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A Drinking Water Crisis in Lake Taihu, China: Linkage to Climatic Variability and Lake Management

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Abstract In late May, 2007, a drinking water crisis took place in Wuxi, Jiangsu Province, China, following a massive bloom of the toxin producing cyanobacteria *Microcystis* spp. in Lake Taihu, China's third largest freshwater lake. Taihu was the city's sole water supply, leaving approximately two million people without drinking water for at least a week. This cyanobacterial bloom event began two months earlier than previously documented for *Microcystis* blooms in Taihu. This was attributed to an unusually warm spring. The prevailing wind direction during this period caused the bloom to accumulate at the shoreline near the intake of the water plant. Water was diverted from the nearby Yangtze River in an effort to flush the lake of the bloom. However, this management action was counterproductive, because it produced a current which transported the bloom into the intake, exacerbating the drinking water contamination problem. The severity of this microcystin toxin containing bloom and the ensuing drinking water crisis were attributable to excessive nutrient enrichment; however, a multi-annual warming trend extended the bloom period and amplified its severity, and this was made worse by unanticipated negative impacts of water management. Long-term management must therefore consider both the human and climatic factors controlling these blooms and their impacts on water supply in this and other large lakes threatened by accelerating eutrophication.

Keywords Cyanobacteria · Blooms · Microcystins · Cyanotoxin · Drinking water · Large lakes · Eutrophication · Climate · Water management

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Introduction

Lake Taihu is the third largest freshwater lake in China. Located in the Changjiang (Yangtze) River delta in eastern China (Fig. 1), Taihu (meaning "Great Lake" in Chinese) is a large shallow (mean depth $\sim$ 2 m) eutrophic lake, with an area of 2338 km^2 and a volume of 4.4 billion m^3 (Pu and Yan 1998; Qin and others 2007). Approximately 40 million people live in cities and towns within the Taihu watershed. The lake is a key drinking water source for the local human population (estimated to be $\sim$10 million), with tourism, fisheries, and shipping being additionally important economic functions. Ironically, it also is a repository for waste from urban centers and nearby agricultural and industrial segments of the rapidly growing local economy (Qin and others 2007; Huang and others 2008). Dramatic increases in nutrient loading, resulting from urban and agricultural development in its watershed have fueled accelerated eutrophication (James and others 2009; Duan and others 2009), characterized by increasingly severe, toxin producing cyanobacterial blooms during summer months (Chen and others 2003a). Cyanobacterial blooms indicate advanced eutrophication of freshwater lakes and reservoirs used for drinking water supplies, fishing and recreational purposes

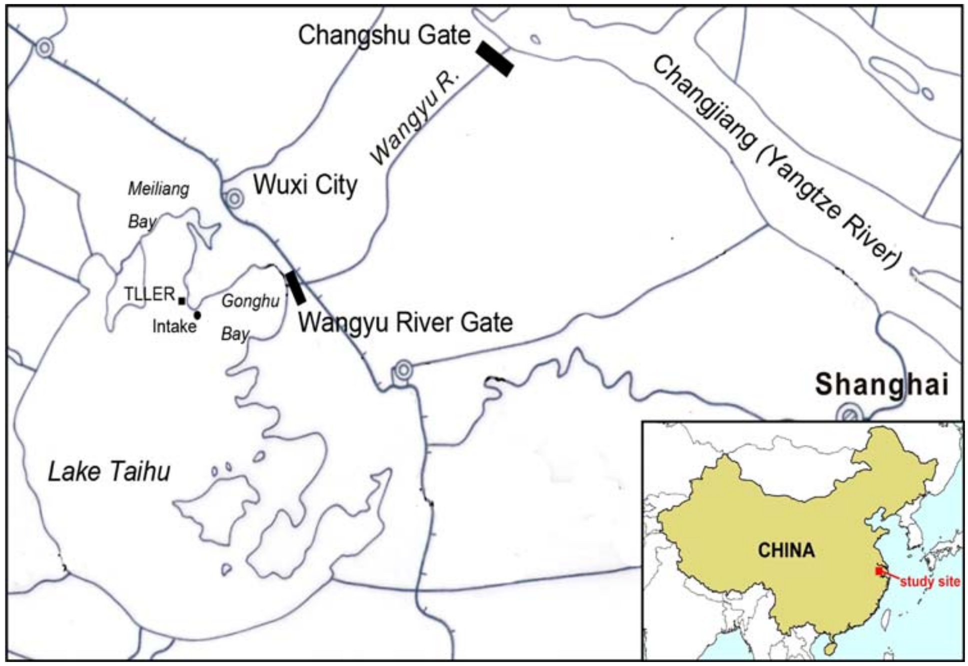


Fig. 1 Location of Lake Taihu, Meiliang Bay, Gonghu Bay, Gonghu Water Works intake (Intake in abbreviation), Wangyu River Gate, Wangyu River Changshu Gate, Wuxi City and Taihu Laboratory for Lake Ecosystem Research (TLLER)

(Fogg 1969; Paerl 1988). This symptom of eutrophication represents one of the greatest threats to the quality, safety, ecological integrity and sustainability of our water resources worldwide (World Health Organization 1998; National Research Council 2000; Paerl and Fulton 2006).

