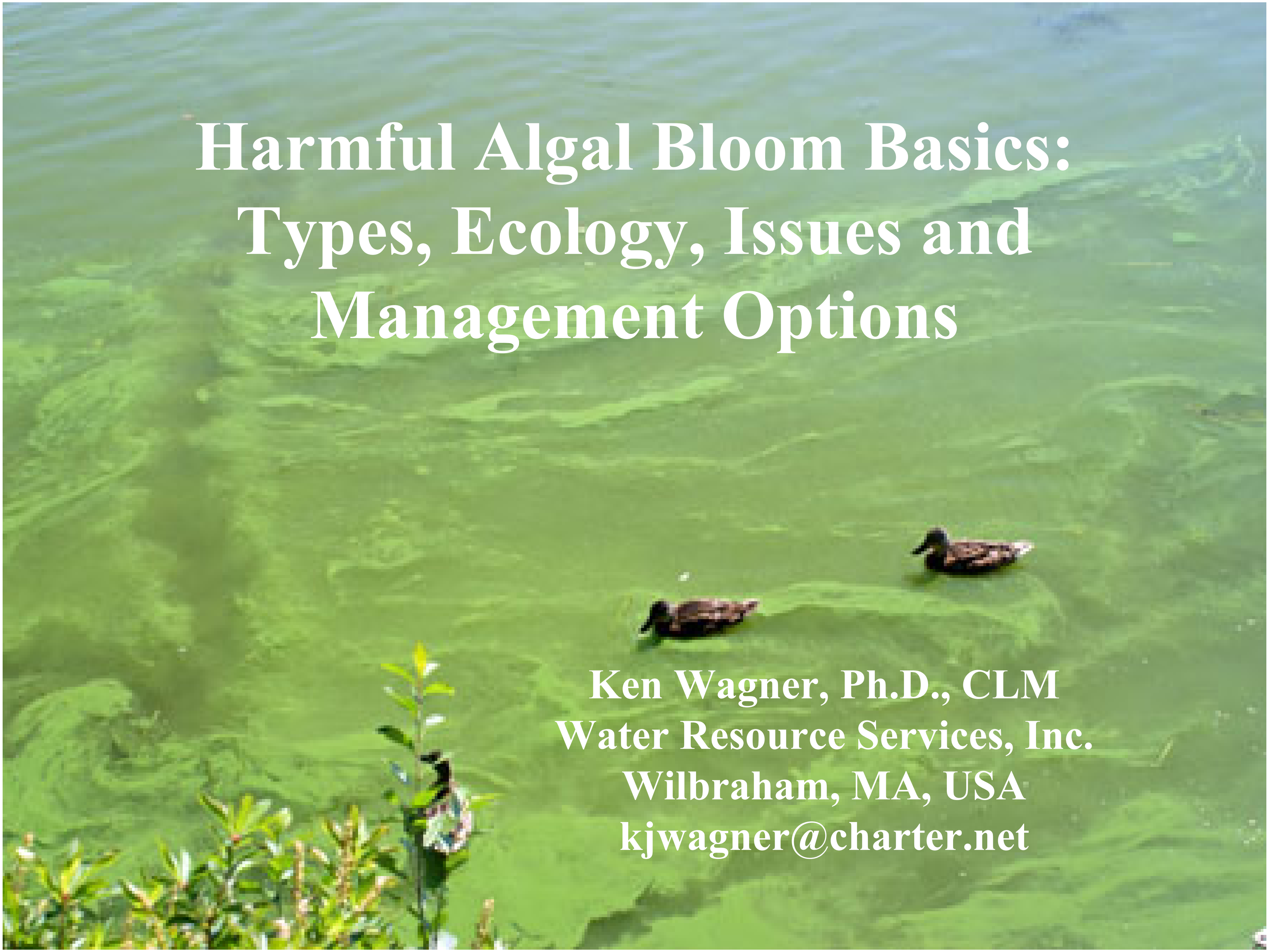

Harmful Algal Bloom Basics: Types, Ecology, Issues and Management Options

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What is a Harmful Algal Bloom?

- Any elevated concentration of algae that can negatively impact a waterbody or its uses
- Can be saltwater or freshwater, but responsible algae differ

What is a Harmful Algal Bloom?

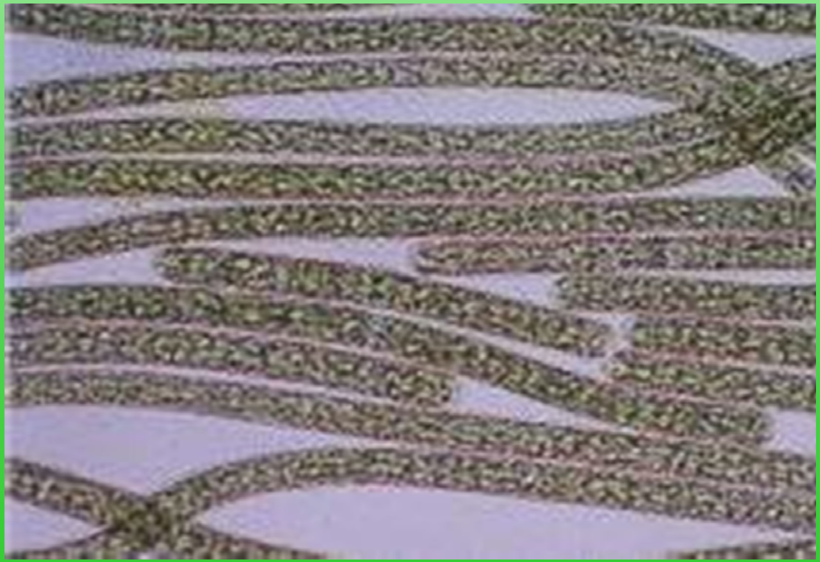
- Toxicity is a primary concern, but non-toxic blooms can depress oxygen, alter pH, add taste/odor, and provide organic compounds that can become carcinogens in water treatment facilities
- While any group of algae could form a HAB, the greatest risk is associated with cyanobacteria (aka blue-green algae)

What are cyanobacteria (blue-green algae)?

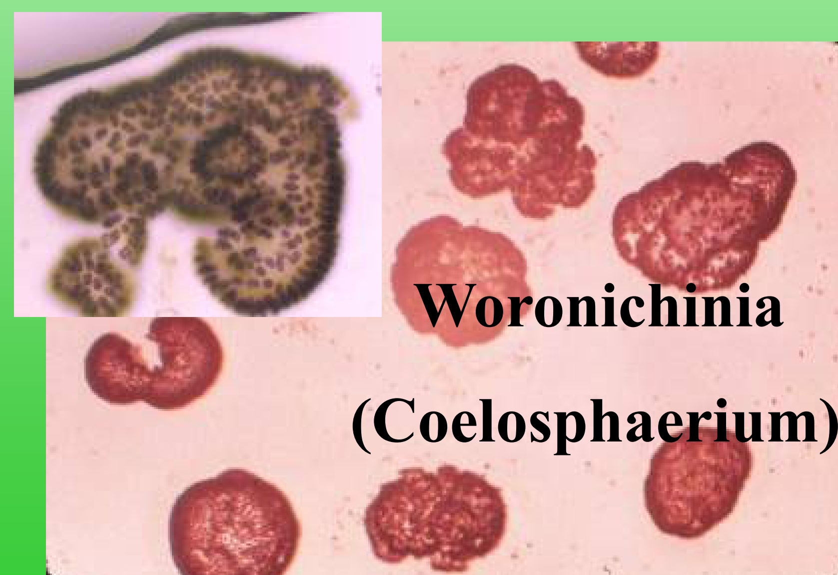
- Photosynthetic bacteria, 2 billion year old group
- Native, natural, part of functioning aquatic system
- Mostly small cells in large aggregations
- Prefer warmer water, elevated phosphorus concentrations, more reduced iron, higher pH

What are cyanobacteria (blue-green algae)?

- Pigments allow photosynthesis under low light
- Many have heterocytes that allow N fixation
- Many can control buoyancy, form surface scums
- Resting stages fall to sediment, germinate later
- Most are capable of producing toxins
- Diverse group, extensive taxonomic revision



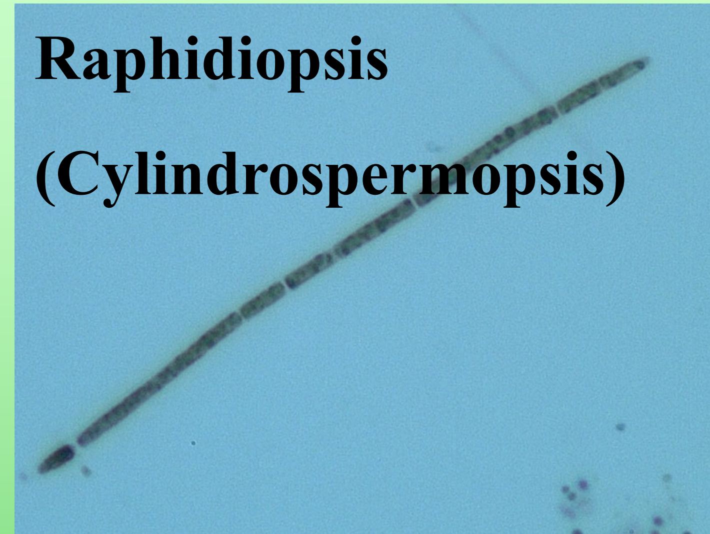
Common planktonic cyanobacteria



Common planktonic cyanobacteria

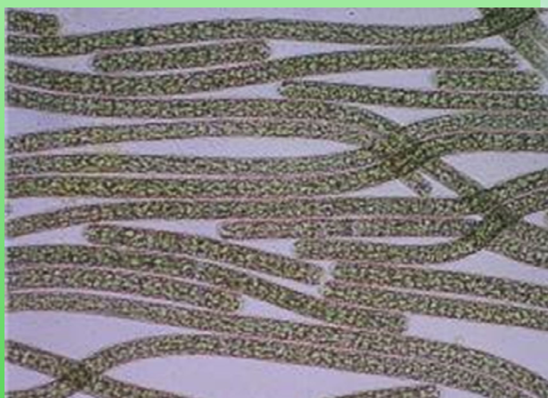
Planktolyngbya

(Lyngbya)



Raphidiopsis

(Cylindrospermopsis)

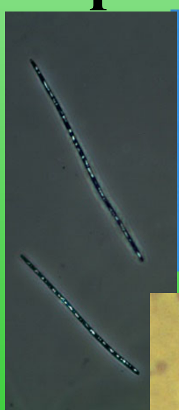
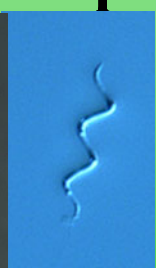


Planktothrix
(Oscillatoria)

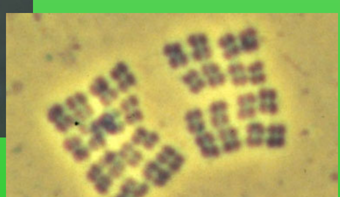
Gloeotrichia

Modes of bloom formation

1. Entry from upstream source in large quantity
2. Organic growth in upper water layer
3. Formation at mid-depth with movement into upper water layer
4. Benthic growth of planktonic forms followed by synchronized rise into the upper water layer

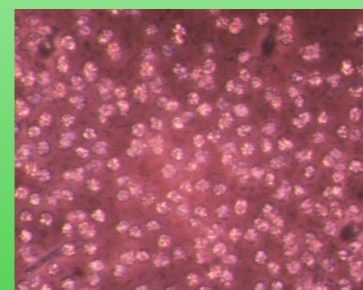
Raphidiopsis



Merismopedia

Planktothrix

Pseudanabaena



Microcystis

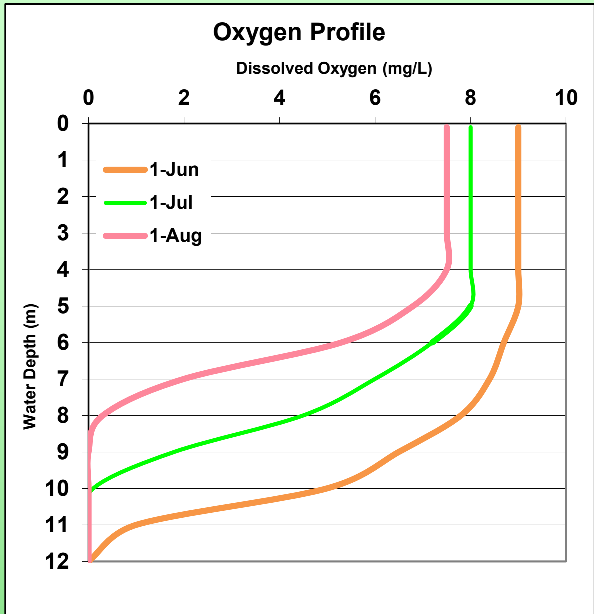
Dolichospermum

Gloeotrichia

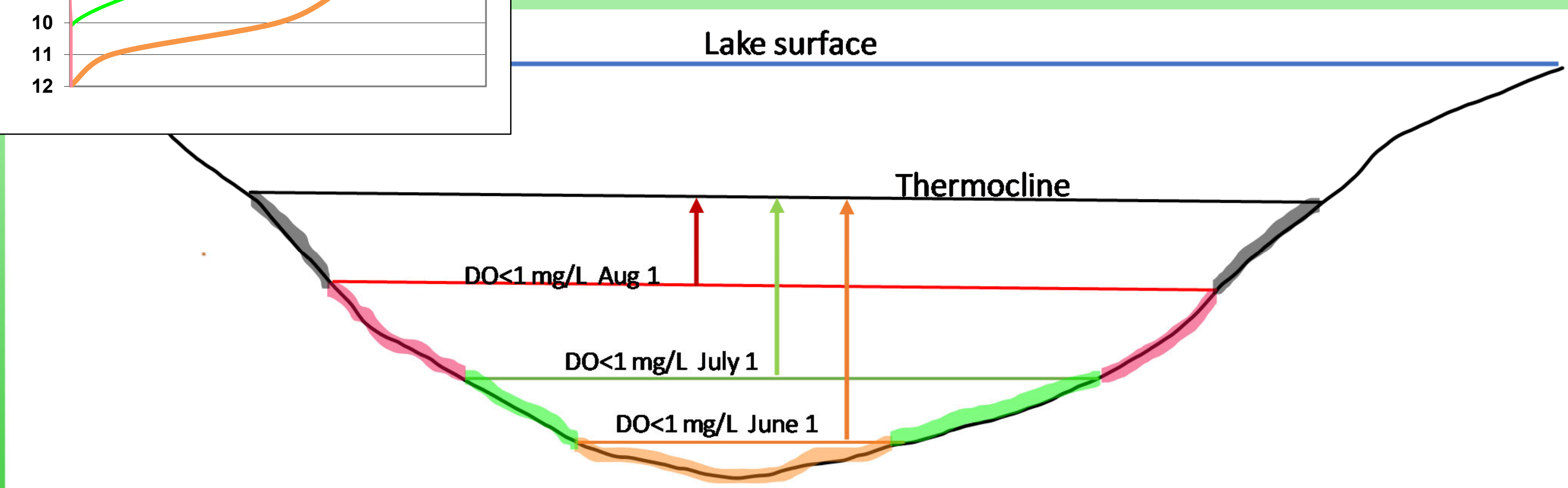
Factors that support cyanoblooms

- **Increased temperature – faster growth rates, cyanobacteria metabolically favored**
- **Increased nutrient inputs – more fertile water**
- **Internal recycling – legacy inputs can become main source of phosphorus**

