Strategic Management of Harmful and Nuisance Algal Blooms Series

Managing the Impacts of Algal Blooms in Drinking Water Treatment Plants

October 16, 2019

CWN Webinars

Connecting water professionals to decision-ready knowledge

Canadian Water Network

Insights for the water sector

helping decision-makers move forward

Canadian Water Network frames what is known and unknown in a way that usefully informs the choices being made.

cwn-rce.ca

Algal Bloom Impacts

- Human health
- Drinking water treatment plants
- Flora and fauna
- Recreational use
- Local economies

Algal Blooms in Canada

- A recurring issue for municipalities
- The severity, frequency & geographical distribution are increasing
- Increases are driven by human activities and climate change
- Difficult to determine extent and costs of algal blooms on a national scale

Factors **causing** algal blooms

- Nutrients
- Light
- Temperature
- Water circulation
- Competition with and predation by other organisms
- Salinity

Factors **causing** algal blooms

- Nutrients
- Light
- Temperature
- Water circulation
- Competition with and predation by other organisms
- Salinity

Factors **exacerbating** algal blooms

- Climate change
- Human activities

Factors **causing** algal blooms

- Nutrients
- Light
- Temperature
- Water circulation
- Competition with and predation by other organisms
- Salinity

Factors **exacerbating** algal blooms

- Climate change
- Human activities

Complete understanding of local contributing factors + holistic management approach

Webinar Speakers

Arash Zamyadi
Research Project Manager at Water Research Australia and Adjunct Academic Fellow at the University of New South Wales

Ron Hofmann
Professor in Civil Engineering at the University of Toronto and NSERC Associate Industrial Research Chair in Technologies for Drinking Water Treatment

Scott Bindner
Vertical Market Manager at Trojan Technologies

Harmful algal and cyanobacterial blooms: Water supply systems and management options

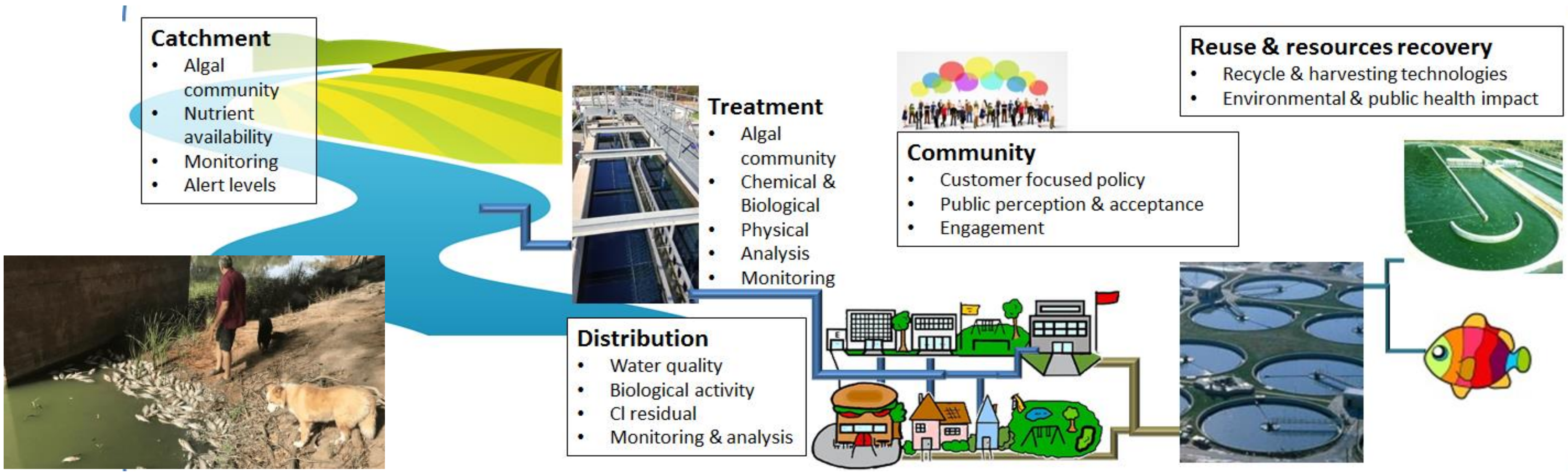
ARASH ZAMYADI, PH.D.

WATER RESEARCH AUSTRALIA (WATERRA) MELBOURNE

WATER RESEARCH CENTRE, UNSW SYDNEY

INTERNATIONAL WATER ASSOCIATION (IWA) FELLOW

Toxic Cyanobacteria Across Our Water Supply Systems!



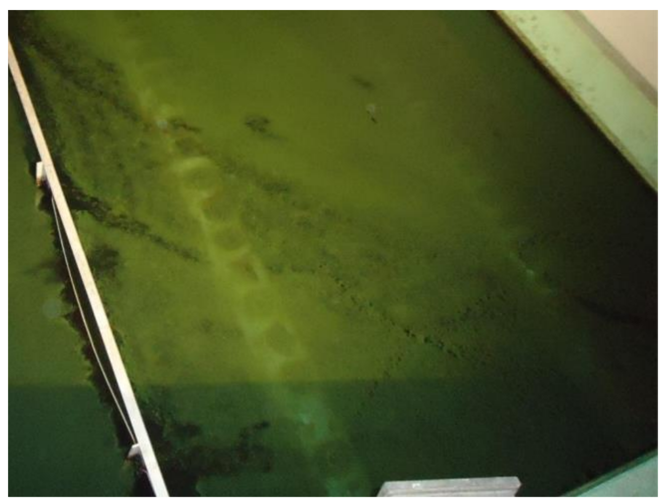
Toxic Cyanobacteria in Our Water Supply Systems!!!

