

U.S. Environmental Protection Agency, Office of Research and Development
SAFE AND SUSTAINABLE WATER RESOURCES RESEARCH PROGRAM

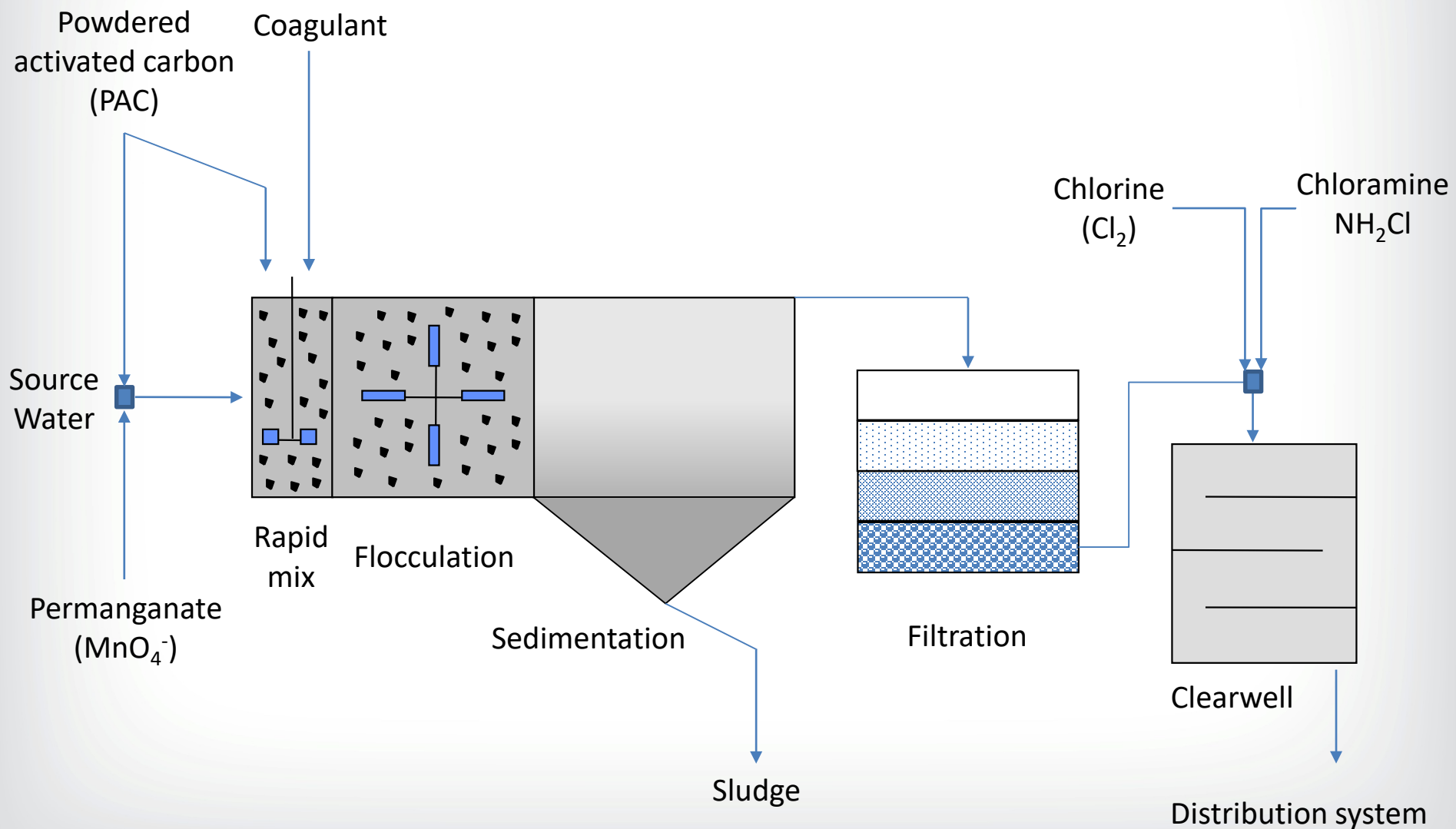


Conventional Treatment Options For HABs Impacted Waters

Nicholas Dugan, PE
Thomas Waters, PE

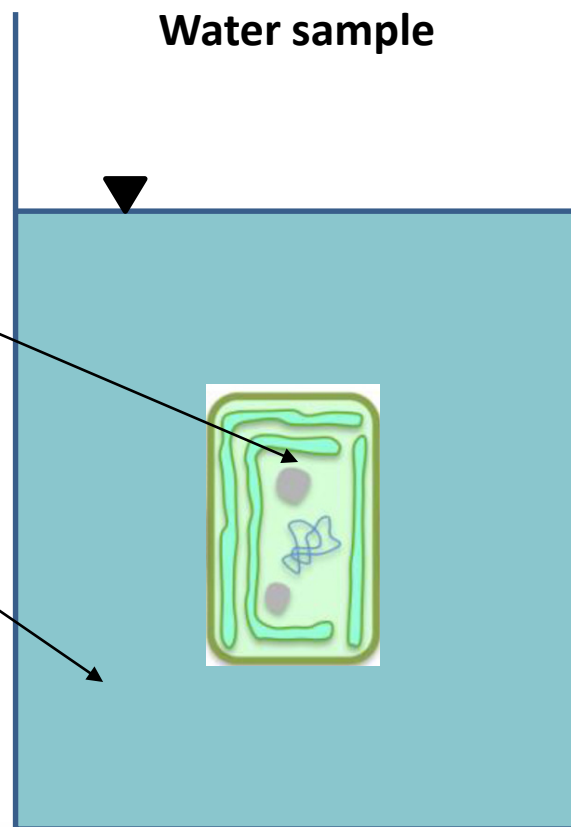


Conventional surface water treatment process



- Cell counts: direct counting of cells under a microscope
- Chlorophyll: pigment molecules in algae and cyanobacteria that play a role in photosynthesis
- Phycocyanin: pigment molecules in cyanobacteria that play a role in photosynthesis
- Microcystin: A type of toxin produced by cyanobacteria, most commonly detected, affects the liver

- Intracellular**
Toxins contained inside the cell
- Extracellular**
Toxins in solution outside the cell
- Combined**
Extracellular + intracellular toxin