Oxygen, internal loading and cyanobacteria



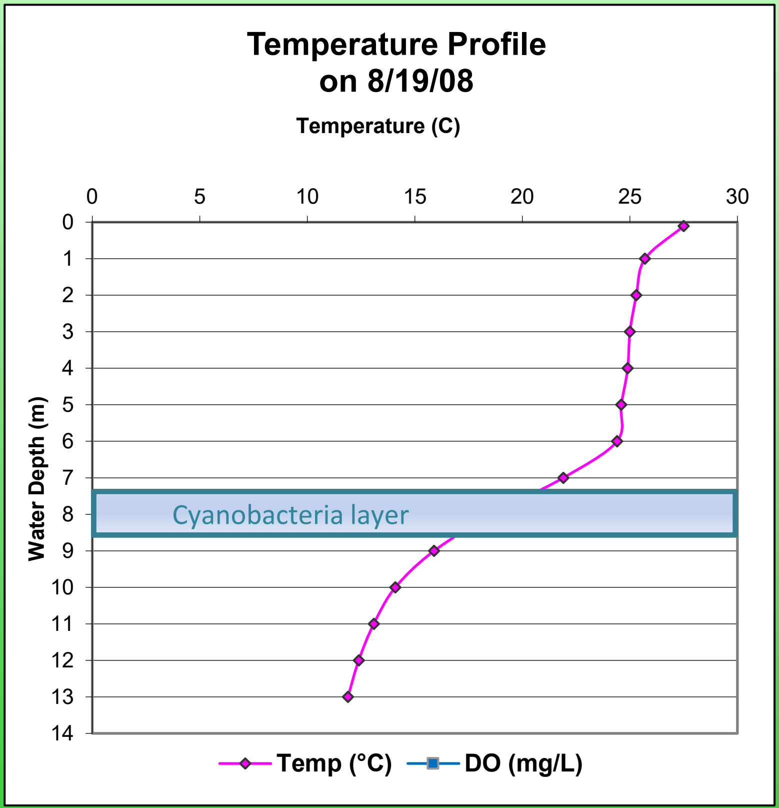
Where the thermocline sets up and how fast oxygen is lost below it can have huge impacts on internal loading and cyanoblooms

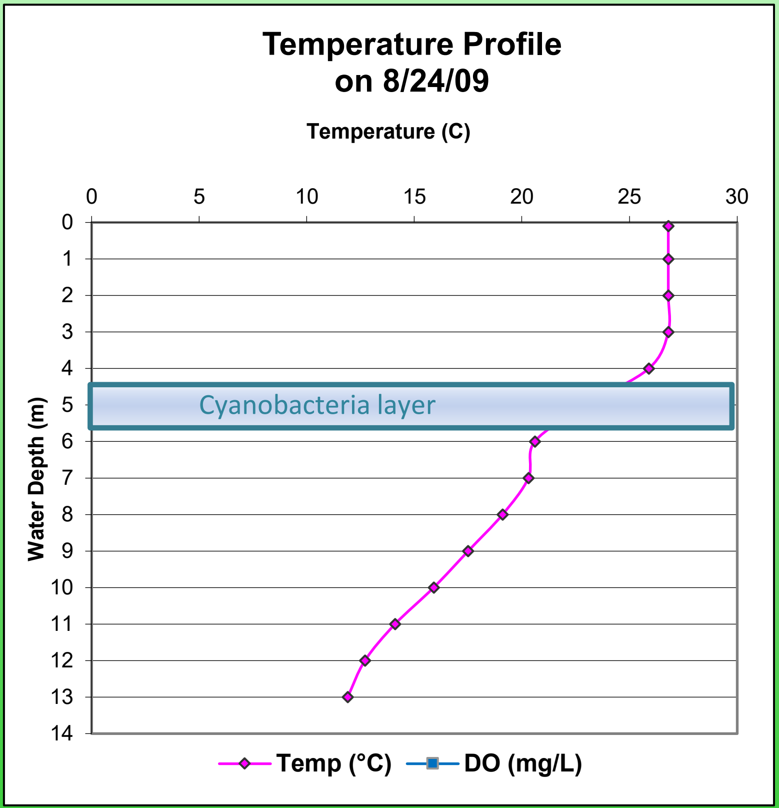


As the top of the anoxic zone rises in the water column, the portion of the lake bottom exposed to anoxia increases and the distance to the thermocline (where light is available) gets shorter.

Metalimnetic cyanobloom

Depth at which thermocline forms will vary with spring weather and could have major consequences for algae impacts

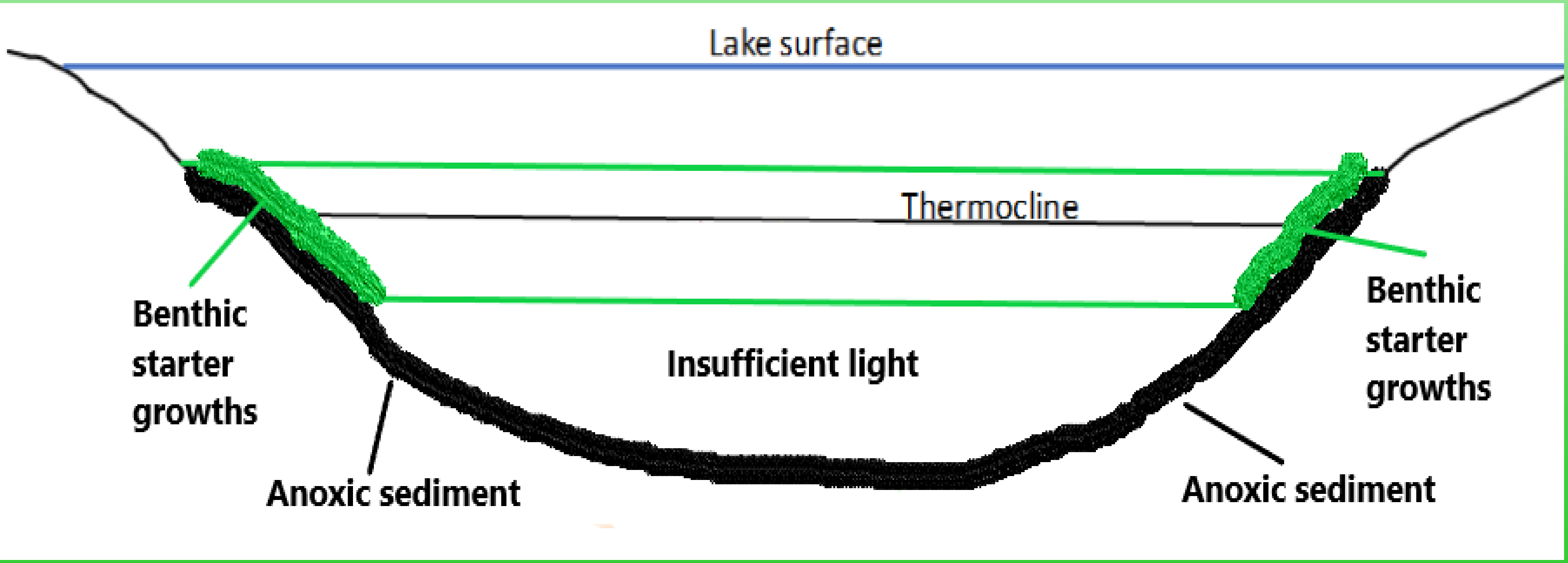




Two successive years in a stratified Cape Cod lake. The bloom came to the surface in 2009 and killed 2 million mussels

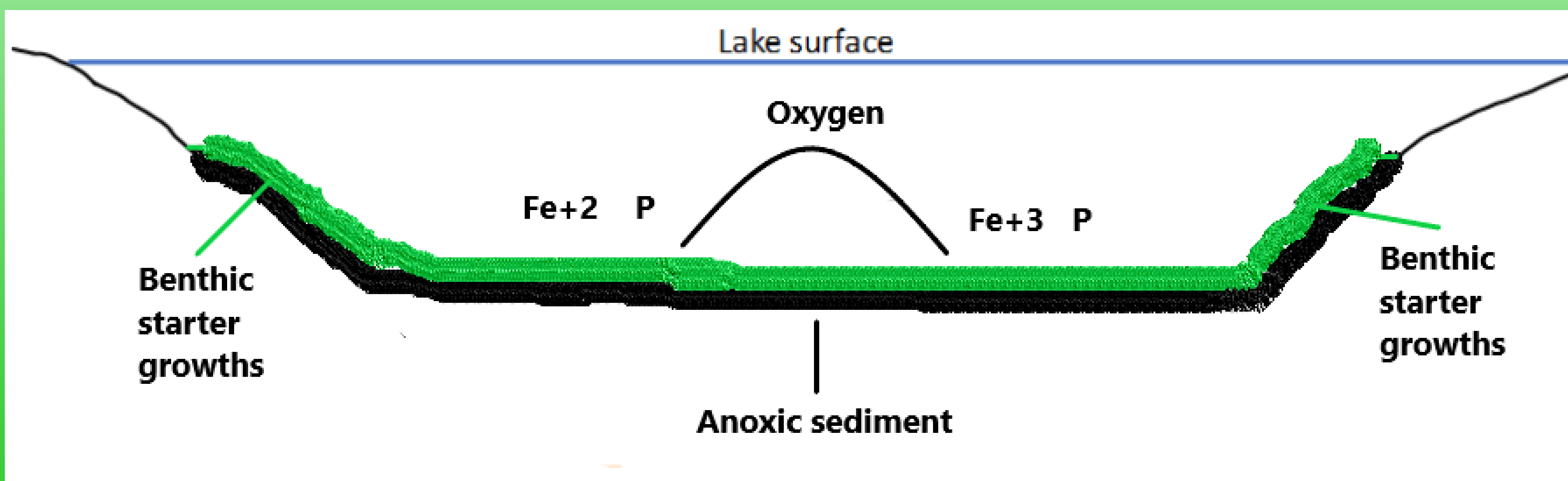
Cyanobacteria blooms with a benthic origin

- Cyanobacteria can grow at the sediment-water interface where P (and Fe) can be released and light is adequate
- P (and Fe) released from sediment by redox reactions (or decomposition) is utilized before it gets into the oxic overlying water and is inactivated
- Cyanobacteria can then rise into upper waters for more light (and sink again to get more nutrients)



Cyanobacteria blooms with a benthic origin

- A lake does not have to be stratified to support blooms of benthic origin
- P and Fe that would not make it far into the water column without being inactivated is still available at sediment-water interface with adequate light
- Cyanobacteria grow then rise into water column



Why cyanobacteria are more linked to internal loading than other algae

- Other algae can utilize the same approach (e.g., filamentous green algae in shallower areas of many lakes, golden algae in metalimnion), just not as well overall
- Many cyanobacteria are adapted to low light, can grow deeper
- Many cyanobacteria have a buoyancy mechanism to allow movement into the upper water
- Internal nutrient release under anoxia has a low N:P ratio and higher Fe^{+2} content that favors cyanobacteria that can fix N_2 gas

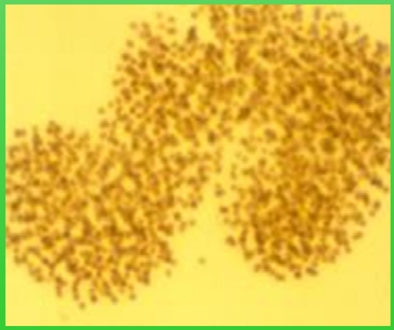
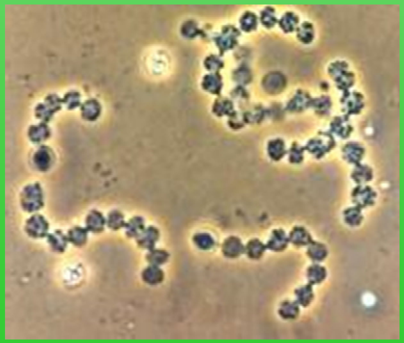
Cyanobacteria bloom trends

