Global Water Research Coalition

Management Strategies for Algal Toxins

Report of the GWRC Research Strategy Workshop

IWA affiliate

Global Water
Research Coalition

Management Strategies for Algal Toxins in Water

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Global Water Research Coalition: Global cooperation for the generation of water knowledge

GWRC is a non-profit organization that serves as the collaborative mechanism for water research. The product the GWRC offers its members is water research information and knowledge. The Coalition will focus on water supply and wastewater issues and renewable water resources: the urban water cycle.

The founder members of the GWRC are: the Awwa Research Foundation (US), CRC Water Quality and Treatment (Australia), Kiwa (Netherlands), Sues Environment- CIRSEE (France), Stowa - Foundation for Applied Water Research (Netherlands), DVGW – TZW Water Technology Center (Germany), UK Water Industry Research (UK), Veolia- Anjou Recherché (France), Water Environment Research Foundation (US), Water Research Commission (South Africa), WaterReuse Foundation and the Water Services Association of Australia.

These organizations are all in charge of a national research program addressing the different parts of the water cycle. They have provided the impetus, credibility, and initial funding for the GWRC. Each brings a unique set of skills and knowledge to the Coalition. Through its member organisations GWRC represents the interests and needs of 500 million consumers.

The Global Water Research Coalition is affiliated with the International Water Association (IWA). The GWRC was officially formed in April 2002 with the signing of the partnership agreement at the International Water Association 3rd World Water Congress in Melbourne. With the US Environmental Protection Agency a partnership agreement was signed in July 2003.

Management Strategies for Algal Toxins in Water

Report of the GWRC Research Strategy Workshop

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Disclaimer

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Preface

The issue of Management Strategies for Algal Toxins in Water is part of the research agenda of most of the members of the Global Water Research Coalition (GWRC). It is on the priority list of GWRC.

The board of the GWRC decided in 2003 to start a project with the aim to review the present knowledge of Management Strategies for Algal Toxins in Water and to organise a workshop to develop a phased research strategy. This project was carried out by CRC for Water Quality and Treatment who also prepared the State of the Science review and hosted the workshop. GWRC members contributed to the project by providing expert knowledge about this issue.

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Executive Summary

Toxic algae have been reported in twenty-seven countries and are found on all continents, including Antarctica. Toxic algae are recognised as a significant water quality problem and a hazard in regard to their potential to contaminate water intended for a range of beneficial uses, including drinking water, recreational activity and agriculture purposes. Cyanobacteria produce a range of toxins and odour compounds which have a deleterious effect upon drinking water quality. To effectively deal with the problems posed by cyanobacteria water authorities require an integrated approach of risk management, monitoring and water treatment.

The issue of toxic algae is one of the priority areas of the GWRC. A project was instigated with the aim to review and exchange the present knowledge on the management of toxic algae and to develop a research strategy for further collaborative activities. GWRC member organisations are involved in three major initiatives for toxic algae research that are underway internationally at the present time. Coordination of these ongoing activities was also one of the objectives of the project. CRC WQT was the lead agent of the project and prepared a comprehensive literature survey on the subject in which the current knowledge on management of toxic algae was consolidated. AwwaRF, Anjou Recherche, STOWA, TZW, WRC-SA and WSAA participated in the research planning workshop. Supporting information was received from US EPA and WHO. The feedback from the participants of the workshop was very positive with all acknowledging the organisation, content and benefits of the workshop.

Research strategy

Within an overall framework of a risk assessment and risk management evaluation of the issue of the toxic algae and water supply, the participants of the workshop discussed and prioritised the identified gaps of knowledge and research needs. Each organisation specified their interest to support the different actions and research projects to address the priority issues and three topics were selected to be of major priority. Sub-groups of interested organisations developed the first draft of the specific research proposals which were further elaborated by the participants of the workshop.

As major gap of knowledge, the limited availability of sound and comprehensive ***toxicological and epidemiological data to develop guidelines*** for toxic algae in water and water supply was identified. With support of all participating organisations it was decided to devise a research project on one of the missing pieces: short-term exposure to algal toxins. Although the information on the impact of algal toxins is limited, the issue is beyond the primary scope of the GWRC – the urban water cycle – and therefore no further initiatives were formulated.

In contrast to the above the available information on ***source water management and water treatment*** is overwhelming. But this valuable knowledge and know-how is not readily accessible and for that reason the consolidation of this information in a ***guidance manual*** is proposed.

With reference to the possible environment impact of chemical means to control algal toxins formation, the urgency to explore non-chemical means for control was expressed as a priority topic by the participants.

Although reliable off-line analytical methods for the identification and quantification of algal toxins are available, the absence of on-line monitoring methods was identified as issue of concern. ***On-line monitoring methods*** would be of great support to evaluate and control water quality in a more efficient, less time-consuming and cheaper way. With the recent and promising technological development, this issue was selected as a priority topic to consider.

Proposed projects and actions

As follow up of the workshop three projects were proposed to address the identified priority gaps of knowledge and research needs. The projects are summarized below and the lead agents are indicated in brackets. More information is given in Appendix 4.

Proposal 1 Toxicological studies for guideline formulation for short-term exposures to cylindrospermopsin and microcystins. Evaluation of reproductive toxicity of cylindrospermopsin. (CRC WQT)

Well-defined guidelines assure appropriate treatment and monitoring expenditure. Cyanobacterial blooms have an impact on economic activity associated with affected water-bodies. Recreational guidelines define when there is, or is not, a real threat to public health.

There is an urgent requirement for studies into the adverse health effects of short-term oral exposures. Such data have application for both drinking water and recreational guideline formulation.

Proposal 2 Towards applying the most appropriate technologies for on-line and direct monitoring of recreational, source and treated waters impacted by toxic cyanobacteria (TZW)

Cyanobacterial cells, cell by-products, taste and odour compounds and toxins are important indicators for monitoring, early warning and modelling for harmful impacts of cyanobacteria. New technology could provide remote detection and cheap, rapid detection for early warning of toxins. The current knowledge on developing technologies such as real-time PCR, selective fluorescence measurements, mass spectroscopy, remote sensing and lake diagnostic systems indicate that this approach is feasible.

Proposal 3 Guidance manual for the management of toxic algae (CRC-WRC)

Over the past 20 years significant research has been conducted into the management of cyanobacteria and the toxins they produce. The work has been published in hundreds of papers, reviews, reports and books. Presently no single document exists that has consolidated this vast knowledge into a guidance manual that can be easily used by water suppliers in the management of toxic cyanobacteria. The objective of this proposal for the GWRC is to combine and consolidate the all information to produce a truly international document, written in a way that all levels of the water industry can appreciate.

In addition to the three specific projects a number of actions were formulated to support the exchange of knowledge and coordination of ongoing activities with the GWRC framework. The actions are given below with the responsible member indicated within brackets.

Exchange of information

- Impact of algal toxins on agriculture (CRC WQT)

- Sampling (all)
- Interlaboratory tests (all)
- Need of a research project on non chemical means for control (WSAA)
- Algal toxin section of GWRC website (CRC WQT, GWRC)
- Coordination of ongoing water treatment projects (AwwaRF)
    - Involved organisations: AwwaRF, Anjou Recherche, CRC WQT and TZW

Certification of standards

- Discuss/facilitate cooperation of (inter)national organisations (GWRC)

Database on occurrence

- Information on WHO, UNESCO initiatives (CRC WQT)

With the three specific projects within this research strategy – toxicological studies, consolidation of the knowledge on source water management and water treatment, and the development of online monitoring methods – the major blank parts of the map of knowledge can collectively and successfully be addressed. The supportive actions will allow members to effectively exchange and make use of the knowledge available within the GWRC network.

1 Introduction

1.1 Background

The first recorded stock death attributed to blue-green algal toxins (cyanotoxins) occurred in South Australia in 1878. Since that time the potential detrimental health effects of the consumption of water affected by algal blooms have been of significant concern to the suppliers of water for both animal and human consumption worldwide. Cyanotoxins can cause a range of adverse health effects, including gastroenteritis, liver damage, tumour promotion, and even death, if consumed in sufficient quantity. They have now been reported in 27 countries and are found on all continents, including Antarctica. A third of the 50 genera of cyanobacteria can produce toxins, and between 50 and 70% of blooms of potentially toxic cyanobacteria are toxic. A number of these are also known to produce the common earthy/musty odour compounds geosmin and 2 methyl isoborneol, leading to the prospect that those water authorities with problematic odours caused by algae may also have toxins present in their water supply. Due to their serious potential health effects, algal toxins are an important issue for the international water industry.

The problem of toxic algae in water sources is one of the priority areas of the Global Water Research Coalition (GWRC) and there are at least three major initiatives, undertaken by members, underway internationally at the present time. A brief description of these is given below.

Cooperative Research Centre for Water Quality and Treatment, Australia

The CRC has a long record in research into all aspects of toxic algae management. Past projects have resulted in publications and conference presentations numbering over 300, covering all aspects of identification of cyanobacteria, ecology, source water management, drinking water treatment, analysis. Current projects, and those in development, cover a range of topics, including toxicology, genetic identification of toxic strains of cyanobacteria, source water strategies, production and degradation of toxins in source waters, treatment options including oxidation, activated carbon adsorption, biofiltration, and identification and analysis of emerging algal toxins. A project currently in development, to be funded jointly by United Water International, CRC and the South Australian Water Corporation, will produce an operators guide for the management of toxic cyanobacteria in the source water and treatment

plant. The aim of this guide is to consolidate all of the knowledge currently available into a form accessible to water utilities.

Three projects are currently jointly funded by AwwaRF and CRC, through a research organisation partnership arrangement.