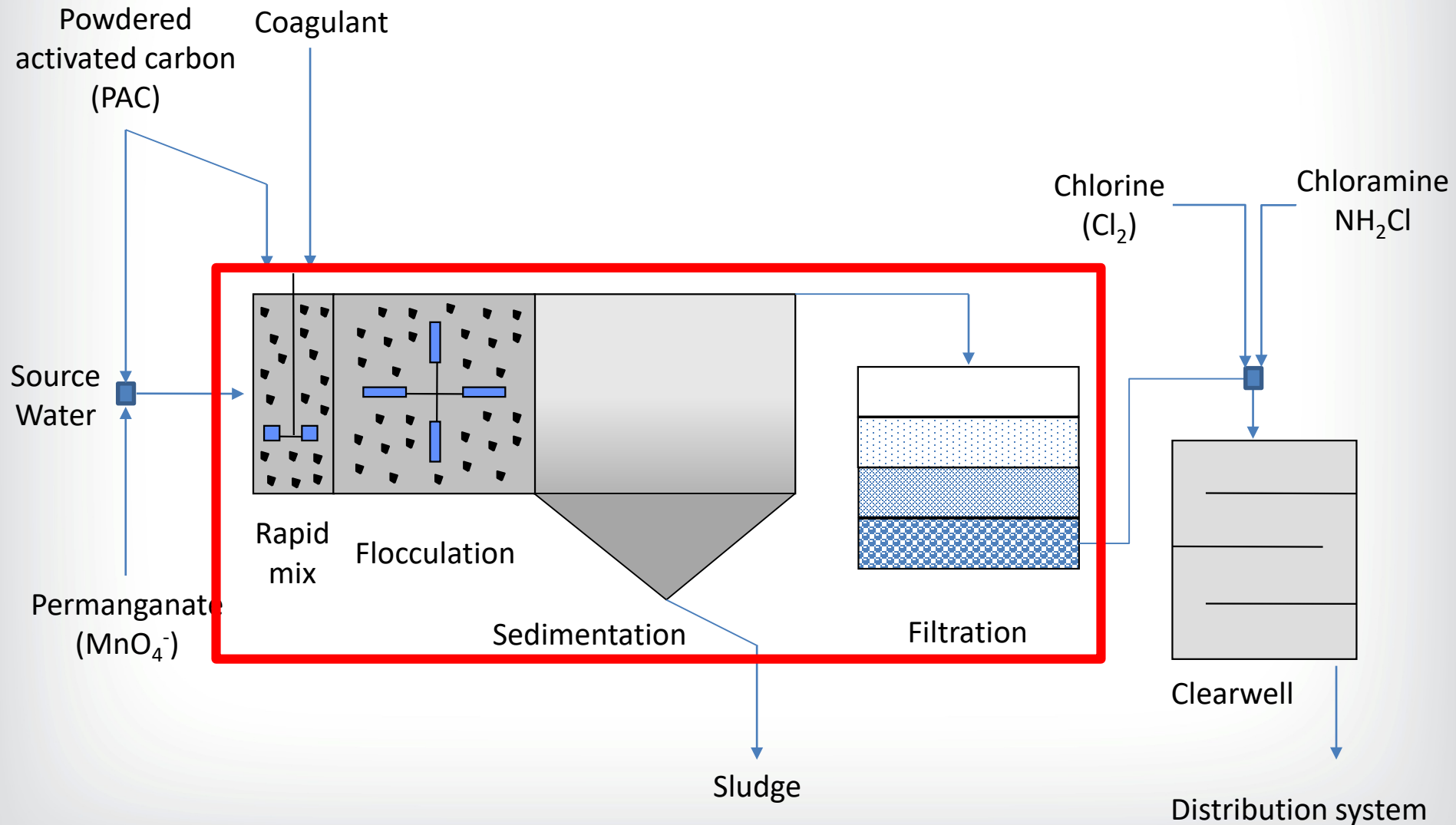


Jar testing



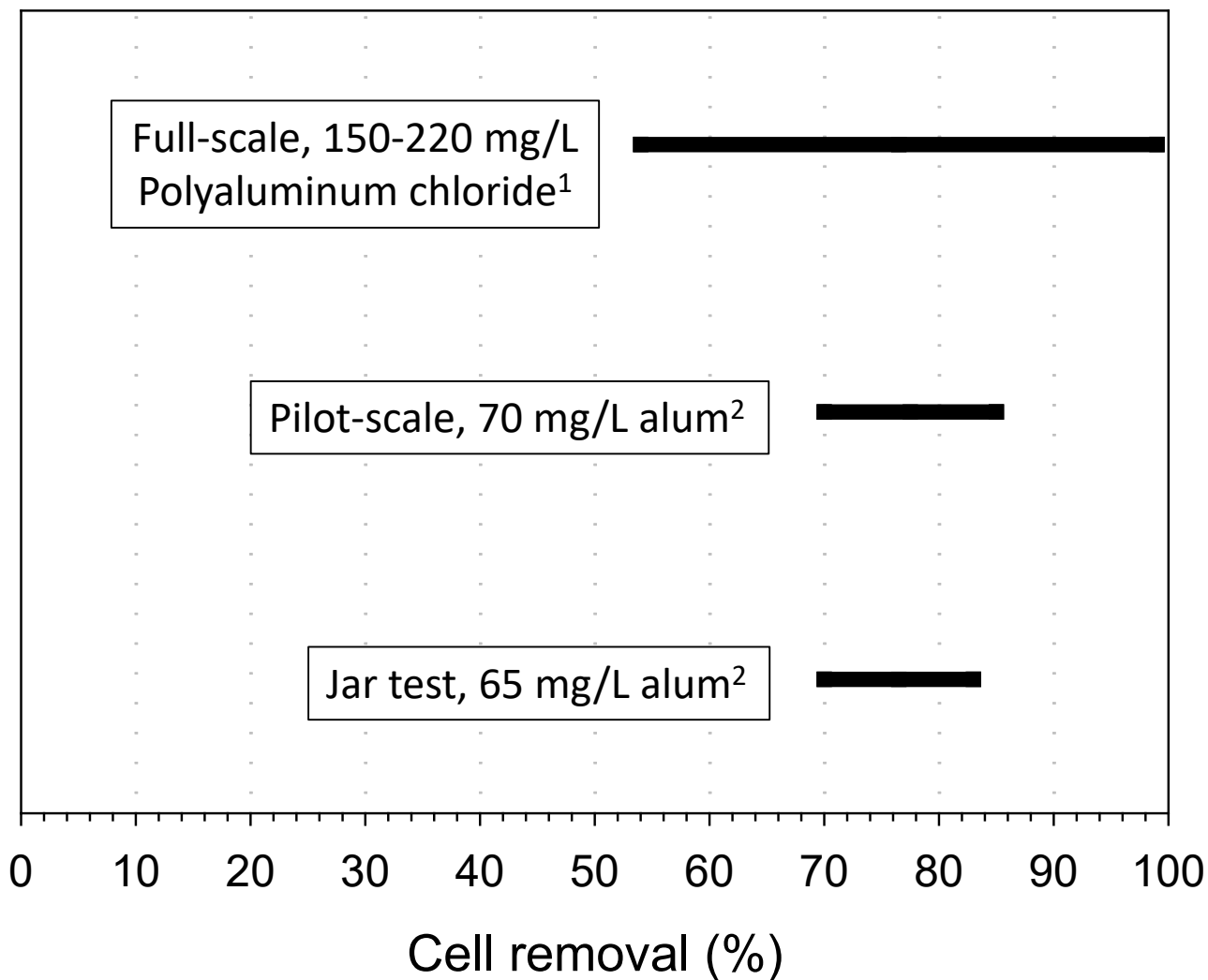


Conventional surface water treatment process





Cell removals through coagulation and sedimentation



¹Zamyadi et al; *Species Dependence of Cyanobacteria Removal Efficiency by Different Drinking Water Treatment Processes*; Water Research; 2013:47:2689-2700

²Drikas et al; *Using Coagulation, Flocculation and Settling to Remove Toxic Cyanobacteria*; Journal AWWA; 2001:93:2:100-111



Toxin removals through pilot-scale coagulation, sedimentation and filtration

Sample point	Toxin type	Microcystin-LR concentration (µg/L)	
		Trial 1	Trial 2
Influent	Combined	119	60
	Extracellular	3	2
Effluent	Combined	3	2
	Extracellular	3	2



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Bench-scale coagulation experiments with *M. aeruginosa*

Water source/pH	Dose necessary to achieve 80% removal of cells (mg/L)		
	Aluminum chlorohydrate	Ferric chloride	Aluminum sulfate
Myponga Reservoir			
pH 7.5 – 7.8	40	40	60
pH 6.3	20	40	60
River Murray			
pH 7.2 – 7.6	20	40	80
pH 6.3	20	20	60

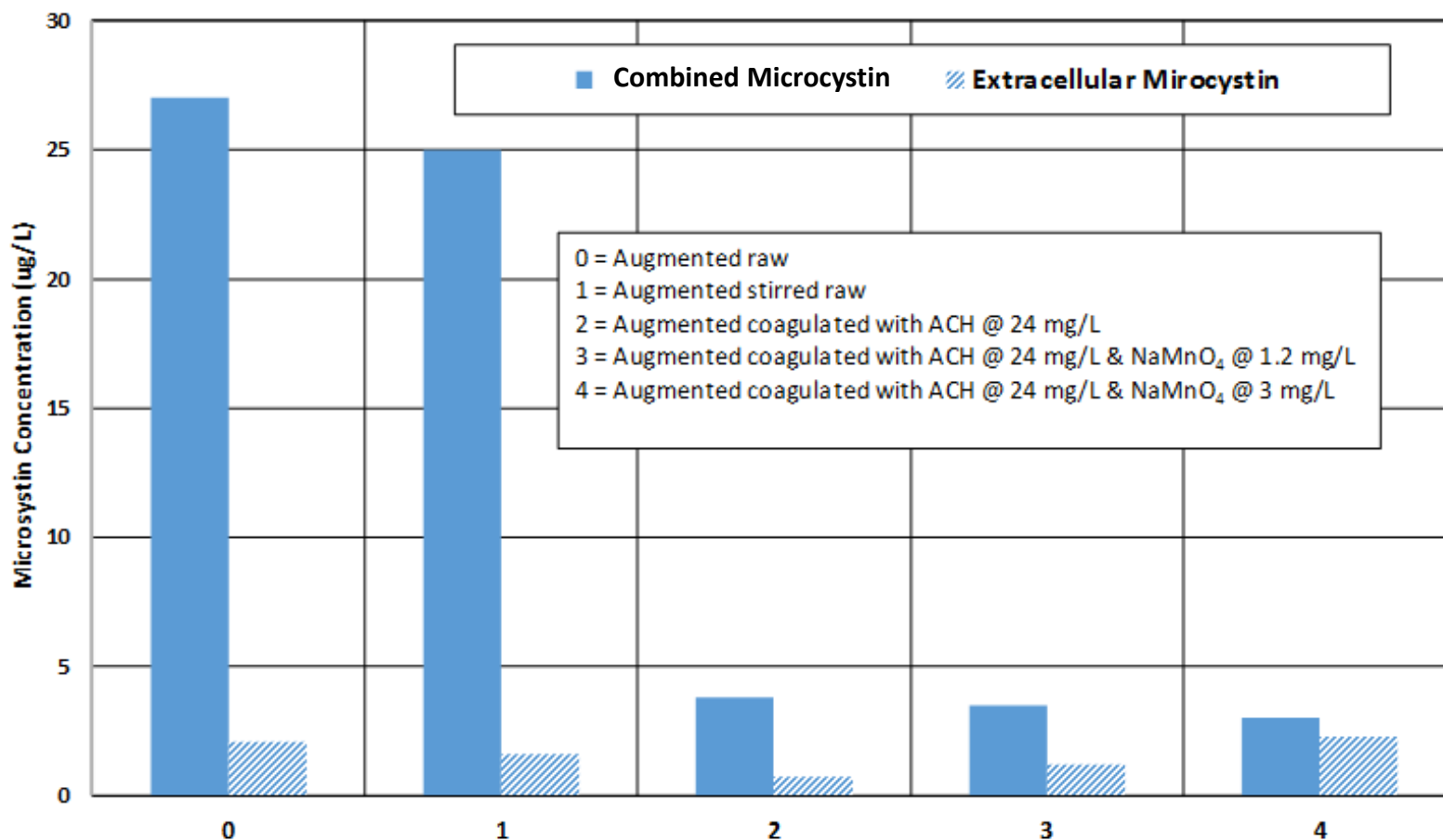
Myponga turbidity = 1.2 – 8.7 NTU, DOC = 10 – 12 mg/L

