Cyanotoxins: Advancing Drinking Water Science to Protect Human Health

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ASDWA 2018 Webinar Series
July 2, 2018
OBJECTIVES

- Provide background information on cyanotoxins.
- Describe approaches used to study cyanotoxins to better understand occurrence, risks to human health, and development of tools to guide decision making.
- Discuss prevalence of cyanotoxins in surface waters and potential for exposure.
- Identify technologies that may enhance source-water monitoring programs.
We need a common language when communicating about harmful algal bloom science

• What puts the “H” in HAB?
  ➢ Algae and cyanobacteria cause human, ecosystem, and economic health concerns but “harm” is often not quantified
  ➢ Abundant algae and cyanobacteria are not inherently harmful – adverse impacts must be carefully defined

• What are Algae?
  ➢ “Algae” no longer has any real taxonomic meaning

• What is a Bloom?
  ➢ Rapid increase in biomass
  ➢ Extremely high cell densities
  ➢ Dominance
  ➢ Visual accumulation

*We need to learn to be as specific as possible in our communications*
Biological phenomena in surface waters, such as cyanobacteria, can cause drinking-water treatment challenges.

Changes in Water Quality:
- Increased biomass
- Elevated pH
- Diurnal swings in pH and dissolved oxygen
- Increased turbidity

Metabolites and Degradates:
- Taste-and-odor causing compounds
  - CYANOTOXINS
- Degradation by-products (DBPs)

Economics:

Treatment Concerns:
- Filter clogging
- Increased carbon feed
- Increased oxidant demand
- Blending or switching sources
- Providing an alternate supply

Human-Health Concerns:
- Exposure to cyanotoxins
- Exposure to DBPs
### Toxicity of known cyanotoxins

#### Acute Toxicity
- Cytotoxic
- Neurotoxic
- Hepatotoxic
- Dermatoxic
- Respiratory Distress

#### Chronic Toxicity
- Carcinogen
- Tumor Promotion
- Mutagen
- Teratogen
- Embryolethality

#### Acute LD₅₀ (mg/Kg bw)

<table>
<thead>
<tr>
<th>Toxicity</th>
<th>Acute LD₅₀ (mg/Kg bw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saxitoxin</td>
<td>0.001</td>
</tr>
<tr>
<td>Anatoxin-a</td>
<td>0.01</td>
</tr>
<tr>
<td>Microcystin-LA</td>
<td>0.1</td>
</tr>
<tr>
<td>Microcystin-LR</td>
<td>1.0</td>
</tr>
<tr>
<td>Microcystin-YR</td>
<td>10.0</td>
</tr>
<tr>
<td>Nodularin-R</td>
<td>100.0</td>
</tr>
<tr>
<td>Microcystin-LY</td>
<td>1000.0</td>
</tr>
<tr>
<td>Homoanatoxin-a</td>
<td>10000.0</td>
</tr>
<tr>
<td>Anatoxin-a</td>
<td>100000.0</td>
</tr>
<tr>
<td>Microcystin-RR</td>
<td>1000000.0</td>
</tr>
<tr>
<td>Cylindrospermopsin (5 days)</td>
<td>10000000.0</td>
</tr>
<tr>
<td>Cylindrospermopsin (24 hr)</td>
<td>100000000.0</td>
</tr>
</tbody>
</table>

#### Toxicity of known toxins
- Cytotoxic: Sarin, Tabun, Rattlesnake Venom
- Neurotoxic: Soman, Tabun, Rattlesnake Venom
- Hepatotoxic: Soman, Tabun, Rattlesnake Venom
- Dermatoxic: Soman, Tabun, Rattlesnake Venom
- Respiratory Distress: Soman, Tabun, Rattlesnake Venom
- Carcinogen: Soman, Tabun, Rattlesnake Venom
- Tumor Promotion: Soman, Tabun, Rattlesnake Venom
- Mutagen: Soman, Tabun, Rattlesnake Venom
- Teratogen: Soman, Tabun, Rattlesnake Venom
- Embryolethality: Soman, Tabun, Rattlesnake Venom

*Based on intraperitoneal injection in mice*
# 2015 USEPA health advisory values for microcystin and cylindrospermopsin in finished drinking water

Cyanotoxin Health Advisory Levels - 10 Day Average Exposure

<table>
<thead>
<tr>
<th></th>
<th>Bottle-fed infants and pre-school kids</th>
<th>School-age kids and adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcystins</td>
<td>0.3 ug/L</td>
<td>1.6 ug/L</td>
</tr>
<tr>
<td>Cylindrospermopsin</td>
<td>0.7 ug/L</td>
<td>3.0 ug/L</td>
</tr>
</tbody>
</table>

Data to quantify cyanotoxin exposures and human health effects through drinking water are sparse.