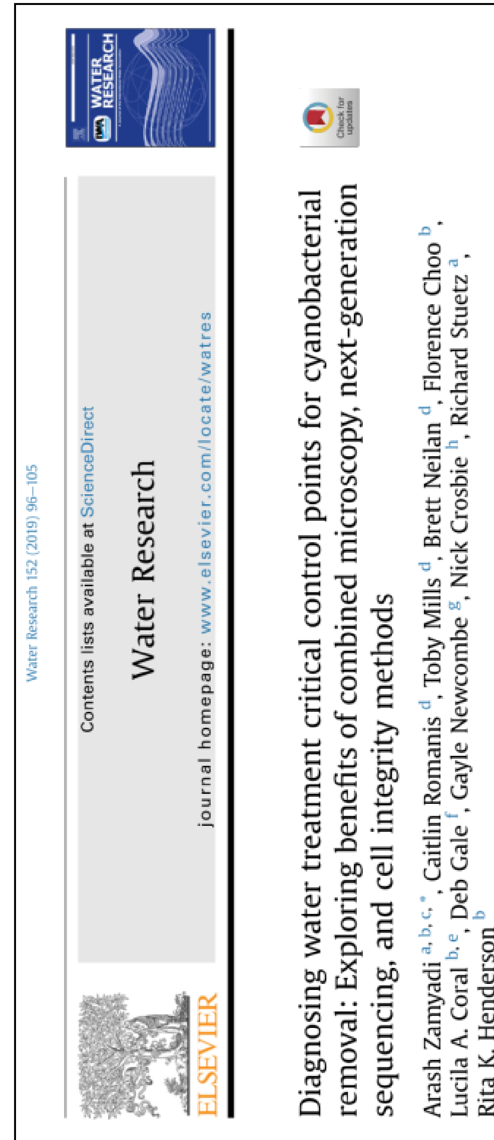
Cyanobacteria breakthrough into flocculation system

Cyanobacteria breakthrough into mixers

Cyanobacteria accumulation inside DAF sludge

Cyanobacteria breakthrough into clarified water




Water Research 152 (2019) 96–105

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

ELSEVIER

Diagnosing water treatment critical control points for cyanobacterial removal: Exploring benefits of combined microscopy, next-generation sequencing, and cell integrity methods

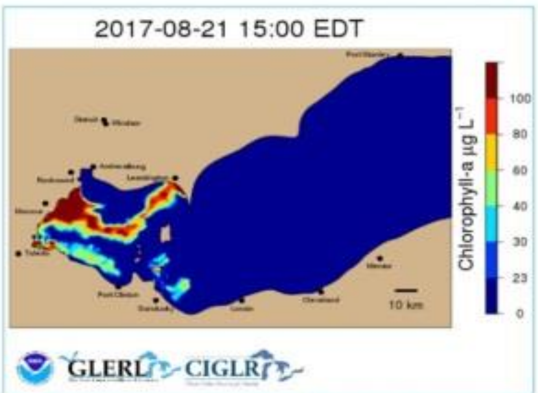
Arash Zamyadi [a, b, c, *], Caitlin Romanis [d], Toby Mills [d], Brett Neilan [d], Florence Choo [b], Lucila A. Coral [b, e], Deb Gale [f], Gayle Newcombe [g], Nick Crosbie [h], Richard Stuetz [a], Rita K. Henderson [b]