Murray turbidity = 23 – 101 NTU, DOC = 5.3 - 17

Source: Newcombe, G. et al; *Optimizing Conventional Treatment for the Removal of Cyanobacteria and Toxins*; Water Research Foundation, Denver CO; 2015

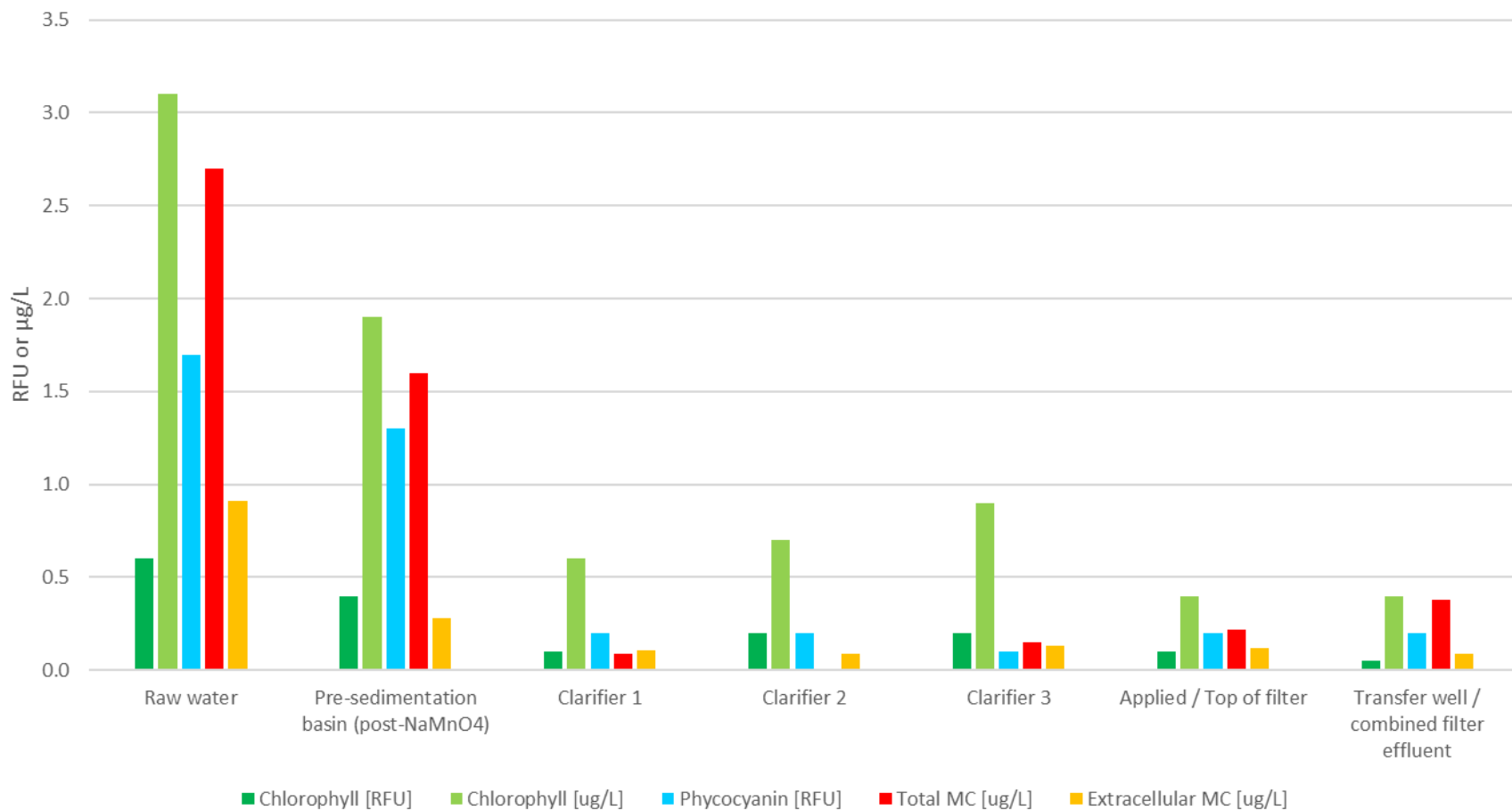


Bench-scale coagulation experiments with Lake Erie water and cyanobacteria



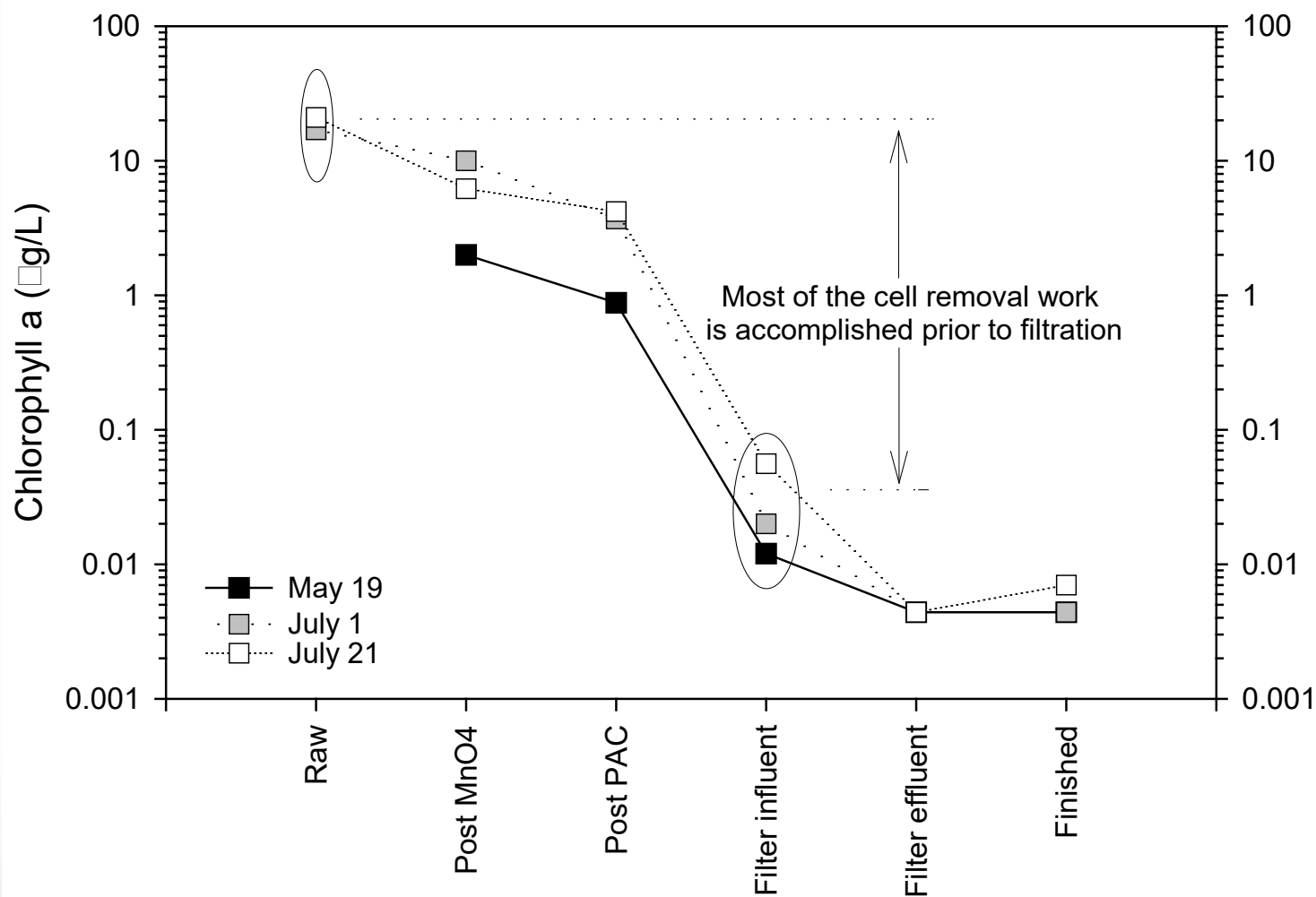


Through-plant sampling – Lake Erie water treatment plant



