Monitoring Recreational Freshwaters

Jennifer L. Graham, Keith A. Loftin, and Neil Kamman

State Monitoring Programs for Cyanobacterial Toxins in Recreational Freshwaters of the United States

Cyanobacterial toxins (cyanotoxins) in freshwaters have been implicated in human and animal illness and death in over 50 countries, including at least 36 states in the United States (Figure 1). The greatest risk of adverse human health effects after exposure to cyanotoxins is through accidental ingestion and inhalation of water and cyanobacterial cells during recreational activities. The cyanobacteria produce a diverse group of toxins with potentially severe human health effects, including acute hepatoenteritis and neurotoxicity; however, the most common complaints after recreational exposure to cyanobacteria and cyanotoxins are gastroenteritis and allergic reactions such as skin rashes, respiratory symptoms, and eye irritation. Despite widespread occurrence, there are relatively few documented cases of severe human health effects after recreational exposure to cyanotoxins. Animal poisonings are more common, likely because people generally avoid contact with extensive accumulations of cyanobacteria. Several animal poisonings throughout the United States (e.g., Minnesota, Nebraska, Oregon, and Vermont) involving cyanotoxins have recently drawn attention and raised public awareness about the potential human health risks associated with cyanobacteria. Increasingly, federal, state, and local organizations are faced with making decisions about cyanobacteria that affect public awareness, exposure, and health. During summer 2008, advisories were posted or beaches were closed at lakes and rivers in at least 13 states because potentially toxic cyanobacteria or cyanotoxins occurred in large enough concentrations to be considered a health risk to animals and people (Figures 2 and 3).

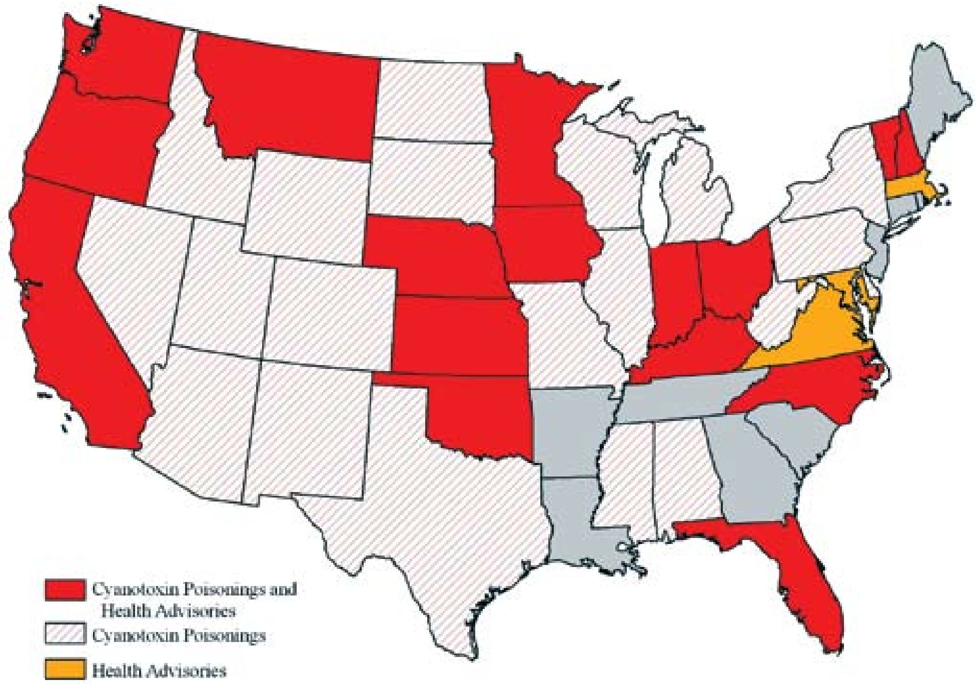


Figure 1. U.S. states with anecdotal reports of acute cyanotoxin poisonings of animals and/or humans and states that have issued recreational health advisories. Anecdotal reports of acute cyanotoxin poisonings were compiled from literature sources (Yoo et al. 1995; Chorus and Bartram 1999; Huisman et al. 2005) and newspaper articles.