There have been many cyanobacteria-caused illnesses and even deaths of humans and animals (Hudnell 2008), not only in developing countries (Teixera and others 1993; Van Ginkel 2001; Albay and others 2003; Pyo and Jin 2007) but also in developed countries (Hawkins and others 1985; Kouzminov and others 1996; Saker and others 1999; Codd and others 1999; Murphy and others 2000; Alonso-Andicoberry and others 2002). The geographic expansion and increases in frequency and magnitude of cyanobacteria-related incidents necessitates identifying the causes and formulating management strategies to ensure long-term availability of safe drinking water supplies, an issue that is now approaching crisis proportion in China and elsewhere. In this contribution, we report a drinking water crisis caused by a massive cyanobacterial bloom in Wuxi, Jiangsu Province, China. The environmental factors (seasonality, nutrient loads, climatic conditions) promoting the 2007 bloom are addressed. We also evaluated the immediate management steps that were taken in an attempt to minimize the bloom. This event, which occurred in response to a very warm spring-summer period, appears indicative of what may be expected to occur more frequently with climatic warming. The implications of this event and the lessons learned for ensuring safe drinking water supply and lake management are discussed.

The Drinking Water Crisis in Wuxi, Jiangsu, China

On the morning of May 29, 2007, local residents in Wuxi, a city with four million inhabitants located on the shore of Taihu, awoke from a warm, humid night to find an intolerable, offensive odor coming from their water taps. Normally, residents are familiar with city water supplies having a slight earthy and musty odor combined with the smell of chlorine, because most of the treated drinking water comes from Lake Taihu. However, the intensity of the odor in the water supply at this time was beyond anything experienced previously. The contaminated drinking water came from the Gonghu Water Works, located at Gonghu Bay, Lake Taihu, approximately 20 km from Wuxi (Fig. 1). This utility treats one million cubic meters of water per day, which accounts for 80% of Wuxi's drinking supply. Our investigation by boat around the water intake found a decomposed cyanobacterial scum, i.e. foam-covered black agglomerates, flowing slowly towards the intake of the water works. These agglomerates had a strong offensive odor and were composed of cyanotoxin producing, bloom-forming cyanobacterial genus *Microcystis*. Because of the odor and concern about cyanotoxins, including microcystins, associated with these blooms, the local residents consumed bottled water instead of city water. This situation continued until June 5, 2007 when the mayor of Wuxi City went on television and drank boiled city water in an effort to demonstrate that the water was safe to drink. This bloom event proved to be a major crisis, directly affecting approximately 2 million people who regularly use the city's water (Guo 2007; Yang and others 2008).

Six water samples containing agglomerates were collected around the intake by boat on the afternoon of June 1, 2007. Concentrations of chemical oxygen demand (COD_{Mn}), total nitrogen (TN), total phosphorus (TP) and chlorophyll a (Chl-a) of these samples ranged from 7.7 to 53.6 mgL^{-1}, 4.7 to 23.4 mgL^{-1}, 0.23 to 1.05 mgL^{-1} and 78.3 to 978.5μgL^{-1}, respectively. These values were up to 10 times the values normally observed in Taihu (Zhu 2008). On June 3, 2007, spatial distributions of COD_{Mn}, TN and TP concentration in Gonghu Bay were examined. Peak concentrations of COD_{Mn}, TN and TP were 13.1 mg L^{-1}, 10.6 mg L^{-1} and 0.54 mg L^{-1} respectively, about 3–5 times the average concentrations for that time of the year in Taihu (Zhu 2008). Spatial distribution analyses showed that the highest COD_{Mn}, TN and TP concentrations were to the northeast of the water intake. This suggested that the bloom originated from the northeast part of Gonghu Bay. Chemical analysis of agglomerates sampled on June 4, 2007 showed that peak concentrations of the odor producing compounds dimethyl trisulfide and alkyl sulfide were 11 and 399 ng L^{-1} respectively (Yang and others 2008). This concentration was more than enough to generate the strong odor that was observed (Yang and others 2008). The additional cyanobacterial odor generating metabolites, 2-methyl-iso-borneol and geosmin, were also detected in the agglomerates (Yang and others 2008). The study by Yang and others (2008) suggests that the drinking water contamination by these metabolites was caused by the toxin-producing cyanobacterial bloom in this eutrophic lake.