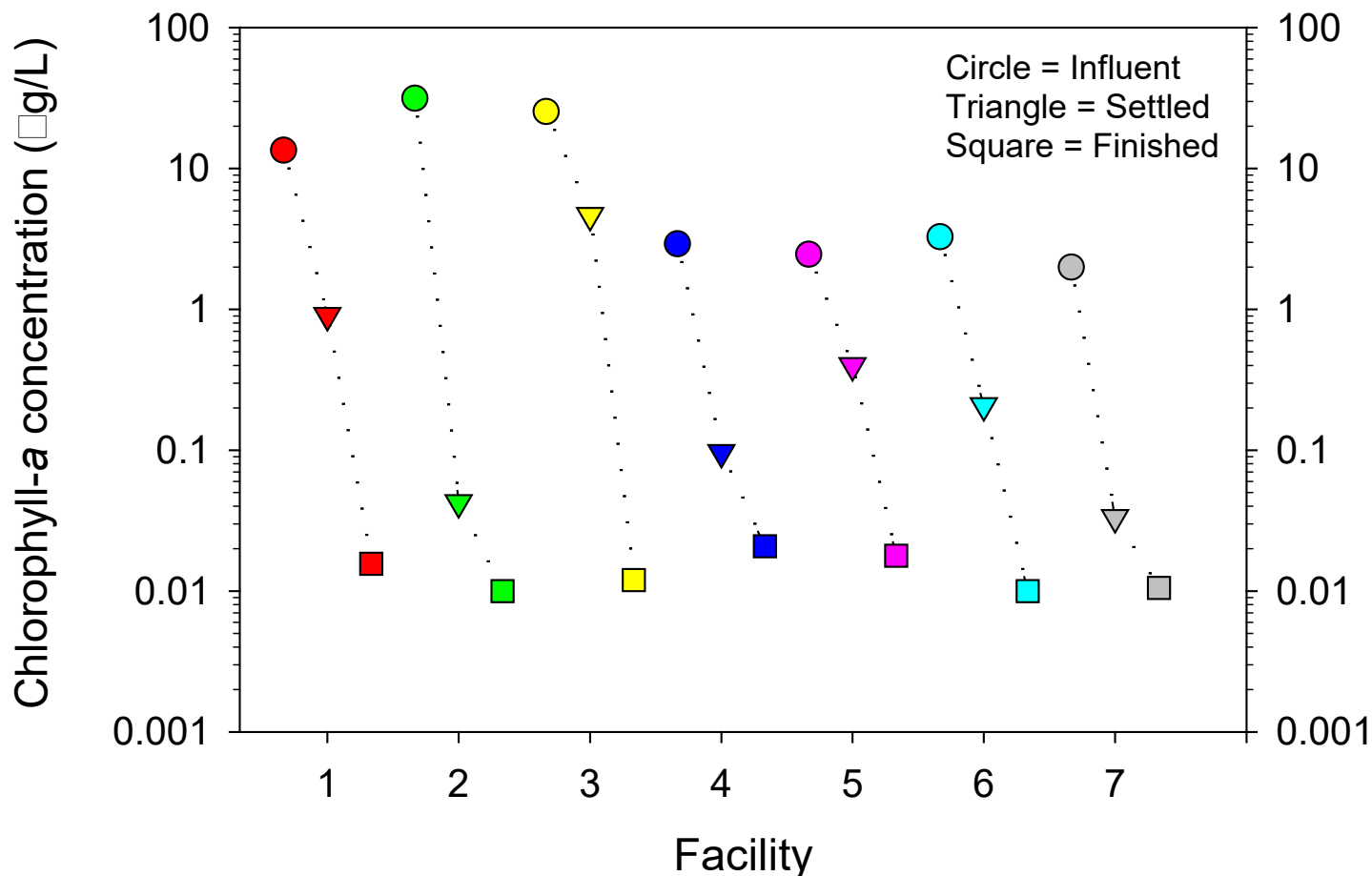


Cell propagation through a full-scale Lake Erie treatment facility





Physical removal of cells through seven full-scale Lake Erie facilities



Each data point represents the average of 5 – 7 samples collected between May and October

West → 150 miles → East



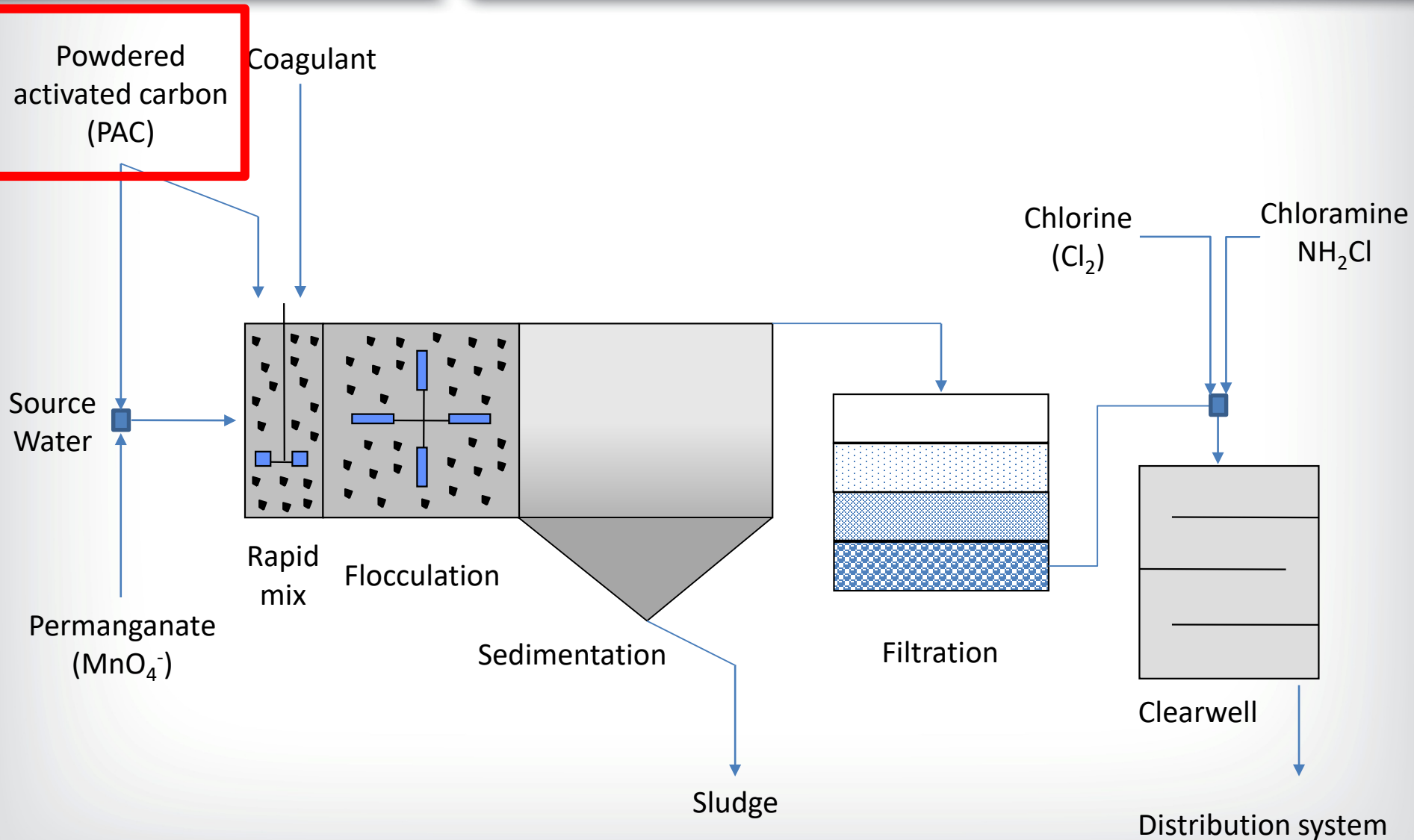
Filtration of *M. aeruginosa* Pilot-scale seeding trial results