World Health Organization Guidelines for Recreational Activities

Because of the concern over potential adverse human health effects, many states have been proactive in informing and educating the public about when, where, and under what conditions potentially toxic cyanobacterial blooms occur. Other states are establishing monitoring programs to protect their citizens. In the United States, there currently (2009) are no federal guidelines for monitoring of recreational hazards associated with cyanobacteria. Therefore, the preliminary World Health Organization (WHO) guidelines for recreational activities serve as the foundation for many monitoring programs. The WHO developed preliminary guidance values for exposure to cyanobacteria during recreational activities and, more specifically, the cyanotoxin microcystin-LR. Table 1 shows the probable risk of adverse human health effects based on measurements of cyanobacterial abundance, microcystin-LR concentration, or chlorophyll-*a* concentration corresponding to categories designated as low, moderate, high, or very high. For example, cyanobacterial cell

Figure 2. Near-shore accumulation of cyanobacteria.

Figure 3. Beach sign warning of the presence of a cyanobacterial bloom.

Table 1. World Health Organization guidancevalues for the relative probability of acute health effects during recreational exposure to cyanobacteria and microcystins, based on information presented in Chorus and Bartram 1999.

Relative Probability of Acute Health Effects	Cyanobacteria[1] (cells/mL)	Microcystin-LR[2] (μg/L)	Chlorophyll-*a*[3] (μg/L)
Low	< 20,000	< 10	< 10
Moderate	20,000-100,000	10-20	10-50
High	100,000-10,000,000	20-2,000	50-5,000
Very High	>10,000,000	>2,000	>5,000

[1] The WHO guidelines were developed for *Microcystis* dominated samples with an assumed toxin content of 0.2 picograms of microcystin per *Microcystis* cell or 0.4 micrograms of microcystin per microgram of chlorophyll-a with a minimum criteria of at least cyanobacterial dominance.

[2] Although the WHO guidelines are specifically for microcystin-LR, enzyme-linked immunosorbent assays (the most commonly used measure of microcystins) do not separate microcystin and nodularin congeners. Therefore, total microcystin and nodularin concentrations often are used to assess the probability of acute health effects instead of microcystin-LR concentrations.

[3] Chlorophyll-*a* measurements serve as a surrogate and may be used singly, in the absence of additional information, or in addition to cyanobacterial abundance and microcystin measurements.

counts ≥ 100,000 cells/mL, microcystin-LR concentrations ≥ 20 μg/L, and chlorophyll-*a* concentrations ≥ 50 μg/L represent a high probability for adverse health effects (Chorus and Bartram 1999).

The WHO guidelines for recreation are derived from several assumptions that do not necessarily correspond to appropriate risk for sensitive populations such as children, the elderly, or the immuno-compromised. The derivation and related assumptions of the WHO guidelines are important to understand before implementation of monitoring programs to ensure objectives can be met. Discussion of the derivation of the WHO recreational guidelines and a critical review of this guidance can be found in Chorus and Bartram (1999) and Dietrich and Hoeger (2005), respectively. One noticeable absence in the WHO guidelines is what action is needed if threshold values are exceeded (for example, posting advisories or preventing exposure through beach closures).

Data Compilation

The objective of this article is to provide a comprehensive overview of state monitoring programs for cyanotoxins in recreational freshwaters of the United States. In an attempt to compile information about monitoring for cyanobacteria and cyanotoxins in the United States, we conducted an Internet search coupled with an inquiry to the Association of State and Interstate Water Pollution Control Administrators (ASIWPCA) working group about guidance values being used to post advisories and beach closures, the results of which are summarized in Tables 2 and 3. While no state programs were purposely excluded from this inquiry, we did not go so far as to contact every individual state for information about their programs. This is because toxic cyanobacterial blooms are an evolving issue of concern and information is continually being updated and changed. Additionally, the authority for determination of guidance values, posting

Table 2. States with information about the human health risks associated with recreational exposure to cyanobacteria and associated toxins available on the Internet. Detail is provided about organizations conducting monitoring and what analyses and guidance values are used to make decisions about when to post health advisories or close beaches. –, indicates information was not readily available on the internet. States were grouped into four categories (routine monitoring, monitoring guidance, event-based response, and public education) based on available information; however, many of the categories are overlapping, and several states have done more research and public education than indicated by the information presented herein.

