Cyanobacteria Presentation

Elizabeth Crafton, PhD, Senior Principal Scientist, Hazen

Bloom Fighers: Building a Statewide Monitoring and Response Protocol to Defend against Cyanotoxins in New Hampshire

Elizabeth Crafton, PhD

Outline

- *Cyanobacteria and Cyanotoxin Background*
- *NHDES Treatment Optimization Plan Project*
  - **Source Water**
  - **Treatment**
- *Conclusions*

Background: Cyanobacteria and Cyanotoxins

Introduction to Cyanobacteria

Six Facts about Cyanobacteria

01

NOT algae

Prokaryotic organisms, oxygenic photosynthesis

02

Product Cyanotoxins

Cyanobacteria produce several types of cyanotoxins, four types are tracked

03

Source of HABs

Cyanobacteria dominate vast majority of freshwater HABs

04

Thrive in Extremes

Cyanobacteria can thrive in a wide range of conditions and habitats

05

Sign of Imbalance

Cyanobacteria dominance is a sign of an imbalance ecosystems causes HABs

06

Visible Scums are Not Needed for Risk

Cyanotoxins can occur without a visible bloom, high concentration can occur at low cell density

Cyanobacteria Impact on Raw Water Quality and WTP

Raw Water Quality

- Large biomass accumulation
- Taste and odor events
- Cyanotoxin occurrence
- Depleted oxygen
- Release of Fe and Mn
- Impact to fisheries
- Contribution of organic carbon
- Accumulation of organics
- Impact on monitoring equipment

WTP Impacts

- Clogging of intake screens
- Increased oxidant demand
- Increased coagulant demand
- Reduced filter performance
- Issues dewatering solids
- Cyanotoxin breakthrough conventional treatment
- Cell lysis during pre-oxidation
- pH adjustment impact on cyanotoxin removal
- Increased DBP formation

Overview of Common Cyanotoxins

Naturally occurring toxins produced by cyanobacteria

Common Freshwater Cyanotoxins (US)

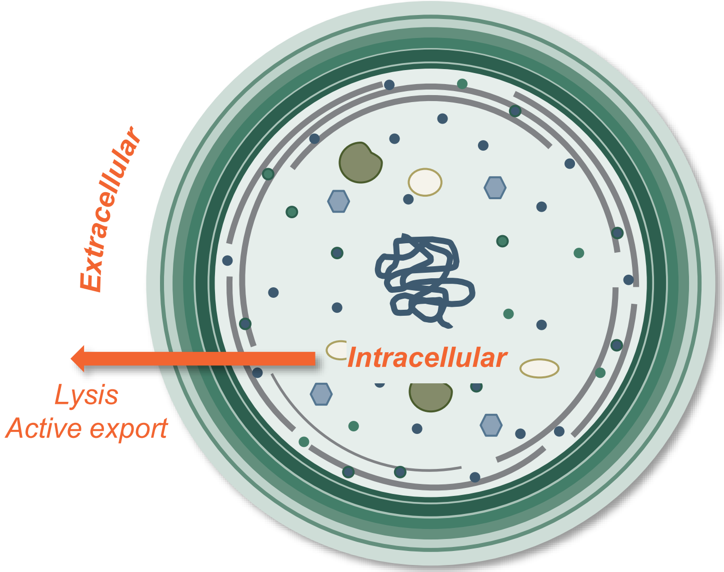
Cyanotoxin	Congeners	Organ(s) Toxicity	Symptoms
Microcystins	270 congeners	Liver (majority), heart, kidneys, nervous system, GI	GI symptoms, stomach pain, nausea, vomiting, diarrhea, severe headache, fever
Cylindrospermopsin	3 congeners	Liver, kidneys, thymus, heart	Fever, headache, vomiting, bloody diarrhea, hepatomegaly, kidney damage
Saxitoxin	57 congeners	Neurons	Nausea, vomiting, floating sensation, headache, muscle weakness, paresthesia, vertigo
Anatoxins	4 congeners	Neurons, neuromuscular junctions, nervous system	Loss of coordination, muscular fasciculation, convulsions, tremors, muscle weakness, shock, death via respiratory paralysis
BMAA		Disruption of protein folding	Motor neuron dysfunction, ALS/PDC symptoms

Hepatotoxin
Neurotoxin

Intracellular vs. Extracellular Cyanotoxins

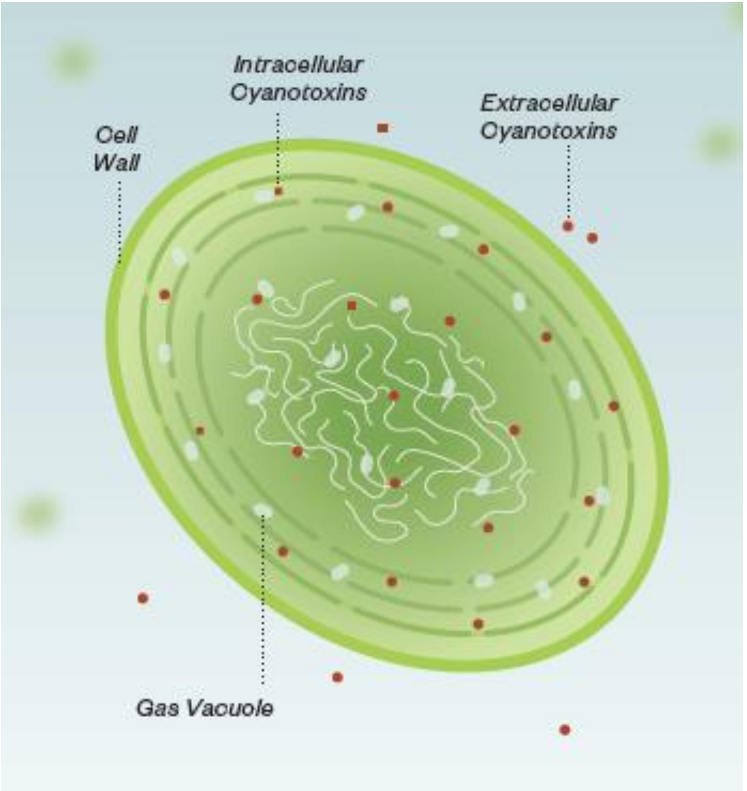
Intracellular accumulation or active release of cyanotoxins

