# Treatment Techniques for Cyanobacteria and their Toxins and Public Water Systems

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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

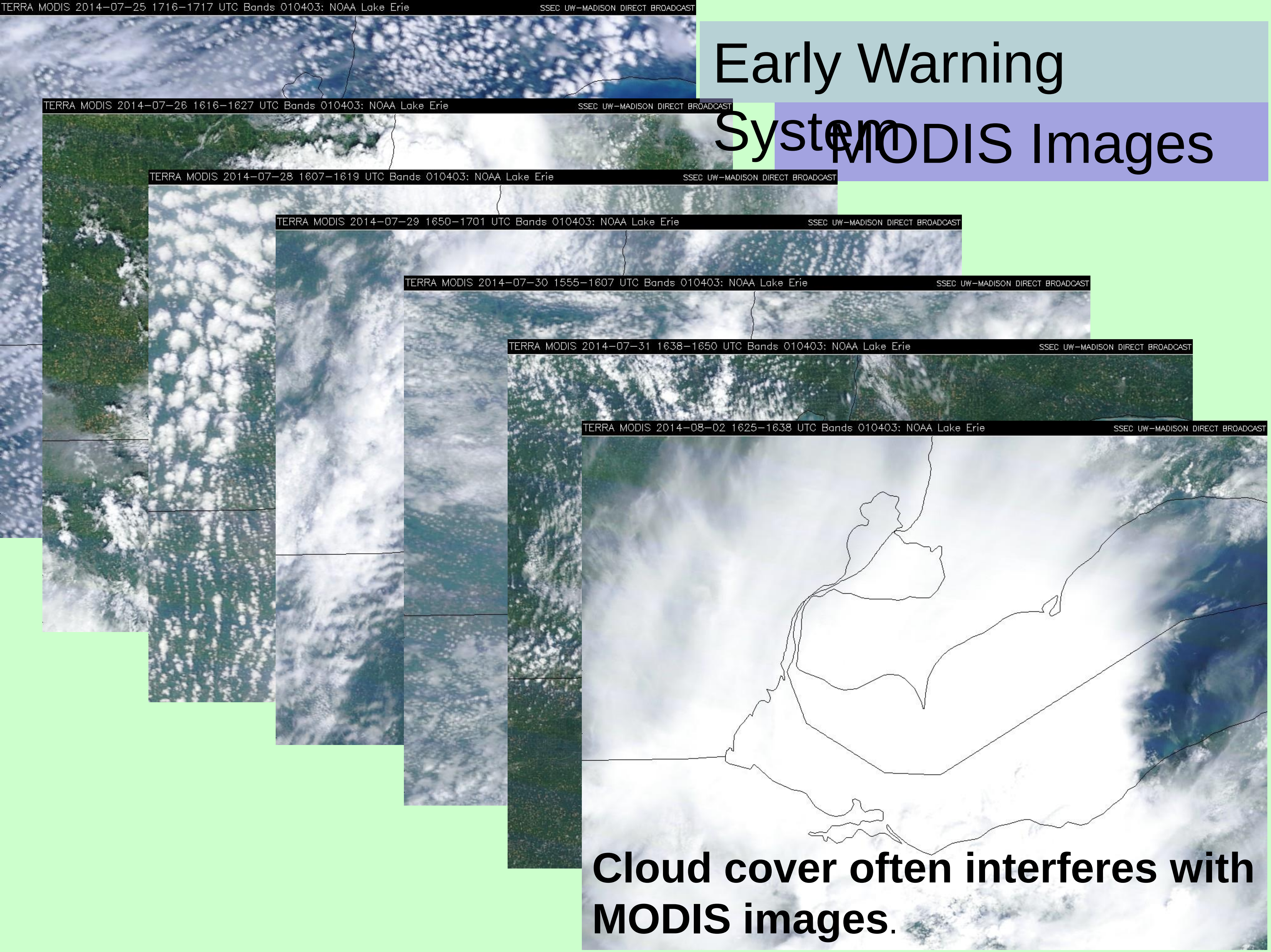
Photo courtesy of John Lehman, University of Michigan