Program	State	Organization	Analyses	Guidance/Action Level	Action
Routine Monitoring	Iowa	Department of Natural Resources Department of Public Health	Microcystin	Microcystin ≥ 20 µg/L	Advisory/Closure
	Maryland	Department of the Environment Department of Health and Mental Hygiene Department of Natural Resources	Cell counts Microcystin	-	Advisory
	Nebraska	Department of Environmental Quality Department of Health and Human Services	Microcystin	Microcystin ≥ 20 µg/L	Advisory/Closure
	New Hampshire	Department of Environmental Services	Cell counts Visual Assessment	> 50% toxigenic cyanobacteria	Advisory
	Vermont	Department of Environmental Conservation Department of Health University of Vermont	Microcystin Visual Assessment	Microcystin ≥ 6 µg/L	Advisory/Closure
Monitoring Guidance	California	CA Environmental Protection Agency Department of Health Local agencies	Cell counts[1] Microcystin[2] Visual Assessment	40,000 to 100,000 cells/ml Microcystin ≥ 8 µg/L Scum associated with toxigenic species	Advisory/Closure
	Florida	Department of Health Department of Environmental Protection Fish and Wildlife Commission Local Water Management Districts	Cell Counts Microcystin Visual Assessment	-	Advisory
	Massachusetts	Department of Health Department of Conservation and Recreation Local Agencies	Cell Counts Microcystin Visual Inspection	≥70,000 cells/ml ≥ 14 µg/L	Advisory/Closure
	Oregon	Department of Human Services Local agencies Portland District Army Corps of Engineers3	Cell counts[1] Microcystin[2] Visual Assessment	40,000 to 100,000 cells/ml Microcystin ≥ 8 µg/L Scum associated with toxigenic species	Advisory
Event-Based Response	Indiana	Board of Animal Health Department of Environmental Management Department of Health Department of Natural Resources Indiana University Purdue University Indianapolis	Microcystin	Microcystin ≥ 20 µg/L	Advisory

	Kansas[4]	Department of Health and Environment Department of Wildlife and Parks Tulsa District Army Corps of Engineers[3]	-	-	Advisory
	Kentucky[4]	Department for Environmental Protection Local agencies	-	-	Advisory
	Minnesota	Minnesota Pollution Control Agency	Cell counts Microcystin	-	Advisory
	Montana	Department of Environmental Quality	-	-	Advisory
	North Carolina	North Carolina HAB Task Force Local Agencies	-	-	Advisory/Closure
	Ohio4	Local agencies	-	-	Advisory
	Oklahoma[4]	Department of Environmental Quality Tulsa District Army Corps of Engineers[3]	Cells counts Chlorophyll Microcystin Visual Inspection	-	Advisory/Closure
	Virginia	Department of Environmental Quality Department of Health	-	-	Advisory/Closure
	Washington	Department of Health Washington Department of Ecology Local agencies	Anatoxin Microcystin Visual Inspection	Anatoxin ≥ 1 µg/L Microcystin ≥ 6 µg/L	Advisory/Closure
Public Education	Michigan	Department of Environmental Quality	-	-	-
	New York	Department of Health	-	-	-
	Wisconsin	Department of Natural Resources	-	-	-

[1] The value of 40,000 cells/ml is used for Microcystis and/or Planktothrix; 100,000 cells/ml is used for other potentially toxic cyanobacteria.

[2] The issuance of advisories is based solely on cell density determinations and is not dependent on analysis of toxins.

[3] The U.S. Army Corps of Engineers is involved on project reservoirs. Other states not indicated in the table also may have similar involvement with the U.S. Army Corps of Engineers.

[4] Advisories have been issued in these states but additional information is not readily available on the Internet.

Table 3. Websites used to compile information about state monitoring programs for cyanobacteria and cyanotoxins. Websites listed were the starting point from which information for each state was obtained.

