Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management
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Chapter 6. SITUATION ASSESSMENT, PLANNING AND MANAGEMENT

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Chapters 3 and 4 of this volume present evidence that cyanobacterial toxins can and do cause significant adverse health effects. These effects are associated with the occurrence of cyanobacterial blooms. As described in Chapter 2, such blooms are a natural occurrence, but occur more frequently in waters which have been subject to certain forms of human interference. The most important types of interference are enrichment of waters with nutrients (eutrophication) from point sources such as municipal wastewater outlets and non-point sources such as agriculture, and the damming of rivers (which increases retention time and exposure to sunlight). Chapter 2 also describes how, although blooms are more frequent and severe in eutrophic waters, they may occur in waters which would be considered in many world regions to be of good or acceptable quality. Of more concern is the fact that the available evidence concerning trends in eutrophication indicates that the situation is severe world-wide (see Table 6.1), although it is improving in some regions whilst deteriorating in others.

The purpose of this chapter is to assist those concerned with assessing or managing the potential risks to human health arising from toxic cyanobacteria. It is intended to serve as a guide to readers who are confronted with immediate questions and issues related to risk management, whether arising from an event or because of the suspicion of a potential hazard. It also provides an axis to assist the reader in using other parts of this book and deals with four major areas:

• The overall risk management framework.

• Situation assessment (Is there a problem? Would a problem be detected if it existed? How can the severity of the problem be interpreted in relation to other demands on resources?).

• Management options (What types of management actions are available? What are their basic characteristics?).

• Planning for management (How should a management, contingency or emergency response and investigation plan be put together?).

Table 6.1 Perceived eutrophication problem in different continents and countries

Region/country	Natural lakes	Reservoirs, rivers and irrigation systems	Estuaries, lagoons and closed areas	Marine coastal waters
AFRICA				
Central	+	++	+	
North		+	++	+
South		++		
CENTRAL AMERICA				
Caribbean	+	+		+
Guatemala/Nicaragua	+			
Mexico	+	++		
NORTH AMERICA				
Canada	++	+	+	
USA	++	++	++	+
SOUTH AMERICA				
Argentina/Chile	+	++	+	+
Brazil	+	++	++	+
Columbia/Ecuador/Peru	+	++	+	+
Venezuela/Suriname	+	+	++	
ASIA				
China	++	+	+	
India/Pakistan	+	++	+	
Indochina	+	+		
Indonesia/Philippines	++	+		
Japan	++	+	++	+
OCEANIA				
Australia/New Zealand	++	++	++	+
EUROPE (EU countries)				
Belgium		+		
Denmark	++			+
France		++	+	++
F. Germany, Fed. Rep.	++	++	+	+
Greece		+	+	+
Ireland	++	+		
Italy	++	++	+	++
Netherlands		++	++	
Portugal		++	+	

Spain		++	+	
UK	++	++		
EUROPE (other countries)				
Austria	++			
Former Czechoslovakia		+		
Finland	++		+	+
Former German Dem. Rep.	+	++	+	+
Hungary	+	+		
Norway	++	+	++	+
Poland	++	+		
Romania				+
Sweden	++		+	++
Switzerland	++			
Former USSR	+	++	+	+
Former Yugoslavia				+

\+ Identified problems

++ Serious problems

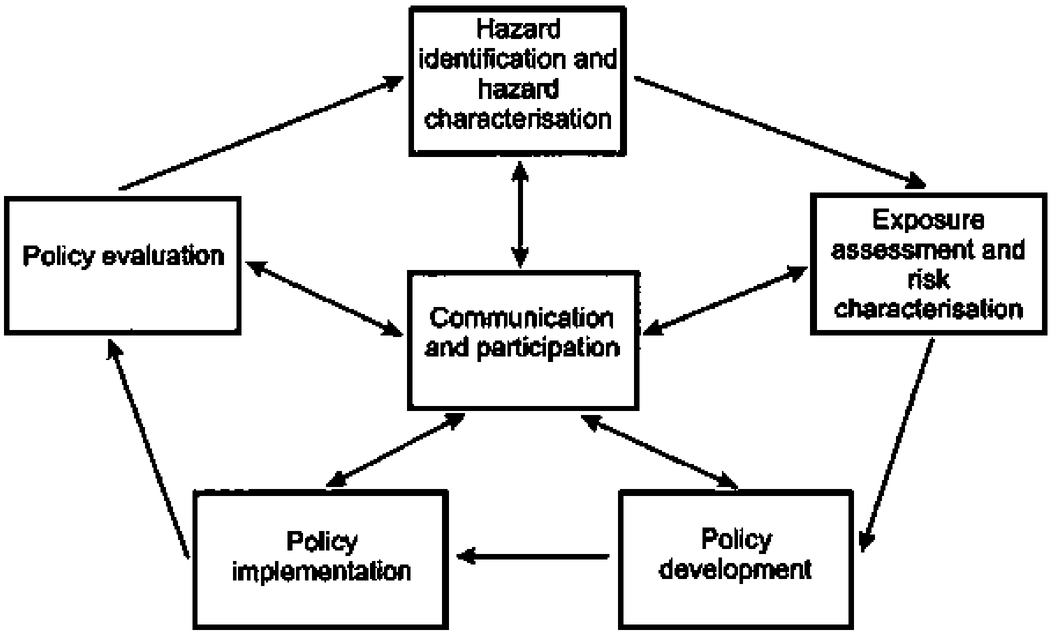
Source: Adapted from Earthwatch, 1992

6.1 The risk-management framework

Risk management is a relatively recent discipline, in which developments are still occurring very rapidly. Various model schemes for risk management have been portrayed, most of which have some common elements. These include the need for an information base upon which to make decisions; the need to make decisions based on often inadequate information; the need to compare and "value" different and often very diverse outcomes with one another; and the need for broad participation in the process in all its stages. One schematic example is presented in Figure 6.1. This representation is different from many others because it completes a circle, showing the feedback of policy evaluation into hazard identification and prioritisation, and thereby into improved risk assessment and eventually into implementation of revised (improved) policy. It also places communication as a central and two-way process, indicating that it has an important role throughout risk management.

The implementation of risk management will vary greatly according to the political, social and economic context in which it takes place. Whilst it is often seen as a highly rational process, it should be recognised that the scientific basis for many of its elements is actually often extremely weak (the status of knowledge regarding some of the cyanobacterial toxins as outlined in Chapters 3 and 4 is a good example of this) and procedures for valuation of health effects are generally poorly developed. More importantly, no scientific assessment will support effective risk management if it fails to address the perceptions and priorities of the society concerned. Public acceptance of cyanobacterial-related turbidity and discoloration in recreational waters in some countries illustrates this point. Thus, a commitment to communication and participation is an essential element of any effective risk management plan.

Figure 6.1 The risk management cycle (Adapted from Soby *et al.,* 1993)



The movement towards a more comprehensive approach to risk management is inhibited by four key impediments, sometimes referred to as "institutional failures" (adapted from Gerrard, 1995):

• *Data limitations* are of two kinds: a lack of historical record on which to base current change and to recognise trends, and the inadequacy of scientific understanding on which to base judgements about cause and consequence. Such data limitations are common in the management of cyanobacterial and eutrophication problems. A common question that faces water managers is whether a cyanobacterial problem is getting worse, due for example to cultural eutrophication, or whether the problem has always been present but has remained unnoticed or, perhaps, unreported. Following widespread dissemination of information concerning the potential toxicity of cyanobacteria, blooms may start to be reported more frequently by, or to, relevant authorities.

• *Poor frameworks for analysis* impede comprehensiveness in assessment and decision-making necessary to make informed judgements. Cyanobacteria are good examples. Until recently, a general lack of knowledge and poor communication by scientists were a serious impediment to sound management action - a constraint which is now being overcome in some countries.

• *Inadequate regulatory principles* which lay too much discretion at the door of the safety official and which lead to discrepancies in levels of safety provided for different groups in society (according to their environmental circumstances and income levels). In some countries, cyanobacteria-infested drinking water sources are the only ones available to the poor or geographically isolated.

• *Insufficient consultation* procedures restrict participation of different interests that have a legitimate role to play in the determination of risk and its management (the important role of multi-agency and vested interest committees or "task forces" in the effective management of toxic cyanobacterial blooms is outlined in section 7.1). Lack of communication between government and industry sectors (including, for example, water suppliers) is especially detrimental in managing cyanotoxin issues. For example, health impact assessment generally requires health sector participation, resource management is generally under the control of environmental and/or local authorities, and abatements such as water treatment may be undertaken by local authorities or the private sector.

6.1.1 Communication and participation

In many cultures, certain characteristics lead to some risks being perceived as high priorities (that is they are little accepted or tolerated). These include:

• Risks which are "new" or unfamiliar to the population.

• Risks which are perceived to have been caused by a (especially distant and unaccountable) third party.

• Risks for which the consequences are poorly characterised and understood.

• Risks with potentially widespread or catastrophic and irreversible consequences.

• Risks outside the control of the individual.

• Risks in which the population or individual has had little possibility of influencing official responses.

