Drinking Water Treatment for Cyanotoxins

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Presentation overview

- Purpose: provide an overview of drinking water optimization approaches for treating HAB-impacted source water

- Multiple barrier approach
- Sampling, monitoring, and bench-scale analysis
- Treatment optimization
- Resources

Multiple barrier strategy for cyanobacteria & cyanotoxin removal

- **Cyanobacteria cell removal**
  - Potential monitoring indicators include turbidity, particle counts, phycocyanin, chlorophyll-*a*, NOM, UV254, color
  - Treatment options focus on particle removal
    - Coagulation/flocculation, clarification, and filtration
    - Membranes
- **Cyanotoxin removal**
  - Analytical measurement by ADDA-ELISA, LC/MS/MS
  - Adsorption: powdered activated carbon (PAC) and granular activated carbon (GAC)
  - Oxidation / disinfection: adequate concentration x contact time (CT) for pathogen inactivation and cyanotoxin oxidation

Unit process sampling

<u>YSI EXO sonde equipped with sensors</u>:

- Chlorophyll-*a (in-vivo, RFU)*
- Phycocyanin (“blue-green algae”) *(in-vivo, RFU)*
- pH, temperature
- Turbidity

<u>Sample in-situ at the following locations in the plant</u>:

- Raw water
- Pre-sedimentation
- Clarifier effluent
- Top-of-filter
- Combined filter effluent

Jar testing

- Optimizing coagulant and polymer dosing can maximize cell removal through the treatment process. This can be effectively evaluated in most plants using jar testing.

- To evaluate optimal coagulant and polymer dosing for cyanobacteria cell removal, the following parameters can be monitored*:
  - Turbidity
  - $\Delta C/C_0$ DOC
  - Pigments (chlorophyll-*a*, phycocyanin)
  - Color
  - UV254
  - Particle counts
  - Streaming current or zeta potential