American Water Works Association Research Foundation, USA

As well as their collaboration on a range of projects with the CRC, AwwaRF and the City of Cocoa, Florida have recently funded a large treatment oriented research project, involving consultants and universities in the USA. The scope of the project includes the study of ozonation, powdered activated carbon, granular activated carbon, membranes, biological filtration, and other oxidants. One of the proposed outcomes is a manual containing advice for utilities on the treatment of a range of toxins.

European Commission , Europe

The European commission has recently funded a wide-ranging research project, *TOXIC, Barriers against cyanotoxins in drinking water*. TZW is the lead agent of the project.
This project involves 10 research groups from 9 European countries, and intends to cover:

- raw water quality
- analysis
- treatment
- cost evaluation

1.2 Coordination of ongoing and future research activities

These research efforts, and other, smaller projects underway internationally, represent a major commitment of funding to this important topic. The many areas of potential overlap indicate clearly that a co-ordinated approach to the work would result in the maximisation of the outcomes for the funding bodies in particular and water suppliers in general. The senior researchers involved in these projects, in association with other members of the GWRC, are also well placed to identify the current research gaps and strategic research directions for the management of toxic cyanobacteria.

1.3 Aims and objectives of the workshop

The major aims of the workshop are to:

- Establish the critical issues of concern for the managers of water supplies
- foster a collaborative approach between groups concerned about the management of toxic algae
- ensure current research undertaken by various groups is complimentary, rather than duplication
- develop a more co-ordinated approach to global toxic algae research, with consequent benefits to all organisations involved
- identify current research needs and strategic research directions

1.4 GWRC organisations represented

CRC, Australia (http://www.waterquality.crc.org.au)

AwwaRF, USA (http://awwarf.org)

WSAA, Australia (http://www.wsaa.asn.au)

WRC - SA, South Africa (http://www.wrc.org.za)

Anjou Recherche, France (http://www.veoliaenvironnement.com)

TZW-WTC, Germany (http://www.tzw.de)

STOWA, the Netherlands (http://www.stowa.nl)

1.5 Global water research coalition workshop on algal toxins, program outline

The proposed program outline is given below.

On **Day 1**, after the general introduction of the scope and aims of the workshop, the CRC WQ&T will present the State-of-the Science paper which was prepared by the CRC WQ&T for the GWRC. Areas that will be addressed are: action of toxins, bloom formation and control, toxin production, removal of toxins from water, monitoring, laboratory production of toxins, regulations and emerging issues.

Following this presentation, invited participants will give presentations of the three major research initiatives (see above) outlining broadly the research they are undertaking currently, and research they propose to undertake within the next 2 – 3 years. Each speaker will also

identify the important research needs in their area that are not being addressed under the current research program. Time will be allowed at the close of each presentation to allow the audience to question and discuss aspects of the work. During this time overlap with other groups will be identified and noted.

After a short summary of the current and proposed research discussed on Day 1, on **Day 2** the GWRC representatives will present their activities and outline the research areas and needs of most interest to them.

Following the presentations the group will identify and prioritise the major knowledge gaps and research needs. Proposals for research projects to address the priority research needs will be developed and discussed. Members will indicate their interest in the specific proposals. On **Day 3** items to be decided are:

- who will initiate and drive the identified priority projects
- research links/collaborations for the successful completion of the projects
- funding sources

The workshop will adjourn on Day 3 at lunch.

1.6 Summary of workshop feedback

The feedback questionnaire, and the summary of responses is given below

Feedback Questionnaire

Please answer the following questions, rating your answers from 1 (strongly disagree or bad) to 5 (strongly agree or excellent). Please refer to the workshop agenda for the background of the different items.

		Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
		1	*2*	*3*	*4*	*5*
	Logistics					
1	The distribution of information and material before the meeting was satisfactory.			**3,5**		
2	The information and assistance regarding the travel and accommodation was satisfactory.			**3,9**		
3	The location was satisfactory.				**4,4**	
4	The support services during the meeting were satisfactory.				**4,2**	
5	The facilitation of the workshop was satisfactory.				**4,4**	

	Quality of content	*Bad*	*Poor*	*Neutral*	*Good*	*Excellent*
		1	*2*	*3*	*4*	*5*
	Day 1					
6	Introduction				**4,2**	
7	Regional Perspectives				**4,1**	
8	Public Health				**4,1**	
9	Detection and Monitoring				**4,2**	
10	Source water management			**3,8**		
11	Water treatment				**4,3**	
	Day 2 and 3					
12	Members presentations				**4,2**	
13	Identification of knowledge gaps and research needs			**3,9**		
14	Brainstorm + identification of items for joint projects			**3,9**		
15	Elaboration of the projects in sub-groups			**3,9**		
16	Presentation of projects				**4,0**	
17	Summary of appointments and follow up				**4,1**	
	Project Development					
18	The quality of the projects developed was…				**4,0**	
19	The quality of the (group) discussions was. …			**3,9**		
20	The process used to develop the research projects was…				**4,1**	
		Bad	*Poor*	*Neutral*	*Good*	*Excellent*
		1	*2*	*3*	*4*	*5*
	Overall Success					
21	The meeting achieved my objectives.				**4,2**	
22	Agreed actions and follow up of the workshop were clear.				**4,4**	

General remarks and suggestions

- Overall very good, minor points
- Final program arrived at conference
- Goals before conference could be better clarified
- Allocate more time in group breakouts to achieve program goals
- Perhaps use one workshop to identify knowledge gaps, assemble interested parties and form groups then use following workshop to complete proposal. This will allow more time for consideration of critic issues
- Overall a very worthwhile exercise that should lead to some very useful collaborative research
- Very pleased with workshop & outcomes
- Preliminary work and communication could have been sharper focused and material delivered in advance of actual meeting
- Instructions and format for lectures
- Information before the event is important

1.7 Workshop website

All information on this workshop, including presentations, proposals, associated documents and this report can be found at the workshop website in the members section of the GWRC website:

http://globalwaterresearchcoalition.net

2 Current State of Knowledge

This section gives a brief outline of each presentation describing the current state of research in toxic cyanobacteria, as well as priorities for future research. A literature survey, summarising all published literature on the management toxic cyanobacteria and cyanotoxins was also presented at the workshop. This report, Management Strategies for Toxic Blue-Green Algae: Literature Review), as well as a GWRC state of the art report "Directions for Cyanobacterial Research" and all presentations can be found at the workshop website.

Additional valuable overviews of the topic can be found in:
Chorus, I. and J. Bartam (Eds) Toxic Cyanobacteria in Water, A Guide to Their Public Health Consequences, Monitoring and Management. E & FN Spon, London 1999.
Yoo R.S., Carmichael W.W., Hoehn R.C., and Hrudey S.E.. Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide. American Water Works Association Research Foundation Report No.90693 (1995), Denver, USA.
Falconer I. Cyanobacterial Toxins of Drinking Water Supplies: Cylindrospermopsins and Microcystins. CRC Press, 2005.

2.1 Introduction

Issues for the international water industry

Dennis Steffensen, CRC

There are three critical questions for the water industry:

- Do cyanobacteria and algae significantly impair water quality?
- How do we know if we have a potential problem?
- What action should be taken?

Impact of algae on water quality

The major impacts of algae on water quality are taste and odours, filter clogging and toxins with the latter of most concern. A limited number of species produce life threatening toxins with a larger number linked to gastric and allergic responses.

Assesment and management

When assessing the seriousness of the problem and when considering management responses the, major issues for the water industry are:

- Determination of the health risks,
- Development of monitoring methods for both the organisms and their toxins,
- Understanding of the factors which promote cyanobacterial growth leading to more effective control in source waters,
- Development of effective water treatment processes to destroy or remove toxins.

Management options

For source water management it is important to understand the ecology in order to manipulate the conditions that promote blooms.

For water treatment there is a need to understand the effectiveness of conventional treatment and for the development of new treatments targeted at cyanobacteria or their toxins

2.2 Regional perspectives

Status of research in the USA

Wayne Carmichael, Wright State University

In the US the necessity for developing an agenda to identify, characterise and prioritise the primary hazards associated with cyanobacterial blooms and their toxins has been driven by a number of events, These include the deaths of birds and animals (alligators) associated with cyanobacterial blooms as well as the recent deaths of dialysis patients in Brazil. In addition potentially toxic *Cylindrospermopsis raciborskii* has now been identified over a wide area of the USA. The priority toxins have been determined as microcystins, cylindrospermopsin, anatoxin-a and the saxitoxins (in that order) with a need for analytical standards, rapid detection methods and water quality guidelines identified. Cyanobacteria and their toxins have been placed on the Contaminant Candidate List of the Safe Dinking Water Act which determines that they will be considered for regulation.

An AwwaRF study undertaken over the period 1996 – 1998 found a high proportion of water samples contained microcystins. This finding also raised the status of cyanobacterial toxins in drinking water as a potential health threat. Guidelines and standards have already been

developed by various countries and organisations, eg, WHO. These have focussed on microcystins with values from 1 – 1.5 µg/L resulting.

TOXIC - EU project on cyanobacteria.

Wido Schmidt – TZW –Water Technology Centre

The issue of cyanobacteria and their toxins in European countries is being addressed under the program the European Union program "TOXIC". The countries involved comprise Germany, UK, Switzerland, Denmark, Spain, Netherlands, Finland, Portugal and Poland. There are a number of groups responsible for specific issues.