Causes of the Drinking Water Crisis

Nuisance cyanobacterial blooms have been recurring summertime events in Taihu since the mid-1980s (Chen and others 2003a, 2008; Duan and others 2009). Why the bloom of 2007 was particularly intense and problematic with respect to contaminating the drinking water supplies is addressed below. The bloom of 2007 occurred earlier in the season than previously observed (Zhu 2008); raising questions as to what factors led to the unusually early appearance of the bloom. It was also unclear how the cyanobacterial agglomerates were so effectively transported to the water intake. Three key environmental factors were investigated as causative agents for the severity of the bloom and its negative impacts on drinking water supplies.

The first is the magnitude and spatial-temporal extent of eutrophication. Nutrient concentrations monitored in mid-lake, at a location that is representative of "average" conditions and integrative of all major discharges (Zhu 2008), showed that TN and TP concentrations have steadily increased since the mid 1980's (Chen and others 2003b; Zhu 2008). Since then, the Chinese government has launched a movement to control industrial wastewater discharge in the Lake Taihu watershed. In spite of this, there have been significant increases in TN, TP and Chl *a* concentrations during 2005 to 2006. In parallel with this nutrient enrichment, the lake has experienced increased frequencies and intensities of cyanobacterial blooms. These blooms have expanded from northern areas such as Meiliang Bay and Gonghu Bay into the open lake (Zhu 2008).

Monthly monitoring of water quality in Gonghu Bay from 1998 to 2007 showed that COD_{Mn} increased from approximately 4 to 6 mg L^{-1}, TN increased from approximately 1 to 5 mg L^{-1}, TP increased from approximately 0.06 to 0.115 mg L^{-1}, and chlorophyll *a* (Chl *a*) increased from approximately 7 to 22 µg L^{-1} (Fig. 2). It appears that the observed increase in nutrient (N and P) enrichment has played a key role in the spatial expansion of the blooms, and the growing potential for blooms so that they now exist on almost a year-round basis. Continuous nutrient over-enrichment has led to a situation where bloom frequencies, intensities and duration in the northern lake areas are now largely dependent on favorable physical conditions, including higher temperatures, and periods of reduced vertical mixing.

Secondly, the extremely warm weather combined with local wind conditions favored bloom expansion. The mean daily water surface temperature from March 1 to May 31 recorded at the Taihu Laboratory for Lake Ecosystem Research (TLLER), Chinese Academy of Sciences, at Wuxi was dramatically and significantly ($P \leq 0.05$, *t*-test) higher than average conditions during this period (Fig. 3). This helps explain why the 2007 bloom occurred two months earlier than normal. Such extremely warm conditions strongly favor cyanobacterial dominance and bloom formation in freshwater ecosystems, because temperatures supporting maximal growth tend to be higher for cyanobacteria than for competing eukaryotic algal groups (i.e.

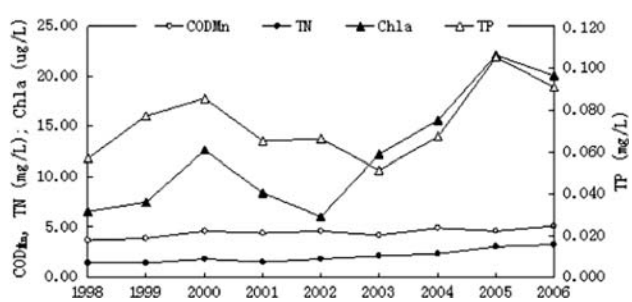


Fig. 2 Changes in concentration of COD_{Mn}, TN, TP and Chl-a at the center of Gonghu Bay from 1998 to 2006