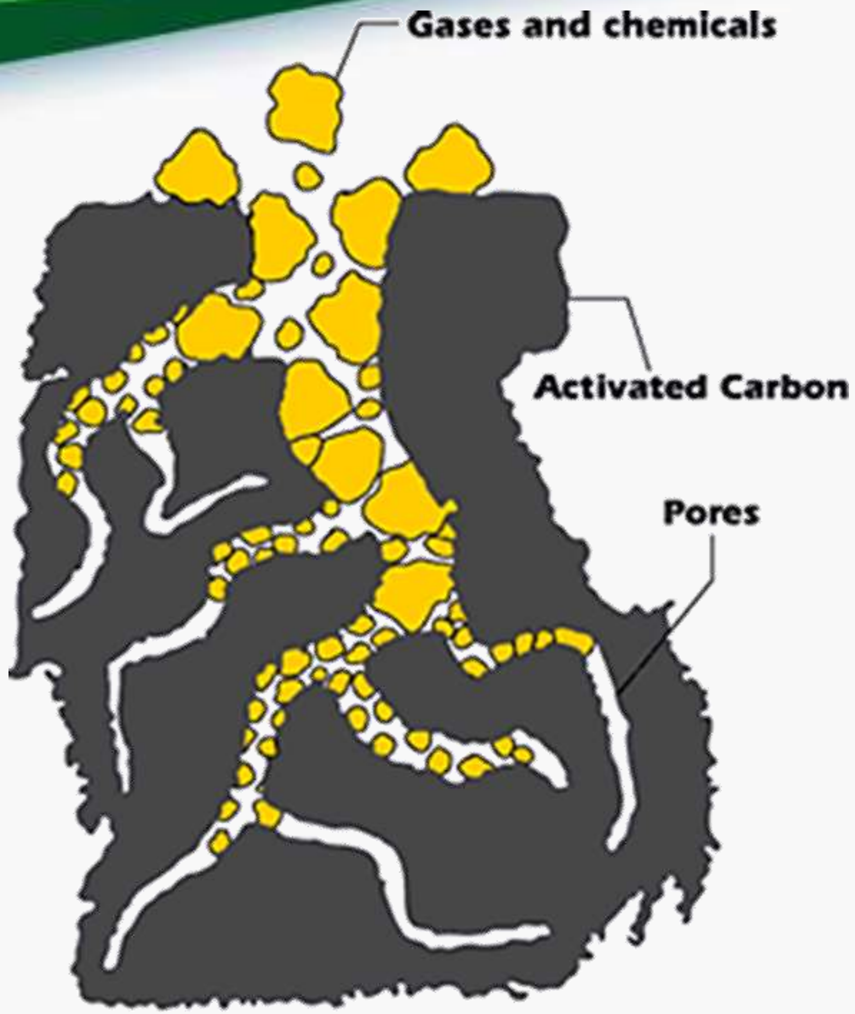
**Newcombe et al., 2015*

Operational considerations for coagulation, flocculation, sedimentation and filtration

- Optimize coagulation, flocculation, and sedimentation process through jar testing
- Rapid sand filters that regularly achieve turbidity ≤ 0.10 NTU are typically better prepared to remove cyanobacteria cells
- Backwashing filters based on water quality data, such as effluent turbidity, can lead to more optimal filter operation
- Trend water quality data regularly to understand baseline operation
- More frequent clarifier sludge removal may be necessary during a cyanobacteria bloom

PAC treatment

- PAC effectiveness depends on:
  - Type of carbon (wood, coconut, coal)
  - Type of cyanotoxin or other compounds to be adsorbed
  - Dose and contact time
  - Natural organic matter (NOM interference)
- Jar testing best for assessing PAC type and dose
- AWWA PAC Jar Testing Protocol for Cyanotoxin Removal in Drinking Water



Micropores: < 2 nm
Mesopores: 2 - 50 nm vs. microcystin-LR: 1-3 nm
Macropores: > 50 nm

Operational considerations for PAC

- Consider sufficient supply, storage space and safety prior to HAB season
- Consider operational impacts of adding PAC on sedimentation and filtration processes
  - Potential need for more frequent sludge removal, higher volumes
  - Potential for filter clogging
  - Test higher PAC feed rates, if needed, prior to HAB season