- Coordination and Project Management (protocols, reports, public presentations)
- Raw Water Quality (data base of blooms in Europe, early warning systems)
- Analysis (pure standards, standard methods, technology transfer)
- Conventional Treatment (screening tests, thresholds for treatment, biodegradation, risk assessment)
- Polishing Treatment (oxidation data, including effects of water quality)
- Final Treatment (behaviour of intra- and extracellular toxins during treatment, optimum treatment)
- Alternative Techniques (membrane filtration)
- Modelling (ozone oxidation, simulation models for cost-effective treatment)
- Economic Evaluation and Exploitation (best practice guidance manual, software for treatment simulation)

2.3 Public health

Toxicology.

Andrew Humpage, Ian Falconer, Glen Shaw CRC

The cyanotoxins fall into two main groups: Hepatotoxins (microcystins and cylindrospermopsin) and neurotoxins (Paralytic Shellfish Toxins (saxitoxins), anatoxin-a, anatoxin-a(s)). The hepatotoxins are of greater public health importance.

The microcystins (MCs) have been extensively studied. Human liver toxicity and hepatocellular carcinoma have been linked with MCs in drinking water, and exposure to MC-contaminated dialysis water caused human fatalities. Animal studies have provided a reasonable understanding of MC toxicology, tumour promotion, and teratogenicity such that a

WHO Guideline for MC-LR has been formulated which has been extended in many countries to other MCs. Commercial ELISA's and Protein Phosphatase Inhibition Assays have been developed. Gaps include identification of a biomarker of low dose exposure enabling better epidemiological studies into links with human cancer, further animal studies into links with cancer, and effects of mixtures of MCs and cylindrospermopsin. Guidelines for short-term drinking water and recreational exposures are still lacking.

Cylindrospermopsin (CYN) is less well studied. One hundred and forty people were most probably poisoned by CYN-contaminated drinking water on Palm Island, Australia, and CYN was also linked with the dialysis patient poisonings. Basic rodent studies provide some understanding of the toxicology, but Guidelines have yet to be formulated. Genotoxicity has been demonstrated. There is some on-going work on genotoxicity and teratogenicity. Carcinogenicity studies are planned by US NTP. A Protein Synthesis Inhibition Assay has been published. Research gaps include human effects (eg a Palm Island follow-up cancer study), animal studies for Guidelines including carcinogenicity and reproductive toxicity, a full understanding of the mechanism(s) of toxic and genotoxic action, identification of biomarkers of exposure and effect, and development of commercial toxicity and antibody-based assays.

There is little relevant on-going work on the neurotoxins. Acute PST toxicity has been extensively studied in the context of shellfish poisoning. An Australian Provisional Guideline is based on acute PST exposure. Little in depth work has been done on the other neurotoxins. For PSTs, there is a neuroblastoma cell-based assay, receptor binding assays, ELISAs, and the Saxiphilin-based assay, but the sensitivity and specificity of these assays for drinking water applications has yet to be fully defined. Effects of chronic exposure (eg neural development) is still lacking. Better toxicity assays sensitive to multiple mechanisms of neurotoxicity would be desirable.

The panel aimed to identify research that would lead to practical outcomes for the water industry and recreational water users, wasn't already planned or being done, and was most urgent. The following research priorities were identified:

- Determination of species differences in sensitivity to CYN and MCs, both separately and in combination. Selection of appropriate animal models, and calibration of existing rodent data.
- Dose-response data for short-term oral exposures to CYN and MCs.
- Evaluation biomarkers of exposure and effect.
- Evaluation of potential CYN reproductive toxicity.
- Formulation of guidelines for short-term drinking water and recreational exposure to MCs and CYN.

Guidelines and regulation - Australian perspective.

Mike Burch, CRC

Australia has had a nationally coordinated program to address the issue of algal blooms in inland waters, with implied focus particularly on toxic cyanobacterial blooms from 1992-2001. This National Algal Management Program was coordinated under the auspices of the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ). The aims of the program were to:

- Identify and coordinate research issues
- Translate research into management strategies

The program operated with a single position called the National Algal Manager who was required to carry out a range of projects and communication activities to facilitate national coordination of management of algal bloom problems by both water resource agencies, health authorities and the water industry. Some of the key projects undertaken as part of this program included:

1. **Review of research needs** in relation to algal blooms in Australia
2. **Development of a strategy and position paper on phosphates in detergents**
3. **Development of drinking water guidelines for cyanotoxins for drinking water** in conjunction with the National Health and Medical Research Council (NHMRC) as part of the rolling revision of the NHMRC/ARMCANZ Australian Drinking Water Guidelines (ADWG). This resulted in the production of four Fact Sheets on Cyanotoxins. The four new fact sheets cover the four classes of toxins relevant to drinking water in Australia: microcystins, saxitoxins, cylindrospermopsin, nodularin.

The fact sheets include a guideline derivation for microcystin, which is the first numerical guideline issued in Australia. These were approved by NHMRC in June 2001.

4. **Review of Analytical methods for Toxin Analysis**. An issue that runs parallel to guidelines for toxins is the assessment of analytical capacity to measure toxins in the water. It is essential that the industry has access to the appropriate methods to measure toxins in raw and finished water to ensure compliance with new guidelines. A review of the status of current analytical methods with respect to their capacity used to monitor water supplies with a view to advising the water industry on their options to meet guidelines was published by the NHMRC in 2001.
5. **ARMCANZ National Sampling and Monitoring Protocol**. This is a comprehensive manual describing a national standard system for monitoring cyanobacteria in source waters. The aim of this protocol is to define and standardise sampling and monitoring techniques for cyanobacteria and cyanotoxins. It addresses issues such as sample types, frequencies and locations for different categories of waterbody in relation to their use. The document will also have an updated Alert Levels Framework as part of its procedural system. This document is in final stages of review.
6. **Algicide Technical Memorandum**. This is a fact sheet on the use of algicides for algal control, covering the list registered chemicals available for control of algae and regulations or steps involved in their use in different states. This document was printed in 2001.

2.4 Detection and monitoring

Chemical methods

Brenton Nicholson, CRC

Analysis of algal toxins is required for a number of purposes, namely monitoring, determining their fate in the environment and during water treatment and toxicity studies. There are various classes of toxins and existing methods generally target an individual toxin, or a particular class of toxins. Methods range from highly sophisticated procedures such a high performance liquid chromatography coupled with mass spectrometric detection, to enzyme inhibition assays and enzyme-linked immunosorbent assays (ELISAs). Analysis is complicated by the fact that new toxins continue to be discovered, with toxins being found in species previously considered to be non-toxic.

Existing analytical methods have their strengths and weaknesses. For example, the ELISA for microcystins can determine all variants in one assay. However, the variants are not identified and are known to cross-react with the antibodies used in the assay to differing degrees. These uncertainties lead to the procedure being considered a screening assay rather than a definitive analytical method.

Several priorities for future research can be identified. many analytical procedures require the toxins to be extracted from the sample matrix and concentrated prior to analysis. Better and more specific procedures are required in this area. Methods which can detect and quantify toxins of various classes in one analysis would result in more cost-effective analyses. To this end cylindrospermopsin, anatoxin-a and the saxitoxins can be separated by hydrophilic interaction chromatography and determined by mass spectrometry. Simpler, more robust screening assays are also required and in the longer term could be incorporated into biosensors, test kits and test strips. Genetic methods to rapidly identify toxic blooms would also be of value.

Genetics of cyanotoxin production

Chris Saint, CRC

Genetic methods for the identification of toxic species of cyanobacteria have a great potential in the management of source waters, and for the development of rapid methods for toxin detection. Toxins that have been, or are currently being, investigated within the CRC are: microcystins, anatoxin a, saxitoxins, nodularin and cylindrospermopsin. Rapid genetic techniques, such as real-time PCR are being developed to allow the identification of toxic cyanobacteria in the field within hours, instead of the common turn-around time measured in days.

The study of the genetics of biological degradation of algal metabolites may also lead to gene-based biosensors. These areas are currently under investigation for microcystins, cylindrospermopsin, and the odour compounds MIB and geosmin.

Topics identified for further research were:

- Continuing reports of toxic cyanobacteria that don’t produce any of the commonly identified toxins

- A comprehensive toxicological screening program probably using rapid screening techniques – cell culture/microarray, is required

2.5 Source water management

Ecology modelling and management

Justin Brookes, CRC

This paper described the issues and options for the control of cyanobacteria in source water and discussed the topics of ecology of cyanobacteria, conditions favouring cyanobacteria, managing cyanobacteria with artificial destratification.

It is considered that we can never completely eliminate cyanobacteria in source water but we can reduce the intensity and frequency of blooms by understanding the ecology and applying some management options based upon this knowledge. In source waters the best way to control toxins is to reduce the cyanobacterial biomass. This requires an understanding of what favours and limits growth, which is a combination of water chemistry, meteorological conditions and hydrodynamics.

The ingredients for algal growth are a combination of the following elements: an inoculum of vegetative cells or akinetes is required to initiate the population; Nutrients, either catchment or sediment derived are needed and this determines the maximum biomass that can be reached; in addition adequate light is needed as this determines the species composition and may limit growth rate. It is known that cyanobacteria prefer shallow mixing relative to light penetration.

In relation to control of cyanobacteria in reservoirs an option that has been studied is the use of artificial destratification either by bubble plume aerators or surface mounted mechanical mixers. The aims of this technique for algal control can be twofold. It can oxygenate the hypolimnion and reduce release of nutrients and metals from sediment and can also mix the storage to light-limit the growth of cyanobacteria. Studies at the CRC for Water Quality and treatment have approached this area by a combination of field investigations and by the use of modelling. Modelling is essential because in trying to understand the problem as weather conditions are never constant and not all mixing scenarios can be monitored or studied in the field.