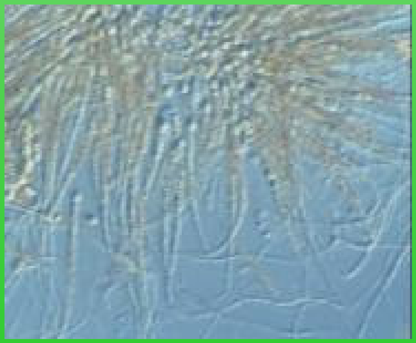
Cyano blooms are increasing:

- Phosphorus rising; decreased N:P ratios favor cyanos
- Temperatures rising; more oxygen demand, more internal loading, plus warmer water favors cyanos

Bottom growth/quick rise blooms seem to be increasing in particular:

- Long-term accumulation of nutrients in sediment fosters such growths; loss of oxygen over larger areas is a big influence
- Light and low oxygen in sediment are key triggers; intermediate depth zone implicated as biggest contributor

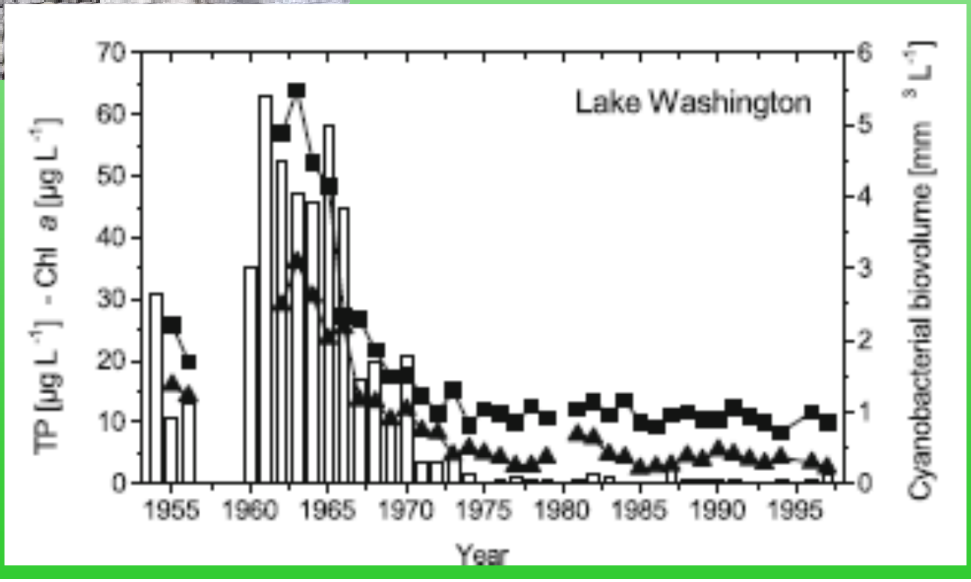


HAB Management Options

- Direct control by algaecides or sonication
- Direct removal by flushing
- Growth limitation by lowered light (dyes)
- Growth limitation by nutrient reduction
  - Watershed input reductions
  - Internal load reduction
    - Dredging
    - Sediment capping
    - Hypolimnetic withdrawal
    - Oxygenation
    - Phosphorus inactivation

HAB Management Options

- Watershed input reductions

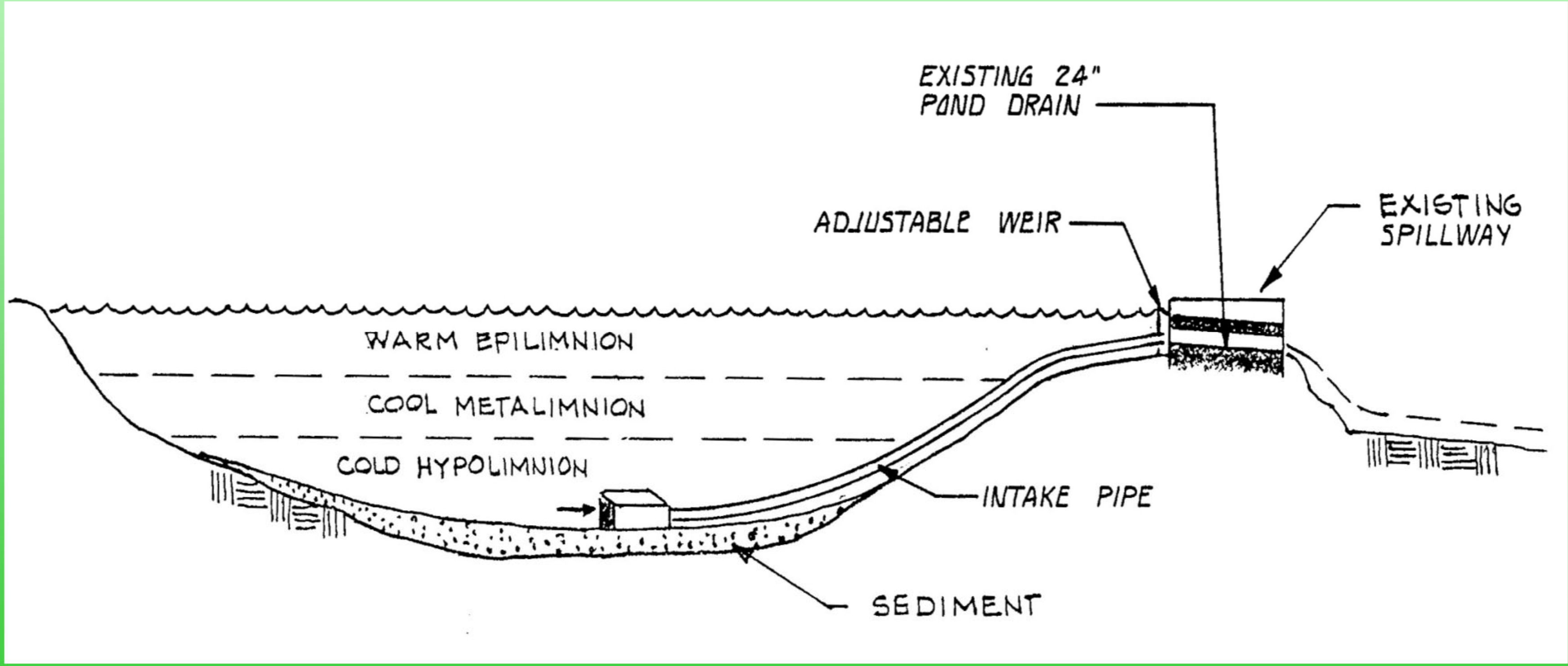


HAB Management Options

- Internal load reduction
  - Dredging
  - Sediment capping

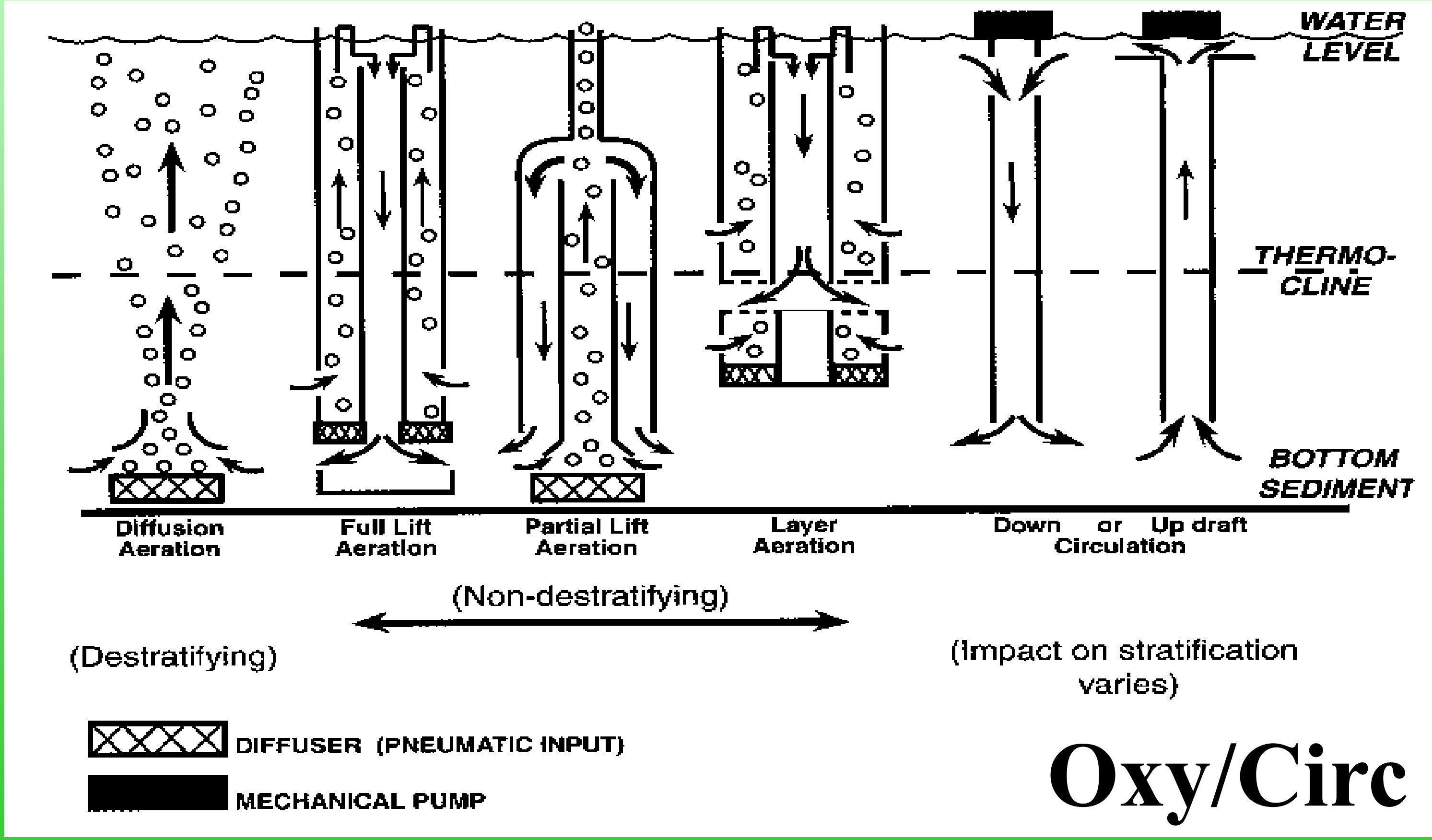
HAB Management Options

- Internal load reduction
  - Hypolimnetic withdrawal



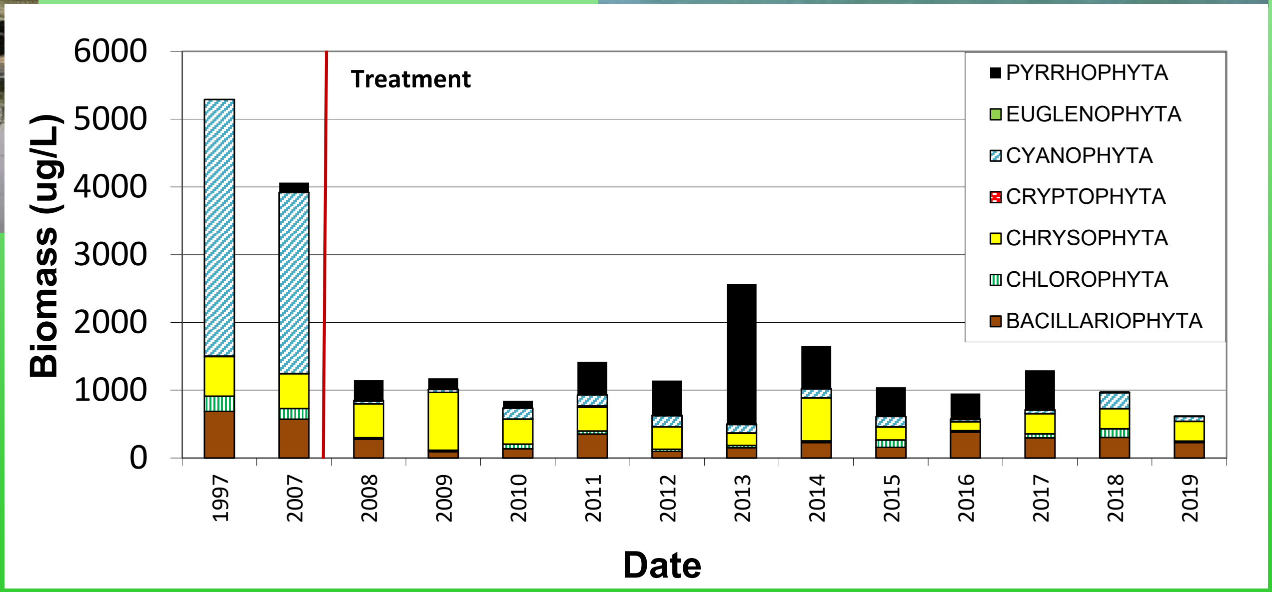
HAB Management Options

- Internal load reduction
  - Oxygenation



HAB Management Options

- Internal load reduction
  - Phosphorus inactivation



Questions and Comments



Controlling HABs in Water Resources: A Review

John H. Rodgers, Jr.
Professor Emeritus

jrodger@clemson.edu

CLEMSON UNIVERSITY

HABs and Water Resources

- **HABs**
- **Water Resources**

Management of HABs in Water Resources

- **Why and when?**
- **Designated uses**
  - **Impaired or obviated - $$$$$ and health**