Coagulant	Baseline filter loading rate (m/hr)	Steady-state removal of chlorophyll- <i>a</i> (Δ log)
Alum + cationic polymer	7	2.8
	10	2.5
Ferric chloride + cationic polymer	7	2.9
	10	3.8

- Average influent chlorophyll-*a* concentration = 26 $\mu\text{g/L}$ (SD = 12 $\mu\text{g/L}$)
- 1 m/hr = 0.41 gal/min $\cdot\text{ft}^2$

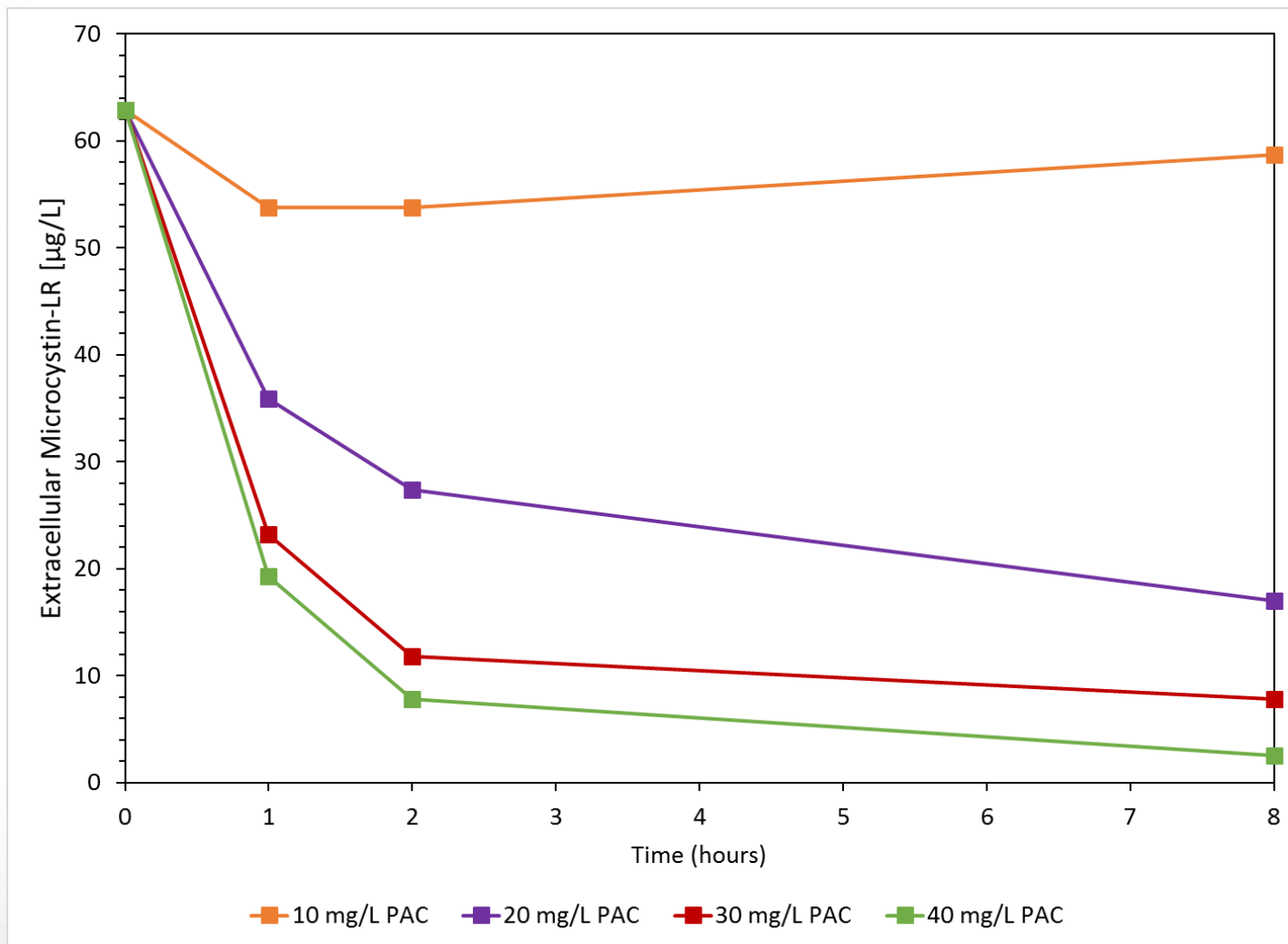


Conventional surface water treatment process



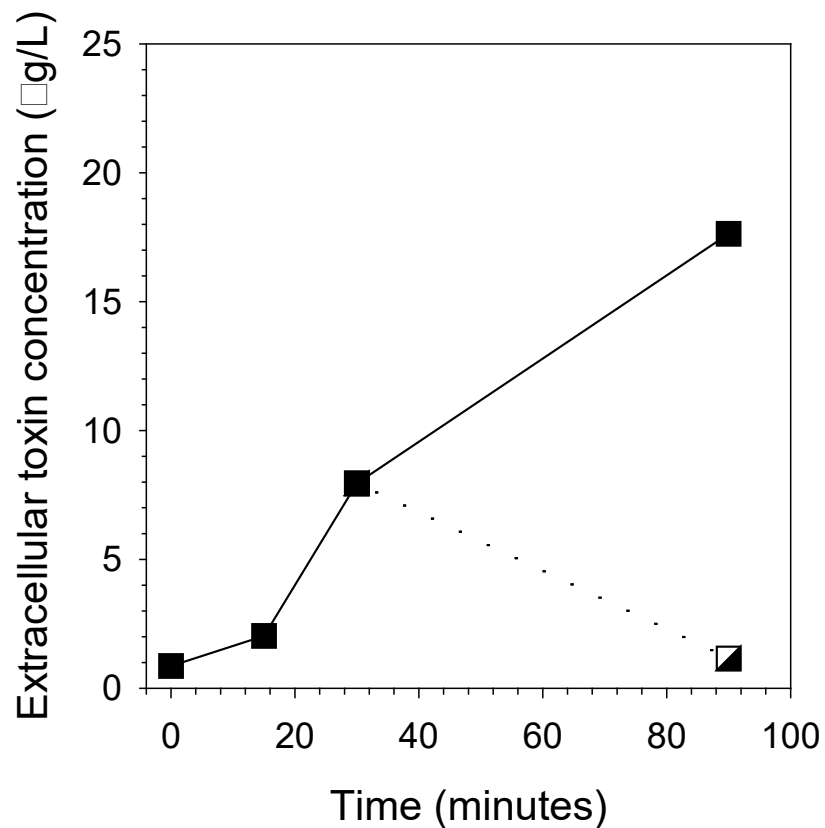
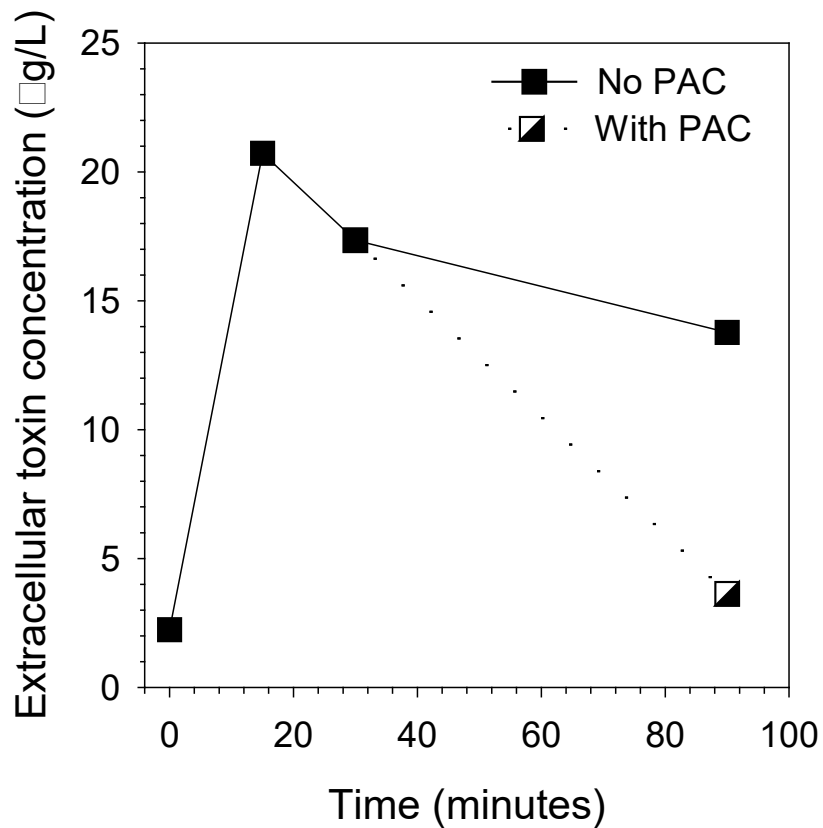


