Treatment Techniques for Cyanobacteria and their Toxins and Public Water Systems

Judy Westrick, PhD

Wayne State University

EPA Region 10 HABs Workshop

March 30, 2016

Understanding microorganism and chemical removal/inactivation

- Living organisms
  - Nonviable/Removal
- Chemical Contaminants
  - Adsorption/nano-RO Filtration/oxidation/ Biodegradation

Overview Drinking Water Treatment

- Treatment to remove intracellular algal toxins
  - Conventional treatment
    - Filtration
    - Membrane technologies
- Treatment to remove extracellular algal toxins
  - Oxidation
  - Physical removal
  - Biologically active filters

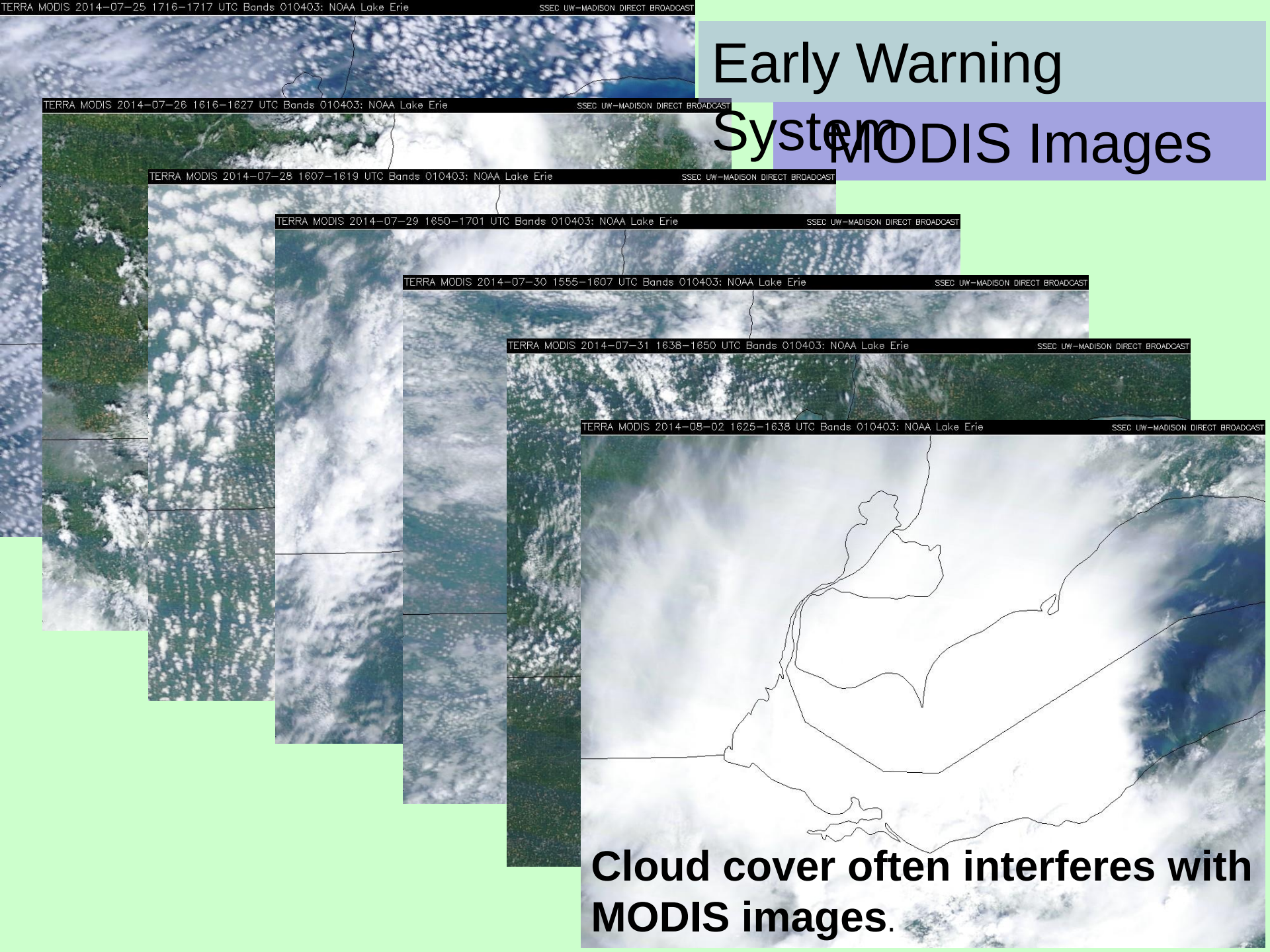
Source Water

Photo courtesy of John Lehman, University of Michigan

- Intracellular Toxin
  - Flushing
  - Harvesting
  - Diversion
  - Flocculants
  - Algaecides (low levels)
  - Ultrasound

