Cyanobacterial Blooms: Tastes, Odors, and Toxins

Jennifer L. Graham and Keith A. Loftin
U.S. Geological Survey
Kansas Water Science Center

New Jersey Water Monitoring Council
September 23, 2015

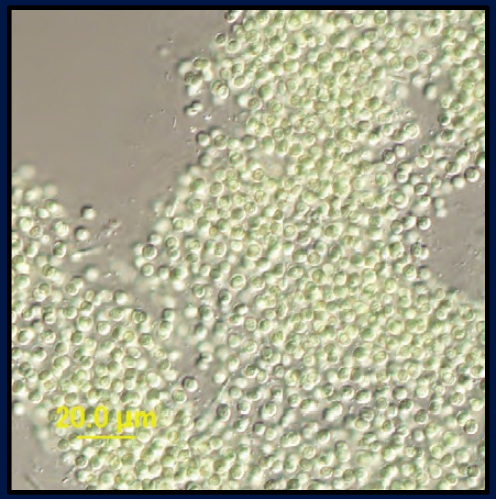
Overview

- Cyanobacterial Harmful Algal Blooms
- USGS Capabilities
- Occurrence
- Spatiotemporal Patterns
- Environmental Influences

What Are Cyanobacteria?

- Cyanobacteria are true bacteria, but have chlorophyll-*a* like algae.
- Structurally the cyanobacteria are bacteria-like, but functionally they are algae-like.
- Because cyanobacteria function like algae in aquatic ecosystems, they typically are considered to be part of algal communities (this is why they often are called blue-green algae).

Gloeotrichia echinulata



Microcystis aeruginosa

Images from Rosen and others, OFR 2010-1289
http://pubs.usgs.gov/of/2010/1289/

What is an Algal Bloom?

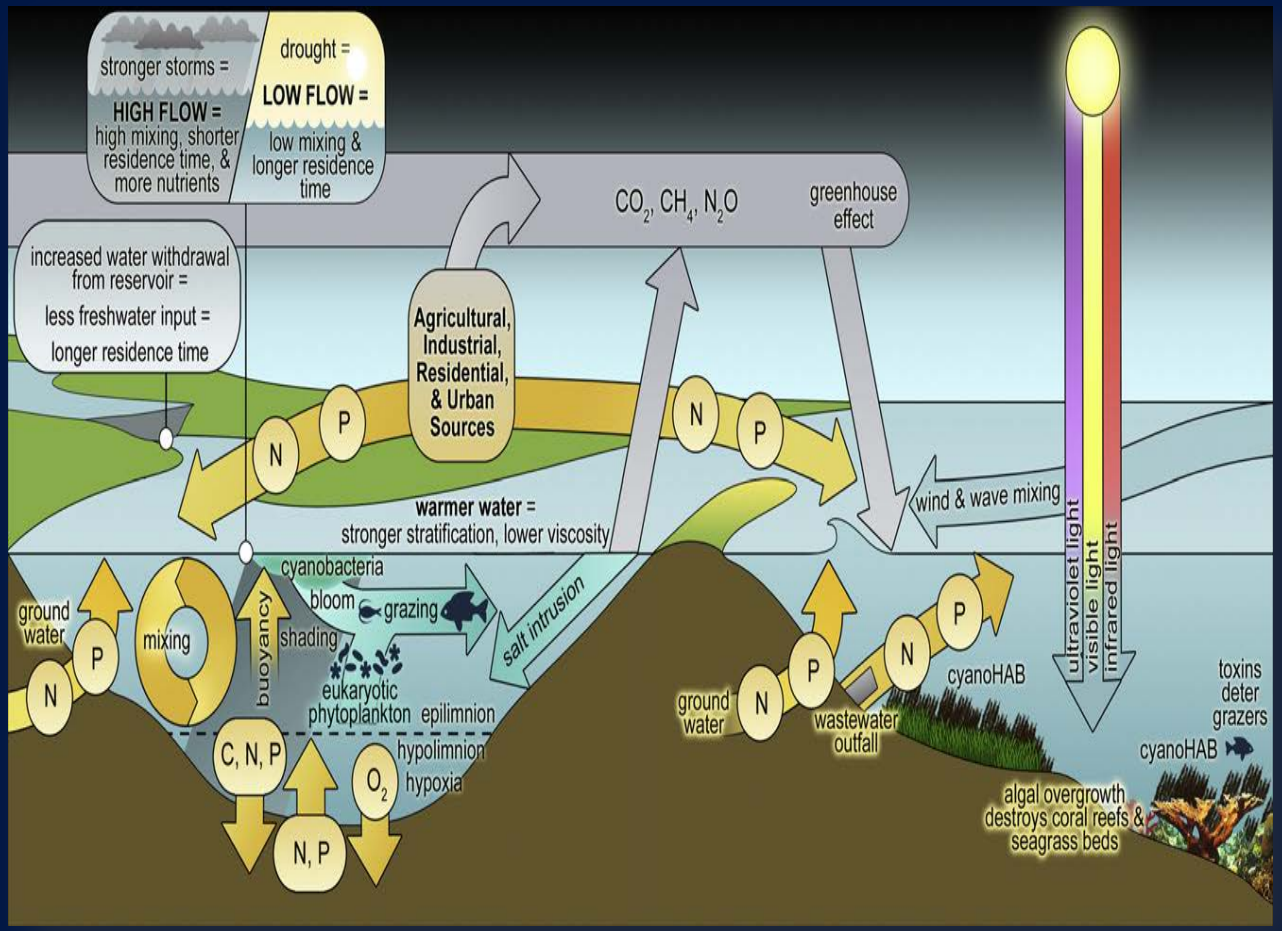
- The definition of a “bloom” is somewhat subjective.
- Common definitions include:
  - Algae have high cell densities (20,000 to 100,000 cells/mL).
  - Proliferation of algae is dominated by a single or a few species.
  - There is a visible accumulation of algae.

South Dakota - green algae bloom

Idaho - cyanobacteria bloom
photo courtesy of F. Wilhelm

What Causes Algal Blooms?

Many environmental factors influence the occurrence of algal blooms. In general, an algal bloom indicates an ecosystem imbalance.



Courtesy of Hans Paerl

What Makes Some Algal Blooms Harmful?

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

- Ecologic Concerns
- Economic Concerns
- Public Health Concerns

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

Kansas – cyanobacterial bloom

Why Are Cyanobacterial Blooms Unique?

Toledo bans tap water after algae toxins found

Toledo Water Ban Persists After New Test Results Cause Concerns

Toledo-area water advisory expected to continue through Sunday as leaders await tests; water stations to remain open

Microcystin found in samples; boiling not recommended

Toledo, Ohio, Headed for Third Day With Drinking Water Ban

Toledo Water Ban Lifted But Test Results Kept Secret

BY KILEY KROH POSTED ON AUGUST 4, 2014 AT 3:21 PM UPDATED: AUGUST 4, 2014 AT 4:51 PM

What Cyanobacteria Produce 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

USGS
science for a changing world

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

Are There Regulations for Cyanotoxins?

USEPA Health Advisory Levels for Cyanotoxins in Finished Drinking Water:

- Microcystin: 0.3, 1.6 µg/L
- Cylindrospermopsin: 0.7, 3.0 µg/L

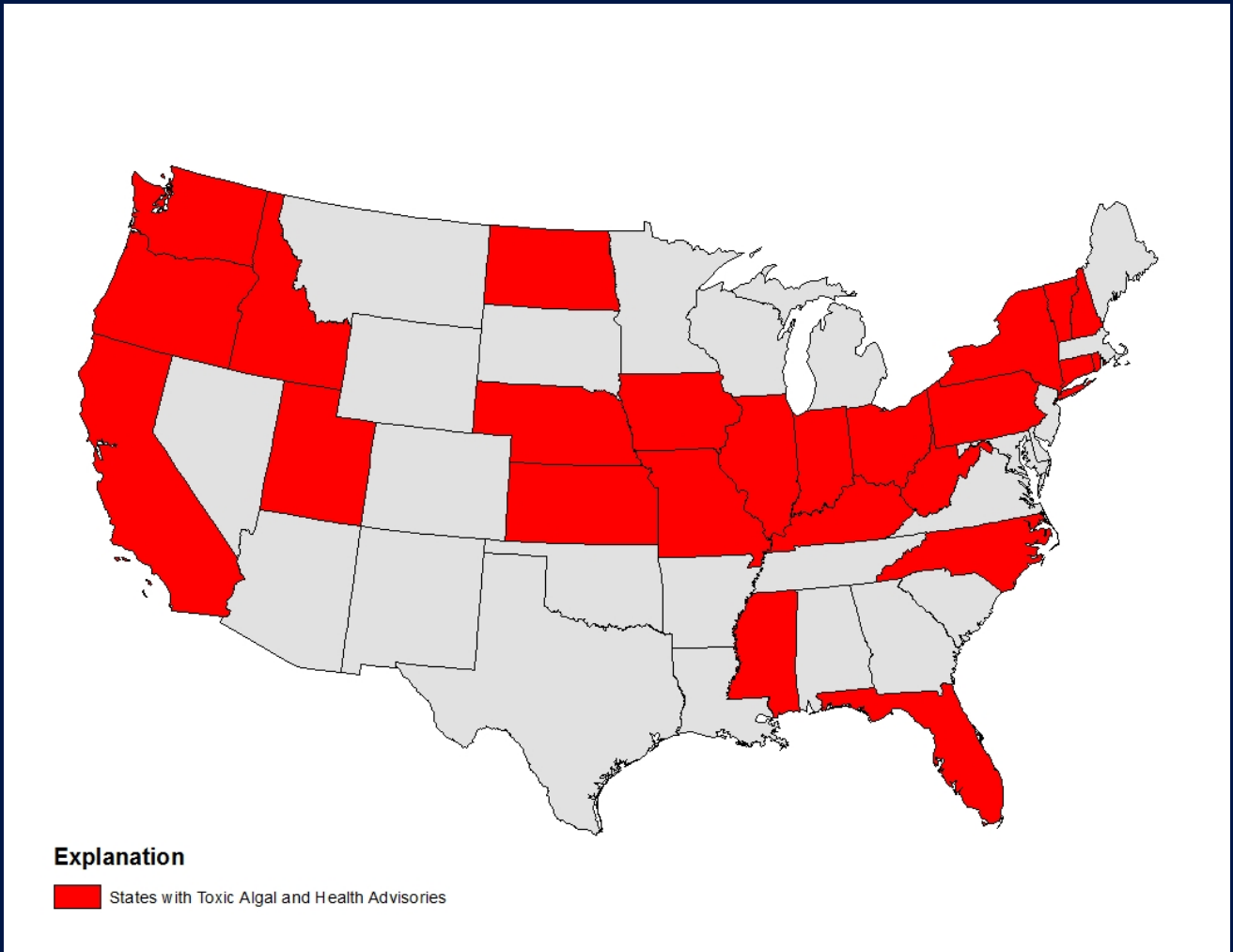
State Recreational Guidance Varies, Most Based on World Health Organization provisional guidelines for microcystin-LR:

- Low Risk: <10 µg/L
- Moderate Risk: 10-20 µg/L
- High Risk: 20-2,000 µg/L
- Very High Risk: >2,000 µg/L

http://water.epa.gov/drink/standards/hascience.cfm
http://www.who.int/water_sanitation_health/dwq/chemicals/microcystinsum.pdf

How Common Are Toxic Cyanobacterial Blooms?

24 States in August 2015 Had Toxic Algal and Health Advisories for Cyanobacteria



USGS
science for a changing world

Data Compiled from EPA Freshwater HAB News

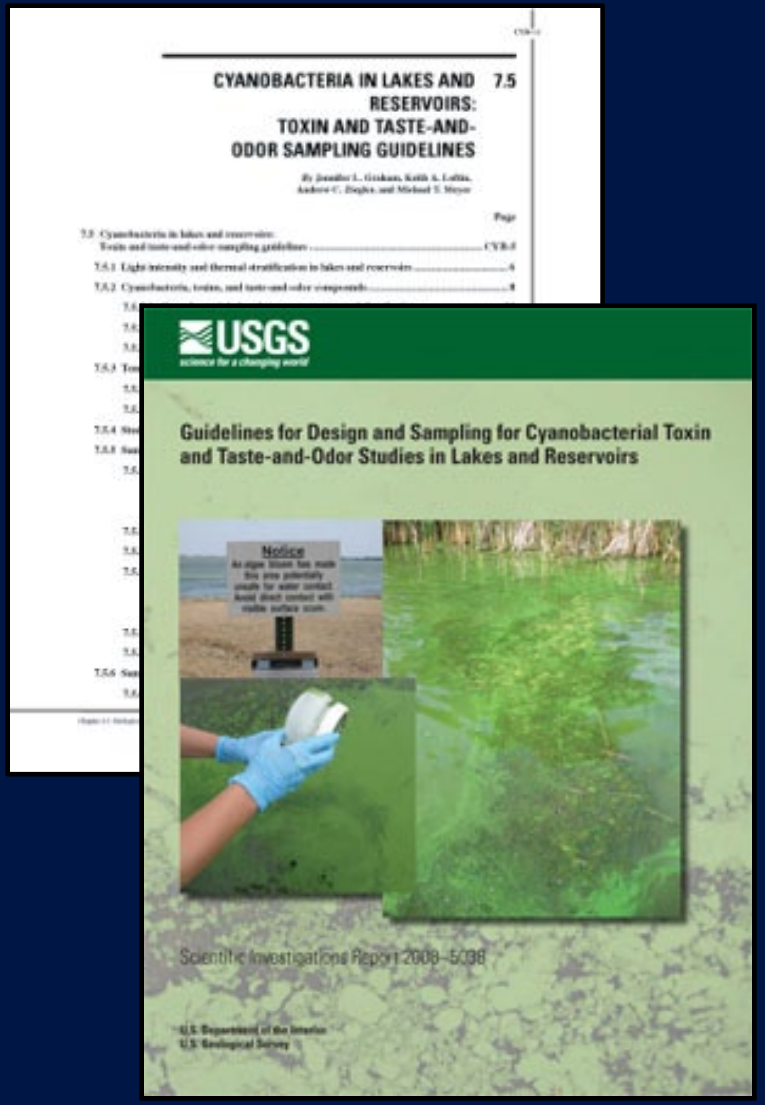
Consistent Guidelines for Study Design and Sample Collection are Essential for Nationally Comparable Data