10 YEARS Water Research AUSTRALIA

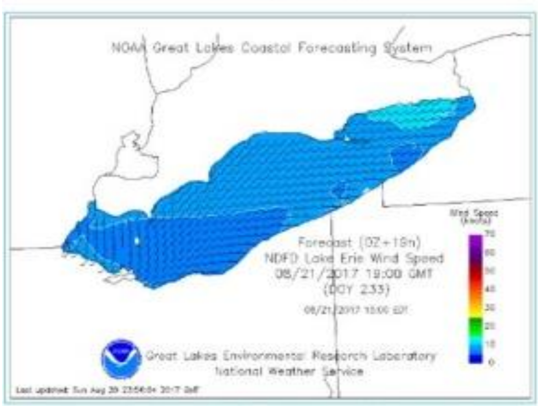
Real-Time Management Strategies

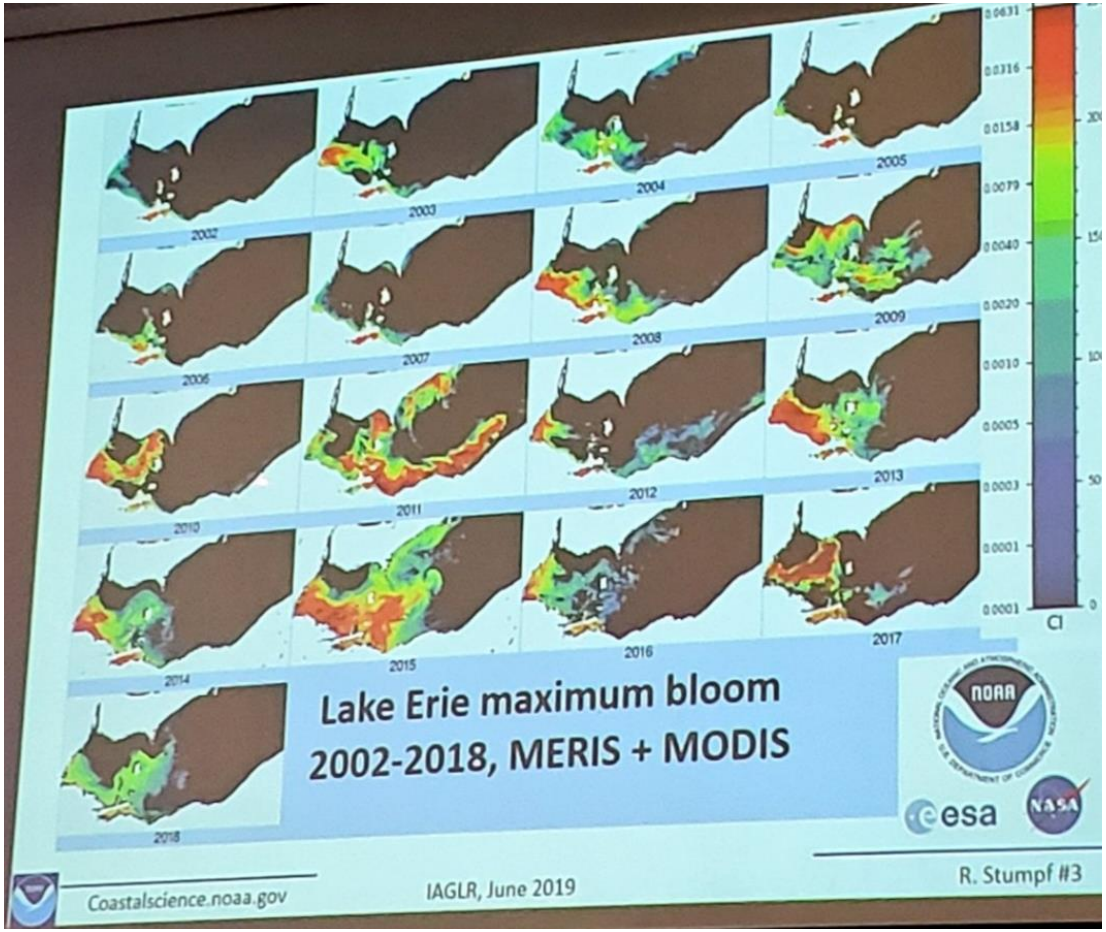
Trigger sampling on satellite imagery:

HAB Tracker forecast



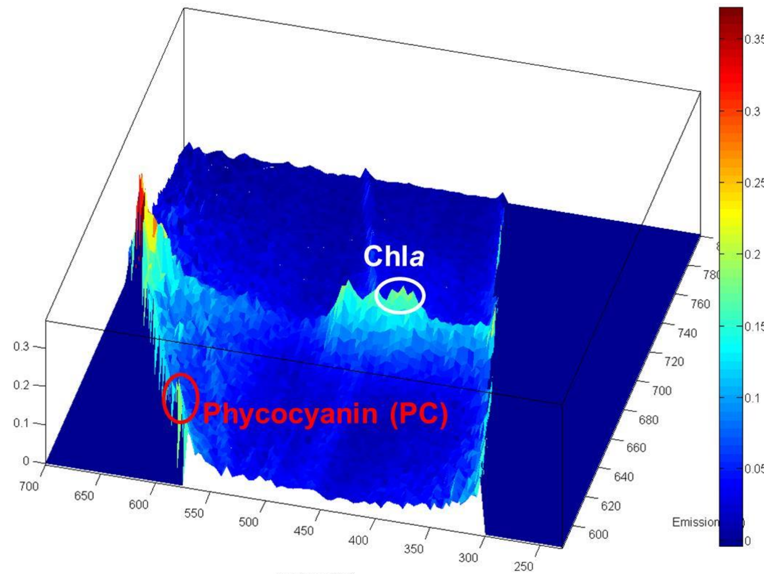
GLCFS nowcast & 5-day wind speed forecast