WARNING
TOXIC ALGAE PRESENT
Lake unsafe for people and pets
Until further notice:
• Do not swim or water ski.
No nade o practique el esquí acuático.
• Do not drink lake water.
No tome el agua del lago.
• Keep pets and livestock away.
Mantenga alejados las mascotas y el ganado.
• Clean fish well and discard guts.
Limpie bien el pescado y deseche las tripas.
• Avoid areas of scum when boating.
Evite las áreas con espuma o verdín cuando ande en lancha.
Call your doctor or veterinarian if you or your animals have sudden or unexplained sickness or signs of poisoning.
Report new algae blooms to Department of Ecology:
360-407-6000
Call your local health department:
For more information: www.doh.wa.gov/ehp/algae/
www.ecy.wa.gov/programs/wq/plants/algae/index.html
Health

Cyanotoxins

- **Hepatotoxins**
  - Disrupt proteins that keep the liver functioning, may act slowly (days to weeks)

microcystin (120+ variants)
nodularin
cylindrospermopsin

- **Neurotoxins**
  - Cause rapid paralysis of skeletal and respiratory muscles (minutes)

anatoxin -a
anatoxin -a (s)
saxitoxin
neosaxitoxin

- **Dermatotoxins**
  - Produce rashes and other skin reactions, usually within a day (hours)

lyngbyatoxin

- **b-*N*-methylamino-L-alanine**
  - Neurological: linked to ALS

BMAA

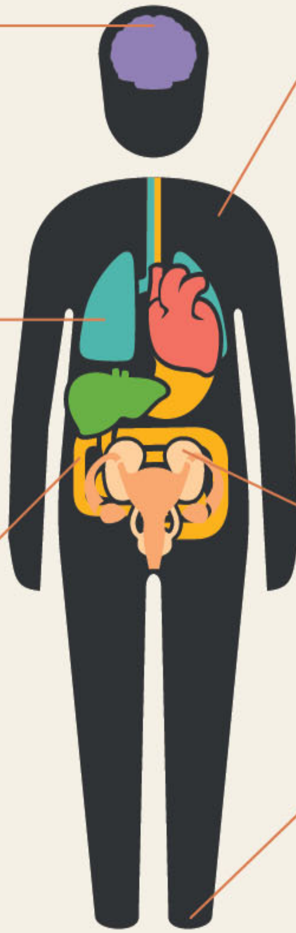
USGS
science for a changing world

Health Impacts of Cyanotoxins

CLEAN WATER ACTION
CLEAN WATER FUND

Note: *Not all cyanotoxins lead to all of these health impacts. These listed impacts are caused by microcystins or cylindrospermopsin, the two cyanotoxins that EPA has issued Health Advisories for.*

IN HUMANS



Brain

Source: Ingestion

Symptoms:

- Headache
- Incoherent speech
- Drowsiness
- Loss of coordination

Respiratory System

Source: Inhalation

Symptoms:

- Dry cough
- Pneumonia
- Sore throat
- Shortness of breath
- Loss of coordination

Digestive System

Source: Ingestion, drinking contaminated water, or eating contaminated fish

Symptoms:

- Abdominal pain
- Nausea
- Vomiting
- Diarrhea
- Stomach cramps

Body

Source: Contact, e.g. swimming

Symptoms:

- Irritation in eyes, nose, and throat
- Blistering around the mouth
- Skin rash, including tingling, burning and numbness
- Fever
- Muscle aches (from ingestion)
- Weakness (from ingestion)

Organs

Source: Ingestion

Symptoms:

- Kidney damage
- Abnormal kidney function
- Liver inflammation

Nervous System

Source: Ingestion

Symptoms:

- Tingling
- Burning
- Numbness

IN PETS

Symptoms:

Vomiting

Fatigue

Shortness of breath

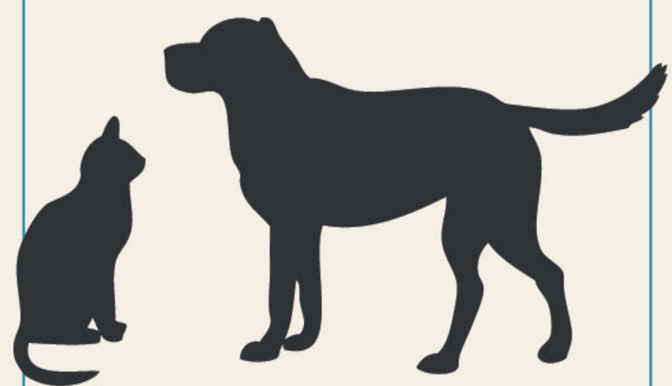
Difficulty breathing

Coughing

Convulsions

Liver failure

Respiratory paralysis leading to death



Noxious Algae in the U.S and Around the World

- Culprits
  - Cyanobacteria
  - Eukaryotes
    - Green
    - Red
    - Brown
    - Diatoms
    - Golden
    - Protists