The studies have shown that mixing systems based upon a hybrid of aerators and surface–mounted mechanical mixers can significantly reduce cyanobacterial growth. However even with these systems there is still a need to develop ways to attack stratification in the surface layer which may persist for months in tropical and sub-tropical systems. It may be possible to develop better-designed aerators with multiple diffusers at several heights.

2.6 Water treatment

Chlorination of toxins and proposed collaboration with TOXIC.

Lionel Ho, CRC

Previously researchers had assumed that the oxidation of microcystins by chlorine would occur through a similar mechanism for all variants, and therefore the chlorine doses required for desired removal of toxicity would be the same. This work showed that, for four microcystin variants, the reaction mechanisms were different, and different chlorine CT values (concentration X time) were required for the four toxins. The variants with more reactive amino acids in the variable positions required lower doses of chlorine for oxidation of the molecule. It is hoped that this work can continue in collaboration with the European Union project TOXIC.

Biological filtration of toxins

Gayle Newcombe, Glen Shaw, CRC

Biological processes for the removal of problem compounds in drinking water are invoking particular interest in the water industry as they:

- Are of low technology, requiring relatively little maintenance and are therefore potentially of significant interest to regional and/or remote communities, and less advanced communities internationally
- Require relatively low infrastructure and running costs
- Do not require additional treatments and are therefore processes involving the *removal* of contaminants without the *addition* of chemicals that in themselves may have potential, or perceived health effects, or may produce by-products that are undesirable in drinking water.

Results so far are very promising for the removal of high concentrations of microcystins and cylindrospermopsin through biological filtration. The genes responsible for the degradation of microcystin have been detected in the biofilm on a sand filter, and this technique will be optimised to develop a technique for the testing of filter biofilms for toxin degrading organisms. This will give water treatment plant managers greater confidence in the removal of these compounds through the plant.

Overview of other AWQC toxin projects

Gayle Newcombe, CRC

Several other projects underway at the AWQC were described. Much effort has been directed towards understanding the mechanisms of adsorption of toxins onto activated carbon, and the effect of water quality on their removal. It has been found that all toxins tested so far adsorb to different extents, and therefore require different powdered activated carbon (PAC) doses for their removal. In addition, water quality, in particular dissolved organic carbon concentration, has a significant effect on the removal of algal toxins. Computer modelling has been successful for the prediction of PAC doses required for the removal of microcystins.

Another important project is the development of a a guide designed to be used by water utilities world wide, which will consolidate all available current knowledge on the management of toxic blue-green algae (cyanobacteria). The guide will cover the topics of health effects, guidelines and standards, sampling and monitoring programs, risk assessment, alert levels for action, mixing strategies, algicides, conventional treatment, oxidation, activated carbon, biological filtration, UV, membranes and multiple barrier options

Topics for further research were identified as:

- Fundamental understanding of the adsorption of toxins onto activated carbon
- Membrane filtration
- UV disinfection

3 Research Activities of GWRC Members

Representatives of the GWRC gave brief overviews of the research activities and priorities of their organisations. Full presentations can be found on the workshop website.

3.1 Don Bursill. CRC

The CRC has identified the issue of cyanobacteria as one of its six major research themes. Within the CRC there are projects focused on cyanobacteria and their toxins in all of the research programs:

- **Program 1 - Health and Aesthetics,**
  Epidemiology, Toxicology and Peoples' Perspective
- **Program 2A - Catchment to Customer**
  Catchments, Reservoir Management, Measurement
- **Program 2B - Catchment to Customer**
  Water Treatment Technology, Distribution Systems, Sustainable Water Resources
- **Program 3 - Policy, Regulation and Stakeholder Involvement**

CRC WQT Priority Issues

Those areas the CRC considers still require substantial research are:

Formulation of guidelines

- Toxicological data from animal models for cylindrospermopsin and saxitoxins
- Mechanisms of toxicity for cylindrospermopsin

Monitoring

- Field tests
- On-line monitoring
- Toxicity screening

Management

- Multi-barrier approach for the catchment, source waters and treatment
- Simple guidelines for operators

3.2 Peter Donlon. WSAA

The key issues identified by Peter were:

Water shortages

With current demand patterns and population growth scenarios, by 2030 Australian cities will be 17% beyond current water yields and in some cities 30% beyond current yields.

New systems

Local storage of reclaimed water and stormwater

Management of algal problems

Droughts and climate change will lead to more problems not less. Issues are:

- Better methods for control of algae in storages
- Scientific understanding of mixing from an algal perspective
- algicides – we cannot continue to rely on copper only
- Knowledge of toxicity operationally
- Improved standards and "high level" laboratory analyses
- Rapid Test Kits – screening at a local level – semi quantitative – cost is an issue
- Removal processes in treatment systems
- Taste and odour in a regulated environment (eg copper)
- Carcinogenicity and teratogenicity
- Uncertainties
- Possible synergism of cylindrospermopsin and microcystin

Knowledge transfer and building trust

Biggest issue is knowledge transfer which must planned as part of the research design.

- Operational Guidance Manuals
- Regulators
- Operational staff (eg cell numbers)
- Beware of the "we need to do more work" reports

Algal knowledge advancement

- Massive changes in last 15 years
- Moved from a "what do we do" issue to a "yes we can manage this" issue
- Expertise available in Australia and elsewhere

- Improved coordination of programs will assist total knowledge advancement

3.3 Bill Harding. WRC - SA

This paper described the chronology of activities in relation to science and management of toxic algae in South Africa since the 1970's. Pre-1988 South Africa maintained an active and diverse eutrophication and cyanobacterial research programmes. From 1990-2000 the activities undertaken included:

- Cyanobacterial initiatives centered in local authority laboratories
- Introduction of "Codd" HPLC method
- Several incidents of animal mortalities (dog, sheep, goats and cattle) due to microcystins and nodularin
- Large scale animal deaths due to unidentified toxins
- Appearance of *Cylindrospermopsis*.

From 2000 to present a number of important initiatives occurred. The year 2000 saw the publication of two keystone reports: "Cyanobacteria in South Africa: A Review" (*Harding and Paxton*). This was a consolidation of all research, incidents and other published information pertaining to cyanobacteria prior to 2000. Secondly "Perspectives on Eutrophication of Surface Waters: Policy and Research Needs in South Africa" (*Walmsley*).

The status of current activities are summarised under eight key topics:

1. ACTIONS OF TOXINS

No current activity in this research area

2. BLOOM FORMATION AND CONTROL

Evaluation of available data and determination of the known extent of cyanobacterial problems in SA water resources

Addendum of Figures to Report 1288/1/03

T G Downing1 & C E van Ginkel2

1 University of Port Elizabeth

2Resource Quality Services , Department of Water Affairs & Forestry

2.1 Situation Assessments

- • Extent of cyanobacterial problems in South African managed water resources [Completed];

- • National survey of the incidence of cyanobacterial blooms [Completed]

2.2 System assessment protocols

- • NEAP – Nutrient Enrichment Assessment Protocol [September 2004];
- • NEMP – National Eutrophication Monitoring Programme [Completed];
- • Generic incident (blue-green algal) management framework (potable supplies) [July 2004].

2.3 Applied Case Studies

- • Implementation of top-down controls by restructuring and balancing coarse fish dominance in fishery assemblages (Hartbeespoort Dam, Zeekoevlei) [Harding, 2004].

3. TOXIN PRODUCTION

- • The role of nutrient utilization and photosynthetic capacity in micro-algal bloom formation and the production of cyanotoxins – in association with Drs Haukka and Kaarina Sivonen (Dept of Applied Chemistry and Microbiology, Finland) (ICA) [Sandra du Plessis, 2005];
- • Development of a model for the prediction of toxic bloom events based on the cellular mechanisms of toxin production by nutritional environmental parameters in the genus *Microcystis* [Tim Downing, 2005]. Pivotal role of N-metabolism and role of NtcA binding site upstream of the *mcyB* gene ;
- • Development of a predictive tool for cyanobacterial blooms considering preceding climatic conditions [Van Ginkel, PhD., 2006/7].

4. REMOVAL OF TOXINS FROM WATER

4.1 Toxin removal (PAC, Ozonation)

- • Use of PAC according to exceedance of pre-determined thresholds for cell counts and/or toxin levels.

4.2 Taste and odour management (PAC)

- • Ongoing routine response protocols in use by large potable water suppliers.

5. LABORATORY PRODUCTION OF TOXINS

- No current activity

6. CYANOBACTERIAL ID / TOXIN DETECTION AND MEASUREMENT

- • Voluntary inter-laboratory algal identification and enumeration proficiency project [ongoing];
- • Phytoplankton monitoring manual [2006];
- • The use of PCR-based genetic markers for the identification of toxic cyanobacteria [2004].

7. GUIDELINES

- • Current guidelines based on an amalgamation of WHO, Australian, Canadian and UK guidelines;
- • No epidemiological studies despite sustained presence of toxicity.

8. EMERGING ISSUES

8.1 Management needs:

- • National level alert and incident registration structure
- • National eutrophication management strategy
- • Education, training and awareness programs
- • Prioritization of the nature and extent of the problem (public health risks, economic and ecosystem losses)
- • Inter-laboratory standardizations – algal identification and toxin analysis
- • Standardized sampling procedures
- • Protection of rural communities, farm dams and irrigation systems
- • Protection of low technology water treatment plants (slow sand filtration and chlorine only)
- • Recreational-use protection

8.2 Research needs:

- • Correlation of trends in frequency and severity of cyanobacterial problem events with climatic variation
- • Furthering of foodweb management initiatives
- • Evaluation and modification of existing predictive models based on available data from South African impoundments
- • Fisheries and bio-magnification
- • Animal morbidity in presence of known species but no (detectable) toxin presence
- • "Toxin-on" switches
- • Collaborative approaches – maximization of locally and internationally-scarce resources
- • Maximization of use of extant or available knowledge (prevent 'reinvention of wheels' syndrome)
- • Mechanisms to review both quality of proposals and research products
- • Research capacity and interest symptomatics overwhelmingly indicative of cyanobacterial hepatotoxicosis but causative agent not confirmed.