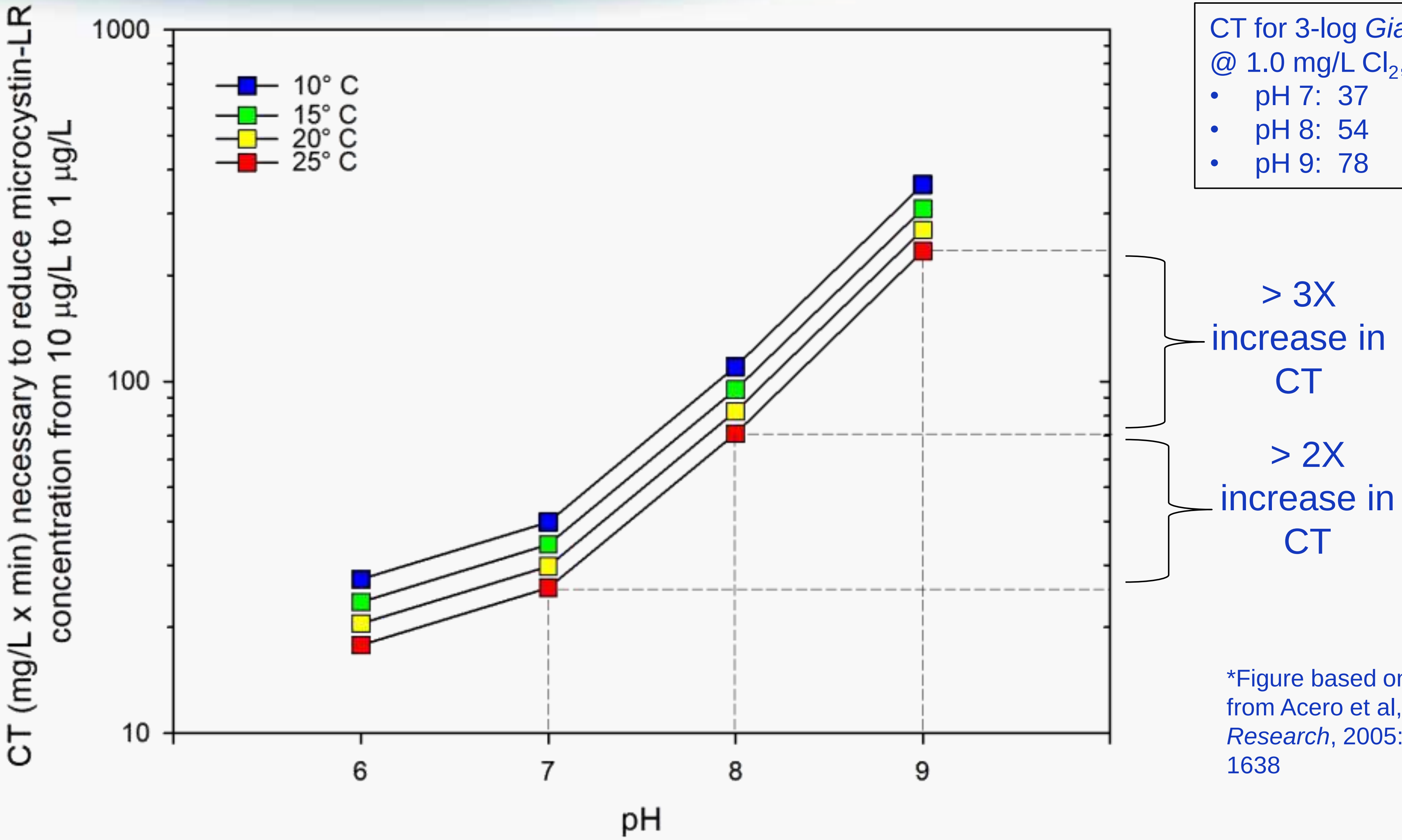
Oxidation treatment summary

Source: Ohio EPA and Ohio AWWA "White Paper on Algal Toxin Treatment", 2015

Oxidant	Anatoxin-a	Cylindrospermopsin	Microcystins	Saxitoxin
Chlorine	Not effective	Effective (at low pH)	Effective*	Somewhat effective
Chloramine	Not effective	Not effective	Not effective at normal doses	Inadequate information
Chlorine dioxide	Not effective at normal doses	Not effective	Not effective at normal doses	Inadequate information
Potassium permanganate	Effective	Data ranges from not effective to possibly effective	Effective*	Not effective
Ozone	Effective	Effective	Very effective	Not effective
UV / advanced oxidation	Effective	Effective	Effective at high UV doses*	Inadequate information

* Dependent on initial cyanotoxin concentration, pH, temperature, and presence of NOM.

Impact of chlorination on microcystin concentrations



CT for 3-log *Giardia* inactivation @ 1.0 mg/L Cl_2, t = 25° C:

- pH 7: 37
- pH 8: 54
- pH 9: 78

*Figure based on data from Acero et al, *Water Research*, 2005:39:1628-1638

AWWA CyanoTOX oxidation calculator

CALCULATOR INPUT PAGE

STEP 1. Select the cyanotoxin of interest from the dropdown list

Cyanotoxin Type: Microcystin-Mix (MC-Mix) →

Variant	MC-LR	MC-RR	MC-YR	MC-LA	MC-LY	MC-LF	MC-Mix
Percent	5%	20%	50%	10%	5%	10%	100%

STEP 2. Input the following system parameters

pH (between 6-10): 9.2

Temperature (between 10-30°C): 10

STEP 3. Input the initial cyanotoxin concentration

Cyanotoxin Initial Concentration (µg/L): 3.79

(If not known, enter an assumed value for the scenario)

STEP 4. Select your target option from the dropdown list

Target. Options: 1) Input target cyanotoxin conc.