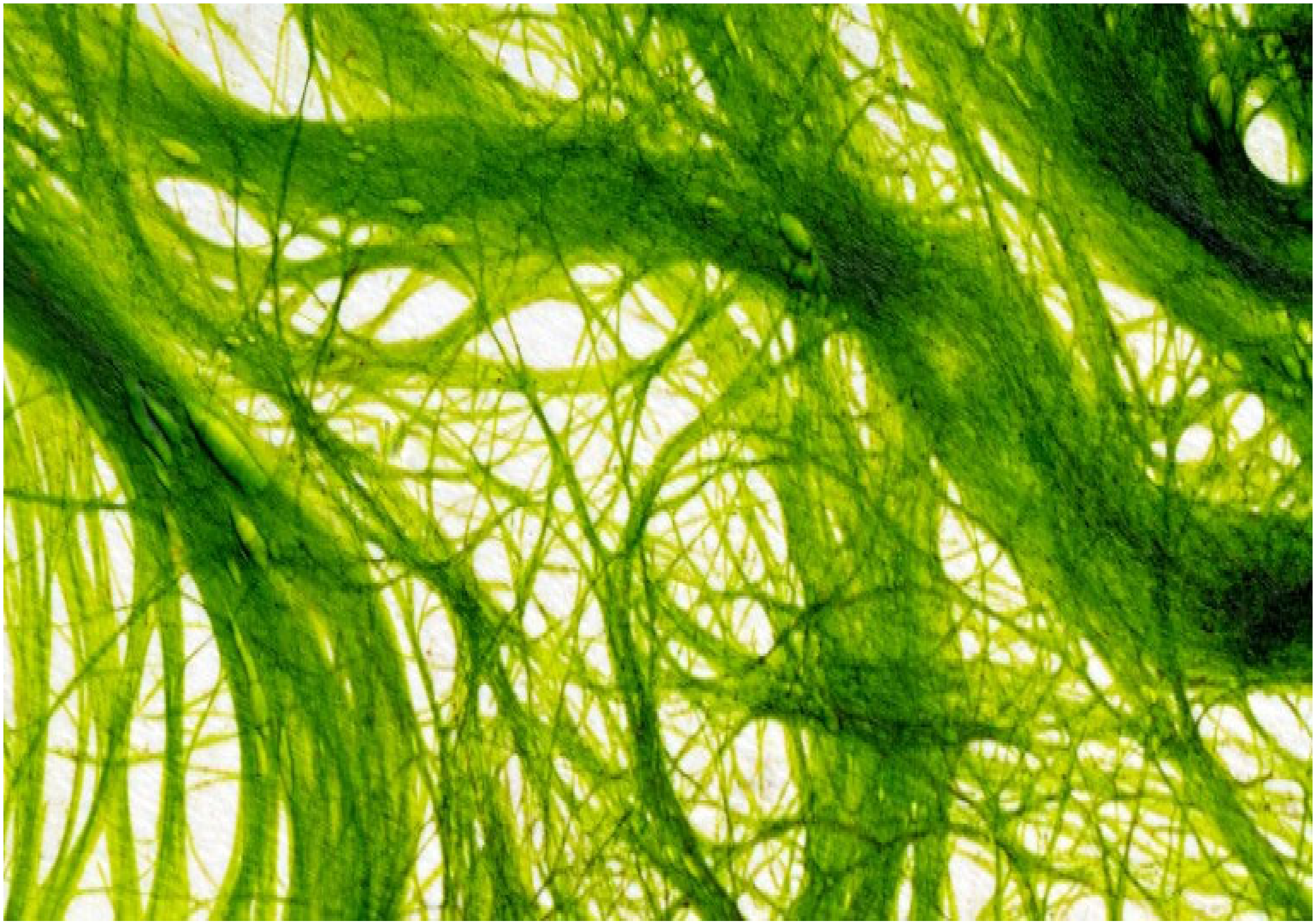
Microcystis

Planktothrix


LOWRANCE

Pithophora

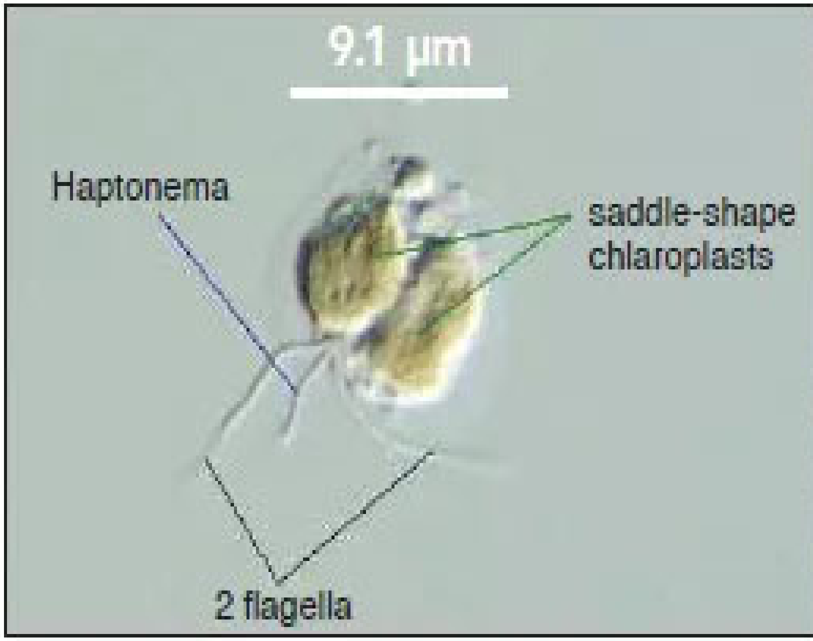
Cladophora

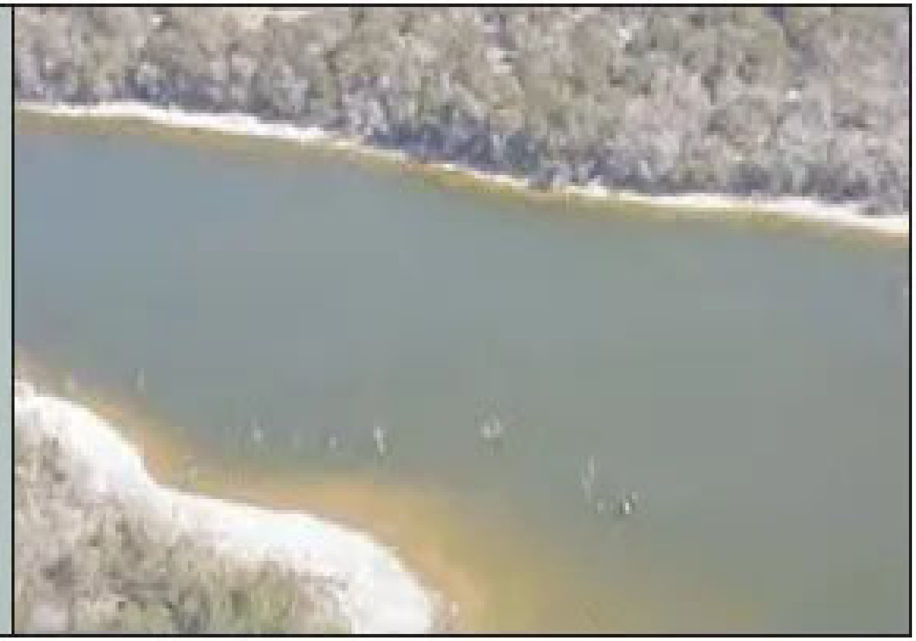


Nitelopsis obtusa

Lake Koronis, MN

Prymnesium

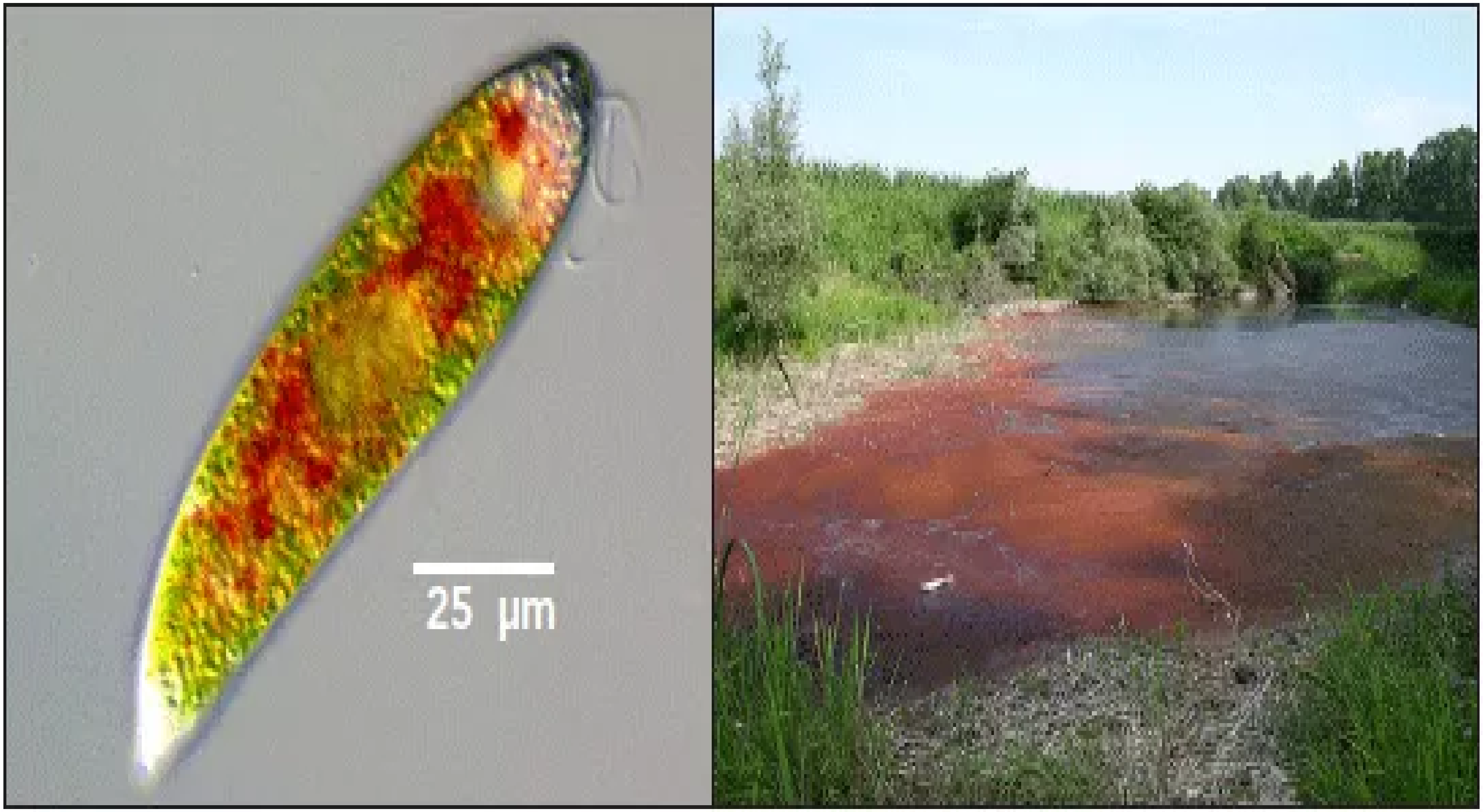




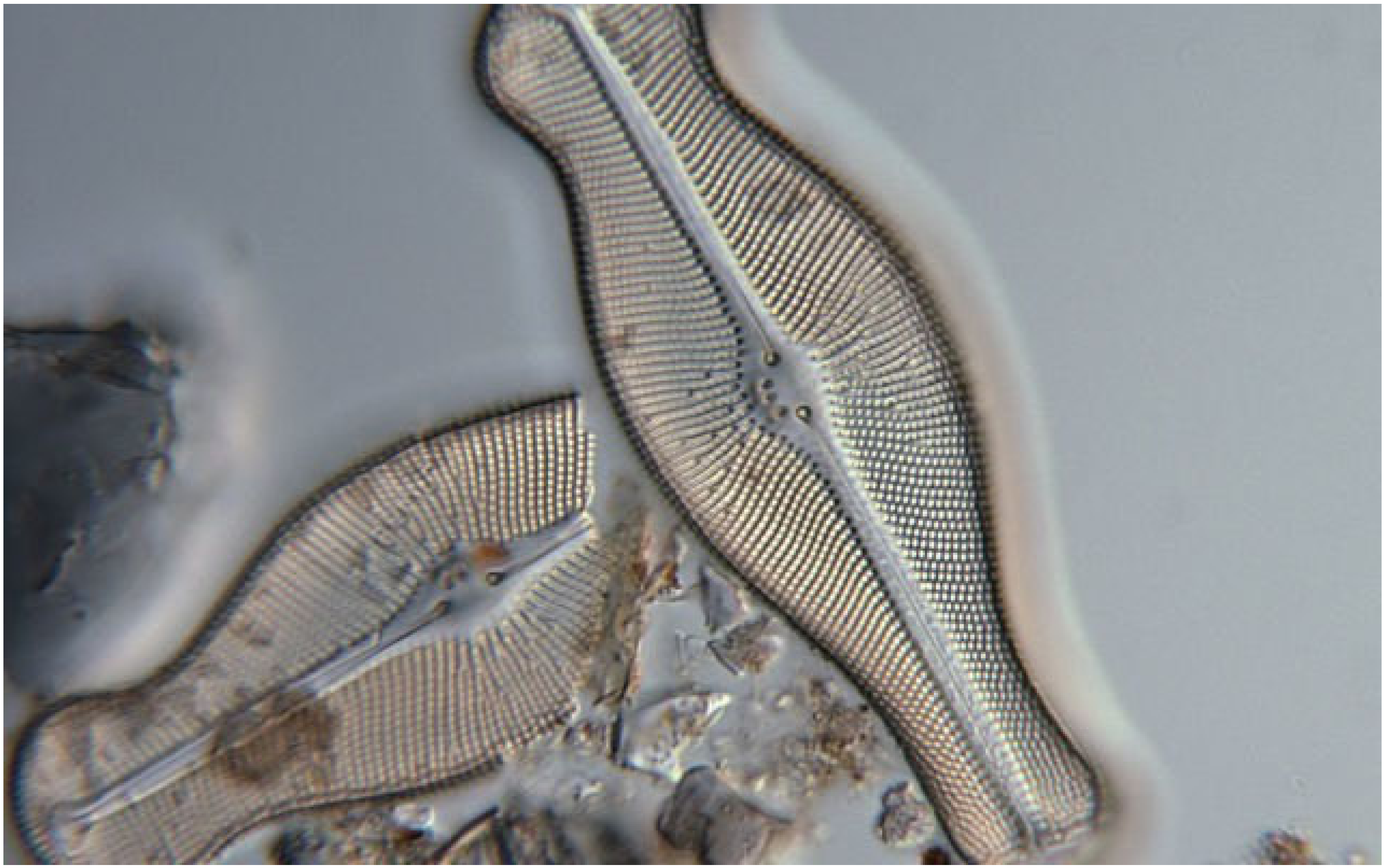
P. parvum "Bloom"

Effects of a *P. parvum* “Bloom”

Euglena



Didymosphenia geminata



STOP AQUATIC HITCHHIKERS!™

Prevent the transport of nuisance species.
Clean all recreational equipment.

www.ProtectYourWaters.net

Lake Hartwell

- **Uses:**
  - Flood risk management
  - Water quality
  - Water supply
  - Downstream navigation
  - Hydropower production
  - Fish and wildlife protection
  - Recreation

Do nothing ≠ Zero risk

Lake Erie algae bloom, August 2011 — Tom Archer, Michigan Sea Grant

What can you do?

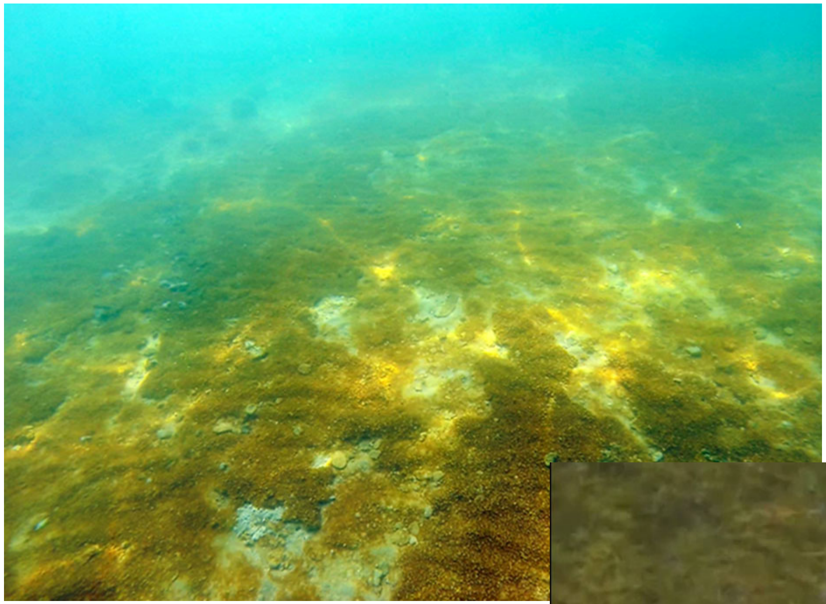
- **Adaptive Water Resource Management**
- **Make a plan!**

Adaptive Water Resource Management

- **What is the problem?**
  - **Who?, Where?, Dimensions?**
  - **Who and what is at risk?**
  - **Triggers?**
- **What can we do about it?**
  - **Political will?, Resources?, Regulatory options?**
- **What are the vulnerabilities?**

Consider all options

- **Physical, Chemical, Biological, Mechanical, Strategic Combinations**

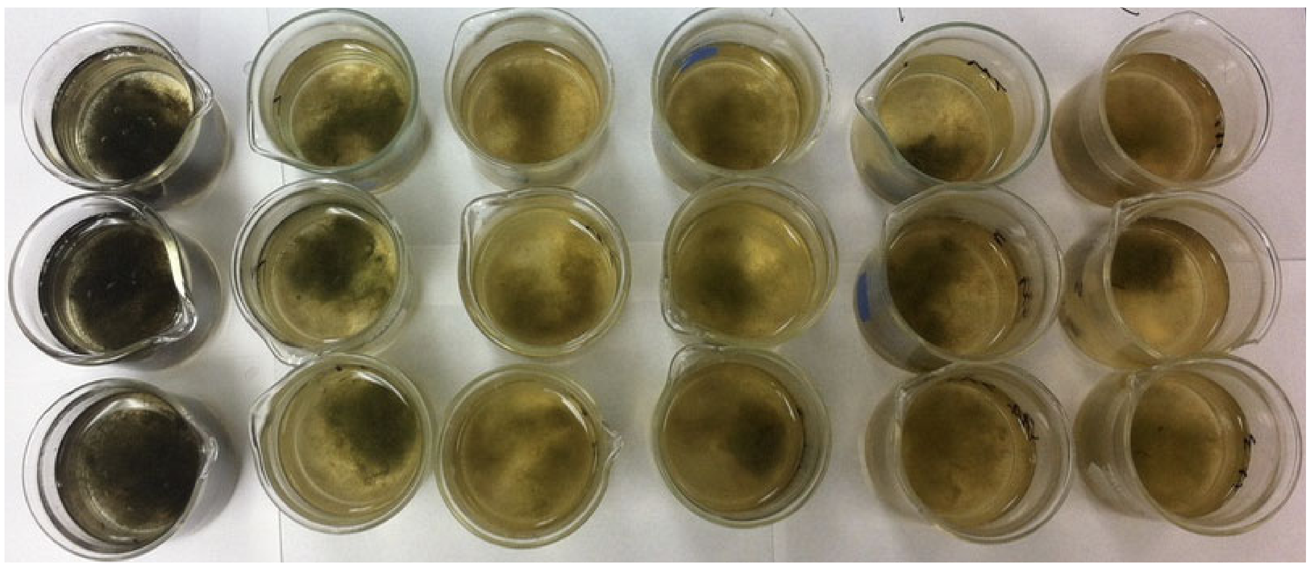


Algaecides

- Copper formulations
- Diquat
- Peroxide formulations
- Endothall

"Algal Challenge Test"

- Algae are "challenged" with selected algaecides
- Laboratory exposures using site water
- Goal: define amount/mass of algaecide required to control 'X' amount of algae with no regrowth



Untreated Control

Increasing Algaecide Concentration

Scale Considerations in Water Resources

- **Algae not uniformly distributed**
- **Uses of water are not the same spatially**
- **Management units!**

Execute Plan

- Plan has to be in place but adaptive!
- Vulnerability data
- Triggers - data
- Permission(s), Permit(s)
- Equipment, Materials, Personnel
- Notices (Public)


Case Study
Taste and Odor Control
in Source Water for the
Anderson Regional Joint Water System (ARJWS)

Drinking Water in the U.S.

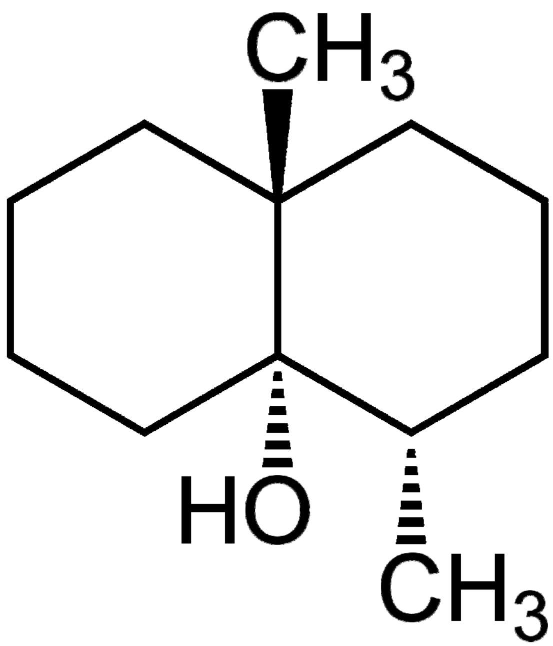
- Over 258 million U.S. residents obtain their drinking water from surface water.
- Every day, 30 billion gallons of water are used for public water use.
- In the past, leading causes of death (e.g. typhoid and cholera) were linked to drinking water.
- Source water protection and management are a high priority.