Risks with these characteristics are perceived as high priorities when compared with other risks which are perhaps of equal or greater importance to health but which are voluntarily undertaken and familiar. The example of the social acceptance of smoking across much of the globe, despite widespread knowledge of the adverse health effects associated with it, is a good example of this.

A brief review of the public perception of cyanobacteria as a health hazard indicates that they will often be perceived as a high priority, perhaps higher than rational analysis of the (limited) available data would otherwise indicate. Newspaper headlines have been printed proclaiming *"Water More Toxic Than Cyanide"* after cyanobacteria were found in a particular water body. While cyanotoxins are, on a per-unit-mass basis, more toxic than cyanide, this does not mean that drinking water containing a low concentration of cyanotoxins is anywhere near as dangerous as drinking a lethal solution of cyanide, as the newspaper headline implied. Being a "new" issue, with which the general population is not familiar, the blame may be assigned to municipalities, public service utilities, or farmers. Individual choice does not enable risk avoidance (at least for drinking water exposure) and entire communities may be affected through their drinking water supply. Experience indicates that, in some countries, public concern regarding cyanobacteria has often been greater than the corresponding concern from the professional community. In other countries exactly the opposite perception exists - the public has become accustomed to "green" or "smelly" water and may disbelieve scientific warnings of risk.

Improved understanding of risk assessment and management, and an improving understanding of effective intervention, has demonstrated that differences in public and professional perceptions are not an error by either party that needs to be corrected (for example through attempts at altering public perception or discrediting scientific attempts to assess objectively and to describe risks), but are legitimate viewpoints to be taken into account through open channels of communication and especially through enabling public participation in risk management. It should be recalled that the factors which lead to a low public tolerance of risk often include the lack of familiarity (i.e. the "newness") and the inability to exert influence. Effective communication and provision of mechanisms for participation will, therefore, often address these directly.

Several sections of this book provide guidance concerning public participation and communication in relation to cyanobacterial hazards. These actions are an important aspect of all types of planning, whether for preventive management (section 6.4.1), for contingency planning (section 6.4.2) or planning in response to an incident (section 6.4.3). They are also discussed in more detail in Chapter 7.

6.1.2 Hazard identification and hazard characterisation

In the context of risk management, a hazard is usually understood to mean the property of a substance (or activity) to cause harm. Many substances are hazardous but will not necessarily lead to harm unless circumstances lead to human exposure. Even after exposure, an adverse health outcome is not necessarily certain, but rather a probability. A hazard is therefore defined as an intrinsic property of a biological, chemical or physical agent to cause adverse health effects under specific conditions. This definition implies some certainty that under similar conditions the agent will cause similar adverse health effects.

The term "risk" refers to a probability that exposure to a hazard will lead to a specific (adverse) health outcome and is usually expressed as a frequency in a given time. Thus, for example, the WHO *Guidelines for Drinking-water Quality* (WHO, 1993) define guideline values as concentrations of specific chemicals estimated to lead to a negligible additional risk for the consuming population. Where such a point of reference is adopted, it is generally referred to as the "acceptable risk", although the term "tolerable risk" is preferred by some people (because the risk is never really acceptable, but it is tolerated).

Hazard identification involves the identification of known or potential adverse health effects associated with a particular agent, based on studies conducted under specific conditions, such as the species tested and the experimental conditions. Epidemiological studies and animal toxicity studies are ranked as providing the greatest predictive information, and this is followed by *in vitro* (test tube) assays and qualitative structure activity relationships (QSAR) predictions.

Hazard characterisation is the extrapolation phase of risk assessment aimed at making a predictive characterisation of the hazard to humans based on animal studies (species extrapolation) under low exposure conditions (extrapolation from high to low dose). The endpoint of hazard characterisation is the estimation of a "safe dose" such as a tolerable daily intake (TDI) or equivalent. In general, TDIs are only determined when there is likely to be a threshold in the relationship between dose and effect, based in part on theoretical knowledge of the mechanism of action. For genotoxic carcinogens it has been accepted that there is no threshold dose below which effects, such as initiation of the carcinogenic process, will not occur. When such chemicals cannot be completely avoided (such as some natural toxicants and contaminants), mathematical models (most of which presume linearity at low doses) have been used to estimate, through extrapolation, the possibility of adverse effects at low doses. The dose corresponding to a risk level of 1 in 1×10^5 or 1 in 1×10^6 has been considered as posing a negligible or tolerable risk.

With cyanotoxins, risk assessment is made more difficult by the paucity of scientifically-sound toxicological and epidemiological studies (see Chapter 4). The available animal data are limited, particularly in the case of chronic or long-term effects of cyanotoxins. The lack of data is reflected in the fact that a WHO guideline has been agreed only for one group of cyanotoxins (i.e. the microcystins, see Chapter 5) and only as a provisional guideline value for the toxin most commonly studied (i.e. microcystin-LR). Uncertainties about the environmental fate of cyanotoxins (for example, to what extent the toxins are accumulated in fish and shellfish that may be consumed by humans, see Chapter 3) add to the difficulty.

6.1.3 Exposure assessment and risk characterisation

Exposure assessment can relate to exposure to cyanobacterial toxins during an outbreak of disease, or it can be an assessment of the likely exposure of people through consuming drinking water or swimming in lakes known to contain certain levels of cyanotoxins or cyanobacteria.

Risk characterisation is the qualitative and/or quantitative estimation, including the attendant uncertainties, of the severity and probable occurrence or absence of known or potential adverse health effects in an exposed population. This estimation is based on hazard identification, hazard characterisation and exposure assessment. If it is calculated as the "probable risk" (such as the number of persons in a population that are expected to get cancer from exposure to a toxic chemical), the estimated risk takes on more meaning than it deserves, because of uncertainties in the process. Alternatively, risk characterisation can be taken as establishing levels of daily exposure over a lifetime at which the risk is "negligible" (see section 4.2).

6.1.4 Policy development

The processes of hazard identification, hazard characterisation, exposure assessment and risk characterisation may be readily viewed as rational, scientific activities. In contrast, policy development takes account of both rational assessment and societal values. It therefore requires the valuation of a specific health outcome (such as skin rash, gastro-enteritis, cancer or death). Most definitions of risk assessment therefore combine a frequency estimation with some valuation of the seriousness of the consequences.

Whilst several approaches have been proposed for the rational comparison of the "value" of different adverse health outcomes it should be recalled that such valuation is principally driven by public perception and societal concerns, and rational analysis may be of very limited relevance. Experience with the enforcement of recreational water quality standards leading to restrictions on bathing has shown that public reaction may vary between the extremes of proclaiming that "there is nothing wrong with the water, we have been swimming in it for years without any illness, the authorities do not know what they are talking about" to "this water has killed a pet dog and must be doing me harm too - something must be done about it immediately".

Knowledge of the characteristics of a hazard, the local occurrence of the hazardous conditions and an assessment of the seriousness of the outcomes of exposure, provides the basis for development of policy. However, other factors should be considered. These may include: the seriousness of other hazards and associated health outcomes that might compete for limited resources; the cost and effectiveness of remedial and preventative actions; and the availability of technical solutions and of experience in their application in the country or region. For effective policy development the above-mentioned factors must be brought together. In most circumstances this is best done in a forum which enables participation of all concerned parties including, for example, water utilities, professional associations, public representatives and experts in the topic under consideration (see section 7.1).

6.1.5 Policy implementation

One of the most frequent failures of policy development is the formulation of legislation in the absence of consideration of its sound and sustainable implementation. In the field of water supply, there has been an increasing recognition by governments of the general need to ensure availability of water supplies, rather than costly treatment only for favoured localities.

A number of actions are available to governments with which to support policy implementation, the most obvious being regulatory enforcement. This implies a capacity to monitor the implementation of the regulations and a will to enforce compliance when the regulations are not met. Other mechanisms for implementation include voluntary codes, conflict resolution, economic instruments and public information and participation (see Chapter 7). Most frequently, multiple actions will be used and will interact with one another to encourage safer behaviours and practices.

6.1.6 Evaluation of management plans and actions

The types of actions described above should, ideally, be combined in appropriate preventative, remedial and contingency plans according to local circumstances and should constitute part of a declared policy for control of adverse human health impacts from cyanobacteria. Thus, they would be integrated into water sector policy more generally, established at national level and operated at local levels supported by legislative frameworks, trained staff and effective institutions with proactive strategies for awareness raising and information dissemination (see Chapter 7).

These plans must be periodically reviewed. In particular, after an incident, it is useful to reflect on the parts of the contingency plan that worked well and those parts that did not function effectively. With long-term, preventative or remedial management actions it is crucial to put in place a system of monitoring that will enable the efficacy of the actions to be evaluated. There may be long delays before any benefit of a management action is perceived in lakes and reservoirs - in some cases 5-10 years or longer.

It is important to consider the tenets and principles of Adaptive Environmental Management (AEM), particularly with long-term management actions. Decisions and actions are often made on the best available advice, recognising that with any complex ecological problem, such as with a toxic cyanobacterial bloom, the information available to guide a specific management action will always be limited and inadequate. It is important, therefore, to monitor the outcome of the management action, and then to modify or revise the action depending upon the response, or as new scientific information and techniques become available.