Target cyanotoxin concentration (µg/L): 0.3

STEP 5. Select the oxidant of interest from the dropdown list

Oxidant Type: Free Chlorine

STEP 6. Go to your chosen calculator version: CT based or Dose-decay based (tabs in blue)

STEP 7. Input the following parameters

Baffling Factor: 1

Oxidant Dose (mg/L): 7

Instantaneous oxidant demand (mg/L): 2.95

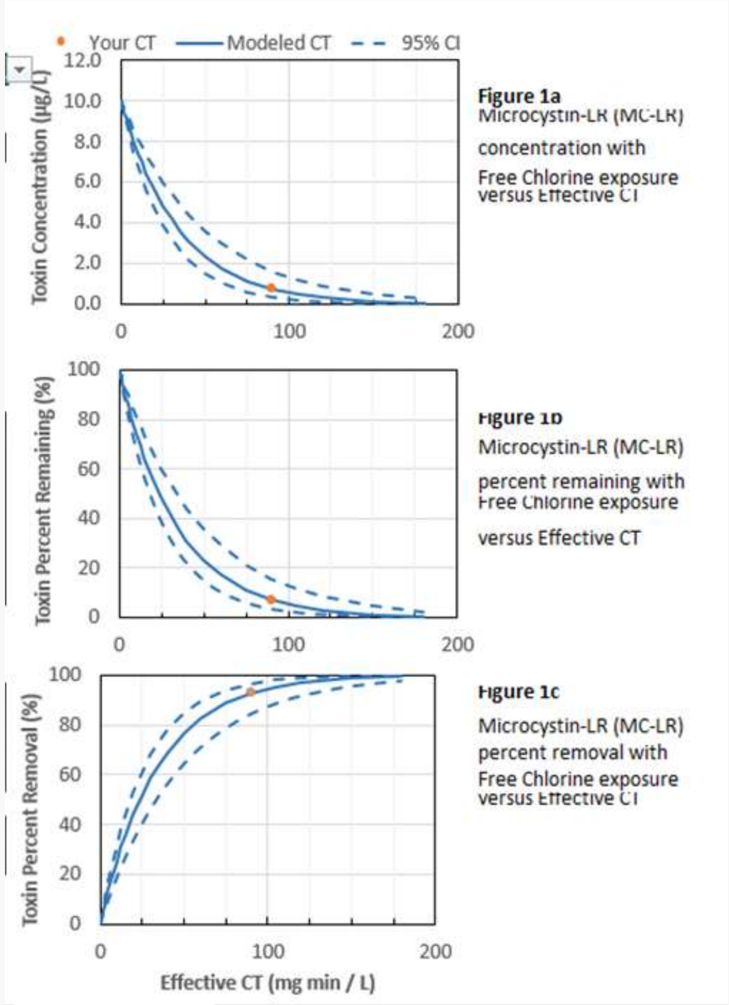
Contact Time (i.e., hydraulic detent. time, min): 300