- Cyanotoxins can be intracellular or extracellular
  - Intracellular is inside the cell
  - Extracellular is outside the cell
- Release of intracellular cyanotoxins
  - Lysis or active export
  - Quorum sensing
- Implications for treatment approaches



Cyanobacteria cell

Treatment: Physical Removal of Cyanobacterial Cells



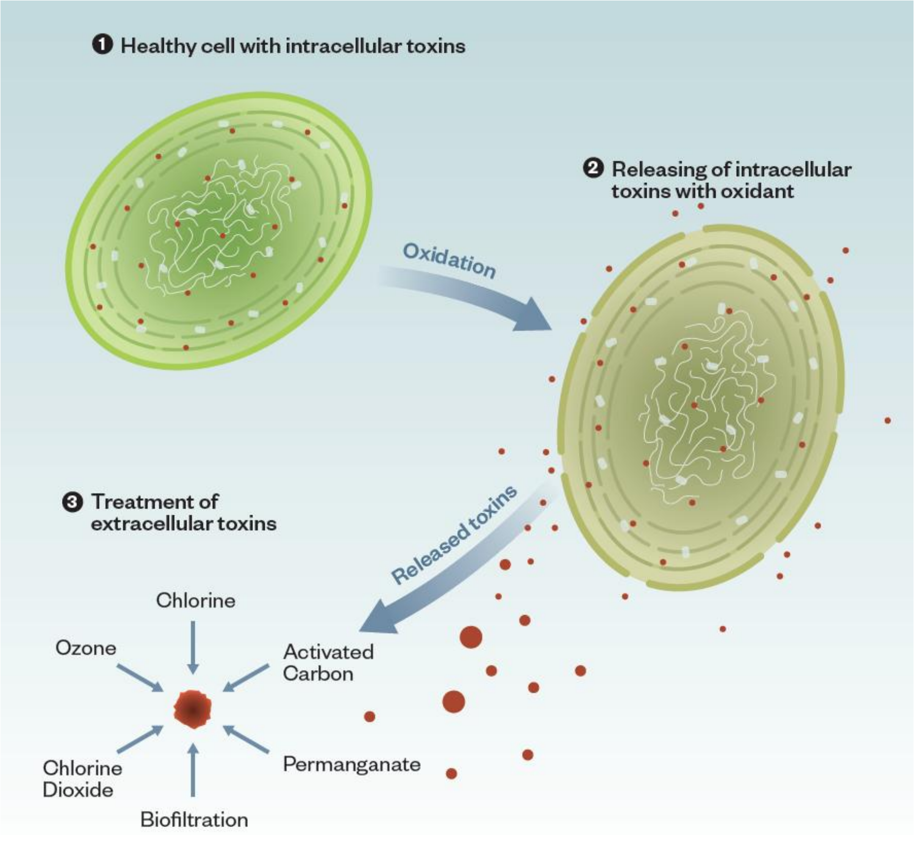
Wert et al. 2019. Utility Guidance Manual for the Management of Intracellular Cyanotoxins. WRF, Denver, CO.

Efficacy of Physical-Chemical Processes

Cyanobacteria / Cyanotoxin	Clarification		Filtration			Membranes		Adsorption	
	Conventional	***DAF***	***Direct Filtration***	***Bank Filtration***	***BAF***	***RO/NF***	***MF/UF***	***PAC***	***GAC***
Cyanobacterial Cell Removal	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Ineffective	Likely
Microcystin	Ineffective	Ineffective	Ineffective	Possible	Possible	Effective	Ineffective	Varies	Varies
Cylindrospermopsin	Ineffective	Ineffective	Ineffective	Possible	Possible	Effective	Ineffective	Varies	Varies
Anatoxin A	Ineffective	Ineffective	Ineffective	Possible	Possible	Effective	Ineffective	Varies	Varies
Saxitoxin	Ineffective	Ineffective	Ineffective	Possible	Possible	Effective	Ineffective	Varies	Varies

Adapted from Hazen Algae White Paper (Summer, 2015) and *Adams, C. (2013) "Tailored Treatment of Cyanotoxins and Cyanobacteria: Oxidation, Adsorption and Other Technologies," WQTC 2013 Workshop.*

Toxin "Release and Treat" Approach



- Once out of the cell, toxins can be treated
- Extensive research has been performed on the rates of toxin degradation by various oxidants

Wert et al. 2019. Utility Guidance Manual for the Management of Intracellular Cyanotoxins. WRF, Denver, CO.

Degradation by Disinfection and/or Oxidation Processes

Oxidant	Microcystins	Cylindro-spermopsin	Anatoxin A	Saxitoxins
Free chlorine	pH	pH	Slow/no oxidation	
Monochloramine	Slow/no oxidation			
Chlorine dioxide	Slow/no oxidation			
Permanganate				
Ozone		pH	pH	
Hydroxyl radical				?
UV	High doses	High doses	High doses	?

Wert et al. 2019. Utility Guidance Manual for the Management of Intracellular Cyanotoxins. WRF, Denver, CO.

Treatment Optimization Plan Development

Project Overview

Background

- NH has had increasing HAB events, record events seen in 2024
- HABs strain water treatment infrastructure
- NH has developed new initiatives for cyanobacteria management and watershed protection strategies
- Project sets foundation for an actionable and adaptive cyanoHAB management strategy
- 13 NH PWSs included in project with varying bloom history

Overall project workplan

Identify and Review
- Data collection and analysis
- Site visits and understanding of limitations

Identify HAB Risk

Develop source water management strategies

Confirm cyanotoxin treatment capabilities and treatment response

Develop:
- Statewide Protocol
- Individual Facility Optimization Plans

Statewide Plan

- *Statewide plan developed as guidance document*

- *Contains background and how-to defining monitoring needs, management strategies, and treatment considerations*

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New Hampshire Statewide Cyanobacteria Water Treatment Optimization Plan

Draft Interim Plan
May 1, 2026

Cyanobacteria Treatment Optimization Plan Outline

Source Water:

Reservoir Risk Assessment

Review historical data to inform source water risk

Reservoir Monitoring

Implement risk-informed source water monitoring plan

Watershed Management

Select strategies based on time-frame and water quality goals/limitations

Treatment:

Cyanotoxin event

Oxidize toxins

Cyanobacteria event

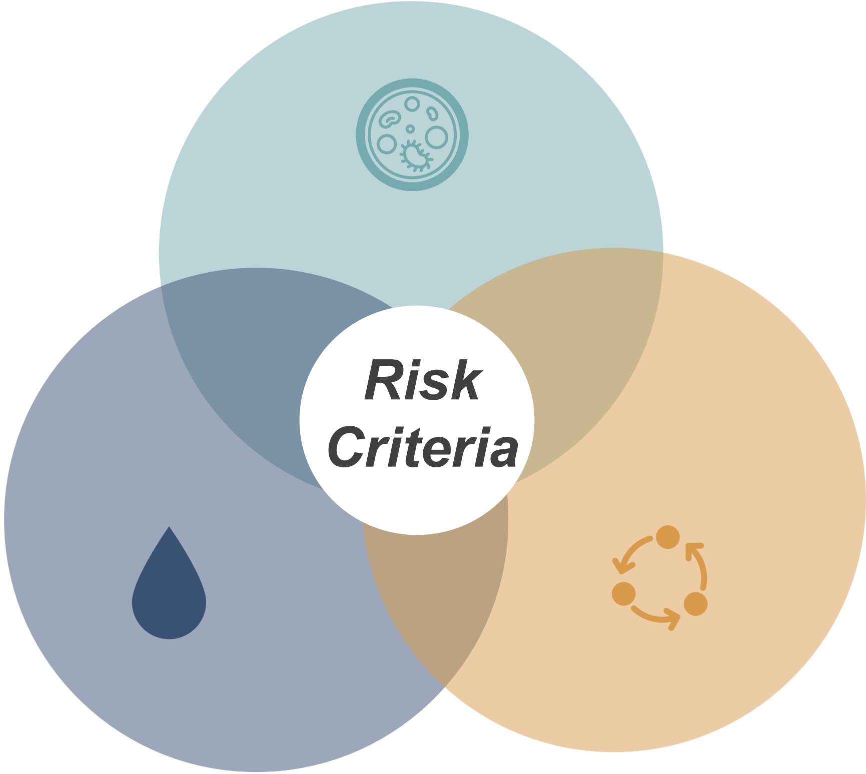
Lyse and/or remove cells (treatment-based)

Cyanotoxin + Cyanobacteria event

Oxidize toxins, lyse and remove cells

Source Water Monitoring

HAB Risk

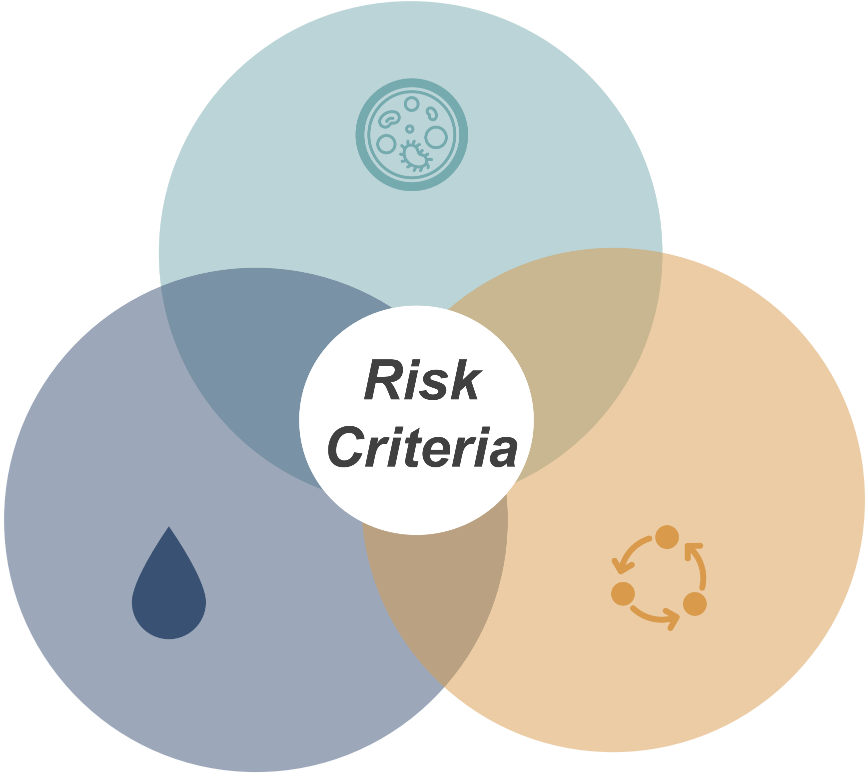


What is a source water monitoring risk criteria?

- Used to determine source water susceptibility to HABs and determine frequency of required monitoring parameters

Increased source water monitoring helps to:

- Protect public health and safety
- Establish baseline conditions
- Prevent cyanotoxin breakthrough in finished drinking water
- Communicate with the public



Water Quality

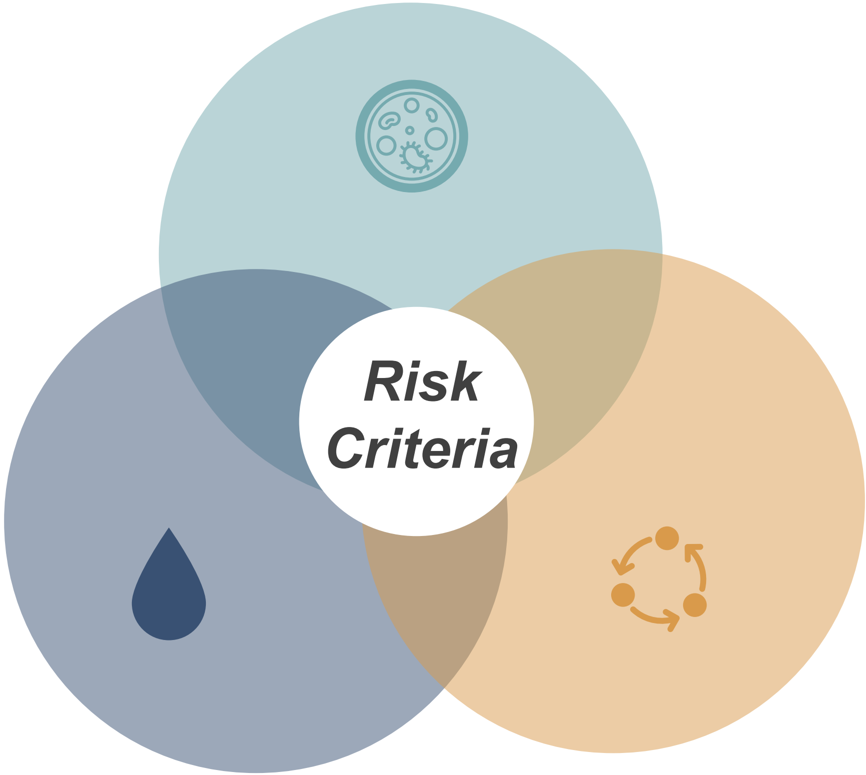
- Eutrophication (TSI-TP)
- Production (TSI-Chlorophyll-a)
- Water Temperature
- Internal and External Nutrient Loading
- Phycocyanin (Lake-Specific Average Above or Below Statewide Average)
- Data Quantity and Representation