6.2 Situation assessment

Assessing the risk posed by toxic cyanobacteria, or the potential for development of cyanobacterial blooms, and linking this to effective measures for the protection of public health within available resources, is complex. Situation assessment may be proactive, for example to determine whether contingency planning is required or to inform long-term action, such as pollution control to minimise bloom formation; or it may be reactive, for example to assist in interpretation of specific local events or conditions to inform emergency or incident response.

An important factor in situation assessment is understanding the adequacy of available information with which to make the assessment. In many, if not all, cases epidemiological evidence of cyanobacteria-related health effects would not be available because of poor or non-standardised, or poorly differentiated, diagnoses; lack of awareness of cyanotoxins as potential causes of symptoms; and inadequate reporting systems, research programmes, or information analysis. In most situations a limited range of information is available to assist in identifying whether a problem or potential problem exists. The types of information possibly available to aid in assessment are summarised in Table 6.2.

6.2.1 Drinking water supply information

The monitoring of water bodies and supply systems for cyanobacteria and cyanotoxins is not yet common practice in most countries in the world. There are a number of critical control points in the potable water supply system where testing for cyanotoxins and intact cyanobacterial cells should be carried out if significant cyanobacterial populations occur in the source water. These may include the water storage reservoir or river; the treatment plant raw water intake; key points in the treatment process; and in the final treated drinking water, depending on local circumstances. Details of such critical points are given in Table 5.1 with more detailed monitoring information being provided in Chapters 10-13.

One requirement is to be aware of which members of the community receive drinking water from which water supply. This information is usually readily available in cities and large towns but this may not be the case in rural areas. In addition, the existence of water treatment systems and their effectiveness in cyanotoxin removal (see Chapter 9) should be ascertained. For small community supplies there may be little or no water treatment, and this must be taken into account by health authorities when assessing any potential risk situation.

To aid in making a rapid situation assessment based on available water supply information, and critical control points as outlined in Table 5.1, the protection categories outlined in Figure 6.2 should be consulted. This schematic flow diagram may be particularly useful in those countries and regions where little or no consideration has been given previously to the potential risk posed by toxic cyanobacteria in drinking water supplies. The flow diagram focuses on the raw water supply and treatment stream, with attention being paid to the likelihood of toxin release from intact cells (either in the storage reservoir or during the transport network to the treatment plant), removal of intact cells (and their toxins), and the capacity for removal or destruction of dissolved cyanotoxins.

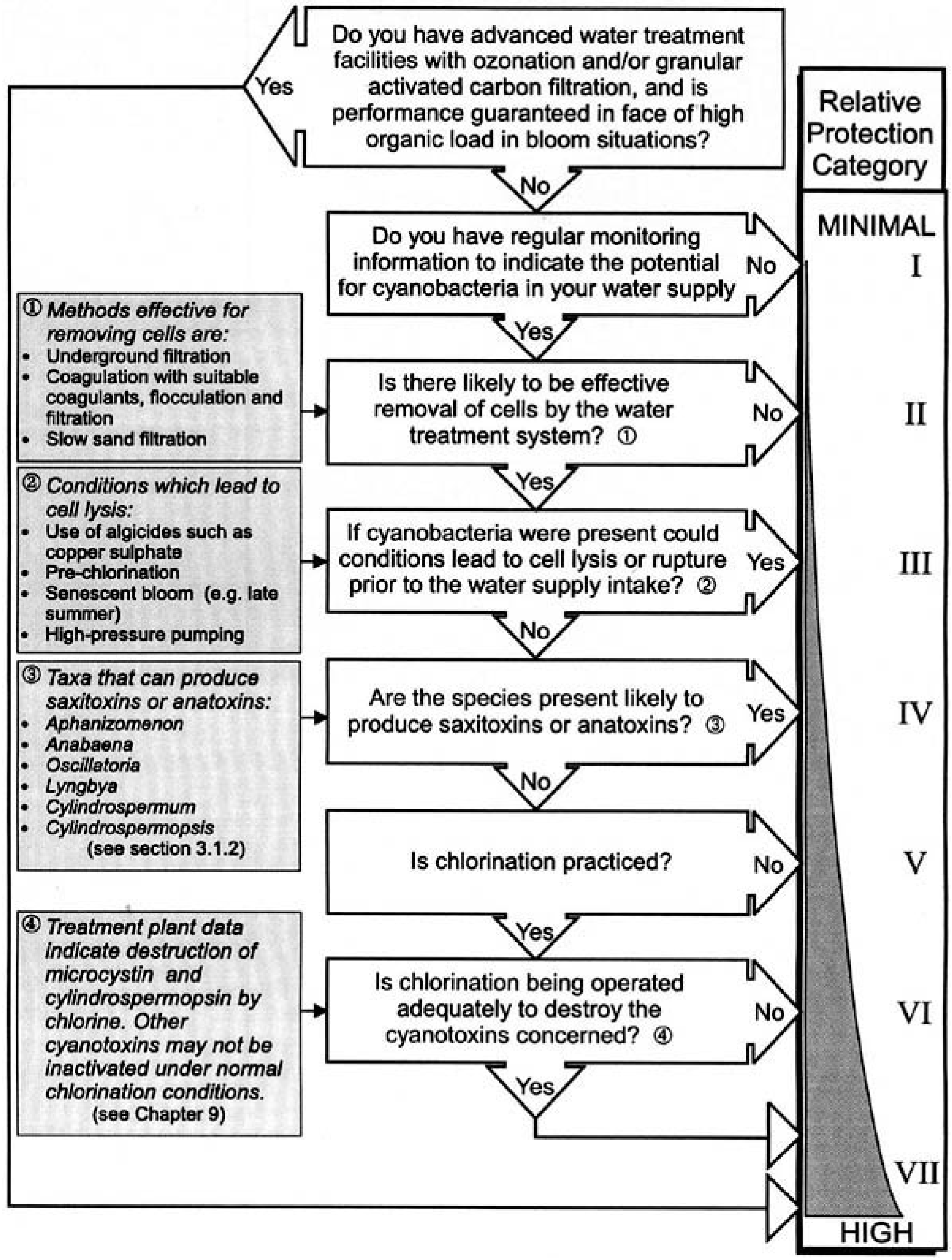
Table 6.2 Types of information of assistance to assess whether a health problem from a cyanobacterial bloom exists or is likely in a particular water body

Observation	Sources of information	Management options
Potential for bloom formation	Water quality monitoring data (nutrients, temperature, etc.)	Basis for proactive management
History of bloom formation	Cyanobacterial blooms may follow marked seasonal and annual patterns	Can inform proactive management
Monitoring of cyanobacteria and/or cyanotoxins	Turbidity, discolouration, cell microscopic identification, cell counts and toxin analysis provide increasingly reliable information	Possible only during event and enables only reactive management
"Scum scouting"	In areas of high public interest the general public and untrained agency staff may play a role in identifying and reporting obvious hazards such as scums	Possible only during event and enables only reactive management
Reporting of animal deaths and human illness	Requires both volition and a mechanism for data collection which may not exist	Possible only during event and informs only reactive management
Epidemiological detection of disease patterns in the human population	Requires both effective reporting and large-scale effects before detection likely	Normally well after an event; can inform future management strategies

6.2.2 Recreational water information

Assessing the potential hazard at recreational water bodies is complicated by the numerous points at which people may enter or move around the water and by the heterogeneous and often rapidly changing distributions of cyanobacterial populations, particularly scums which may be blown around by the wind. As noted in section 5.2.2, concentrated scums pose the greatest risk to bathers. However, monitoring of their potentially rapid formation and dispersal, as well the monitoring of all water bodies used for recreational purposes, is rarely likely to be achievable, nor is it appropriate unless conditions indicate otherwise. Therefore, additional approaches to assessing cyanobacterial risks at recreational sites are needed.

Figure 6.2 Simple and rapid assessment of the degree of protection afforded by drinking water supply systems. Note that this figure should be used with, rather than instead of, more detailed health investigations



Visual monitoring for scums around bathing areas considered to be at-risk is crucial for protecting human health and is quite easy to perform (see Chapters 11 and 12). Operators of recreational sites can be involved in assessing changes of situation.

Furthermore, participation of the public in monitoring for cyanobacteria, and particularly for scums, is a very effective approach (see Table 6.2 under "scum scouting"). This involves education on appearance and toxicity of scums, as well as on recognition of cyanobacteria at high cell densities when they do not form scums (see Chapter 7). An example of a message to convey this may be:

"If you walk into the water up to your knees, carefully, without stirring up sediment, and cannot see your feet because of a greenish discoloration, don't swim and inform the local authority using the following telephone number".

In many countries and regions, the current situation is that public awareness is negligible and knowledge of the risk posed by bathing in cyanobacterial scums is lacking. Eye witness accounts in Australia, Germany and Japan report swimmers deliberately covering themselves in cyanobacterial scum for the sake of an "exciting" photograph, and one well-documented poisoning case in the UK resulted from army cadets undertaking kayak "Eskimo rolls" in cyanobacterial scum. If public education not only addresses personal health risk but also stimulates a sense of responsibility in reporting scums, valuable support for risk assessment at recreational sites can be gained (see Chapter 7).

