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Cyanobacterial Blooms: Toxins, Tastes, and Odors

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Overview

- Cyanobacterial Harmful Algal Blooms
- Cyanotoxins in the United States
  - Occurrence
  - Spatiotemporal Patterns
  - Environmental Influences
- Treatment Options

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What is an Algal Bloom?

- The definition of a "bloom" is somewhat subjective.
- Common definitions include:
  - Algae have high cell densities (20,000 to 100,000 cells/mL).
  - Proliferation of algae is dominated by a single or a few species.
  - There is a visible accumulation of algae.

South Dakota - green algae bloom

Idaho - cyanobacteria bloom
photo courtesy of F. Wilhelm

What Makes Some Algal Blooms Harmful?

Harmful algal blooms (HABs) can occur anytime water use is impaired due to excessive accumulations of algae

- Ecologic Concerns
  - Low dissolved oxygen
  - Food-web disruption
- Economic Concerns
  - Loss of recreational revenue
  - Taste and odor
  - Added drinking water treatment costs
- Public Health Concerns
  - Allergic reactions
  - Toxicity (cyanobacteria only)

Texas – golden algae bloom
Photo courtesy of TPWD and G. Turner

Kansas – cyanobacterial bloom

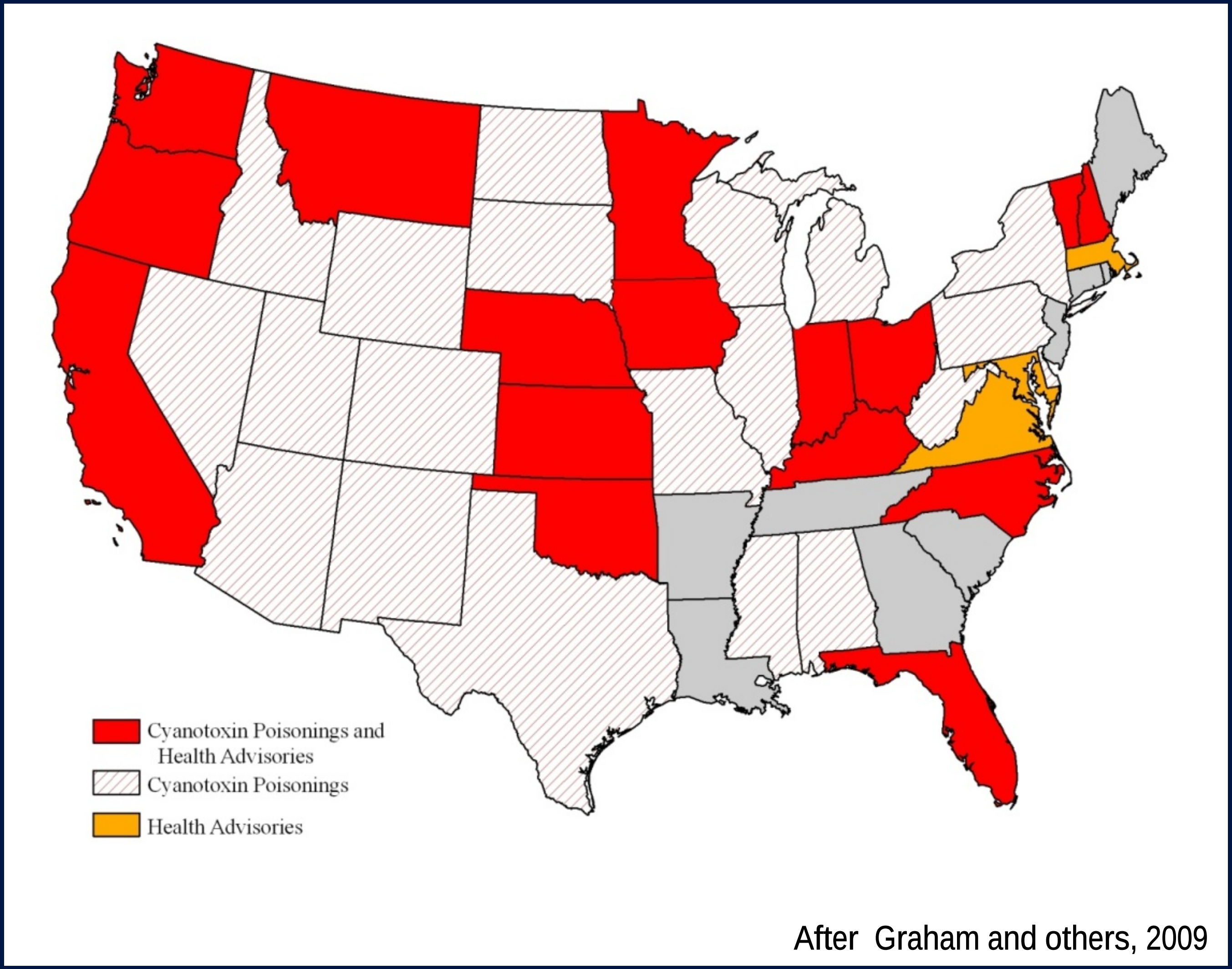
Cyanobacterial Toxins and Taste-and-Odor Compounds

	Hepatotoxins		Neurotoxins		Dermatoxins	Taste/Odor	
	CYL	MC	ANA	SAX		GEOS	MIB
Anabaena	X	X	X	X	X	X	?
Aphanizomenon	X	?	X	X	X	X	
Microcystis		X			X		
Oscillatoria/Planktothrix		X	X	X	X	X	X

Photos courtesy of A. St. Amand

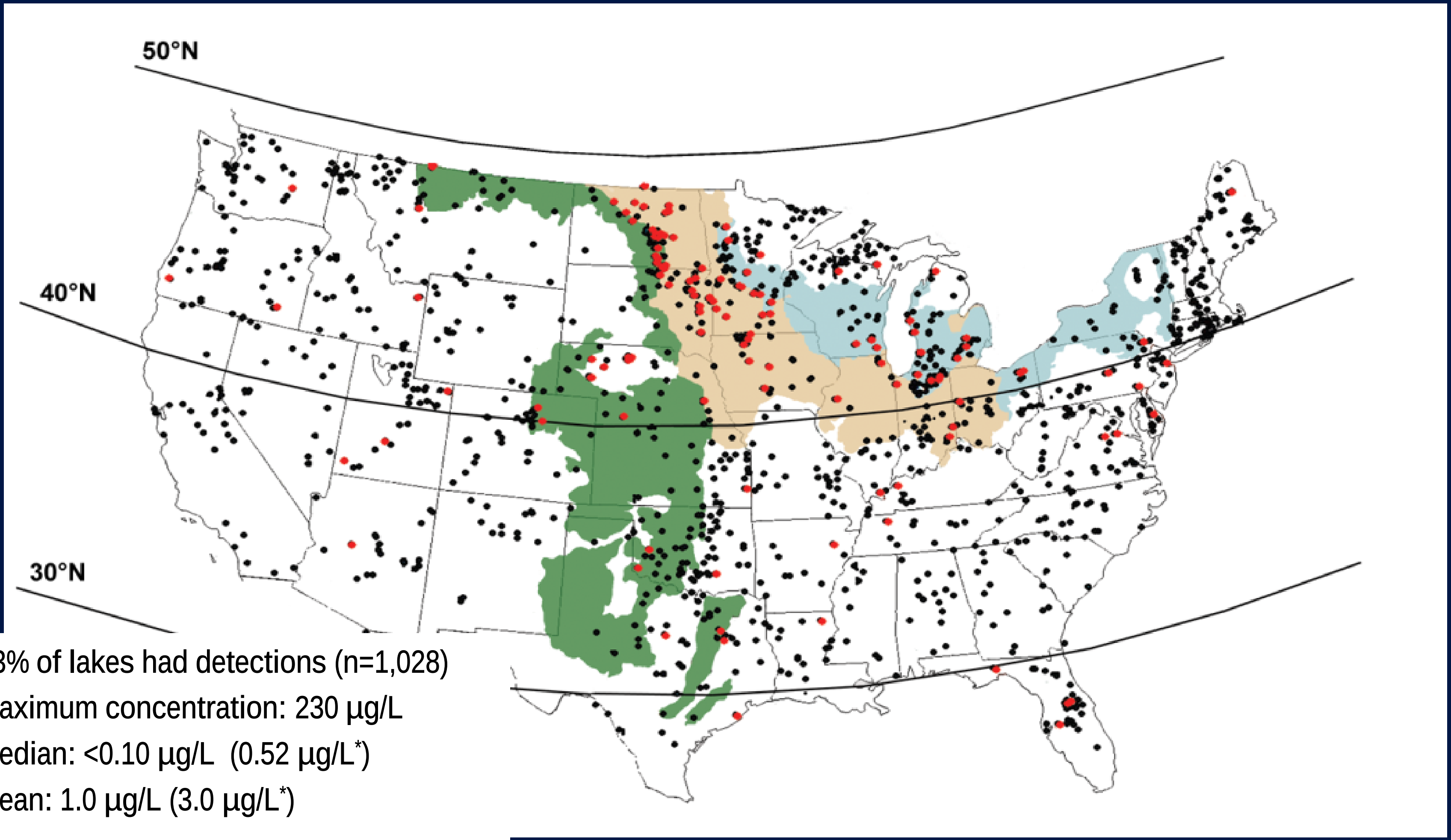
After Graham and others, 2008, TWRI Chapter 7.5
http://water.usgs.gov/owq/FieldManual/

At Least 36 U.S. States Have Anecdotal Reports of Human or Animal Poisonings Associated with Cyanotoxins



Occurrence

High Microcystin Concentrations (> 1 µg/L) in the 2007 National Lake Assessment Were Most Common in the Upper Midwest



33% of lakes had detections (n=1,028)

Maximum concentration: 230 µg/L

Median: <0.10 µg/L (0.52 µg/L*)

Mean: 1.0 µg/L (3.0 µg/L*)

*Detections only

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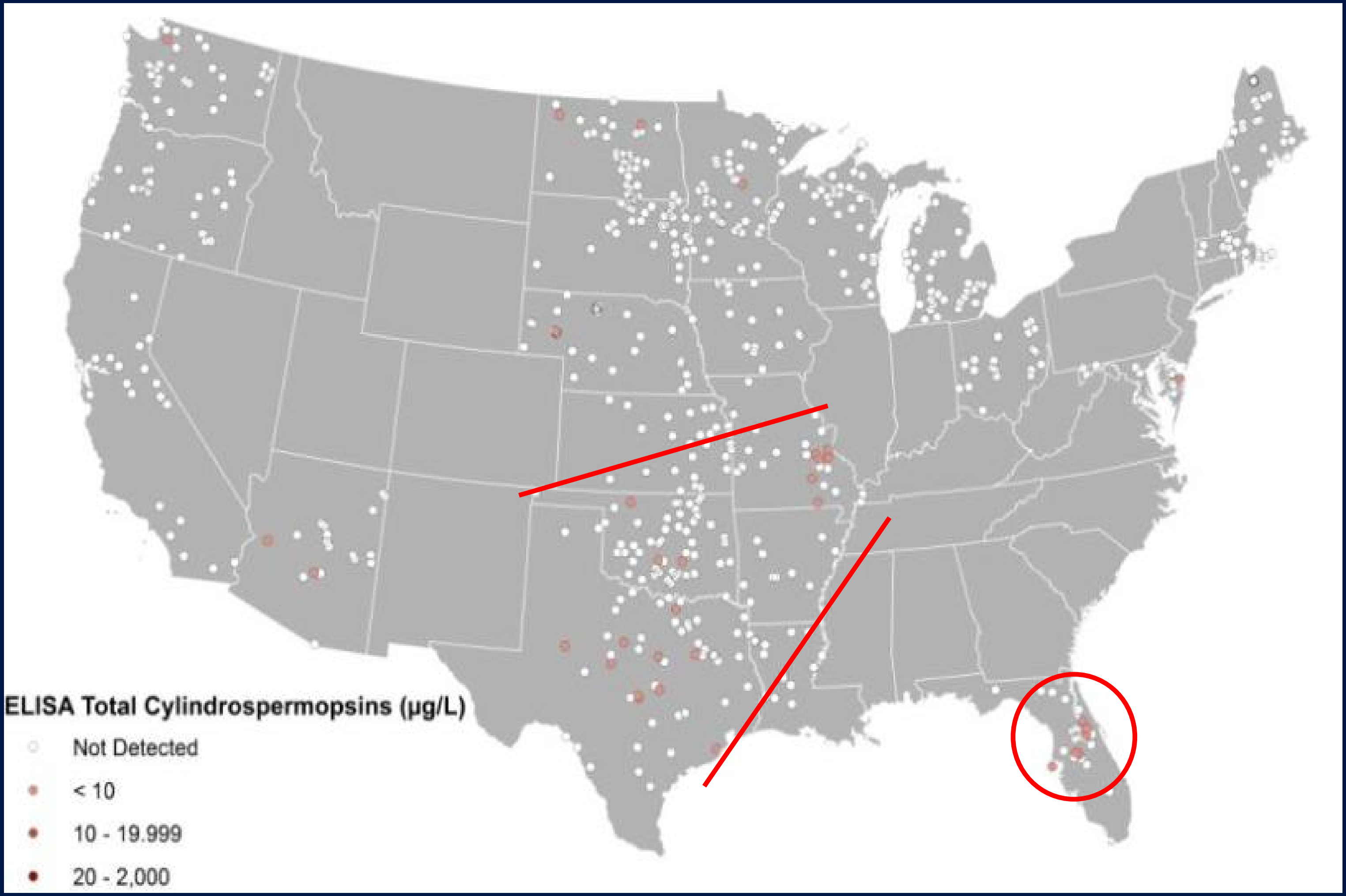
After Beaver and others, 2014