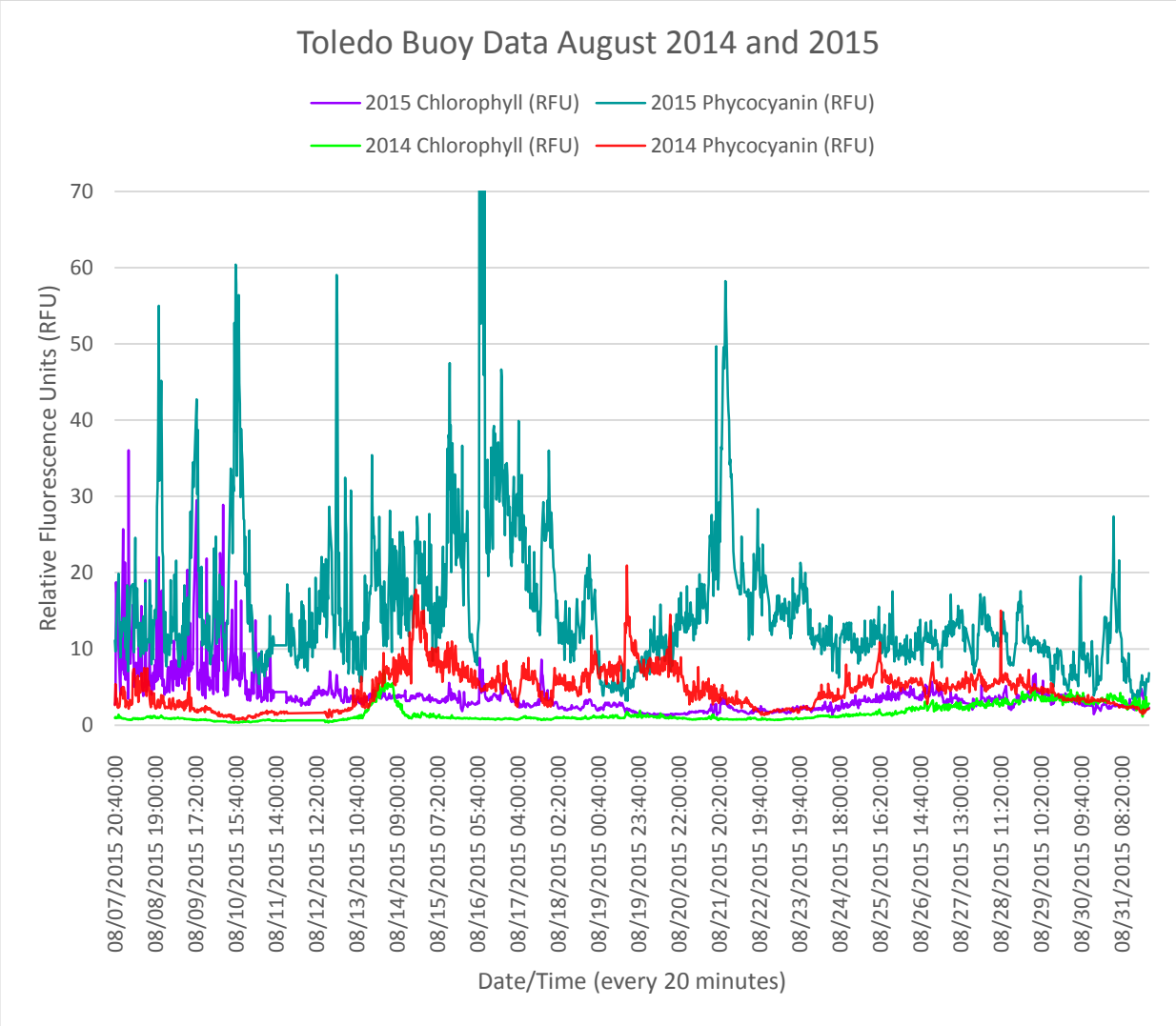
- Extracellular Toxin
  - Awareness and get ready to treat

Early Warning System MODIS Images



Cloud cover often interferes with MODIS images.

