EXHIBIT

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THE TESTIMONY OF
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Guidelines for safe recreational water environments

VOLUME 1
COASTAL AND FRESH WATERS

WORLD HEALTH ORGANIZATION
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Guidelines for safe recreational water environments

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CHAPTER 8

Algae and cyanobacteria in fresh water

The term algae refers to microscopically small, unicellular organisms, some of which form colonies and thus reach sizes visible to the naked eye as minute green particles. These organisms are usually finely dispersed throughout the water and may cause considerable turbidity if they attain high densities. Cyanobacteria are organisms with some characteristics of bacteria and some of algae. They are similar to algae in size and, unlike other bacteria, they contain blue-green and green pigments and can perform photosynthesis. Therefore, they are also termed blue-green algae (although they usually appear more green than blue).

Human activities (e.g., agricultural runoff, inadequate sewage treatment, runoff from roads) have led to excessive fertilization (eutrophication) of many water bodies. This has led to the excessive proliferation of algae and cyanobacteria in fresh water and thus has had a considerable impact upon recreational water quality. In temperate climates, cyanobacterial dominance is most pronounced during the summer months, which coincides with the period when the demand for recreational water is highest.

Livestock poisonings led to the study of cyanobacterial toxicity, and the chemical structures of a number of cyanobacterial toxins (cyanotoxins) have been identified and their mechanisms of toxicity established. In contrast, toxic metabolites from freshwater algae have scarcely been investigated, but toxicity has been shown for freshwater species of Dinophyceae and also the brackish water Prymnesiophyceae and an ichthyotoxic species (*Peridinium polonicum*) has been detected in European lakes (Pazos et al., in press; Oshima et al., 1989). As marine species of these genera often contain toxins, it is reasonable to expect toxic species among these groups in fresh waters as well.

Although many species of freshwater algae proliferate quite intensively in eutrophic waters, they do not accumulate to form dense surface scums (often termed blooms) of extremely high cell density, as do some cyanobacteria. The toxins that freshwater algae may contain are therefore not accumulated to concentrations likely to become hazardous to human health or livestock. For these reasons, this chapter will focus primarily on the health impacts of cyanobacteria. More detailed coverage of cyanobacteria and human health is available in *Toxic Cyanobacteria in Water* (Chorus & Bartram, 1999).

8.7 Guideline values

As discussed above, approaches to recreational water safety should address the occurrence of cyanobacteria as such, because it is as yet unclear whether all important cyanotoxins have been identified, and the health outcomes observed after recreational exposure—particularly irritation of the skin and mucous membranes—are probably related to cyanobacterial substances other than the well known toxins listed in Table 8.1. Additionally, the particular hazard of liver damage by microcystins should be considered. In face of the difficulty of representative quantitative sampling due to the heterogeneous distribution of cyanobacteria in time and space, particularly with respect to scum formation and scum location, approaches should further include addressing the capacity of a water body to sustain large cyanobacterial populations.

Health impairments from cyanobacteria in recreational waters must be differentiated between the chiefly irritative symptoms caused by unknown cyanobacterial substances and the potentially more severe hazard of exposure to high concentrations of known cyanotoxins, particularly microcystins. A single guideline value therefore is not appropriate. Rather, a series of guideline values associated with incremental severity and probability of health effects is defined at three levels (Table 8.3).