Effective Oxidant Half Life (min): 360

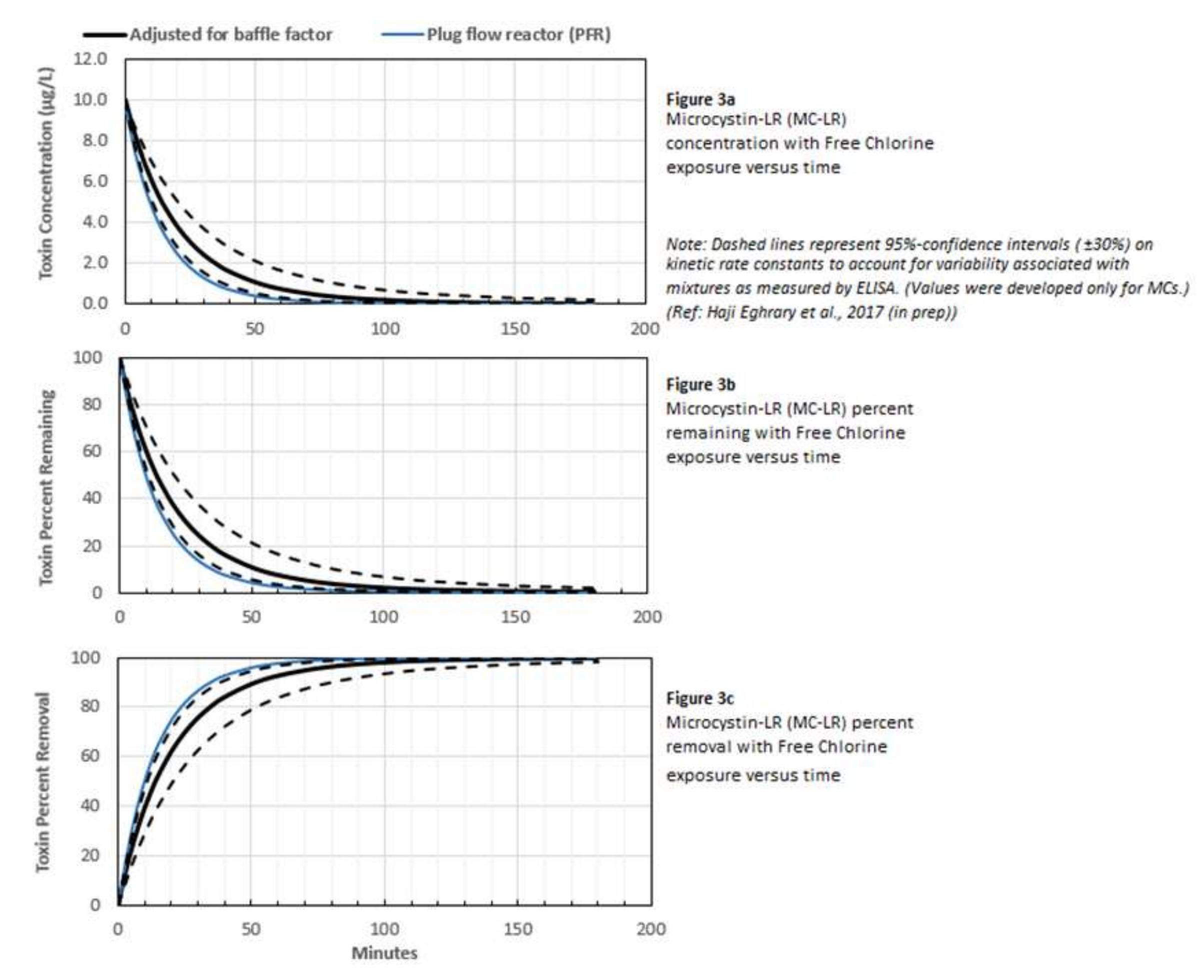
(Enter a value in minutes OR "ND" for No Decay")

AWWA CyanoTOX oxidation calculator

CT-based results:



Dose-decay based results:

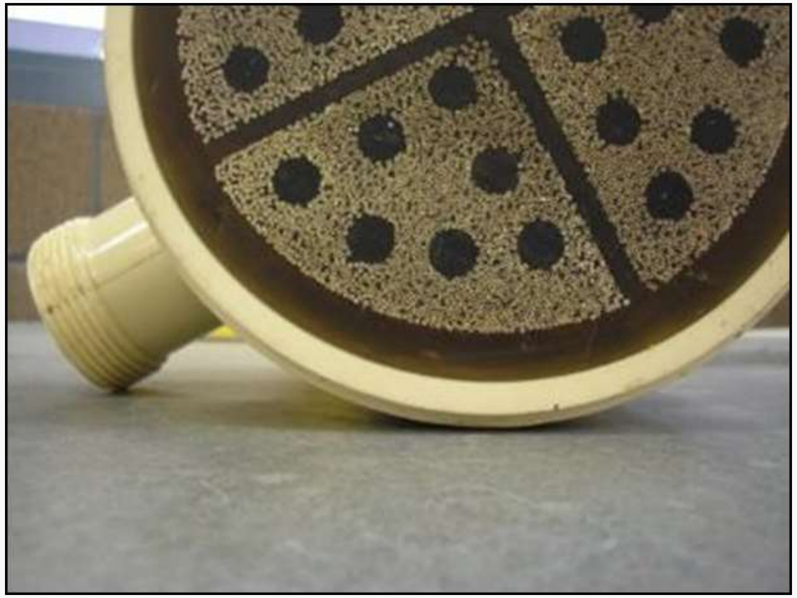


Operational considerations for chlorination

- Consider where chlorine is dosed and if any competing technologies would limit its effectiveness
- Consider the potential for formation of disinfection byproducts