SIR 2008-5038 *Guidelines for Design and Sampling for Cyanobacterial Toxin and Taste-and-Odor Studies in Lakes and Reservoirs* (Graham and others)

http://pubs.usgs.gov/sir/2008/5038

USGS National Field Manual Chapter 7.5 *Cyanobacteria in Lakes and Reservoirs: Toxin and Taste-and-Odor Sampling Guidelines* (Graham and others)

http://water.usgs.gov/owq/FieldManual/Chapter7/7.5

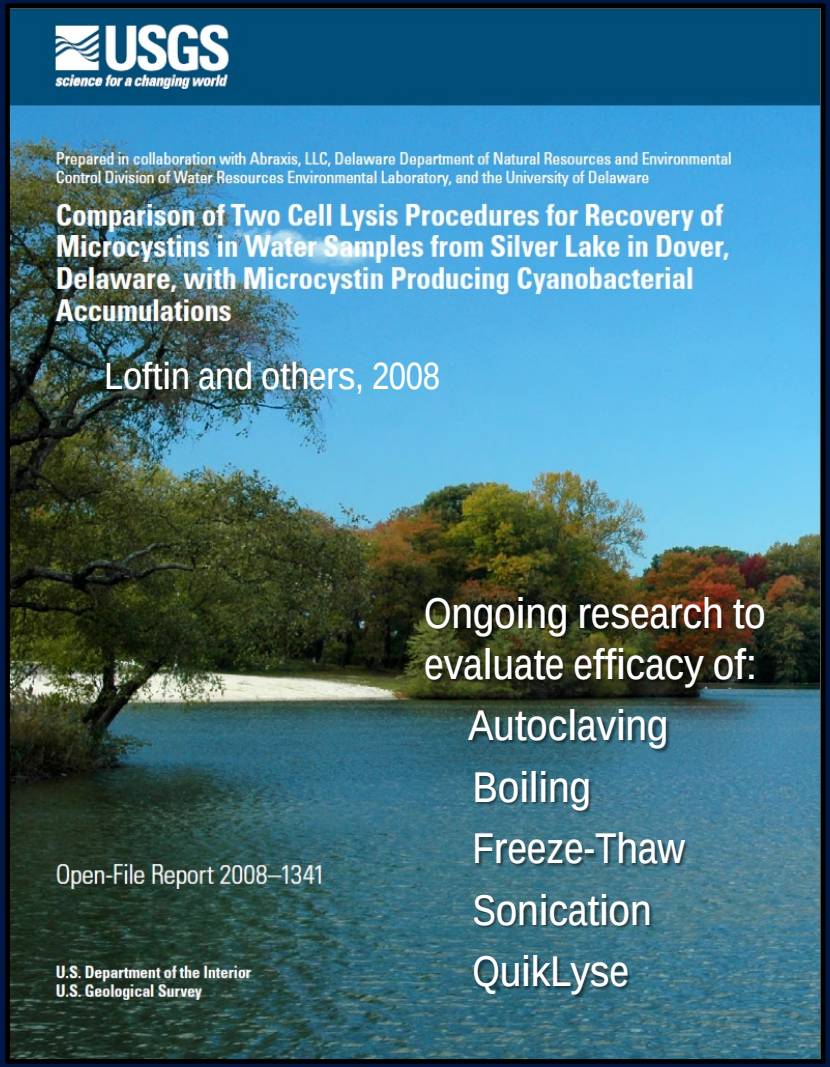


Robust and Quantitative Analytical Methods are Essential to Adequately Characterize Cyanotoxin Occurrence, Fate, and Transport

USGS Organic Geochemistry Research Laboratory

- Enzyme-Linked Immunosorbent Assays (ELISA)
- LC/MS/MS
- Toxicity Assays

http://ks.water.usgs.gov/researchlab

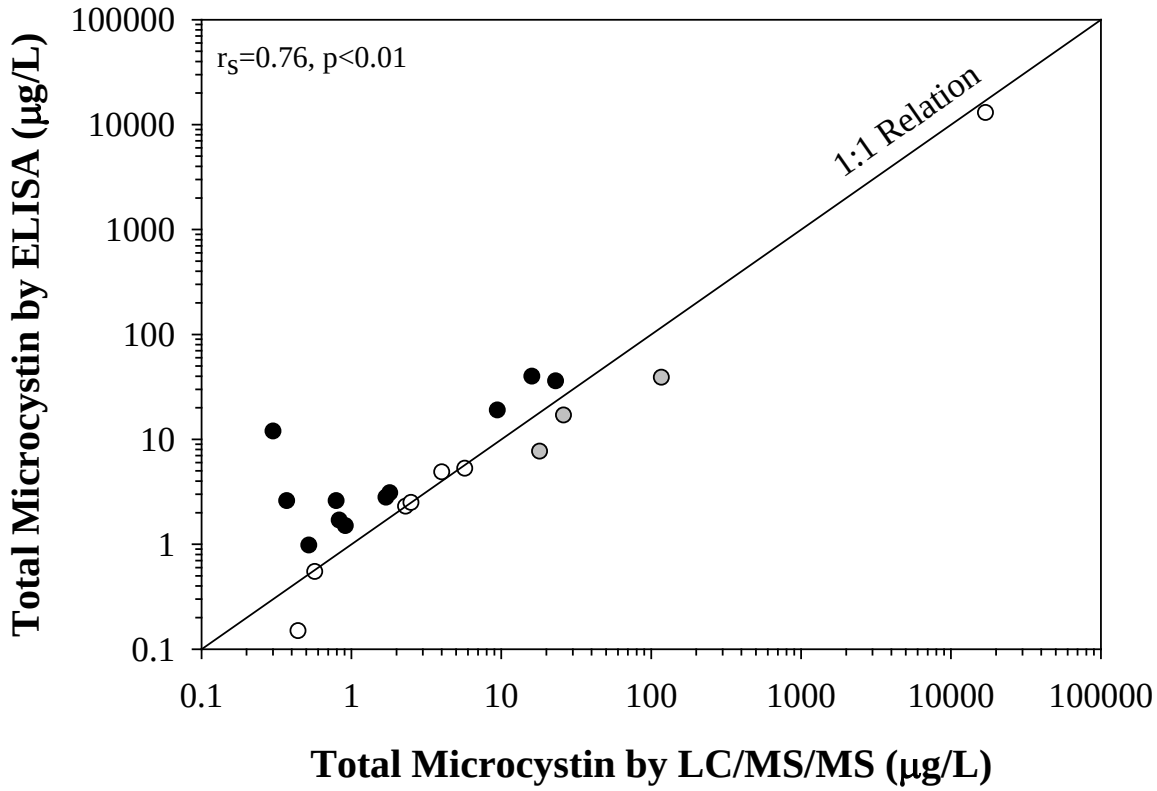


Ongoing research to evaluate efficacy of:

- Autoclaving
- Boiling
- Freeze-Thaw
- Sonication
- QuikLyse

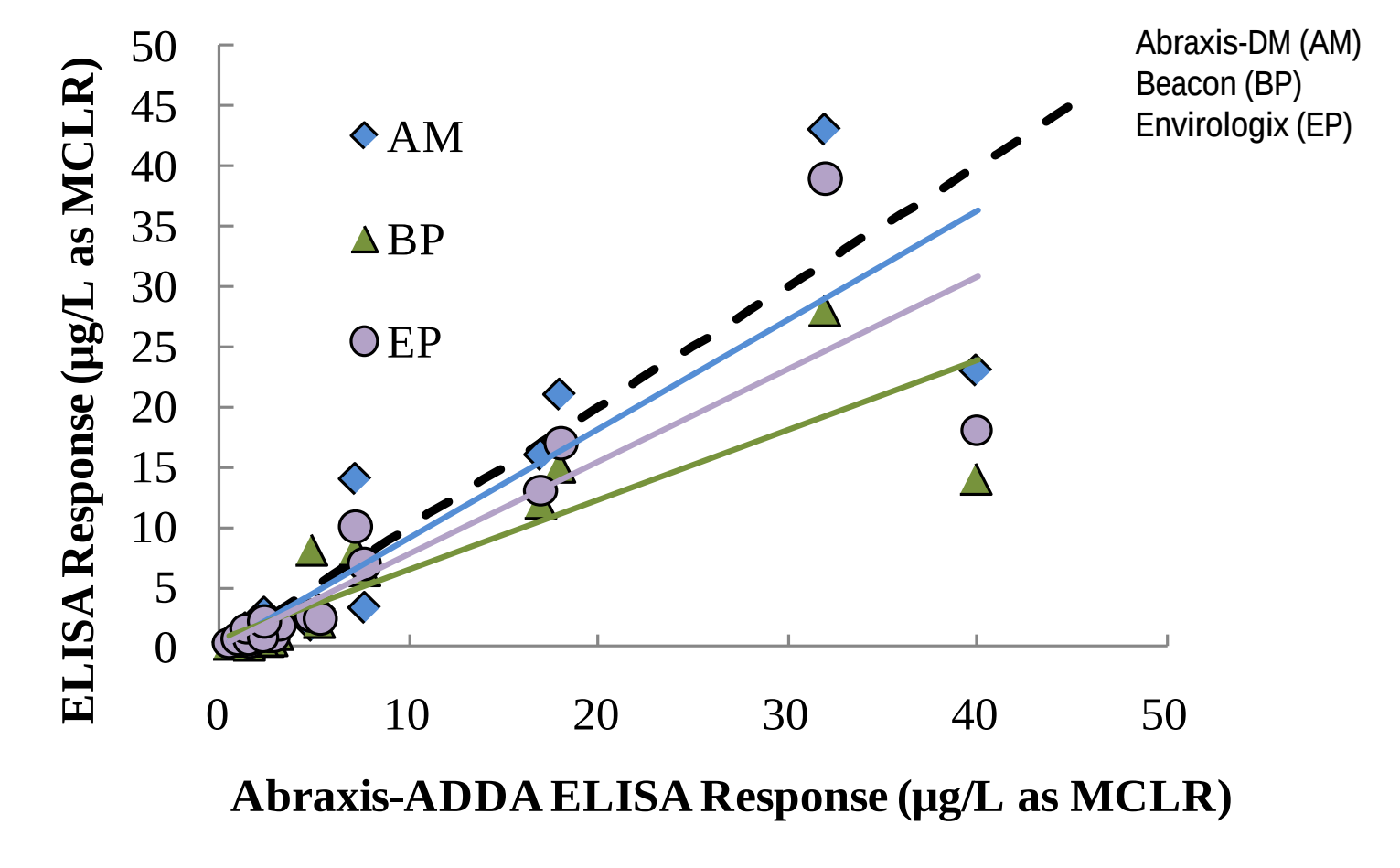
http://pubs.usgs.gov/of/2008/1341/

Total Microcystin Concentrations Measured by LC/MS/MS and ELISA are Generally Comparable (But Comparability Varies Depending on the ELISA Kit Used)



After Graham and others, 2010

Microcystin Results May Vary Depending on the ELISA Used for Analysis

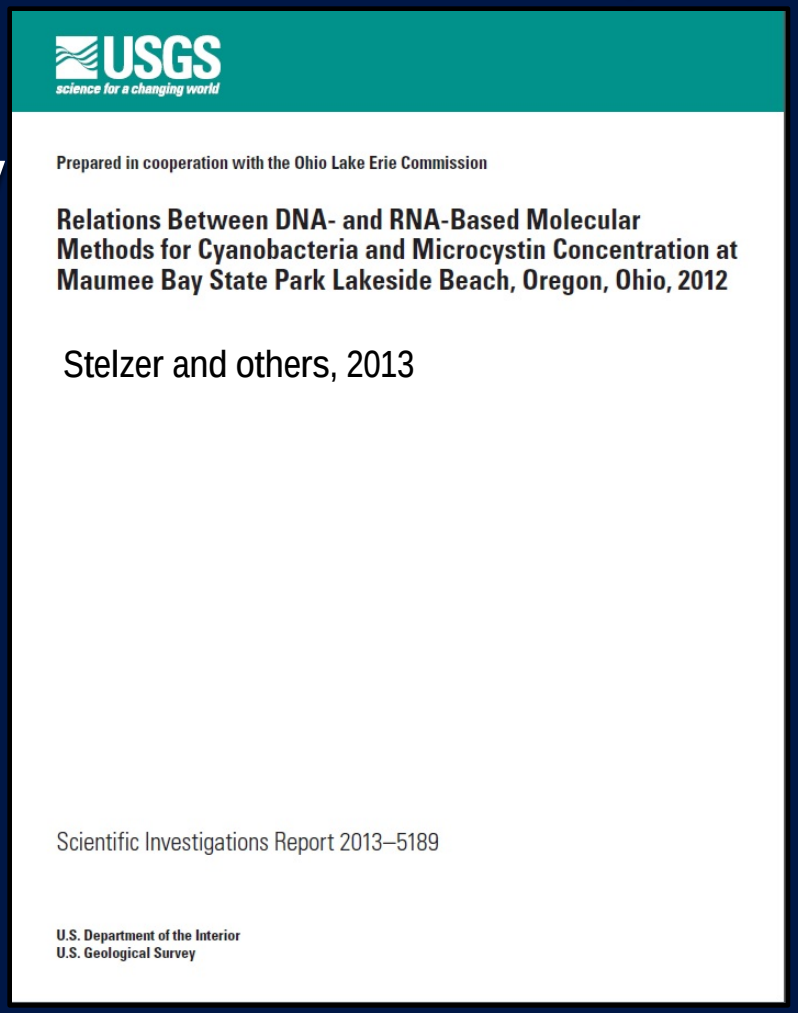


Loftin and others, in preparation

New Methods will Enhance Understanding and Characterization of Occurrence, Fate, and Transport

USGS Ohio Microbiology Laboratory

- Molecular qPCR DNA and RNA assays for:
  - Total cyanobacteria
  - Total *Microcystis*
  - *Microcystis*-specific microcystin genes
  - *Anabaena*-specific microcystin genes
  - *Planktothrix*-specific microcystin genes



USGS
science for a changing world

Prepared in cooperation with the Ohio Lake Erie Commission

Relations Between DNA- and RNA-Based Molecular Methods for Cyanobacteria and Microcystin Concentration at Maumee Bay State Park Lakeside Beach, Oregon, Ohio, 2012