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

- Extracellular Toxin
  - Awareness and get ready to treat

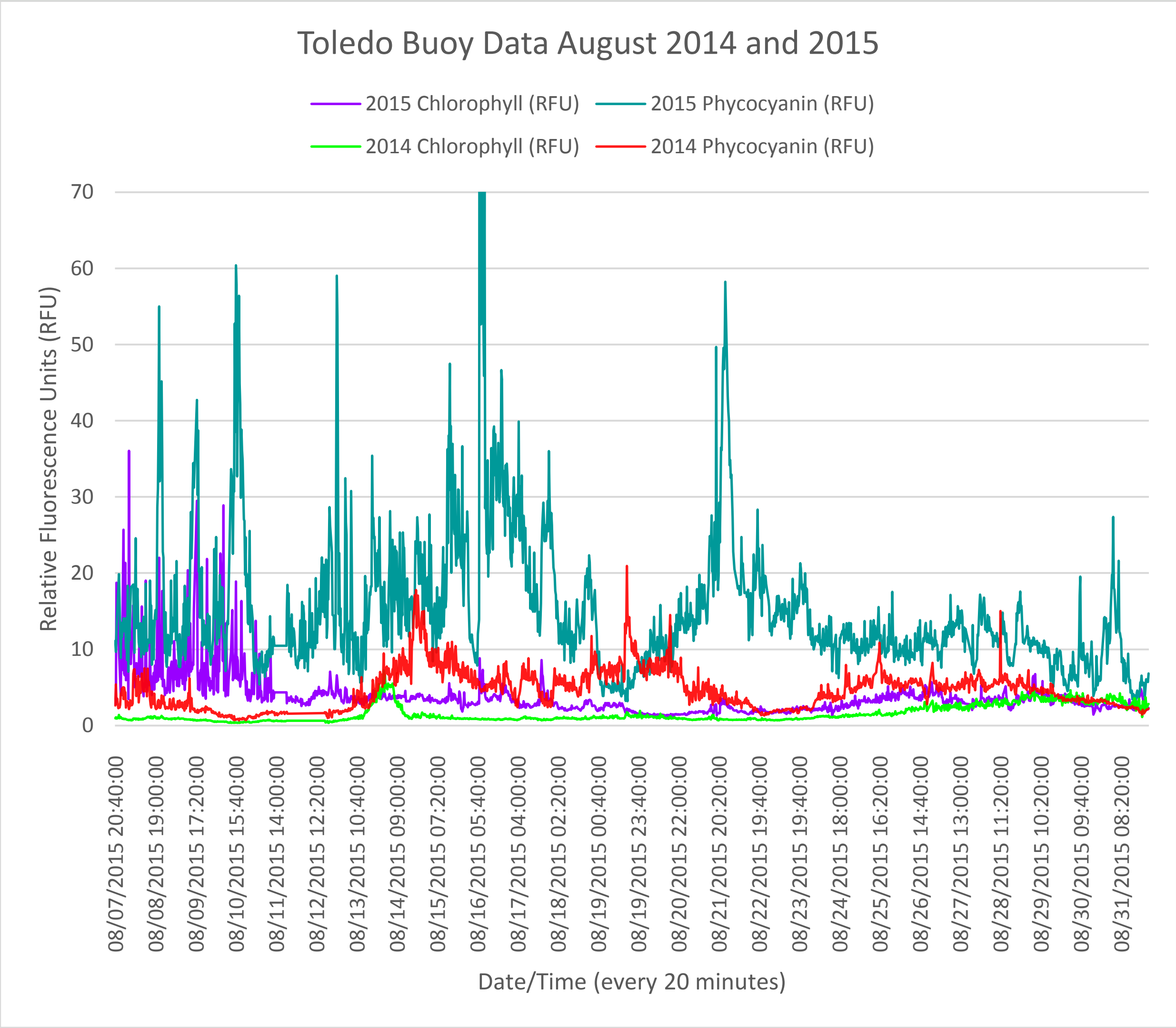
# Early Warning System

## MODIS Images




**Cloud cover often interferes with MODIS images**.

# Early Warning Systems

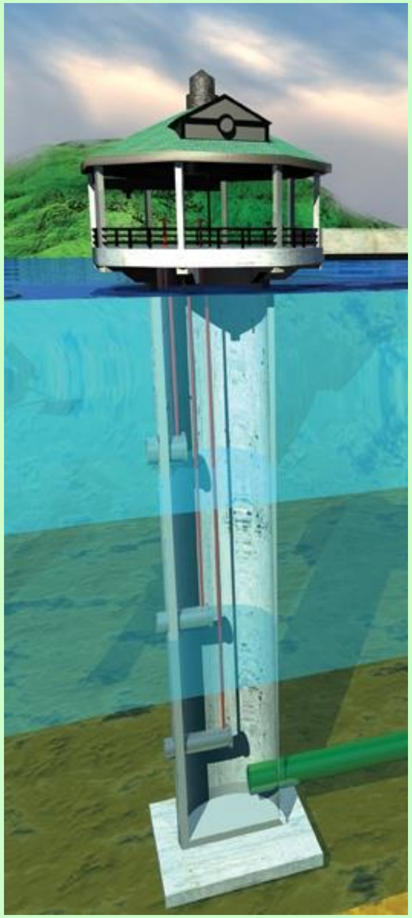


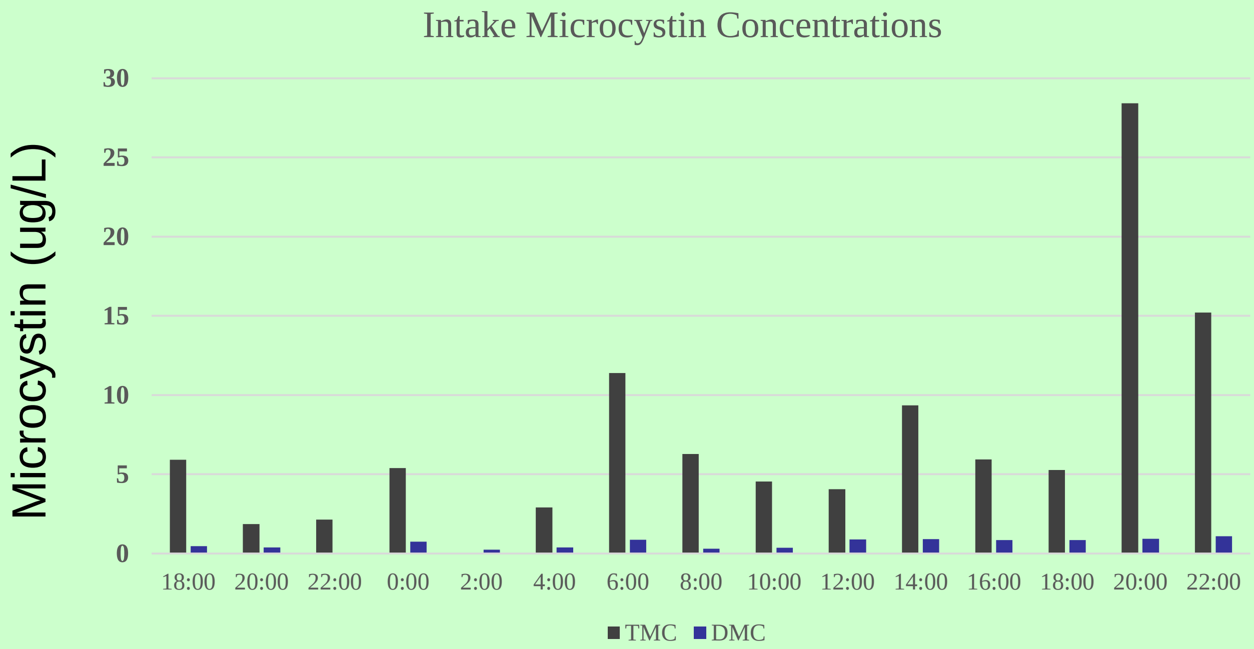

Buoys: Fluorescence Probe

Remote sensing: MODIS

# Intake

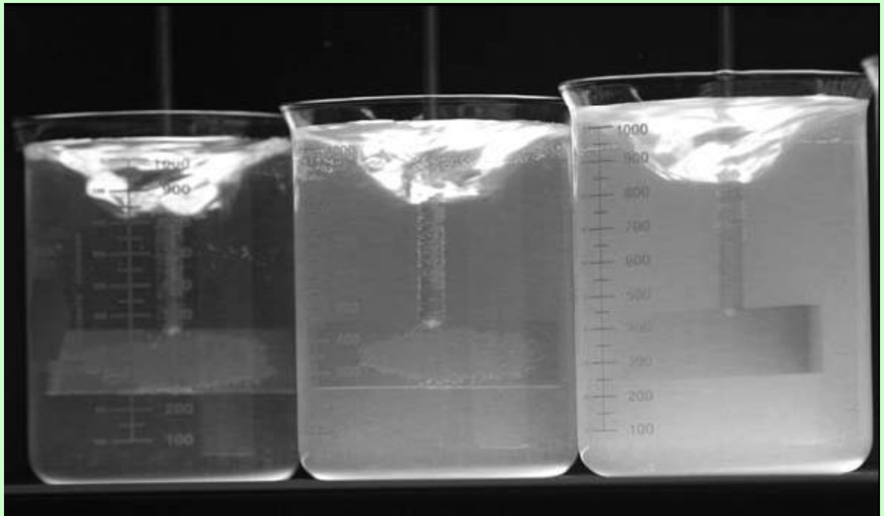
- Intracellular Toxin
  - Adjustable Intake