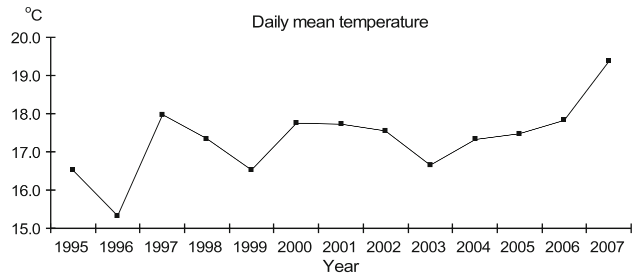


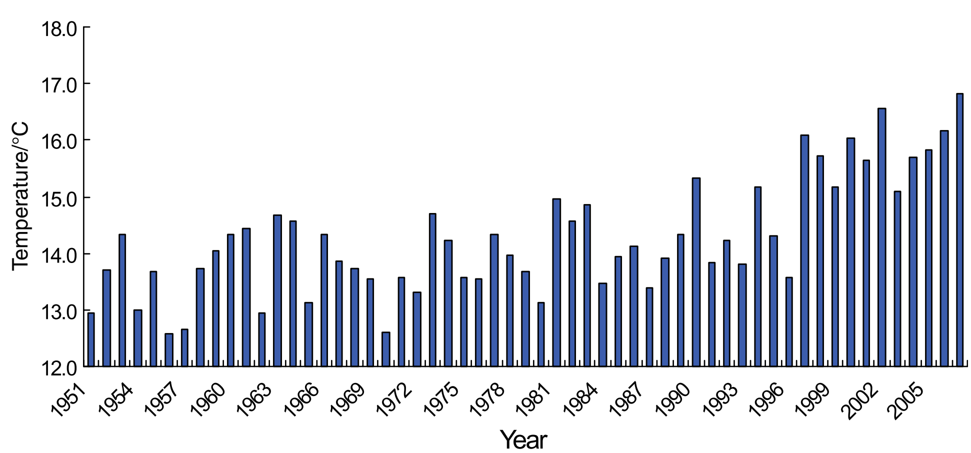
Fig. 3 Changes in daily mean surface water temperature from March 1 to May 31 in Lake Taihu since 1995

diatoms, dinoflagellates, cryptomonads, chlorophytes) (Paerl and Huisman 2008). The higher spring water temperature is indicative of elevated spring air temperature. According to records from the Shanghai meteorological station, Meteorological Bureau of China, spring surface air temperature (March to May) of 2007 was the warmest since 1950 ($P \leq 0.01$, *t*-test) (Fig. 4). This regional shift to earlier seasonal warming may be associated with a recently reported global warming trend (National Research Council 2006; National Climate Data Center 2007; Intergovernmental Panel on Climate Change 2007). The global December–February (2006–2007) land-surface temperature was the warmest on record, while the ocean surface temperature tied for the second warmest year in its 128-year recorded history (National Climatic Data Center 2007).

Moreover, the wind direction was favorable for cyanobacterial bloom accumulation in Gonghu Bay and the northern shoreline zone area. Wind measurements made from March to May, 2007 at TLLER on the shore of Taihu near Wuxi, indicate that westerly winds accounted for 40.9% of all wind direction, but northerly, easterly and southerly winds only accounted for 29.1%, 12.9% and 12.1%, respectively. Using a two-dimensional hydrodynamic model, a numerical experiment examining the wind direction effect on the cyanobacterial bloom accumulation in Gonghu Bay was developed (Li and others 2007). Four wind directions, i.e. westerly, northerly, southerly and easterly, with a constant wind velocity (~5 m/s) were provided to the model and an observed spatial distribution of chlorophyll *a* concentration in August 2006 was assigned. The initial chlorophyll *a* concentrations in August 2006 were 98.4 μg L^{-1} in Meiliang Bay, 30 μg L^{-1} in Gonghu Bay and 15 μg L^{-1} in the lake center. Results of the two dimensional hydrodynamic model suggest that a westerly wind is favorable for cyanobacterial bloom accumulation in Gonghu Bay and the northern shoreline zone (Fig. 5). This is in agreement with satellite image observation of surface water chlorophyll on May 7, 2007, which showed the highest chlorophyll a concentrations along the northwestern side of Taihu and the northern side of Gonghu Bay (Wang and Shi 2008).

Thirdly, bloom management efforts played a role in the crisis. To control the blooms, a project was initiated on May 11, 2007 by the Ministry of Water Resources and Jiangsu Province to divert water from the Yangtze River to Lake Taihu in an effort to flush the bloom from the lake. Yangtze River water was pumped through the gates at Changshu and channeled through the Wangyu River gate and discharged into Gonghu Bay (Fig. 1). While this measure increased flushing of water from the lake, it also had unintended negative effects. The diversion helped create a stable water current which transported the concentrated cyanobacterial agglomerates to the Wuxi city drinking water plant intake. Because the bloom began in March, 2007, the Yangtze River water diversion was initiated relatively late that year (May) with the goal of expeditiously improving water quality by minimizing nuisance blooms in Taihu (Report of the Taihu Basin Authority of the Ministry of Water Resources, P. R. China). The program started on May 11, 2007 with a discharge rate of 100 m^3 s^{-1}, which was increased to 120 m^3 s^{-1} on May 24 and 150 m^3 s^{-1} on May 30. From May 11 to June 1, about 2.05×10^8 m^3 of water was channeled to Gonghu Bay. With the mean width of Gonghu Bay being about 10 kilometers and the mean depth being about 2 meters, and the distance from the Wangyu River gate to the water works intake being about 14 kilometers, it was

Fig. 4 Changes in spring surface air temperature (March–May) since 1951 at Shanghai Meteorological Station, Meteorological Bureau of China