Membrane filtration

- Cyanobacteria cell removal effective with MF or UF
- Cyanotoxin removal possible with NF or RO
- Low pressure membranes, such as MF or UF are not effective for removing extracellular cyanotoxins
- High pressure membranes, such as nanofiltration or RO, can remove some extracellular cyanotoxins depending on the type
- Consider reevaluating backwash and cleaning frequencies during a cyanobacteria bloom



Photos courtesy of Oregon Health Authority

Slow sand filtration

- Avoidance strategies:
  - Evaluate how much DS storage. Filter to waste until bloom passes?
  - Change intake location or depth
  - Switch sources or blend with other sources
  - Purchase water from neighboring systems
- Reevaluate disinfectant CT

Ensure water quality compatibility if changing or blending sources and evaluate impacts to DS water quality

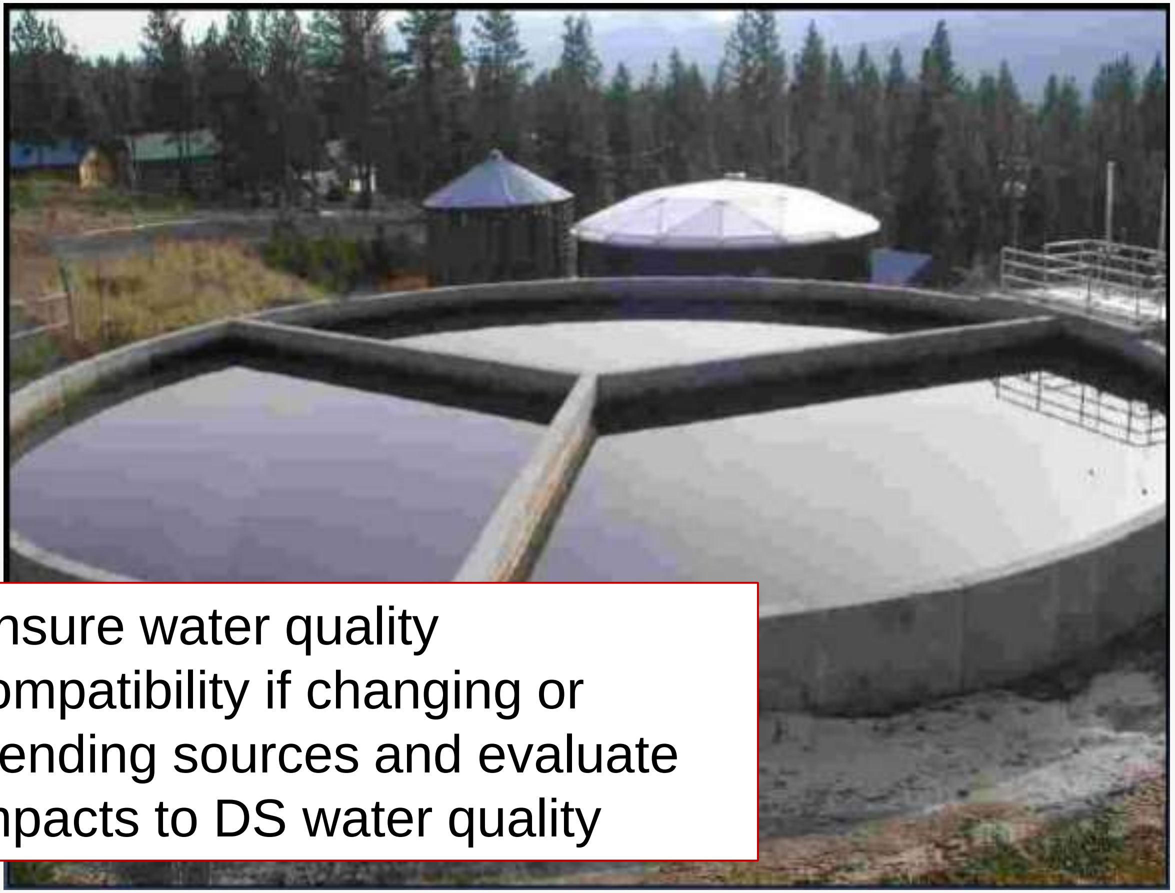


Photo courtesy of Oregon Health Authority

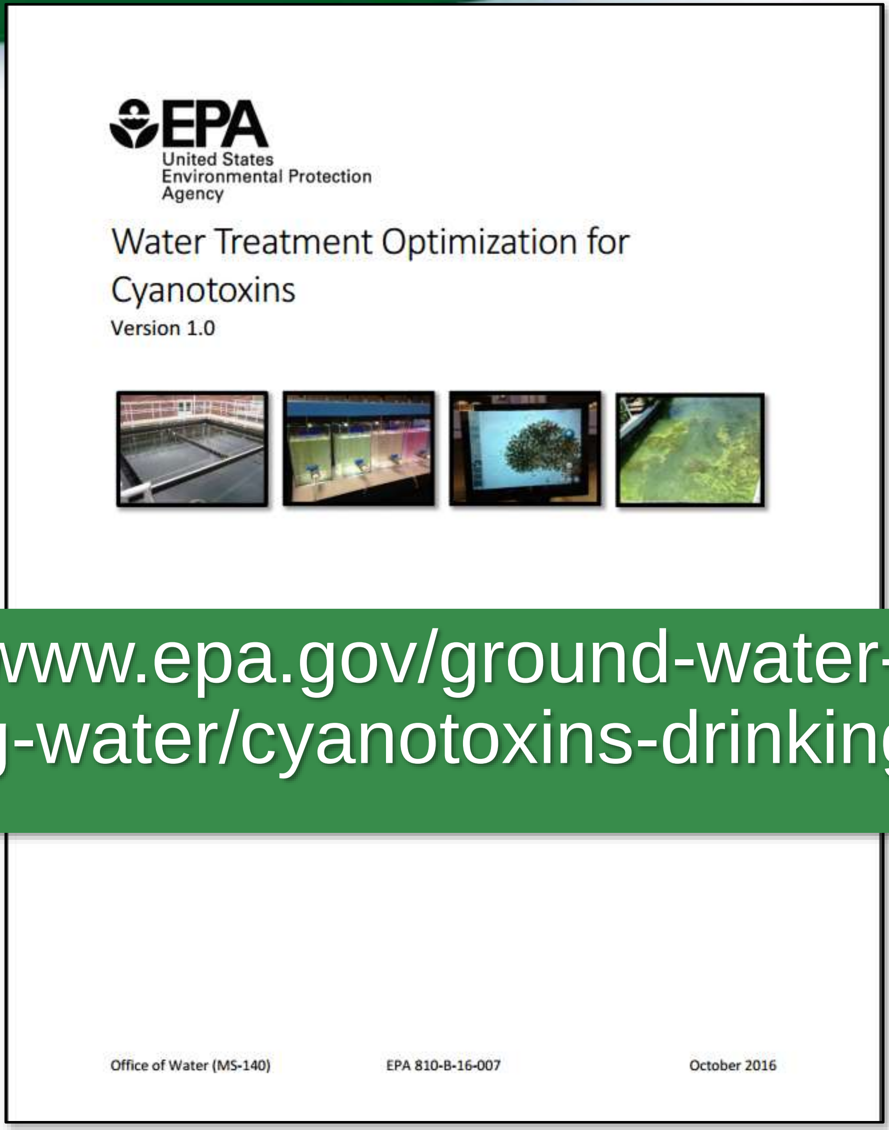
Slow sand filtration

- Cyanobacteria cell removal by filtration
- Cyanotoxin removal by biotransformation/biodegradation
- Effectiveness depends on:
  - Water temperature
  - Filter contact time and hydraulic loading rate – longer/lower is better
  - Abundance of specific bacteria capable of degrading the cyanotoxins present in source water
  - Concentration of influent cyanobacteria and cyanotoxins
  - Presence of organic matter
  - Presence of metals
- Some studies have shown biodegradation products of saxitoxin may result in more toxic forms
- Lag period of up to 6 days
- No disinfectant residual prior to biological filter