Historical Events

- Akinetes Presence
- HAB Occurrences
- Cyanotoxins

Morphology

- Max Depth, Perimeter/ Surface Area



Water Quality

- Eutrophication (TSI-TP)
- Production (TSI-Chlorophyll-a)
- Water Temperature
- Internal and External Nutrient Loading
- **Phycocyanin (Lake-Specific Average Above or Below Statewide Average)**
- **Data Quantity and Representation**

Historical Events

- **Akinetes Presence**
- **HAB Occurrences**
- Cyanotoxins

Morphology

- **Max Depth, Perimeter/ Surface Area**

If data is not available, assumes moderate risk (3)

Summary of Risk Methodology

Criteria	Risk Category				
Description	**1**	**2**	**3**	**4**	**5**
Eutrophication (TSI-TP)		Oligotrophic (TSI <40)	Mesotrophic (TSI 40-50)	Eutrophic (TSI 50-60)	Hypereutrophic (TSI >60)
Production (TSI-Chla)		Oligotrophic (TSI <40)	Mesotrophic (TSI 40-50)	Eutrophic (TSI 50-60)	Hypereutrophic (TSI >60)
Water Temperature	Short period of germination temperatures		Moderate period of germination temperatures		Long period of germination temperatures
Internal and External Nutrient Loading	No significant internal or external loading		Significant loading from either internal or external sources		Significant loading from both internal and external sources
Data Quantity and Representation	Comprehensive Monitoring		Passive Monitoring		No Monitoring
Akinetes presence	No				Yes
Phycocyanin (Lake-Specific Average Above or Below Statewide Average)				Below	Above
HABs Occurrences	No previously known occurrences	1 previous occurrence	2 previous occurrences	3+ previous occurrences	Annual occurrences
Cyanotoxins	No previously known detections		Infrequent, low concentrations		Frequent, high concentrations
Max Depth, Perimeter/Surface Area		Depth > 10 m; circularity > 0.5	Depth > 10 m; circularity <= 0.5	Depth ≤ 10 m; circularity > 0.5	Depth <= 10 m; circularity <= 0.5

Summary of Risk-Based Monitoring

Risk	Baseline Methods	Frequency	Triggered Methods
High	Sonde/Probe Microscopy	Weekly	qPCR ELISA LC-MS/MS
Moderate	Sonde/Probe Microscopy	2x/month	qPCR ELISA LC-MS/MS
Low	Sonde/Probe Visual Observation*	Monthly	Microscopy qPCR ELISA LC-MS/MS

Monitoring Frequency
Spatial Coverage

**visual observations should be done weekly; defined as lake surveillance without samples, visual observation should be logged with each sampling event*

Summary of Methods

Biomass

Cyanotoxins

Microscopy

Pigments

FlowCam

Remote Sensing

qPCR

Test Strip

ELISA

LC-MS/MS Methods

Cyanotoxin Monitoring Flowchart- Moderate and High Risk

Monitoring framework for cyanotoxins to ensure public health and safety

Parameter	Early Warning Threshold
Cell Count	2,000 cells/mL
Phycocyanin	2 µg/L
Chlorophyll	2.5 µg/L

qPCR Genetic Screening

Bi-monthly or Weekly qPCR screening as part of baseline monitoring

Sonde/Probe Enumeration

Within Baseline

Continue baseline monitoring

Above Early Warning

ELISA Toxin Screening qPCR

No Detection

Return to baseline monitoring after 2 consecutive negative results

Above Raw Water Threshold

Collect paired samples 3x week until below raw water threshold for 2 consecutive samples*

Detection

Collect paired samples weekly until 2 consecutive negative results (raw)*

ELISA – Raw Water
LC-MS/MS – Finished Water

Below Finished Water Threshold

Monitor paired daily until 2 consecutive negative results (finished)*

Above Finished Water Threshold

Resample twice: (1) within 24 hours (2) 48 hours

If results are above early warning level Contact NHDES

Initiate In-Plant Optimization

*Scum forming blooms that are observed will be simultaneously sampled for qPCR and ELISA
*Test strip can be done with qPCR for near-term results

Cyanotoxin Treatment Flowchart

Raw Water Toxin Detection

Can the current treatment processes effectively reduce the cyanotoxin concentrations?

Cyanotoxin Treatment Threshold:

The cyanotoxin concentration which can always be effectively treated under typical plant operating conditions

Cyanotoxin	Target Effluent Cyanotoxin Concentration (µg/L)
Anatoxin-a	0.3
Cylindrospermopsin	0.7
Microcystin	0.3
Microcystin-mix	0.3

$$Minimum\ CT = \frac{Min\ Tank\ Volume\ (gal) * Baffling\ Factor}{95th\ Percentile\ Flow\ \left(\frac{gal}{min}\right)} * 5th\ Percentile\ Oxidant\ Residual\ \left(\frac{mg}{L}\right)$$

Identify worse case ‘summer’ pH and Temperature (April-November as Default)

Treatment Reference Sheet

Cyanobacteria Treatment Reference Sheet:

In-Plant Treatment Adjustments to Meet Cyanotoxin Removal

If the current CT value is insufficient for reducing cyanotoxins below the threshold value, one or more treatment adjustments can be made:

Recommended Order: (1) Increase Disinfectant Concentration, (2) Add a Pre-Oxidant and/or Adjust pH

Cyanotoxin Treatment Reference Sheet:

In-Plant Treatment Adjustments to Meet Cyanotoxin Removal

If the current CT value is insufficient for reducing cyanotoxins below the threshold value, one or more treatment adjustments can be made:

Recommended Order: (1) Increase Disinfectant Concentration, (2) Add a Pre-Oxidant and/or Adjust pH

Increase Disinfectant Concentration

Directly increases the CT.