Secondary Compounds

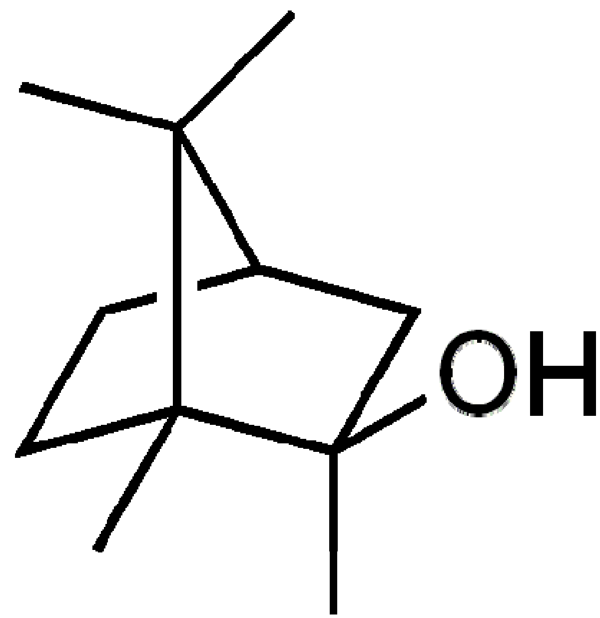
- Toxins
- Taste and Odor Compounds

Taste and Odor Compounds - Problems in Potable Water Resources

- Geosmin

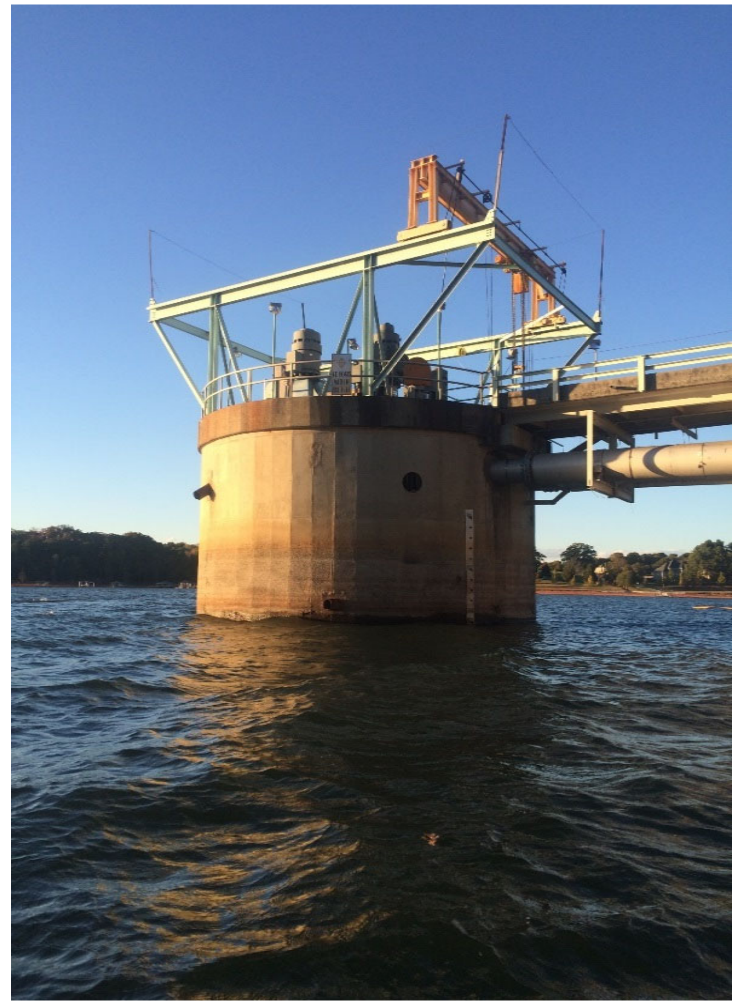


- Methyl isoborneol



- **Anderson Regional Joint Water System is supplied by surface water from the U.S. Army Corps of Engineers' Hartwell Lake Reservoir, on the border of South Carolina and Georgia.**
- **Serves about 200,000 people and plant treats ~5.4 billion gallons of water per year.**
- **The plant is operated by state certified operators.**

Six and Twenty Creek Cove of Hartwell Lake, SC



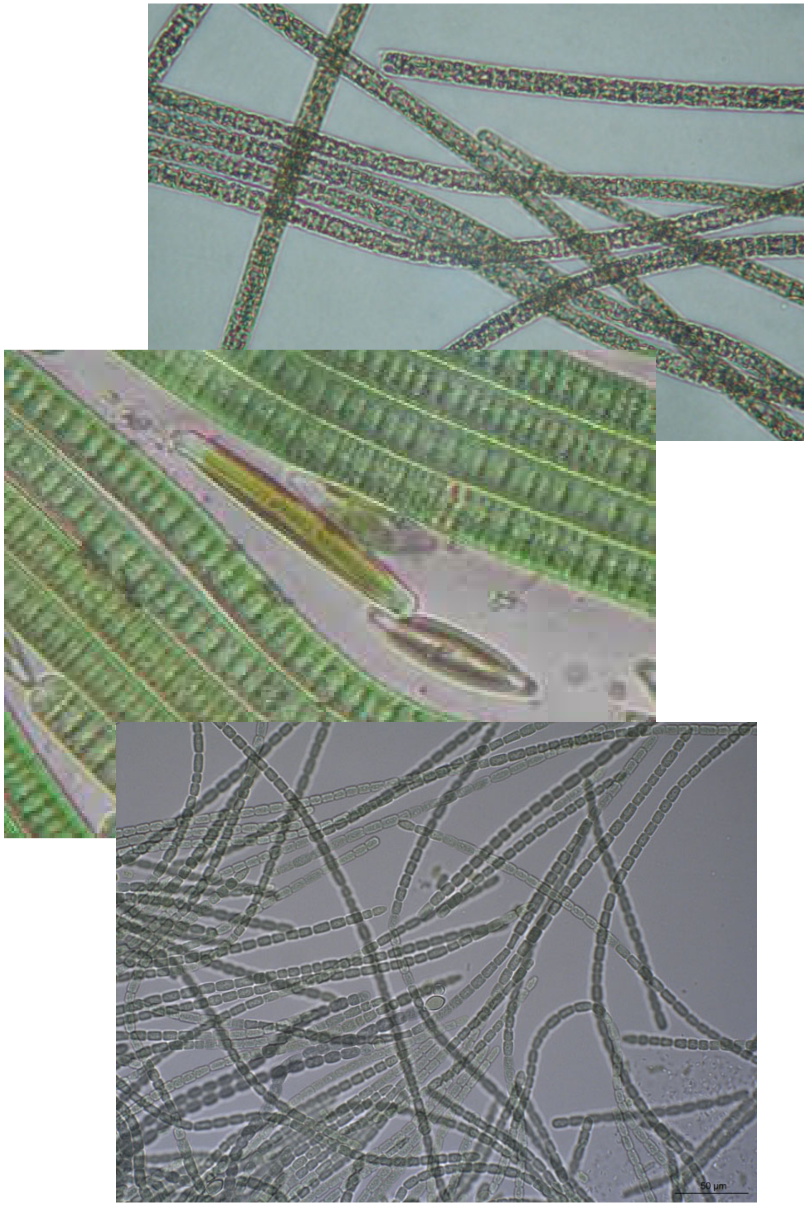
Adaptive Water Resource Management

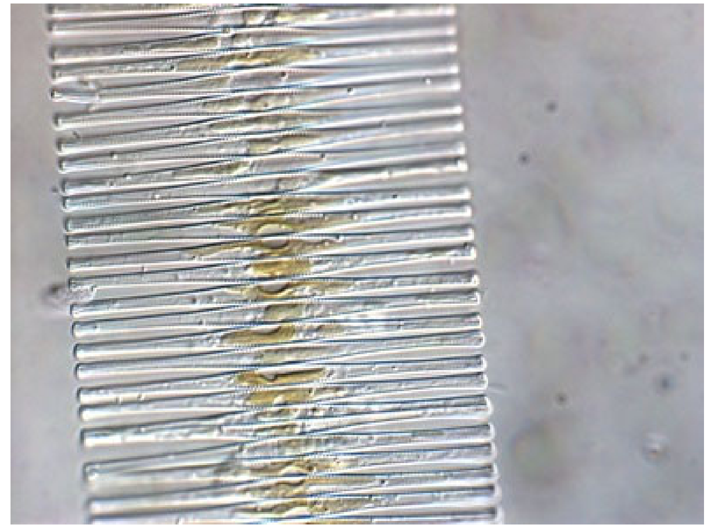
- What is the problem?
- Where is it located?
- What can we do about the problem? Vulnerability? (ACT)
- What is the “trigger”?
- Design treatment. Implement the best option.
- What happened? Monitor. Durability/Efficacy? Non-target species effects?
- What is next?

Background

- **ARJWS - Ongoing taste and odor issues with water (2013-2014)**
- **In-house treatment options (e.g., pre-chlorination, powdered activated carbon) – expensive with limited effectiveness**
- **August 2014 - identified putative T&O producers *Planktothrix*, *Oscillatoria*, and *Anabaena* and the diatoms *Fragilaria* and *Tabellaria***

Planktothrix, *Oscillatoria*, and *Anabaena* and the diatoms *Fragilaria* and *Tabellaria*