Conclusions

- When optimized, conventional treatment processes (coagulation, flocculation, sedimentation, filtration) are highly effective at removing cyanobacteria cells
- PAC effectively adsorbs microcystins; however, the exact carbon dose will vary depending on the type of cyanotoxin, type of carbon, and the NOM background concentration
- Slow sand filters can be effective if consideration is given to ripening/lag time and hydraulic parameters
- Low pressure membranes are effective at cyanobacteria cell removal, but need another barrier for extracellular cyanotoxin removal
- Chlorine effectively degrades microcystins, but the rate of degradation is temperature and pH dependent. Reevaluate CT.

EPA document



EPA United States Environmental Protection Agency

Water Treatment Optimization for Cyanotoxins

Version 1.0

Office of Water (MS-140) EPA 810-B-16-007 October 2016

https://www.epa.gov/ground-water-and-drinking-water/cyanotoxins-drinking-water

EPA document appendices

Process evaluation for various types of treatment:

- For intracellular cyanotoxins:
  - Conventional treatment (coagulation, flocculation, sedimentation and filtration)
  - Membranes
- For extracellular cyanotoxins:
  - Powdered activated carbon (PAC)
  - Granular activated carbon (GAC)
  - Membranes (NF, RO)
  - Oxidation

Appendix B: Process evaluation for treatment of extracellular toxins.

These tables (arranged by treatment technology) are intended for systems with cyanobacteria blooms that have a significant portion of the cyanotoxins in extracellular form (i.e., outside the cell). The tables can be used as a planning tool, or by systems in the midst of a bloom. The best strategy for controlling cyanotoxins will be system specific, but these tables can be used as a starting point to evaluate some common approaches. Even if toxins are primarily intracellular, the tables in Appendix B can provide information on treatment for the fraction that exists as extracellular toxins; the tables can also be used to address situations involving toxin release due to algaecide or pre-oxidation. The treatment processes evaluated in Appendix B can be utilized in combination to increase the removal or destruction of cyanotoxins (particularly using post-oxidation as outlined in Table B-4). For removal of intracellular toxins, refer to Section 3.1 and Appendix A: *Process evaluation for treatment of intracellular toxins for treatment considerations for intracellular toxins.*

It is important to ensure that proper process control monitoring plans are in place prior to implementing any treatment approaches for cyanotoxins, so that the impact and effectiveness of treatment can be assessed and informed treatment decisions can be made. Water treatment plant staff can design process control monitoring plans for cyanotoxins to best fit their situation (e.g., grab samples and/or online instruments depending on location, access, and availability of sampling ports). The monitoring plan should include sampling for cyanotoxins if detected in the source water; surrogate parameters, as discussed in Section 2 of the main document; and other process control parameters specific to each technology (e.g., chemical dosing, feed rates, residuals, etc.).

It is also important to coordinate with the appropriate state or primacy agency prior to utilizing new or substantial changes in treatment in regard that state's or primacy agency's permitting requirements.

Table B-1. Powdered activated carbon (PAC)

Can my facility use PAC to treat extracellular cyanotoxins?

	Question	If yes	If no	Comments/Notes
1.	**PAC equipment:** Is PAC feed equipment currently in-place, or could it be installed in a short period of time (i.e., 24-48 hours)?	Continue to next step – for both immediate (short-term) and longer-term implementation of PAC.	Is this a long-term strategy that warrants pursuing (i.e., possibly for the next bloom season)? If PAC feed equipment is not available in short order, other treatment strategies should be considered for removing extracellular	Document immediate and/or longer-term equipment needs, if applicable. New PAC feed equipment should generally be piloted for short periods of time prior to implementing on a full-time basis in order to understand the plant's response to the new

Questions?

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