Important Considerations:

Regulatory Chlorine Residual Limits:

- Chlorine MRDL = 4.0 mg/L as Cl_2
- Chloramine MRDL = 4.0 mg/L as Cl_2
- Chlorine Dioxide MRDL = 0.8 mg/L as ClO_2

Increases formation of Disinfectant Byproducts

Aesthetic-Related Complaints (Taste + Odor)

Add a Pre-Oxidant

Provides an additional CT zone

Important Considerations:

Many systems do not have this capability

Increases formation of Disinfectant Byproducts

Downstream treatment related issues with this- i.e. filters/membranes

Adjust pH

Higher cyanotoxin removal at lower pHs for chlorine and at higher pHs for ozone.

Important Considerations:

Do NOT adjust pH outside typical operating range.

Many systems do not have this capability

Corrosion Concerns:

- Increased Lead + Copper Solubility at lower pHs
- Destabilization of pre-existing scale

Increase Tank Volume (Clearwell, Contact Basin, Etc.)

Larger tank volumes, at the same flowrate, result in higher detention times. This will increase the CT.

Important Considerations:

Increases formation of Disinfectant Byproducts

Decrease Plant Flowrate

A lower plant flowrate, at the same tank volume, will result in higher detention times. This will increase the CT.

Important Considerations:

Increases formation of Disinfectant Byproducts

Other Potential Options:

Change Disinfectant:

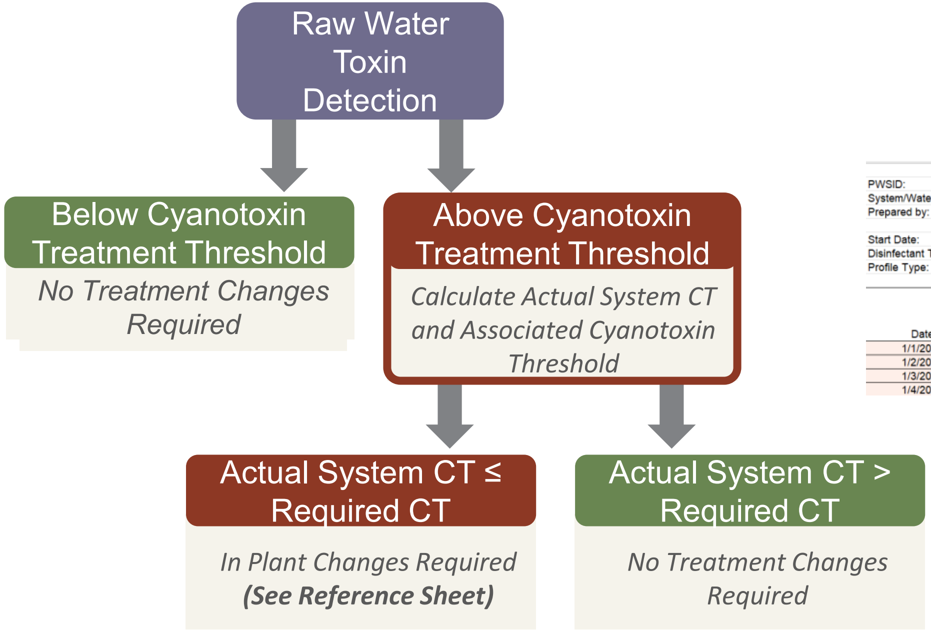
Changing a pre-oxidant chemical could provide additional protection to different cyanotoxins

Powder Activated Carbon (PAC):

Removal of cyanotoxin

$$CT = \frac{Tank\ Volume\ [mg/L] * Baffling\ Factor}{Flowrate\ [\frac{L}{min}]} * Disinifection\ Residual\ [\frac{mg}{L}]$$

Cyanotoxin Treatment Flowchart



Determine if Actual CT Values are Effective at Treating Toxins using the CT Reporting Tool

PWSID:
System/Water Source:
Prepared by:

Start Date:
Disinfectant Type: Free Chlorine
Profile Type: Microcystin-Mix

Template based on EPA Disinfection Profiling and Benchmarking technical guidance manual, Appendix C
[Disinfection Profiling and Benchmarking: Technical Guidance]