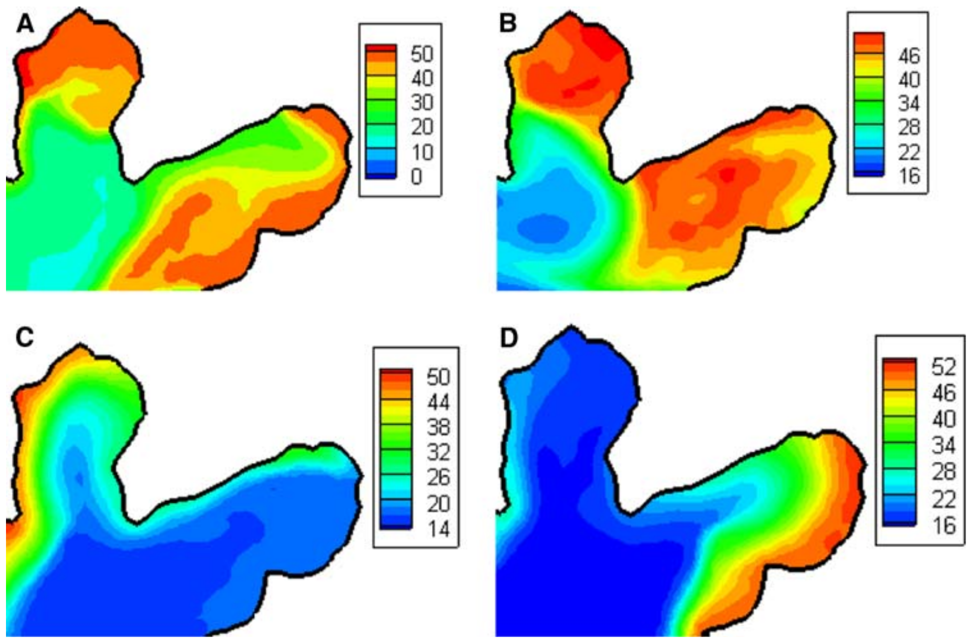


Fig. 5 Simulated spatial distribution of chlorophyll concentration (μg L^{-1}) under the influence of different wind regimes. **a** easterly wind; **b** westerly wind; **c** southerly wind; **d** northerly wind. Bloom intensities are shown as chlorophyll *a* concentrations

estimated that the flushing of water from the Wangyu River gate to the intake took about 20 days. This matched the time from the beginning of water diversion to the initiation of the drinking water crisis. In addition, the time for replacing water in Gonghu Bay with diversion water was estimated at about 20 days. Moreover, both investigations on June 1 and June 3, 2007 showed that the agglomerates were to the east of the intake and near the northern bank of Gonghu Bay, indicating that the agglomerates originated from northeast of Gonghu Bay. Clearly, flushing water from the Yangtze River drove these accumulated cyanobacterial agglomerates along the shoreline toward the intake.

It is concluded that these three above mentioned sets of factors jointly contributed to the drinking water crisis.

Discussion

Implications for Lake Management

The Intergovernmental Panel on Climate Change (IPCC) concluded in 2007 that warming of the climate system is now "unequivocal," based on observations of increases in global average air and ocean temperatures, widespread increases in melting of snow and ice, and rising global average sea level (Intergovernmental Panel on Climate Change (IPCC) 2007). This warming trend will persist into the future with mean surface air temperature increases of 1.8 to 4.0°C by the end of the 21st century as projected by most global circulation models (GCM) (Intergovernmental Panel on Climate Change (IPCC) 2007). In the Taihu basin, 5 model projections (CSIR, NCAR, CGCM, CCSR, HADLEY) suggest that this area will experience continued spring (March–May) warming, ranging from 0.21 to 0.89°C higher over the upcoming decade (2010–2019), than the previous four decades (1960–2000). This suggests that cyanobacterial blooms will likely reoccur earlier than historically observed in this lake (Chen and others 2003a; Zhu 2008).

The earlier (seasonally) warming trend will also increase the probability that cyanobacterial bloom species will be exposed to the relatively high spring nutrient loading (James and others 2009). High spring nutrient loading, particularly nitrogen loading, results from the increased use of chemical fertilizers in the Taihu basin for the spring crops (Xu and others 2006). In addition, the spring season is the dry season (as opposed to summer wet season) and the lake level is normally lowest during this period, which means that the nutrients will be concentrated. Thus, earlier warming, combined with high nutrient inputs encountering a low lake level and resulting increases in nutrient concentration will increase the potential for maximum algal bloom development and proliferation. Given the propensity for Taihu to support toxic cyanobacterial genera (i.e. *Microcystis*, *Anabaena*, *Aphanizomenon*), the risk of drinking water pollution will likely increase in the next decade if no nutrient input reductions take place. However, this situation might be dampened by earlier increases in precipitation induced by earlier seasonal temperature increases.