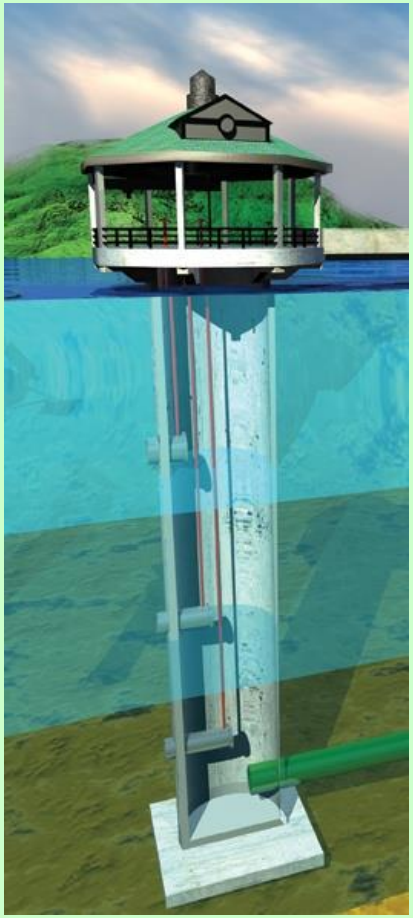
Early Warning Systems



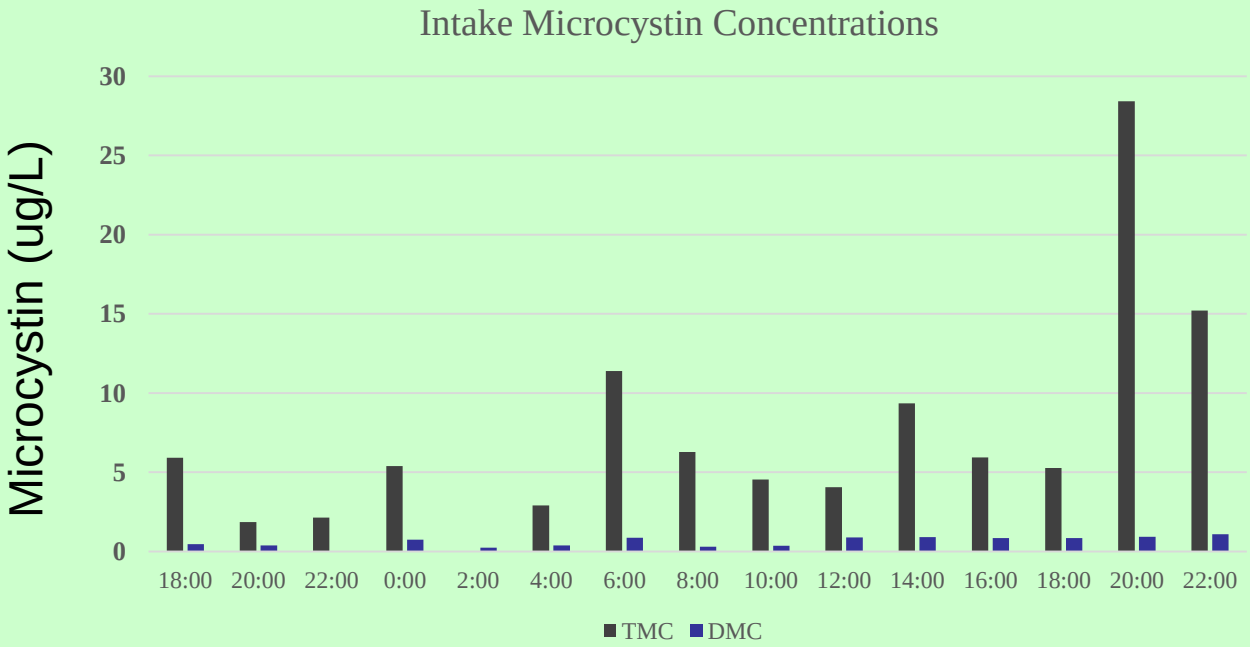
Buoys: Fluorescence Probe

Remote sensing: MODIS

Intake

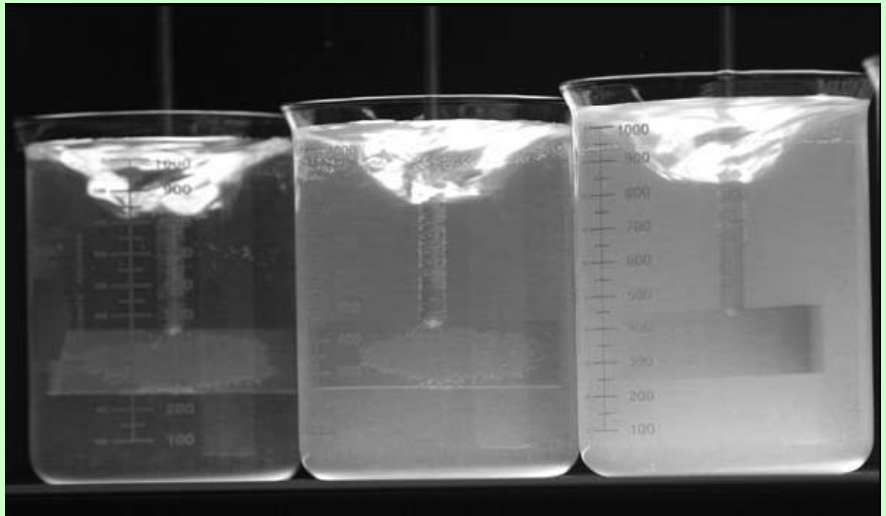


- Intracellular Toxin
  - Adjustable Intake
  - Night vs Day
- Extracellular Toxin
  - Oxidants
  - Inline Powdered Activated Carbon (PAC)
- A conventional treatment plant will want to keep the cells intact.



Powdered Activated Carbon

- Wood-based PAC is more effective the coconut based and bituminous PACS in the removal of microcystins
- Jar Test
- Pre-chlorination is not recommended before the use of PAC



Particulate Removal Treatment

A Summary of Cyanobacteria Intact Cell Efficiency

Treatment	% Optimized Removal
Coagulation/sediment or dissolved air flotation/rapid sand filtration	>99.5%
Lime precipitation/sedimentation/rapid sand filtration	>99.5%
Ballasted Flocculation/filtration	>95%
Coagulation/sedimentation microfiltration	>90%
Coagulation/sedimentation ultrafiltration	>90%

Conventional Treatment

Table 3.1. Utility Information.

Site Identification Number	State	Source Water	PAC	Coagulation/ Flocculation	Clarification	Filtration	Disinfection
123	VT	Lake		x	x	Sand/Anthracite	Chlorine
485	FL	River/Reservoir	x	x	x	x	Chloramines
619	OK	Reservoir	x	x	x	Sand/Anthracite	Chlorine
762	CA	Reservoir		x	x	Sand/Anthracite	Ozone/Chloramines
929	TX	Reservoir	x	x	x	Sand/Anthracite	Chloramines

Table 2.2.1. Range of cell removal by water treatment for total cyanobacteria and toxin-producers.
* log removal cannot be determined. Toxin producer numbers were very low in the raw water, and not detected in the finished water.

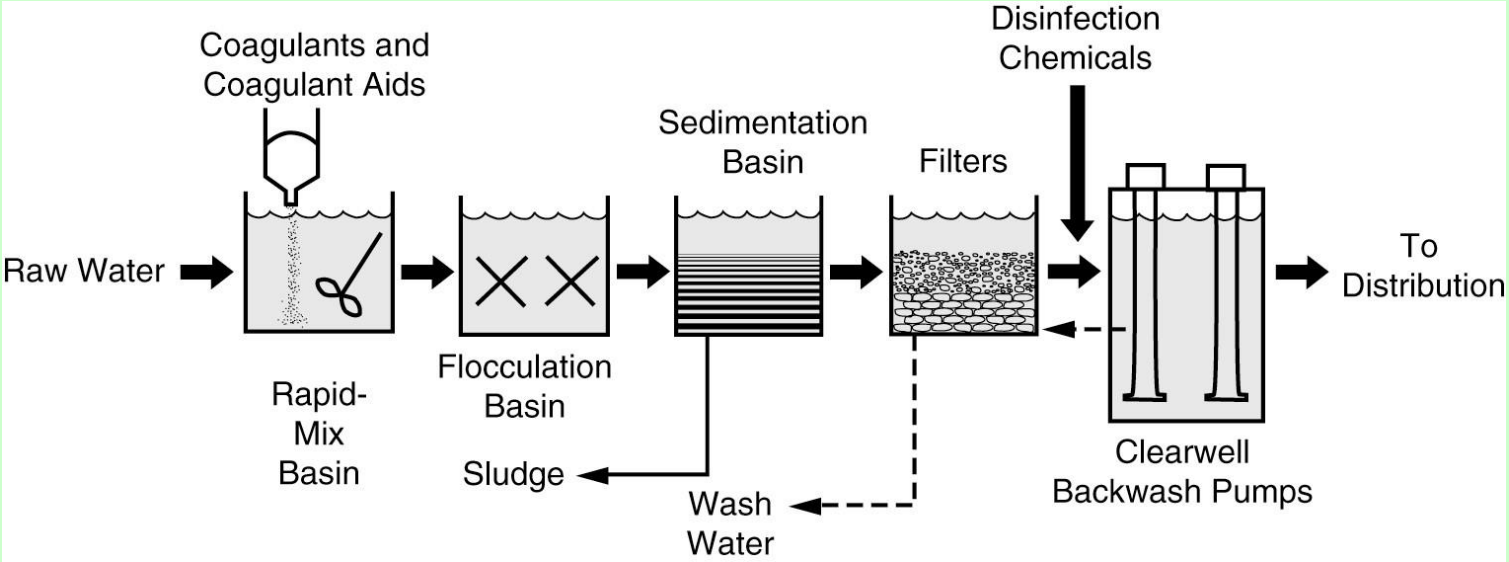
Location	Total Cyanobacteria (Range of cell removal (log_{10}))	Toxin Producers (Range of cell removal (log_{10}))
California	1.5 to >5.5	1.5 to >5.5
Oklahoma	1.6 to >3.4	0.2 to >3.2
Vermont	>2.5 to 3.1	* to >2.2
Texas	>2.8 to >4.0	>1.6 to >4.0
Florida (both sources)	1.6 to 3.8	1.6 to 3.3