8.7.1 Relatively low probability of adverse health effects

For protection from health outcomes not due to cyanotoxin toxicity, but rather to the irritative or allergenic effects of other cyanobacterial compounds, a guideline level of 20 000 cyanobacterial cells/ml (corresponding to 10 µg chlorophyll-a/litre under conditions of cyanobacterial dominance) can be derived from the prospective epidemiological study by Pilotto et al. (1997). Whereas the health outcomes reported in this study were related to cyanobacterial density and duration of exposure, they affected less than 30% of the individuals exposed. At this cyanobacterial density, 2–4 µg microcystin/litre may be expected if microcystin-producing cyanobacteria are dominant, with 10 µg/litre being possible with highly toxic blooms. This level is close to the WHO provisional drinking-water guideline value of 1 µg/litre for microcystin-LR (WHO, 1998), which is intended to be safe for lifelong consumption. Thus, health outcomes due to microcystin are unlikely, and providing information for visitors to swimming areas with this low-level risk is considered to be sufficient. Additionally, it is recommended that the authorities be informed in order to initiate further surveillance of the site. The results of the epidemiological study (Pilotto et al., 1997) reported some mild irritative effects at 5000 cells but the level of health effect and the small number of people affected were not considered to be a basis to justify action.

8.7.2 Moderate probability of adverse health effects

At higher concentrations of cyanobacterial cells, the probability of irritative symptoms is elevated. Additionally, cyanotoxins (usually cell-bound) may reach concentrations with potential health impact. To assess risk under these circumstances, the data used for the drinking-water provisional guideline value for microcystin-LR

TABLE 8.3. GUIDELINES FOR SAFE PRACTICE IN MANAGING RECREATIONAL WATERS[a]

Guidance level or situation	How guidance level derived	Health risks	Typical actions[b]
Relatively low probability of adverse health effects			
20 000 cyanobacterial cells/ml *or* 10 µg chlorophyll-a/litre with dominance of cyanobacteria	• From human bathing epidemiological study	• Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Post on-site risk advisory signs • Inform relevant authorities
Moderate probability of adverse health effects			
100 000 cyanobacterial cells/ml *or* 50 µg chlorophyll-a/litre with dominance of cyanobacteria	• From provisional drinking-water guideline value for microcystin-LR[c] and data concerning other cyanotoxins	• Potential for long-term illness with some cyanobacterial species • Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Watch for scums or conditions conducive to scums • Discourage swimming and further investigate hazard • Post on-site risk advisory signs • Inform relevant authorities
High probability of adverse health effects			
Cyanobacterial scum formation in areas where whole-body contact and/or risk of ingestion/aspiration occur	• Inference from oral animal lethal poisonings • Actual human illness case histories	• Potential for acute poisoning • Potential for long-term illness with some cyanobacterial species • Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Immediate action to control contact with scums; possible prohibition of swimming and other water contact activities • Public health follow-up investigation • Inform public and relevant authorities

[a] Derived from Chorus & Bartram, 1999.

[b] Actual action taken should be determined in light of extent of use and public health assessment of hazard.

[c] The provisional drinking-water guideline value for microcystin-LR is 1 µg/litre (WHO, 1998).

(WHO, 1998) may be applied. Swimmers involuntarily swallow some water while swimming, and the harm from ingestion of recreational water will be comparable to the harm from ingestion of water from a drinking-water supply with the same toxin content. For recreational water users with whole-body contact (see chapter 1), a swimmer can expect to ingest 100–200 ml of water in one session, sailboard riders and waterskiers probably more.

A level of 100 000 cyanobacterial cells/ml (which is equivalent to approximately 50 µg chlorophyll-a/litre if cyanobacteria dominate) represents a guideline value for a moderate health alert in recreational waters. At this level, a concentration of 20 µg microcystin/litre is likely if the bloom consists of *Microcystis* and has an average toxin

content of 0.2 pg/cell, or 0.4 µg microcystin/µg chlorophyll-a. Levels may be approximately double if *Planktothrix agardhii* dominates. With very high cellular microcystin content, 50–100 µg microcystin/litre would be possible.

The level of 20 µg microcystin/litre is equivalent to 20 times the WHO provisional guideline value concentration for microcystin-LR in drinking-water (WHO, 1998) and would result in consumption of an amount close to the tolerable daily intake (TDI) for a 60-kg adult consuming 100 ml of water while swimming (rather than 2 litres of drinking-water). However, a 15-kg child consuming 250 ml of water during extensive playing could be exposed to 10 times the TDI. The health risk will be increased if the person exposed is particularly susceptible because of, for example, chronic hepatitis B. Therefore, cyanobacterial levels likely to cause microcystin concentrations of 20 µg/litre should trigger further action.

