Advancing Sensor Technology for Priority Water Parameters

May 4, 2016
National Water Quality Monitoring Council Meeting
Tampa, FL

Disclaimer

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Goal

- Advancing water sensor technologies & data analytics

- Accelerate development & use of sensors for:
  - **Arsenic**
  - **Harmful algal bloom (HAB) toxins**
  - **Total nitrogen and phosphorus**
  - ***E. coli* & *Enterococcus***

Collaborators

- Association of Clean Water Administrators
- Association of State Drinking Water Administrators
- National Water Quality Monitoring Council
- U.S. Agency for International Development
- U.S. Bureau of Reclamation
- U.S. Department of Agriculture
- U.S. Environmental Protection Agency
- U.S. Geological Survey
- U.S. Park Service
- Water Environment Federation

Session purpose

- Communicate our current understanding of performance and usability requirements
- Verify or modify that understanding based on discussion with and input from you
- Communicate current plans for Arsenic and HAB toxins
- Hear your thoughts and insights

Feedback and input

Topic	Input Forms	Webinars
Arsenic	43	88
Cyanobacteria	62	145
TN/TP	120	57
E.coli	76	164

Session structure

- Short intro to each topic
- Move to topic area(s) of interest
- Contribute your thoughts and insights:
  - Who else should we talk to?
  - Are these the ideal requirements?
  - What is audacious yet feasible?
  - Thoughts on next steps?

Speakers

- Joel Creswell, PhD – AAAS Fellow, US EPA
- Beth Stauffer, PhD – Assistant Professor, University of Louisiana at Lafayette
- Brian Pellerin, PhD – Research Soil Scientist, US Geological Survey
- Alan Lindquist, PhD – Associate Division Direction, US EPA

Arsenic

Joel Creswell, PhD

AAAS Fellow, U.S. EPA

Arsenic – What is it?

- Naturally-occurring semi-metal
- Results from natural deposits, agricultural & industrial activity
- Drinking water wells mobilize groundwater arsenic

https://www.theguardian.com/science/2011/jun/09/naming-the-new-elements

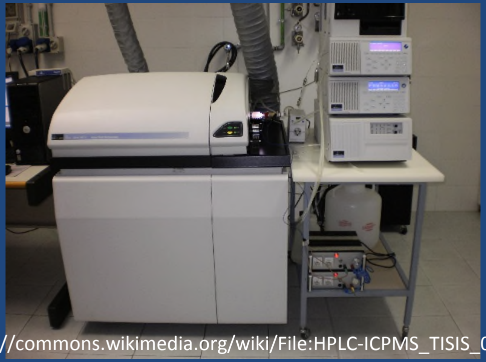
Arsenic – Why is it important?

- Tasteless, odorless human toxin & carcinogen
- Chemical form is important
  - Inorganic arsenic highly toxic
  - Organic arsenic much less toxic
  - Total arsenic measurement doesn't distinguish forms
- Regulated by EPA at 10 ppb (drinking water)
- Dietary sources (rice, apple juice)

http://blogs.discovermagazine.com/crux/files/2013/08/bowl-of-rice1.jpg

Current Approach – Arsenic Monitoring

- **Laboratory Methods**
  - Colorimetry ✓
  - Hydride Generation Atomic Absorption Spectrometry ✓
  - Electrothermal Atomic Absorption Spectrometry ✓
  - Inductively Coupled Plasma-Atomic Emission Spectrometry ✓
  - Inductively Coupled Plasma-Mass Spectrometry ✓


https://commons.wikimedia.org/wiki/File:HPLC-ICPMS_TISIS_01.JPG

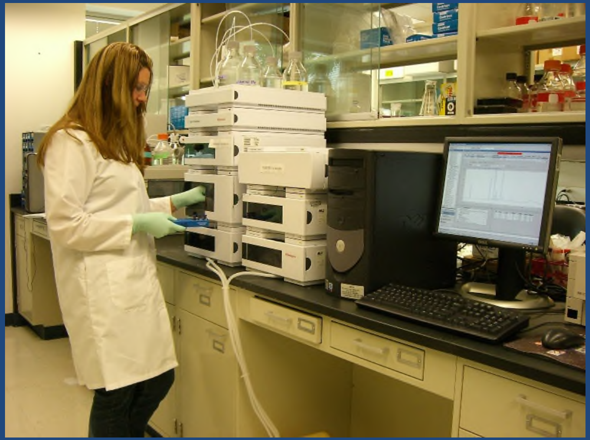
- **Field and on-line methods**
  - On-line voltammetry instruments ✗
  - Field test strips ✗