  - Night vs Day
- Extracellular Toxin
  - Oxidants
  - Inline Powdered Activated Carbon (PAC)
- A conventional treatment plant will want to keep the cells intact.





# 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 |

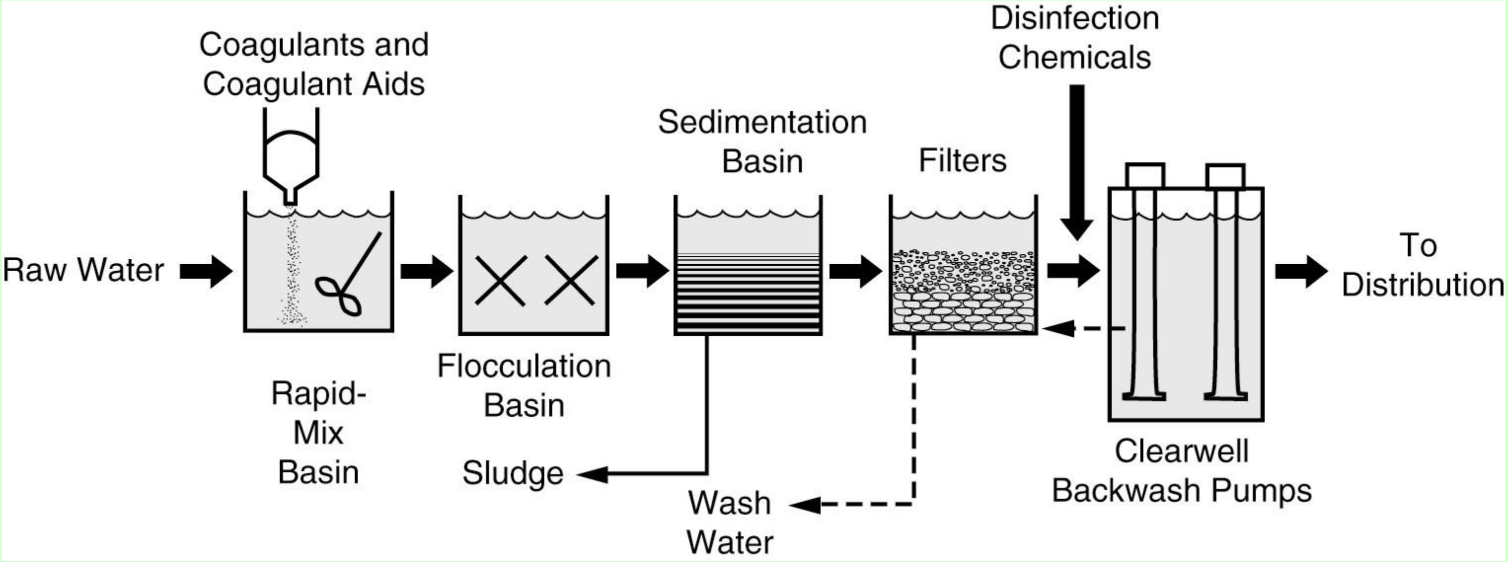
**Table 2.2.1.** Range of cell removal by water treatment for total cyanobacteria and toxin-producers.
* log removal cannot be determined. Toxin producer numbers were very low in the raw water, and not detected in the finished water.