6.2.3 Environmental information

Environmental information, including physical, chemical and biological data can aid in the prediction and assessment of the likelihood, or presence, of cyanobacterial mass developments, including blooms, scums and mats. It can also help predict and assess types of cyanobacterial toxins and their location.

Historical records and local knowledge

Consultation of historical records, if available, can indicate whether a water body has been prone to cyanobacterial bloom development. Useful information is sometimes available from the local community, including descriptions of the water body and examples of human health incidents, livestock mortalities and fish-kills associated with blooms and scums. However, a lack of historical and local evidence of blooms cannot be taken as assurance that cyanobacterial blooms have not occurred, or will not occur, because data may be lacking and recognition of cyanobacterial blooms and associated problems may have been inadequate (Skulberg *et al.,* 1984) and because increases in cultural eutrophication may be ongoing.

Physical data

Environments in which various species of cyanobacteria can flourish, together with the physical conditions that promote such developments are outlined in Chapter 2. In the case of the many species of planktonic cyanobacteria whose growth is favoured in warm, thermally-stratified environments, the onset of favourable growth conditions is indicated by a rise in surface water temperature above about 18 °C and the establishment of persistent thermal stratification (Reynolds, 1984; NRA, 1990). For example, the Queensland Department of Natural Resources in Australia undertook a two-year survey of thermal stratification in its major water supply reservoirs to aid in its assessment of reservoirs potentially at risk of developing cyanobacterial blooms. The study enabled reservoirs to be categorised as seasonally strongly stratified, weakly stratified or well mixed, with the strongly stratified bodies being considered most at risk. In addition, the seasonal timing and persistence of stratification was used as a trigger to increase monitoring effort (i.e. as an indicator of when to switch from monthly to fortnightly or weekly sampling) (Chudek *et al.,* 1998).

Hydraulic mixing and transport processes

The ratio between the depth of the mixed layer and the depth to which sufficient light for photosynthesis penetrates, strongly influences cyanobacterial mass development and the extent to which the populations may be dominated by particular cyanobacterial types. Data on flushing rates in lakes as well as river flow rates are useful because planktonic cyanobacteria do not usually attain high population densities in highly flushed environments with retention times (i.e. the time it takes for the water volume to be exchanged once) of less than 5-10 days, or in the open channels of flowing rivers. If river flows are reduced due to drought and/or excessive abstraction of water, cyanobacterial bloom development can be anticipated provided nutrient concentrations and light penetration are adequate (e.g. Bowling and Baker, 1996). Section 2.3 on cyanobacterial "ecostrategists" provides further details of this, together with section 8.5 on the hydrophysical control of cyanobacteria.

Chemical data

The mass development of cyanobacteria is dependent on the nutrient concentrations (especially phosphorus and nitrogen) in a water body. The relationship between mean chlorophyll *a* concentrations (as a simple measure of cyanobacterial and planktonic algal biomass) and annual mean phosphorus concentrations provides a valuable (but easily misused) basis for assessing the likelihood of planktonic biomass development; this is discussed critically in Chapter 8 (Vollenweider, 1968; Vollenweider and Kerekes, 1980). Inputs and concentrations of nitrate and ammonia should also be considered because these can influence growth rates, maximum biomass and phytoplankton species composition. The ability of several toxigenic cyanobacterial genera to fix dissolved atmospheric nitrogen under aerobic conditions (e.g. *Anabaena, Aphanizomenon, Nodularia),* but not others (e.g. *Microcystis, Oscillatoria,* emphasises the need to take physical, chemical and biological factors into account when attempting to predict the likelihood of cyanobacterial mass development.

Biological data

Long-term and within-year monitoring records are useful in contributing to the assessment of the likelihood, onset and persistence of cyanobacterial mass developments. Such long-term data sets are not widely available, and often their value may not be apparent to managers who may see long-term monitoring as difficult to justify. This may be the case particularly in water bodies that have no history of cyanobacterial problems. Health authorities responsible for the quality of recreational waters and drinking water resources in many countries may not be sufficiently informed of data available in environmental authorities or local research institutions. Establishing such contacts is strongly recommended for assessing potential cyanobacterial risks.

In addition to monitoring for total phytoplankton biomass (measured by cell counts or as chlorophyll *a* concentration) and cyanobacterial genera or species distribution and numbers (see Chapter 12), information on other biota in the reservoir, lake or river can be useful. This could include the types and abundance of phytoplankton grazers (zooplankton) and of zooplanktivorous fish (see section 8.5 for details).

6.2.4 Health information

Information on the health of the population is collected in nearly all countries for the purpose of providing assistance in the prevention and control of disease. Often included in this information are records of outbreaks of gastro-enteritis and, where possible, their causes. Most sources of gastro-enteritis are infectious organisms, although in most cases of gastro-enteritis a specific cause is not identified. When a substantial outbreak of gastro-enteritis occurs it will generally be investigated in order to determine the source and the causative organisms. Faecal, food and water samples may be screened for a variety of possible pathogens, and only if no pathogens have been identified will the possibility of toxicity in the water or food be investigated. As awareness of cyanobacterial toxicity increases, the likelihood of these toxins being considered as a possible cause for clinical illness increases.

Routine monitoring for the presence of cyanobacterial cells or cyanotoxins in drinking water is undertaken in only a few countries at present, and then only by some water supply companies or authorities. In those countries where there is an awareness of the problem, monitoring of reservoirs after the onset of a cyanobacterial bloom has been detected is more common. As a result of the absence of routine monitoring, reports of gastro-enteritis outbreaks that have been later attributed to cyanobacterial poisoning have been made in the absence of cell counts or toxin measurement at the time of the event (for examples see section 4.1).

It is unlikely that an outbreak of illness will be related to cyanobacteria in the drinking or bathing water unless a specific local investigation is conducted. A link between data gathered by health authorities and cyanobacterial data obtained from water monitoring will be required if acute gastro-enteritis caused by cyanotoxins is to be understood and avoided. This may be established by the reporting of monitoring data collected by water supply agencies to health authorities. In outbreaks of gastro-enteritis in which no pathogen has been detected, it may be useful to look at the geographical distribution of cases to see whether the drinking water distribution system is the likely source. Investigation of the presence of cyanotoxins can follow (if still present), or proactive investigation for a subsequent bloom can be introduced.

Until cyanobacterial monitoring and cyanotoxin analysis are more widely established, it will remain difficult to correlate clinical findings with the toxic effects of cyanobacteria.

6.2.5 Other data

In addition to the drinking water, recreational water environment and health information that may assist in developing a situation assessment, additional information may be gleaned from veterinary records of animal deaths and *post mortem* examinations (see Chapter 4 for likely symptoms and pathologies). While in many cases it may not be possible to attribute unequivocally animal deaths, or even poor water quality, to toxic cyanobacteria, consistent relationships between these observations and particular water bodies at certain times of the year may be indicative of water bodies with potential cyanobacterial problems.

6.3 Management actions, the Alert Levels Framework

An Alert Levels Framework is a monitoring and management action sequence that water treatment plant operators and managers can use to provide a graduated response to the onset and progress of a cyanobacterial bloom. Circumstances and operational alternatives will vary depending upon the source of the water supply and the analytical and water treatment facilities available. The managerial response model, presented as a "decision tree" in Figure 6.3, is based upon the critical control points identified in Table 5.1, the drinking water supply protection categories defined in Figure 6.2, and on an alert levels framework developed earlier in Australia. The decision tree should be seen as a general framework, recognising that it may be appropriate to adapt specific alert levels and actions to suit local conditions in different countries.

