/nwqms/index.html). Individual Guideline documents (http://environment.gov.au/water/publications/quality/index.html), and the Strategy as a whole, are jointly endorsed by the Environment Protection and Heritage Ministerial Council (EPHC), the Natural Resource Management Ministerial Council (NRMMC), and / or the National Health and Medical Research Council (NHMRC). The National Water Quality Management Strategy aims to achieve sustainable use of water resources by protecting and enhancing their quality while maintaining the economic and social development of Australian and New Zealand communities.

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000*, and the *Australian Guidelines for Water Quality Monitoring and Reporting 2000*, employed in conjunction with the with the *Australian Drinking Water Guidelines 2004* (NHRMC and NRMMC 2004) and the *Guidelines for Managing Risks in Recreational Water* (NHMRC 2005), form the national "benchmark" Guidelines for the management, monitoring and reporting of Blue-Green and other algal blooms in fresh, coastal, and marine waters.

The NHMRC's Water Quality Advisory Committee is currently reviewing elements of the *Australian Drinking Water Guidelines 2004*. Complementing this, the EPHC, NRMMC, and NHMRC have initiated a joint review of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000* and the *Australian Guidelines for Water Quality Monitoring and Reporting 2000*. While only in the initial stages of project implementation, this Guideline revision work is likely to have implications for the way Blue-Green Algae and associated toxins are monitored and reported into the future, and is likely to be align with more closely with other NWQMS documents such as the NHMRC's *Guidelines for Managing Risks in Recreational Water*.

For more information on the revision and approval process, contact Bruce Gray from the Australian Government Department of the Environment, Water, Heritage and the Arts (bruce.gray@environment.gov.au), Amanda Hunt from the New Zealand Government Ministry for the Environment (amanda.hunt@mfe.govt.nz), or Heather Bishop from the National Health and Medical Research Council (heather.bishop@nhmrc.gov.au).

The development of practical guidance manuals for the management of cyanobacteria

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For over thirty years many papers, reports and fact sheets have been published on various aspects of cyanobacteria and their management. Several years ago a research project was developed through the CRC for Water Quality and Treatment to consolidate that wealth of knowledge into a practical, user-friendly manual that could be used by Australian water quality managers and operators to help manage cyanobacteria blooms in source waters and the consequent tastes and odours and toxins in the treatment plant. During the following years manuals with similar aims were developed in South Africa and Europe. In 2007 a workshop was held in South Africa, funded by the Global Water Research Coalition and attended by those responsible for the development of the three regional manuals, with the aim of developing an international guidance manual incorporating the most important aspects of the three manuals to enable its application worldwide. This international manual was to be constructed on three levels:

Level 1 was to be aimed at the novice in the area, giving an overview of the problem, issues associated with cyanobacteria, and management strategies in general terms

Level 2 would give more detail in terms of specific management strategies, for example, copper sulphate or powdered activated carbon doses

Level 3 was to offer readers a series of case studies to illustrate the effective application of the strategies.

This paper will describe the content of the manuals, the philosophy behind their development and the anticipated outcomes of their implementation.

Risk and regulation in environmental toxicology, application to cyanobacterial toxins

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Led by the World Health Organisation, the human health risks from environmental contaminants are assessed and guidelines determined for safe levels of ingestion. One example is the Guidelines for Drinking Water Quality, which are used by national authorities, often revised, and incorporated into health legislation. Toxic contaminants, which are potentially present in drinking water, include cyanobacterial toxins. The health risks posed by these toxins have been assessed, and in many countries Guideline Values adopted. Acute toxicity from highly contaminated water, and adverse health from continued exposure, are both possible.

Drinking water utilities have the responsibility for supplying safe water to consumers, and this may be enforced by legislation. There is often a ‘grey’ area between the Guidelines and the quality of water supply. The utility may not measure the contaminant at all, whether it is a cyanobacterial toxin or a pesticide, so a harmful event may not be reported. Utilities may not take action until a contaminant exceeds the Guideline by ten-fold, and then undertake remediation. Public reporting may be annual, so an adverse event is well past before the news appears.

Recreational guidelines are even more problematic; no local authority wants to close a recreational water in mid-summer when blooms occur, and water users do not want to give up holiday fun just because the water is green! The outcomes vary, but risks are taken, especially in sports like water skiing and swimming, which result in swallowing or inhalation.