Program	State	Website
Routine Monitoring	Iowa	http://wqm.igsb.uiowa.edu/Default.htm
	Maryland	http://www.dnr.state.md.us/bay/hab/index.html
	Nebraska	http://www.deq.state.ne.us/
	New Hampshire	http://des.nh.gov/organization/divisions/water/wmb/beaches/cyano_bacteria.htm
	Vermont	http://healthvermont.gov/enviro/bg_algae/bgalgae.aspx
Monitoring Guidance	California	http://www.waterboards.ca.gov/water_issues/programs/bluegreen_algae/
		http://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Bluegreenalgae.aspx
	Florida	http://www.floridamarine.org/features/default.asp?id=1018
		http://www.dep.state.fl.us/water/bgalgae/
	Massachusetts	http://www.mass.gov/Eeohhs2/docs/dph/environmental/exposure/protocol_cyanobacteria.pdf
		http://www.mass.gov/?pageID=eohhs2terminal&L=7&L0=Home&L1=Consumer&L2=Community+Health+and+Safety&L3=Environmental+Health&L4=Environmental+Exposure+Topics&L5=Beaches+and+Algae&L6=Algae&sid=Eeohhs2&b=terminalcontent&f=dph_environmental_c_beach_microcystis&csid=Eeohhs2
	Oregon	http://oregon.gov/DHS/ph/hab/index.shtml
		http://www.oregon.gov/DHS/ph/envtox/maadvisories.shtml
Event-Based Response	Indiana	http://www.in.gov/idem/algae/
	Kansas[1]	http://www.kdheks.gov/news/web_archives/2005/08182005b.htm
	Kentucky[1]	http://www.nkyhealth.org/docs/News/Algaerelease8-22-08.htm
	Minnesota	http://www.pca.state.mn.us/water/clmp-toxicalgae.html
	Montana	http://deq.mt.gov/press/ToxicAlgaeFactSheet.asp
	North Carolina	http://www.epi.state.nc.us/epi/oee/bluegreen.html
	Ohio[1]	http://www.nkyhealth.org/docs/News/Algaerelease8-22-08.htm
	Oklahoma[1]	http://www.swt.usace.army.mil/
	Virginia	http://www.deq.state.va.us/watermonitoring/pfiest.html
	Washington	http://www.doh.wa.gov/ehp/algae/default.htm
		http://www.ecy.wa.gov/programs/wq/plants/algae/index.html
Public Education	Michigan	http://www.deq.state.mi.us/documents/deq-ead-tas-algae.pdf
	New York	http://www.health.state.ny.us/environmental/water/drinking/bluegreenalgae.htm
	Wisconsin	http://dnr.wi.gov/lakes/bluegreenalgae/

[1]Advisories have been issued in these states but additional information is not readily available on the internet.

advisories and closures, and monitoring programs may be vested across multiple program entities within a state. Thus, the information presented herein may be incomplete.

At least 22 states in the United States (44 percent) have information available on the Internet about cyanobacteria, cyanotoxins, and potential health risks to humans and animals. Based on the information available we divided programs into four categories: routine monitoring conducted at the state level, guidance for monitoring conducted at the local level, event-based response, and public education. Many of the categories are overlapping, and several states have done substantially more research and public education than indicated by the information presented in Table 2. Cyanobacteria and cyanotoxin monitoring has been addressed differently by each state, with two striking similarities. Most programs are collaborative efforts among multiple organizations and are focused on cyanobacterial cell counts and microcystin.

State Monitoring Programs

At least five states have routine statewide (Iowa, Nebraska, and New Hampshire) or watershed-based (Maryland and Vermont) monitoring programs for cyanotoxins in freshwaters at the state level, and four others (California, Florida, Massachusetts, and Oregon) have developed guidance documents to support monitoring at the local level. Several coastal states (e.g., Florida, Maryland, and Massachusetts) have incorporated the largely freshwater cyanotoxins into existing programs monitoring recreational hazards associated with marine algal toxins. Only the basic core of each state monitoring program has been presented in Table 2. Several of the programs are tier-based approaches with multiple alert levels to increase sampling as cyanobacterial abundance increases over the course of the recreational-use season. Many also use multiple data sources to determine whether or not to post an advisory or close a beach. For example, visual assessment of cyanobacterial accumulations are coupled with cell counts and/or microcystin concentrations in six of the nine states with routine monitoring or guidance for monitoring.

In general, less detail was available on the approaches used in states with an event-based response to potentially toxic cyanobacterial blooms. Most of these states respond to reports from those who routinely observe lakes and reservoirs as part of their jobs (for example, park rangers and wildlife officers) and concerned citizens. Several states provide information for concerned citizens to collect their own samples and submit them for analyses. Advisories and beach closures may be based solely on large accumulations of cyanobacteria or the results of cyanobacterial cell counts and/or cyanotoxin analysis.

At least 11 states have established guidance values for cyanobacterial cell counts and/or microcystin to help determine when advisories should be posted or beaches should be closed, and several others are in the process of developing guideline values; WHO guidance values often are used when state guidelines have not been established. All of the established state guidance values are similar to, or more conservative than, the preliminary WHO guidance values (Tables 1 and 2). While chlorophyll-*a* is included in the WHO guidance, it is not commonly used as the basis for advisories.