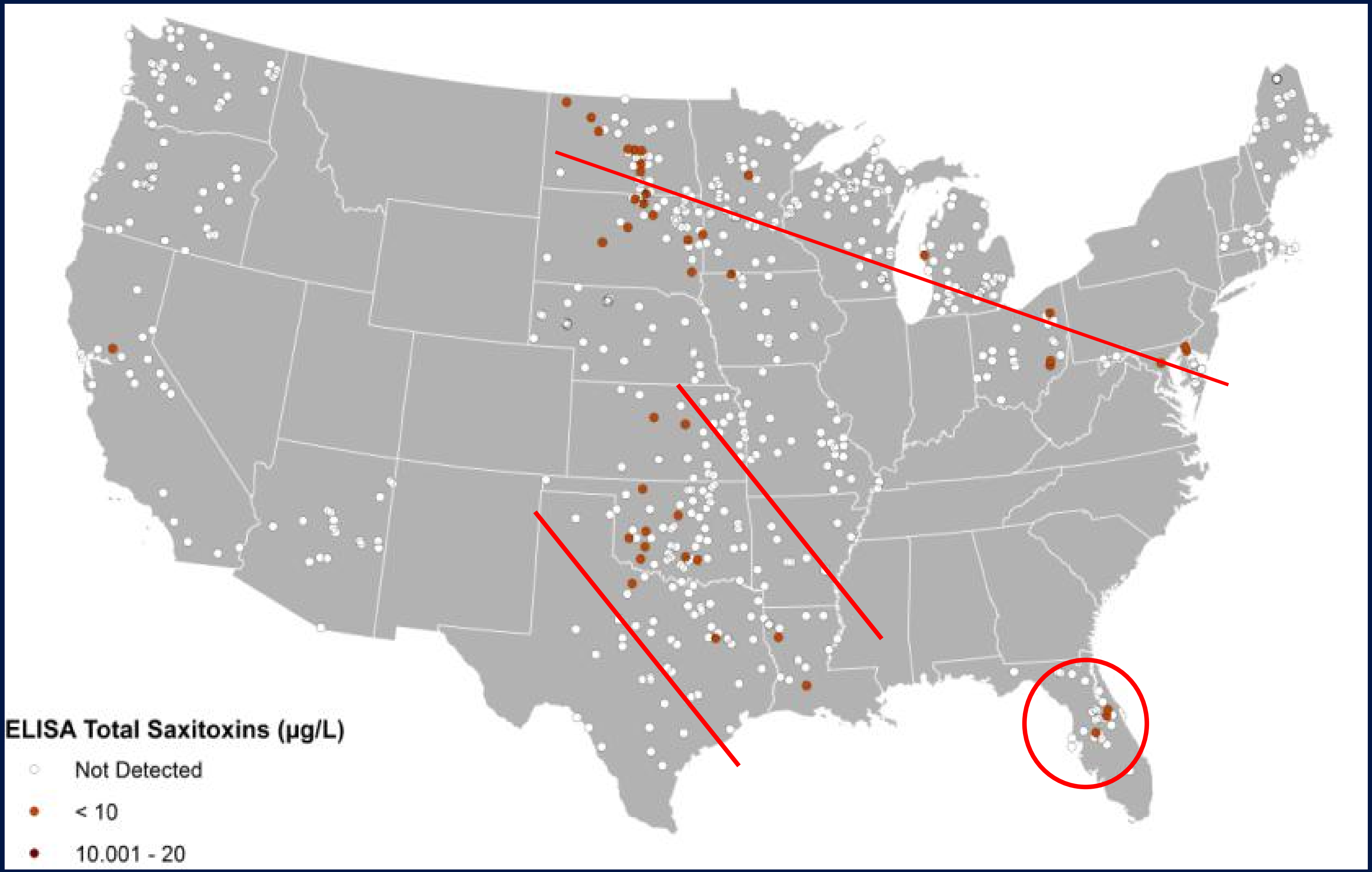
Cylindrospermopsins Were Detected by ELISA in About 5% (n=659) of Analyzed Lakes; Occurrence was Most Common in the South



Loftin and others, in preparation

Occurrence

Saxitoxins Were Detected by ELISA in About 8% (n=678) of Analyzed Lakes; Occurrence was Most Common in the Upper Midwest and the South



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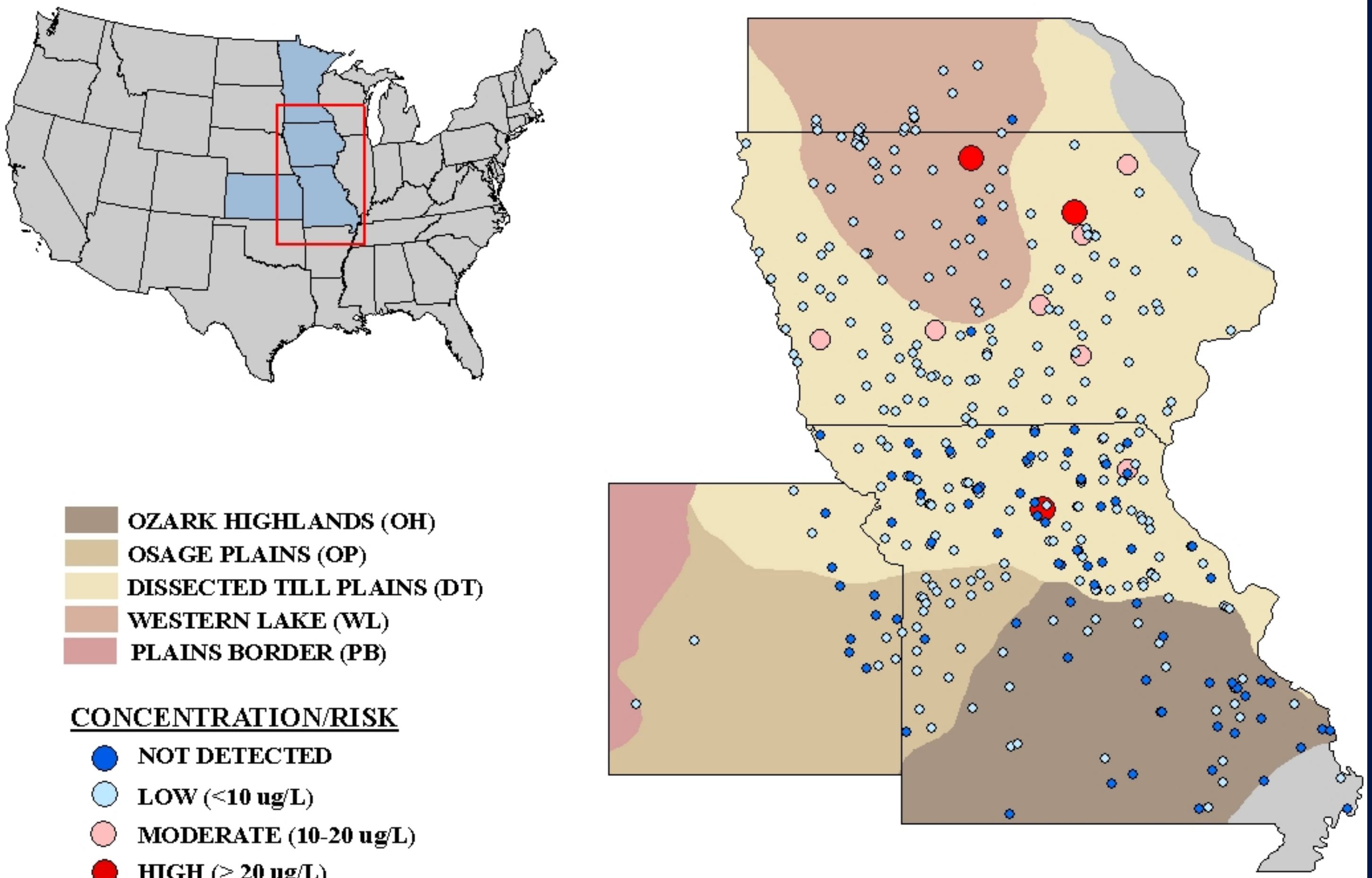
Loftin and others, in preparation

Microcystins are Widespread and Common in the Midwest



78% of lakes had detections (n=359)

Maximum concentration: 52 µg/L

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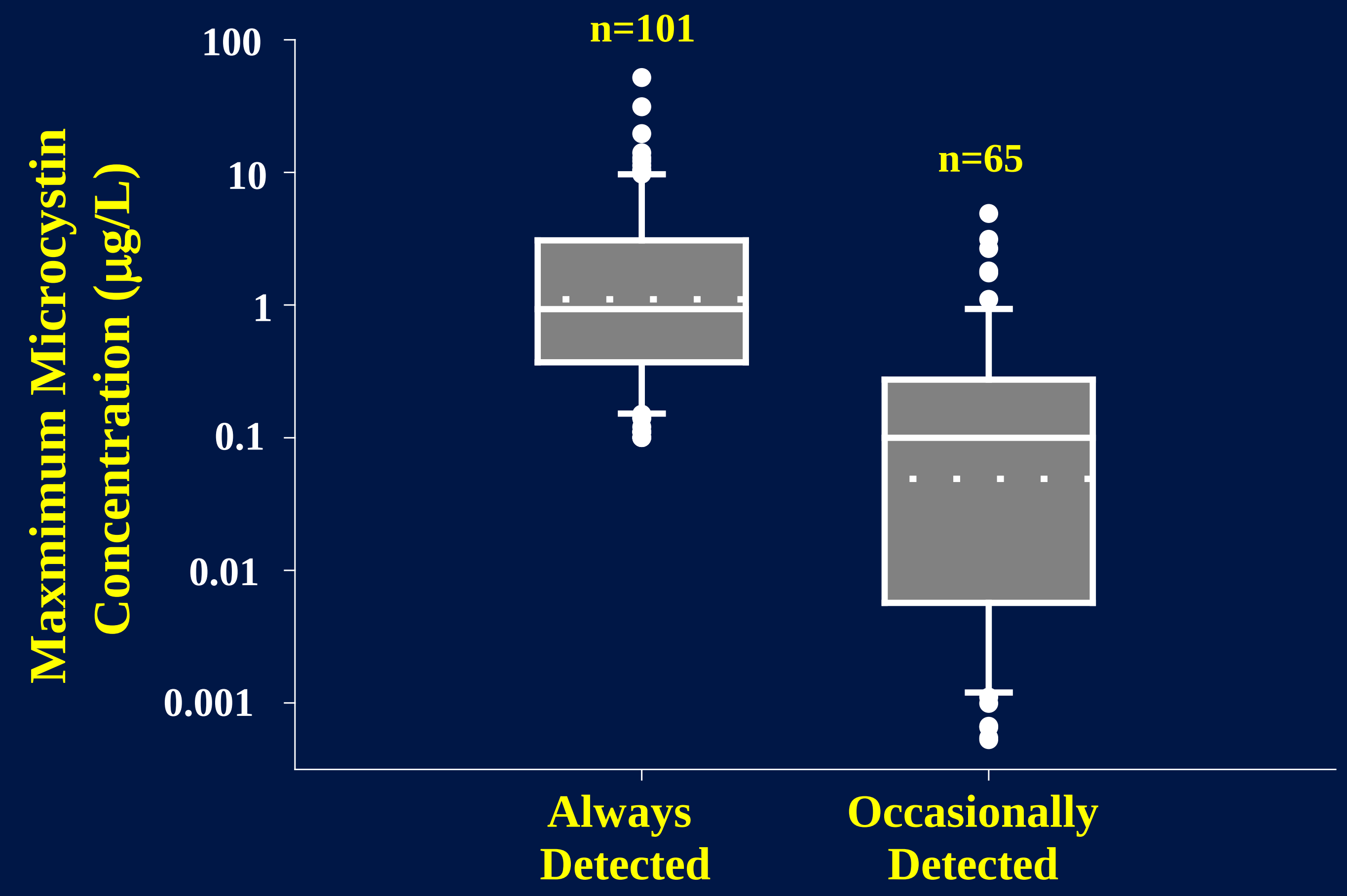
After Graham and others 2004, 2006, and 2009