Non-scum-forming species of cyanobacteria such as *Planktothrix agardhii* have been observed to reach cell densities corresponding to 250 µg chlorophyll-a/litre or even more in shallow water bodies. Transparency in such situations will be less than 0.5 m measured with a Secchi disc. *Planktothrix agardhii* has been shown to contain very high cell levels of microcystin (1–2 µg microcystin/µg chlorophyll-a), and therefore toxin concentrations of 200–400 µg/litre can occur without scum formation.

An additional reason for increased alert at 100 000 cells/ml is the potential for some frequently occurring cyanobacterial species (particularly *Microcystis* spp. and *Anabaena* spp.) to form scums. These scums may increase local cell density and thus toxin concentration by a factor of 1000 or more in a few hours (as illustrated in Figure 8.1), thus rapidly changing the risk from moderate to high for bathers and others involved in body-contact water sports. Cyanobacterial scum formation presents a unique problem for routine monitoring at the usual time intervals (e.g., 1 or 2 weeks) because such monitoring intervals are unlikely to pick up hazardous maximum levels. Because of the potential for rapid scum formation at a cyanobacterial density of 100 000 cells/ml or 50 µg chlorophyll-a/litre (from scum-forming cyanobacterial taxa), intensification of surveillance and protective measures are appropriate at these levels. Daily inspection for scum formation (if scum-forming taxa are present) and measures to prevent exposures in areas prone to scum formation are the two principal actions important in these situations.

Intervention is recommended to trigger effective public information campaigns to educate people on avoidance of scum contact. Furthermore, in some cases (e.g., areas with frequent scum formation), restriction of water contact activities may be judged to be appropriate. An intensified monitoring programme should be implemented, particularly looking for scum accumulations. Health authorities should be notified immediately.

8.7.3 High probability of adverse health effects

Abundant evidence exists for potentially severe health outcomes associated with scums caused by toxic cyanobacteria. No human fatalities have been unequivocally associated with cyanotoxin ingestion during recreational water activities, although

numerous animals have been killed by consuming water with cyanobacterial scum material. This discrepancy can be explained by the fact that animals will drink greater volumes of scum-containing water in relation to their body weight, whereas accidental ingestion of scums by humans during swimming will typically result in a lower dose.

Cyanobacterial scums can represent thousand-fold to million-fold concentrations of cyanobacterial cell populations. Calculations suggest that a child playing in *Microcystis* scums for a protracted period and ingesting a significant volume could receive a lethal dose, although no reports indicate that this has occurred. Based on evidence that a lethal oral dose of microcystin-LR in mice is 5000–11 600 µg/kg body weight and sensitivity between individuals may vary approximately 10-fold, the ingestion of 5–50 mg of microcystin could be expected to cause acute liver injury in a 10-kg child. Concentrations of up to 24 mg microcystin/litre from scum material have been published (Chorus & Fastner, 2001). Substantially higher enrichment of scums—up to gelatinous consistency—is occasionally observed, of which accidental ingestion of smaller volumes could cause serious harm. Anecdotal evidence indicates that children, and even adults, may be attracted to play in scums. The presence of scums caused by cyanobacteria is thus a readily detected indicator of a risk of potentially severe adverse health effects for those who come into contact with the scums. Immediate action to control scum contact is recommended for such situations.

8.7.4 Conclusions

The approach outlined in this section does not cover all conceivable situations. Swimmers may be in contact with benthic cyanobacteria after a storm breaks off clumps of filaments or cyanobacterial mats naturally detach from the sediment and are accumulated on shorelines (Edwards et al., 1992). Measures of cyanobacterial cell density will not detect these hazards. Instead, this cyanotoxin hazard calls for critical and well informed observation of swimming areas, coupled with a flexible response.