| 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

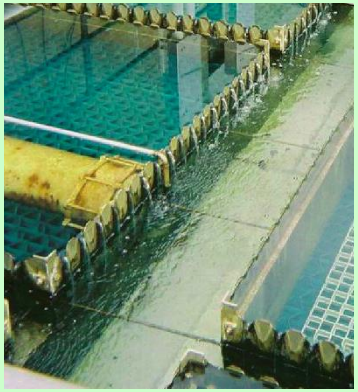
- Intracellular Toxin
  - Oxidants (not often used, afraid of lysing cell)
  - Flocculent aides
  - Settled water with less than 100 units algae/mL
- Extracellular Toxin
  - Activated Carbon
    - Powder (PAC)
    - Granular (GAC)
  - Filtration
    - Conventional
    - Biologically Active
- Monitoring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

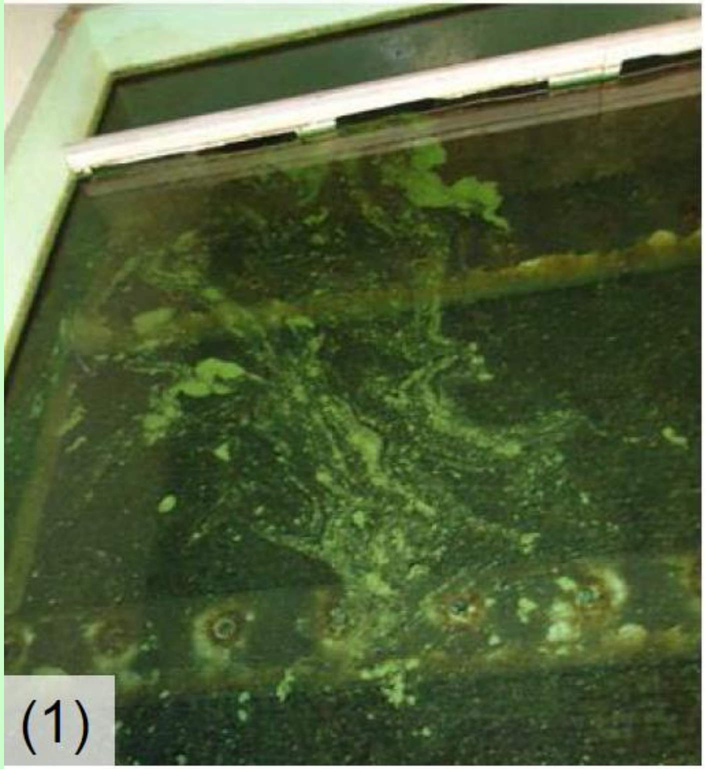
# Ultrasonic Technology Treatment



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