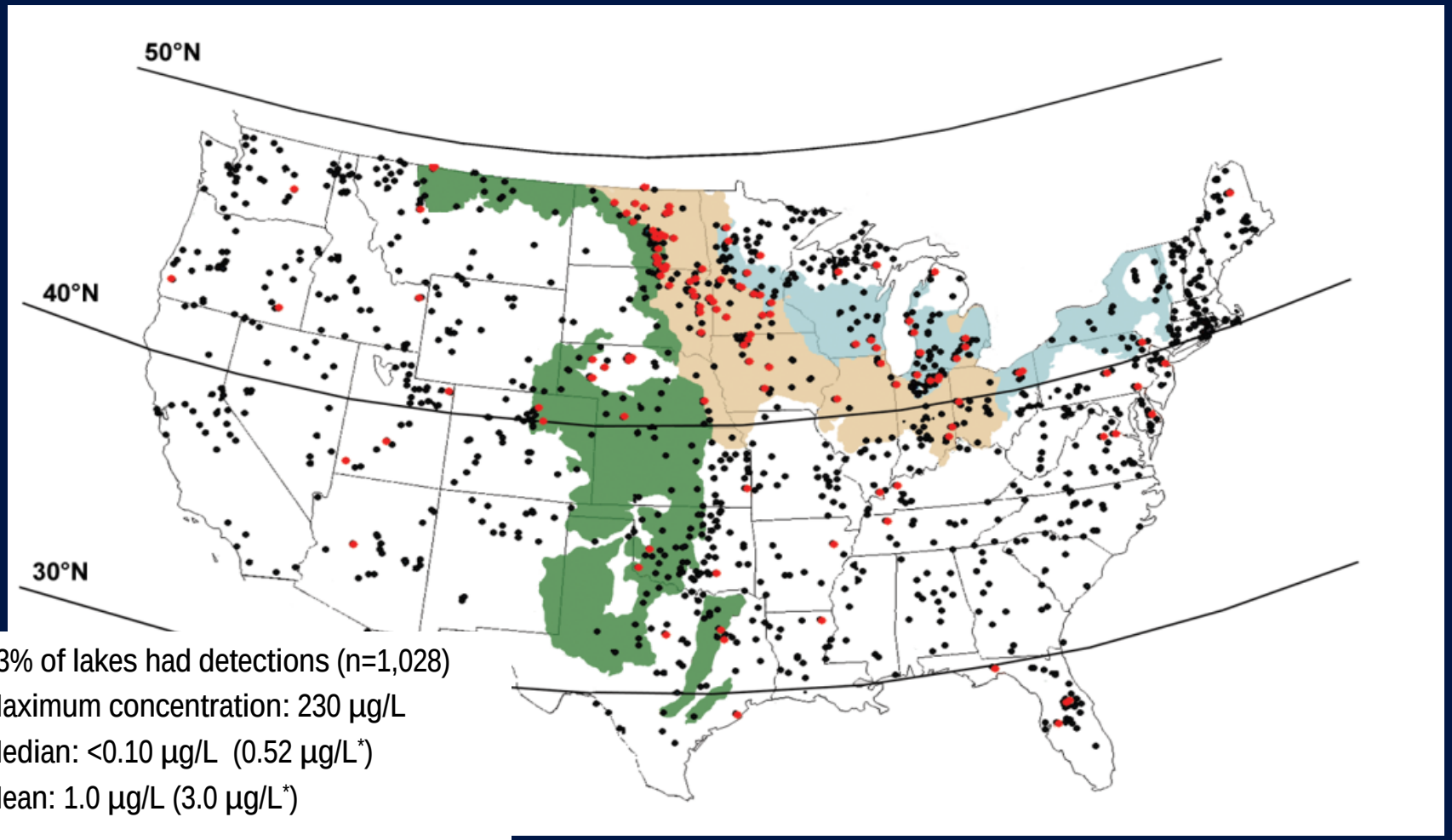
Stelzer and others, 2013

Scientific Investigations Report 2013–5189

U.S. Department of the Interior
U.S. Geological Survey

http://dx.doi.org/10.3133/sir20135189

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*)

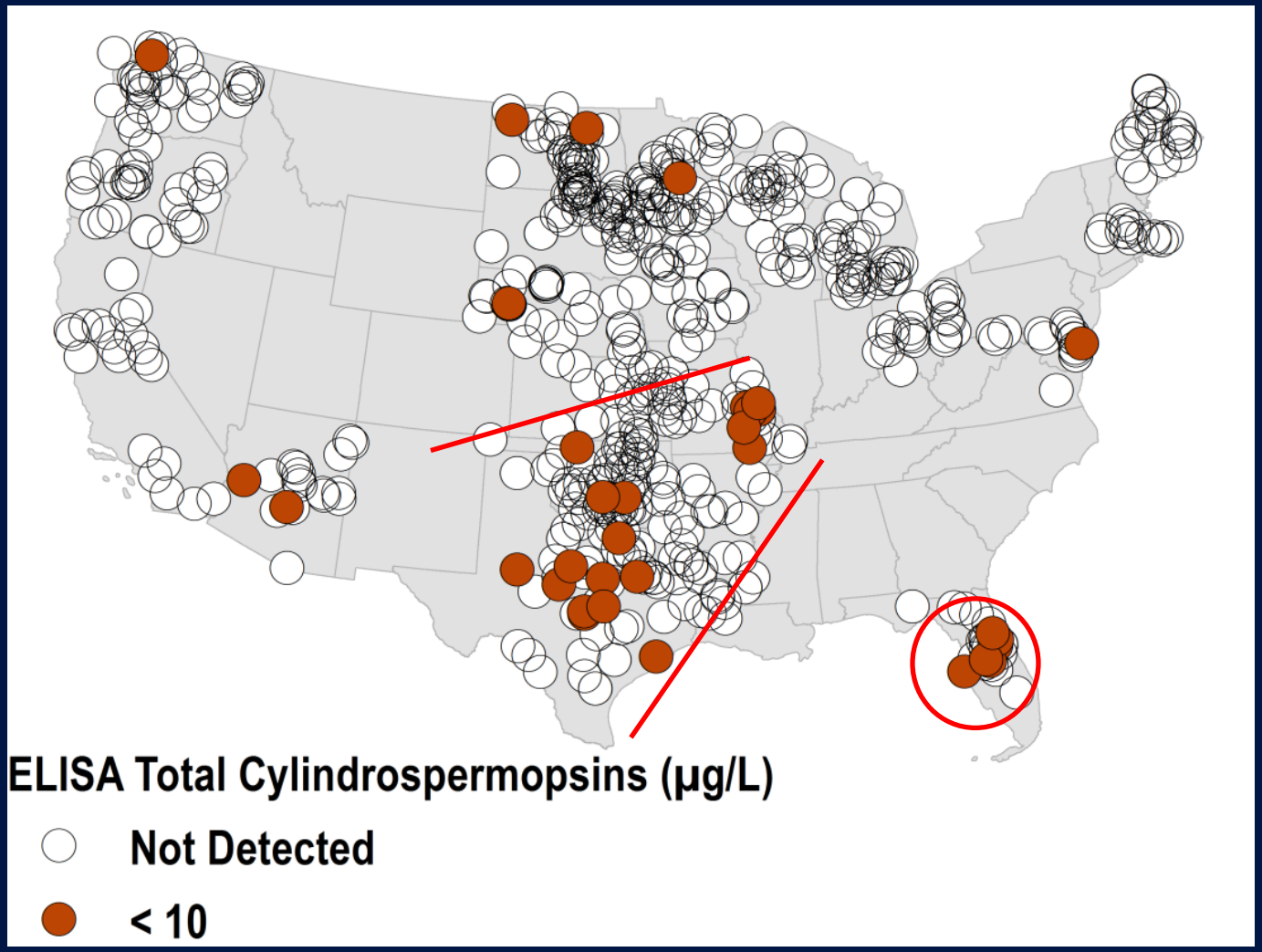
Mean: 1.0 µg/L (3.0 µg/L*)

*Detections only

USGS
science for a changing world

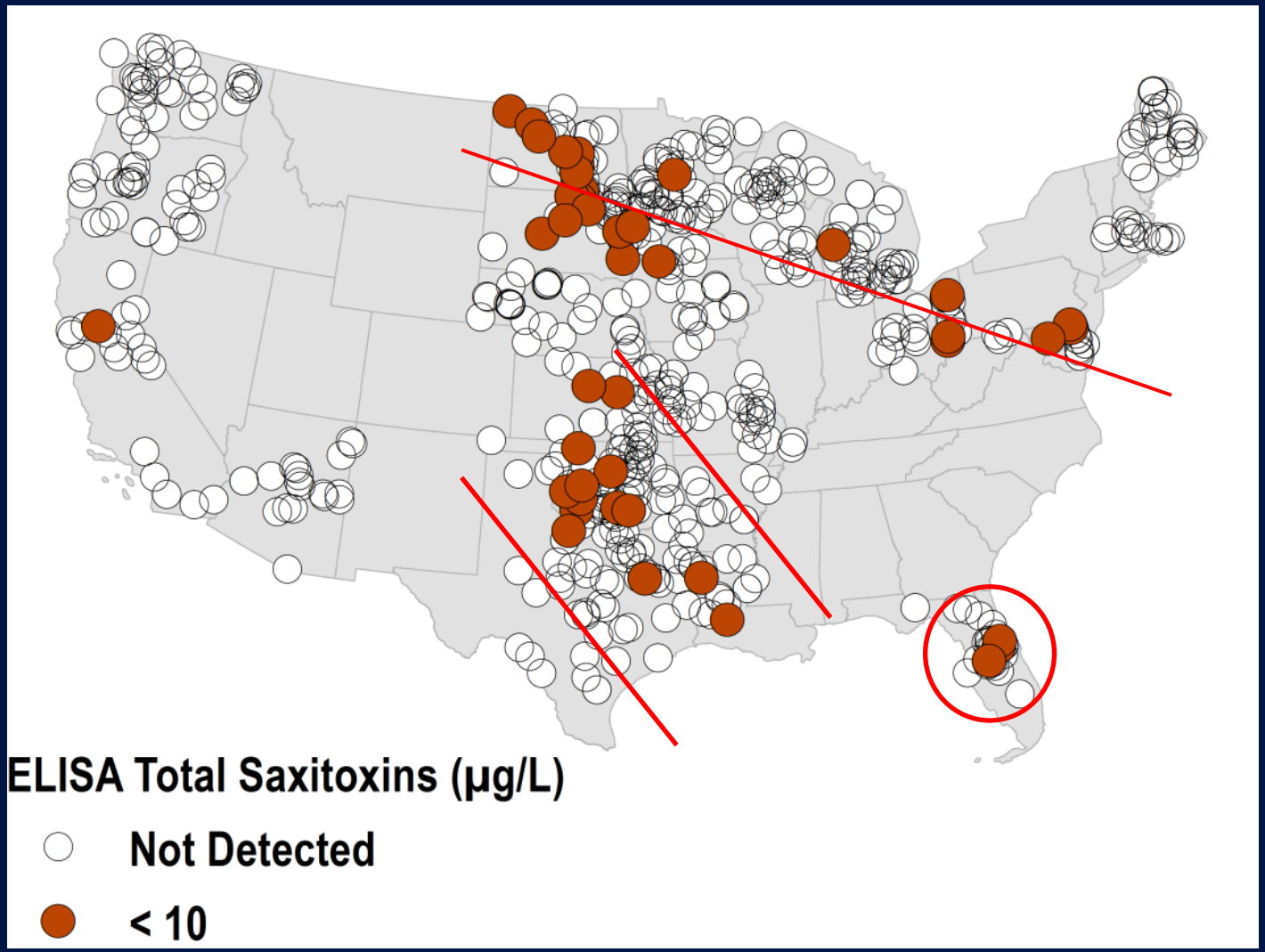
After Beaver and others, 2014

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



Loftin and others, submitted

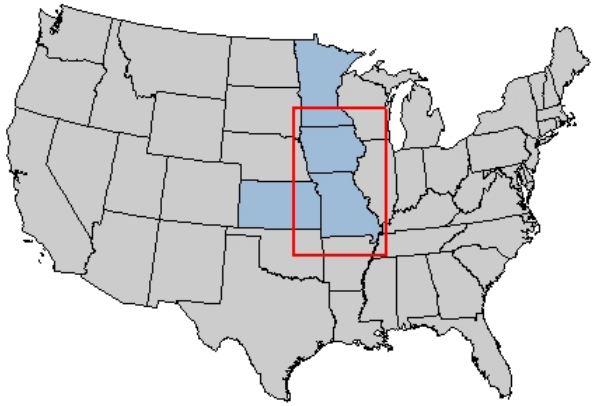
Saxitoxins Were Detected by ELISA in About 8% (n=678) of Analyzed Lakes; Occurrence was Most Common in the Upper Midwest and the South

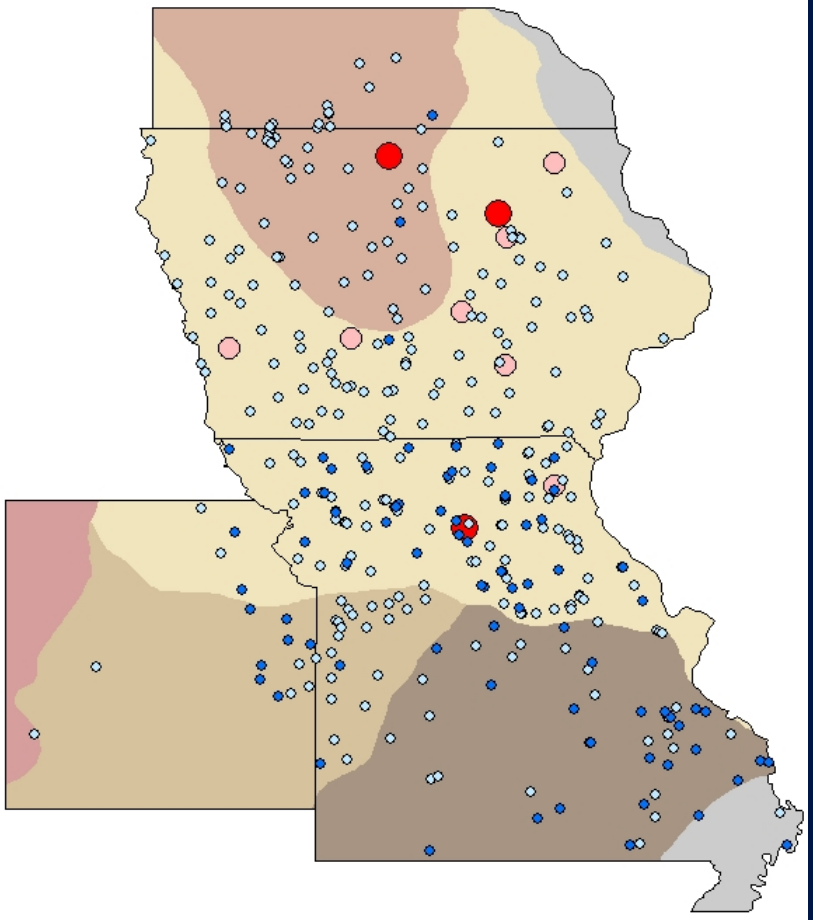


USGS
science for a changing world

Loftin and others, submitted

Microcystins are Widespread and Common in the Midwest



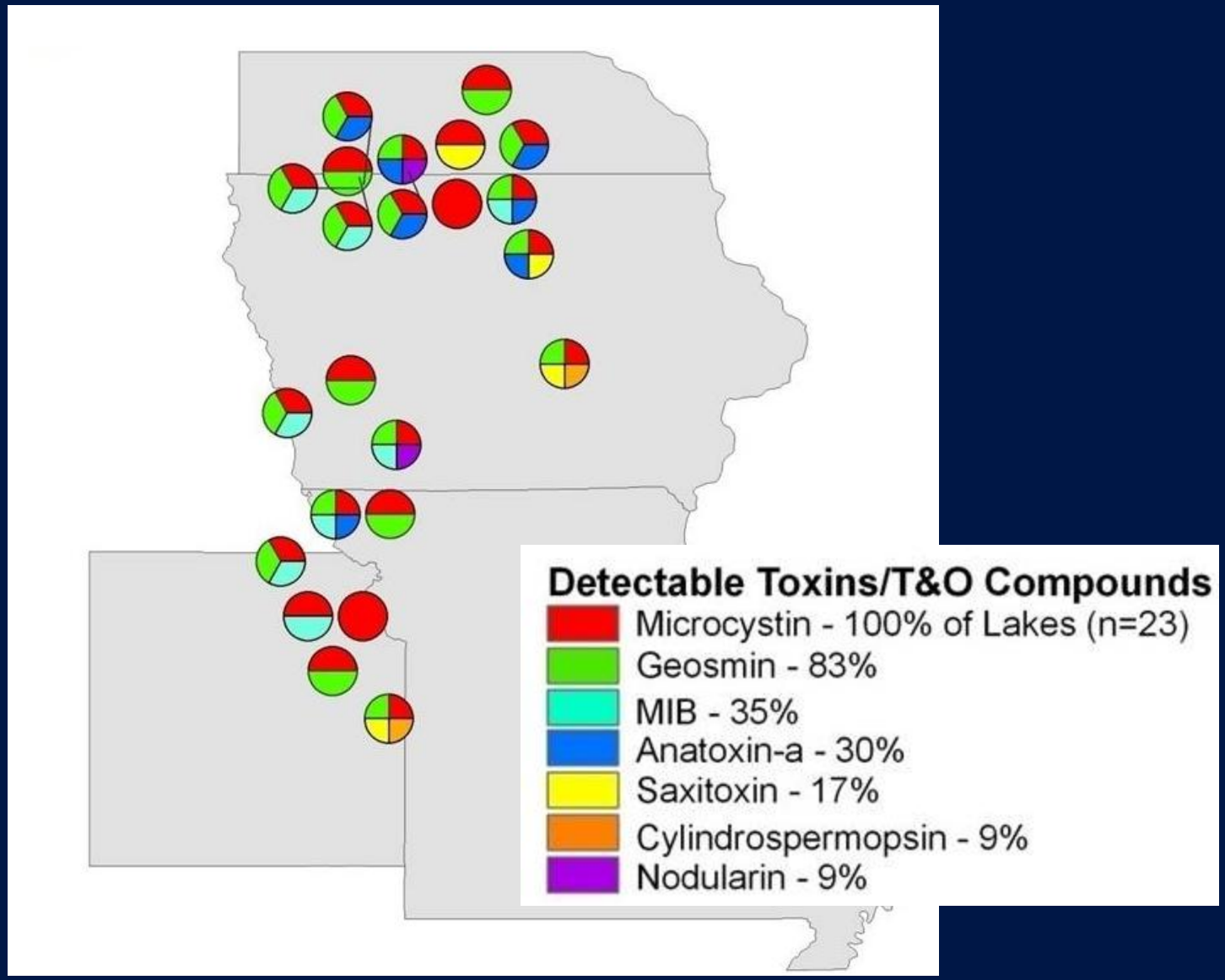


78% of lakes had detections (n=359)