The use of water diversion to improve water quality merely moves pollutants from one place to another, without necessarily removing the contaminants from the water. Therefore, this approach should be viewed as a temporary measure to circumvent a drinking water crisis, but it should not be viewed as a long-term solution to improving water quality and safe water use. Numerical simulation results suggest that water diversion from the Yangtze River can improve water quality in a confined region of Lake Taihu but not for the entire lake (Hu and others 2008). In fact, recent water quality monitoring results have shown that total phosphorus concentrations in Gonghu Bay have increased, which is most likely the result of water diversion from the nutrient-rich Yangtze River (Zhu 2008).

Increases in bloom recurrence will increase the risk of contaminated drinking water supply. The bloom in Lake Taihu is largely comprised of toxin-producing *Microcystis* spp., which have increased in dominance over the past decade and now contribute from 40% to 98% of total phytoplankton biovolume during summertime periods (Chen and others 2003a). These species are known producers of the potent cyclic peptide liver toxins microcystins (MCs) (Carmichael 2001). MCs are potent inhibitors of the protein-serine family of protein phosphatases, and target these enzymes primarily in liver cells. At acute lethal concentrations, the liver cytoskeleton becomes disaggregated and liver failure occurs. At low exposure levels or under sub-chronic exposures, MCs are considered to be tumor promoters. MCs comprise a family of about 80 related cyclic heptapeptides. The main variable amino acids in all microcystins are two L-amino acids. Since 2001, it has been known that MCs are present in the bloom material (Shen and others 2003). Monthly sampling and analysis from February 2005 to January 2006 revealed that MCs were present throughout the entire water column at all times of the year in Gonghu Bay and nearby Meiliang Bay (Song and others 2007). During this period, the maximum level of MCs (cell bound) were 1.81 mg G^{-1} (dry weight), while dissolved MCs were 6.69 μg L^{-1} (Song and others 2007). Both the magnitudes of chlorophyll *a* and *Microcystis* biomass were higher in Meiliang Bay than in Gonghu Bay. However, concentrations of MCs were higher in Gonghu Bay than in Meiliang Bay (Chen and others 2008). This may be related to a higher ratio of toxic to non-toxic strains in the former (Chen and others 2008).

Currently, the World Heath Organization (WHO 1998) has a guideline value of 1 μg L^{-1} in finished drinking water for microcystin-LR, the primary microcystin variant. Analysis of Wuxi's finished water for microcystins by ELISA (Lin and others 2003) yielded a range of 63 to 76 ng L^{-1} in about 31% of the samples tested. The remaining samples were below detection levels by ELISA (Lin and others 2003). These levels are below the WHO guideline value (WHO 1998). In Brazil, where human deaths have occurred from MC contaminated kidney dialysis water, the values were about 20 μg L^{-1} (Carmichael and others 2001). Based upon these limited MC tests, the concentrations were not high enough to warrant high health risk, although thorough monitoring for MCs throughout the water bloom period will be needed to confirm overall exposure and health risk to humans. Because Gonghu Bay functions as the main drinking water source for approximately 2 million people, the MC issue needs to be carefully evaluated and addressed in the context of ecosystem and human health impacts (Carmichael 2001).

Finally, despite the presence of a massive *Microcystis* spp. bloom throughout the lake in the summer of 2007, Yang and others (2008) found that concentrations of microcystin-Leu-Arg (MC-LR) and microcystin-Arg-Arg (MC-RR) in water samples taken on June 4 and June 8 near the Wuxi city water intake were low or undetectable. A possible reason for the lack of MC detection at this time may have been that Yang and others (2008) collected water samples on June 4 and June 8 when the water of Gonghu Bay was almost replaced by water diverted from the Yangtze River. Another possibility is that the dominant MCs were analogues other than those analyzed for. We believe the concentration of MCs was neither indicative of Gonghu Bay or greater Lake Taihu, but rather of the diverted Yangtze River water.

Conclusions

A combination of environmental factors, including human activities and extreme climatic conditions, caused a massive, toxin producing cyanobacterial bloom dominated by *Microcystis* spp., which produced microcystins, that led to a major drinking water crisis at Taihu. At least two decades of excessive nutrient loading have created the potential for these cyanobacteria blooms. Because nutrient loading currently exceeds cyanobacterial growth requirements, the magnitude, spatial extent and duration of these blooms is mainly controlled by physical factors, including temperature, wind intensity and direction and irradiance. As observed worldwide, a general warming trend reflecting climate change (Bates and others 2008) favors regional cyanobacterial bloom expansion, and longer periods of bloom persistence (Jöhnk and others 2008; Paerl and Huisman 2008). Conditions at Taihu appear to reflect this trend.

Because toxin producing strains of *Microcystis* are now present almost year-round in Taihu, and animals and humans in the Taihu basin drink untreated lake water, the risk from MCs may be high for these groups. Concentrations of microcystins, exceeding the WHO acceptable level of 1 μg L^{-1}, have been measured in association with previous blooms (Song and others 2007), and it is possible that these elevated levels occurred during the 2007 bloom. Therefore, improved monitoring for cyanotoxins coupled with significant efforts at remediating the Taihu cyanobacterial blooms should be given high priority.