Lakes with Frequent Microcystin Detections Also Had the Highest Microcystin Concentrations



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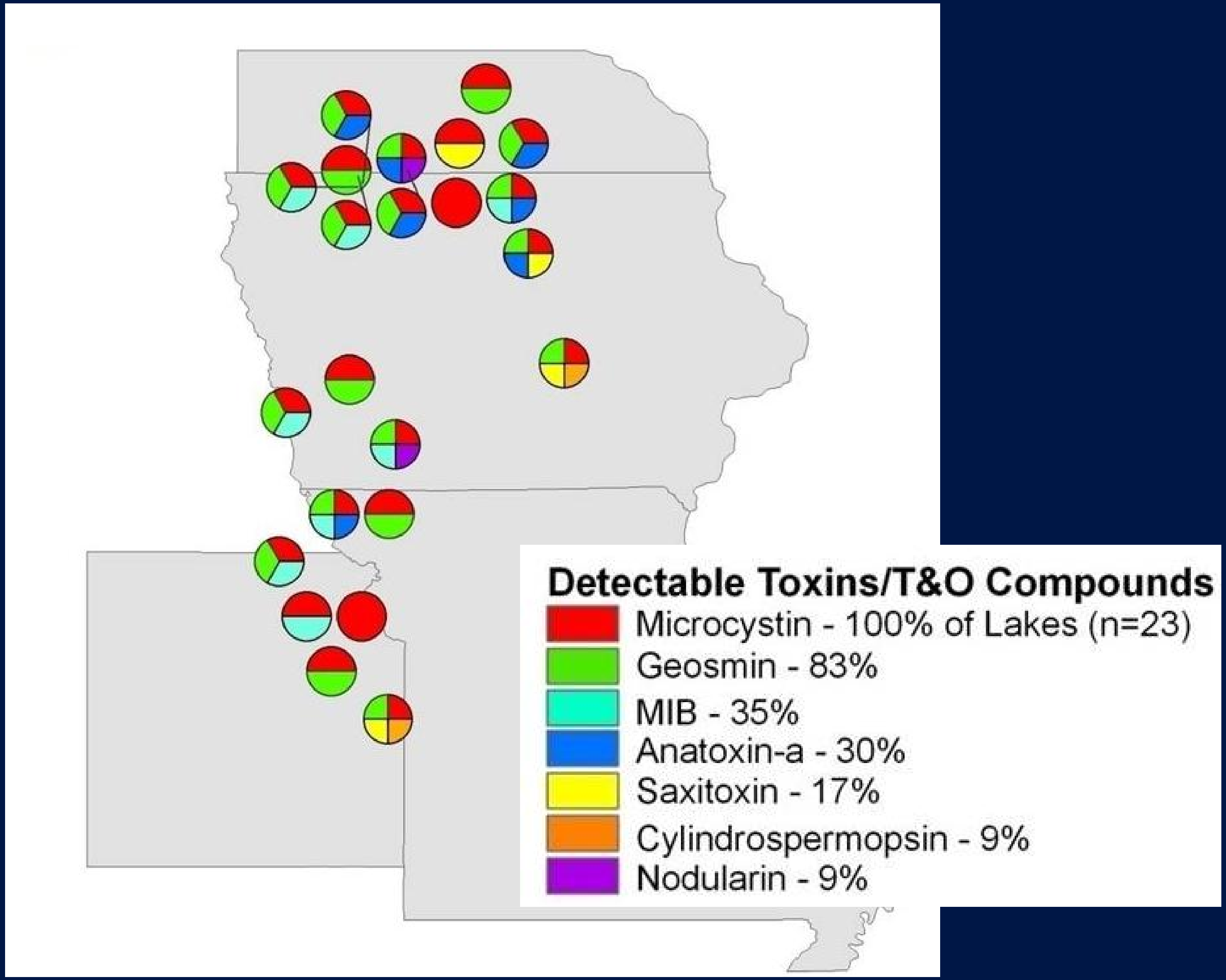
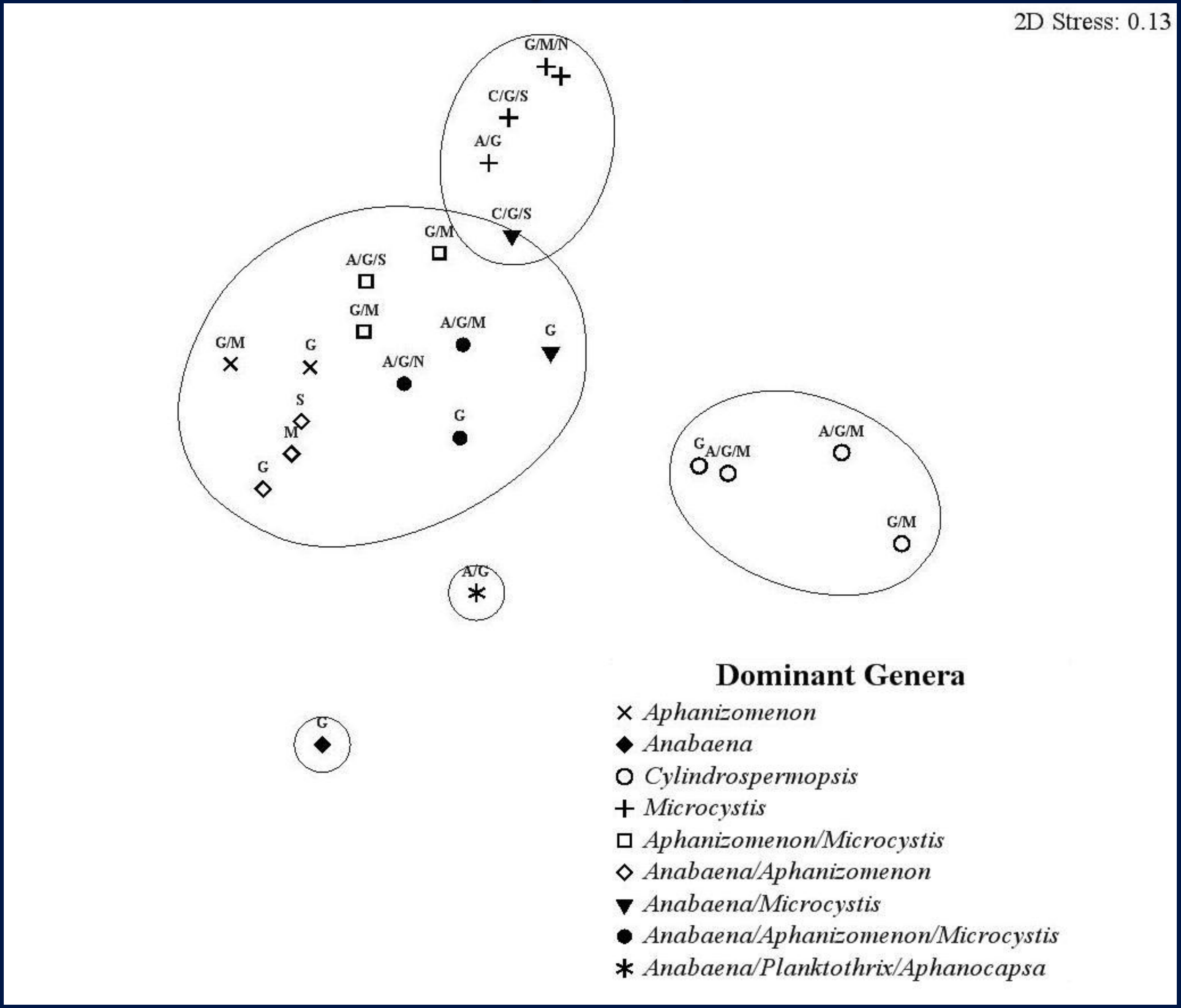
After Graham and others 2004, 2006, and 2009

Multiple Toxins and Taste-and-Odor Compounds Frequently Co-Occur in Cyanobacterial Blooms



After Graham and others, 2010

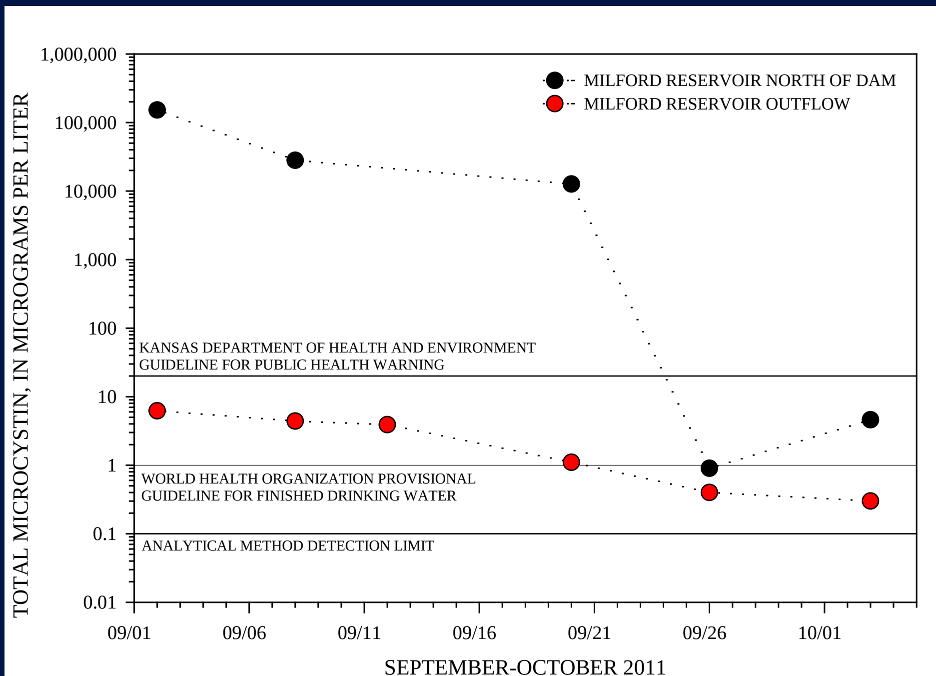
Occurrence of Cyanotoxins and Taste-and-Odor Compounds is Not Tightly Coupled to Cyanobacterial Abundance or Community Composition



After Graham and others, 2010

Occurrence

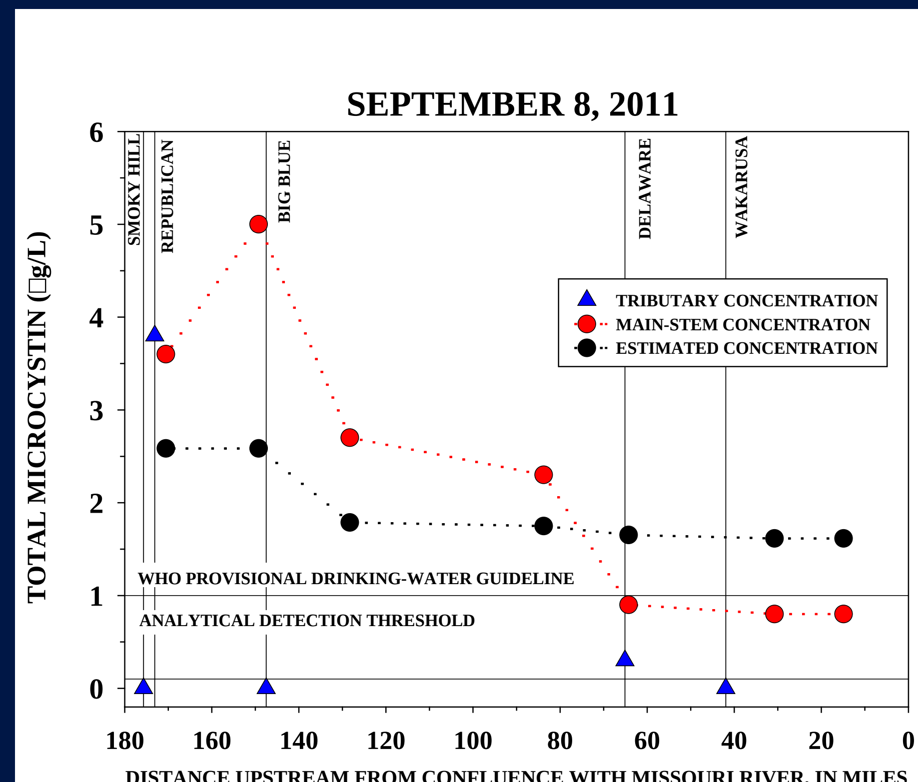
Cyanobacterial Toxins and Taste-and-Odor Compounds May Be Transported for Relatively Long Distances Downstream from Lakes and Reservoirs