In conclusion, South Africa is preparing to formulate a five-year Strategic Research Programme for cyanobacteria and cyanobacterial toxins. It is extremely important that this programme maximizes scarce research and financial resources, and the research undertaken is both locally and internationally relevant. South Africa's research programme is only likely to be successful if it can benefit from mutual international collaboration. We believe that this situation is not unique to South Africa.

3.4 Misha Hasan. AwwaRF

Misha Hasan summarized previous and on-going research projects supported by AwwaRF and other organizations in the USA. A full list and brief outline of each project can be found in Appendix 2. Future research needs were identified:

Methods

- Sample preparation – extraction methods
- Detection assay sensitivity
- Analytical standards are needed for all algal toxins
- Availability of field kits

Biological / Chemical Interactions

- What triggers toxin production in a cell?
- How is toxin production related to geosmin / MIB production, if at all?

Treatment

- Treatment practices for algal toxins (other than microcystins)
- Alternative treatment technologies – UV, membranes
- Treatment effects on intracellular algae toxin and taste and odor compounds
- Treatment effect of pre-oxidants – what is the effect on cells and the release of intracellular compounds?

Health Effects

- Risk assessment – health effects; chronic and acute
- Guidance for utilities

3.5 Stephanie Rinck-Pfeiffer. Anjou Recherche

Anjou Recherche is interested in the following areas in the field of cyanobacteria and cyanobacterial toxin research:

Analysis

- standardisation of analytical methods
- analytical standards
- Development of early warning systems and rapid tests, ie biosensors for rapid testing or on-line testing

Management

- management of algal blooms and associated toxins
- research into alternative algicides

3.6 Wido Schmidt, TZW-WTC

TZW-WTC in Germany has been investigating the use of cyanobacterial pigments as a surrogate for toxins. Pilot plant studies, including UF treatment, have shown that the change in concentration of dissolved toxins mirrors the change in dissolved pigment concentrations. Laboratory experiments on lysis of cyanobacterial cells also demonstrated that toxin release mirrored the release of pigments. Further research identified includes:

- the relationship between pigment and toxins in the environment, including the effect of environmental factors on the relationship.
- Behaviour of pigments in relation to toxins during water treatment
- Application of on-site fluorescence of pigments as an early warning system
- occurrence of benthic cyanobacteria with associated toxin, and taste and odour problems.

3.7 Roelof Veeningen, STOWA

This paper presents an overview of the problems and research in relation to occurrence of algal toxins in the Netherlands. Firstly the problems were discussed in relation to the various uses of surface water in the country, which include for recreation, drinking water, agricultural uses, and ecosystem or environmental uses.

In relation to recreation the potential impact of toxic cyanobacteria is significant as up to 125,000 people are estimated to swim each day in lakes in the Netherlands. The potential problems that are regarded as a risk and could be encountered include surface scums and toxins. For drinking water, 38% of surface water in the Netherlands is sourced from surface water, and theoretical studies have been done to estimate the worst possible case toxin concentration in some supplies, this has been estimated at up to 2.9 μg/l for microcystin. For agricultural water use there have been no reports of adverse effects on animals or via crops, which are regarded as the routes for risk of toxic effects. In relation to adverse impacts upon ecosystems there are several examples of toxicity suspected to be associated with toxic cyanobacteria. These include death of 4,300 birds in 2002 in Volkerak Zoommeer, and 10,000 birds in 2003 in Oostervaardersplassen. Ther was a suspected association with botulism in these cases. In 1994- 1996 there were also large-scale fish kills IJsselmeer. There is currently some research underway into toxins in food-webs considering the pathway of phytoplankton – zooplankton - zebra mussels – fish – diving ducks, (*Ref. Ibelings submitted for Microbial ecology*).

In relation recreational and swimming water use there are a range of initiatives and procedures in the Netherlands covering communication, policy and guidelines, monitoring and research.

In relation to communication, advice is given by a combination of websites, TV/video text/telephone, press releases in cases of emergency. In the case of a warning or ban, signs are erected and leaflets with information policy and guidelines are distributed.

The guidelines used in the Netherlands are a combination of the following: WHO Guidelines for Safe recreational water environments (1999); EU: European Bathing Water Quality Directive; National Health Council: Advice: Microbial risks while swimming in nature; CIW: Guidance for cyanobacteria (2003); RIZA Leaflet Blue green algae (2003); Leaflet for fieldworkers (2003).

In the case of monitoring recreational waters the following procedures are in place: Surveys every two weeks; Chemical and bacteriology sampling; General environmental observations for the presence of scums, dead animals etc. Where scums are present and microcystins are detected the following procedure is applied:

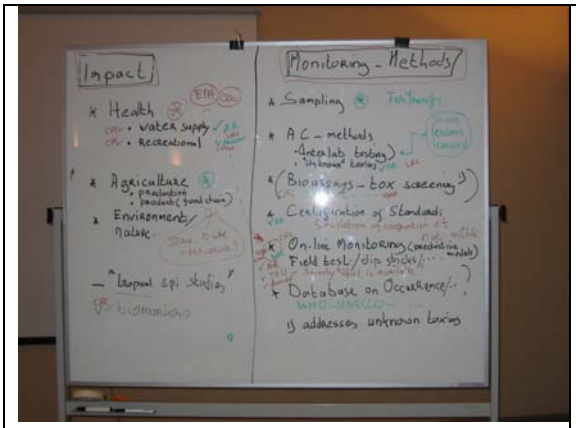
- < 20 ug MC/l : no action
- > 20 ug MC/l: ban on bathing.

There is also repeat monitoring.

In relation to research in the Netherlands STOWA has budget for applied research. In addition a “National platform on cyanobacteria” has been established comprised of Research institutes, Universities, water boards, drinking water companies. This platform produces a newsletter on cyanobacteria. The research topics that are being pursued in a variety of projects include: bloom and toxin formation, bloom control, modelling, epidemiological studies, analytical methods

4 Knowledge Gaps and Research Needs

The current knowledge of the different aspects of the management of toxic algae in recreational water and drinking water supply – i.e. impact, monitoring, source water management and water treatment –were comprehensively addressed in the State-of-the-Science report, the literature review and the presentations on the first day of the workshop. Together with the overview of the research activities of the participating GWRC members, they are the cornerstones of the map of knowledge regarding the issue of toxic algae in water. This information was reviewed and discussed by the participants during the workshop. In addition, in each of the specific aspects, gaps of knowledge were identified, prioritised and research needs or other actions to address the knowledge gaps were formulated. The results are summarised in the next paragraphs.



Prioritising the important issues for the international water industry

4.1 Impact of toxic algae

Regarding the impact of toxic algae in water systems, one has to differentiate between effects on public health by exposure via recreational water or drinking water, effects on the aquatic environment and the impact on agricultural production processes, the products and the food chain. It was felt that sufficient information is available to assess and manage the risk to agriculture associated to toxic algae. In contrast to this, there is only very limited knowledge available about the impact of toxic algae towards the aquatic environment.

Concerning the impact on public health, well documented reports exist of human poisonings from drinking water contaminated with cyanobacterial blooms. Toxicological studies carried out on animals have provided information on the role of toxins in poisonings and on the comparative toxicity. However, little is known of the scale and nature of either short-term or long-term effects of these toxins. In fact, the current guidelines do not address short-term or intermittent exposure. In the view of a risk assessment – risk management approach, the health significance of algal toxins in water is the key issue. But more sound and comprehensive toxicological information is needed before reliable guidelines can be derived. Epidemiological studies in tropical areas could be a source of valuable information.

Identified research needs:

- Exchange of information on agriculture impact
- Limited knowledge about the impact of the toxic algae on the aquatic environment
- Need of toxicological studies for guideline formulation

4.2 Monitoring

Monitoring covers the two major components of sampling of the water body and analysis of the collected samples in the laboratory.

Sampling strategies include issues like access point of sampling, sampling method, number of samples taken and the frequency of the sampling. Over the years a lot of knowledge and know-how on sampling has been gathered and the main activity now should be focused on technology transfer and implementation of this information.

A number of *analytical techniques* for detection and quantification of cyanotoxins has been developed during the last decade. Comprehensive review reports about this subject are available. Interlaboratory testing is of importance to compare and validate the methods and to make sure comparable data is produced. Exchange of information and lessons learned on these round robins exercises is needed to develop a suite of robust methods. The use of certified standards would be of great support to improve the quality of the analytical data. Certification of standards is very costly and time consuming and some sort of coordination of the different national and international activities should be useful.

Online and direct monitoring (field test, dip stick etc.) in combination with predictive modelling of recreational, source and treated waters was identified as the major knowledge gap for this area. But technologies such as real-time PCR, selective fluorescence and remote sensing are developing rapidly and this approach will become feasible. It is worthwhile to make an overview of "what is presently available" and identify and support the most promising developments.

Worldwide a large number of monitoring studies have been undertakne but a comprehensive overview of the collected data is missing. A database of occurrence of cyanotoxins in water systems would be very valuable and supportive to for example the development of guidelines and management strategies. Support of the WHO – UNSECO initiative could be considered.