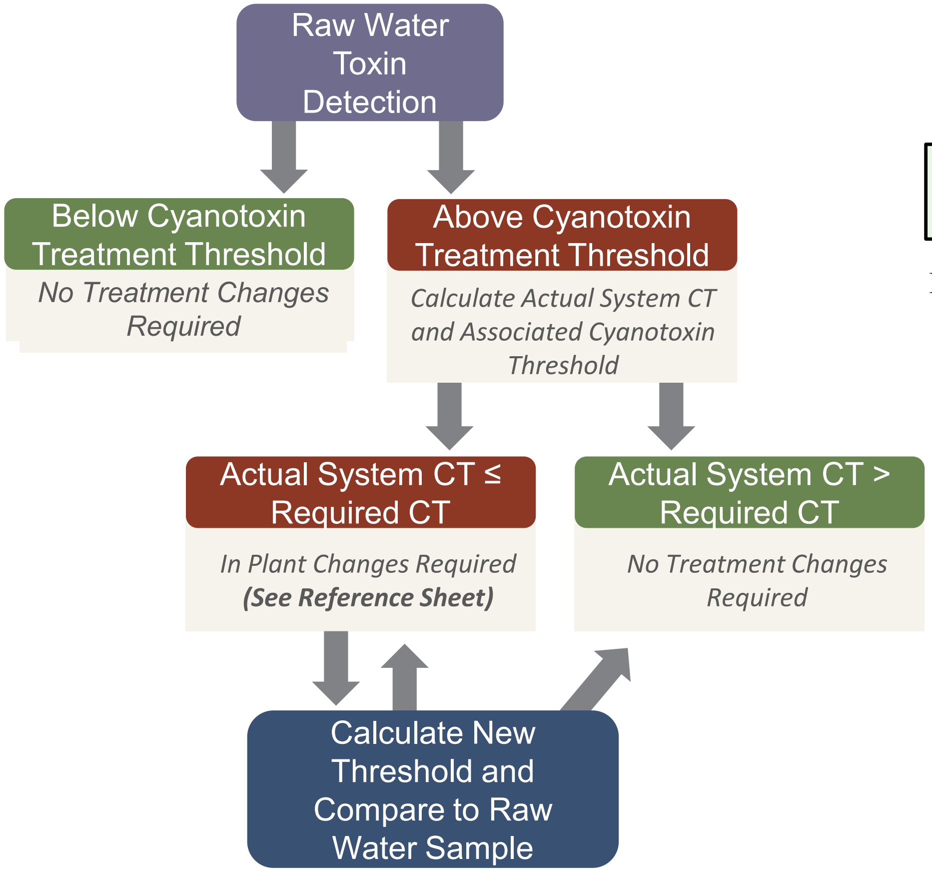
= user entry
= calculated

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

Date	Residual Disinfectant Concentration, mg/L	pH	Water Temperature (°C)	Peak Hourly Flow Through Disinfection Zone, gpm	Disinfection Zone Volume, gal	Baffling Factor	Disinfection Contact Time, min	CT, min-mg/L	Log Inactivation*	Breakthrough Concentration, µg/L
1/1/2025	1	8	12	700	100000	0.5	71.43	71.43	8.9	3.38
1/2/2025	1	7.9	13	800	100000	0.5	62.50	62.50	1.4	3.47
1/3/2025	1	8.1	12.2	750	100000	0.5	66.67	66.67	1.3	2.18
1/4/2025	1	8.3	14.1	800	100000	0.5	62.50	62.50	1.4	1.28

$$\text{Actual } CT = \frac{Tank\ Volume\ (gal) * Baffling\ Factor}{Flow\ \left(\frac{gal}{min}\right)} * Oxidant\ Residual\ \left(\frac{mg}{L}\right)$$

Cyanotoxin Treatment Flowchart



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If the current CT value is insufficient for reducing cyanotoxins below the threshold value, one or more treatment adjustments can be made:

Recommended Order: (1) Increase Disinfectant Concentration, (2) Add a Pre-Oxidant and/or Adjust pH

CT Reporting Tool is being developed to calculate total cyanotoxin treatment capabilities with two zones

Cyanobacteria Treatment Flowchart

Raw Water Cyanobacteria Detection

Cells present but no toxins detected

→

Add a pre-oxidant

Benefits vary based on oxidant and cyanobacteria type. Do not use pre-oxidant if sheath-forming benthic organism identified. If using DAF, do not pre-oxidize if benthic organism identified

→

Optimize Coagulation

NOM drives coagulant dosing and organic material expected to increase. Increasing doses are likely to be required. Perform jar tests, streaming current, zeta if available to confirm dose needs

→

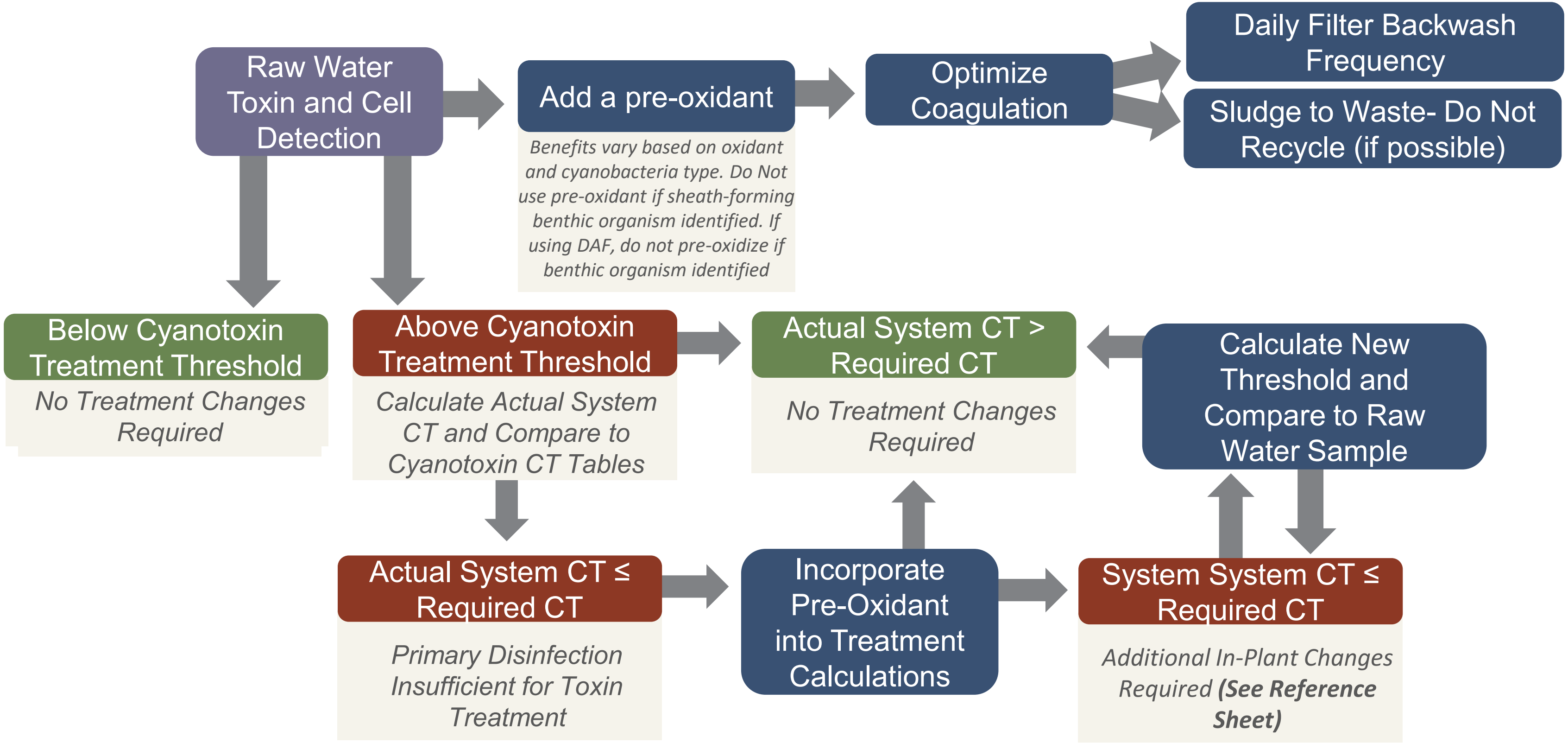
Daily Filter Backwash Frequency

Sludge and Backwash to Waste - Do Not Recycle (if possible)