Milford Lake release sends algae to Kansas River

MARIA SUDEKUM FISHER, Associated Press

Published 09:10 p.m., Wednesday, September 21, 2011



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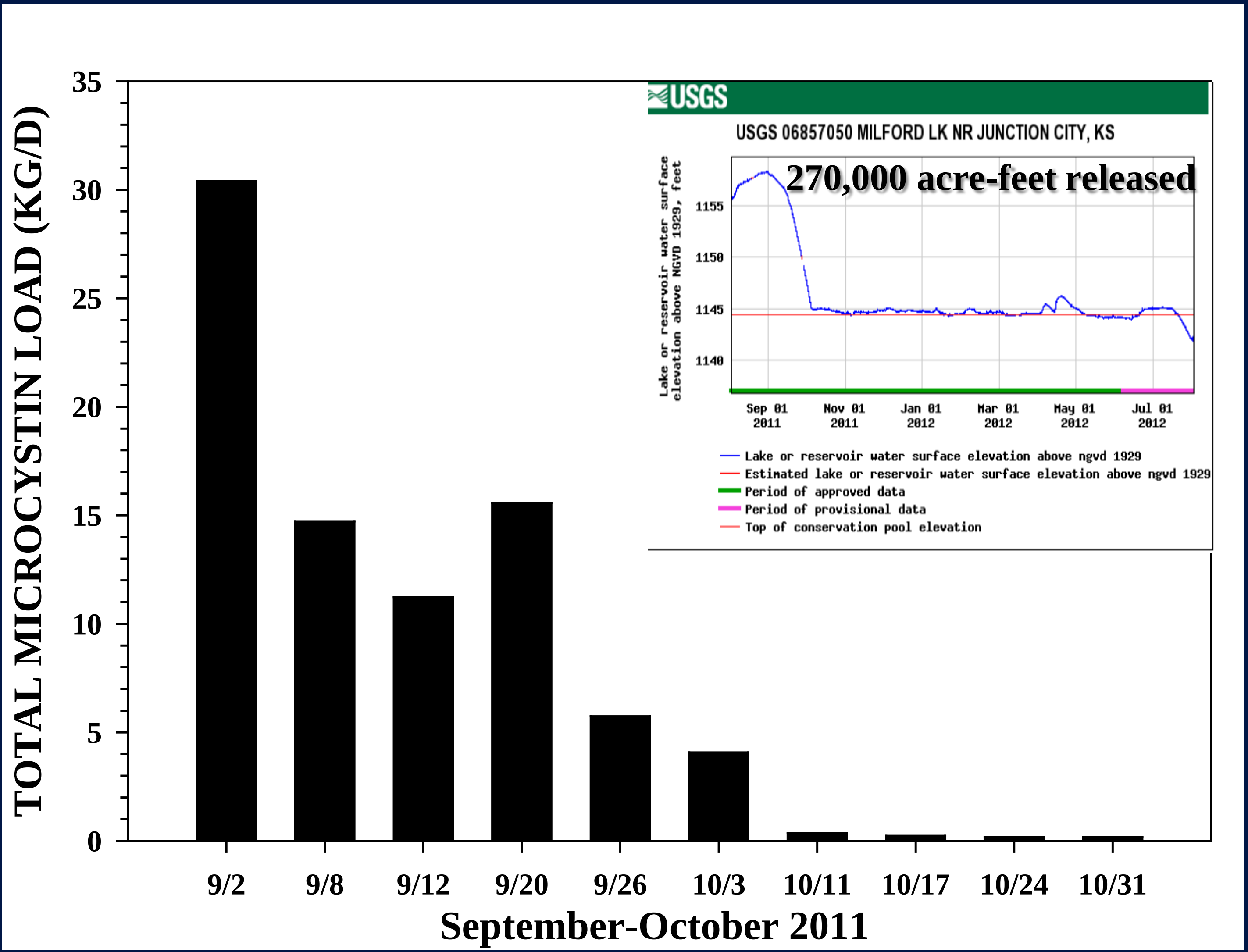
http://pubs.usgs.gov/sir/2012/5129/

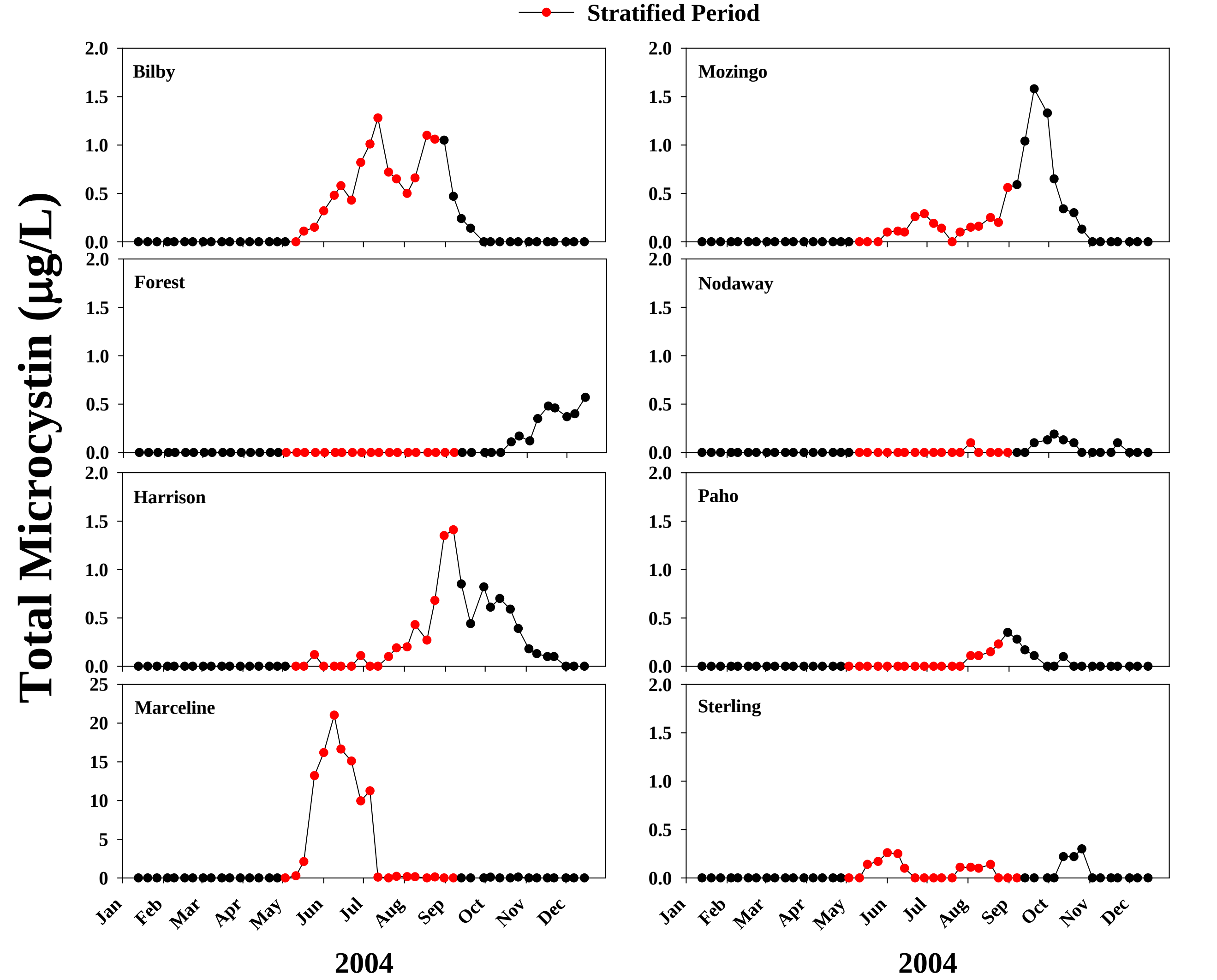
Graham and others, 2012

Total Microcystin Loads from Milford Lake Ranged from About 0.1 to 30 kg/d



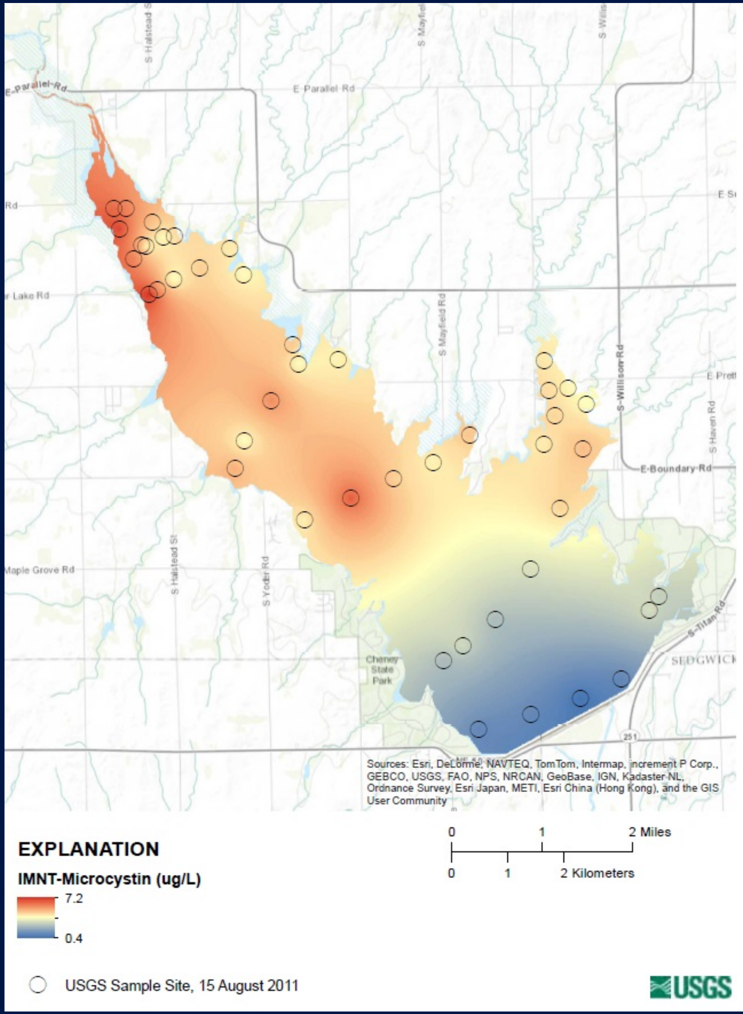
After Graham and others, 2012

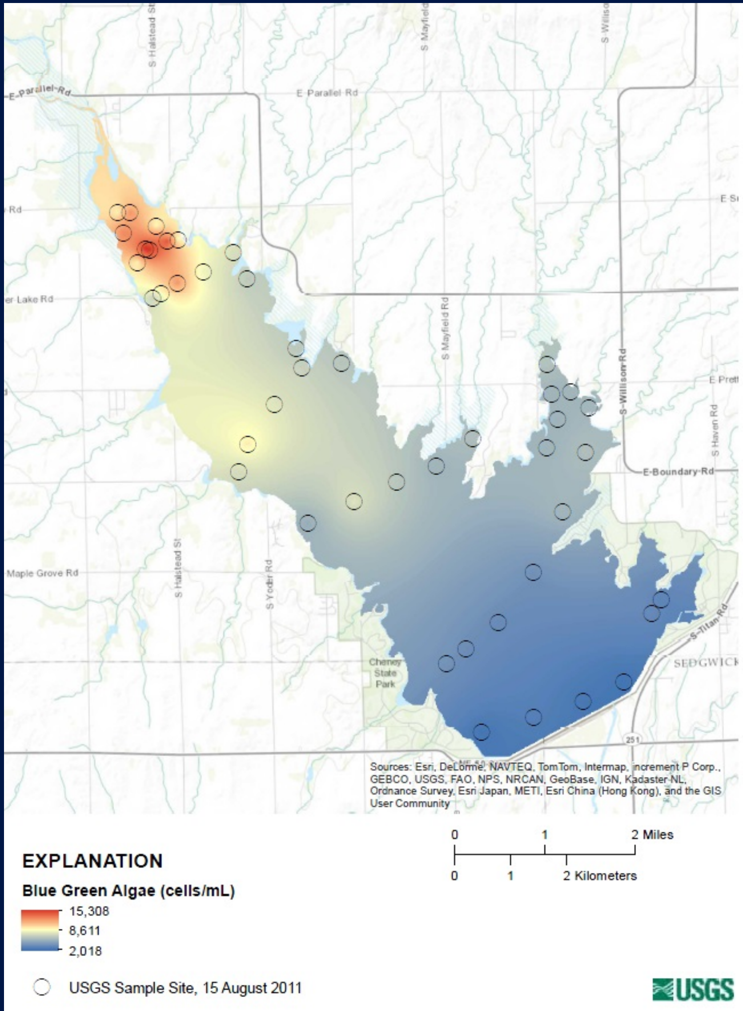
Seasonal Patterns in Microcystin Concentration are Unique to Individual Lakes and Peaks May Occur Anytime Throughout the Year