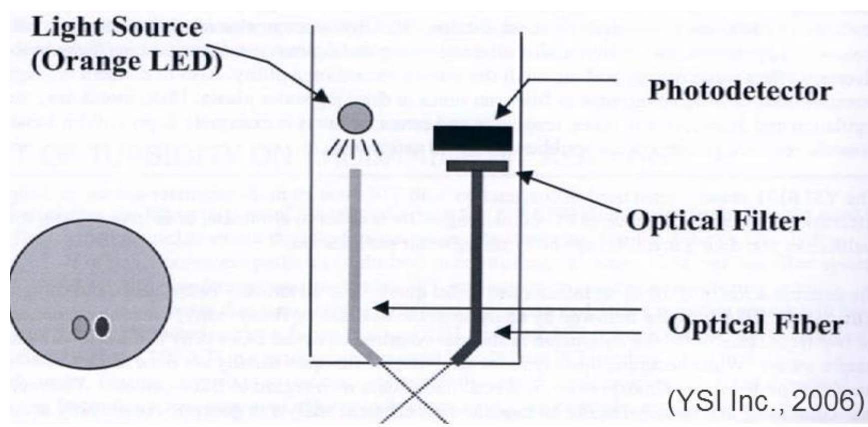




Real-Time Monitoring Tool

Online & intensive monitoring:





Real-Time Monitoring Tool

Online cyanobacterial fluorescence monitoring probes:

10 YEARS Water Research AUSTRALIA

YSI V6600

YSI EXO2

bbe AlgaeTorch

bbe AOA

bbe FluoroProbe

TriOS

Turner Designs

Be Aware of In Situ Measurements Bias

Source of Interference	± Error
Fluorescence emissions of chlorophyll *a* from other algae	6
Water turbidity	2.5
Variation in biovolume of present species	1.2-1.9
Base probe calibration	1.7