✓ EPA-Approved

✗ Not EPA-Approved

Drawbacks to Current Approach

- Lab-based methods:
  - Time lag from sample collection to data
  - Difficult to make real-time decisions (e.g. process control)
- High per-sample collection & analysis cost
- Limited data (due to cost)
- Lab instruments require trained analysts



https://upload.wikimedia.org/wikipedia/commons/d/dd/Icos_Laboratories.JPG

Potential Benefits of Advanced Arsenic Sensors

Benefits

- "Real-time" data
- Easy to operate
- Continuous monitoring
- Field-deployable
- Portable
- Affordable

Applications

- Drinking water:
  - Source monitoring
  - Point of use monitoring
  - Treatment optimization
- Wastewater treatment
- Contaminated site monitoring

Next Steps: Arsenic

Announcing The Arsenic Sensor Challenge

- Collaboration between EPA, USBR, USAID, USDA, NIST, Indian Health Service

- Phase I: Ideation
  - Cash prize
- Phase II: Prototype development
  - Cash prize, opportunities for commercialization or cooperative agreement
- Launch date: Fall, 2016

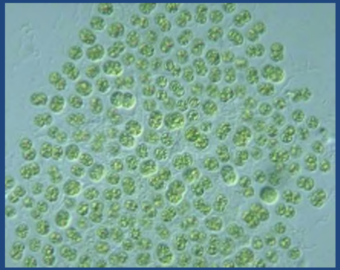
Cyanobacteria/Cyanotoxins

Beth Stauffer, Ph.D.
University of Louisiana at Lafayette

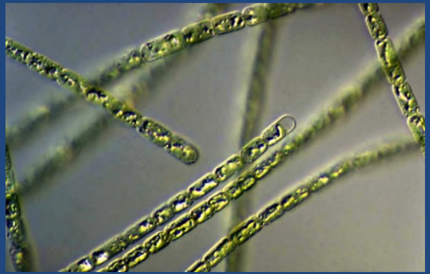
What are Cyanobacteria/Cyanotoxins?

- Photosynthetic bacteria capable of blooming to high abundance and producing harmful toxic compounds

Cyanotoxin	Mode of toxicity	Cyanobacteria genera
Microcystins	Hepatotoxin	*Microcystis, Anabaena, Nostoc, Planktothrix*
Anatoxins	Neurotoxin	*Anabaena, Phormidium, Planktothrix*
Saxitoxins	Neurotoxin	*Anabaena, Aphanizomenon, Cylindrospermopsis, Planktothrix*
Cylindrospermopsins	Hepatotoxin+	*Aphanizomenon, Cylindrospermopsis*

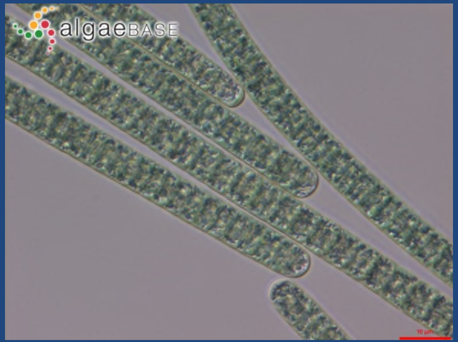


Microcystis aeruginosa
protist.i.hosei.ac.jp



Aphanizomenon flos-aquae
cfb.unh.edu

Anabaena sp.
cfb.unh.edu



Planktothrix sp.
algaebase.org

Why do Cyanotoxins Matter?