After Graham and others, 2006

Cyanobacteria and Associated Compounds May Vary Longitudinally in Reservoirs Due to Gradients in Water-Quality and Hydrologic Conditions





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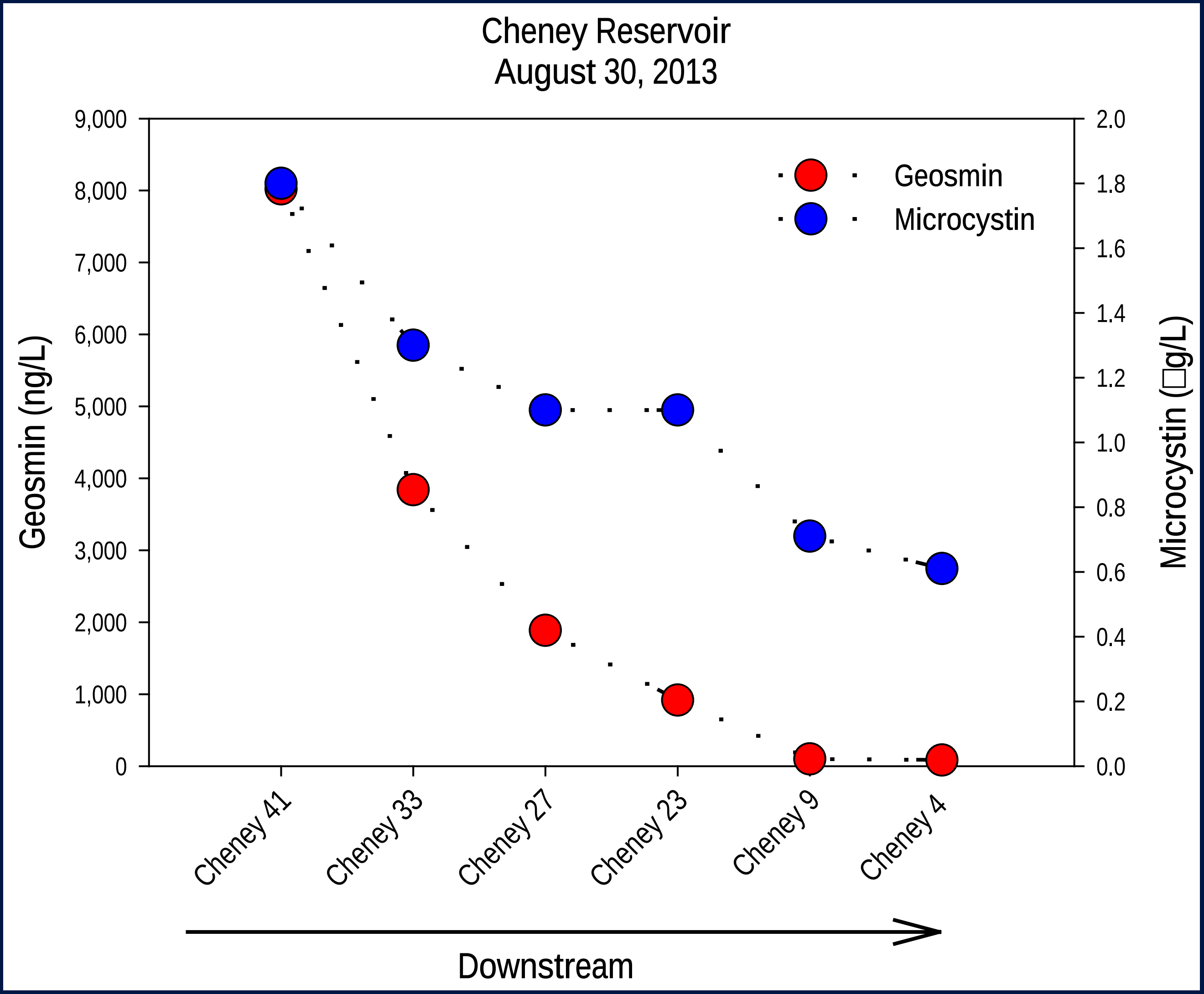
Spatiotemporal Patterns

Cyanobacteria and Associated Compounds May Vary Longitudinally in Reservoirs Due to Gradients in Water-Quality and Hydrologic Conditions



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Vertical Migration or Wind Movement of Surface Accumulations May Rapidly Change the Areal Distribution of Cyanobacteria

Rock Creek Lake, Iowa
2006 Beach Closure Event

Beach Area
Monday
July 31

Photos Courtesy of IA DNR

Photo Courtesy of IA DNR

Beach Area
Thursday
August 3

Boat Ramps
Friday
August 11

Temporal and Spatial Patterns

Vertical Migration or Wind Movement of Surface Accumulations May Rapidly Change the Aerial Distribution of Cyanobacteria

Rock Creek Lake, Iowa
2006 Beach Closure Event

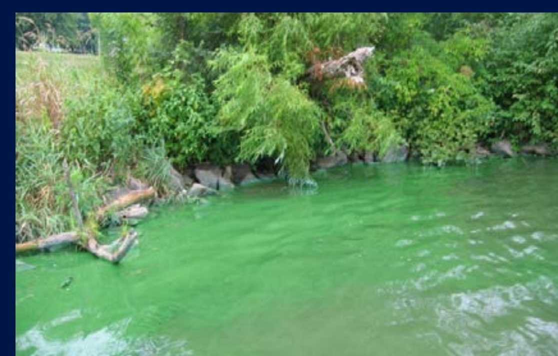
Beach Area

Beach Area
Thursday
August 3

WHERE DID THE CYANOBACTERIA GO?

Most likely explanation is
redistribution in the water column

Photos Courtesy of IA DNR



Boat Ramps
Friday
August 11

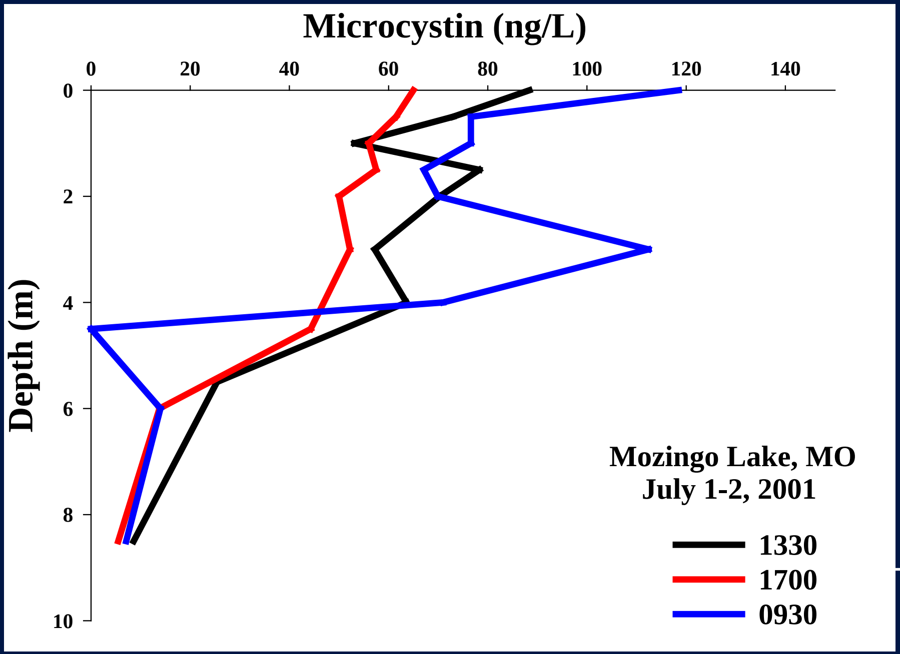
Sample Concentrations Can Vary Considerably Depending on When, Where, and How Samples Are Collected

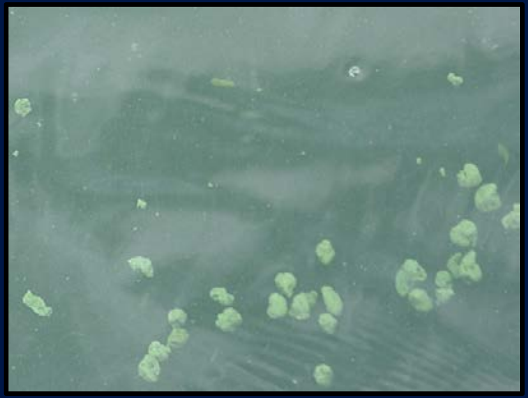
Microcystin: 13 µg/L
Geosmin: 0.25 µg/L

Microcystin: 4 µg/L
Geosmin: Not Detected

Cheney Reservoir, Kansas
September, 2006

Sample Concentrations Can Vary Considerably Depending on When, Where, and How Samples Are Collected





Microcystis aeruginosa colonies

Time	Surface	Integrated Photic Zone	Integrated Epilimnion	Integrated Water Column
	Sample Type and Microcystin Concentration (ng/L)			
0930	118	74	84	61
1330	88	64	70	58
1700	65	50	55	45

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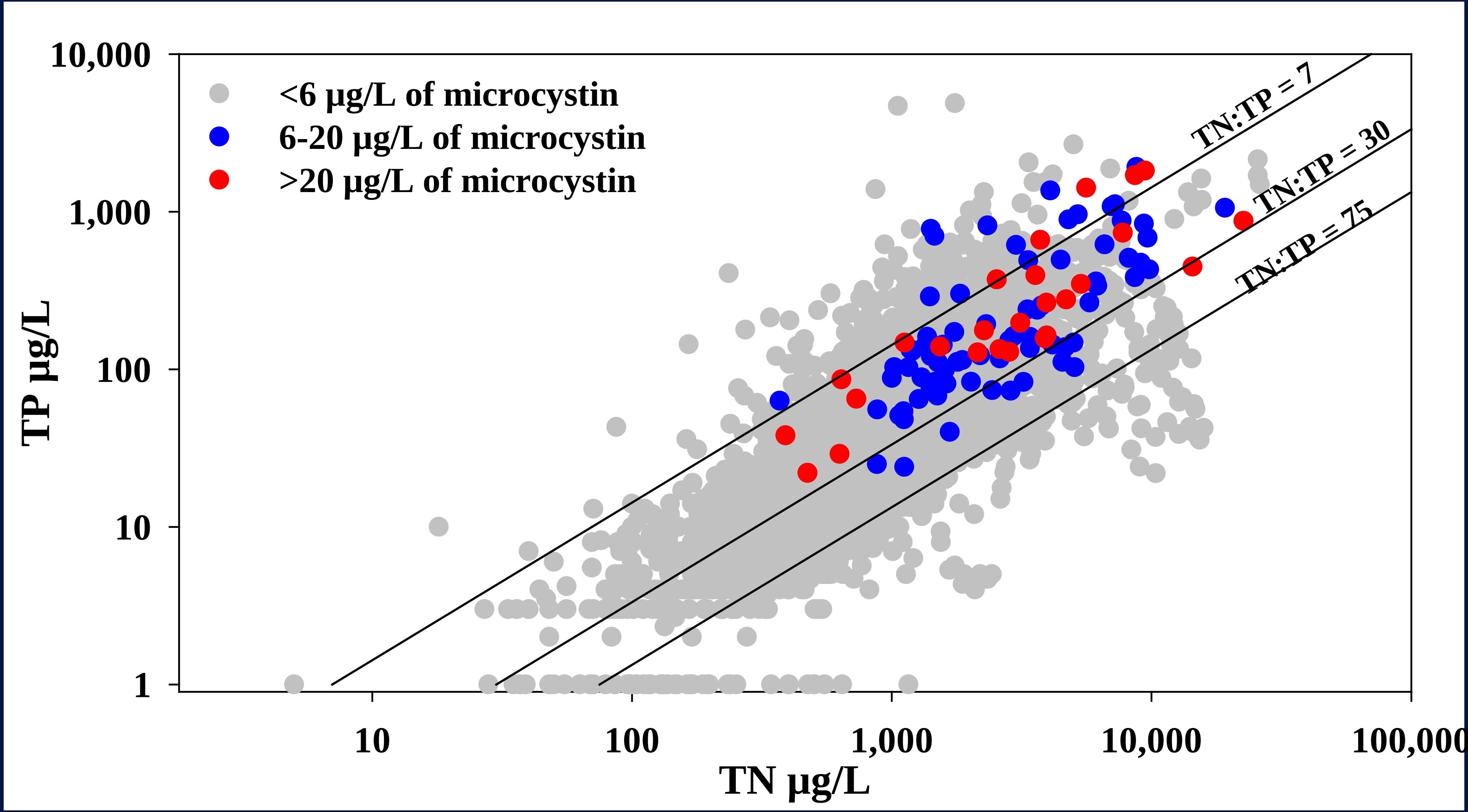
After Graham and others, 2006