Trends in Analytical Chemistry 82 (2016) 1–14

Contents lists available at ScienceDirect

Trends in Analytical Chemistry

journal homepage: www.elsevier.com/locate/trac

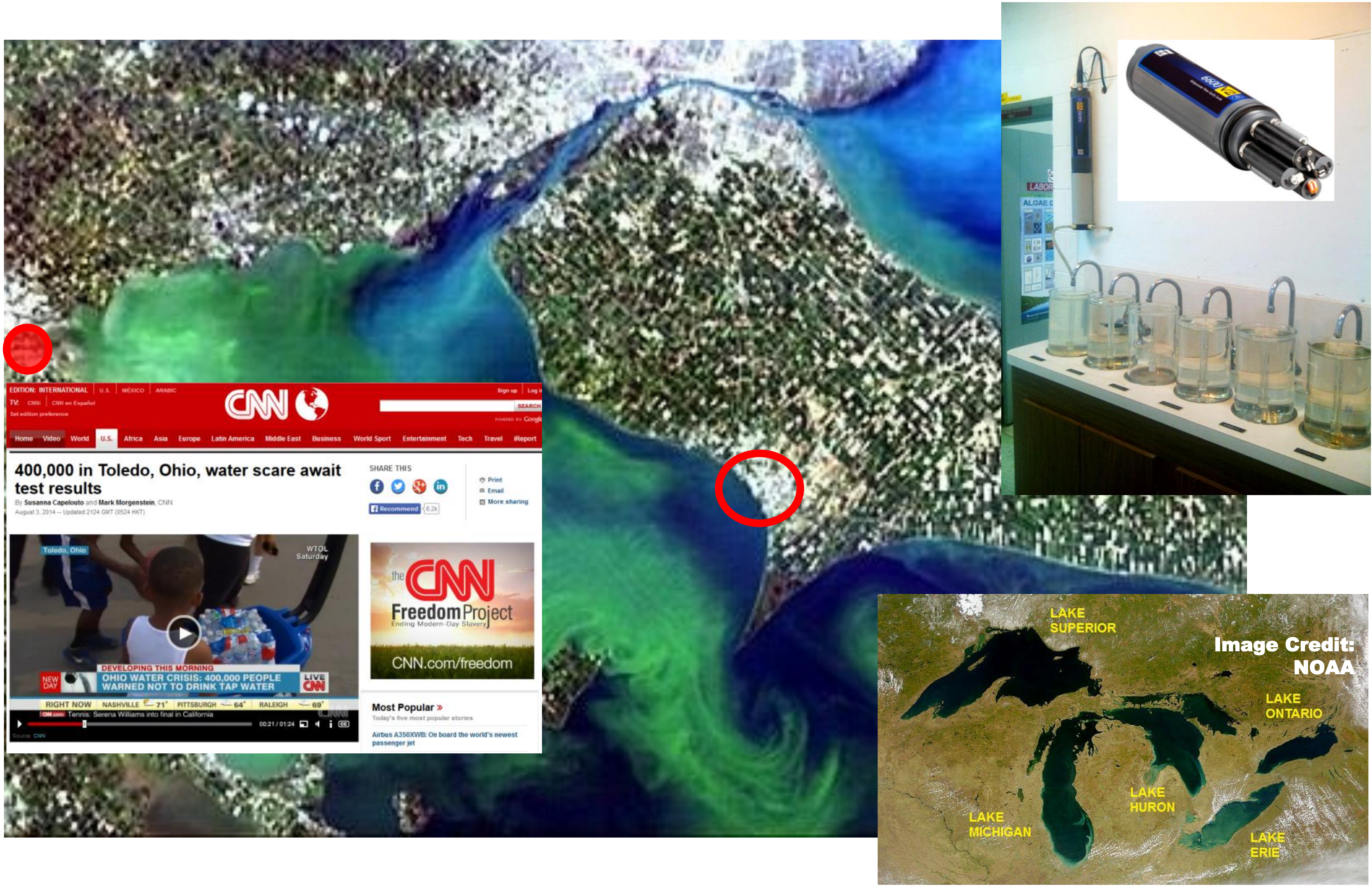
ELSEVIER

TrAC

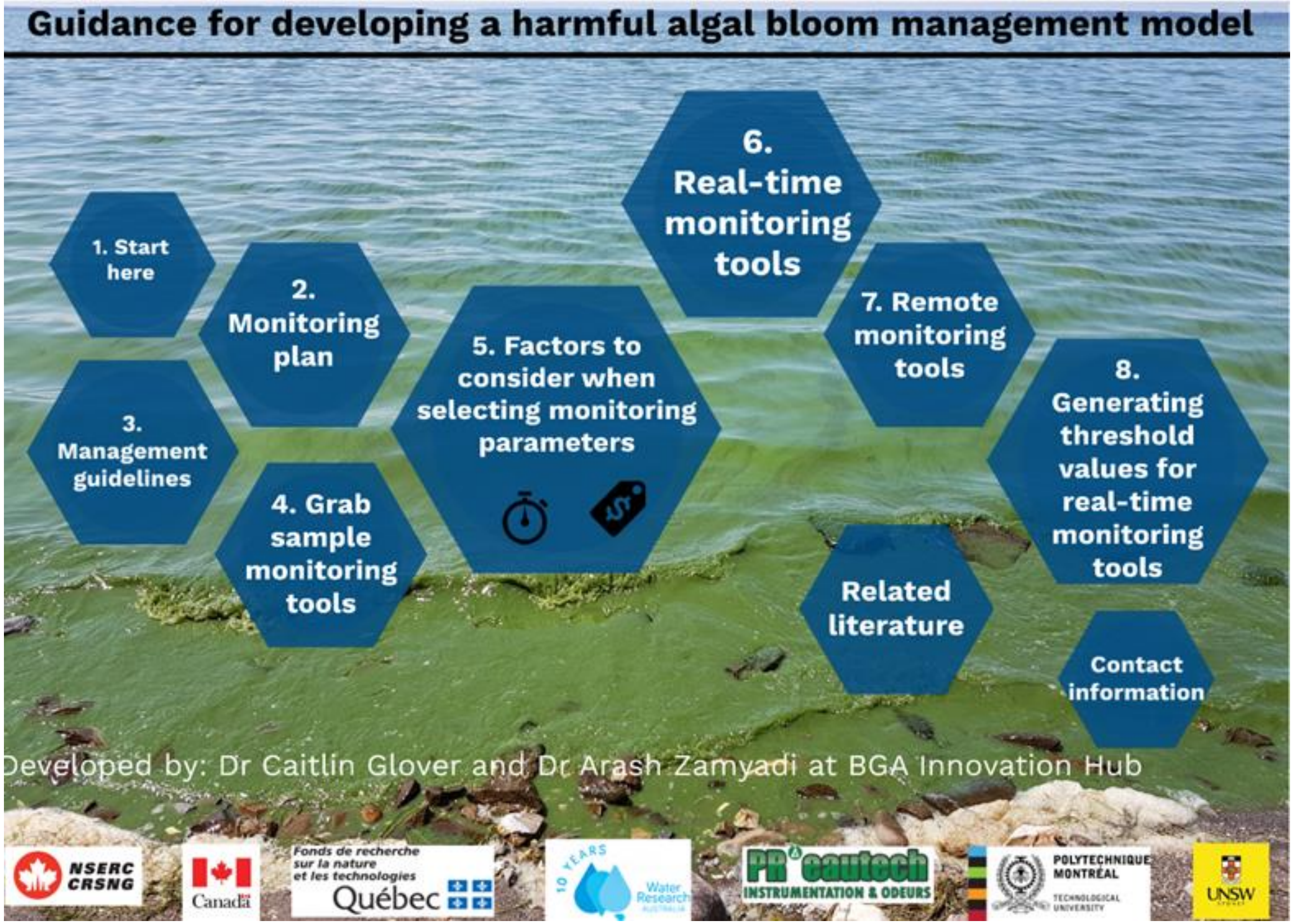
A review of monitoring technologies for real-time management of cyanobacteria: Recent advances and future direction

Arash Zamyadi [a,b,*], Florence Choo [b], Gayle Newcombe [c], Richard Stuetz [a], Rita K. Henderson [b]

Benefits of Using the Probes:



Do you need guidance developing a harmful algal bloom management strategy? Beginner's guide: https://www.arashzamyadi.com/designsservices.htm
and/or
https://prezi.com/view/z5GIySlfwFP5ctTQNxFx/



Benefits of Using the Probes:

Cyanobacterial cell accumulation in the sludge;

Example of smart treatment adjustment used by Melbourne Water:


