CYANOBACTERIA/CYANOTOXINS

(An Emerging Issue)

BACKGROUND

- Cyanobacteria are photosynthetic bacteria (aka blue-green algae) (contain chlorophyll-a and and phycocyanin) (single cells, filaments, colonies)

- Some cyanobacteria produce T&O byproducts (Geosmin, 2-MIB)

- Some Cyanobacteria produce cyanotoxins

  eg, Microcystins (liver toxin), Anatoxin-a (nerve toxin), Cylindrospermospsin (liver toxin), Saxitoxins (nerve toxin), etc.

- There are 100 congeners of Microcystin

  (vary based on amino acid composition)

- Microcystin-LR is one of the most potent congeners

  (most available toxicological data is for this congener)

- Cyanobacterial genera that produce cyanotoxins include:

Microcystis	*Anabaena*
Nodularia	*Nostoc*
Oscillatoria	*Fischerella*
Planktothrix	*Gloeotrichia*

- Microcystins are water soluble
- Tend to remain within cyanobacterial cell (intracellular) until cell ruptures and releases them (extracellular)

EPA NATIONAL LAKES ASSESSMENT (2007)

- Detected microcystin in 30% of lakes
- Conc >1 ppb in 1% of lakes

Factors Contributing to Bloom Formation

- Sunlight
- Stagnant water
- Water column stratification
- pH
- Warm water temperatures
- Organic matter availability
- Runoff of limiting nutrients into water body
  - nitrogen
  - phosphorous
- Ratio of nitrogen to phosphorous

- Lake Erie is at elevated risk
  - shallowest and warmest of Great Lakes
  - problem originally corrected in 1980's & 90's (federal government regulated discharge from POTWs)
  - problem has worsened over past decade (main source is agricultural runoff)

HEALTH IMPACTS OF CYANTOXINS

- Health impacts of microcystin:

    From consumption of drinking water:

    - gastroenteritis
    - Liver damage (hepatotoxins)
    - kidney damage

    From recreational exposure:

    - eye & ear irritation
    - allergic reactions
    - skin irritation (dermatotoxins)
    - gastrointestinal illness

Routes of exposure:

- dermal contact
- inhalation of toxins in aerosols
- recreational activities
- consumption of drinking water and food (including consumption of fish)
- intravenous exposure (Brazil 1996 – 52 people killed in dialysis unit)

MONITORING CYANOBACTERIA AND CYANOTOXINS

Important to Note -

- Blue/green water does not necessarily indicate presence of toxins
- Cyanobacteria do not necessarily indicate presence of toxins
- Geosmin and 2-MIB do not necessarily indicate presence of toxins

Parameters Used to Monitor Water Body for Cyanobacteria

- Gross visualization and Secchi disk
- Microscopic analysis (algal counts)
- Chlorophyll a
- Cyanopigments (phycocyanin)
- PCR

Note: Composite samples should be collected from various depths since cyanobacteria move up and down in water column

Satellite Monitoring

- NOAA, NASA, EPA, and USGS are undertaking a $3.6 million research effort to establish an early warning system for HABs using satellite color imagery

Biochemical Assays for Cyanotoxins

- Immunological – ELISA test
  (Enzyme Linked Immunosorbent Assay)
- Antibodies have been developed against various cyanotoxins and congeners
- ADDA ELISA also includes antibodies against the amino acid ADDA

ELISA (cont)

- Good for relative trending but questions questions exist concerning absolute quantitation
- Typically used for screening
- Detection of ‘total’ microcystins is expressed as sum of congeners provided from ADDA ELISA

Analytical Chemical Assays for Cyanotoxins

- Liquid Chromatography with mass spec (LC/MS) or tandem mass spec (LC/MS/MS) detectors
- Detects 8 individual microcystin congeners and nodularin
- Typically used for more precise confirmation and quantification of positive ELISA results
- More expensive and time consuming than ELISA

DRINKING WATER TREATMENT

- Algecides ($CuSo_4$) – not recommended due to potential release of intracellular toxins

- Conventional Treatment – (clarification/filtration) – very effective in removing cyanobacterial cells and intracellular toxins (but not extracellular toxins) (DAF may be particularly effective)

When relying on optimized conventional treatment to remove intact cells:

- minimize sludge age in clarifiers because it can contain viable cells
- increase frequency of filter backwashing because filters trap viable cells
- stop recirculating filter backwash water to head of plant because backwash contains viable cells

- Oxidants:

  -Chlorine dioxide and chloramines are ineffective

  -Ozone may release intracellular toxins

  -Cl_2 and $KMnO_4$ are effective

  (Cl_2 only effective at ph < 8)