Maximum concentration: 52 µg/L

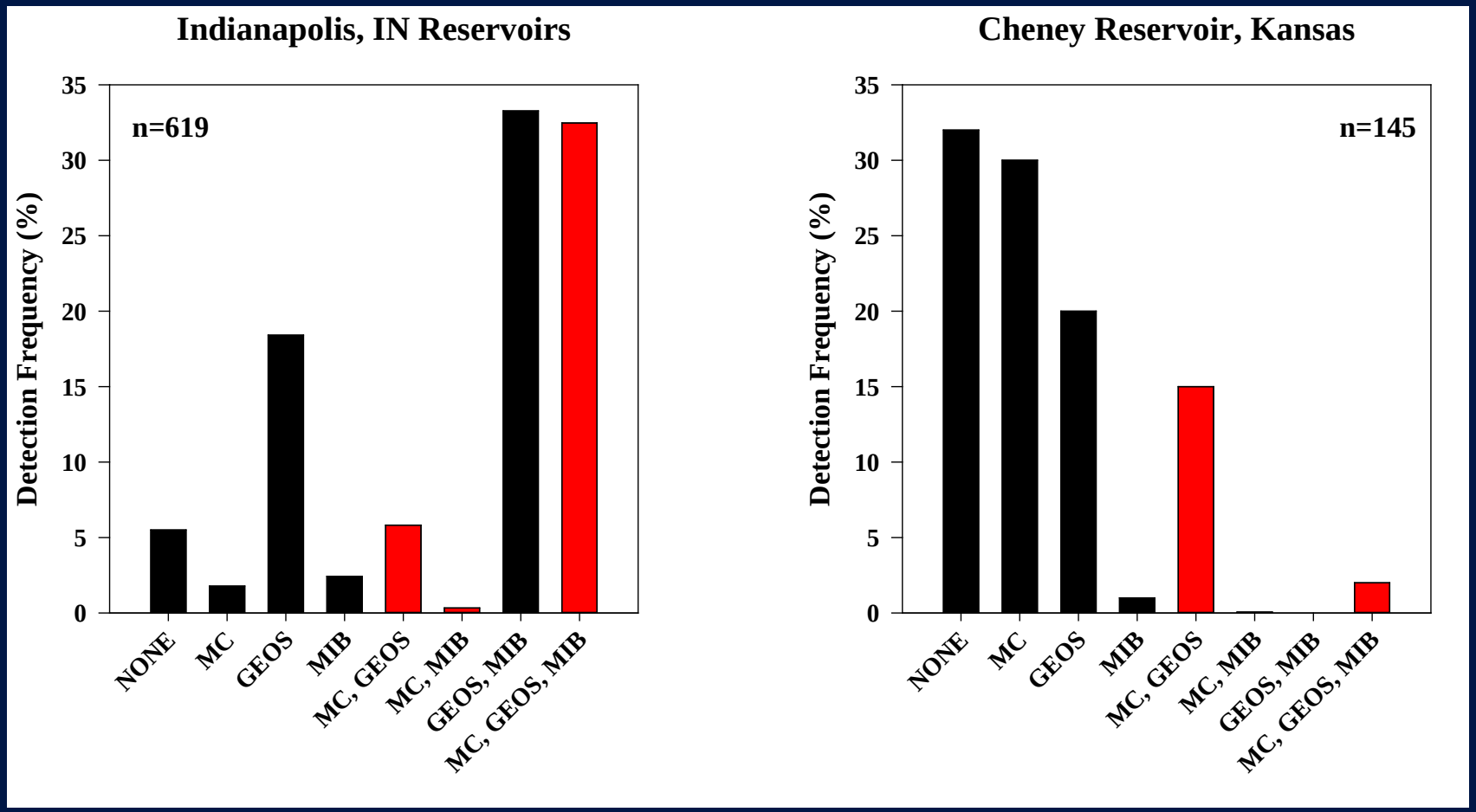
After Graham and others 2004, 2006, and 2009

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



After Graham and others, 2010

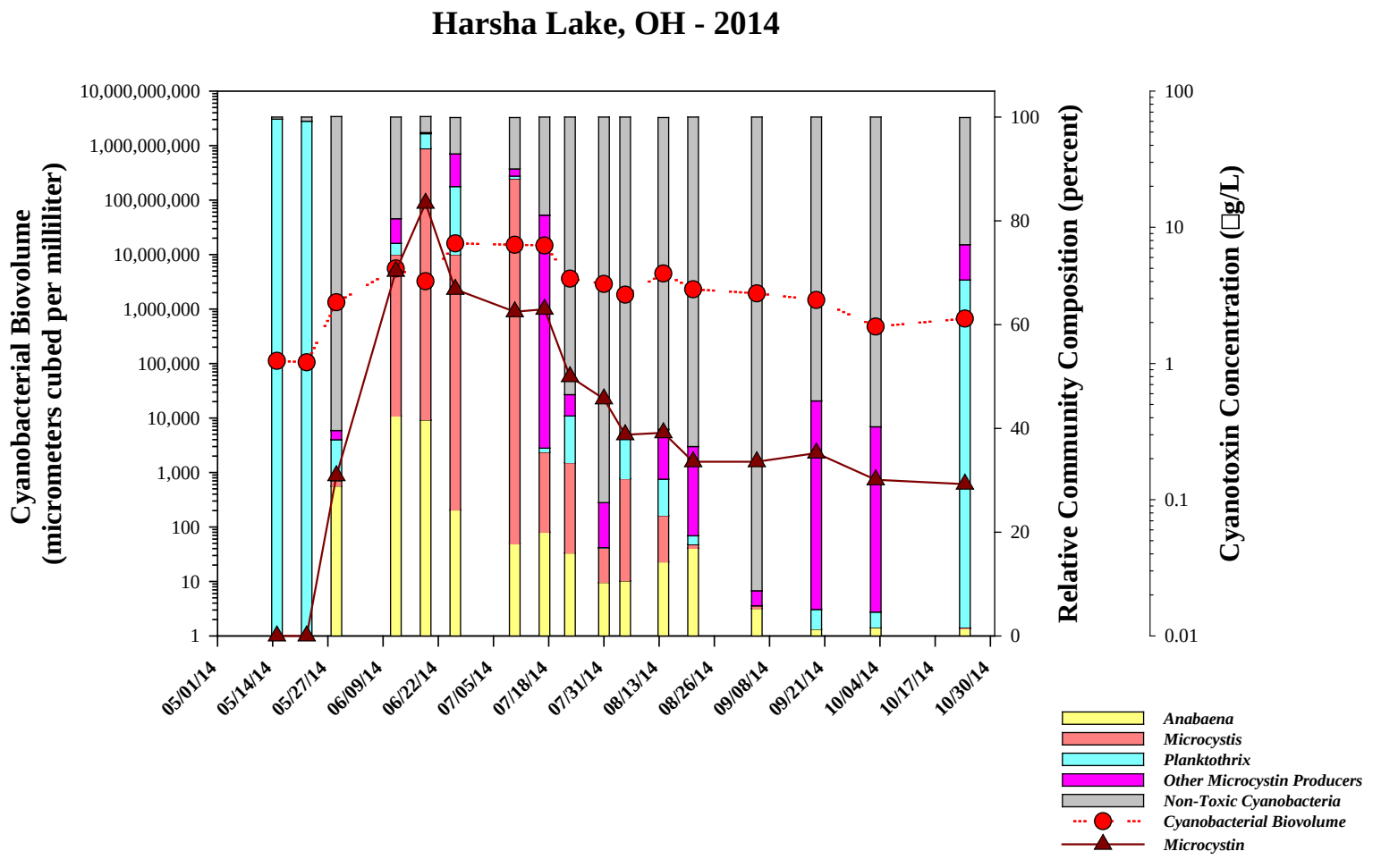
Cyanotoxins and Taste-and-Odor Compounds Co-Occur Less Frequently in Routinely Collected, Non-Bloom Samples



USGS
science for a changing world

Graham and others, in preparation

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

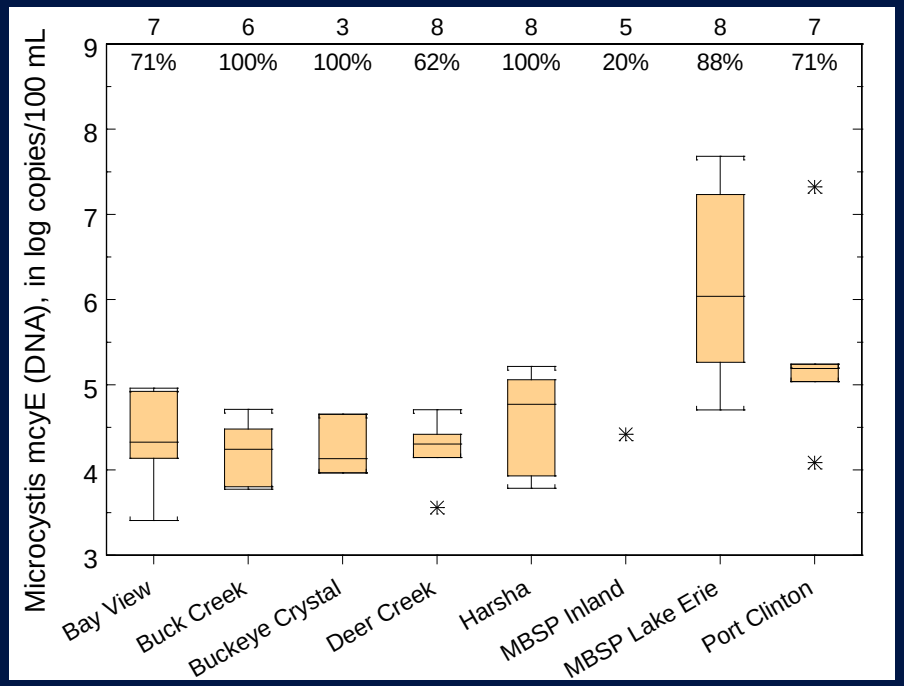


Francy and others, in publication

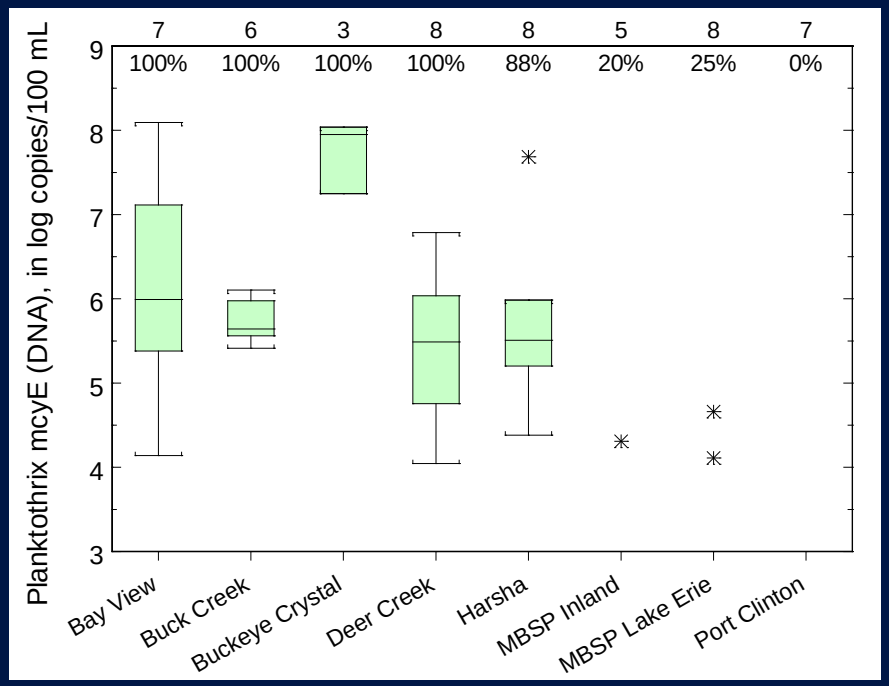
Genetic Data Help Identify Systems with the Potential for Cyanotoxin Production