Identified research needs:

- Technology transfer on sampling methodology
- Exchange of information on interlaboratory testing of AC methods
- Coordination of development of certification of standards
- Support of development of a Database on Occurrence
- State-of-the-Science and development of Online Monitoring

4.3 Source water management

On the issue of source water management an extensive amount of information has become available during the last decades, especially in South Africa and Australia. Consolidation of this knowledge and know-how in a guidance manual would be very useful to make this information widely available.

The issue of non chemical means for control of the formation of toxic algae was identified as an issue for further research. The possible impact on the environment of chemical treatment methods is the underlying reason.

Although not discussed in depth at the workshop, the effects of global warming and climate change on aquatic productivity and eutrophication, and hence on the formation of toxic algae could be an issue of future study and concern.

Identified research needs:

- Consolidation of knowledge => guidance manual
- Non chemical means for control of formation or algal toxins

4.4 Water treatment

In the field of water treatment much progress has been made on the removal of cyanotoxins during the last decade. The effectiveness of both conventional and advanced water treatment has been subject of comprehensive studies. Information is readily available on the removal capability of conventional treatment (coagulation, flocculation and clarification), biological filtration and advanced technologies like oxidation, adsorption, UV and membrane technology. Several member organisations are conducting research studies on the performance of the different systems in pilot situations and the practice of water supply.

In general, effective building blocks are available to design multiple barrier systems for the removal of cyanobacteria and their metabolites in water supply systems. In addition to this technology, natural "treatment" systems like river bank filtration and/or aquifer storage and recovery (ASR) could be considered as an effective option. These options were judged to be also effective in the case of water reuse systems. The development of small systems and low technology solutions especially applicable in rural areas were identified as an issue where more knowledge is needed. Similar to source water management the consolidation of the existing knowledge in a guidance manual would be very useful to make all this information widely available.

Identified research needs:

- Consolidation of knowledge => guidance manual
- Coordination of on-going projects

4.5 Research strategy

Within an overall framework of a risk assessment and risk management evaluation of the issue of the toxic algae and water supply, the participants of the workshop discussed and prioritised the identified gaps of knowledge and research needs. Each organisation specified their interest to support the different actions and research projects to address the priority issues and three topics were selected to be of major priority. Sub-groups of interested

organisations developed the first draft of the specific research proposals which were further elaborated by the participants of the workshop.

As major gap of knowledge, the limited availability of sound and comprehensive toxicological and epidemiological data to develop guidelines for toxic algae in water and water supply was identified. With support of all participating organisations it was decided to devise a research project on one of the missing pieces: short-term exposure to algal toxins. Although the information on the impact of algal toxins is limited, the issue is beyond the primary scope of the GWRC – the urban water cycle – and therefore no further initiatives were formulated.

In contrast to the above the available information on source water management and water treatment is overwhelming. But this valuable knowledge and know-how is not readily accessible and for that reason the consolidation of this information in a guidance manual is proposed.

Although reliable off-line analytical methods for the identification and quantification of algal toxins are present, the absence of on-line monitoring methods was identified as issue of concern. On-line monitoring methods would be of great support to evaluate and control water quality in a more efficient, less time-consuming and cheaper way. With the recent and promising technological development, this issue was selected as a priority topic to consider.

With these three specific activities within this research strategy – toxicological studies, consolidation of the knowledge on source water management and water treatment, and the development of online monitoring methods – the major blank parts of the map of knowledge can collectively and successfully be addressed.

4.6 Proposed projects and actions

As follow up of the workshop three projects were proposed to address the identified priority gaps of knowledge and research needs. The projects are summarized below and the lead agents are indicated in brackets. More information is given in Appendix 4.

Proposal 1 Toxicological studies for guideline formulation for short-term exposures to cylindrospermopsin and microcystins. Evaluation of reproductive toxicity of cylindrospermopsin. (CRC WQT)

Well-defined guidelines assure appropriate treatment and monitoring expenditure. Cyanobacterial blooms have an impact on economic activity associated with affected water-bodies. Recreational guidelines define when there is, or is not, a real threat to public health.

There are no WHO-approved guidelines for cylindrospermopsin although de facto water treatment targets are being incorporated into performance contracts, and several countries have already included them in their legislated or approved guidelines. This will lead to inadequate protection of public health and potentially increased costs for water treatment and analyses. The same concerns apply to recreational conditions.

There is an urgent requirement for studies into the adverse health effects of short-term oral exposures. Such data have application for both drinking water and recreational guideline formulation. Current guidelines for drinking water do not address short-term or intermittent oral exposures. The cyanotoxins of primary concern are cylindrospermopsin and microcystins. Microcystin analogues other than mLR need to be assessed to determine the applicability of current drinking water guidelines to actual microcystin occurrence. Animal studies addressing potential carcinogenicity are either underway (microcystins) or planned (cylindrospermopsin) by the US National Toxicology Program and so are not contemplated in this proposal. Potential reproductive toxicity of cylindrospermopsin also needs to be assessed before comprehensive guidelines can be formulated.

Proposal 2 Towards applying the most appropriate technologies for on-line and direct monitoring of recreational, source and treated waters impacted by toxic cyanobacteria (TZW)

Cyanobacterial cells, cell by-products, taste and odour compounds and toxins are important indicators for monitoring, early warning and modelling for harmful impacts of cyanobacteria. New technology could provide remote detection and cheap, rapid detection for early warning of toxins. The current knowledge on developing technologies such as real-time PCR, selective fluorescence measurements, mass spectroscopy, remote sensing and lake diagnostic systems indicate that this approach is feasible.

The water quality framework requires that the critical control points are continuously monitored to assess effectiveness of barriers and risk from hazards. The rapid detection of toxin outbreaks is essential for risk management. In the first phase of the project the existing knowledge will be assembled and based on new promising technologies methods for toxin monitoring will be developed. In the second phase of the project the technologies will be validated and deployed to the pilot or field environment.

Proposal 3 Guidance manual for the management of toxic algae (CRC)

Over the past 20 years significant research has been conducted into the management of cyanobacteria and the toxins they produce. The work has been published in hundreds of papers, reviews, reports and books. Presently no single document exists that has consolidated this vast knowledge into a guidance manual that can be easily used by water suppliers in the management of toxic cyanobacteria; however, a number of research groups are planning to produce such a guide within the next two years. While most of these groups will still produce their own "regional" guide, the objective of this proposal for the GWRC is to combine and consolidate the information in these guides to produce a truly international document, written in a way that all levels of the water industry can appreciate. The GWRC will then be able to take advantage of the combined knowledge such a document would represent, and the information contained in the regional manuals would be enriched with additional views and approaches.

In addition to the three specific projects a number of actions were formulated to support the exchange of knowledge and coordination of ongoing activities with the GWRC framework. The actions are given below with the responsible member indicated within brackets.

Exchange of information

- Impact of algal toxins on agriculture (CRC WQT)
- Sampling (all)
- Inter-laboratory tests (all)
- Need of a research project on non chemical means for control (WSAA)
- Algal toxin section of GWRC website (CRC WQT, GWRC)

Coordination of ongoing water treatment projects

- Involved organisations: AwwaRF, Anjou Recherche, CRC WQT and TZW
- Lead: AwwaRF

Certification of standards

Discuss/facilitate cooperation of (inter)national organisations (GWRC)

Database on occurrence

Information on WHO, UNESCO initiatives (CRC WQT)

5 Conclusions and Follow Up

5.1 Workshop aims and outcomes

Below is a list of the goals of the workshop, and a brief description of how these were achieved.

A review of existing knowledge and activities, sharing the results within the GWRC

A review of existing knowledge on the management of cyanobacteria was undertaken prior to the workshop by the CRC. This effort was funded by the CRC, SA Water and United Water, and resulted in a publication, "Management of Toxic Blue Green Algae: Literature Survey" which was presented to the participants at the workshop. It is also available on the GWRC members section of the GWRC website. In addition, a paper "Directions for Cyanobacterial Research" was prepared before the workshop, and presented on the first day by Dr Dennis Steffensen. During the workshop the presentations by CRC researchers and members of the GWRC summarized the current activities worldwide in the management of cyanobacteria. These presentations are also available to GWRC members on the website.

Identification of knowledge gaps and research needs and development of a research strategy

After the presentations of the first and second days, a very valuable session took place where the issues with adequate knowledge available were indicated and knowledge gaps and additional research needs of the GWRC members were identified. These research needs were then prioritized and clarified to allow further development of the research needs into specific research projects. Following the workshop, a document outlining this research strategy for the GWRC was developed for Board discussion and approval.

Priority issues and a portfolio of research projects

Three projects were identified as the highest priorities:

- Toxicological studies for guideline formulation for short-term exposures to cylindrospermopsin and microcystins. Evaluation of reproductive toxicity of cylindrospermopsin. (CRC)
- Towards applying the most appropriate technologies for on-line and direct monitoring of recreational, source and treated waters impacted by toxic cyanobacteria (TZW)

- International guidance manual for the management of toxic algae (CRC - WRC)

5.2 Follow-up

One organization was nominated to lead each of the projects mentioned above. A project leader for each further developed the proposals and circulated them to the workshop participants for comments. These proposals form Appendix 4 of this reports, and are available on the GWRC Toxic algae workshop website.
Other actions identified as important, to be carried out after the workshop were:

- Continuing exchange of information
- Coordination of ongoing water treatment projects
- Certification of standards
- Database on occurrence

5.3 Workshop feedback

Workshop feedback was very positive (see section 1.6). From the feedback by the participants it can be concluded that the way of working to develop the map of knowledge and the research strategy was quite effective and very valuable to create a common understanding of this important research area.