Szlag, et. al, Cyanobacteria and Cyanotoxins Occurrence and Removal from Five High-Risk Conventional Treatment Drinking Water Plants. Toxins 2015, 7, 2198-2220

Coagulation/Sedimentation

- Intracellular Toxin
  - Oxidants (not often used, afraid of lysing cell)
  - Flocculent aides
  - Settled water with less than 100 units algae/mL
- Extracellular Toxin
  - Activated Carbon
    - Powder (PAC)
    - Granular (GAC)
  - Filtration
    - Conventional
    - Biologically Active

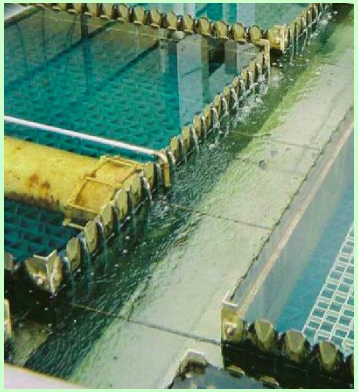
- Monitoring Techniques to determine treatment
  - Turbidimeter
  - Streaming current detector
  - Particle Counter
  - Chlorophyll-a
  - Cell counts
  - ELISA
    - Saxitoxin, Anatoxin-a, Cylindrospermopsin, Microcystin
    - Plate, Test tube kit, Dip Stick



Harboring/Culturing within the Treatment Process

	Source Water			Plant Interior			After Filtration		
Location	***cyr***	***sxt***	***mcy***	***cyr***	***sxt***	***mcy***	***cyr***	***sxt***	***mcy***
OHIO 1	BLD	YES	YES	BLD	<	<	BLD	BLD	BLD
OREGON 1	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
OHIO 2	BLD	BLD	YES	BLD	*YES*	>	BLD	BLD	BLD
COLORADO 1	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
COLORADO PLANT 2	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
KENTUCKY	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
FLORIDA	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
OREGON	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
NEW YORK	BLD	BLD	YES	BLD	BLD	BLD	BLD	BLD	BLD
OKLAHOMA	BLD	BLD	YES	BLD	BLD	BLD	BLD	BLD	BLD

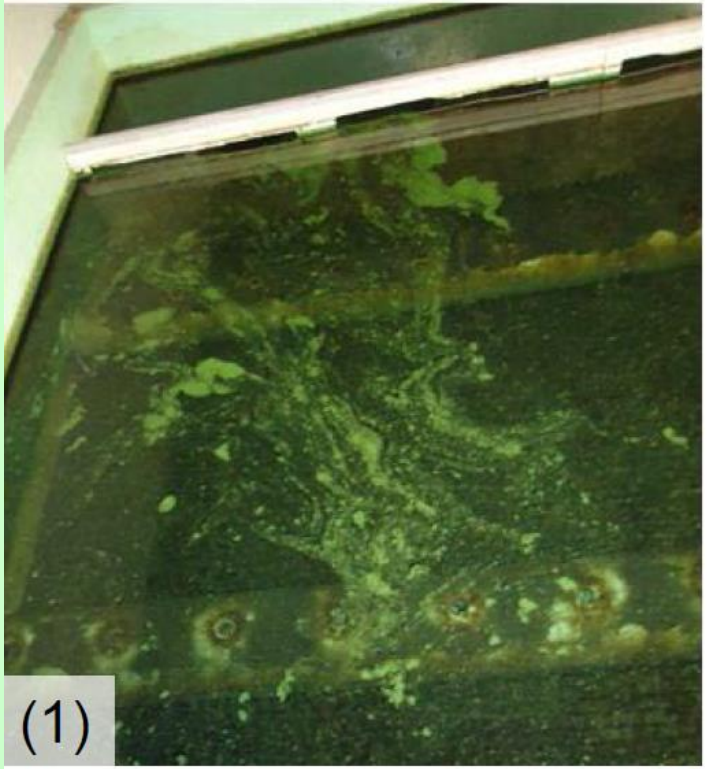
Ultrasonic Technology Treatment



Low power ultrasound
Tunable (79 frequencies)
Critical resonance (gas vesicles)
Cyanobacteria – *Microcystis*, *Anabaena, Lyngba (Sonic Solutions)*