In most states, either state or local health departments are responsible for deciding when to post advisories and beach closures. Posting often includes placing signs and information pamphlets at recreational areas and press releases, and sampling results often are available on the internet. Many states have Web pages devoted to recreational advisories and closures so recreational users can regularly check on lake and reservoir conditions. Additionally, some states will send recreational users e-mail updates on local advisories and closures.

Challenges to the Development of Monitoring Programs

Cyanobacteria and cyanotoxins present unique challenges for the development of monitoring programs for recreational areas. When, where, and how samples are collected, and what analyses are performed can substantially influence monitoring results. Wind movement of surface accumulations may change the location of cyanobacteria within a water body over relatively short periods of time: a beach with no evidence of cyanobacteria in the morning may have a heavy accumulation of cyanobacteria by late afternoon. There are several potential cyanobacterial producers for most cyanotoxins and some strains may produce multiple toxins simultaneously while others do not produce any toxins. Cyanobacterial cell counts can identify the presence and abundance of potential cyanotoxin producers, but not the presence and concentration of cyanotoxins. Cyanotoxin analyses will conclusively determine presence and concentration; however, there are a wide variety of cyanotoxins and it currently is not feasible for most monitoring programs to incorporate all potential cyanotoxins of concern. Additionally, new cyanotoxins are continually being discovered. Cyanotoxin analyses, most frequently microcystins as measured by enzyme-linked immunosorbent assays (ELISA), provide the concentration of measured compounds but may exclude other unmeasured or unknown compounds. Most cyanotoxin analyses are costly and results typically are not available within a time-frame relevant to potential recreational exposure. Microcystins as measured by ELISA has become the toxin test of choice when gauging human health risks because it is relatively inexpensive, results are available within hours, and ELISA for microcystins has been commercially available for over a decade (Fischer et al. 2001; Metcalf and Codd 2003; Hawkins et al. 2005); ELISA's for other cyanotoxins (cylindrospermopsins and saxitoxins) have only recently become available (Metcalf and Codd 2003; Bláhová et al. 2009). Because of these challenges, many monitoring programs incorporate the flexibility to change sampling locations and include multiple tools for making decisions about when advisories and closures should be made.

The establishment of guidance values is equally challenging. Not all cyanobacterial blooms are toxic, and relying on cell counts and taxonomic identification may appear to be more conservative when compared to microcystins results and may result in unnecessary advisories and beach closures. However, other toxin classes, such as anatoxins, cylindrospermopsins, and saxitoxins also may be present and are not detected by microcystin-based assays. In addition, little is known about the toxicity of cyanotoxin mixtures. Because of the diversity of the cyanotoxins and the paucity of toxicological information on all but a select few compounds, assessing risks to human health are difficult. Currently, microcystin-LR is the only cyanotoxin with enough toxicological data to establish guidance values for recreation.

Summary

Based on the information found in our Internet search, at least 19 states (Figure 1) have issued health advisories or closed recreational areas because of cyanobacterial blooms since 2005. Cyanobacteria and associated toxins will continue to cause human health concerns. Many states have taken steps to educate the public about the health risks associated with cyanotoxins, and several more are in the process of developing programs or are interested in developing programs. Knowing that cyanobacteria pose potential health risks and extensive accumulations should be avoided can substantially reduce the risk of human exposure; therefore, public education programs provide key information that can protect public health. As more is learned about cyanobacteria and cyanotoxins, and as new analytical techniques become available, monitoring programs will continue to evolve. Shared information and experiences will facilitate development of new programs and help solve problems within existing programs. Program implementation is a challenging and multifaceted endeavor and it is encouraging that so many states are taking a proactive approach to protect their citizens from the potential health risks caused by cyanobacteria. All efforts are to be applauded.

Author's Note: Links to the websites listed in Table 3 will be made available on the NALMS Blue-Green Initiative Web page (http://www.nalms.org/Resources/BlueGreenInitiative/Overview.htm) after the updates to the NALMS Website are complete.

Selected References and Additional Reading

Backer, L.C. 2002. Cyanobacterial harmful algal blooms (CyanoHABs): Developing a public health response. *Lake and Reservoir Management*. 18: 20-31.