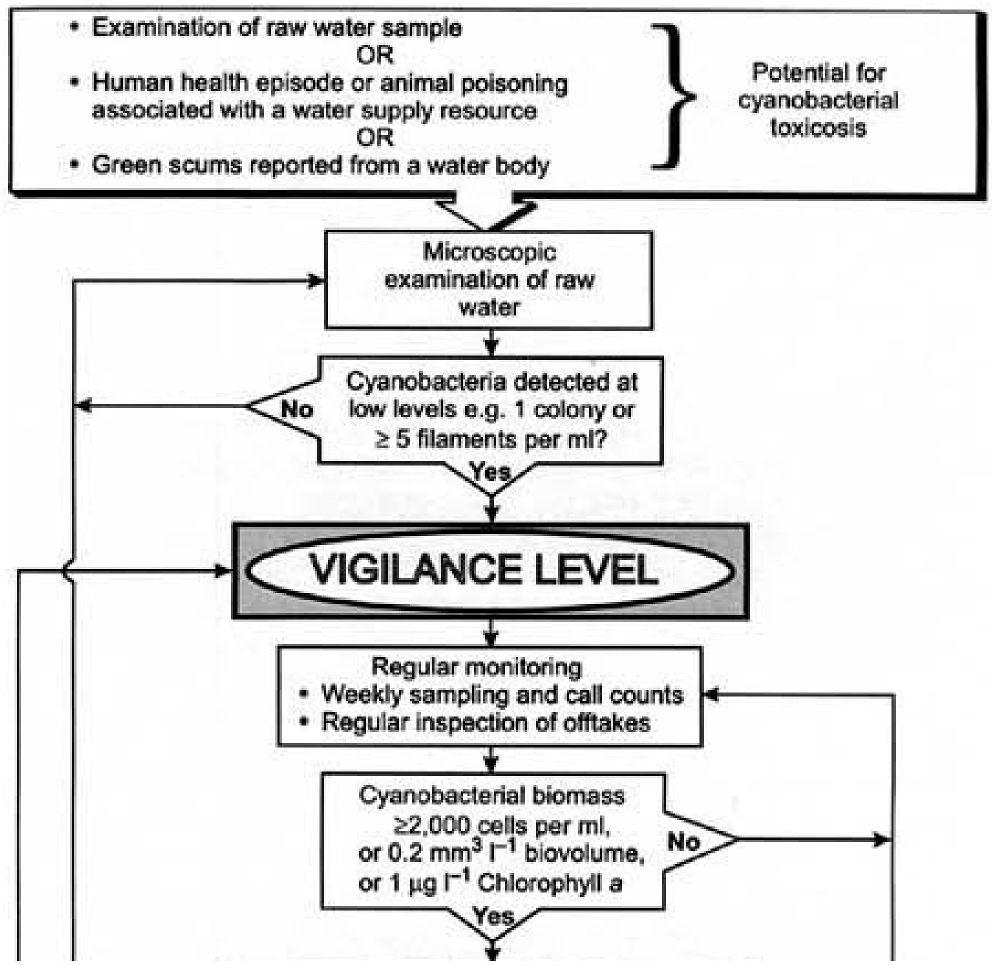
The decision tree provides for the assessment of a potentially toxic cyanobacterial bloom, with appropriate actions and responses, through three "threshold" stages. The sequence of response levels is based upon the initial detection of cyanobacteria at the Vigilance Level, progressing to moderate to high cyanobacterial numbers and possible detection of toxins above guideline concentrations at Alert Level 1. Alert Level 1 conditions require decisions to be made about the suitability of treated drinking water based on the efficacy of water treatment and the concentrations of toxins detected (if such measurements can be made). At very high cyanobacterial biomass levels in raw water, the potential health risks associated with treatment system failure, or the inability to implement effective treatment systems at all, are significantly increased. This justifies progression to a heightened risk situation denoted by Alert Level 2 conditions.

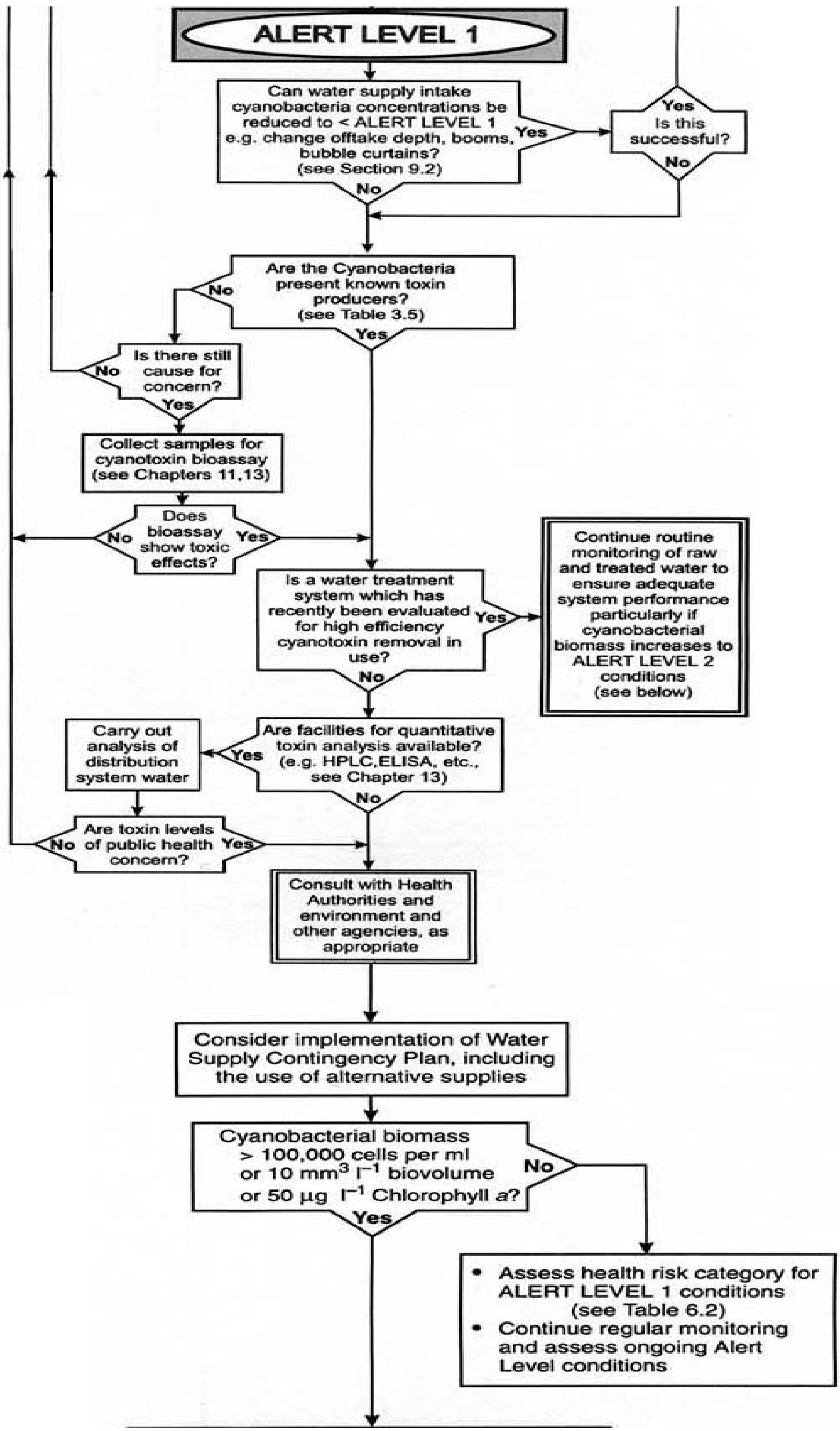
The framework has been developed largely from the perspective of the drinking water supply operator but is also important for the manager of the raw water supply. The actions accompanying each level cover categories such as additional sampling and testing, operational options, consultation with health authorities and media releases. An important part of the framework is consultation at various stages with other agencies, particularly health authorities that generally have responsibility to oversee the safety of water for potable supply.

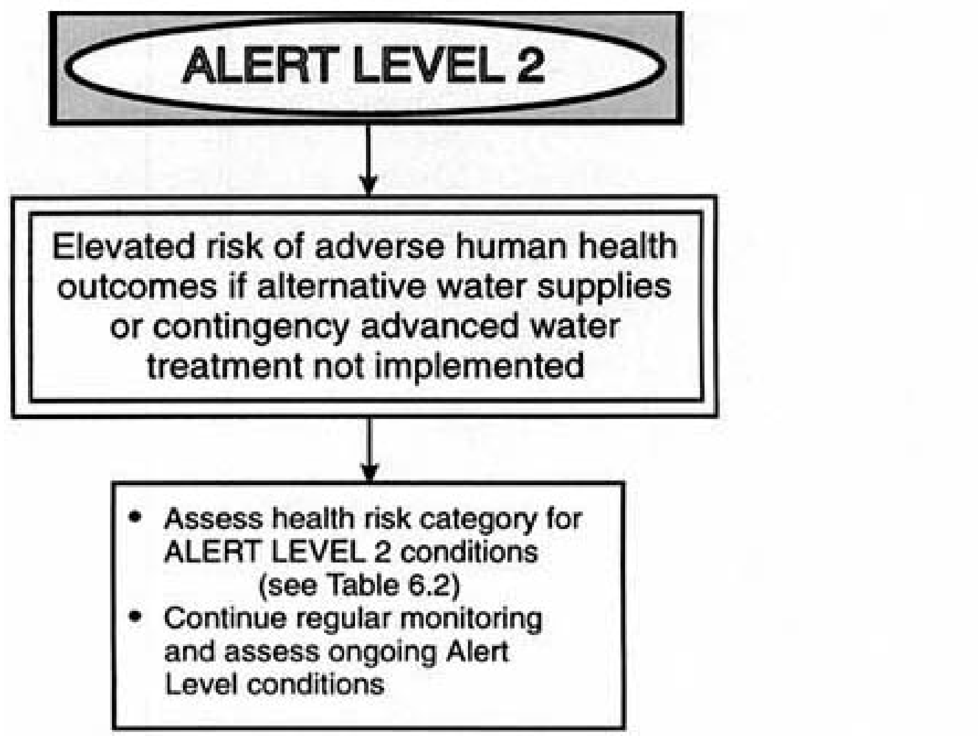
6.3.1 Vigilance Level

The Vigilance Level encompasses the possible early stages of bloom development, when cyanobacteria are first detected in unconcentrated raw water samples (see Chapter 12). The indicative value for the Vigilance Level is the detection of one colony, or five filaments, of a cyanobacterium in a 1 ml water sample, although this threshold may be adapted according to local knowledge and prior monitoring history. Taste and odours may become detectable in the supply as the population develops above the Vigilance Level, but their absence does not indicate absence of toxic cyanobacteria. For example, recognition of the highly odorous earthy/muddy smelling compound geosmin, produced by *Anabaena,* may occur at concentrations less than 1,000 cells per ml (Jones and Korth, 1995). In contrast, *Microcystis* produces weakly odorous compounds that will be detected only at cell concentrations 100-1,000 times higher than this, and are therefore unlikely to be noticed in raw water.