George Hutchinson, Opflow April 2008

Breakthrough of cyanobacteria into the clarified water



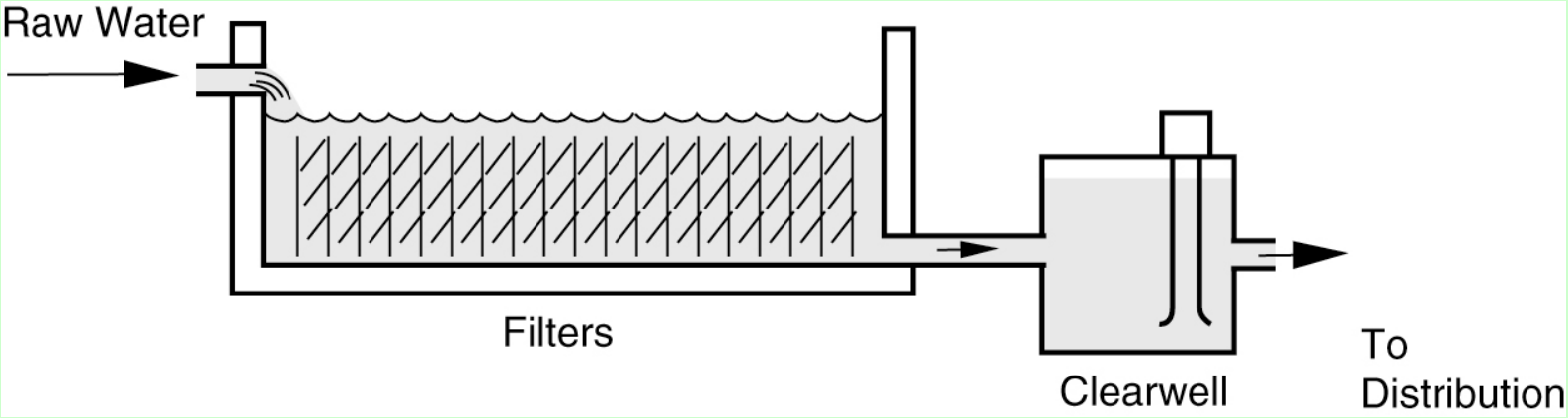
WARNING: 9180 µg/L MC-LR

References:

1) Zamyadi et al. (2012) Water Research 46, 1511-1523
2) Zamyadi et al. (2013) Water Research 47, 1080-1090

Filtration

- Conventional
- Biologically Active
- GAC
- Low Pressure Membrane

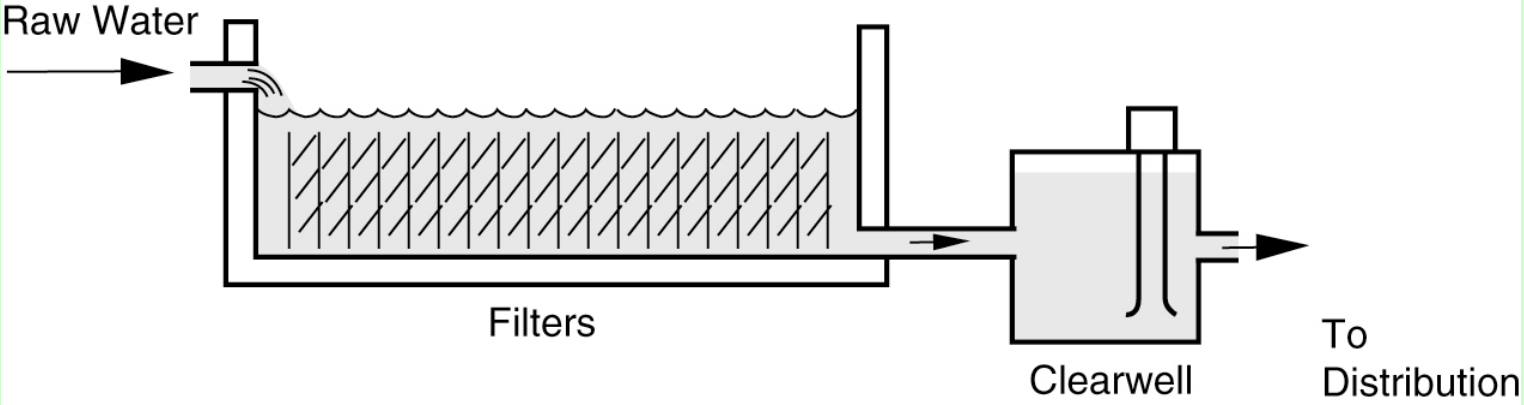


Biologically active filters

- INTRACELLULAR TOXIN
- MCY-LR, MCY-LA, cylindrospermopsin, and anatoxin-a can be removed by biologically active sand and GAC filters
- Empty bed contact times-- 5 to 15 minutes.
  - Slow filtration
  - Rapid filtration
- Saxitoxin - not removed

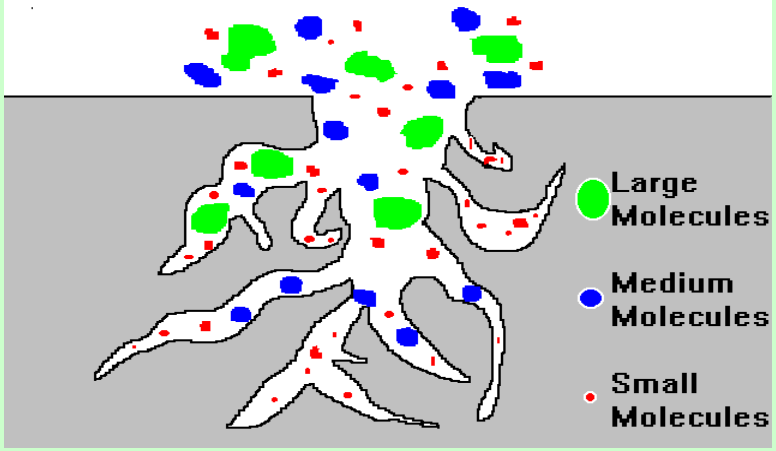
GAC filtration

- Effectiveness of GAC filtration against cyanotoxins is source water dependent
- Significant differences in adsorption between LA and LR
- Saxitoxins and anatoxin-a are more readily adsorbed than microcystins



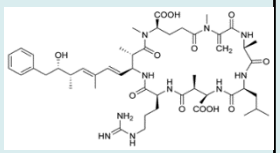
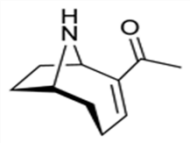
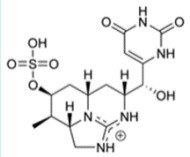
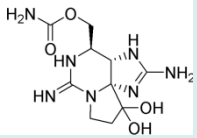
Pore Size

- Equilibrium
  - Micropore
    - Taste and odor
    - Industry spills, solvents
    - Anatoxin-a
  - Mesopore
    - Microcystins RR>YR>LR>LA
    - Cylindrospermopsin
    - Saxitoxin