- Human health and animal effects
  - 500,000 residents without tap water in Toledo, August 2014
  - 52 human deaths in Brazilian dialysis center (Carmichael et al. 2001)
  - 368 confirmed canine poisoning cases since 1920’s (Backer et al. 2013)
  - Many cases of livestock poisoning (Stewart et al. 2008)
- Significant costs associated with treatment
  - $3-4 million/year in Toledo

True color satellite image showing last year's bloom in Lake Erie at its maximum intensity on September 29, 2014. Data from NASA's Aqua satellite. (Credit: NASA).

Cyanotoxins Standards and Guidelines

- 1998: World Health Organization provisional drinking water guideline for microcystin-LR
  - 1 µg L^{-1} microcystin-LR
- U.S. States' standards:
  - Drinking water (3)
  - Recreational waters (21)

- June 2015: U.S. EPA 10-Day Drinking Water Health Advisories (HAs) for microcystins and cylindrospermopsin

Demographic	Microcystin (µg L^{-1})	Cylindrospermopsin (µg L^{-1})
< 6 years old	0.3	0.7
> 6 years old and adults	1.6	3.0

Adopted from U.S. EPA Cyanotoxins Fact Sheet (2015)

Current Approach – Cyanotoxins Monitoring

- Well-developed **laboratory** methods for measuring toxins
  - Biological assays, i.e. ELISA, PPIA, etc.
  - Chromatographic Methods, e.g. GC/FID, GC/MS, TLC
- Also **field** methods for estimating cyanobacterial biomass

- Drawbacks to current methods
  - Largely applicable in lab settings.
  - No single method for measuring multiple/all cyanotoxins.
  - Expensive and time consuming analyses
  - Lack of standard reference materials.

Potential Benefits of Advanced Cyanotoxins Sensors

- "Real-time" data
- Continuous monitoring
- Field-deployable
- Portable
- Affordable
- Easy to operate

Next Steps: Cyanotoxins

- Alliance for Coastal Technologies (ACT)
  - Third-party testbed for evaluating technologies
  - Forum for capacity and consensus building
  - Information clearinghouse for environmental technologies

- ACT and HABs
  - Two past technology workshops (2002, 2007)
  - Upcoming technology workshop, including cyanobacteria/toxins (Late 2016 – Early 2017)

www.act-us.info

Total Nitrogen / Total Phosphorous

Brian Pellerin, PhD

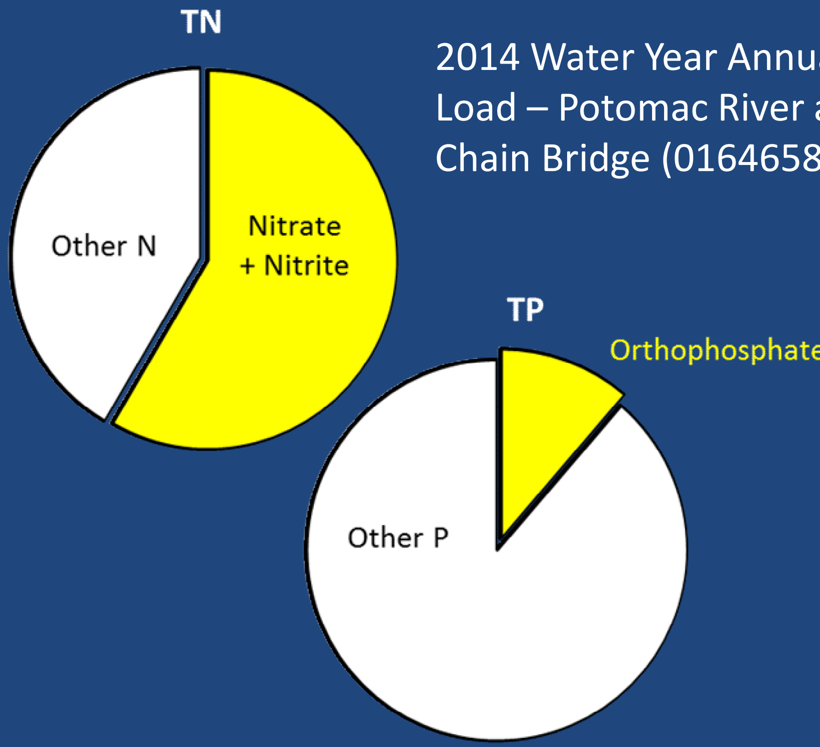
U.S. Geological Survey

What are TN/TP?