5.4 Website

All information on this workshop, including presentations, proposals, associated documents and this report can be found at the workshop website in the members section of the GWRC website:
http://globalwaterresearchcoalition.net

Appendix 1: Full Program

Tuesday May 4 2004

INTRODUCTION

9.00am Welcome and Opening of Workshop
Frans Schulting, Managing Director GWRC
9.15am Overview of the issues
Dennis Steffensen, Deputy CEO CRC

REGIONAL PERSPECTIVES

9.30am Status of Research in the USA,
Wayne Carmichael, Wright State University
9.55am TOXIC - EU project on cyanobacteria.
Wido Schmidt – TZW –Water Technology Centre
10.20am World Health Organisation Perspective
Wido Schmidt – TZW –Water Technology Centre
10.45am Discussion

11.00am Morning Tea

PUBLIC HEALTH

11.30am Toxicology.
Andrew Humpage, Ian Falconer, Glen Shaw CRC
11.50am Guidelines and Regulation - Australian Perspective.
Mike Burch, CRC
12.10 Discussion

12.30pm Lunch

DETECTION AND MONTITORING

1.20pm Chemical Methods
John Papageorgiou, Brenton Nicholson, CRC
1.45pm Genetics of Cyanotoxin Production
Chris Saint, CRC
2.10pm Discussion

SOURCE WATER MANAGEMENT

2.30pm Ecology Modelling and Management
Justin Brookes, CRC
3.00pm Discussion.

3.20pm Afternoon Tea

WATER TREATMENT

3.30pm Chlorination of Toxins and Proposed Collaboration with TOXIC.
Lionel Ho, CRC
3.50pm Biological Filtration of Toxins
Gayle Newcombe, Glen Shaw, CRC
4.10 pm Overview of other AWQC toxin projects
Gayle Newcombe, CRC
4.30 pm Discussion
5.00pm Wrap up

Wednesday May 5 2004

9.00am Presentations by GWRC members on emerging issues and priorities for future research

Don Bursill. *CRC*

Peter Donlon. *WSSA*

Bill Harding. *WRC - SA*

Misha Hasan. *AwwaRF*

Stephanie Rinck-Pfeiffer. *Anjou Recherche*

Wido Schmidt. *TZW-WTC*

Roelof Veeningen, *STOWA*

After the presentations, the group will identify four major priorities and break into discussion groups to develop a research proposal for each.

Each of the four research proposals will be presented to group for discussion.

Buses leave for dinner at 4.45 pm from the Town Hall.

Dinner will be preceded by a guided dusk walk at Warrawong Sanctuary (a very warm jacket and walking shoes will be required for the walk).

Dinner 7.00 pm at Warrawong Sanctuary

Thursday May 6 2004

9.00am Each proposal will be discussed. The major points to be identified for each proposal during this session will be:

- who will initiate and drive the project
- research links/collaborations for the successful completion of the project

- funding sources

12.00pm **Lunch**

Wrap up

Appendix 2: List of Participants

Below is a list of participants in the 3 day workshop activities

TITLE	SURNAME	NAME	ORGANISATION
Dr	Brookes	Justin	Australian Water Quality Centre
Dr	Burch	Michael	Australian Water Quality Centre
Dr	Carmichael	Wayne	AwwaRF
Mr	Craig	Keith	Veolia Water Australia
Mr	Donlon	Peter	Water Services Association Australia
Dr	Falconer	Ian	CRC Water Quality and Treatment
Dr	Harding	Bill	Water Research Commission - SA
Ms	Hasan	Misha	AwwaRF
Dr	Humpage	Andrew	Australian Water Quality Centre
Dr	Newcombe	Gayle	Australian Water Quality Centre
Dr	Nicholson	Brenton	Australian Water Quality Centre
Ms	Rinck-Pfeiffer	Stephanie	Anjou Recherche
Dr	Saint	Chris	Australian Water Quality Centre
Dr	Schmidt	Wido	TZW - Water Tecnology Centre
Dr	Schulting	Frans	GWRC
Dr	Shaw	Glen	National Research Centre for Environmental Toxicology
Dr	Steffensen	Dennis	Australian Water Quality Centre
Dr	Veeningen	Roelof	Stowa

Appendix 3: Research Projects in the USA Supported by AwwaRF

The presentation by Misha Hasan sumarised previous and on-going research, outlined the regulations that apply in the USA and identified the future research needs.

Research - Toxic Algae 1993 - 1997

Cyanobacterial Toxins: A Resource Guide

Summarized international experiences into a comprehensive resource document for water utilities.

Assessment of Blue-Green Algal Toxins in Raw and Finished Drinking Water

Evaluated the occurrence of toxins in North America.

Algae Detection and Removal Strategies for Drinking Water Treatment Plants

Guidelines to optimize the removal of algae and their extracellular organic matter using conventional treatment processes.

Removal of Algal Toxins from Drinking Water Using Ozone and GAC

Assessed the conditions of ozone residual and contact time necessary to destroy various algal toxins and toxin removal efficiency with GAC.

On-going research

Detection of Methods and Occurrence of Algal Biotoxins

Developing analytical techniques used to assess the occurrence of total and dissolved biotoxins in water supplies.

Treatability of Algal Toxins Using Oxidation, Adsorption, and Membrane Technologies

Characterize various treatment technologies (ozone, advanced oxidation, PAC, GAC, biological filtration, membranes) for algal toxin removal

Early Detection of Cyanobacterial Toxins Using Genetic Methods

Assess the development and potential for applying molecular tools for detecting organisms that produce cyanotoxins.

The Feasibility of Allelochemicals as a Means to Control Toxic Cyanobacterial Blooms in Water Bodies

Identify and characterize naturally occurring biochemical agents to control toxic *Microcystis* in fresh water lakes.

Criteria for Quality Control Protocols for Various Algal Toxin Methods

Establish a criteria to be used by laboratories providing algal toxin analysis and provide a QA/QC checklist for drinking water utilities.

Reservoir Management Strategies for Control and Degradation of Algal Toxins

Elucidate the mechanisms that trigger the production and release of algal and cyanobacterial toxins. Develop reservoir management approaches for the control of toxin production.

The Development of Biosensors for the Analysis of MIB and Geosmin

Characterize the genes involved in MIB and geosmin degradation

Lorraine Backer, Centers for Disease Control and Prevention

- Identify drinking water utilities with current *microcystis* bloom in source water
- Determine presence of microcystins in source, finished, and tap water
- Rely on volunteers to complete questionnaire and provide blood sample to rate levels of toxins

United States Environmental Protection Agency

- Assessment of Cyanobacteria Risk
- Develop an analytic approach to assess the health risks due to cyanobacteria / cyanotoxins
- Assess when and under what conditions there may be health risks, determine exposure relationships
- The outcomes are expected to support the development of monitoring toxin ranges and eventually support the development of regulation.

American Water Systems

- Reviewed the current state of water treatment for cyanotoxins
- In summer of 2003, surveyed 33 North American water treatment plants for microcystin levels in raw water supplies (midwest and eastern USA)
- 87% of the raw samples and 30% of the effluent samples tested positive for microcystins
- All detectable plant effluent levels were below the WHO guideline of 1ppb

Wisconsin State Lab. of Hygiene

- A two year study examined the occurrence of microcystin algal toxins and their removal during drinking water treatment. Five utilities and two lakes were included in the study.
- Toxin levels increased throughout the summer months and levels exceeded the WHO guideline towards the end of the summer
- Treatment processes effectively reduced toxin to levels ranging from no detection (<2 ng/L) to an average of 20 ng/L in finished drinking water
- Pretreatment (potassium permanganate, PAC, citric acid, copper sulfate) accounted for more than 50% of the reduction in microcystins

USEPA's Contaminant Candidate List (CCL)

- Primary source of priority contaminants for evaluation by EPA's drinking water program.
- Contaminants on the CCL may be regulated depending on occurrence and health effects.
- Currently cyanobacteria, other freshwater algae, and their toxins are on the CCL.
- Unregulated Contaminant Monitoring Rule (UCMR)

  Prior to considering regulation, a contaminant is assessed based on occurrence, method availability, and health impacts.
- Cyanobacteria and toxins are currently being evaluated under this rule – research on methods is needed.

Appendix 4: Project proposals

Three projects were identified as priorities for the GWRC members, and drafts were developed during the workshop. Completed proposals are given below.

Health impacts

Project Title:	***Toxicological studies for guideline formulation for short-term exposures to cylindrospermopsin and microcystins. Evaluation of reproductive toxicity of cylindrospermopsin.***				
Name of Proposer & Affiliation:	Andrew Humpage, Ian Falconer, Glen Shaw, Mike Burch (all CRCWQT), Bill Harding				
Collaborators:	CRCWQT. Potential collaborators: USEPA, Dr Lorraine Backer/CDC, ……..				
Estimated Total Cost of Research (Euro)	**2004**	**2005**	**2006**	**Beyond**	**Total**
			318k	258k	576k
Background:	**Justification:** There is an urgent requirement for studies into the adverse health effects of short-term oral exposures. Such data have application for both drinking water and recreational guideline formulation. Current guidelines for drinking water do not address short-term or intermittent oral exposures. The cyanotoxins of primary concern are cylindrospermopsin and microcystins. Microcystin analogues other than mLR need to be assessed to determine the applicability of current drinking water guidelines to real world microcystin occurrence. Animal studies addressing potential carcinogenicity are either underway (microcystins) or planned (cylindrospermopsin) by the US National Toxicology Program and so are not contemplated in this proposal. Potential reproductive toxicity of cylindrospermopsin also needs to be assessed before comprehensive guidelines can be formulated.				
Consequences if work not carried out:	There are no WHO-approved guidelines for cylindrospermopsin although de facto water treatment targets are being incorporated into performance contracts, and several countries have already included them in their legislated or approved guidelines. This will lead to inadequate protection of public health and potentially increased costs for water treatment and analyses. The same concerns apply to recreational conditions.				
Benefits to be achieved:					
- Political	Assurance of public safety for drinking water and recreational use of freshwaters.				
- Economic	Well-defined guidelines assure appropriate treatment and monitoring expenditure. Cyanobacterial blooms have impact on economic activity associated with affected water-bodies. Recreational guidelines define when there is, or is not, a real threat to public health. Ability to demonstrate guideline compliance minimises exposure to litigation.				