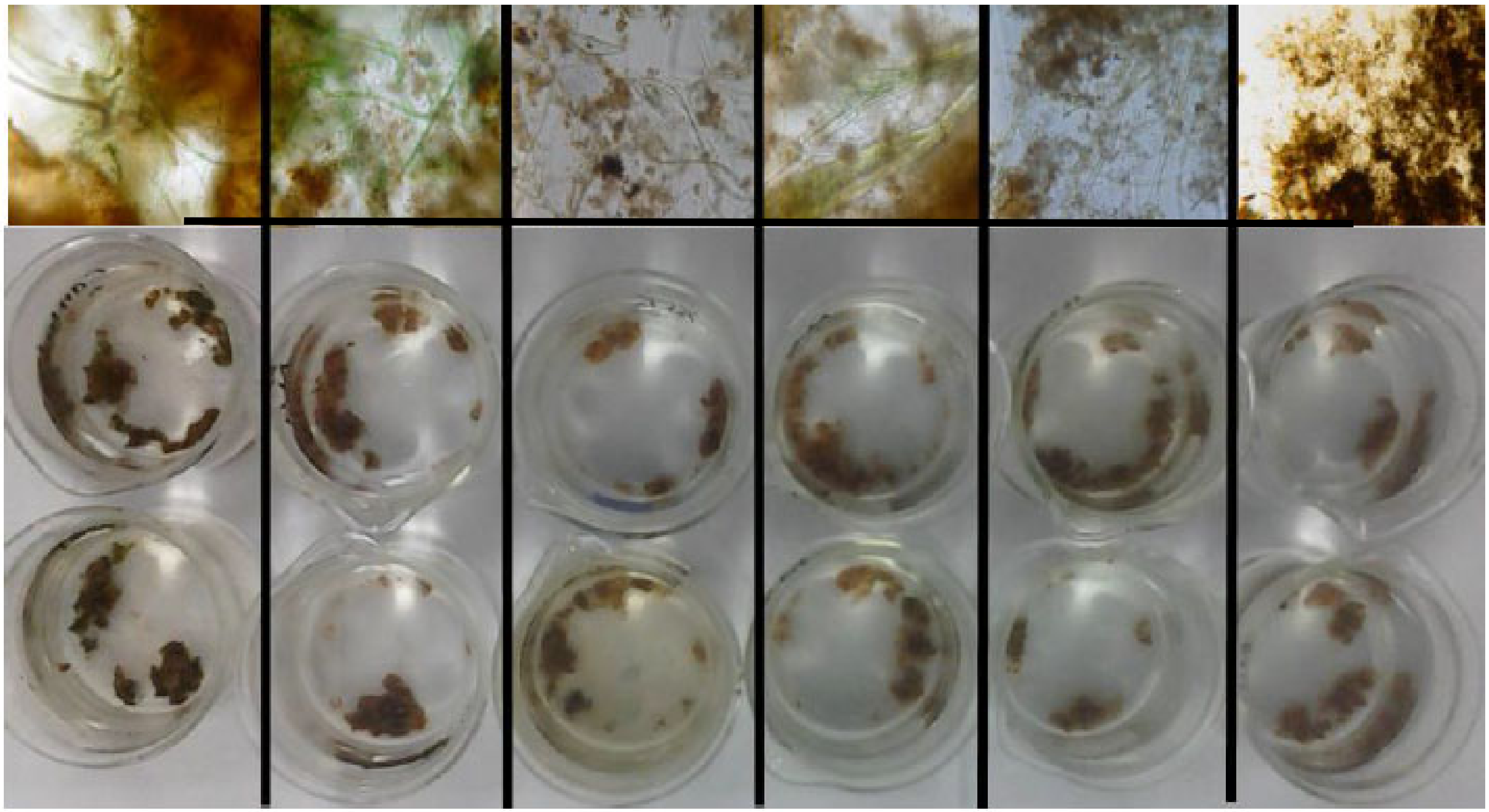




Background

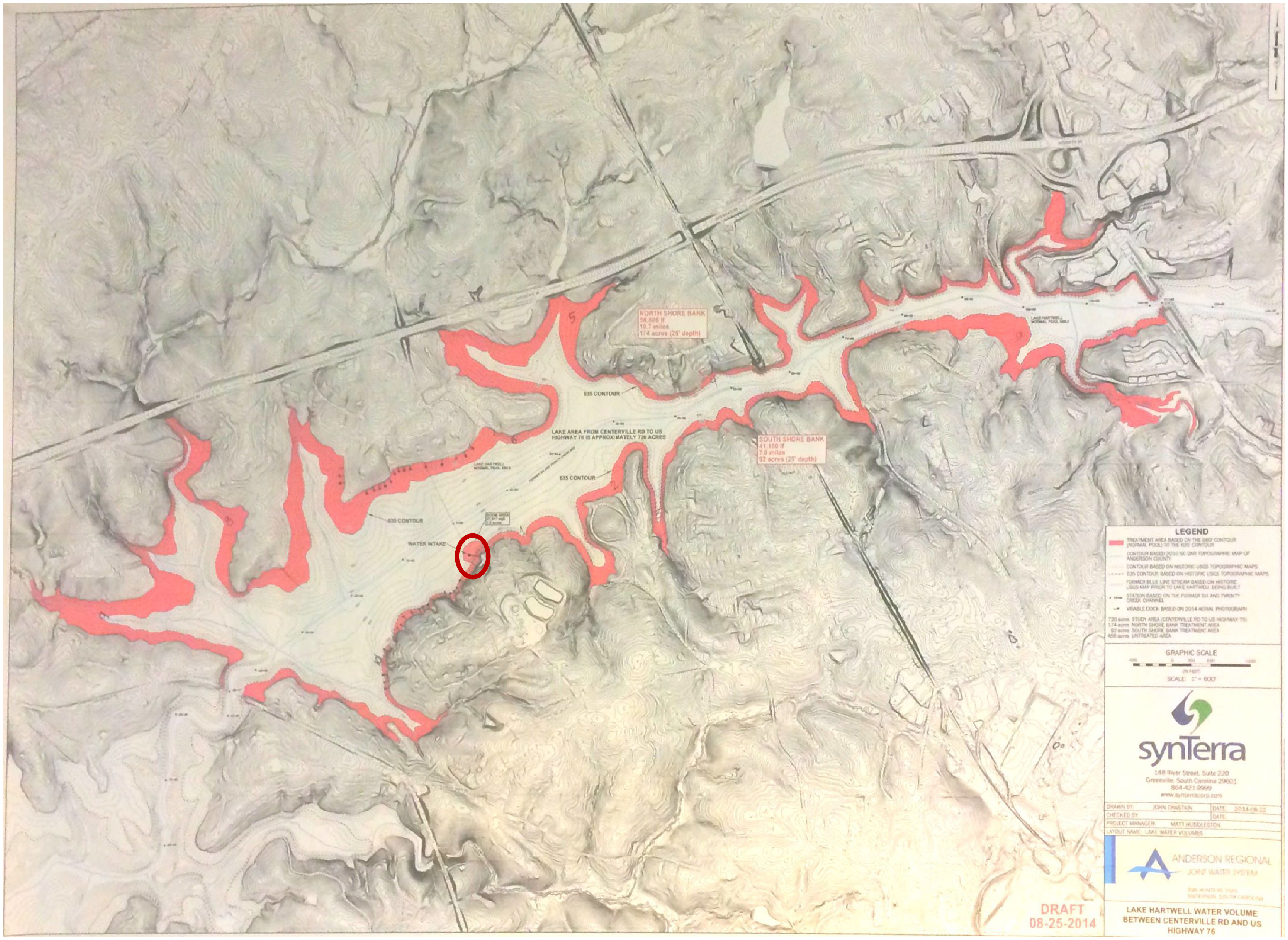
- Conducted Algal Challenge Test
- Prepared plan & bids for Pilot Treatment
- Pilot Treatment - September 4-5, 2014

Laboratory ACT



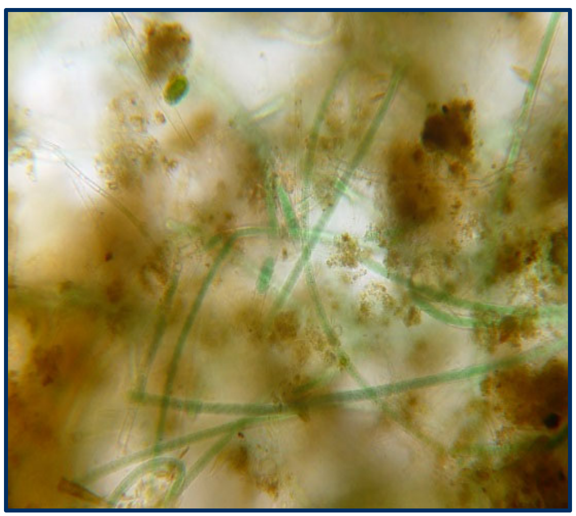
Untreated Control | 1.2 mg Cu as Algimycin®/ g algae | 3.5 mg Cu as Algimycin®/ g algae | 5.8 mg Cu as Algimycin®/ g algae | 8.2 mg Cu as Algimycin®/ g algae | 11.7 mg Cu as Algimycin®/ g algae

Treatment Area

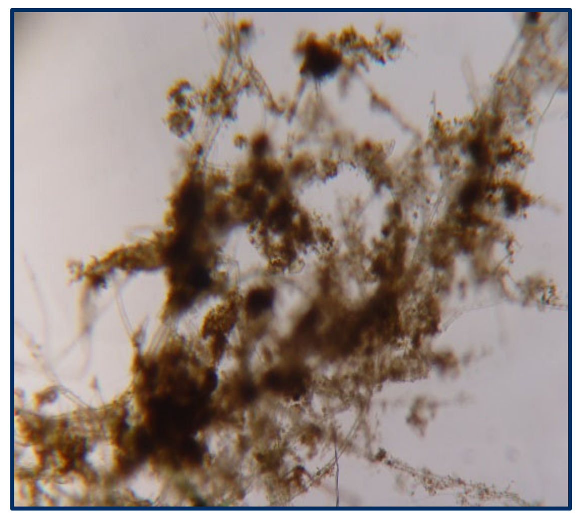


Pretreatment Monitoring

- water and sediment samples
- algae samples
- MIB and geosmin samples



Microscopic View of Algae
Pre-Treatment



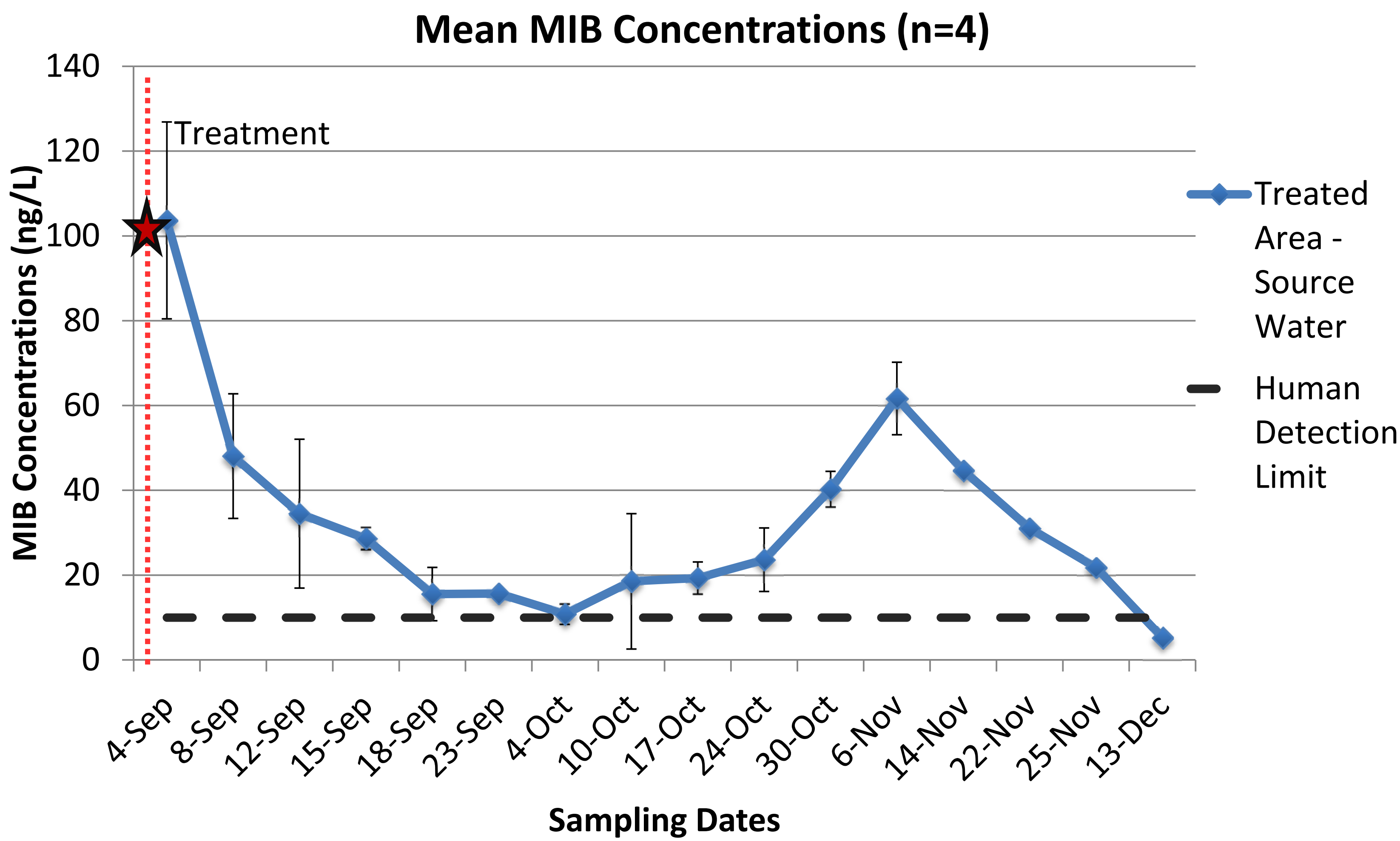
Microscopic View of Algae
Post-Treatment


MERCURY

Algaecide Applications

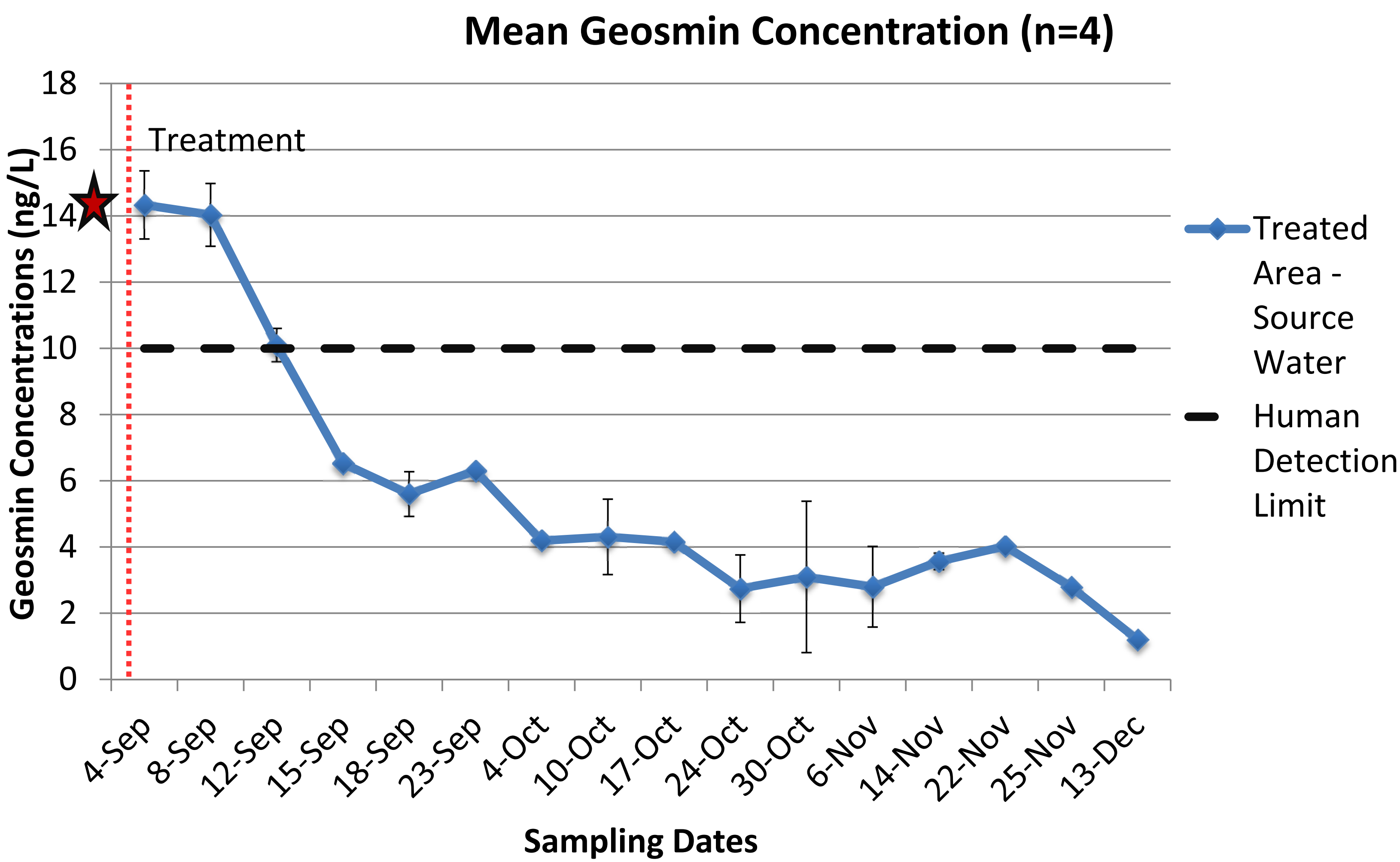
- Chelated Copper – gluconate and citrate (2.66 gallons/ acre-foot)
- Sodium Carbonate Peroxyhydrate (100 pounds per acre-foot)
- Precision Applications
- Bottom 2 feet – littoral zone
- Based on flow study and contour mapping