Impact of powdered activated carbon (PAC) addition – microcystin spiked into raw surface water



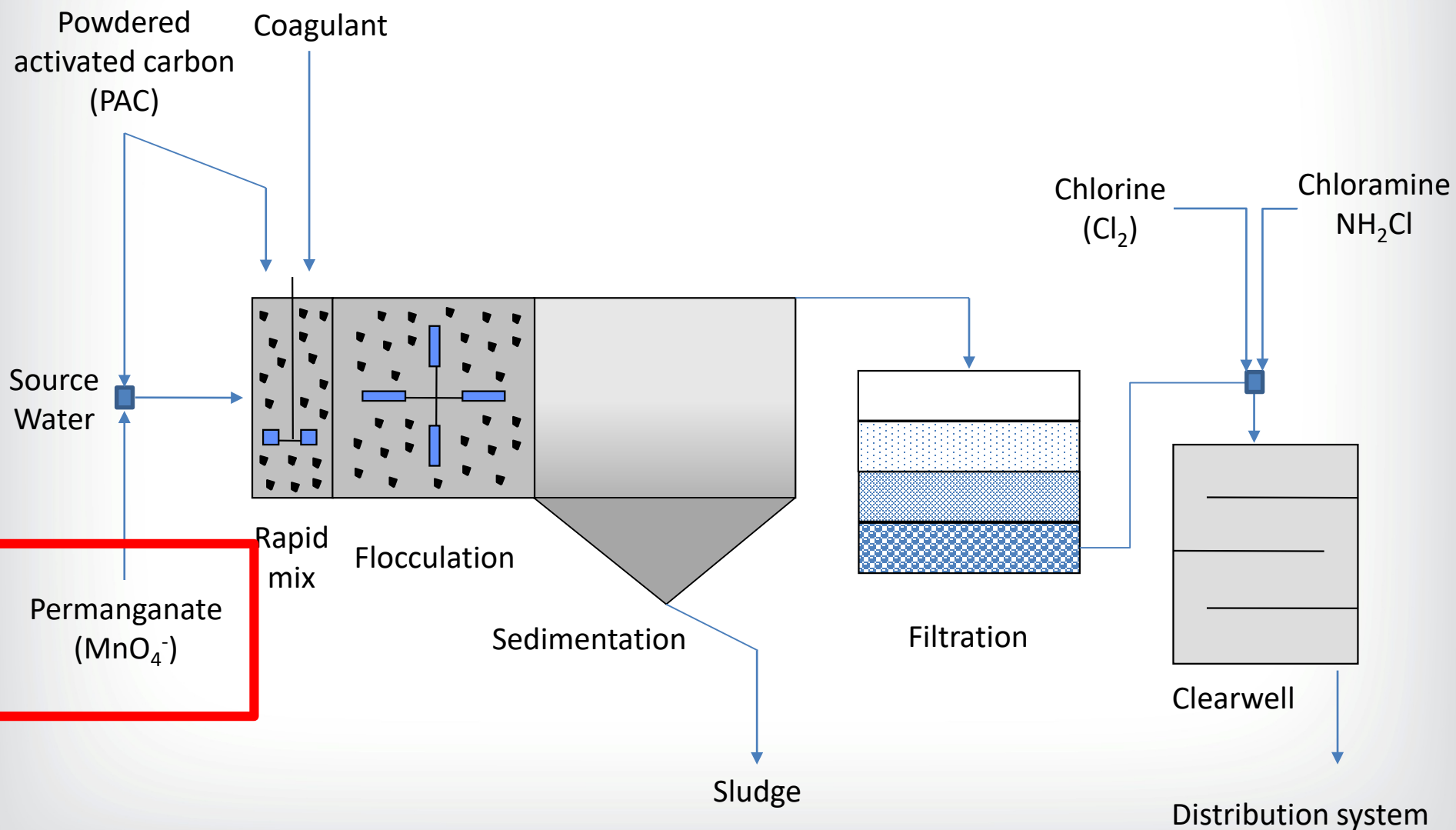


Impact of powdered activated carbon (PAC) addition – carbon added after toxin release from cyanobacterial cells