Bláhová, L., M. Oravec, B. Maršálek, L. Šejnohová, Z. Šimek and L. Bláha. 2009. The first occurrence of the cyanobacterial alkaloid toxin cylindrospermopsin in the Czech Republic as determined by immunochemical and LC/MS methods. *Toxicon*. 53:519-524.

Chorus, I. and J. Bartram (Eds.). 1999. *Toxic Cyanobacteria in Water*. London: World Health Organization. 416 p.

Dietrich, D. and S. Hoeger. 2005. Guidance values for microcystins in water and cyanobacterial supplement products (blue-green algal supplements): A reasonable or misguided approach? *Toxicology and Applied Pharmacology*. 203: 273-289.

Fischer, W.J., I. Garthwaite, C.O. Miles, K.M. Ross, J.B. Aggen, N.R. Towers and D.R. Dietrich. 2001. Congener-independent immunoassay for microcystins and nodularins. *Environmental Science and Technology*. 35:4849-4856.

Graham, J.L. 2006. Harmful algal blooms. U.S. Geological Survey Fact Sheet 2006-3147.

Graham, J.L., K.A. Loftin, M.T. Meyer and A.C. Ziegler. 2008. Guidelines for design and sampling for cyanobacterial toxin and taste-and-odor studies in lakes and reservoirs. U.S. Geological Survey Scientific Investigations Report 2008-5038. 39 p.

Hawkins, P.R., S. Novic, P. Cox, B.A. Neilan, B.P. Burns, G. Shaw, W. Wickramasinghe, Y. Peerapornpisal, W. Ruangyuttikarn, T. Itayama, T. Saitou, M. Mizuochi and Y. Inamori. 2005. A review of analytical methods for assessing the public health risk from microcystin in the aquatic environment. *Journal of Water Supply: Research and Technology*. 54:509-519.

Hudnell, H.K. (ed.). 2008. Cyanobacterial harmful algal blooms. Springer, New York. 949 p.

Huisman, J., H.C.P. Matthijs and P.M. Visser (Eds.). 2005. Harmful Cyanobacteria. Springer, The Netherlands. 241 p.

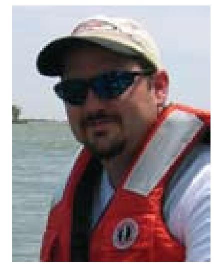
Jacoby, J.M. and J. Kann. 2007. The occurrence and response to toxic cyanobacteria in the Pacific Northwest, North America. *Lake and Reservoir Management*. 23:123-143.

Metcalf, J.S. and G.A. Codd. 2003. Analysis of cyanobacterial toxins by immunological methods. *Chemical Research in Toxicology*. 16:104-111.

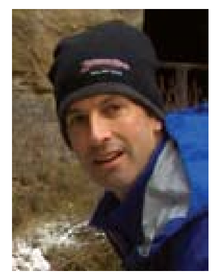
Stone, D. and W. Bress. 2007. Addressing public health risks of cyanobacteria in recreational freshwaters: The Oregon and Vermont framework. *Integrated Environmental Assessment and Management*. 3:137-143.

Yoo, R.S., W.W. Carmichael, R.C. Hoehn and S.E. Hrudey. 1995. Cyanobacterial (blue-green algal) toxins: a resource guide. AWWA Research Foundation and the American Water Works Association. 229 p.

Jennifer Graham is a limnologist with the U.S. Geological Survey in Lawrence, Kansas. For the past ten years she has conducted research on environmental factors influencing the occurrence and concentration of cyanobacterial toxins in the Midwestern United States. She has conducted both regional and single system studies at a variety of spatiotemporal scales.



Keith Loftin is a chemist and environmental engineer with the U.S. Geological Survey in Lawrence, Kansas. His research has been focused on the national-scale occurrence, fate, effects, transport, and treatment of emerging contaminants including antibiotics and cyanotoxins.



Neil Kamman is a water quality monitoring and assessment specialist in the Vermont Department of Environmental Conservation. He oversees planning and implementation of the State of Vermont Ambient Water Quality Monitoring Program. Neil has authored numerous peer-reviewed research publications regarding mercury in the northeast North American environment, and studies the impacts of development on the ecological integrity northeastern waterways. Neil is currently working on assignment to the U.S. Environmental Protection Agency to manage the analysis and reporting of the National Lakes Assessment.