Globally, Microcystin Occurs in Lakes of All Trophic Status, But Occurrence and Concentration Increase with Trophic Status



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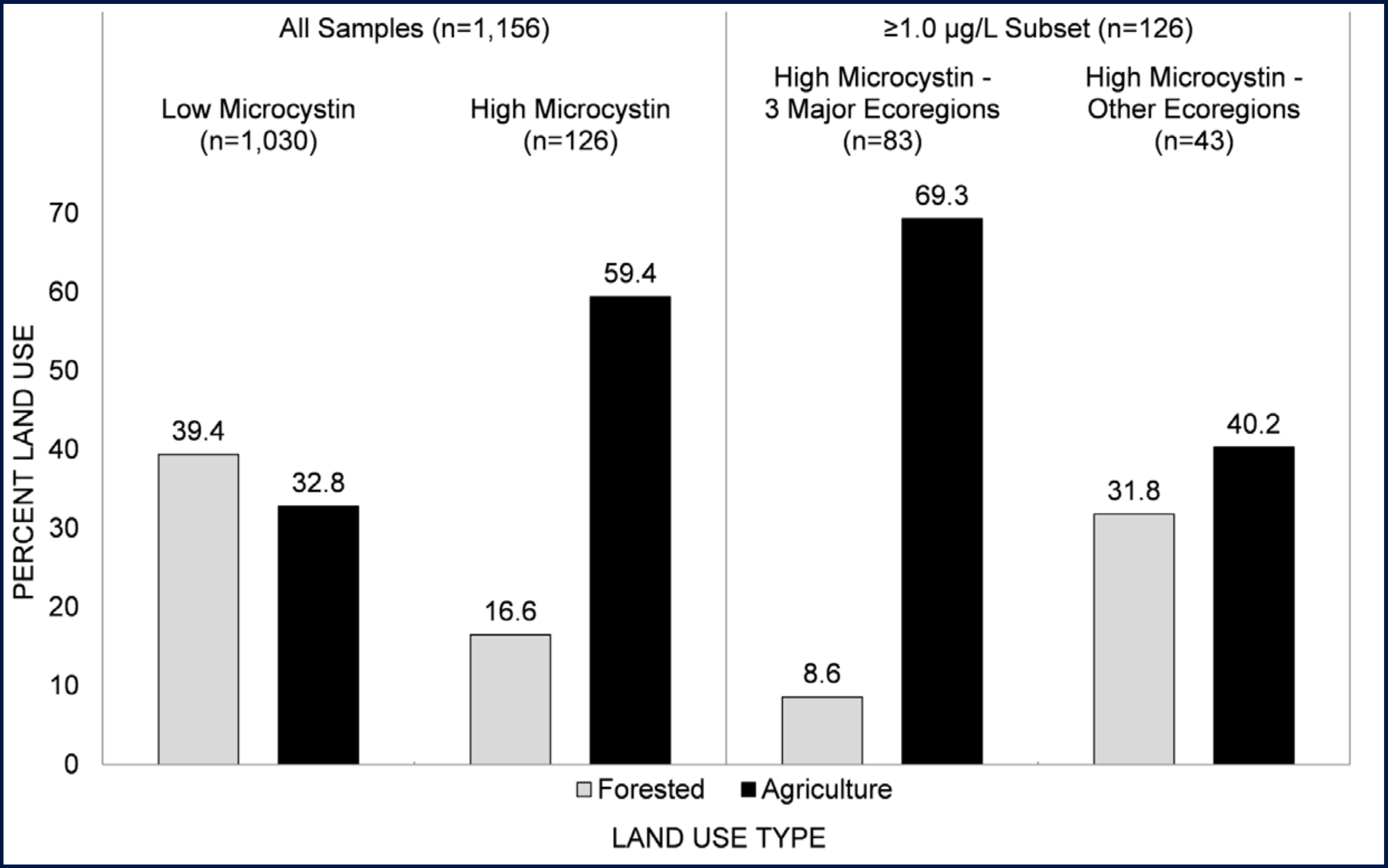
After Harris and others 2014

Microcystin Occurrence in the United States is Related to Agricultural Land Use



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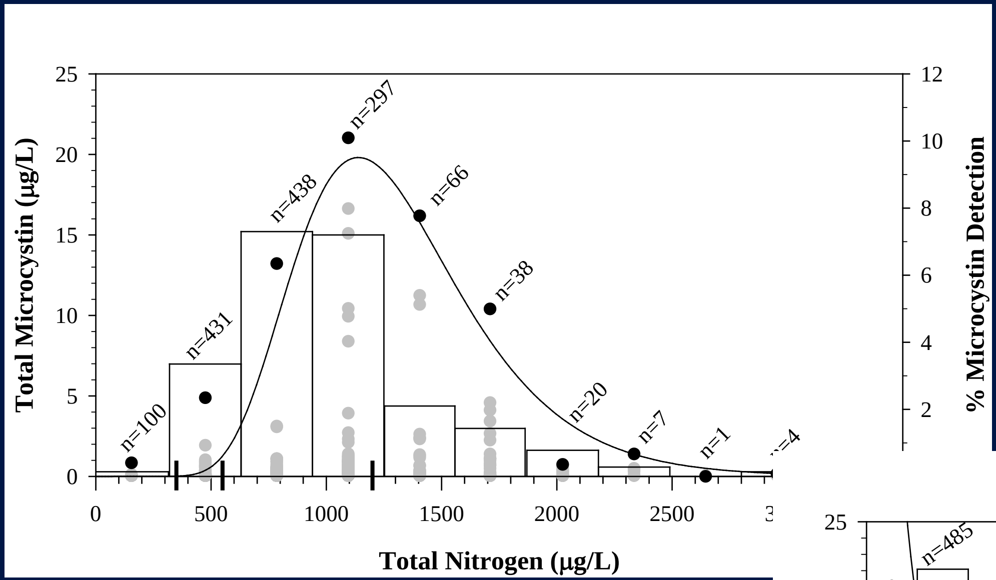
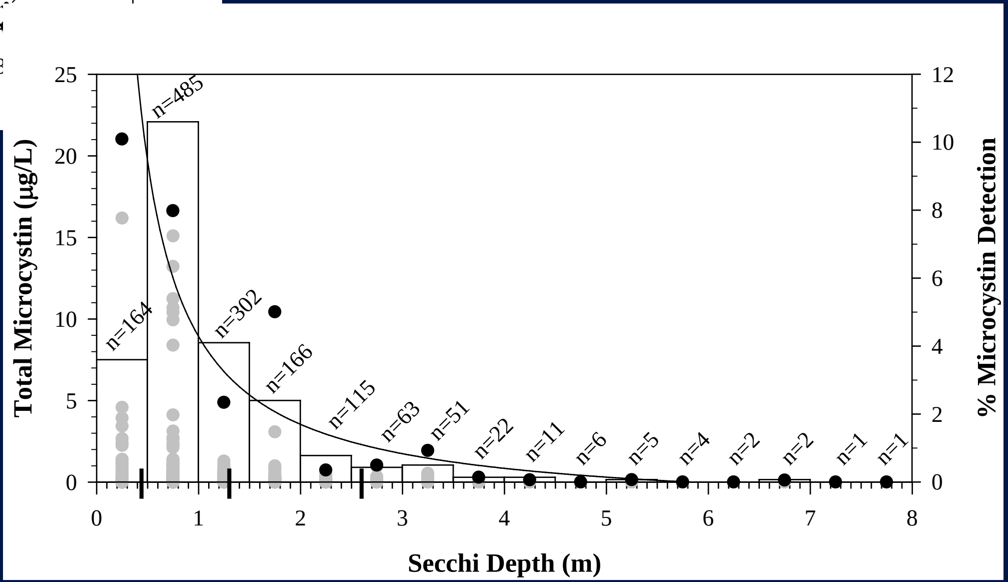
After Beaver and others 2014

Regional Associations Between Microcystin and Environmental Variables May Not Be Linear





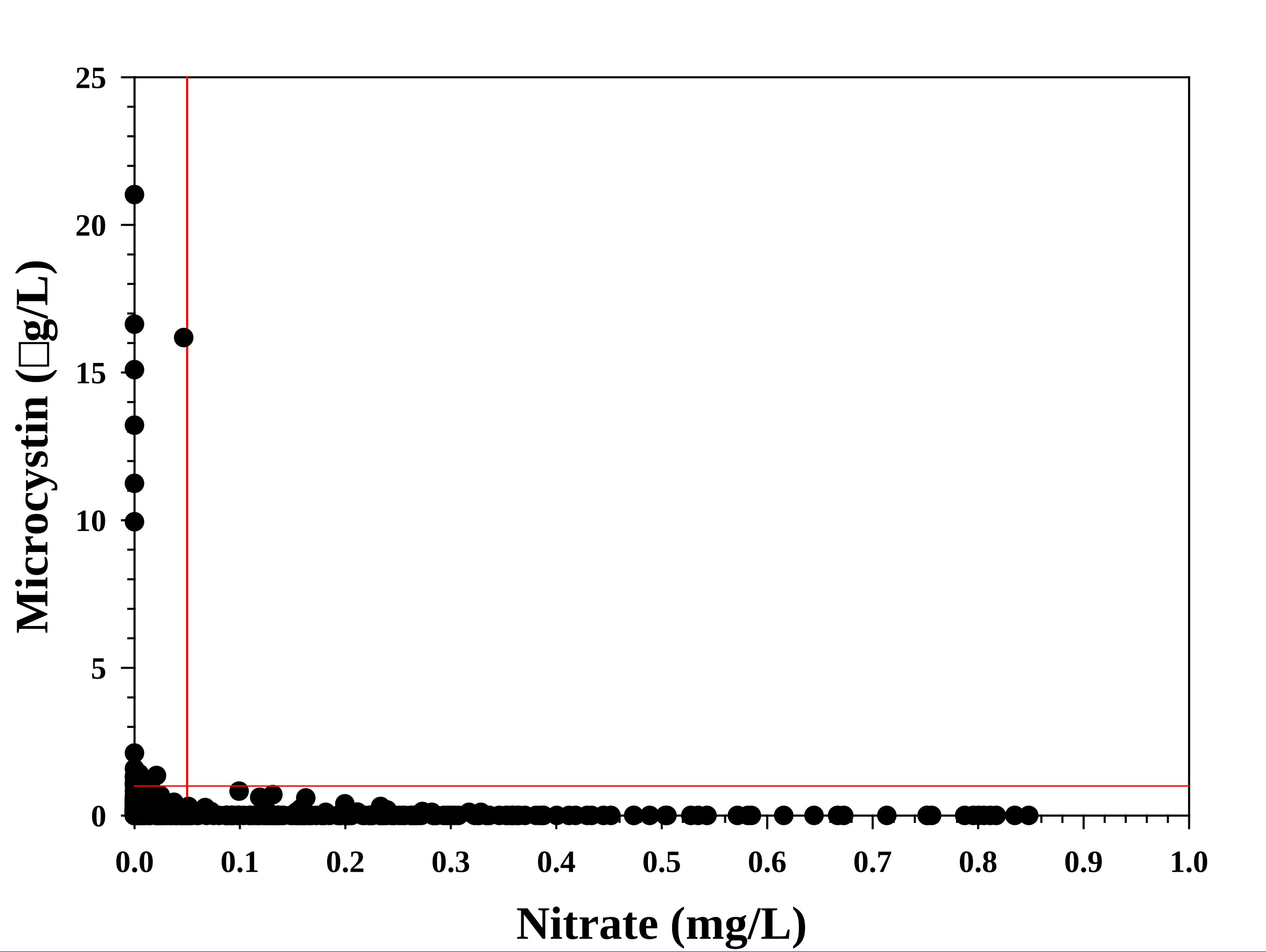
After Graham and Jones, 2009

There is No Single Environmental Variable that is Consistently Associated with Microcystin Occurrence and Concentration