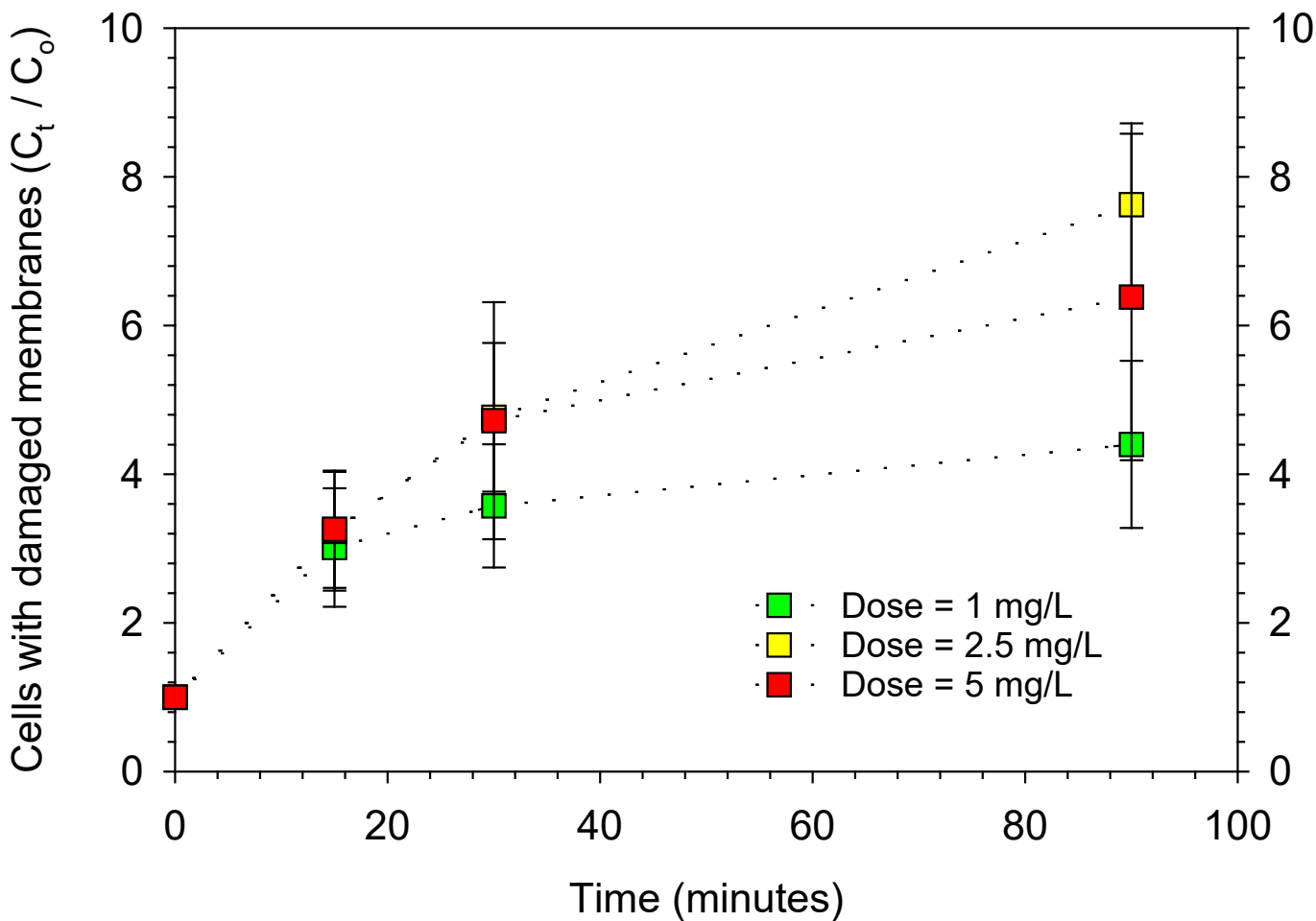


Conventional surface water treatment process



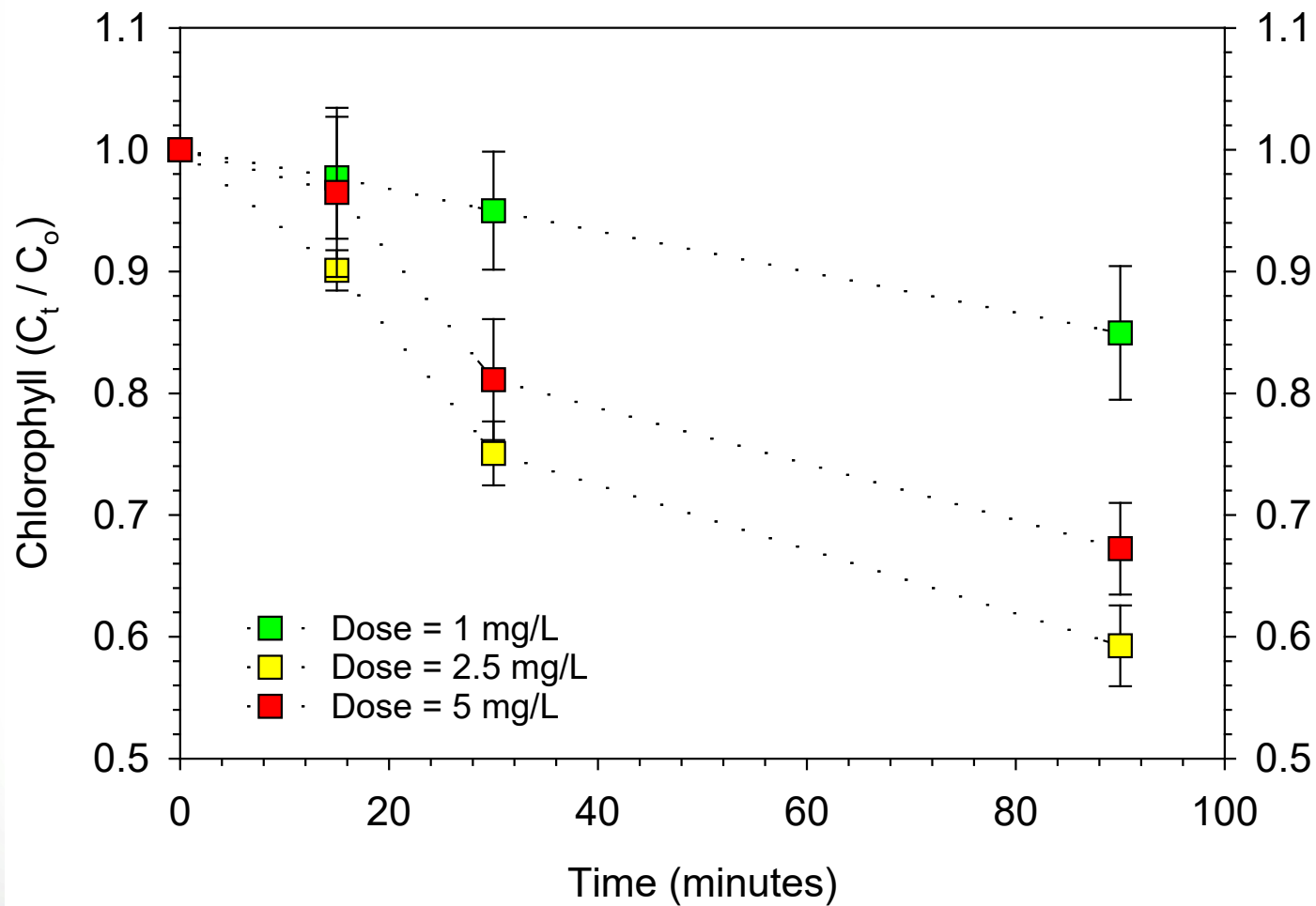


Impact of KMnO_4 on cyanobacterial cell membrane integrity



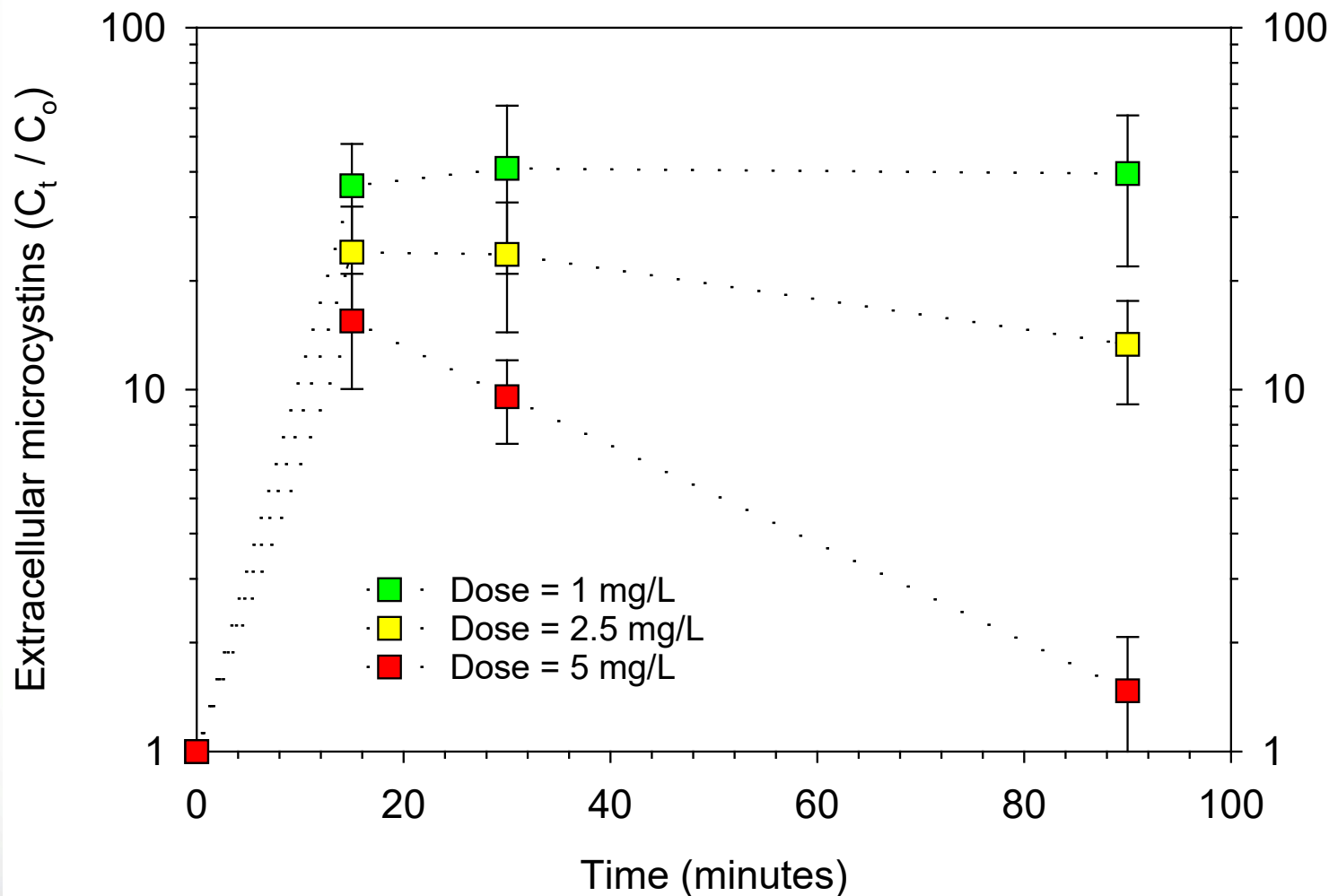


Impact of KMnO_4 on chlorophyll in cyanobacterial cells



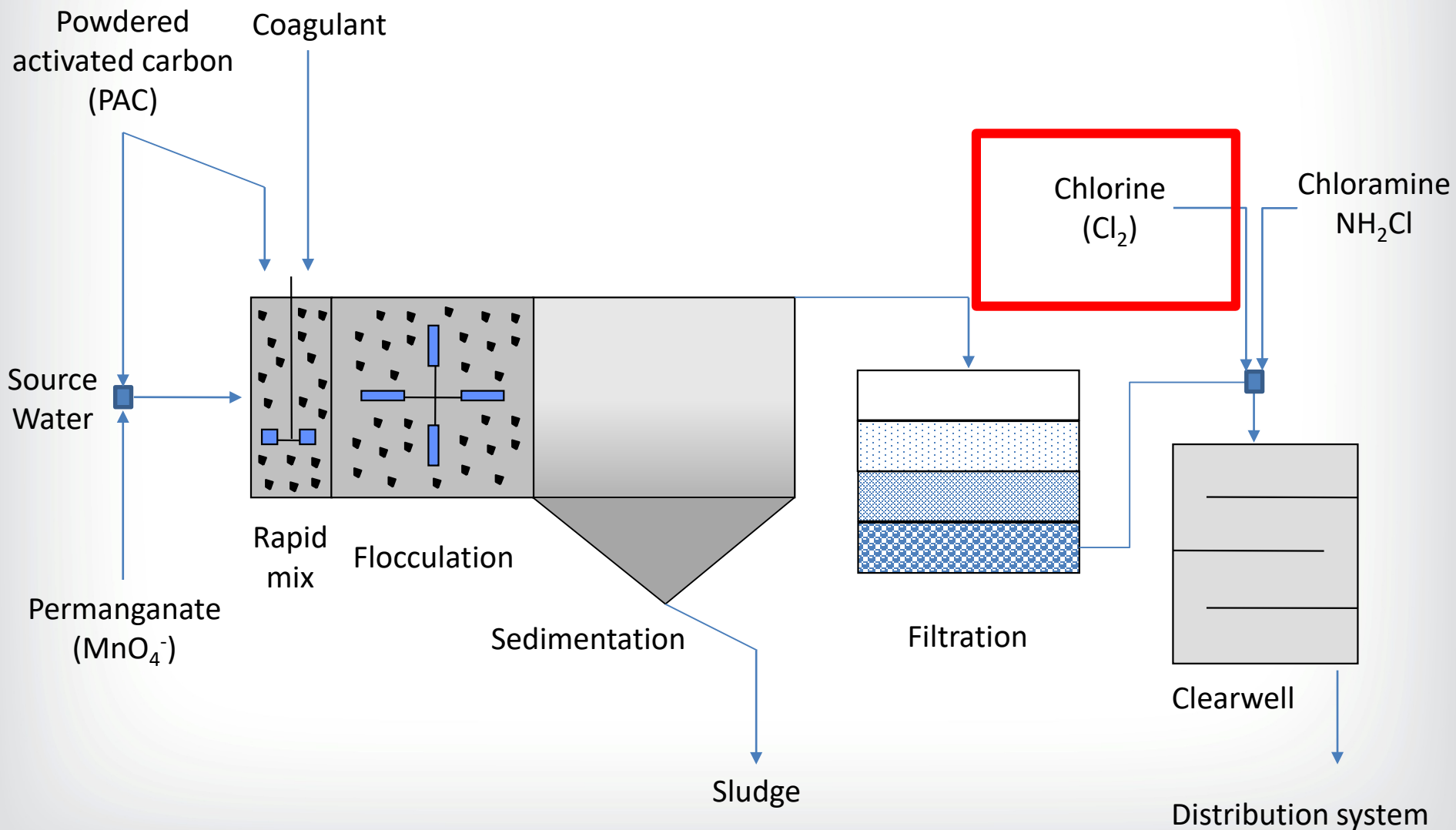


Impact of KMnO_4 on toxin release from cyanobacterial cells and subsequent degradation





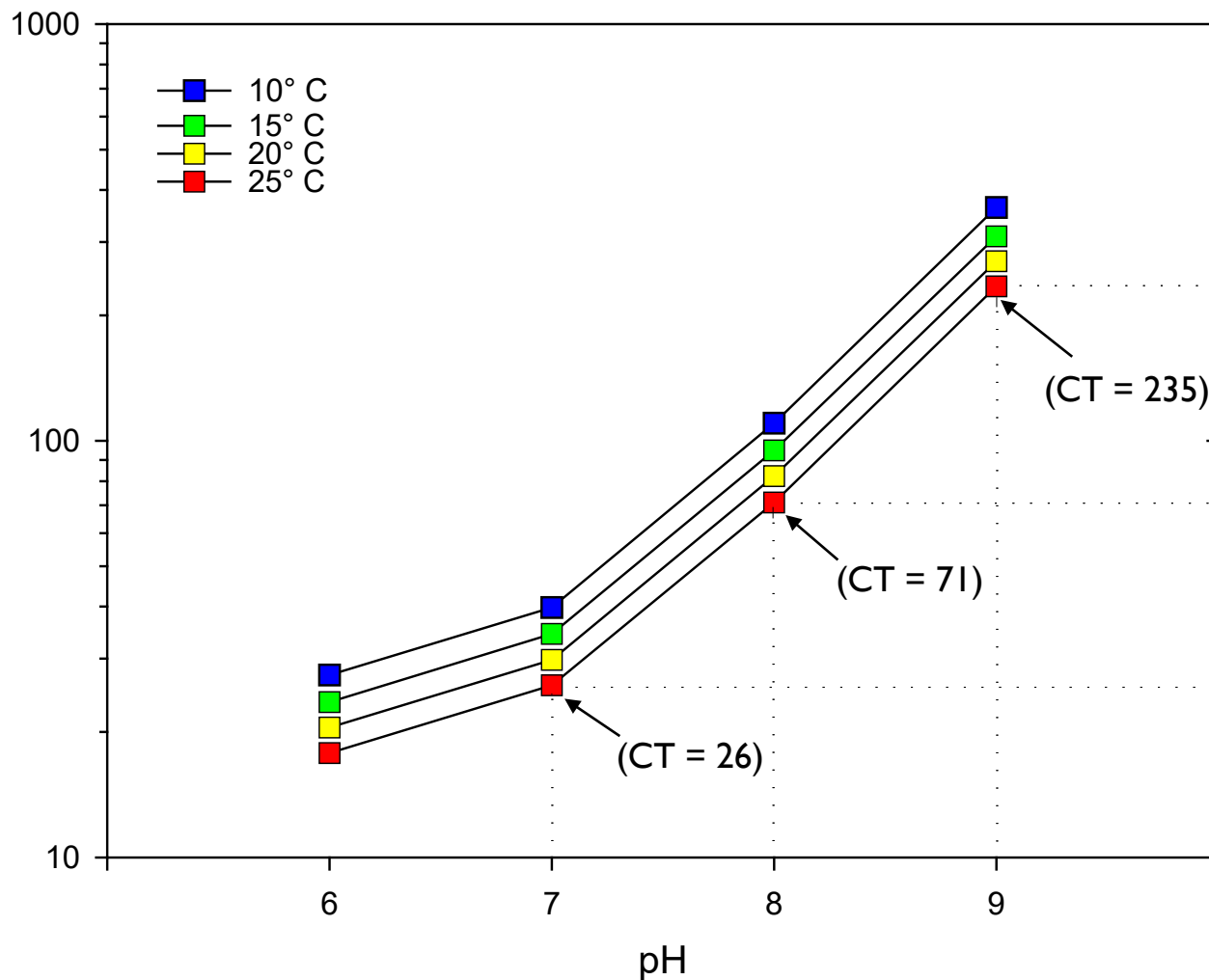
Conventional surface water treatment process





Impact of chlorination on microcystin concentrations

CT (mg/L x min) necessary to reduce microcystin-LR concentration from 10 μ g/L to 1 μ g/L



CT for 3-log *Giardia* inactivation
@ 1.0 mg/L Cl_2 , $t = 25^\circ \text{C}$:

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

> 3X increase
in CT

> 2X
increase in
CT

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



UV irradiation

- UV contactors installed toward the end of the treatment process – cells and intracellular toxins have been removed, only extracellular toxin remaining
- Required UV doses for 2-log disinfection of *Cryptosporidium* = 5.8 mJ/cm², *Giardia* = 5.2 mJ/cm², virus = 100 mJ/cm²
- These doses drive full-scale UV contactor design
- UV doses required for microcystin degradation are significantly higher – existing UV infrastructure not a barrier to toxin passage



Ozone and chlorine dioxide

- Chlorine dioxide, at the doses used in drinking water treatment (to limit the formation of chlorite) is not considered effective against microcystins – reaction rate is approximately 3 orders of magnitude lower than permanganate
- Ozone has been proven effective at degrading microcystins as well as cylindrospermopsins and anatoxin – reaction rate is sufficient to achieve degradation within the confines of ozone contactors used in full-scale drinking water treatment

- Core conventional treatment processes – coagulation, flocculation, sedimentation, filtration - are highly effective at removing cyanobacterial cells – shown to work across a range of coagulants
- PAC effectively adsorbs microcystins – however, the exact carbon dose will vary depending on the type of carbon and the concentration of background of organic material



Conclusions

- Chlorine effectively degrades microcystins – but the rate of degradation is temperature and pH dependent
- Ozone effectively degrades microcystins
- Chlorine dioxide and UV, at the dose levels commonly employed in drinking water treatment, are not effective
- Permanganate effectively degrades dissolved microcystins – however, the typical location for permanganate addition, early in the treatment process where cyanobacterial cell concentrations are still high, sets up a potential for toxin release – vigilance is recommended



Disclaimer

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Contact information

Nicholas Dugan

dugan.nicholas@epa.gov

513-569-7239

US Environmental Protection Agency
Water Supply and Water Resources Division
26 West Martin Luther King Drive
Cincinnati, OH 45268