Ohio Lakes, Summer 2013

Microcystis mcyE DNA



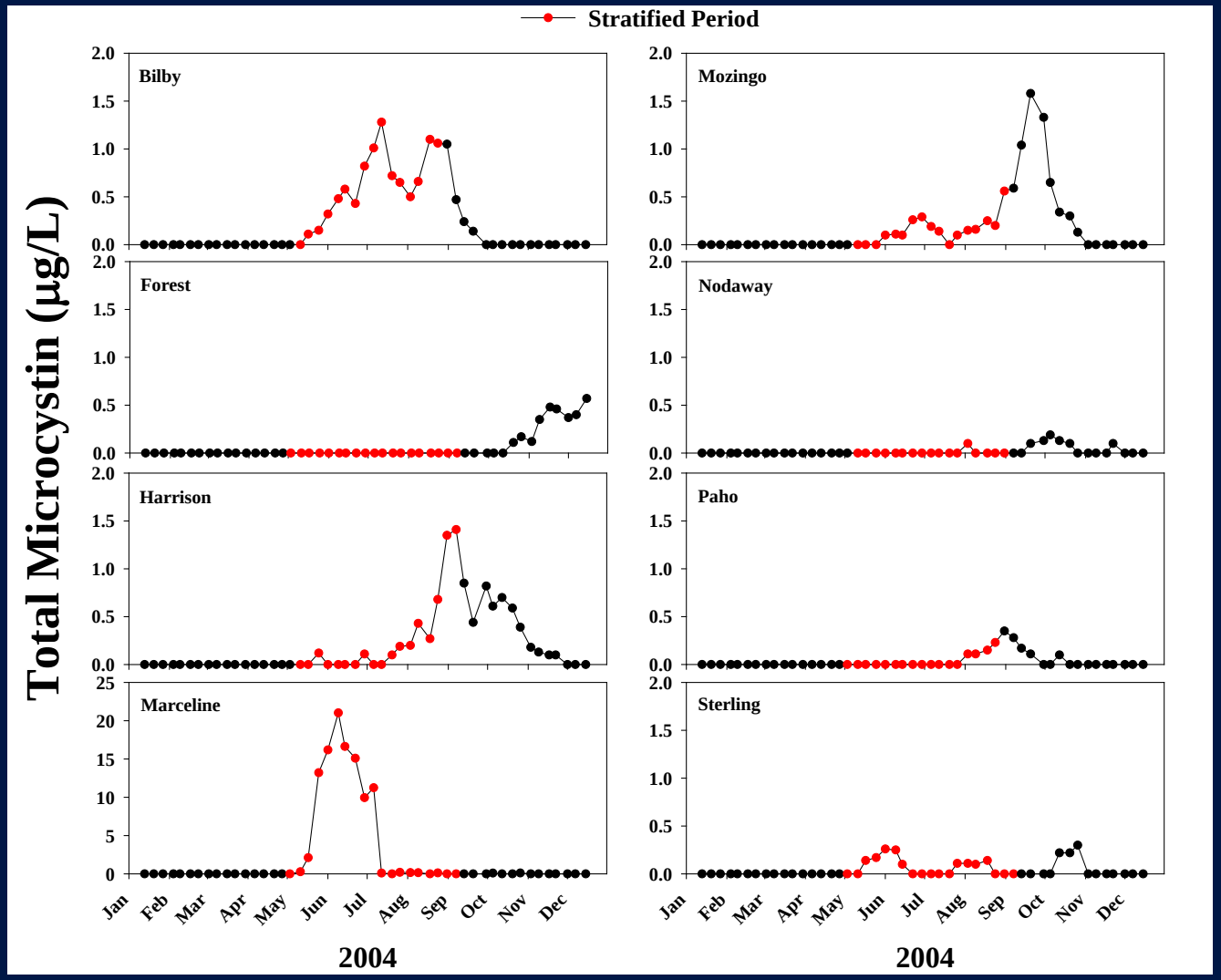
Planktothrix mcyE DNA



USGS
science for a changing world

Francy and others, in publication

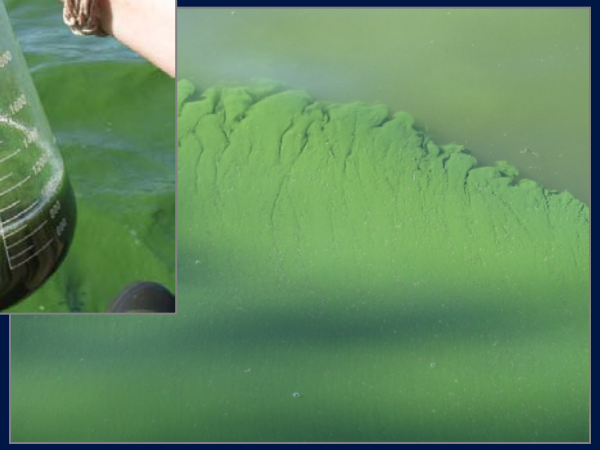
Seasonal Patterns in Microcystin Concentration are Unique to Individual Lakes and Peaks May Occur Anytime Throughout the Year



After Graham and others, 2006

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

Rock Creek Lake, Iowa
2006 Beach Closure Event

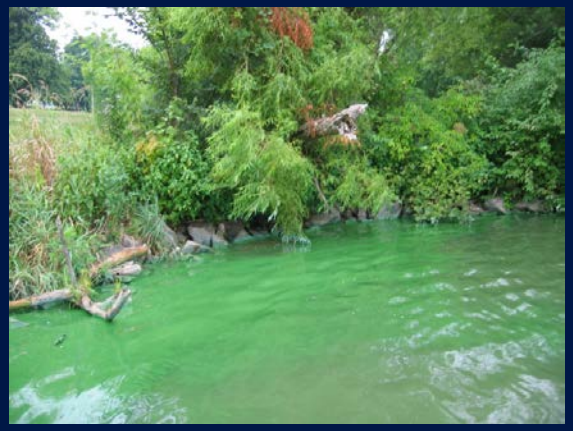


Beach Area
Monday
July 31

Photos Courtesy of IA DNR

Beach Area
Thursday
August 3

Photo Courtesy of IA DNR



Boat Ramps
Friday
August 11

Spatiotemporal 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?

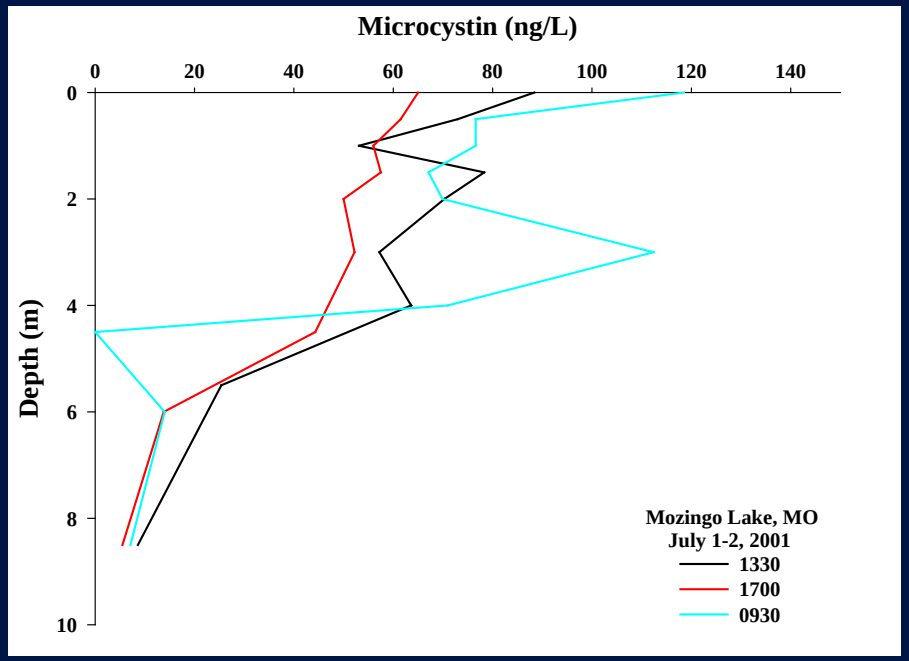
Most likely explanation is redistribution in the water column

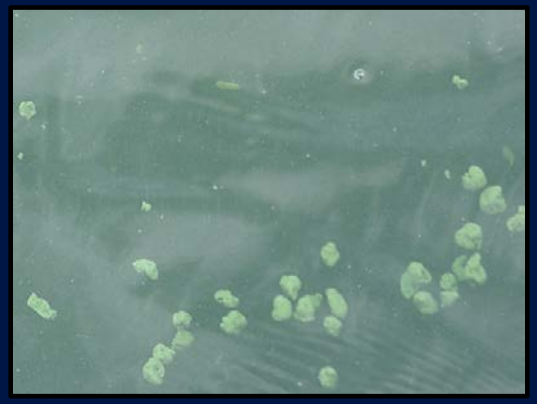
Photos Courtesy of IA DNR

Boat Ramps
Friday
August 11

USGS
science for a changing world

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



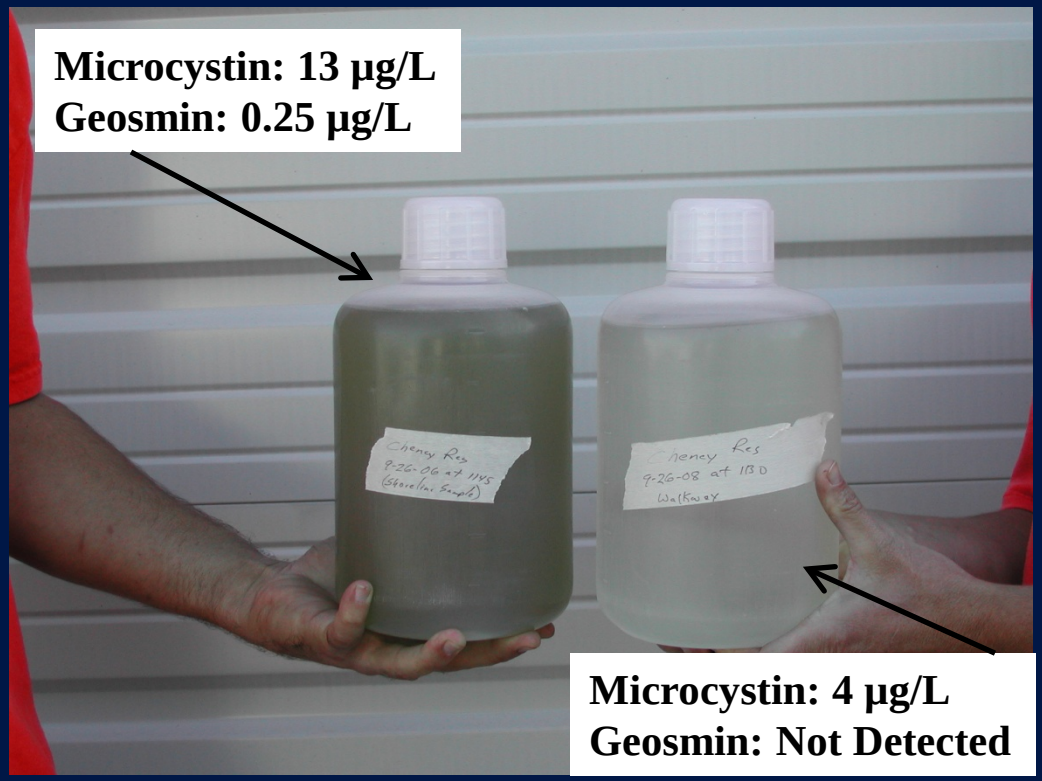


Microcystis aeruginosa colonies

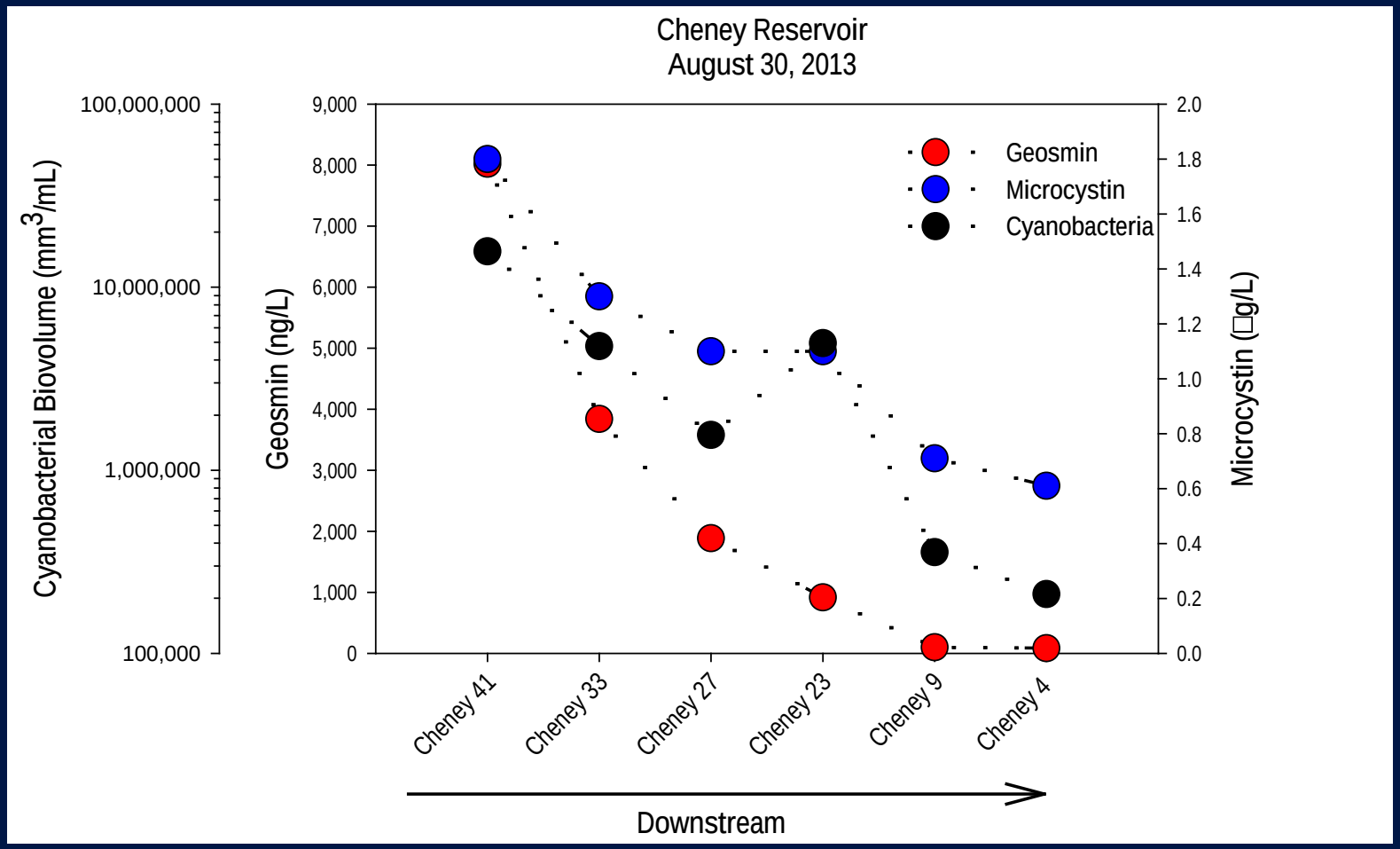
	Sample Type and Microcystin Concentration (ng/L)			
Time	Surface	Integrated Photic Zone	Integrated Epilimnion	Integrated Water Column
0930	118	74	84	61
1330	88	64	70	58
1700	65	50	55	45