Environmental Science
Water Research & Technology

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal | View Issue

CrossMark

Cite this: Environ. Sci.: Water Res. Technol., 2016, 2, 362

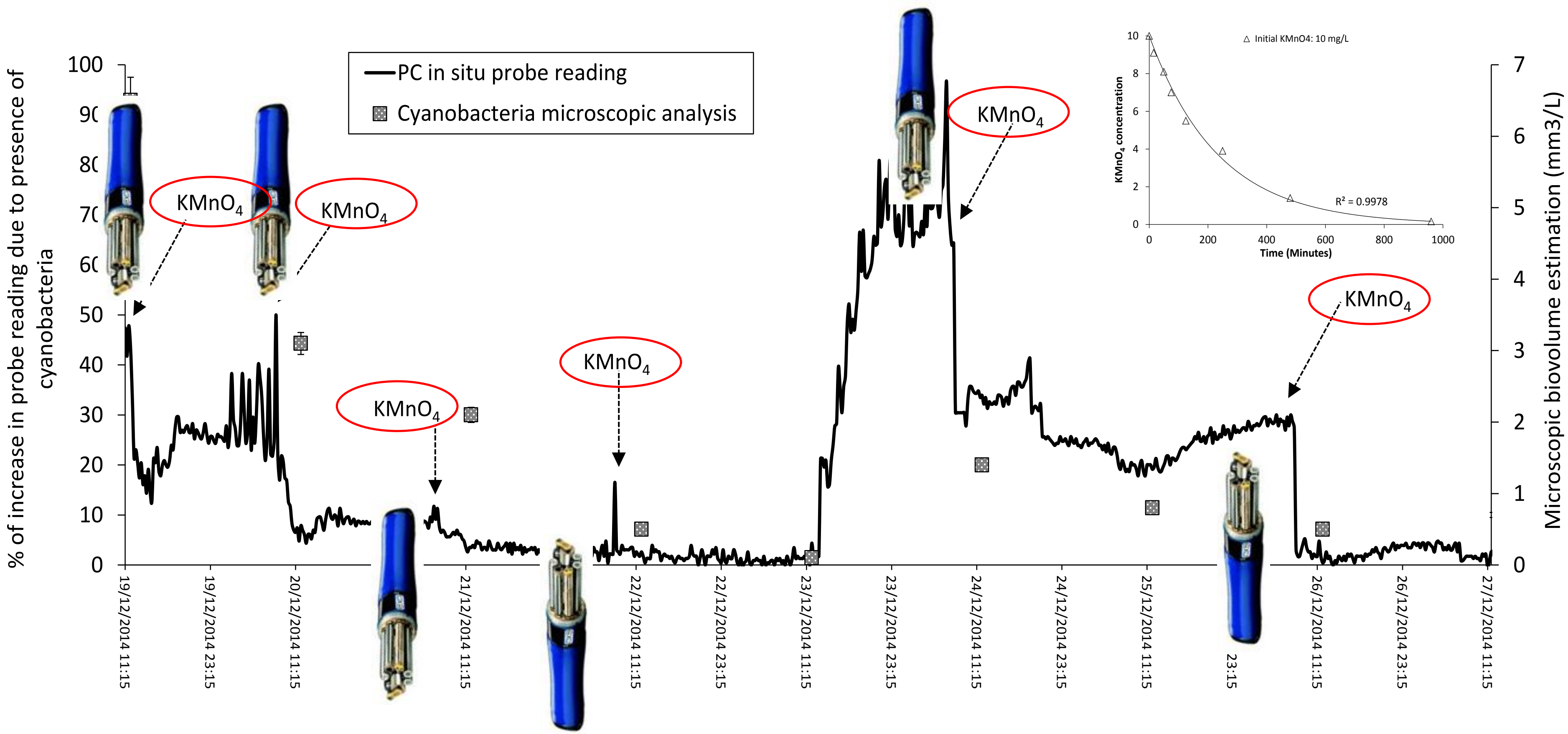
Cyanobacterial management in full-scale water treatment and recycling processes: reactive dosing following intensive monitoring

Arash Zamyadi,*[ab] Rita K. Henderson,[b] Richard Stuetz,[a] Gayle Newcombe,[c] Kelly Newtown[c] and Brendan Gladman[d]

Benefits of Using the Probes:

Single point use: Cyanobacterial cell accumulation in the sludge;