Avoid solids build up to prevent biomass growth and risk of additional issues

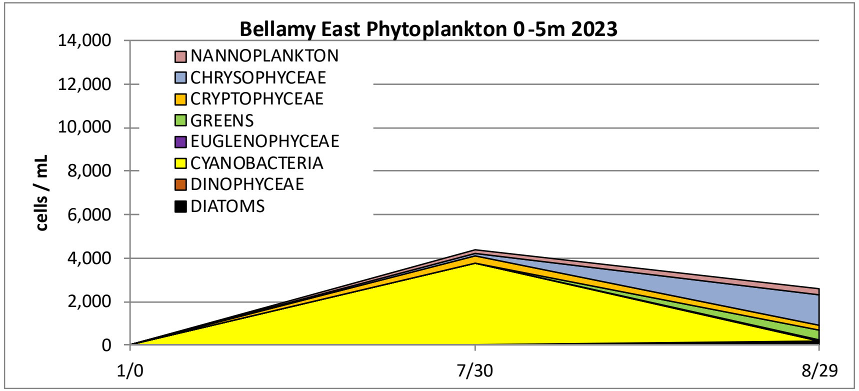
Free Chlorine > Permanganate ~ Chlorine Dioxide

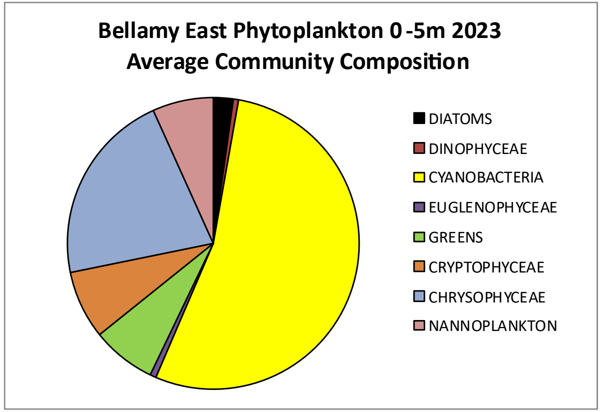
Cyanotoxin and Cyanobacteria Flowchart

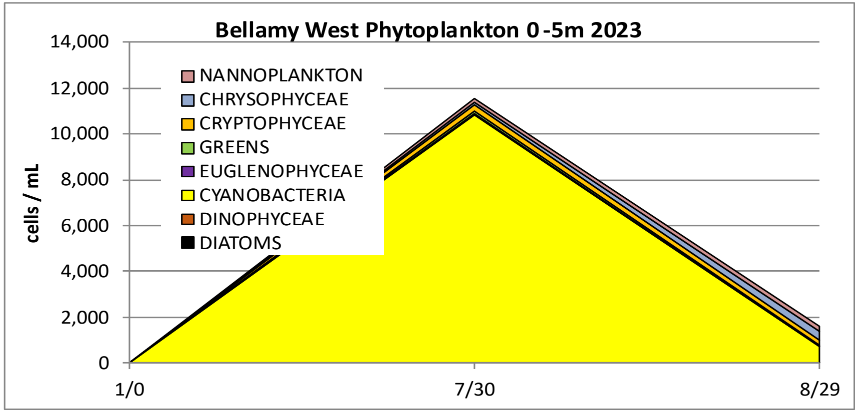


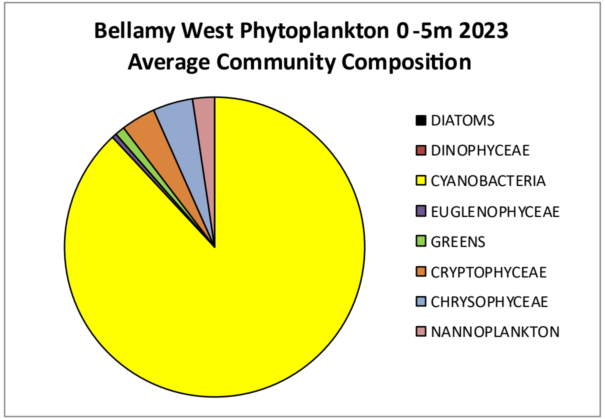
Bellamy Reservoir

City of Portsmouth: Bellamy Reservoir Snapshot









HAB Source Water Risk Scoring for Bellamy

Risk Criteria	Master Data	Score
Data Quantity and Representation	Representative; No monitoring	3
Phycocyanin (PWS Average Above/Below Statewide Average 3.57 µg/L)	Below (1.61 µg/L)	4
Akinetes Presence	Present	5
Historical HAB Occurrences	2 previous occurrences	4
Morphology (Max Depth, Perimeter/Surface Area)	Depth= 9.1 M; Circularity = 0.10	3
Risk Score		20
Total Possible Score		25
Risk Tier		High

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Raw Water Concentration for Cyanotoxins

Cyanotoxin	Threshold Concentration (µg/L)
Anatoxin	0.3
Cylindrospermopsin	> 1000
Microcystin	3.8
Microcystin-mix	7.7

Source Water Management

Source Water Monitoring and Management

Harmful algal blooms (HABs) are a persistent and recurring issue for water bodies

PWSs are responsible for monitoring and managing bloom impacts

Management approaches include:

- **Reactive: responding after blooms occur**
- **Preventative: reducing conditions that promote blooms**

Without management, blooms tend to:

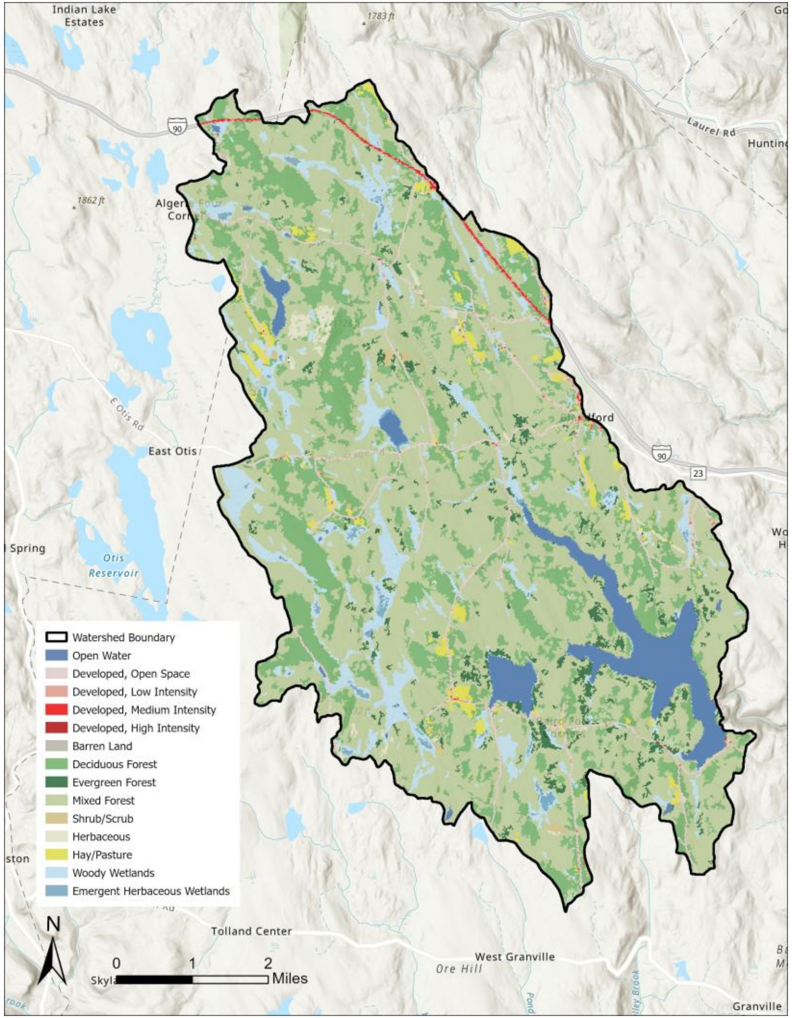
- **Occur more frequently**
- **Become more severe**
- **Persist for longer durations**
- **Jeopardizes future water quality**

Cyanobacteria produce akinetes (dormant resting cells), enabling seasonal recurrence

Excess nutrients (e.g., nitrogen and phosphorus) build up over time, fueling bloom growth

Watershed Management

- In-situ strategies are temporary without addressing watershed loads
- Common culprits:
  - **Wastewater treatment discharges**
  - **Agricultural runoff**
  - **Impervious surfaces**
  - **Septic systems**
- Monitoring is key to understanding watershed loads
  - **Streams monitoring**
  - **Reservoir influent monitoring and modeling**
  - **Remote sensing**
- Long-term approach



Overview of Common Mechanical Control Methods

Strategy	Strengths	Limitations	Considerations	Impacts
Hypolimnetic Oxygenation /Aeration	• Raise DO • Suppress internal nutrient/metal cycling • Maintains/disrupts stratification	• Installation and operational cost • Bathymetry	• Onsite O2 generation or LOX storage • Single or multi-level intake • Sediment oxygen demand for sizing	• Beneficial ecological impacts, great for fish habitats
Sediment Dredging	• Removal of nutrient rich sediments • Increase reservoir volume	• Operational cost • Sediment disposal logistics • Suspension of sediment-bound nutrients/metals	• Ineffective if external nutrients not controlled • Hydraulic or mechanical options	• Disturbance of microbial community
Ultrasound	• No treatment residuals	• Limited supporting data • Potential toxin release	• Limited history and success	• May impact non-target organisms
Littoral Zone Restoration/ Hydroponic Floating Wetlands	• Nutrient removal - sediments • Corrects ecosystem imbalances	• Challenging to establish plants • Regular O&M	• Herbivore protection • Biomass harvesting • Community engagement	• Habitat restoration, beneficial ecological impacts

Algaecide Treatment: Preventative vs. Reactive Approach

Preventative

- Begin treatment before blooms begin
- Seasonal/temperature trigger
- Treat at regular intervals (6 weeks for H_2O_2)
- Reduced risk of T&O compounds and cyanotoxins

Reactive

- Begin treatment once bloom presents
- Larger product costs
- Higher risk of T&O compounds and cyanotoxins
- Higher potential for bloom recurrence

Overview of Common Chemical Control Methods

Strategy	Strengths	Limitations	Considerations	Impacts
Hydrogen Peroxide Algaecide	• Selective to cyanobacteria • Degrades into H_2O and O_2 • No accumulation	• No internal nutrient control • Cell lysis/toxin release if overdosed • Short residence time	• Timing to catch early growth + sunny conditions • Accurate dosing	• Potential impact to non-target species
Copper Algaecide	• Cheap and effective • Long residence time	• Blanket toxicity • Cell lysis/toxin release • Cyanos can develop tolerance • No internal nutrient control • Accumulation in sediment	• Chelated products decrease toxicity • Accurate dosing • Rebound growth	• Kills non-target species, can result in fish kills • Accumulation in water column and sediments
Lanthanum Bentonite	• Internal P binding • Long-term benefits	• Ineffective if external loading not controlled • Performance impacted by organic matter content	• Ineffective if external loading not controlled	• La ions accumulation • Potential bioaccumulation
Alum	• Internal P binding • Long-term benefits	• Ineffective if external loading not controlled • Water quality dependance (pH, alkalinity)	• Dose optimized based on available P • Avoid if sediment resuspension is frequent	• Metal ions accumulation

Conclusions

Conclusion and Recommended Actions

Building a proactive, adaptive cyanoHAB management framework for New Hampshire

Be proactive!

Implement Risk-Based Monitoring

- Adopt tiered source water monitoring protocols tailored to each system's risk level
- Establish early warning thresholds and cyanotoxin monitoring flowcharts for all 13 PWSs

Optimize Treatment Processes

- Evaluate in-plant barriers for cyanotoxin removal
- Develop system-specific treatment optimization protocols (TOPs) and response flowcharts

Invest in Source Water Management

- Prioritize preventative algaecide treatment and in-situ management over reactive approaches
- Address root causes through watershed management to reduce external nutrient loading