Figure 6.3 Decision tree incorporating a model Alert Levels Framework for monitoring and management of cyanobacteria in drinking water supplies. Note that this framework should be adapted according to local conditions




ALERT LEVEL 1
Can water supply intake cyanobacteria concentrations be reduced to < ALERT LEVEL 1 e.g. change offtake depth, booms, bubble curtains? (see Section 9.2)
Yes
No
Is this successful?
Yes
No
Are the Cyanobacteria present known toxin producers? (see Table 3.5)
No
Yes
Is there still cause for concern?
No
Yes
Collect samples for cyanotoxin bioassay (see Chapters 11,13)
Does bioassay show toxic effects?
No
Yes
Is a water treatment system which has recently been evaluated for high efficiency cyanotoxin removal in use?
Yes
No
Continue routine monitoring of raw and treated water to ensure adequate system performance particularly if cyanobacterial biomass increases to ALERT LEVEL 2 conditions (see below)
Are facilities for quantitative toxin analysis available? (e.g. HPLC,ELISA, etc., see Chapter 13)
Yes
No
Carry out analysis of distribution system water
Are toxin levels of public health concern?
No
Yes
Consult with Health Authorities and environment and other agencies, as appropriate
Consider implementation of Water Supply Contingency Plan, including the use of alternative supplies
Cyanobacterial biomass > 100,000 cells per ml or 10 mm³ l⁻¹ biovolume or 50 µg l⁻¹ Chlorophyll a?
No
Yes
• Assess health risk category for ALERT LEVEL 1 conditions (see Table 6.2)
• Continue regular monitoring and assess ongoing Alert Level conditions



The presence of cyanobacteria in low numbers (and sometimes detection of characteristic tastes and odours) constitutes an early warning for potential bloom formation; therefore, when the Vigilance Level is exceeded, it is generally appropriate to increase the sampling frequency to at least once a week, so that potentially rapid changes in cyanobacterial biomass can be monitored.

6.3.2 Alert Level 1

The Alert level 1 threshold (cyanobacterial biomass 2,000 cells per ml or 0.2 $mm^3\ l^{-1}$ biovolume or 1 $\mu g\ l^{-1}$ chlorophyll *a*) is derived from the WHO guideline for microcystin-LR (see Chapter 5) and the highest recorded microcystin content for cyanobacterial cells (Chapter 3). In other words, threshold is the cyanobacterial biomass level, assuming the species is a potential producer of microcystin, where raw water microcystin concentration could exceed the WHO guideline. Consequently, Alert Level 1 conditions require an assessment to be made (preferably based on an analysis of total toxin concentration in the raw water by a quantitative technique such as high pressure liquid chromatography (HPLC) or enzyme linked immuno sorbent assay (ELISA), see Chapter 13) as to whether the concentration of potentially toxic cyanobacteria in the raw water supply can be reduced (e.g. by offtake management) or whether the water treatment system(s) available are effective in reducing toxin concentrations to acceptable levels (see Figure 6.2 and Chapter 9).

Alert Level 1 conditions require consultation with health authorities for ongoing assessment of the status of the bloom and of the suitability of treated water for human consumption. This consultation should be initiated as early as possible and continue after the results of toxin analysis on drinking water become available. Clearly, as the biomass of potentially toxic cyanobacteria increases in the raw water, so does the risk of adverse human health effects in the absence of effective water treatment systems. Therefore, on-going monitoring for cyanobacterial biomass and toxin concentrations is essential. The monitoring programme, which should be at least weekly in frequency, may be extended throughout the source water body to establish the spatial variability of the cyanobacterial population and of toxin concentration. It may also be appropriate at this time to issue advisory notices to the public through the media or other means. Government departments and authorities with possible interests or legal responsibilities should also be contacted (see Table 7.1), as should organisations or facilities that treat or care for special "at risk" members of the public (such as kidney dialysis patients, see Chapter 4).

For toxic cyanobacteria other than those that produce microcystin (see Chapter 3, or as indicated by bioassay results) it will be necessary for local health authorities to undertake a detailed risk assessment based on the inherent hazard of the toxin detected (Chapter 4), its concentration in treated drinking water, and the exposure expected. If Alert Level 1 biomass levels are maintained, but toxins or toxicity are not detected in cyanobacterial or raw water samples, regular monitoring should continue to ensure that toxic strains or species do not develop over ensuing weeks or months (see Chapter 3).

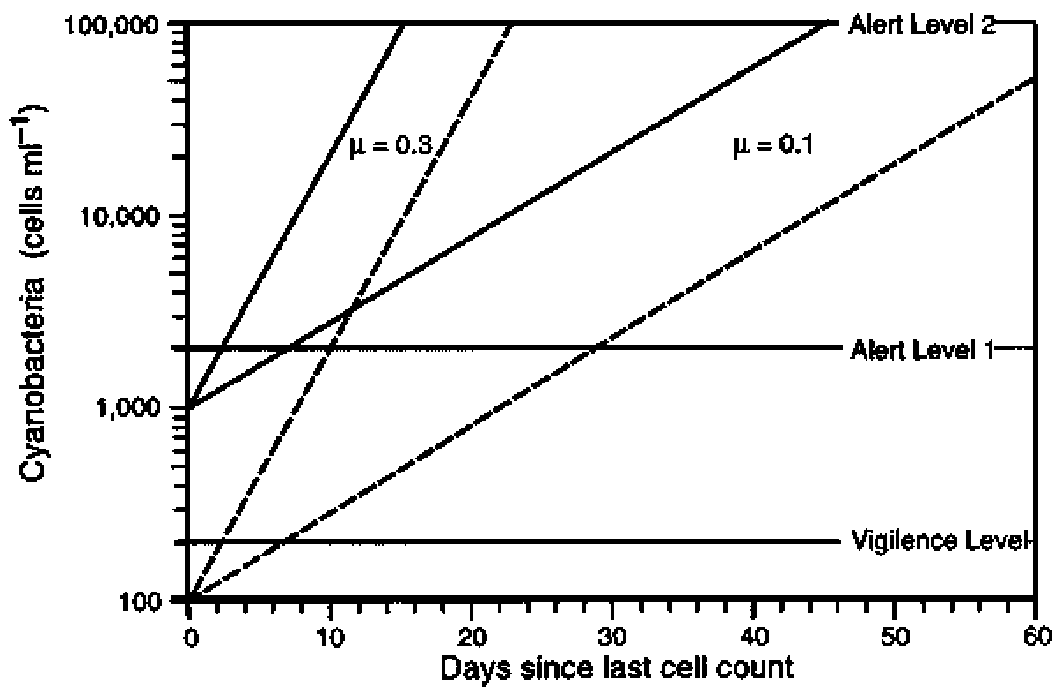
6.3.3 Alert Level 2

The threshold for Alert Level 2 (cyanobacterial biomass 100,000 cells per ml or 10 $mm^3 l^{-1}$ biovolume or 50 µg l^{-1} chlorophyll *a,* with the presence of toxins confirmed by chemical or bioassay techniques) describes an established and toxic bloom with high biomass and possibly also localised scums (although scums may also form under Alert Level 1 conditions). The sampling programme will have indicated that the bloom is widespread with no indication of a cyanobacterial population decline in the short term. Conditions in Alert level 2 are indicative of a significant increase in the risk of adverse human health effects from the supply of water that is untreated, or treated by an ineffective system (see Chapter 9), even for short-term exposure. The need for effective water treatment systems and on-going assessment of the performance of the system thus becomes of heightened importance. Whereas hydrophysical measures to reduce cyanobacterial growth may still be attempted in this phase (Chapter 8), application of algicides can enhance the problem by causing high concentrations of dissolved toxins as a consequence of cell lysis. Whereas filtration systems (possibly combined with flocculation-coagulation) may have removed cell-bound toxins, dissolved toxin is more likely to break through treatment systems.

If effective activated carbon or other advanced treatment is not available, Alert Level 2 conditions should result in the activation of a contingency water supply plan which is appropriate for the operator and the user or community. This may involve switching to an alternative supply for human consumption, the implementation of contingent treatment systems, or in some circumstances the delivery of safe drinking water to consumers by tanker or in bottles. More extensive media releases, and even direct contact with consumers via letterbox delivery of leaflets with appropriate advice to householders, may be necessary (see Chapter 7). Where advice is provided to the public because of a cyanobacterial hazard to human health, it will generally be advisable to emphasise that the water would still be suitable for purposes such as washing, laundry, toilet flushing, etc. Withdrawal of a piped drinking water supply because of a cyanobacterial toxin hazard is usually not justifiable because the adverse health effects resulting from disruption of supply (e.g. lack of toilet flushing, lack of fire fighting) are likely to outweigh substantially the cyanobacterial toxin risk itself.