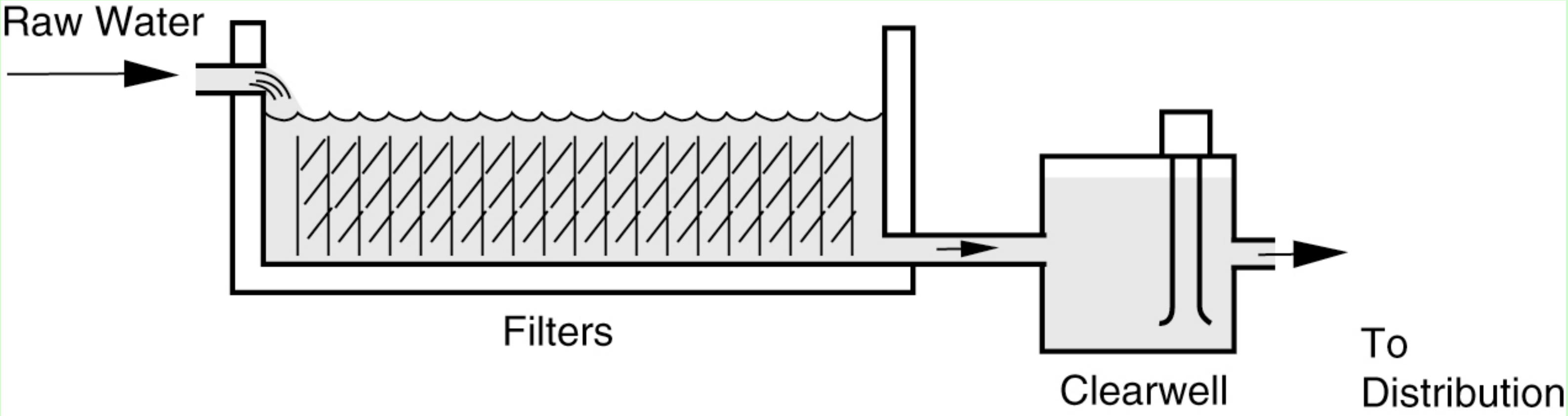
**WARNING: 9180 µg/L MC-LR**


**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

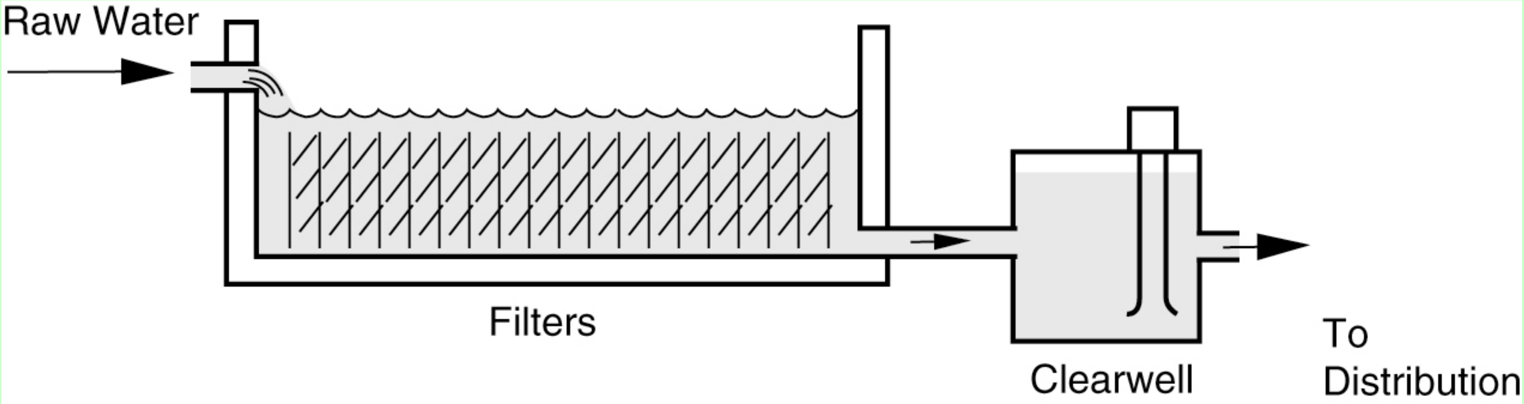


# Biologically active filters

- 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

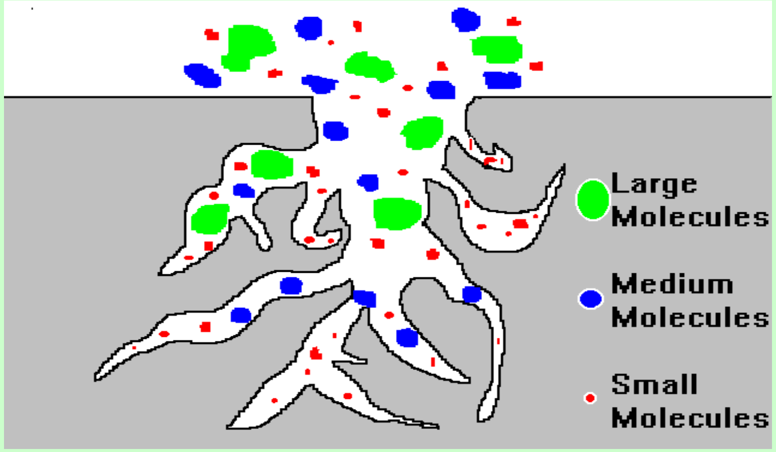
# GAC filtration

- 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



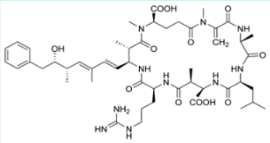
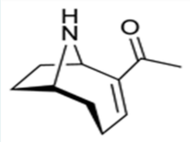
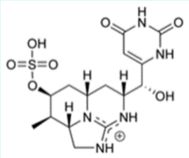
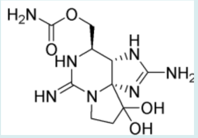
# Pore Size