Reservoir*	Strongest Correlate	r_s	p-value	n
Bilby	Conductance	-0.86	<0.01	48
Forest	Chlorophyll > 35 µm	0.67	<0.01	49
Harrison	Total Nitrogen	0.78	<0.01	49
Marceline	Dissolved Organic Carbon	0.66	<0.01	49
Mozingo	Magnesium	-0.84	<0.01	13
Nodaway	Nitrate	-0.46	<0.01	49
Paho	*Ceriodaphnia* abundance	0.81	<0.01	28
Sterling	Sodium	0.60	0.03	13

*Reservoirs were sampled weekly during January-December 2004

Thresholds and Probabilities May Better Define Relations Between Environmental Variables and Microcystin Occurrence and Concentration and Provide Insight into Potential Management Scenarios



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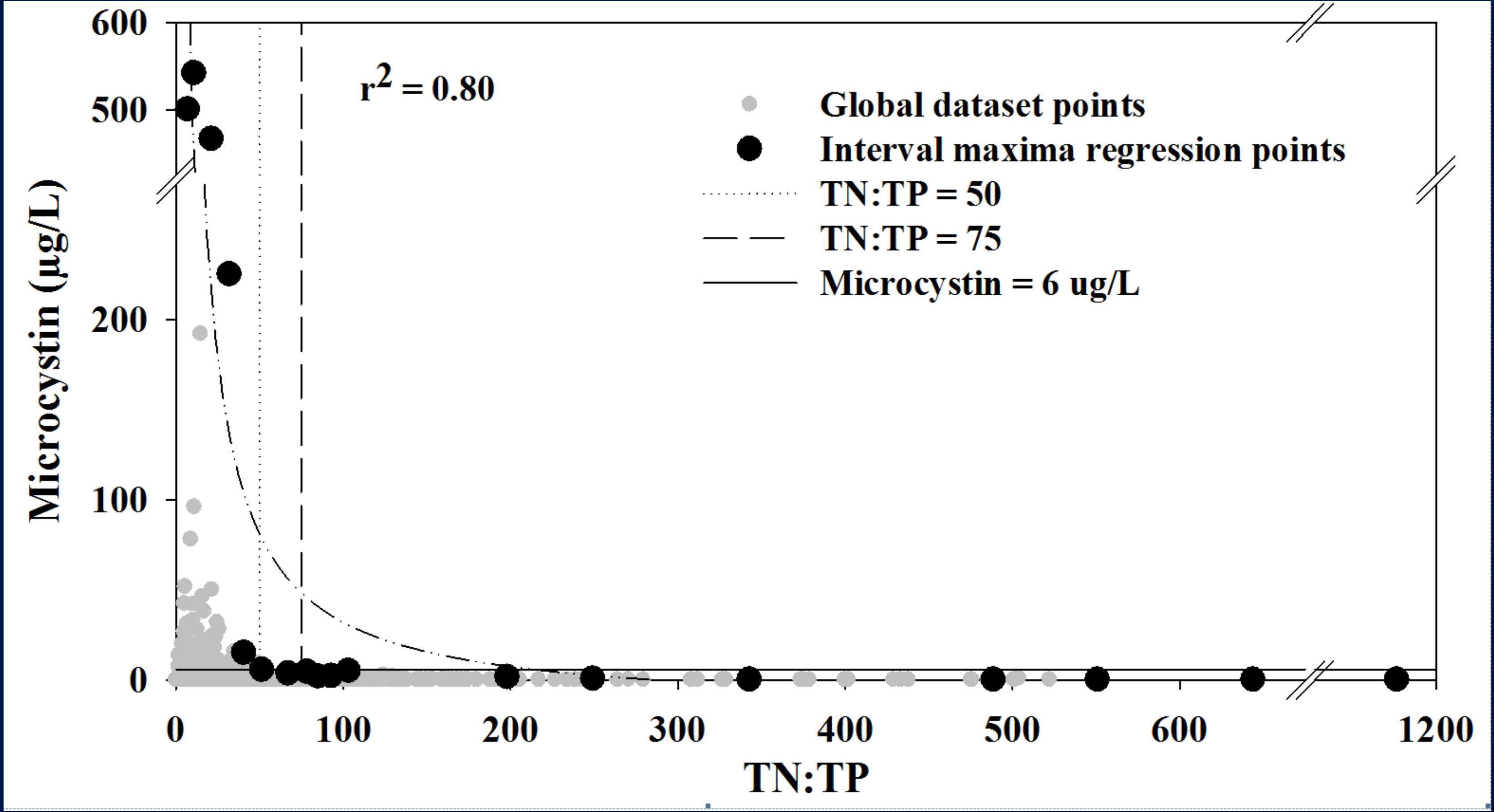

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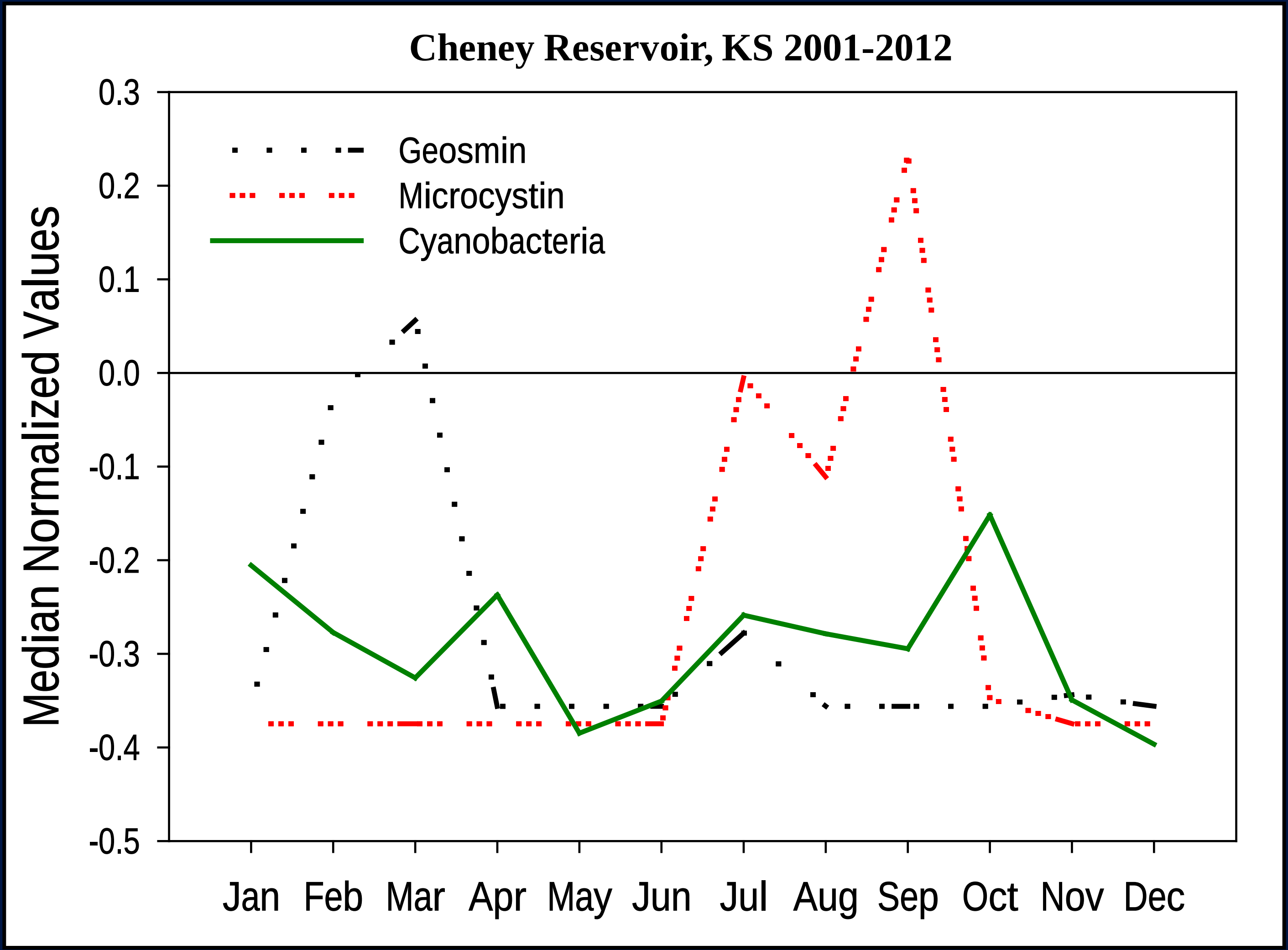
Seasonal Patterns and Environmental Influences May Be Relatively Consistent Between Years in Some Lakes



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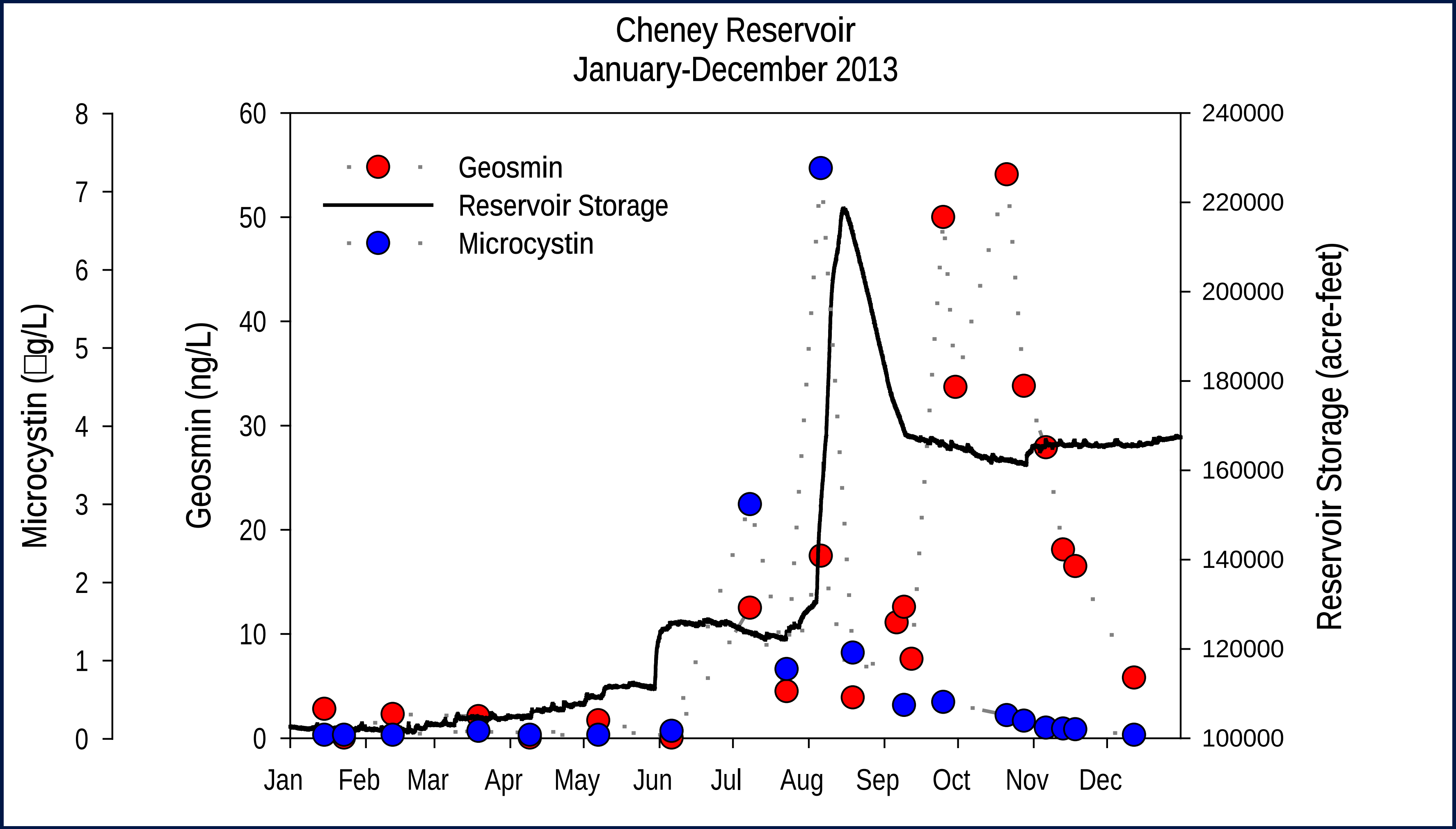
Anomolous Events, Such as Large Summer Inflows, May Disrupt Typical Seasonal Patterns