In May 2018, at least 15 states had recreational beach closures or health advisories associated with cyanotoxins in lakes and rivers.

Cyanotoxin breakthrough in DWTP (* - denotes an advisory)
- Toledo, OH (2014) *
- Ingelside, Texas (Jan/Feb 2016)
- Des Moines, IA (Aug 2016) *
- Cayuga County, NY (Sept/Oct 2016)
- Salem, OR (May 2018)*

Cyanobacteria bloom entered DWTP
- Norton, KS (June 2018) – resulted in switch to GW (toxin results pending)

After USEPA Freshwater HAB News, May 2018
Personal Communication, Lesley D’Anglada, US EPA 6/20/2018
USGS cyanotoxin occurrence collaborations

Lakes and Reservoirs

- 2006 USGS Midwestern Lake Reconnaissance
- 2006, 2017-2018 USGS Texas Reconnaissance
- 2007 EPA National Lakes Assessment
- 2012 USGS Illinois Reconnaissance
- 2014-2017 USGS GLRI Lake Erie
- 2015 EPA National Coastal Assessment (Great Lakes)

Wetlands

- 2011 EPA National Wetlands Assessment
- 2016 EPA National Wetlands Assessment

Graham and others, 2016, USGS OFR 2016-1174
http://dx.doi.org/10.3133/ofr20161174
USGS cyanotoxin occurrence collaborations (cont.)

Estuaries
- 2012-2014, 2017 USGS Albemarle Sound, NC
- 2015 EPA National Coastal Assessment
- 2016 - 2019 NOAA MERHAB

Wadeable Streams
- 2013/2016 USGS Midwestern Stream Quality Assessment
- 2014 USGS Southeastern Stream Quality Assessment
- 2015 USGS Pacific Northwest Stream Quality Assessment
- 2016 USGS Northeastern Stream Quality Assessment
- 2017 USGS California Stream Quality Assessment

Rivers
- 2017-2018 NAWQA Fixed Site Pilot Study
USGS capabilities: field and laboratory methods

- Guidelines for Nationally Consistent Science
  
  https://water.usgs.gov/owq/FieldManual/Chapter7/7.5.html

- Robust and Quantitative Analytical Methods for Cyanotoxins in Water, Tissues, and Sediment
  
  https://pubs.usgs.gov/of/2008/1341/
  https://pubs.er.usgs.gov/publication/ofr20101289

- Morphological Taxonomy
  
  https://pubs.er.usgs.gov/publication/ofr20151164

- Molecular Methods
  
  https://doi.org/10.3133/sir20135189

- Other Developing Approaches
USGS capabilities: laboratory methods based on cyanotoxin mode of action

| Known Modes of Action | Aeruginosins | Anabaenopeptins | Anatoxin-a(s) | Biogenic amines | Cylindrospermopsins | Cyanopeptilins | Cylindrospermopsins | Cyanotoxins | Deoxyribonuclease Inhibition | Depsipeptides | Lipopolysaccharides | Lyngbyatoxins | Microcystins | Microginins | Micropeptins | Microviridins | Microviridins | Microviridins | Nodularins | Oscillopeptins | Oscillatorins | Oscillatorins | Oscillatorins | Oscillatorins | Oscillatorins | Oscillatorins | Retinoic Acids | Saxitoxins | Spumigens |
|-----------------------|--------------|-----------------|---------------|----------------|-------------------|-----------------|------------------|-------------|--------------------------|-------------|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Acetylcholinesterase Inhibition | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Amino Protease Inhibition | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Blood Pressure Modifier | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| CYP450A            | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ion Channel Blocker | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Astrocyte Impairment | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Membrane Disruption | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nicotinic Agonist        | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Protein Kinase C Activator | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Protein Phosphatase Inhibitor | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Protein Synthesis Inhibitor | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Serine Protease Inhibitor | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Teratogenic                | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Summarized from Handbook of Cyanobacterial Monitoring and Cyanotoxin Analysis (2017)
USGS capabilities: targeted versus non-targeted cyanotoxin analyses

Non-Target Mode of Action Screening
- PP2A Inhibition
- AChE Inhibition
- Nicotinic Acetylcholine RBA

Targeted Screening
- ELISAs
  - Anabaenapeptins
  - Anatoxins
  - Cylindrospermopsin
  - Microcystins/Nodularins
  - Saxitoxins

Targeted Quantitative Analysis
- Anatoxins
- Cylindrospermopsins
- Microcystins
- Nodularins
- Saxitoxins
USGS capabilities: bioaccessibility of cyanotoxins

Human Exposure = Recreation + Drinking Water + Food
Microcystin may affect juvenile recruitment of endangered suckers in Upper Klamath Lake, Oregon.