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



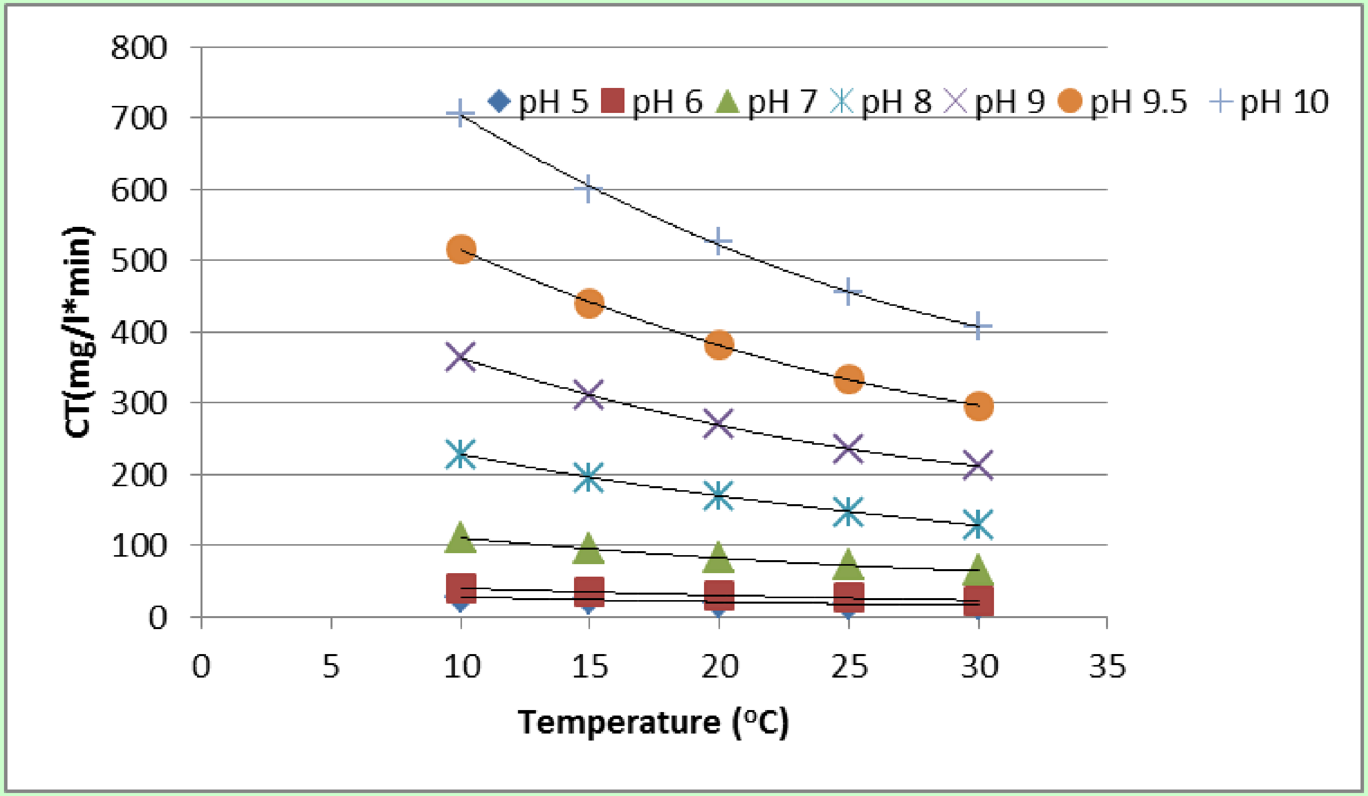

- Kinetic <1 hour contact time
- Large pore volume seems to be more effective

# 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