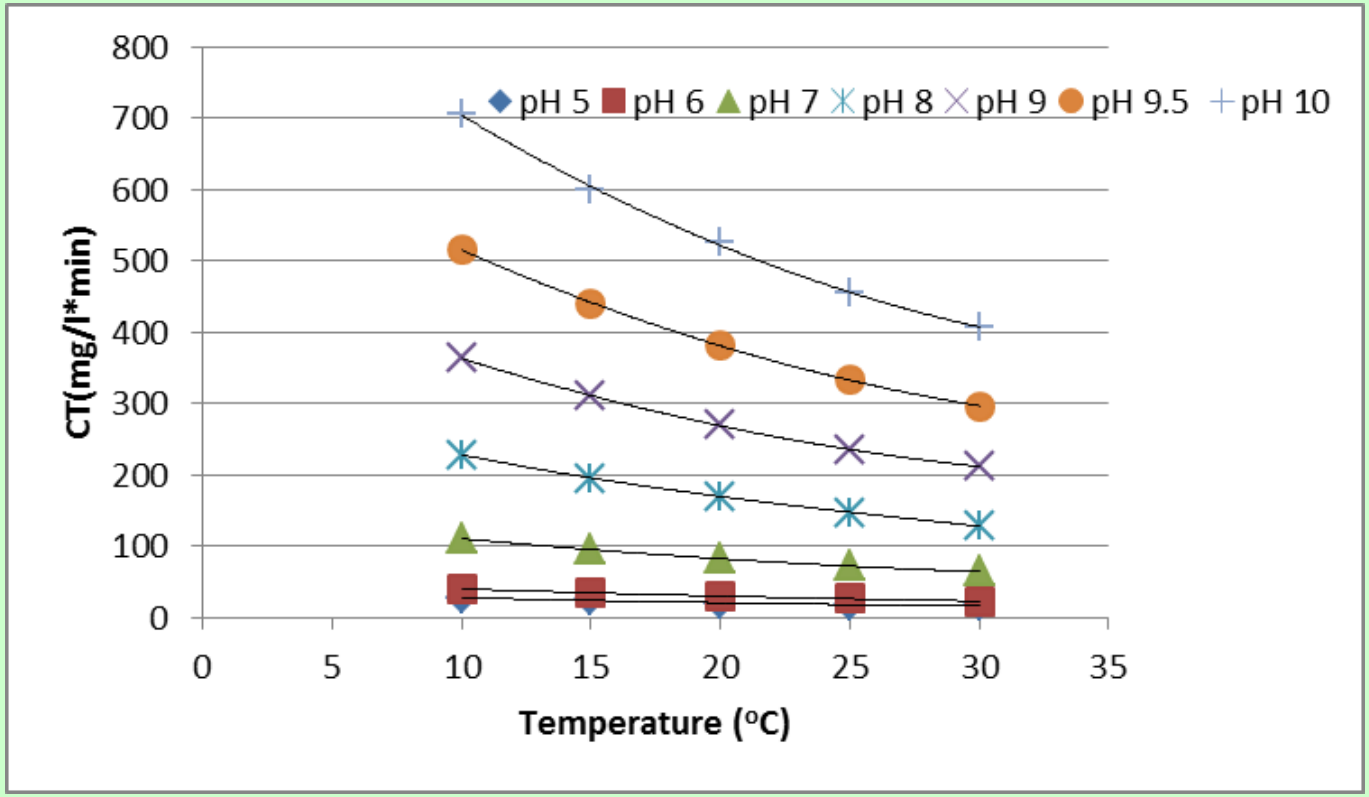
- Kinetic <1 hour contact time
- Large pore volume seems to be more effective

Summary of Oxidation Treatment Processes Extracellular Toxins

				
Chlorine	Yes	No	No	Yes
Ozone	Yes	Yes	Yes	No
Chloramine	No	No	No	?
Chlorine dioxide	No	No	No	?
Hydroxyl radical	Yes	Yes	Yes	?
KMnO4	Yes	Yes	Yes	No

Westrick et. al. Anal. Bioanal. Chem. (2010) 397:1705–1714

Clearwell: Chlorination of Microcystin (1 log removal)