Results



Mean MIB Concentrations (n=4)
MIB Concentrations (ng/L)
140
120
100
80
60
40
20
0
Treatment
4-Sep
8-Sep
12-Sep
15-Sep
18-Sep
23-Sep
4-Oct
10-Oct
17-Oct
24-Oct
30-Oct
6-Nov
14-Nov
22-Nov
25-Nov
13-Dec
Sampling Dates
Treated Area - Source Water
Human Detection Limit

Results



Mean Geosmin Concentration (n=4)
Geosmin Concentrations (ng/L)
18
16
14
12
10
8
6
4
2
0
Treatment
4-Sep
8-Sep
12-Sep
15-Sep
18-Sep
23-Sep
4-Oct
10-Oct
17-Oct
24-Oct
30-Oct
6-Nov
14-Nov
22-Nov
25-Nov
13-Dec
Sampling Dates
Treated Area - Source Water
Human Detection Limit

Experiments with non-target organisms to understand site-specific potential effects on fish and invertebrates in Hartwell Lake

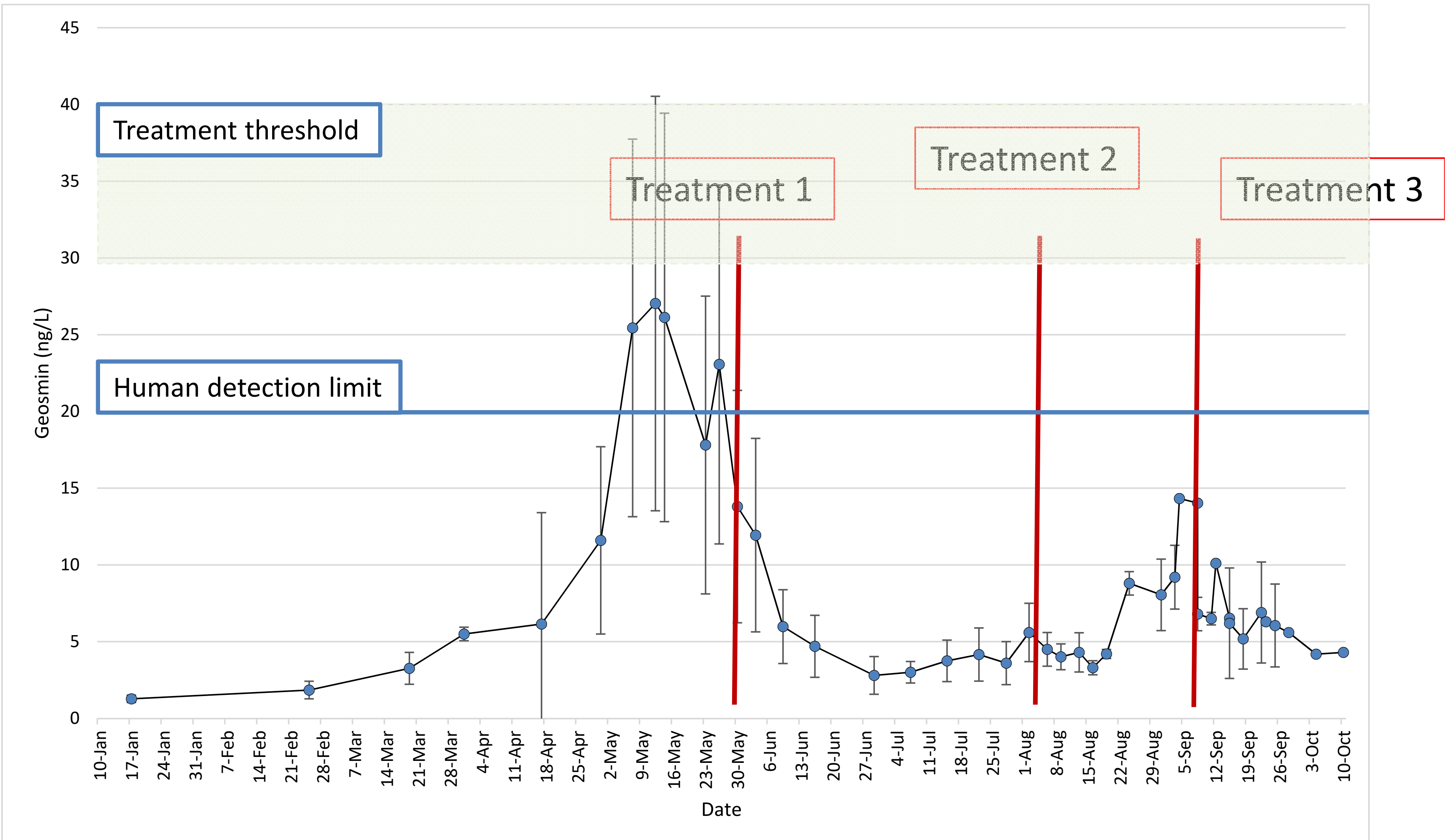
Hyalella azteca

Chironomus dilutus

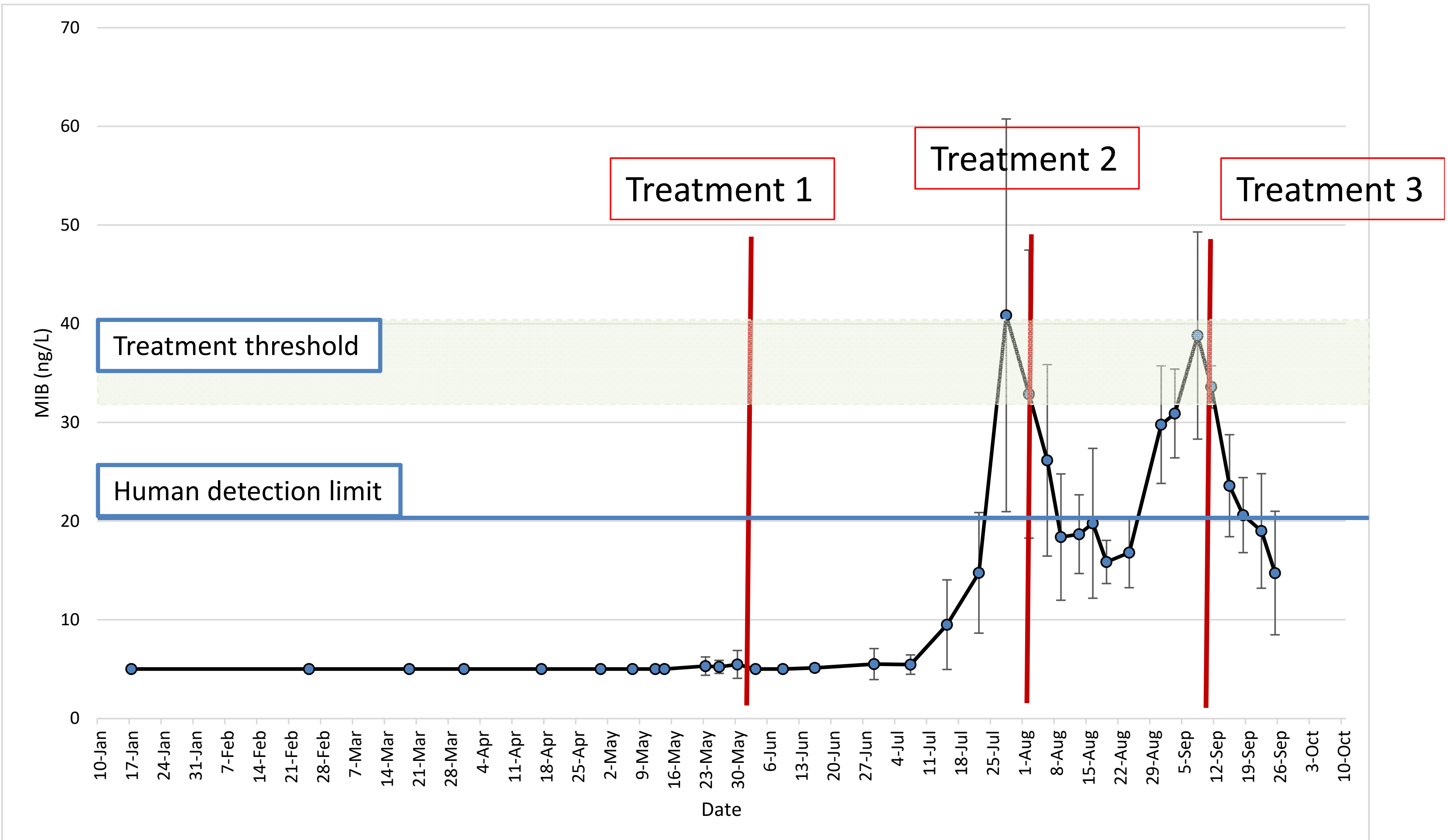
Pimephales promelas

- Laboratory experiments with algaecides in site waters and sediments.
- Measure exposure:response relationships.

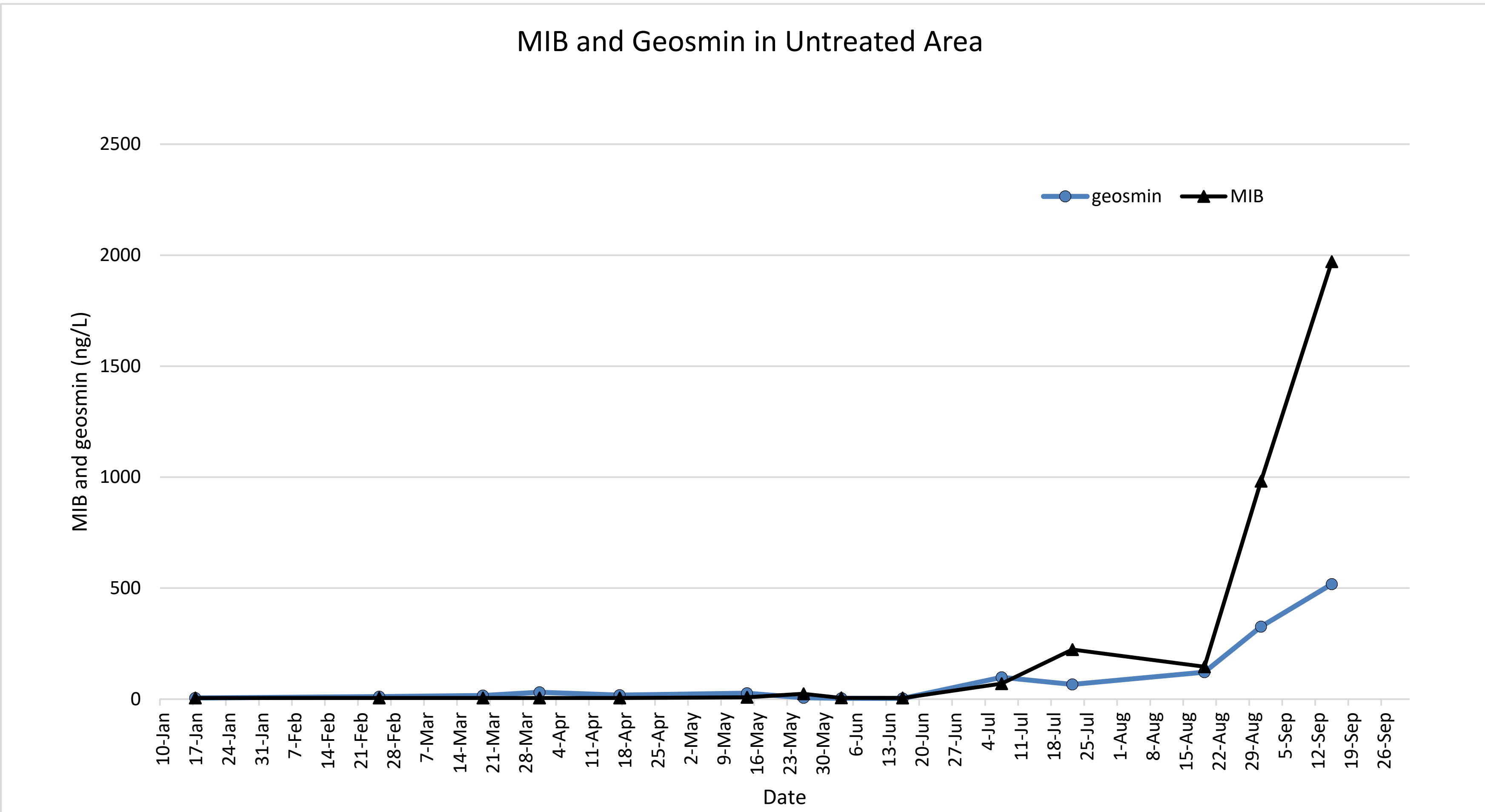
Results of 2015 Treatments: Geosmin Concentrations



Results of 2015 Treatments: MIB Concentrations



MIB and geosmin concentrations measured in the untreated area of the Six and Twenty cove January 17, 2015 – September 25, 2015.




NO BOATS
WITHIN
100 FEET

Conclusions

- Management of benthic algae producing MIB and geosmin in source water is a viable option.
- Growth of target algae can be controlled with minimal to no impacts on non-target species.
- Adaptive water resource management is the key.
- Approach is effective and cost effective.

Thank you!