It is difficult to define "safe" concentrations of cyanobacteria in recreational water for allergenic effects or skin reactions, as individual sensitivities vary greatly. Aggravation of dermal reactions due to accumulation of cyanobacterial material and enhanced disruption of cells under bathing suits and wet suits may be a problem even at densities below the guideline levels described above.

8.8 Management options

For purposes of management, it is important to understand that cyanotoxins are chiefly found within cyanobacterial cells. Liberation into the surrounding water is possible, particularly when cells die and lyse, and differences may occur between toxins and species regarding "leakage" from intact cells. However, toxin dissolved in water is rapidly diluted and probably also degraded, whereas hazardously high toxin concentrations usually result from the accumulation of cell material as scums.

Because adequate surveillance is difficult and few immediate management options are available (other than precluding or discouraging use or cancelling water sports

activities such as competitions), provision of adequate public information is a key short-term measure. Medium- to long-term measures are identification of the sources of nutrient (in many ecosystems phosphorus, sometimes nitrogen) pollution and significant reduction of nutrient input in order to effectively reduce proliferation not only of cyanobacteria, but of potentially harmful algae as well.

8.8.1 Short-term measures

Providing adequate information to the public on the cyanobacterial risk associated with using a particular recreational water area is important not only for avoiding this hazard, but also for understanding symptoms potentially caused by exposure and identifying their cause. Communication of warnings to the public may occur through local news media, by posting warning notices and through other means. They may accompany information on other recreational water quality parameters regularly monitored by the authorities and/or some further information on cyanobacteria.

Differentiation between the degree of water contact in different types of water sports should be included in warning notices. Information on the frequently transient nature and very variable local distribution of scums is important to convey the message that recreational activities are restricted only temporarily and often only very locally, and that in such cases acceptable water quality may be found nearby, e.g., at another site of the same lake.

As a precaution, the following guidance is recommended for all freshwater-based recreation and should be included in public information:

- Avoid areas with visible cyanobacterial or algal concentrations and/or scums in the water as well as on the shore. Direct contact and swallowing appreciable amounts are associated with the greatest health risk.
- Where no scums are visible, but the water shows strong greenish discoloration and turbidity, test if you can still see your feet when standing knee-deep in the water (after wading in without stirring up sediment). If not, avoid bathing—or at least avoid ingestion of water, i.e., submersion of your head.
- In such situations, avoid water-skiing because of potentially substantial exposure to aerosol.
- If sailing, sailboarding or undertaking any other activity likely to involve accidental water immersion in the presence of cyanobacterial or algal blooms, wear clothing that is close fitting in the openings. The use of wet suits for water sports may result in a greater risk of rashes, because cyanobacterial or algal material in the water trapped inside the wet suit will be in contact with the skin for long periods of time.
- After coming ashore, shower or wash yourself down to remove cyanobacterial or algal material.

- Wash and dry all clothing and equipment after contact with cyanobacterial or algal blooms and scum.

8.8.2 Long-term measures

The aim of long-term measures to minimize health risks due to toxic algae and cyanobacteria is to prevent or reduce the formation of cyanobacterial blooms in water used for recreational water activities. This can be achieved by keeping total phosphorus concentrations below the "carrying capacity," which sustains substantial population densities. Experience from numerous water bodies shows that this can be achieved if total phosphorus concentrations are 0.01–0.03 µg/litre (depending somewhat on the size and mixing regime of the water body).

This threshold may be difficult to reach in water bodies with multiple sources of nutrient pollution. However, nutrient sources are locally very variable. Therefore, identifying the chief sources and developing strategies for preventing the formation of cyanobacterial blooms are recommended and may in many cases prove to be more feasible than initially assumed (Chorus & Mur, 1999). In particular, nutrient input from agricultural runoff may in many cases be reduced by decreasing the application of fertilizers to match the actual demand of the crop or by protecting the shoreline from erosion by planting shrubs along a buffer strip about 20 m wide along the shoreline, rather than ploughing and fertilizing to the very edge of the water.

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