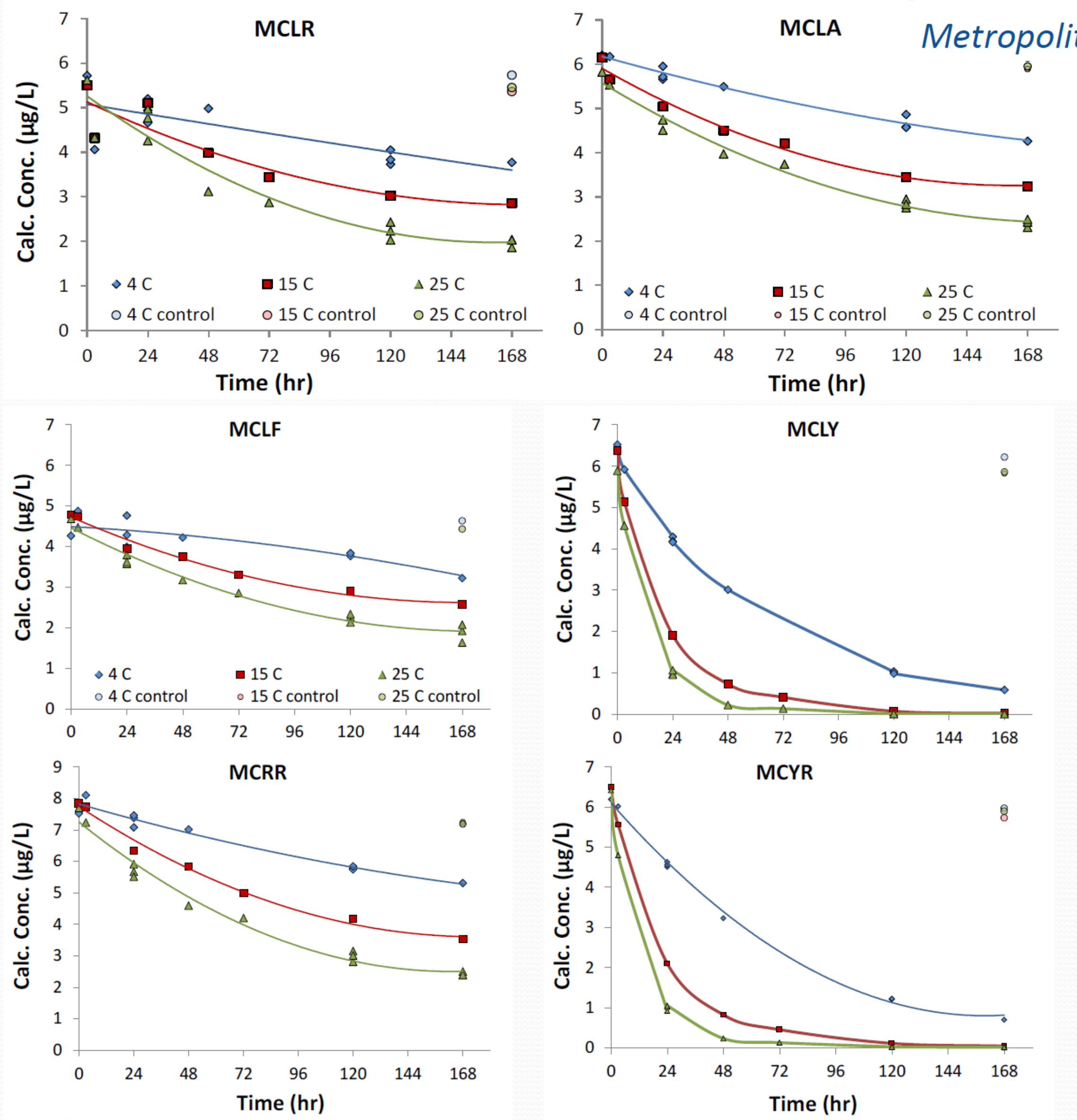
# Contact Time and Temperature

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

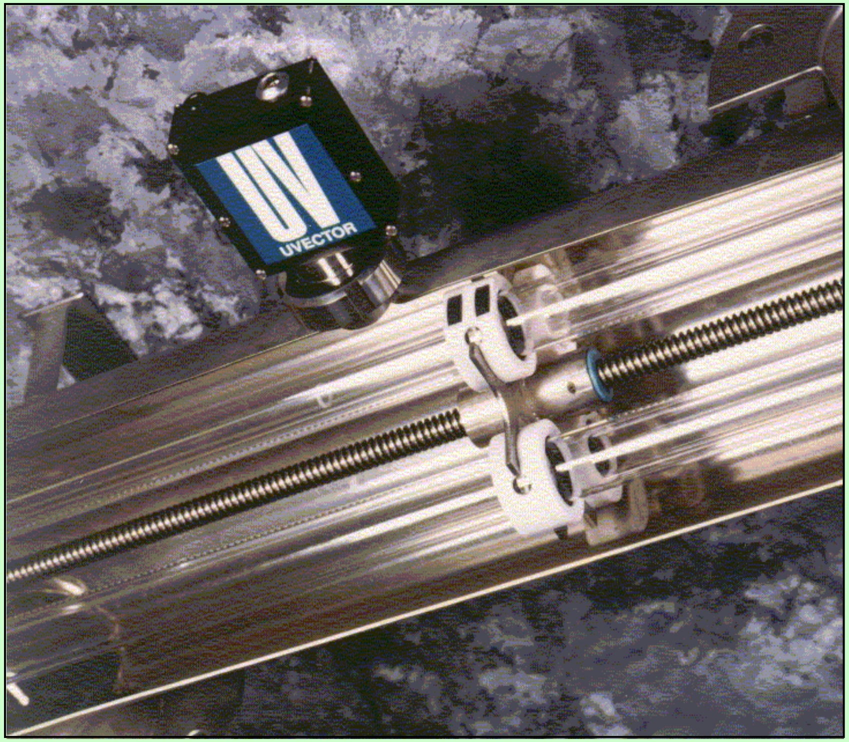
Temperature Dependence
the warmer the better