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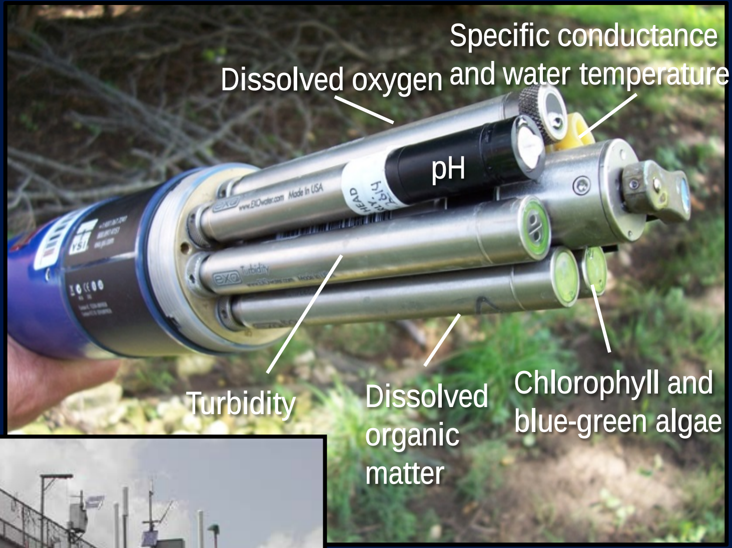
Continuous Water-Quality Monitors Can Be Used to Develop Models to Compute Microcystin and Geosmin Concentrations in Real Time

- Recorded and transmitted hourly
- Data available online:
  http://waterdata.usgs.gov
  http://nrtwq.usgs.gov/ks
- Develop relations to estimate concentrations of variables that cannot be measured in real time



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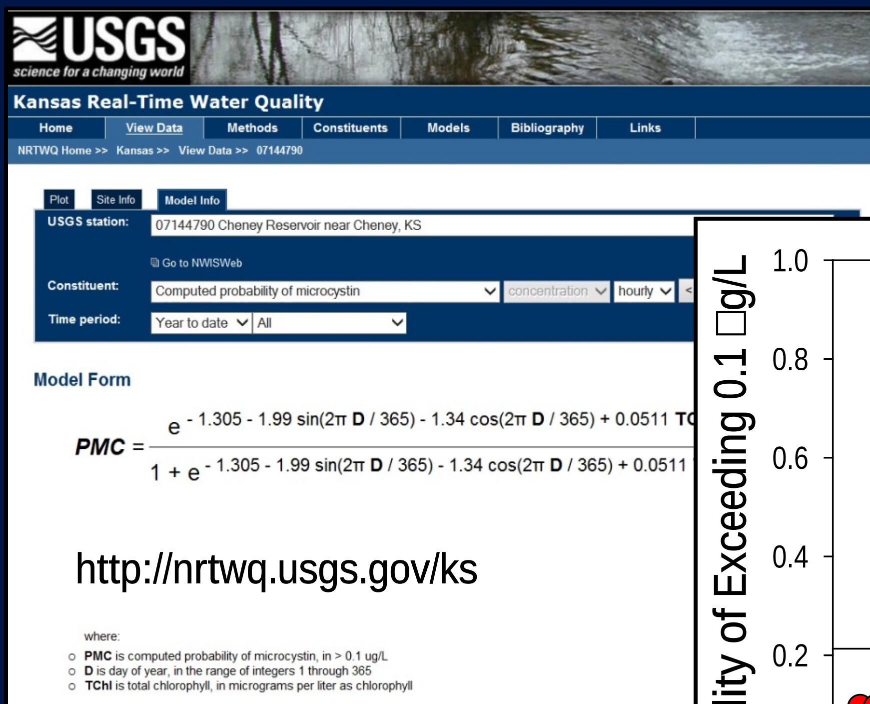
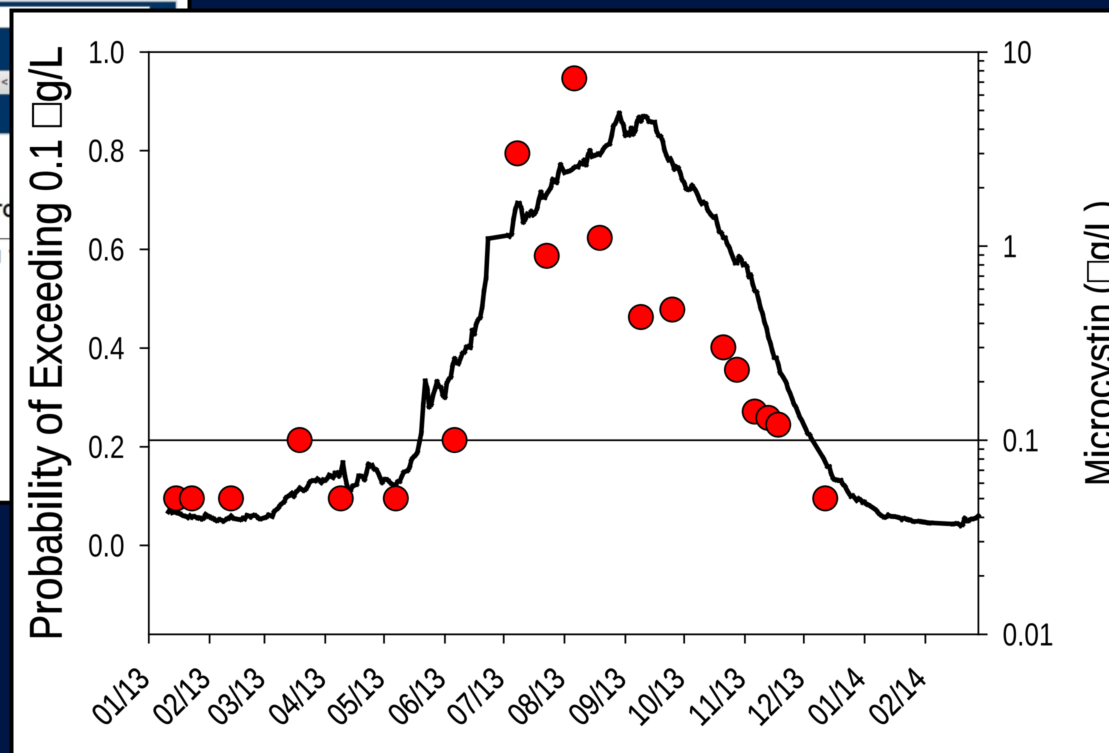
The Logistic Regression Model for Probability of Microcystin Concentrations > 0.1 µg/L in Cheney Reservoir Includes a Seasonal Component and Chlorophyll as Explanatory Variables





Stone and Graham, http://pubs.usgs.gov/of/2013/1123/

Watershed Management is a Long-Term Solution and Changes in Water-Quality May Not Be Evident for Many Years

- Point Source Pollutants
  - Elimination or diversion
  - Reduction in loads through additional treatment
- Non-Point Source Pollutants
  - Implementation of Best Management Practices
    - Reduction in fertilizer use
    - Urban stormwater volume reduction
    - Urban stormwater treatment
    - Porous pavement
    - Riparian buffers
    - Wetlands
    - Rain gardens
    - Livestock waste control systems
    - Terraces
    - Conservation Tillage
    - Grassed waterways

Cheney Reservoir Watershed
Photo courtesy of J. Blain

Planting of an Overland Park, KS bioretention cell
Photo courtesy of Johnson County Stormwater

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In-Lake Treatment Approaches

- Algicides
- Aeration/Circulation
- Water-Quality Manipulation
  - Phosphorus Removal
  - Silica Addition
- Biological Controls
  - Species Addition (bacteria, viruses, fish, macrophytes)
  - Floating Wetlands
  - Biomanipulation
- Ultrasonication
- Dredging

Lake Aeration Unit

Lake Dredging

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Photos Courtesy of K. Wagner

Removal of Cyanobacterial Toxins and Taste-and-Odor Compounds During the Drinking Water Treatment Process

- Removal of intact cells through coagulation and filtration.
- Removal or destruction of toxins.
  - Adsorption
    - Powdered Activated Carbon (PAC)
    - Granulated Activated Carbon (GAC)
  - Oxidation
    - Chlorine and Chloramines
    - Permanganate
    - Ozone
    - Advanced Oxidation Processes (AOPs)
  - Biological Filtration
  - Membranes
    - Nanofiltration (tight)
    - Reverse Osmosis
    - Microfiltration with PAC addition
    - Ultrafiltration with PAC addition

Photos courtesy of C. Adams

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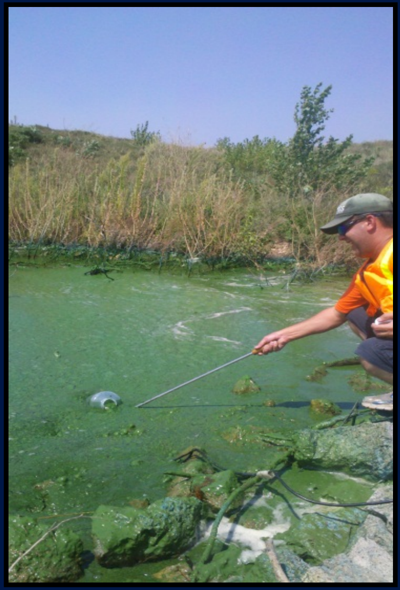
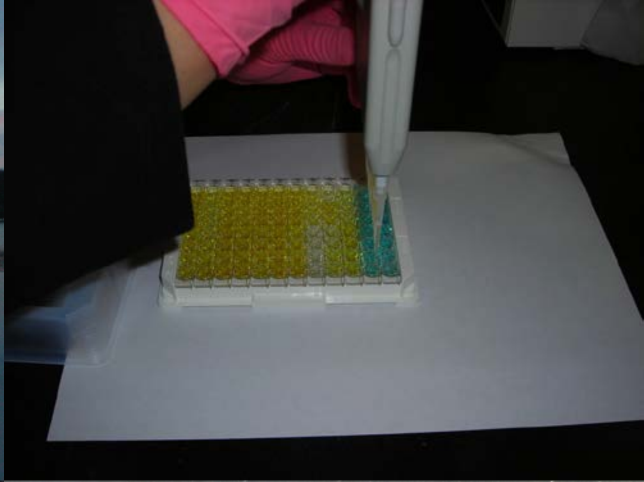
Conclusions

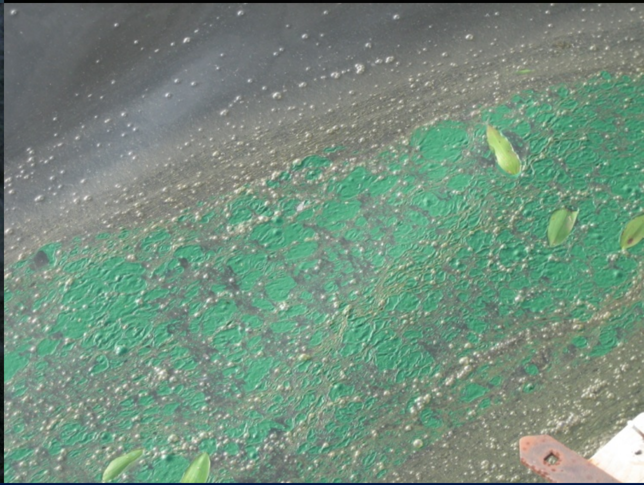
- Cyanobacterial blooms and associated toxins and taste-and-odor compounds commonly occur throughout the United States.
- Seasonal patterns are unique to individual lakes.
- Relations between microcystin and other variables are not necessarily linear and vary among lakes and years.
- Real-time water-quality monitoring can provide a tool to predict the occurrence of cyanobacterial blooms and associated nuisance compounds
- Much more study is needed to develop reliable means of predicting and responding to cyanobacterial blooms to ensure public health protection.



Milford Lake, Kansas
September 2011





Additional Information:

http://ks.water.usgs.gov/studies/qw/cyanobacteria/

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