Poster - Cyanobacterial Bloom Monitoring in New South Wales

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The Office of Water, Department of Environment, Climate Change and Water (and its predecessors) have been instrumental in the ongoing management of blue-green algal blooms in New South Wales (NSW) since the early nineties. The basis of the model of algal risk management has been the nine Regional Algal Coordinating Committees (RACC). Each RACC includes representatives from local government, state government agencies, water management authorities and local authorities who manage blue-green algal blooms and/or their impacts. RACCs provide a coordinated, whole of government approach to algal management, aiming to minimise impacts and provide adequate warnings and advice to the public. Strategic direction and technical advice for regional implementation is via a State Algal Advisory Group and technical groups.

RACCs in conjunction with State Water Corporation, local government and water authorities, maintain an extensive blue-green algae and water quality monitoring network across NSW. Sampling frequency is monthly in winter, increasing to fortnightly in summer if no blooms are detected. Upon detection of a bloom, sampling may increase to weekly or even bi-weekly, depending on the water body and public risk.

The continuing drought across most of NSW provided ideal conditions for algal growth in 2008-2009. Results show numerous large storages were on Red Alert for recreational use for more than half of 2008-2009, including Malpas Reservoir (Armidale), Pindari Reservoir (Ashford/Inverell), Copeton Reservoir (Inverell) and Windamere Reservoir (Mudgee). The detection of a bloom in the Murray River became the focal point in March 2009, with some 800 kilometres of the Murray River from Hume Dam to Tooleybuc and other local river systems being placed on Red Alert.

In NSW, blooms are usually of mixed taxa, with many small non toxic species. Algal data are assessed against guidelines that vary depending on the water's use (i.e. drinking water, livestock watering and recreational use). Algal alert levels for recreational use are based on the biovolume guidelines from the National Health and Medical Research Council (2005), rather than cell counts.

Management actions when recreational guidelines are exceeded include enacting warning communication strategies for affected stakeholders such as issuing media releases to warn water users, erecting warning signs at affected water bodies, updating algal information line phone numbers and web site information and continued monitoring. For potable supplies management is largely focussed on water treatment, or switching to alternative supplies. Some smaller town supplies, may resort to algaecides. Artificial destratification has shown mixed results in reducing blooms, especially in large storages, and can prove expensive.

The majority of nutrients in the river systems originate from diffuse sources. Catchment Management Authority (CMA) and landholder activities such as establishing riparian buffer strips, limiting stock access and maintaining groundcover provide simple and effective means to reduce nutrient input, however significant reduction is unlikely in the short term. Environmental water releases are available in some catchments to suppress or flush algal blooms, although, these have not historically been enacted. In some areas (e.g. Murray and Paterson Rivers) dam storage releases in summer can contribute to algal bloom transmission in the main river. The recent blue-green algal bloom in the Murray River highlighted the strength and resilience of algal bloom management in NSW, with DWE able to mobilise resources to monitor and co-ordinate a response with other states and agencies.

Poster - River Murray 800km Algal Bloom – March/April 2009

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At the beginning of 2007, the predictions for River Murray low flows into South Australia were concerning. The potential water quality issues from these low flows included elevated cyanobacterial blooms, contaminant release from benthic sediments and wetland discharges into the main river channel. SA Water in conjunction with the Murray Darling Basin Commission (now Authority), undertook a pilot project to investigate the use of high resolution aerial photography for the early detection of particular water quality issues. During this project, and subsequent implementation of this tool into the routine monitoring program, numerous issues were identified in both the main channel of the River Murray, and also the tributaries and wetlands. The aerial imagery enabled improved management of these water quality issues and have helped establish a benchmark in River Murray and associated river Management with regard to high quality imagery and turnaround.

Just prior to Easter 2009, it was reported that the River Murray from Hume Dam downstream had an 800km Algal Bloom. The bloom was the end result of a combination of factors such as low flows, low storage level (Hume Dam), high temperatures and generally poor water quality with high nutrient load. Past history suggested that low storage levels during this period have led to seeding downstream. Such a long bloom down the Murray was a serious public health and environmental issue. It was decided to initially fly the river from Hume Dam in the Upper Murray to Swan Hill including the Edwards River on the 28-29th March to access the extent of the bloom. A follow up flight on April 9th and 13th enabled management to determine the true extent of the bloom with regard to travel time downstream. Based on the data, the Murray RACC was able to issue regular media releases and briefings to the Minister. Public health warnings and regular updated information was important considering the large amount of people camping and using the river over the Easter holidays.

The poster documents the timeline for surveillance flights, lessons learnt and samples of imagery taken during this algal bloom event.