Acero et. al 2005

Extrapolation for pH above 9.0

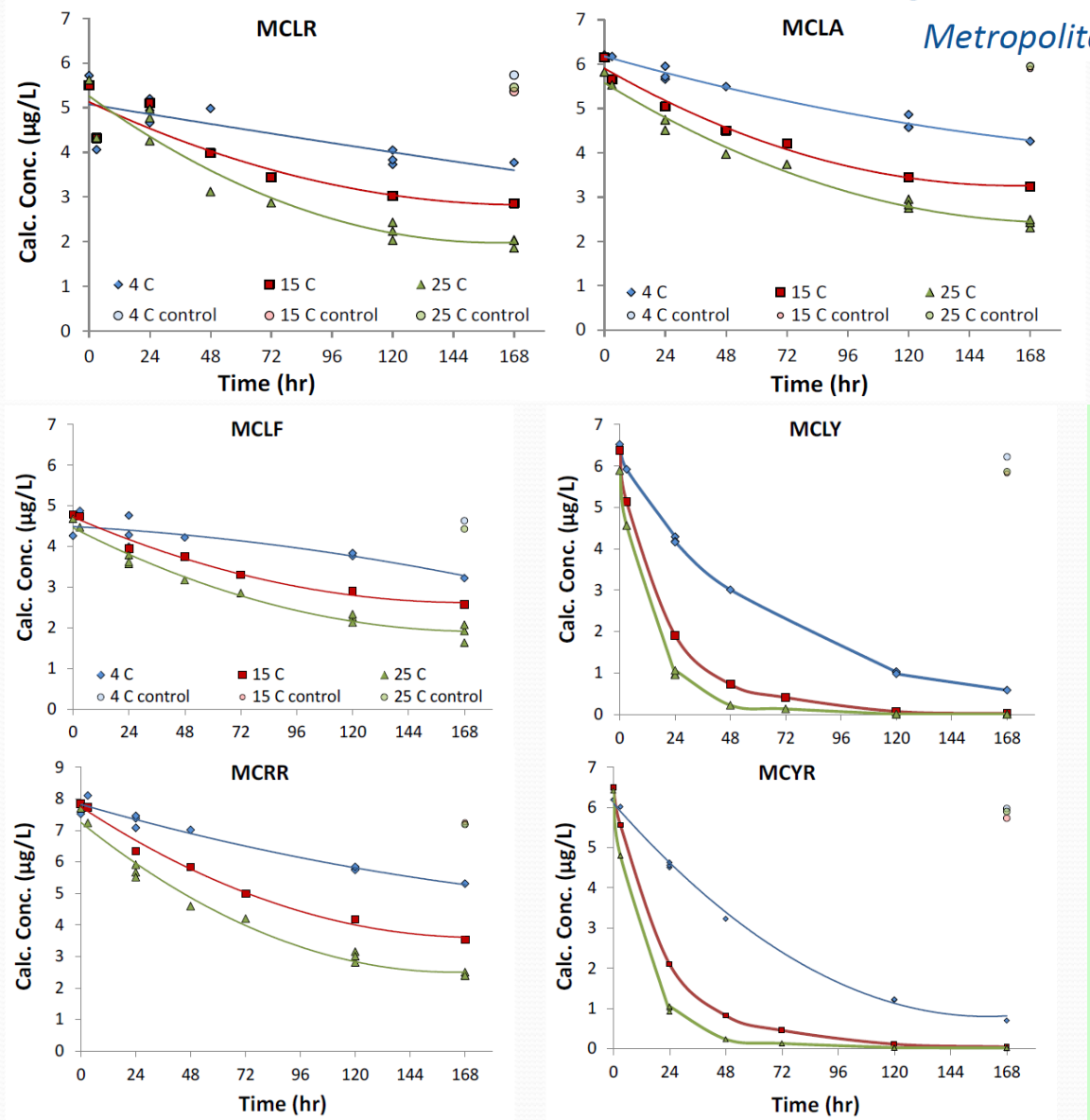
Contact Time and Temperature

PE; Initial T-Cl2 = 2.6 mg/L; pH = 8.2

Yingbo C. Guo, Stuart W. Krasner and Matthew D. Prescott

Metropolitan Water District of Southern California

WQTC, Nov. 17, 2015



Chloramination

Goal – To achieve additional removal of MC if pre-oxidation is not adequate

Summary
LW, LY, YR >> LR, RR> LA, LF, dmLR

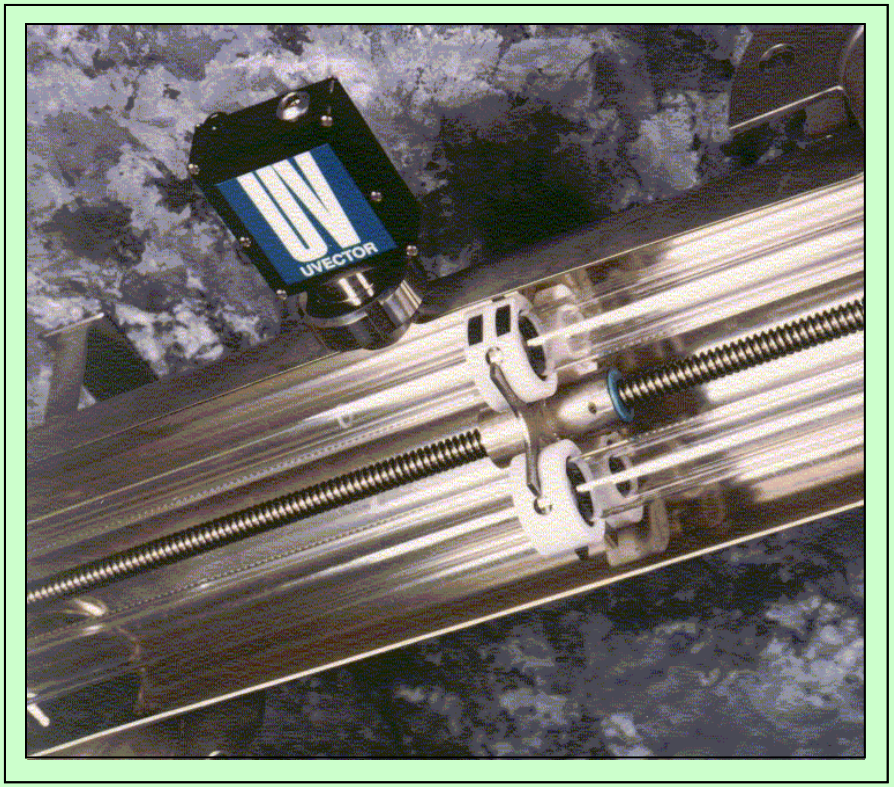
Temperature Dependence
the warmer the better

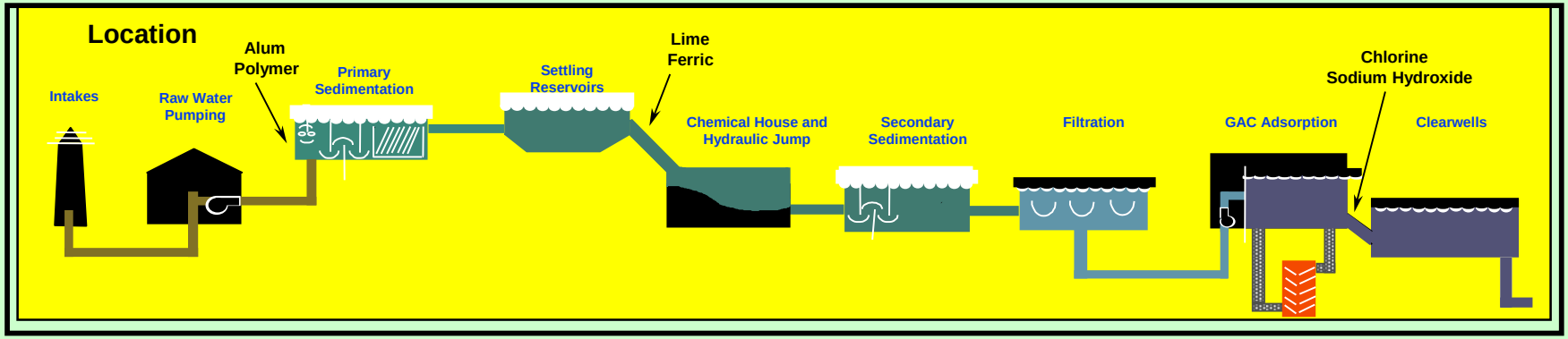
pH Dependence
7 is better than 9

UV Treatment

- UV inactivation dose is about 40 mJ/cm^2 – inactivation of *Crytosporidium parvum*.