Monitoring of the bloom should continue in order to determine when the bloom starts to decline so that normal supply can be resumed. The sequence at Level 2 may follow through to deactivation of alert level conditions with media releases, and advice to government departments and health authorities to confirm this. It is possible that the collapse of a bloom, or a management action such as flushing, could lead to a rapid decline from Level 2 back to Level 1 or beyond. Likewise the sequence might escalate rapidly, bypassing Level 1 to Level 2, if adequate monitoring and early warning information is not available. Cyanobacterial populations in natural water bodies, especially in hot climates, may double in size in less than two days (growth rate, μ, 0.35 d^{-1}). Therefore, monitoring frequency needs to take such potentially rapid population growth rates into account. Figure 6.4 gives an indication of the rate of change of an exponentially dividing population at two growth rates observed in field studies of cyanobacteria.

Figure 6.4 Predicted development of cyanobacterial population from initial concentration of 100 or 1,000 cells per ml and at growth rates (μ) of 0.1 and 0.3 d^{-1} (After Jones, 1997)



6.3.4 Overall risk assessment and summary of action-response thresholds

The information presented in Table 6.3 will enable water resource managers, treatment plant operators and health authorities to make a rapid assessment of the potential risks associated with increasing levels of potentially toxic cyanobacteria in water (based on the Alert Levels Framework presented above and in Figure 6.3) and the protection afforded by the monitoring and water treatment systems in place (based on the protection categories given in Figure 6.2). The risk category outcomes in Table 6.3 take into account the possibility of toxin persistence after a bloom has collapsed and the possibility, therefore, that dissolved toxins are present in the absence of viable cyanobacterial cells (hence the different risk outcomes for long term compared with short term, low biomass), and the increased risk associated with treatment system failure at very high cyanobacterial biomass (Alert Level 2).

Table 6.3 Relative risk categories for adverse human health outcomes due to toxic cyanobacteria in drinking waters

Protection category[2]	Cyanobacterial biomass category[1]			
	Absent or low (long term)	**Absent or low (short term)**	**Moderate - high (Alert Level 1)**	**Very high (Alert Level 2)**
I	-	Low	High	Very high
II	Minimal	Low	High	Very high
III	Minimal	Low	Medium- high	High
IV	Minimal	Low	Low - medium	Medium
V	Minimal	Low	Low	Medium
VI	Minimal	Minimal	Minimal - low	Low
VII	Minimal	Minimal	Minimal	Minimal - low[3]

[1] The cyanobacterial biomass categories are defined as follows (see Figures 6.3 and 6.5):

Low: Cyanobacterial biomass < 2,000 cells per ml or 0.2 mm^3 l^{-1} biovolume or 1 µg l^{-1} chlorophyll a; the category is "long term" when based on data compiled over at least a two-month period, and "short term" when based on data compiled over less than two months (including analysis of a single sample only and taking into account the risk of toxin persistence after a bloom collapses)

Moderate - high: Whether for a single measurement or for repeated measurements over several weeks, cyanobacterial biomass greater than in low category but, < 100,000 cells per ml or 10 mm^3 l^{-1} biovolume or 50 µg l^{-1} chlorophyll *a*

Very high: Cyanobacterial biomass > 100,000 cells per ml or 10 mm^3 l^{-1} biovolume or 50 µg l^{-1} chlorophyll a, and presence of toxins confirmed by chemical analysis or bioassay

[2] Protection categories from Figure 6.2

[3] Risk category is greater than minimal because of the increased risk associated with treatment system breakthrough or failure at high biomass loads

Finally, Figure 6.5 provides an "at a glance" summary of the threshold managerial action levels for drinking water (Vigilance and Alert Levels) and the health guidance levels for recreational waters outlined in Chapter 5, Table 5.2.

6.4 Planning and response

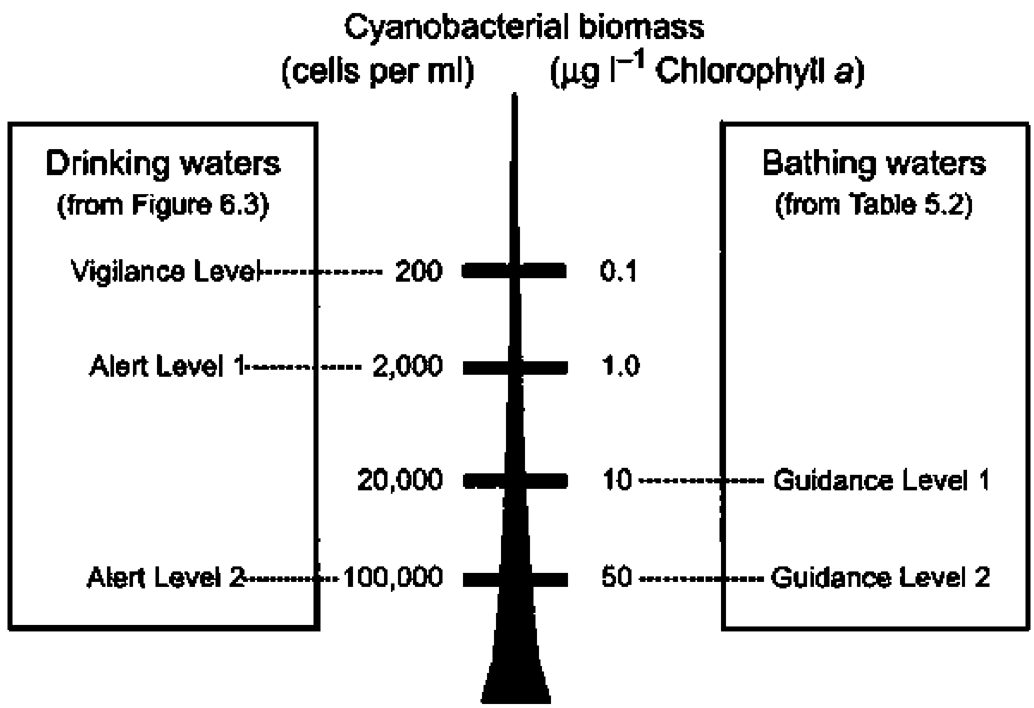
The intensity and scope of management actions to control human health hazards associated with cyanobacteria may vary widely. In the simplest case, a one-off study may indicate little or no cause for concern or it may lead to an information dissemination and public awareness and education campaign. An initial situation assessment that indicates significant risk calls for the establishment of a monitoring programme, formulation of contingency plans, changes in pollution control and water supply management, and a more substantial public information and participation strategy. Which type of response is appropriate in a given situation will depend on a number of complex and interconnected factors, of which rational assessment of human health risk is one part. Other important aspects include, for example, technical and institutional capacities, economic considerations and social values. The principal management actions that may be taken fall into three main groups:

- *Water resource and catchment management.* Most long-term actions are intended to minimise nutrient inputs to water bodies, both from external (watershed) and internal (sediment) sources, as well as altering the hydro-logic conditions in such a way as to prevent or reduce conditions favourable for cyanobacterial bloom formation (see Chapter 8 for guidance on long-term measures). Other actions may include manipulation of the aquatic food web to increase grazing pressure on cyanobacteria (see Chapter 8).

- Remedial measures in drinking water supply. Some of these actions may be seen to be applicable in short time frames and may therefore be deployed in response to a specific situation; other are also medium- or long-term actions, such as installing safeguards (such as treatment steps) in drinking water supply that will assist in controlling risks while such safeguards remain installed and operated. Other actions are associated with contingency plans to be activated in case of need (see Chapter 9).

- *Public information and awareness-raising.* A well-informed public (see Chapter 10), aware of the potential and real risks of toxic cyanobacteria, is important for many reasons. These reasons include an improved surveillance capacity through public participation; for example swimmers and other users can contact local authorities if they see cyanobacterial scums, and householders can report unusual odours in their drinking water supply. Several Australian States have community-based "WaterWatch" or "Stream-Watch" monitoring programmes that are undertaken by high school students and community groups. Experience has shown that more aware communities, which are adequately informed by appropriate authorities, will be less likely to react inappropriately in the event of a bloom.

Figure 6.5 Summary of managerial action levels for drinking waters (see Alert Levels Framework decision tree in Figure 6.3) and for bathing waters (see Guidance Levels in Table 5.2). Note that for bathing waters, the special Guidance Level 3 (scum formation) can be achieved during calm weather conditions at open water biomass levels similar to Guidance Level 1



Few remedial measures specific to recreational water sites are available in addition to those for minimising bloom formation, increasing public awareness, and informing the public. In some instances, fencing-off or the placing of a boom to prevent accumulation of scums may be considered for densely used and highly impacted areas, in addition to public information and awareness-raising.

Proactive management, that is taking action before significant cyanobacterial proliferation has occurred, is generally preferable to reactive (or crisis) management, that is placing controls in place once significant cyanobacterial proliferation has begun. Few countries presently operate monitoring programmes capable of identifying potentially hazardous conditions and early warning systems have not as yet been developed (for example giving several weeks notice of impending toxic cyanobacterial hazards), even though previous monitoring data may indicate annual "high risk" months or periods. In practice, therefore, management of cyanobacterial hazards typically occurs in three ways, preventative management plans, contingency plans and planning in emergency situations.