After Graham and others, 2006

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



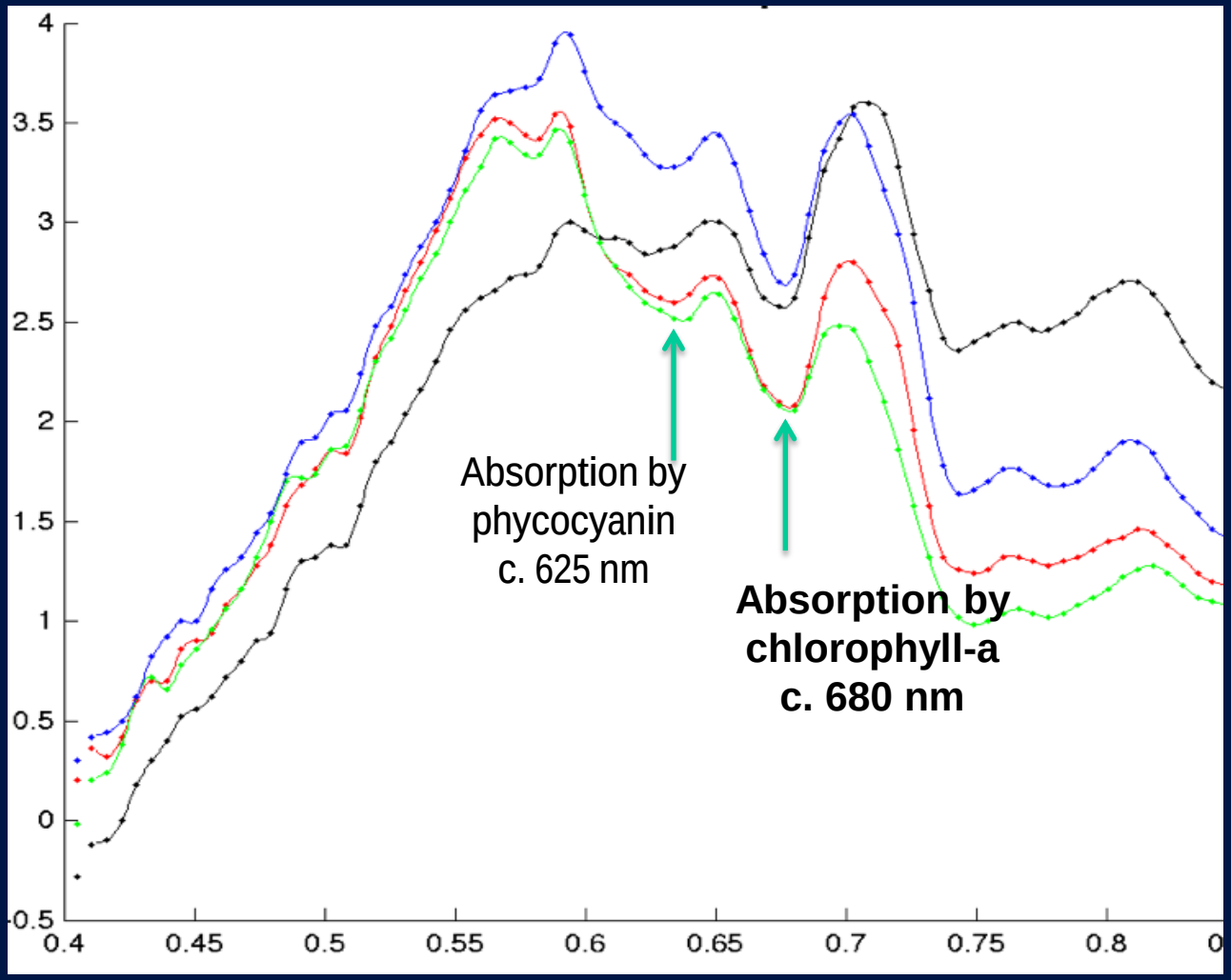
Sample Concentrations Can Vary Considerably Depending on When, Where, and How Samples Are Collected



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

http://www.kdheks.gov/algae-illness/

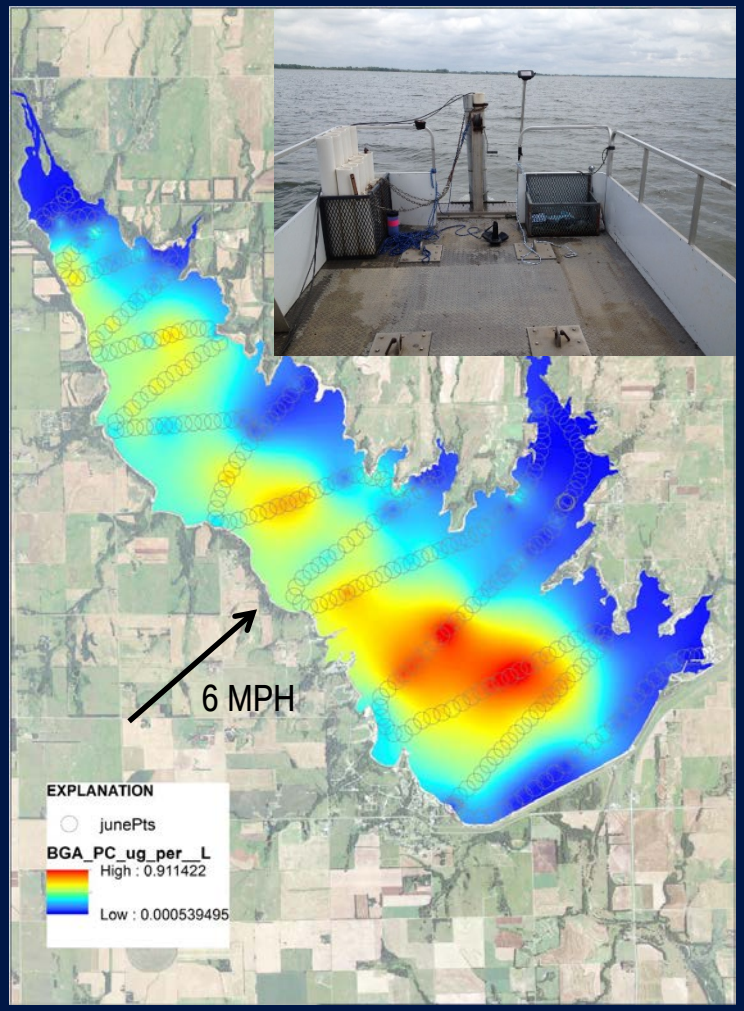
Satellite (and Other Aerial) Imagery Captures Spatial Variability Across an Entire Lake Surface

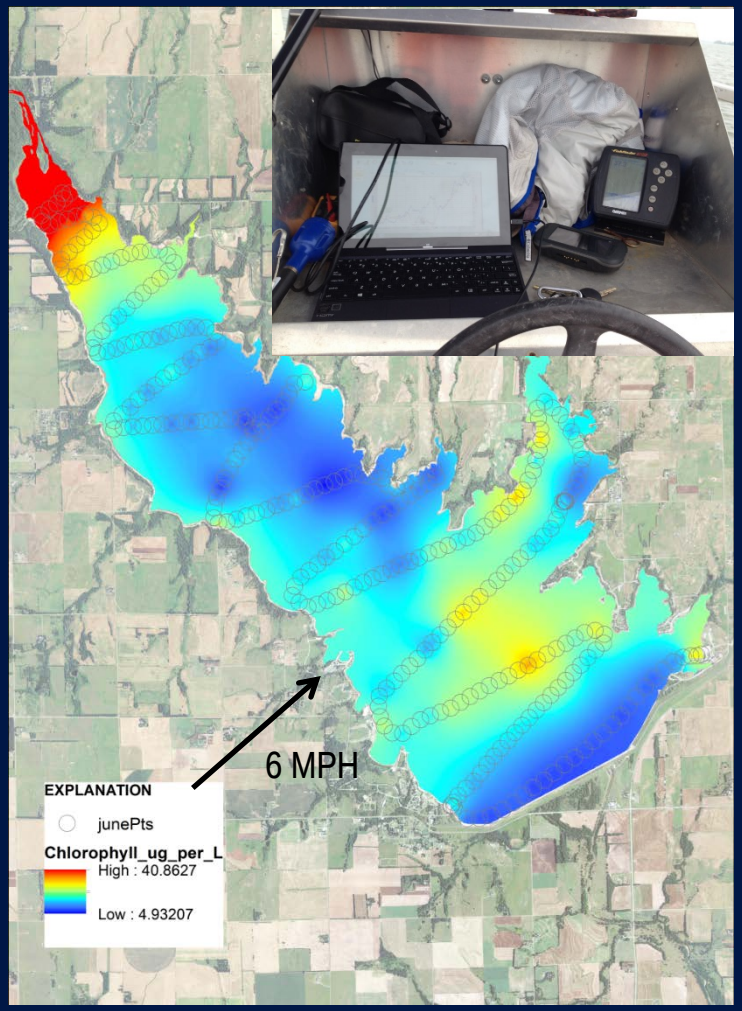


Cheney Reservoir, KS
July 2014 HICO Imagery

USGS
science for a changing world

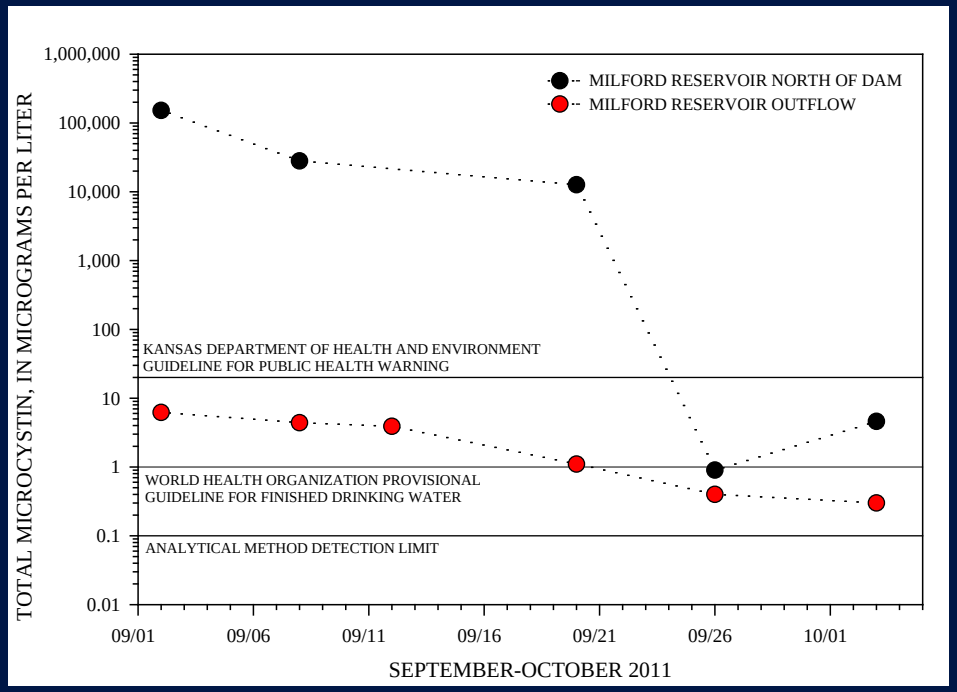
Ground Truth Data Are Required to Develop Models to Estimate Cyanobacterial Abundance Using Satellite Imagery





Cheney Reservoir, KS
June 2014

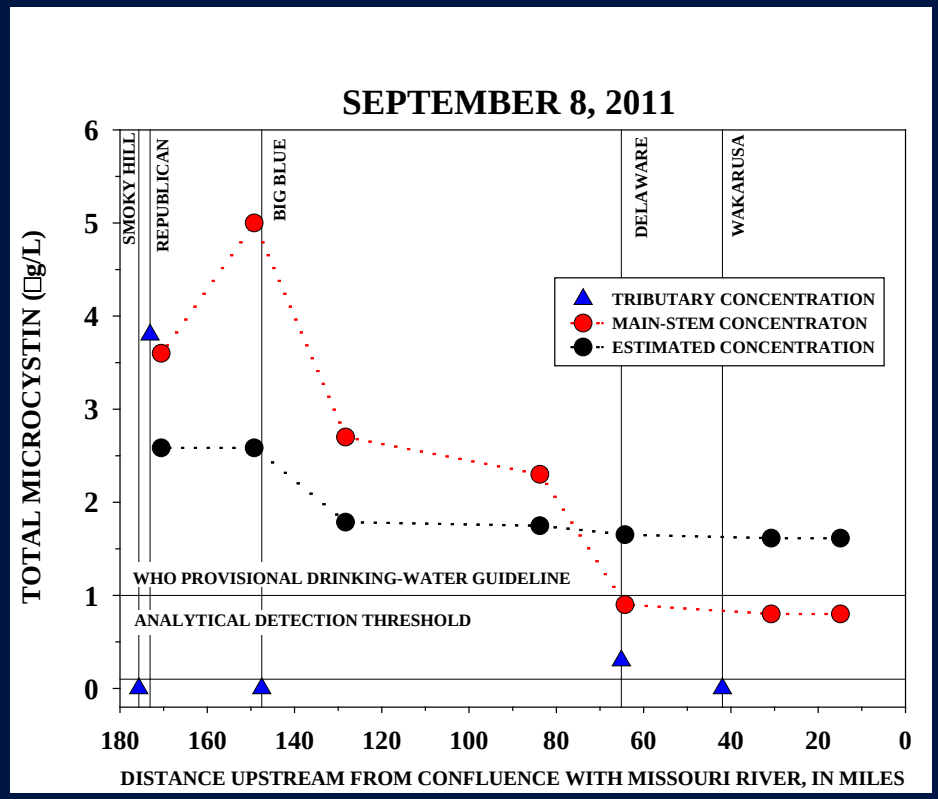
Cyanobacterial Toxins and Taste-and-Odor Compounds May Be Transported for Relatively Long Distances Downstream from Lakes and Reservoirs