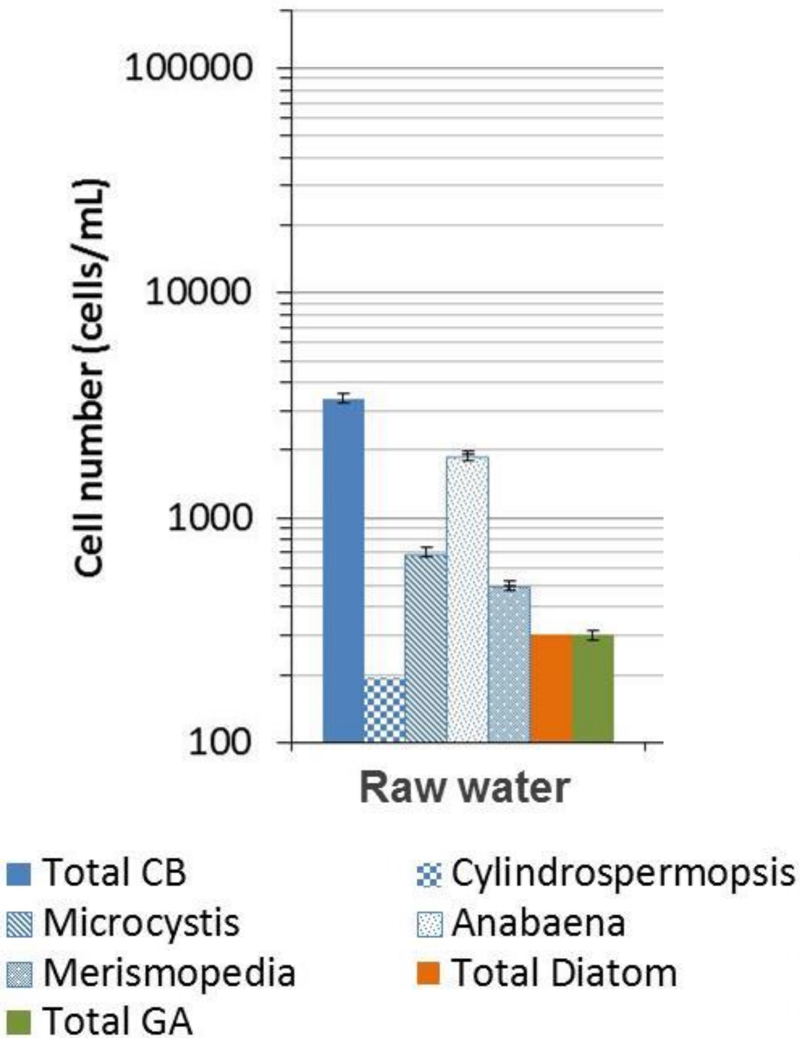
Example of smart treatment adjustment used by Melbourne Water:

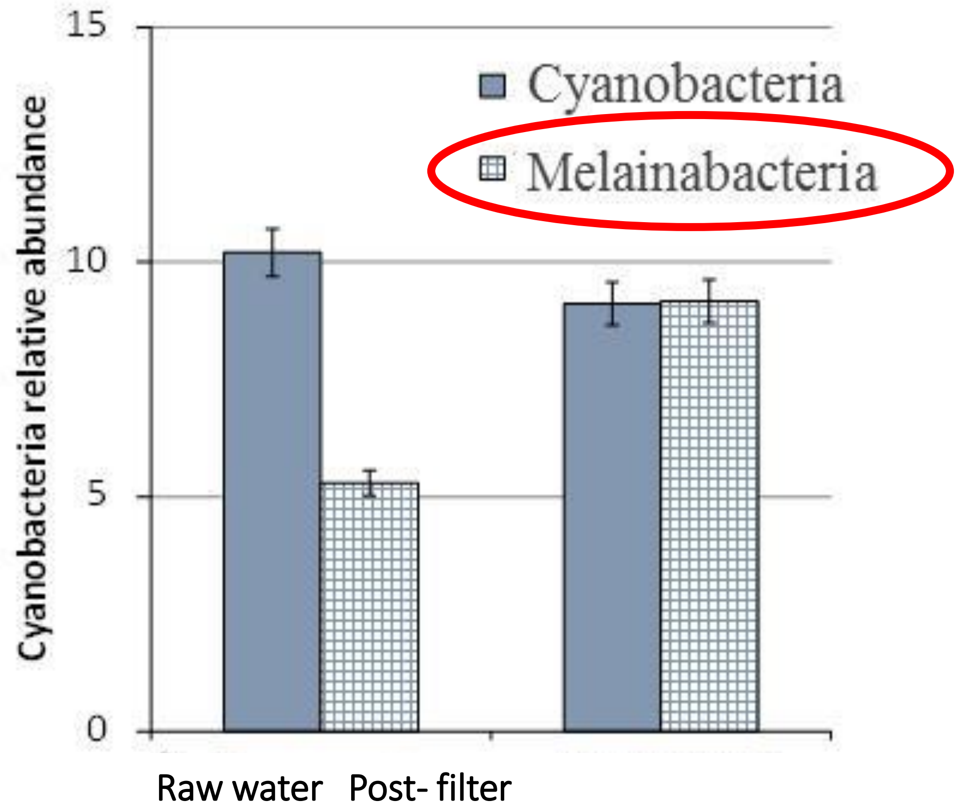


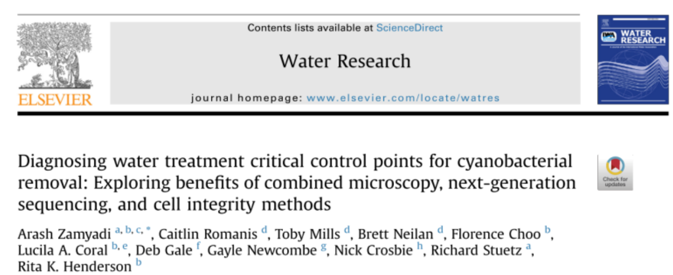
Toxic Cyanobacteria Breakthrough

Identified organisms using macroscopic taxonomy

Extra info obtained by genomics







Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

Diagnosing water treatment critical control points for cyanobacterial removal: Exploring benefits of combined microscopy, next-generation sequencing, and cell integrity methods

Arash Zamyadi [a, b, c, *], Caitlin Romanis [d], Toby Mills [d], Brett Neilan [d], Florence Choo [b], Lucila A. Coral [b, e], Deb Gale [f], Gayle Newcombe [g], Nick Crosbie [h], Richard Stuetz [a], Rita K. Henderson [b]

Solutions: Oxidation

WRF4692 - #WRFCyanoToxinOxid:

Summary of up-to-date knowledge on dissolved toxin oxidation. But the toxins are produced by cells and oxidation occurs I presence of cells and cellular debris?