- TN: sum of dissolved N (**nitrate***, nitrite, ammonia/ammonium, and organic N) and particulate N
- TP: sum of dissolved P (**ortho-phosphate***, polyphosphate, organic phosphate) and particulate P

***Sensor available**

2014 Water Year Annual Load – Potomac River at Chain Bridge (01646580)



http://cbrim.er.usgs.gov/index.html

Why does TN/TP matter?

- National aquatic resource surveys consistently find TN and TP are widespread pollutants in lakes and rivers and streams
- More than 2 out of 5 river and stream miles are impacted by excess nutrients (EPA National Rivers and Streams Assessment)
- Impacts to drinking water, eutrophication, and the development of harmful algal blooms

MERIS/ESA, processed by NOAA/NOS/NCCOS (Oct. 8, 2011)

Current Approach – TN/TP Monitoring

- **Laboratory Methods – Whole Water Samples**
  - Persulfate digestion for N and P (colorimetric) ✗
  - High-temperature catalytic oxidation for N (chemiluminescence) ✗
- **Laboratory Methods – Computation**
  - Total Kjeldahl digestion *plus* dissolved constituents not oxidized (e.g. TKN plus nitrate plus nitrite) ✗
  - Dissolved N *plus* particulate N measured by high temperature combustion oxidation ✗
- **Surrogate Modelling Techniques** ✗

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Drawbacks to Current Approach

- Lab-based methods:
  - Time lag from sample collection to data
  - Difficult to make real-time decisions (e.g. process control)
- High per-sample collection & analysis cost
- Limited data (due to cost)
- Lab instruments require trained analysts
- High uncertainty, site-specific (*surrogates)*

E. Coli / Enterococci

Alan Lindquist, PhD

U.S. EPA

E. Coli & Enterococci – what are they?

- *E. coli* is a species of Gram-negative rod shaped bacteria commonly found in the intestines of animals and humans.
- Enterococci are a large genus of Gram-positive non-spore forming cocci forming bacteria, also commonly found in the intestines of humans and other animals.
- *E. coli* and enterococci levels are used as indicators of the presence of contamination of drinking and recreational waters.

E. Coli & Enterococci – why are they important?

- Some stains of *E. coli* and species of *Enterococcus* spp. are pathogenic.

- These bacteria are also indicators of the possible presence of other disease-causing bacteria, viruses, and protozoa.

- Such pathogens may pose health risks to people drinking, fishing and swimming.

Current Approach – *E. coli* and Enterococci Monitoring

- *Escherichia coli*
  - DW WW AW **Culture based methods**
- Enterococci
  - WW AW **Culture based methods**
  - AW **TaqMan® quantitative PCR based methods**

DW	Drinking Water –SDWA
WW	Wastewater and Sewage Sludge - CWA
AW	Ambient Water - CWA

Investigational Approaches – *E. coli*/ *Enterococci* Monitoring

- Rapid detection of growth in a sensor format
- Detection of genetic material, or PCR product in a sensor
- Antibody or other protein or DNA capture based sensors
- Image analysis
- Light scatter, including spectroscopy and hybrid multispectral analysis
- Electromagnetic resonance
- Electron transfer

Drawbacks and Challenges

- Current Approach Drawbacks
  - Time, qualified personnel, equipment, supplies
  - Do not provide continuous, streaming, real time, information
  - Methods are for indicators
- Challenges for Sensors
  - Relationship between “positive detection” and public health
  - Data quality (eg. cfu, gene copy, cell number, live, dead, VNBC)
  - Detection limit, sample volume and interferences
  - Quality of taxonomic identification
  - Performance (field and statistical)

Thank you!

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