Milford Lake release sends algae to Kansas River

MARIA SUDEKUM FISHER, Associated Press

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

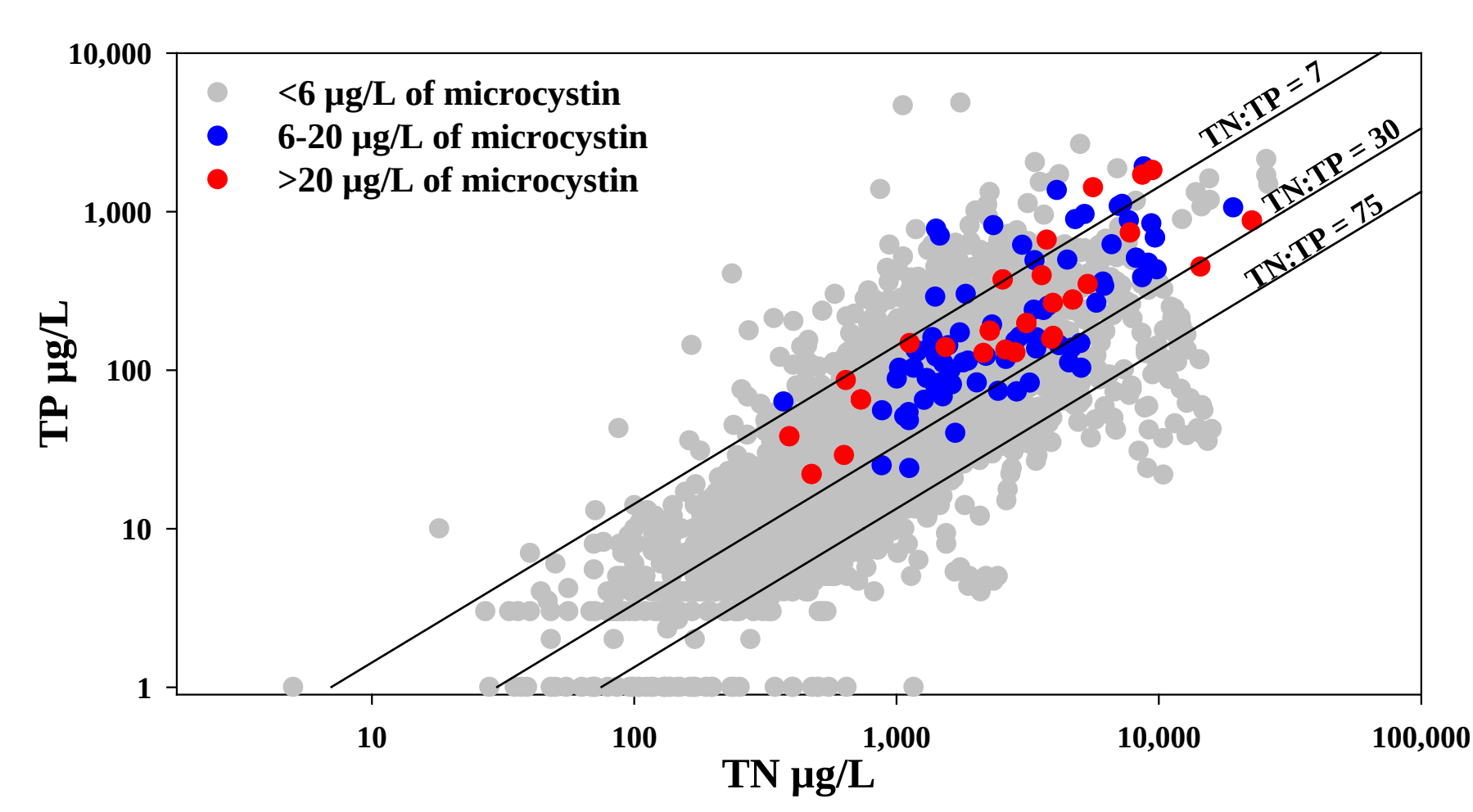


USGS science for a changing world

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

Graham and others, 2012

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



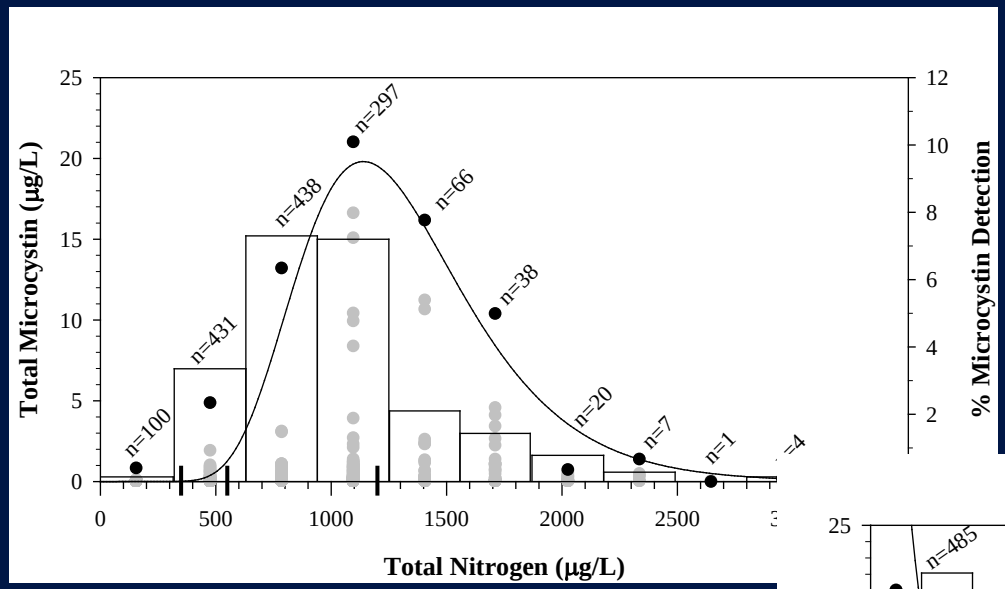
After Harris and others 2014

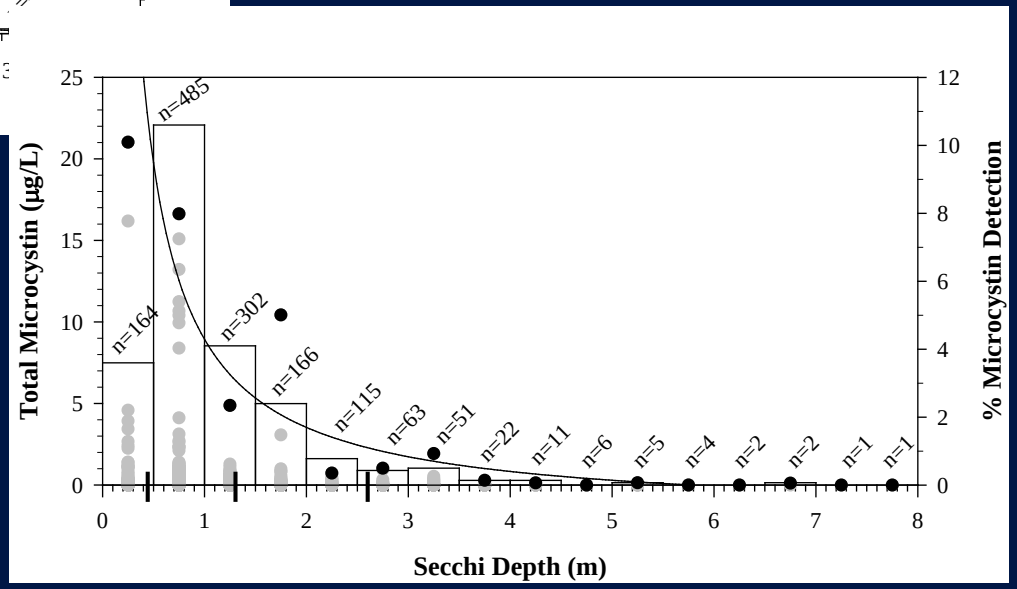
There is No Single Environmental Variable that is Consistently Associated with Microcystin Occurrence and Concentration

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

Graham and others, in preparation

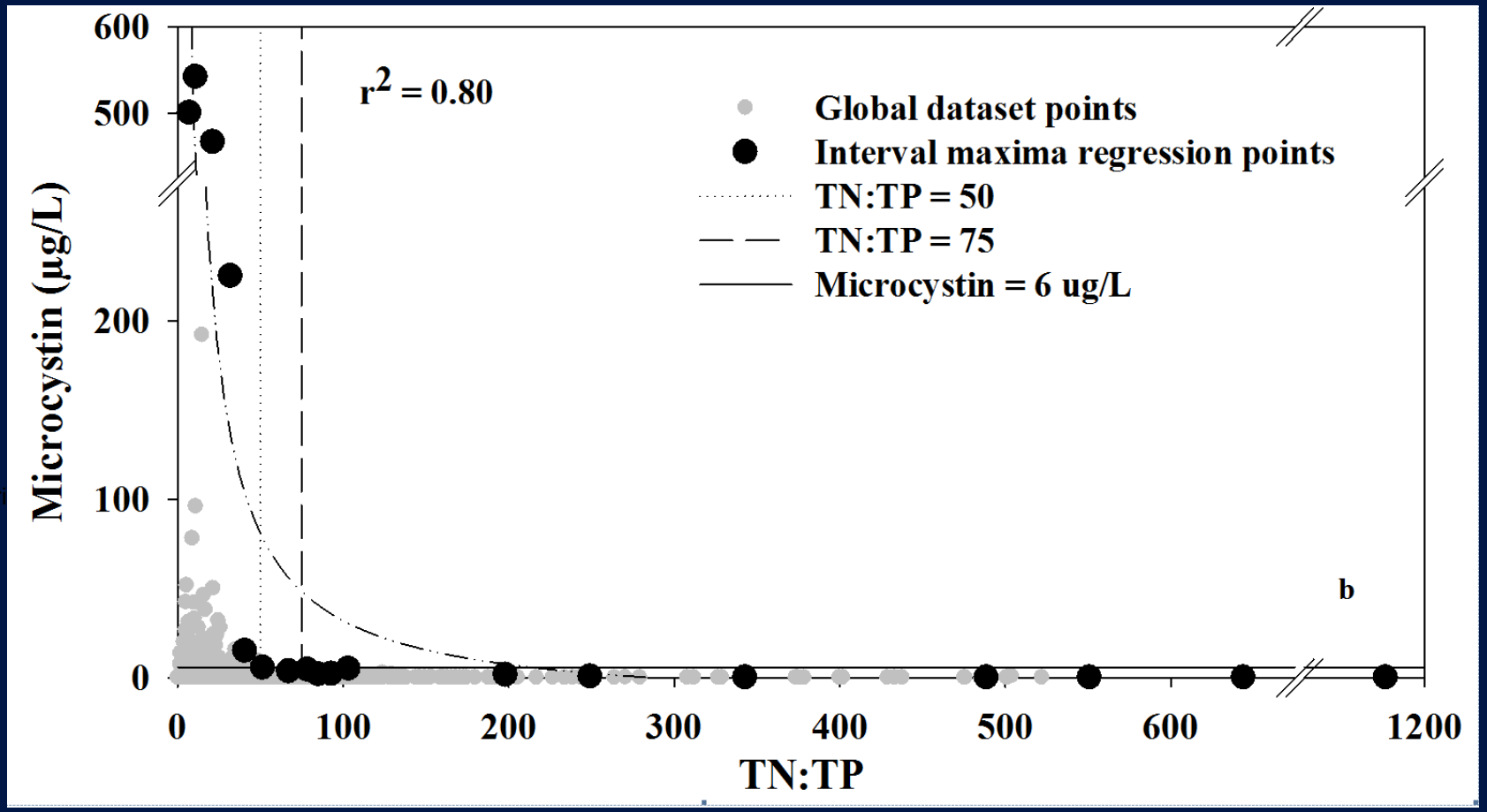
Regional Associations Between Microcystin and Environmental Variables May Not Be Linear





After Graham and Jones, 2009

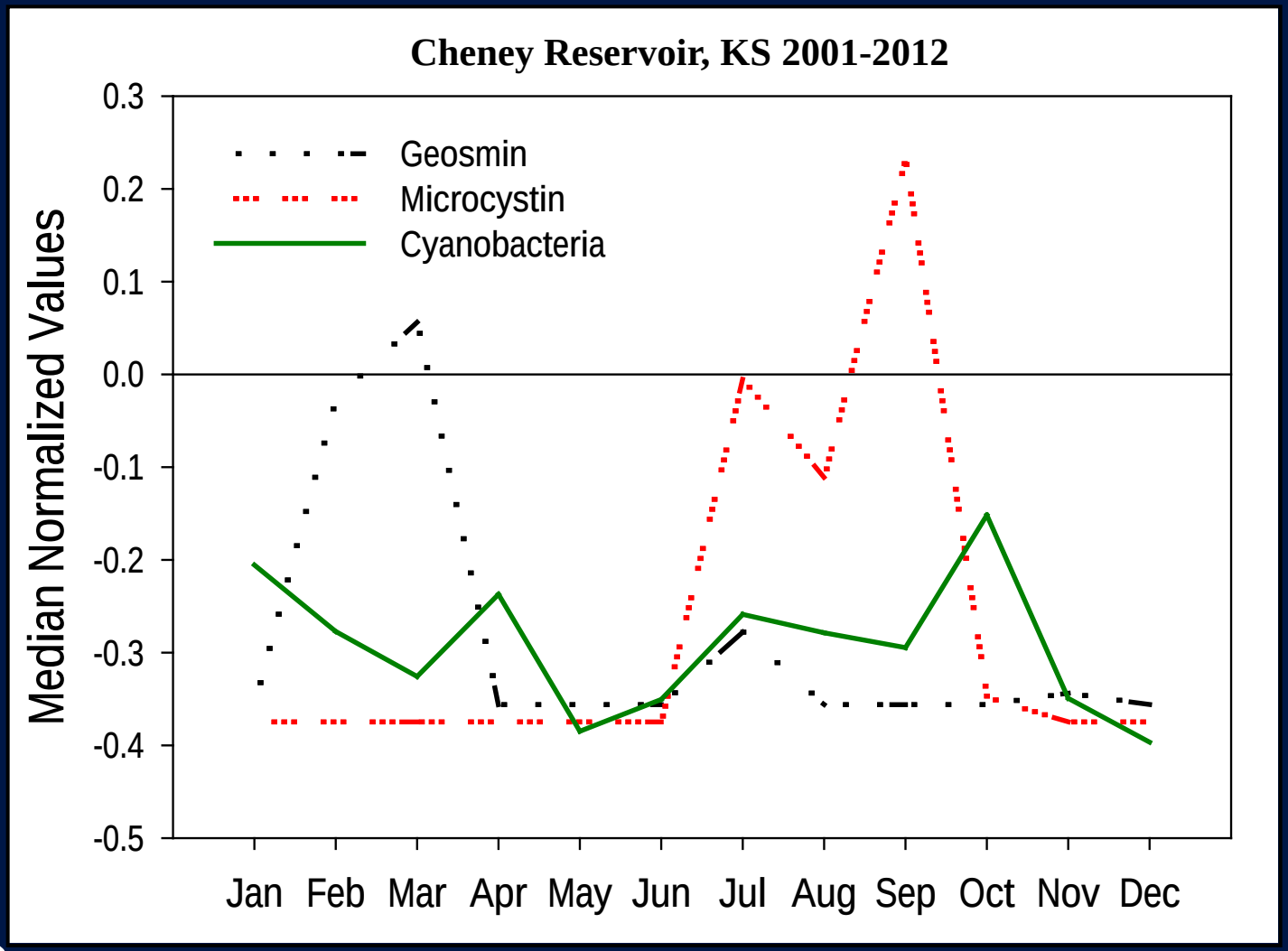
Thresholds and Probabilities May Better Define Relations Between Environmental Variables and Microcystin Occurrence and Concentration and Provide Insight into Potential Management Scenarios