In addition to their toxin producing characteristics, the Taihu cyanobacterial blooms also adversely affect water quality, important for maintaining viable fisheries in the future (Fogg 1969; Paerl 1988; Paerl and Fulton 2006). These blooms are a source of organic matter fueling bottom water hypoxia, a major cause of fisheries habitat loss. Furthermore, toxin-producing, inedible cyanobacterial filaments and aggregates can disrupt and alter food webs, leading to losses of commercially and recreationally important finfish and shellfish species (Paerl and Fulton 2006). Lastly, blooms are an aesthetic nuisance that can reduce the recreational value of affected waters, by causing skin irritation and more serious adverse allergic reactions among bathers, fisherman, boaters and other users.

Although nutrient input reductions will be needed for long-term control of nuisance blooms, we also believe that climatic change, specifically warming, plays an interactive role in the establishment, duration and severity of the blooms. Long-term management must therefore consider both the human and climatic factors controlling these blooms and their impacts on water supply in this and other large lakes threatened by accelerating eutrophication.

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References

Albay M, Akcaalan R, Tufekci H, Metcalf JS, Beattie KA, Codd GA (2003) Depth profile of cyanobacterial hepatotoxins(microcystins) in three turkish freshwater lakes. Hydrobiologia 505(1–3):89–95

Alonso-Andicoberry C, Garcia-Villada L, Lopez-Rodas V, Costas E (2002) Catastrophic mortality of flamingos in a Spanish national park caused by cyanobacteria. Veterinary Record 151(23):706–707

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (eds) (2008) Climate change and water, technical paper of the intergovernmental panel on climate change. IPCC Secretariat, Geneva, 210 pp

Carmichael WW (2001) Health effects of toxin producing cyanobacteria: the cyanoHABs. Human Ecological Risk Assessment 7:1393–1407

Carmichael WW, Azevedo MFO, An JS, Molica RJR, Jochimsen EM, Lau S (2001) Human fatalities from cyanobacteria: chemical and biological evidence for cyanotoxins. Environmental Health Perspectives 109(7):663–668

Chen W, Song LR, Peng L, Wan N, Zhang XM, Gan NQ (2008) Reduction in microcystin concentrations in large and shallow lakes: Water and sediment-interface contributions. Water Research 42:763–773

Chen YW, Qin BQ, Teubner K, Dokulil MT (2003a) Long-term dynamics of phytoplankton assemblages: *Microcystis*-domination in Lake Taihu, a large shallow lake in China. Journal of Plankton Research 25:445–453

Chen YW, Fan CX, Teubner K, Dokullil M (2003b) Changes of nutrients and phytoplankton chlorophyll-a in a large shallow lake, Taihu, China: an 8-year investigation. Hydrobiologia 506(509):273–279

Codd GA, Bell SG, Kaya K, Ward CJ, Beattie KA, Metcalf JS (1999) Cyanobacterial toxins, exposure routes and human health. European Journal of Phycology 34:405–415

Duan H, Ma R, Xu X, Kong F, Zhang S, Kong W, Hao J, Shang L (2009) Two decade reconstruction of algal blooms in China's Lake Taihu. Environmental Science and Technology 43:3522–3528

Fogg GE (1969) The physiology of an algal nuisance. Proceedings of the Royal Society London B 173:175–189

Guo L (2007) Doing battle with the green monster of Lake Taihu. Science 317:1166

Hawkins PR, Runnegar MT, Jackson AR, Falconer IR (1985) Severe hepatotoxicity caused by the tropical cyanobacterium (blue-green alga) *Cylindrospermopsis raciborskii* (Woloszynska) Seenaya and Subba Raju isolated from a domestic water supply reservoir. Applied Environmental Microbiology 50:1292–1295

Hu WP, Zhai SJ, Zhu ZC, Han HJ (2008) Impacts of the Yangtze River water transfer on the restoration of Lake Taihu. Ecological Engineering 34(1):30–39

Huang WY, Xu G, Wu QL, Qin BQ (2008) Pollution and eutrophication. In: Qin BQ (ed) Lake Taihu, China, dynamics and environmental change. Springer Science+Business Media B.V., pp 23–42

Hudnell HK (2008) Cyanobacterial harmful algal blooms-state of the science and research needs. Proceedings of the interagency, international symposium on cyanobacterial harmful algal blooms. RTP North Carolina, Sept. 2005. Advances in experimental medicine and biology, vol 619, 949 pp. Springer Science.