  (may require an initial Cl_2 dose of 3 ppm, and 0.5 to 1.5 ppm of free Cl_2 remaining after 30 min contact time)

- Activated Carbon

  -GAC and PAC are both effective in adsorbing cyanotoxins

  -GAC EBCT should be 10 to 20 min or more

  -Wood-based PAC may be more effective than coal or coconut-based PAC

- Activated Carbon (cont)
  - 20 mg/L (or more) PAC dose and 45 min (or more) contact time may be required to remove microcystins
  - PAC can be:
    - added before coagulation and removed in settling tanks
    - added to settling tanks and removed during filtration

- Biologically active sand and GAC filters effectively remove cyanotoxins
- Microfiltration and ultrafiltration effectively remove cyanobacterial cells w/o causing release of cyanotoxins
- Nanofiltration removes 82% of cyanotoxins
- RO removes 95% of cyanotoxins

- Dosage of UV light needed to inactivate cyanotoxins (even with hydrogen peroxide) is much higher than that needed to disinfect microorganisms

USEPA Recommended Treatment Approach

- 1) Remove intact cells first
  (coag, floc, sed, filtration)
- 2) Minimize preoxidation of raw water
  (to prevent lysing of cells)
- 3) Increase PAC (>20 ppm recommended)
- 4) Increase post chlorination
  (CT value to oxidize microcystin may be greater than needed to inactivate Giardia)

HAB INCIDENTS

Lake Alexandria, Australia (1878)

- First documented case of toxic impacts of HAB on animals

Charleston, WV (1931)

- Microcystis bloom in river sickened 5,000-8,000 people via drinking water
- Drinking water treatment was not adequate to control problem that developed in Ohio and Potomac Rivers

Washington DC (1975)

- 23 dialysis patients experienced toxic shock after water was used from a reservoir with a large cyanobacterial bloom

Sewickley, PA (August 1975)

- Outbreak of diarrheal illness broke out among 60% of residents who obtained water from Sewickley municipal water system
- No specific bacteriological or viral causative agent was isolated
- Suspicion was that a heavy growth of cyanobacteria (Schizothrix calcicola) may have been responsible

Toledo, OH (August 2014)

- Fri evening (1 Aug) – Toledo utility personnel detected microcystin and contacted Ohio EPA
  (14.5 ppb in raw intake)
  (2.5 ppb in finished water)
- Sat (2 AM) – ‘Do Not Drink’ advisory issued
  (following second round of testing)

Toledo (cont)

- Over weekend – microcystin > 1 ppb found in 8 distribution system samples
- Mon (11 AM) – conc decreased to near detection limit and advisory was lifted
- Source of problem – cyanobacterial mat formed over Toledo's treatment plant intake
- 500,000 people impacted

Ohio River (Aug-Oct 2015)

- Substantial HABs observed from Wheeling, WV to Cannelton, IN (636 of 981 miles) (4 states)
- No drinking water affected but some cities issued advisories recreational advisories for river
- Some cities (eg, Cincinnati) modified their water treatment

- Note: It has been suggested that HAB incidents may increase with climate change

GOVERNMENT ADVISORIES, REGULATIONS, AND GUIDANCE

WORLD HEALTH ORGANIZATION (WHO)

- > 1 ppb – unsuitable for human consumption
- >20 ppb – unsuitable for recreational use

USEPA

- May 2015 – EPA set health advisory levels

  (non regulatory)

  (based on 10 day ingestion of drinking water)

  children < 6yr old:

  microcystin – 0.3 ppb

  cylindrospermopsin – 0.7 ppb

  people > 6yr old:

  microcystin – 1.6 ppb

  cylindrospermopsin – 3.0 ppb

USEPA (cont)

- June 2015 – USEPA published full health advisories for microcystin and cylindrospermospsin

sources & occurrence	environmental fate
health effects	health advisory levels
analytical methods	treatment technologies

- 2016 - USEPA will issue recreational criteria for cyanotoxins

USEPA (cont)

- USEPA placed 10 cyanotoxins on SDWA's Contaminant Candidate List (draft CCL4):
  - total microcystin
  - microcystin-LA
  - microcystin-LF
  - microcystin-LR
  - microcystin-LY
  - microcystin-RR
  - microcystin-YR
  - nodularin
  - anatoxin-a
  - cylindrospermopsin

STATE HAB PROGRAMS

- Ohio:
  - mandatory 'Do Not Consume' orders based on USEPA advisories
  - mandatory testing (of source and finished waters) for cyanobacteria and cyanotoxins on regular basis
- Pennsylvania:
  - developing program focused on recreational exposure