After Harr

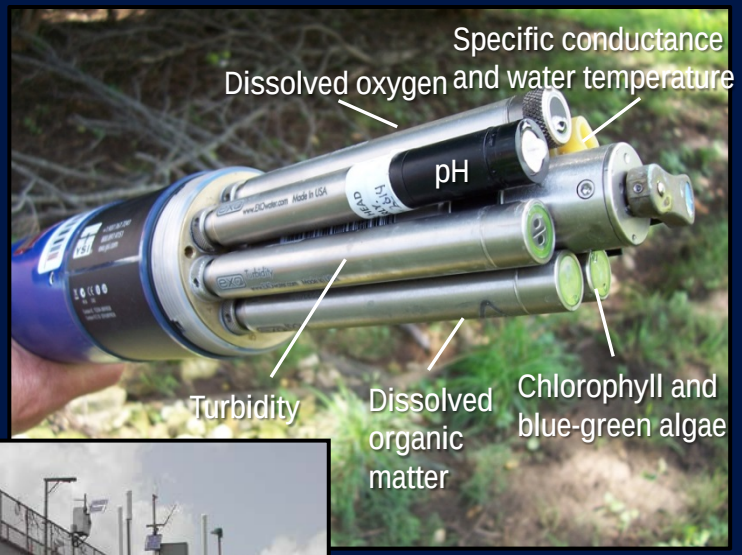
After Harris and others 2014

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

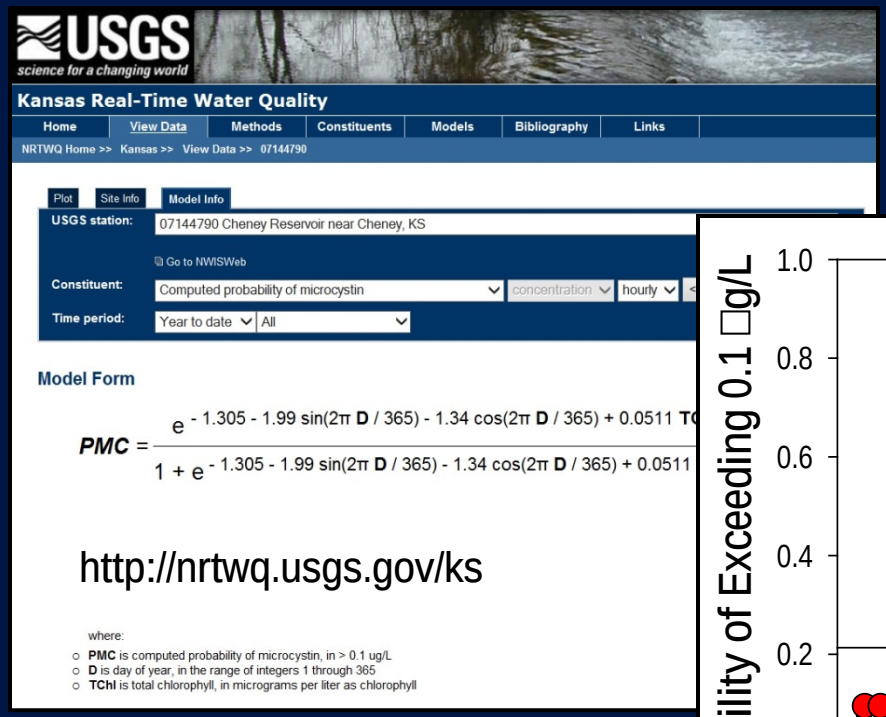


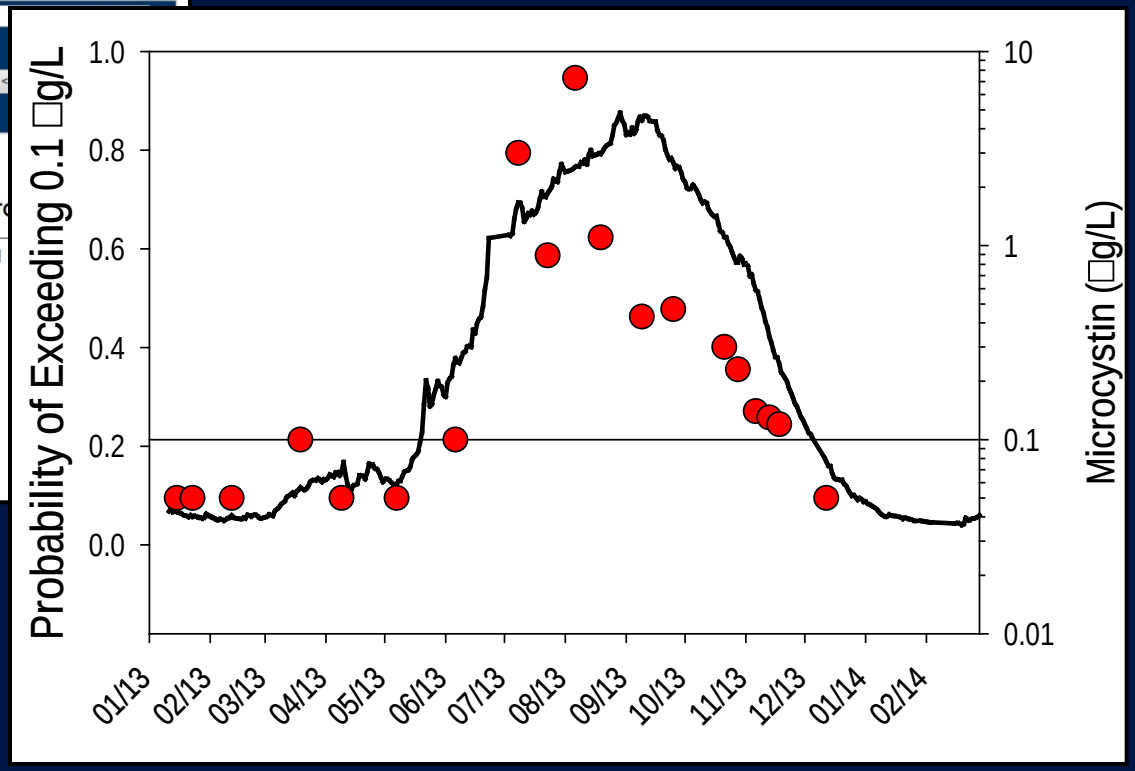
Continuous Water-Quality Monitors Can Be Used to Develop Models to Compute Microcystin and Geosmin Concentrations in Real Time

- 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



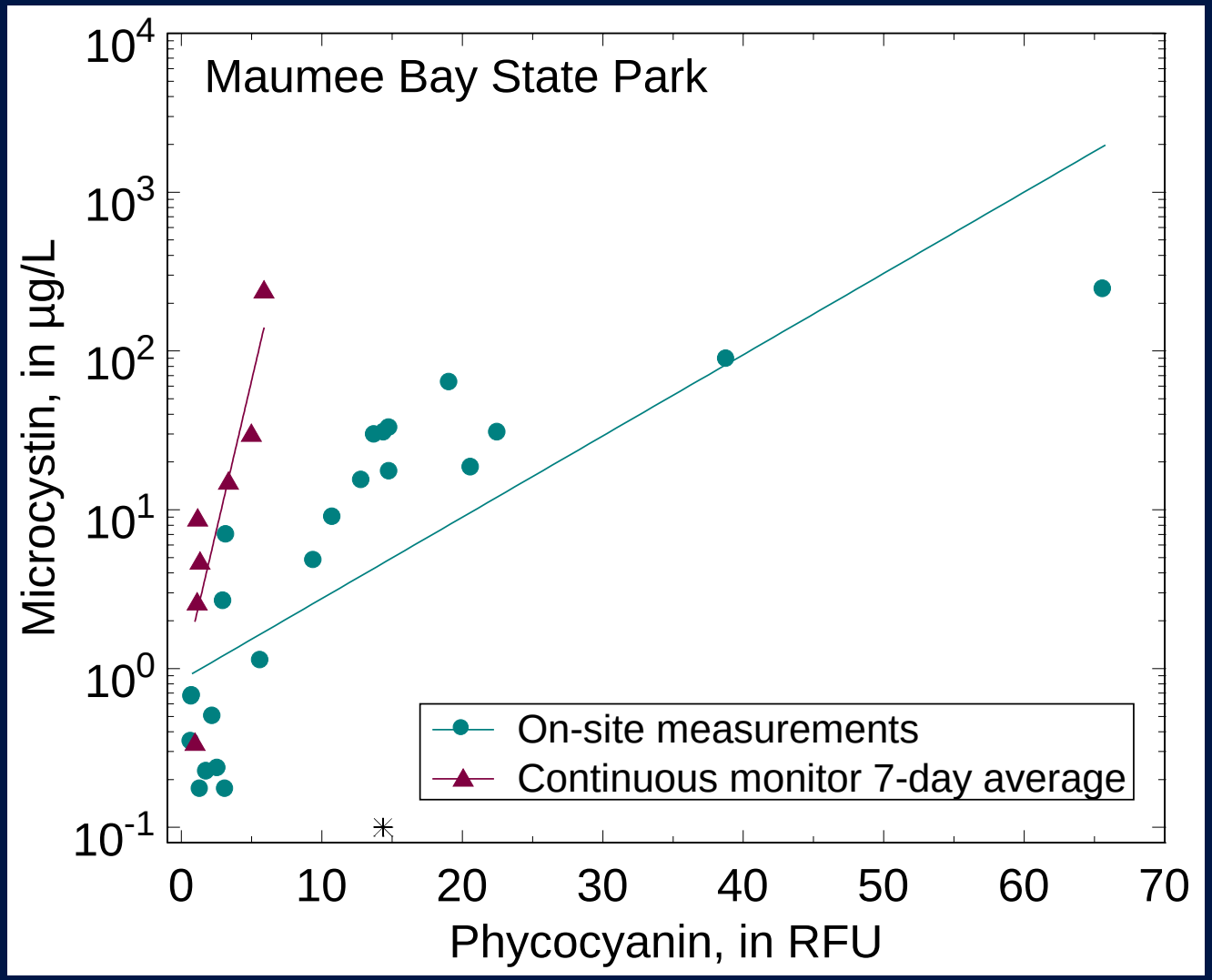
The Logistic Regression Model for Probability of Microcystin Concentrations > 0.1 µg/L in Cheney Reservoir Includes a Seasonal Component and Chlorophyll as Explanatory Variables





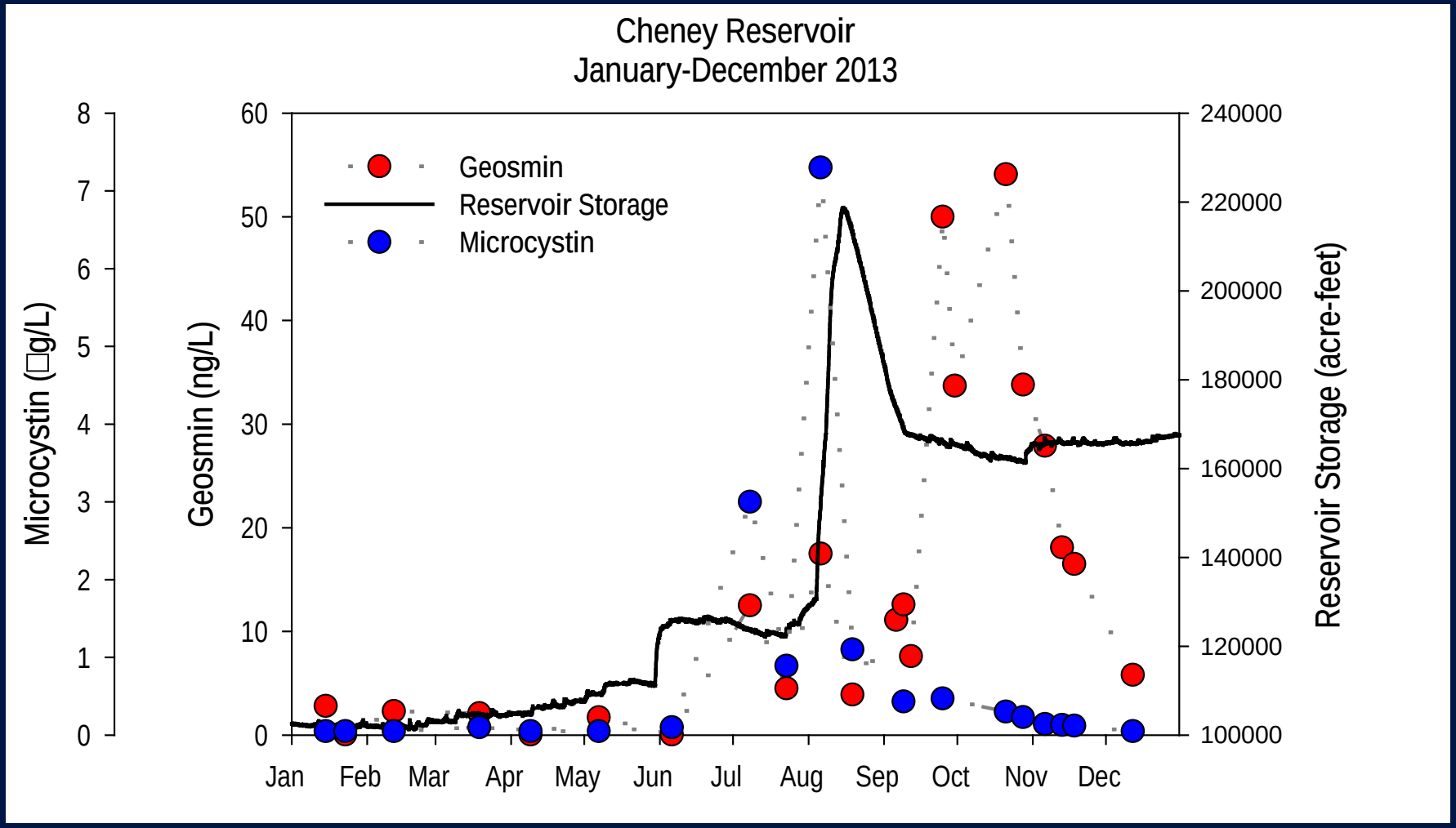
Stone and Graham, http://pubs.usgs.gov/of/2013/1123/

Continuous Water-Quality Models are Site Specific



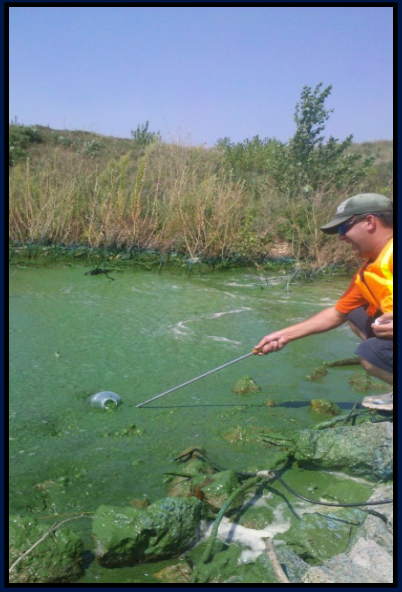
Francy and others, in publication

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

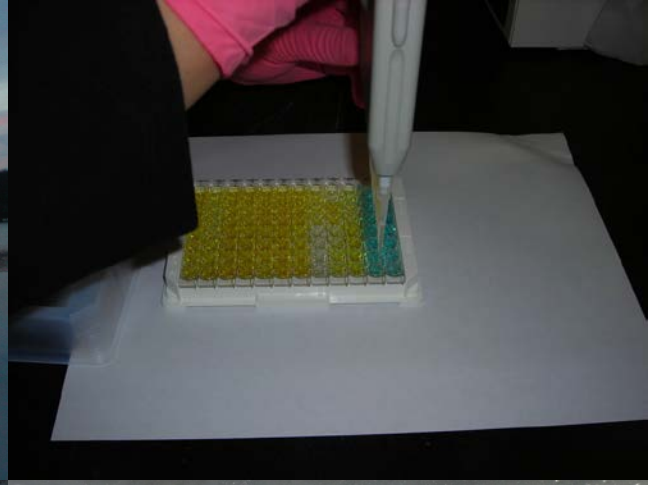


Conclusions

- Cyanobacterial blooms and associated toxins and taste-and-odor compounds commonly occur throughout the United States.
- Several relatively new approaches are available to help describe the spatiotemporal variability and environmental factors driving the occurrence of cyanobacterial blooms and associated 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/cyanobacteria/

jlgraham@usgs.gov
785-832-3511

USGS
science for a changing world