Intergovernmental Panel on Climate Change (IPCC) (2007) Climate change 2007: the physical science basis. In: Solomon S, Qin D, Manning M (eds) Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK

James RT, Havens K, Zhu GW, Qin BQ (2009) Comparative analysis of nutrients, chlorophyll and transparency in two large shallow lakes (Lake Taihu, P.R. China and Lake Okeechobee, USA). Hydrobiologia (in press)

Jöhnk KD, Huisman J, Sharples J, Sommeijer B, Visser PM, Stroom JM (2008) Summer heatwaves promote blooms of harmful cyanobacteria. Global Change Biology 14:495–512

Kouzminov A, Ruck J, Wood SA (1996) New Zealand risk management approach for toxic cyanobacteria in drinking water. Australian and New Zealand Journal of Public Health 31(3):275–281

Li W, Zhang CK, Wang RY (2007) A numerical storm surge model based on unstructured meshes and finite volume method. Journal of Tropical Oceanography 26(2):9–14 (in Chinese)

Lin YD, Yu SZ, Xu M, Yang JB, Chen Y, Hu L (2003) A study on the relationship between Wuxi Taihu waters pollution by algae toxin and health of the population. Shanghai Journal of Preventitive Medicine 15:435–437 (in Chinese)

Murphy T, Lawson A, Nalewajko C, Murkin H, Ross L, Oguma K, McIntyre T (2000) Algal toxins - Initiators of avian botulism? Environmental Toxicology 15:558–567

National Climatic Data Center (2007) Climate of 2007—February in historical perspective. http://www.ncdc.noaa.gov/oa/climate/research/2007/feb/feb07.html

National Research Council (NRC) (2000) Clean coastal waters: understanding and reducing the effects of nutrient pollution. National Academy Press, Washington, DC

National Research Council (NRC) (2006) Surface Temperature Reconstructions For the Last 2, 000 Years. National Academy Press, Washington, DC
Paerl HW (1988) Nuisance phytoplankton blooms in coastal, estuarine, and inland waters. Limnology and Oceanography 33:823–847
Paerl HW, Fulton RS (2006) Ecology of harmful cyanobacteria. In: Graneli E, Turner J (eds) Ecology of harmful marine algae. Springer-Verlag, Berlin, pp 95–107
Paerl HW, Huisman J (2008) Blooms like it hot. Science 320:57–58
Pu P, Yan J (1998) Taihu Lake–a large shallow lake in the East China plain. Journal of Lake Sciences (China) 10(suppl):1–12
Pyo D, Jin J (2007) Production and degradation of cyanobacterial toxin in water reservoir, Lake Soyang. Bulletin of Korean Chemistry Society 28(5):800–804
Qin BQ, Xu PZ, Wu QL, Luo LC, Zhang YL (2007) Environmental issues of Lake Taihu, China. Hydrobiologia 581:3–14
Saker ML, Thomas AD, Norton JH (1999) Cattle mortality attributed to the toxic cynaobacterium *Cylindrospermopsis raciborskii* in an outback region of North Queensland. Environmental Toxicology 14(1):179–182
Shen PP, Shi Q, Hua ZC, Kong FX, Wang ZG, Zhuang SX (2003) Analysis of microcystins in cyanobacteria blooms and surface water samples from Meiliang Bay, Taihu Lake, China. Environment International 29:641–647
Song LR, Chen W, Peng L, Wan N, Gan NQ, Zhang XM (2007) Distribution and bioaccumulation of microcystins in water columns: A systematic investigation into the environmental fate and the risks associated with microcystins in Meiliang Bay, Lake Taihu. Water Research 41:2853–2864
Teixera MGLC, Costa MCN, Carvalho VLP, Pereira MS, Hage E (1993) Gastroenteritis epidemic in the area of the Itaparica Dam, Bahia, Brazil. Bulletin of Pan American Health Organization (PAHO) 27(3):244–253 (1993)
Van Ginkel CE (2001) Toxic algal incident in the Grootdraai Dam, 2001. Internal report No. N/C110/02/DEQ/0401. Institute for Water Quality Studies. Department of Water Affairs and Forestry, Pretoria, South Africa
Wang M, Shi W (2008) Satellite-observed algae blooms in China's Lake Taihu. EOS 89(22):201–202
World Heath Organization (WHO) (1998) Guidelines for drinking water quality, Addendum to vol 1, 2nd ed. World Health Organization, Recommendations. Geneva
Xu PZ, Qin BQ, Horst B, Huang WY, Yu SM, Zhang YP (2006) Nitrogen surplus of upstream agriculture land of Lake Taihu and eutrophication impact. Journal of Lake Sciences 18(4):395–400 (in Chinese with English abstract)
Yang M, Yu JW, Li ZL, Guo ZH, Burch M, Lin TF (2008) Taihu Lake not to blame for Wuxi's woes. Science 319:158
Zhu GW (2008) Eutrophic status and causing factors for a large, shallow and subtropical Lake Taihu, China. Journal of Lake Sciences 20(1):21–26 (in Chinese with English abstract)