6.4.1 Preventative management plans

Management to prevent human health effects will typically involve prevention and minimisation of cyanobacterial blooms, deployment of appropriate drinking water treatment where required, and controls on recreational water use in order that human populations are not exposed to significant risks. It will also involve general contingency planning, which is considered in section 6.4.2.

History has shown that single-action management plans tend to have poor success rates; one example of this was the ban during the 1970s in several European countries on the use of detergents containing phosphate. Where only this action was applied, little success was seen in the abatement of cyanobacterial and algal blooms because other sources of phosphorus pollution were largely ignored (including the remaining 50-70 per cent of phosphorus in sewage that does not arise from detergents).

Reduction of nutrient pollution below threshold values which control cyanobacterial bloom formation is highly effective and sustainable. However, many water bodies require large reductions in nutrient loads, and the implementation of the necessary measures is likely to take a number of years. Furthermore, the high nutrient concentrations within such water bodies may decline only slowly in response to reduced external loading, particularly if water exchange rates are low or release from sediments is high. Thus, total prevention of cyanobacterial bloom development may require extended recovery time spans, and may even be unachievable in naturally eutrophic systems. In such situations, bloom minimisation will generally be accompanied by contingency planning and, if blooms are expected to occur, by application of appropriate drinking water treatment either continuously or at times of cyanobacterial occurrence in the source water.

Preventative management may effectively address the hydrophysical conditions of cyanobacterial growth through the use of hydraulic management (flushing, artificial mixing), or reduce drinking water intake concentrations by offtake management.

An effective approach to preventative management may be changing the drinking water source (where this is feasible). This approach was illustrated by the change from using water in shallow eutrophic ponds and ditches to using groundwater in China (see Box 5.3).

There is no single formula that can be followed to compile a good preventative management plan. However, key elements may include:

• The convening of a multi-agency and multidisciplinary committee to develop the plan and to co-ordinate its implementation.

• Development of comprehensive policy relating to point and diffuse source pollution control, and for the regulation of river flows and reservoir management for the prevention of cyanobacterial problems.

• Compilation or review of relevant technical information (such as for bloom prevention and management, drinking water treatment and recreational water management), and the involvement of key technical (e.g. scientific and engineering) personnel to provide expert advice.

• Development of procedures (including financial and institutional procedures) for implementing key actions arising from the plan.

- Development of monitoring systems to determine the effectiveness of management actions.

- Establishment of response mechanisms for modification of action in the light of feedback on management plans.

- Development of means for effective communication between agencies and with the public and media.

Two examples of how preventative plans may be co-ordinated are provided in Boxes 7.2 and 7.4.

6.4.2 Contingency plans

Plans and actions for prevention of health hazards arising from cyanobacterial blooms should aim to prevent and curtail blooms and ensure that plans are in place to respond to blooms when they do occur. Planning for such events is an important part of the overall strategy for managing health hazards associated with toxic cyanobacterial blooms.

Contingency plans are normally developed and managed at a local or regional level. National and regional authorities may, nevertheless, have important roles to play in supporting and facilitating plan formulation and in providing expertise, should an event occur. Key elements of a contingency plan overlap with those for preventative management and include:

- The convening of a multi-agency and multidisciplinary committee to develop, maintain and, if necessary, modify the plan and co-ordinate its implementation if required. The members of such a committee should be aware of their authority and responsibility as committee members in advance of an occurrence (see Chapter 7).

- Development of a comprehensive response plan including specific actions at different alert levels and the responsibilities of different agencies.

- Compilation of a manual or guide for incident response addressing the major areas of activity and including management, drinking water treatment and recreational water management, and communication with the public and media.

- Plans for effective communication between key government agencies, health authorities, water supply agencies, hospitals and the public need periodic testing.

- Ensuring the availability of technical capacity (especially analytical capacity and access to expertise) to deal with the demands of the contingency plan. The specified experts or institutions should be able to respond to specific questions in time horizons relevant to incident response, such as:

- What is the size, extent and toxicity of the bloom?

- If toxic, what types and concentrations of cyanotoxins are present in the drinking water supply and how are they partitioned between cell-bound and dissolved phases?

- Is an adequate water treatment system in place (see Chapter 9 and Table 6.2 for details), and if not will the general public be exposed to "unsafe" concentrations of cyanotoxins?

- Special precautions (e.g. portable water treatment systems, or transported safe water supplies) may be advisable for "at risk" groups especially susceptible to cyanotoxins, such as patients with previous acute liver damage.

- Special precautions (usually additional treatment facilities with careful monitoring of performance) are of crucial importance for hospitals treating patients with kidney dialysis or intravenous therapy.

- Identification of potential alternative water supplies, preferably from uncontaminated groundwater (there is the possibility that other local surface water storage facilities may be suffering simultaneously from cyanobacterial problems) to be exploited in the case of severe health hazards. This may include plans for transporting clean, treated water from other areas or deploying portable water treatment systems.

- Establishment of awareness amongst local health practitioners where significant hazards are believed to exist and development of systems for communicating with them in the event of an outbreak, including for example advice regarding the possible symptoms of cyanobacterial intoxication and what treatments are advised.

- Prior agreements regarding standardised press releases and the conditions under which their release would be justified. Release of information to the media should be co-ordinated through the main organising committee or task force.

6.4.3 Emergency responses and incident investigation

The actions to be taken in responding to an incident are similar to the elements listed under "contingency planning" (above). However, time constraints will be greater and, because of lack of prior preparation, resources may be less available. The risk of contradictory "messages" from concerned authorities is proportionately greater. Experience has shown that initiating interagency co-operation, especially between the drinking water supplier and the health authority, securing an expert opinion on the real risk to human health and initiating communication with the media and public, are crucial elements in the earliest stages of responding to an incident. It should be recalled that whilst true emergencies can arise from cyanobacterial blooms, as was the case with the Caruaru dialysis tragedy in Brazil (see Box 4.4), an event may be perceived as an emergency or "environmental crisis" by the public and the media even if this is not the case from a health viewpoint.

If the incident is deemed to be severe (as was the case in the Palm Island Mystery Disease, see Box 4.3), a health investigation should be instigated without delay. A follow-up investigation of an incident will often provide valuable information for both preventative and contingency planning. It may also lead to substantial improvement of the regional assessment of hazard due to cyanotoxin exposure, as in the case of one such investigation from Canada (Box 6.1).

Box 6.1 The Manitoba incident

Deacon Reservoir is the City of Winnipeg's main storage facility for water from Shoal Lake. The lake is generally considered to be of high quality and its water is only disinfected with chlorine prior to distribution for drinking. In late August 1993, a large cyanobacterial bloom developed in Deacon Reservoir. In an attempt to control both cyanobacterial density and taste and odour problems, municipal officials isolated the reservoir and treated it with copper sulphate. This action raised concerns that if the bloom contained toxin-producing cyanobacteria, significant quantities of the toxins may have been released into the reservoir.

Sampling determined that toxin-producing cyanobacteria were not present in the Deacon Reservoir, but they were present in Shoal lake, the dominant species being *Microcystis aeruginosa.* Analysis of water samples indicated that microcystin-LR produced by *M. aeruginosa* was present in samples collected from Shoal Lake and from the distribution system, but it was not present at detectable levels (< 0.05 µg l^{-1}) in samples from Deacon Reservoir. Maximum microcystin-LR concentrations measured in the raw water of Shoal Lake and in treated tap water were 0.45 µg l^{-1} and 0.55 µg l^{-1}, respectively. Subsequent monitoring showed a steep decline in concentrations, suggesting that higher microcystin-LR levels may have been present earlier in August 1993.

As the weather during the summer of 1993 was characterised by below-normal temperatures and above-normal precipitation (conditions that are usually not supportive of cyanobacterial bloom formation) there was concern that higher levels of microcystin-LR could develop in Shoal Lake during the more usual relatively hot, dry summers. As a result, Manitoba Environment, in co-operation with the City of Winnipeg, continued to monitor for microcystin-LR in Winnipeg's water supply. On six occasions between 1994 and the end of 1996, microcystin-LR was detected at concentrations ranging from 0.1 to 0.5 µg l^{-1}.

Because Shoal Lake (a relatively nutrient-poor water body) had supported a toxic cyanobacterial bloom, Manitoba Environment became concerned that toxic blooms might also occur in rural surface water supplies in southern Manitoba, which are generally more nutrient-rich. A comprehensive two-year study was conducted on water quality in rural south-western Manitoba surface water supplies in 1995 and 1996. In the first year of the study, microcystin-LR was found to be widely distributed in all water supply categories. Rural municipal water supplies had a higher detection frequency (93 per cent) than on-farm domestic/livestock dugouts (57 per cent), suggesting that conventional treatment methods were only partially successful in removing the toxin. Mean concentrations ranged from 0.23 µg l^{-1} in recreational sites to 0.35 µg l^{-1} in dugouts used exclusively for livestock. In the second year of the study, seven rural surface water supplies were intensively sampled for microcystin-LR. The hepatotoxin was found throughout the entire sampling period (June to December 1996), sometimes at levels greater than 0.5 µg l^{-1}, which was the "Emergency Health Advisory Guideline" formulated by Health Canada in response to the 1993 incident.

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