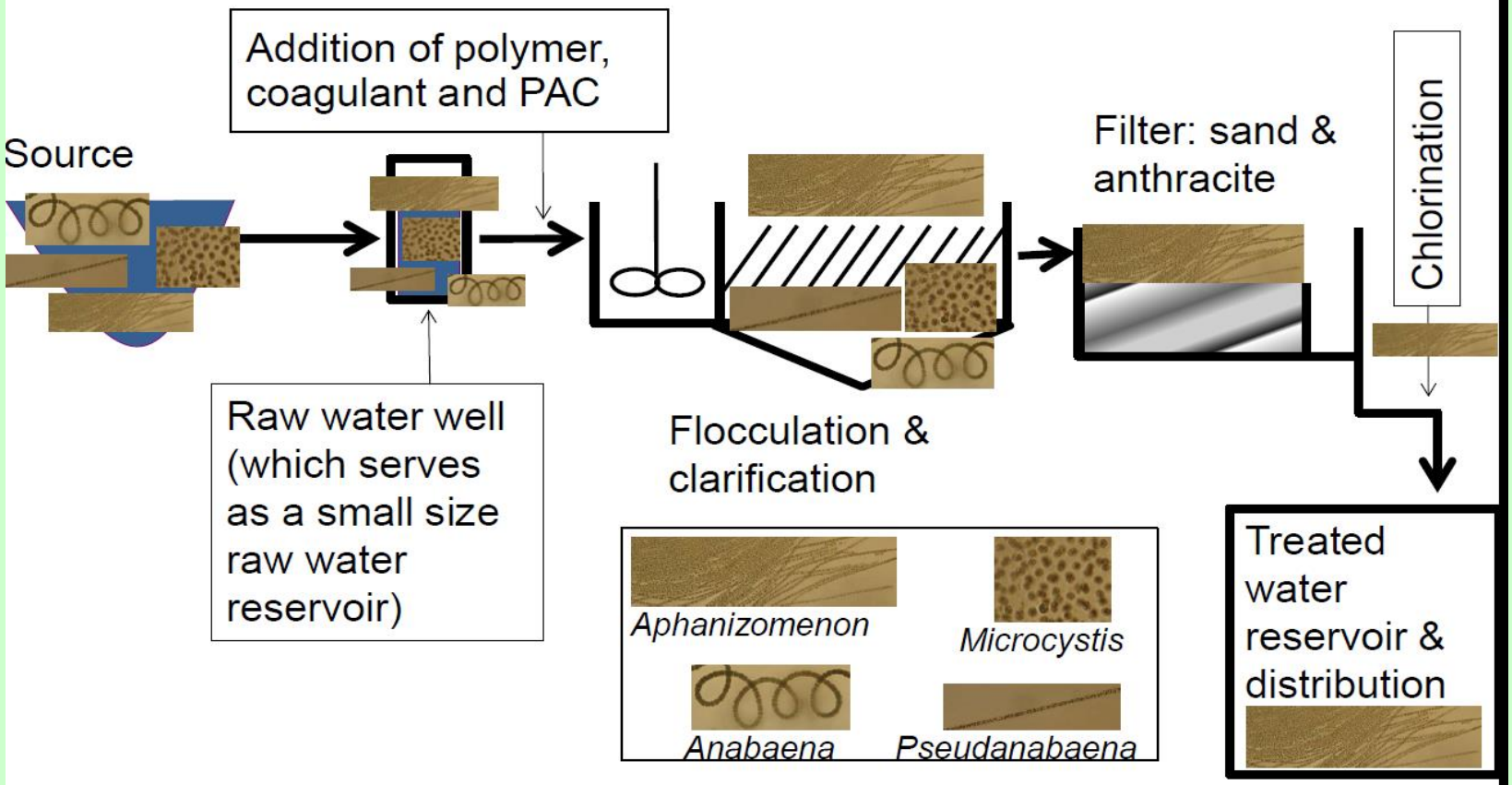
- Photolytic destruction dose for microcystin, cylindrospermospin, anatoxin-a and saxitoxin is 1530 to 20,000 mJ/cm^2.





- Intake
- Inline Chemical
- Coagulation/Flocculation/Sedimentation
- Storage Reservoir
- Filtration
- Carbon Adsorber
- Chlorine

CONCLUSION: Breakthrough of cyanobacteria into the WTP



Zamyadi et. al. "Management of toxic cyanobacteria in full scale treatment plants. 4th National Cyanobacteria Workshop Adelaide, SA(9/23/114)

Szlag, et. al, Cyanobacteria and Cyanotoxins Occurrence and Removal from Five High-Risk Conventional Treatment Drinking Water Plants. Toxins 2015, 7, 2198-2220

Harboring/Seeding/Growing Cyanobacteria

	Source Water			Interior Plant			After Filtration		
Location	**CYL**	**SAX**	**MCY**	**CYL**	**SAX**	**MCY**	**CYL**	**SAX**	**MCY**
NEW YORK	BLD	BLD	YES	BLD	BLD	BLD	BLD	BLD	BLD
OHIO 1	BLD	YES	YES	BLD	<	<	BLD	BLD	BLD
OHIO 2	BLD	BLD	BLD	BLD	>	>	BLD	BLD	BLD
KENTUCKY	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
FLORIDA	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
ARIZONA	BLD	BLD	YES	BLD	BLD	BLD	BLD	BLD	BLD
COLORADO 1	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
COLORADO PLANT 2	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
OREGON 1	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD
OREGON	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD	BLD

Questions?