Health and Condition of Endangered Juvenile Lost River and Shorthose Suckers Relative to Water Quality in Upper Klamath Lake, Oregon and Clear Lake, California

Effects of Microcystin on Juvenile Lost River Suckers

Barbara A. Martin¹, Kathy R. Echols², Kevin Feltz², Diane G. Elliott³, and Carla M. Conway³

¹USGS, Western Fisheries Research Center, Klamath Falls Field Station, 2795 Anderson Avenue Suite 106
²USGS Columbia Environmental Research Center, ³USGS Western Fisheries Research Center
USGS capabilities: near-real time data acquisition and delivery through a variety of platforms

Remote Sensors

Cameras

In Situ Sensors
Converging lines of evidence from (sub)-cells to satellites are needed to advance the science.
In the 2007 National Lakes Assessment, microcystins were detected by ELISA in about 32% (n=1252) of analyzed samples.
In the 2007 National Lakes Assessment, cylindrospermopsins were detected by ELISA in about 4% (n=1252) of analyzed samples.
In the 2007 National Lakes Assessment, saxitoxins were detected by ELISA in about 8% (n=678) of analyzed samples.
Multiple toxins and taste-and-odor compounds frequently co-occur in cyanobacterial accumulations.
During summer 2014, microcystins occurred in 39% of small stream sites sampled in the southeastern United States.
The potential for cyanotoxin production was detected at all large river sites except one during June-September 2017.
Cyanobacteria and associated compounds may be transported for relatively long distances downstream from lakes and reservoirs.
2017 tapwater exposure & effects pilot study

Systematic assessment of correlation between *residential* human exposure at the tap, biomarkers of exposure, and human health metrics.

**Analytes**
- PESTS designed-bioactive
- PHARMS designed bioactive
- DBPs
- Anions/Cations (metals)
- PFAS
- VOCs
- Hormones
- Nutrients
- Pathogens
- CYANOTOXINS

**Screening tools**
- Bioassays USGS/EPA/NIEHS
- Non-target (Q-TOF)
- Human Health Metrics
  - UIC PMI: biomarkers...
  - NIEHS/CDC Human Databases

“Understanding chemical and microbial contaminants in drinking water: raw, treated, and tap water”, ASDWA Webinar, Date: TBD in August
Current focus on personal, mobile POU DW treatment.

To assist outdoor community and evaluate as an alternative to bottled water during emergency do not drink orders.

Working on:

- Review of treatment options
- Development of standardized testing approach
- Study design

*If you have source waters you would like us to consider, please let us know*
Satellite imagery may capture spatial and temporal variability across a regional scale.
Tools to utilize satellites for inland monitoring of cyanobacteria are being developed.

Cyanobacteria Assessment Network (CyAN) Project
Water-quality sensors show promise as early warning tools

Real-Time Chlorophyll, in µg/l

April 10, 2018 11:31ET

https://waterwatch.usgs.gov/wqwatch
Diurnal or noisy patterns in dissolved oxygen, pH and algal fluorescence may be indicative of cyanotoxin occurrence.
Water-quality monitors can be used to develop site-specific models to compute probability of cyanotoxin occurrence.

After Graham and others, 2017
https://pubs.er.usgs.gov/publication/sir20175016

https://nrtwq.usgs.gov/ks

https://ny.water.usgs.gov/maps/nowcast/
Anomalous events, such as large summer inflows, may alter ecosystem processes and require model recalibration.
Water-quality monitors can be used to develop site-specific models to compute cyanotoxin concentrations.

This information is preliminary and subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.

January 2016

Foster and others, in preparation
USGS has developed converging lines of evidence to identify when and where cyanotoxins may pose potential human health risks, but data gaps remain.

- Status and trends
- Environmental fate and transport
- Environmental drivers
- Ecosystem effects
- Exposure and health
  - Real versus perceived risks
- Drinking water and food impacts
- Mitigation and management
Cyanotoxins: Advancing Drinking Water Science to Protect Human Health
Ohio Case Study

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Additional Information:
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