- Technical	Sound guidelines underpin selection of appropriate technology for monitoring, treatment, water-body management.
	Objectives:
Aiming to achieve:	Toxicological data for guideline formulation addressing short-term or intermittent oral exposures to cyanotoxins via drinking water and recreational water use. Evaluation of potential for reproductive toxicity.
Specific questions answered:	Determination of species differences in sensitivity to cylindrospermopsin and microcystins, both separately and in combination. Selection of appropriate animal models, and calibration of existing rodent data. Dose-response data for short-term oral exposures to cylindrospermopsin and microcystins. Evaluation biomarkers of exposure and effect. Evaluation of potential cylindrospermopsin reproductive toxicity. Formulation of guidelines for short-term drinking water and recreational exposure to these cyanotoxins.
Tasks set for contractor:	Design and implement inter-species toxicological studies using hepatocytes. Design and implement short-term oral in vivo studies based on EPA/OECD protocols using an appropriate animal model as determined in hepatocyte study. Evaluate reproductive effects of sub-chronic exposure using EPA/OECD protocols.
Deliverables:	Basic data for formulation of guideline values for short-term oral exposure to cylindrospermopsin and microcystins Data to determine whether reproductive toxicity is an issue for cylindrospermopsin.
Completion date to maximise benefits:	Hepatocyte study 12 months from funding approval. In vivo data available 18 months from funding approval. Reproductive effect data available 3 years from funding approval.
Target audience for the output?	Global water industry. Health regulatory authorities. WHO and Pan-American Health Association.
Which groups should receive any reports resulting from this work?	GWRC partners including US EPA and CDC. Also WHO, PAHA, regional health regulators.
Should the output be submitted for independent peer review to add authority to the work?	Yes.

Operational Guide

Project Title:	***Guidance manual for the management of toxic algae***

<table>
<tr><td>Name of Proposer & Affiliation:</td><td colspan="5">Gayle Newcombe, CRC WQT/AWQC</td></tr>
<tr><td>Collaborators:</td><td colspan="5">Mike Burch, CRC WQT/AWQC, Peter Donlan, WSAA, Bill Harding, WRC, Misha Hasan, AwwaRF, Keith Craig, Veolia Australia, Stéphanie Rinck-Pfeiffer, Anjou Recherche, Ingrid Chorus, UBA, Wido Schmidt, TZW –Water Technology Centre</td></tr>
<tr><td rowspan="2">Estimated Total Cost of Research (Euro)</td><td>2004</td><td>2005</td><td>2006</td><td>Beyond</td><td>Total</td></tr>
<tr><td></td><td>60000</td><td>10000</td><td></td><td>70000</td></tr>
<tr><td>Background:</td><td colspan="5">Justification:
Over the past 20 years significant research has been conducted into the management of cyanobacteria and the toxins they produce. The work has been published in hundreds of papers, reviews, reports and books. Presently no single document exists that has consolidated this vast knowledge into a guidance manual can be easily used by water suppliers in the management of toxic cyanobacteria; however, a number of research groups are planning to produce such a guide within the next two years. While most of these groups will still produce their own “regional” guide, the objective of this proposal for the GWRC is to combine and consolidate the information in these guides to produce a truly international document, written in a way that all levels of the water industry can appreciate,
A Guidance Manual for the Management of Toxic Algae</td></tr>
<tr><td>Consequences if work not carried out:</td><td colspan="5">The GWRC will not be able to take advantage of the combined knowledge such a document would represent, and the information contained in the regional manuals would remain with their respective organisations.</td></tr>
<tr><td>Benefits to be achieved:

- Political

- Economic

- Technical</td><td colspan="5">• An excellent opportunity to foster collaboration within the GRWC.
• Potential for collaboration with the WHO in the production of the revised version of the book “Toxic Cyanobacteria in Water, A Guide to Their Public Health Consequences, Monitoring and Management”.
• The guide will include management strategies that are applicable to regional or remote areas, as well as developing regions
• All the information required for the management of toxic cyanobacteria in one document will result in shorter response times for actions
• Consolidation of many years of research will help both water suppliers and researchers
• The guide will result in improved management strategies in many water sources and treatment plants</td></tr>
<tr><td>Aiming to achieve:

Specific questions answered:</td><td colspan="5">Objectives:
The production of an internationally-applicable guide to the management of toxic cyanobacteria for water suppliers
What is the best way to manage my problem with cyanobacteria?</td></tr>
<tr><td>Tasks set for contractor:</td><td colspan="5">• Gayle Newcombe, Frans Schulting and Ingrid Chorus will discuss the possibility of this document becoming a complementary publication to the revised WHO book
• Review of the manual of the European TOXIC project
• Additional reviews of regional manuals by South African, Australian, US and German colleagues</td></tr>
</table>

	▪ Conference call in early 2005 to discuss content of Guide and designate principal editor ▪ Two drafts to be circulated between collaborators ▪ Workshop to be held in the second half of 2005 to finalise document ▪ Final review, final draft and publication of manual, early 2006
Deliverables: **Completion date to maximise benefits**:	***Guidance Manual for the Management of Toxic Algae*** Mid 2006
Target audience for the output? **Which groups should receive any reports resulting from this work?** **Should the output be submitted for independent peer review to add authority to the work?**	All water suppliers interested in toxic cyanobacteria As above The collaborators involved in this project will review the documents at length, and submit to a range of reviewers internal to their organisations, including staff at the level where the resulting management actions will be applied. (eg water treatment plant operators)

On-line monitoring

Project Title:	***Towards applying the most appropriate technologies for on-line and direct monitoring of recreational, source and treated waters impacted by toxic cyanobacteria***				
Name of Proposer & Affiliation:	Wido Schmidt (TZW)				
Collaborators:	Wayne Carmichael WSUni), Stèphanie Rinck Pfeiiffer (AR), Chris Saint (CRCWQT), Roelof Veeningen (STOWA), Paul Rassmussen , Justin Brookes, Brenton Nicholson (all CRCWQT), Bill Harding (WRC), Misha Hasen (AWWA), Ingrid Chorus (UBA) WSAA				
Estimated Total Cost of Research (Euro)	**2004 Year 1**	**2005 year 2**	**2006 Year 3**	**Beyond**	**Total**
	100,000	100,000	200,000	200,000	**600,000**

Background:	**Justification:** Cyanobacterial cells, cell byproducts, taste and odour compounds and toxins are important indicators for monitoring, early warning and modelling for harmful impacts of cyanobacteria. The technology could provide remote detection and cheap, rapid detection for early warning of toxins. The current knowledge on developing technologies such as real-time PCR, selective fluorescence measurements, mass

	spectroscopy, remote sensing and lake diagnostic systems indicate that this approach is feasible. The water quality framework requires that the critical control points are continuously monitored to assess effectiveness of barriers and risk from hazards. The rapid detection of toxin outbreaks is essential for risk management
Consequences if work not carried out:	There is a requirement to monitor at the appropriate time-scale relative to the time-scale of hazard development. Inappropriate management to a significant toxin event increases the risk of supplying poor quality water.
Benefits to be achieved: - Political - Economic - Technical	 Protection of public water supplies and recreational waters Enhanced treatment including effective and rapid control measures in response to cyanobacteria. The System which has to be developed is practicable for small an medium companies without expensive laboratory equipment Public confidence in water supply Benefits for recreational sector New methods and technologies for detection, monitoring and management of toxic cyanobacteria and taste and odorous algal metabolites
Aiming to achieve: **Specific questions answered:**	**Objectives:** Promote early, rapid, accurate and cost effective technologies for remote sensing and on-line monitoring (source water and treatment plant) of harmful cyanobacteria in water blooms. Adopt existing lab-based technologies using the fluorescence technique and gene based assays for toxins, pigments, taste and odours to deployable platform based or treatment plant formats. Can existing technologies be miniaturised and applied in remote situations for monitoring of cyanobacteria and their metabolites? Can existing technologies, used for raw water monitoring, be incorporated as monitoring and control measure in water treatment trains?
Tasks set for	Develop and deploy (apply) technologies for remote sensing/on-

contractor:	line monitoring and indication for cyanobacteria, their toxins and taste and odours.
Deliverables: **Completion date to maximise benefits**:	Methods for rapid (on-line/on-site) determination of the occurrence and removal of cyanobacteria and cyanotoxins in raw and treated waters Standard Operational Procedures for application on-line(on-site) techniques Five years Phase 1 (2 years) - **Assemble existing knowledge (4-6 month)** - Develop new technologies for toxin monitoring Phase 2 (3 years) Validate and deploy technologies to laboratory, pilot or field
Target audience for the output? **Which groups should receive any reports resulting from this work?** **Should the output be submitted for independent peer review to add authority to the work?**	Water authorities, Fisheries, Parks and Recreation Authorities All managers of water supply reservoirs, recreational waters and water treatment plants Yes