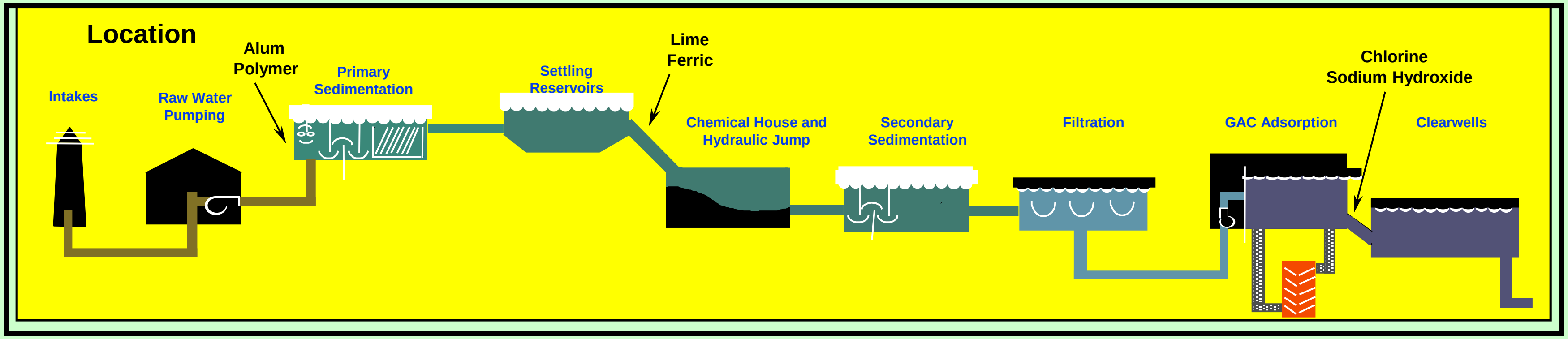
pH Dependence
7 is better than 9

# UV Treatment

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

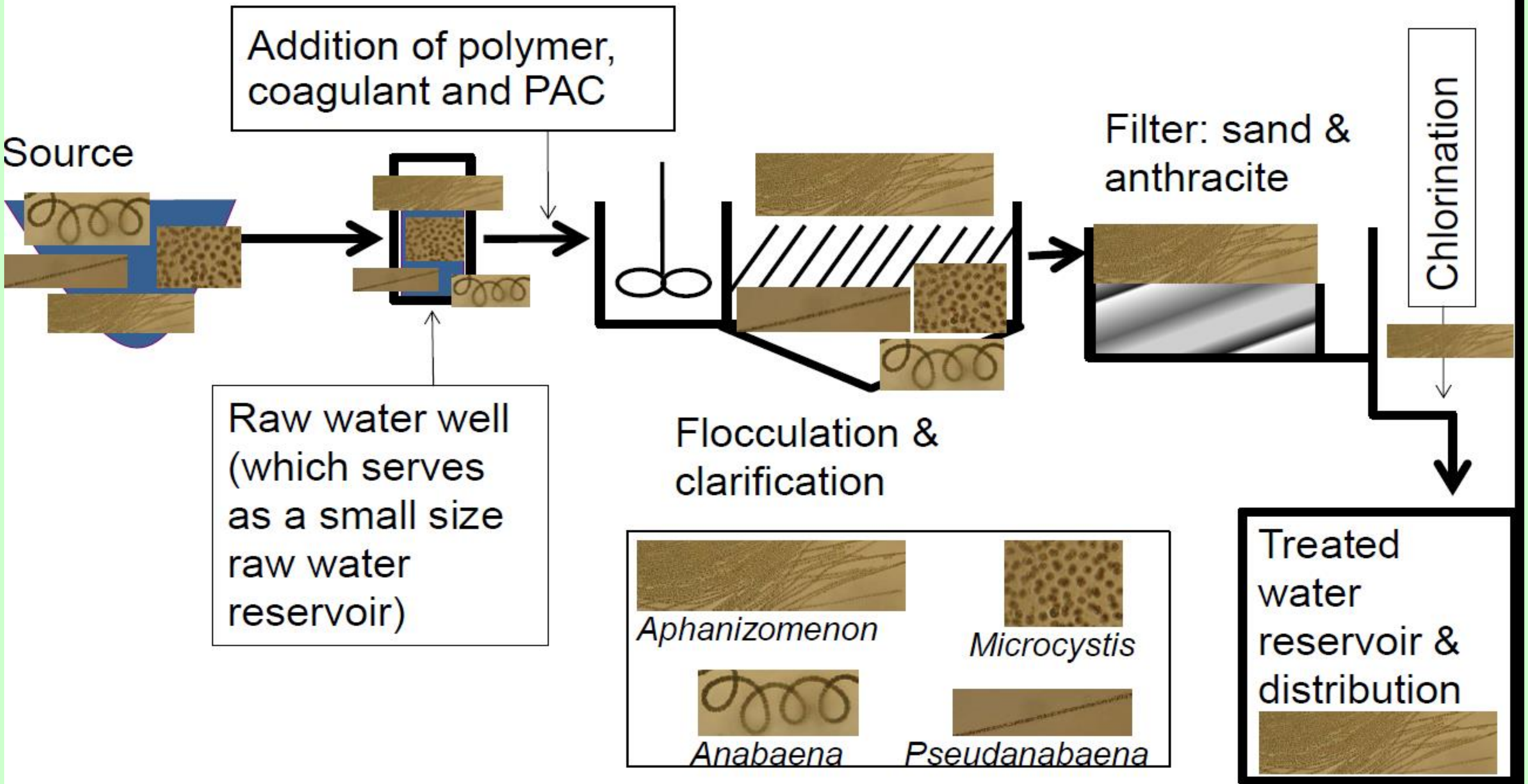
- Photolytic destruction dose for microcystin, cylindrospermospin, anatoxin-a and saxitoxin is 1530 to 20,000 $mJ/cm^2$.






- 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 |
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| OREGON | BLD | BLD | BLD | BLD | BLD | BLD | BLD | BLD | BLD |

# Questions?