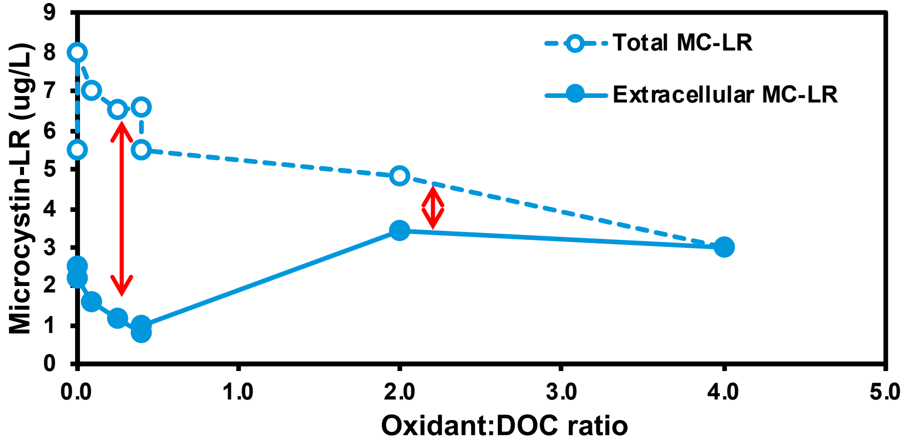
Oxidant	Microcystins	Microcystin-LA	Cylindrospermopsin	Anatoxin A	Saxitoxins	GTX2, GTX3 and C1, C2	Nodularins	MIB and geosmin	BMAA
Free chlorine	pH		pH	Slow/no oxidation			pH		pH
Monochloramine	Slow/no oxidation					?			?
Chlorine dioxide	Slow/no oxidation					?	?		?
Permanganate						?	?	?	Slow
Ozone			pH	pH					pH
Hydroxyl radical					?	?			pH
UV	High doses	High doses	High doses	High doses	?	?	?	High doses	High doses
Cold plasma oxidation*	LR and LL	?	?	?	?	?	?	?	

*Treatment technology currently at bench-scale.

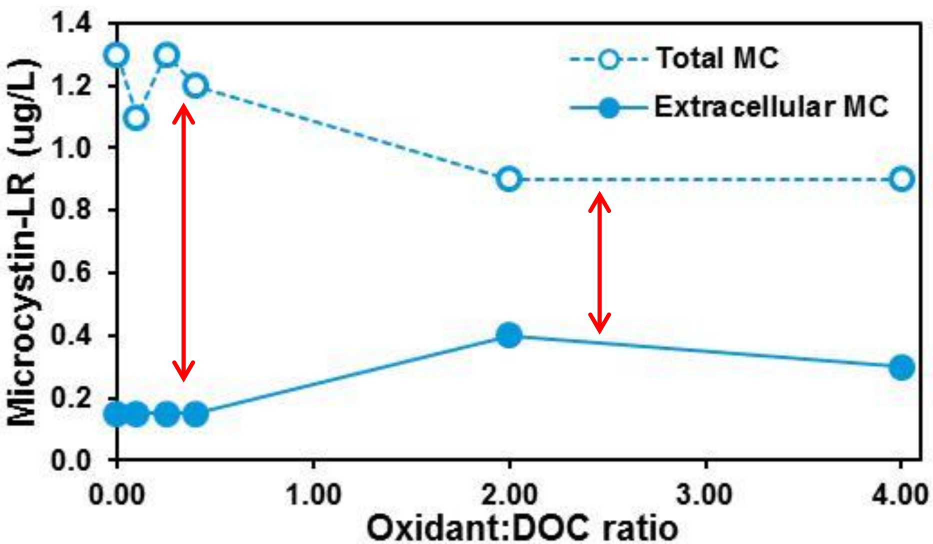
Solutions: Oxidation

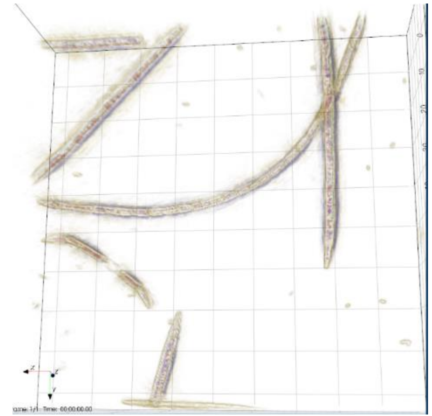
WRF4692 - $KMnO_4$ (time ≤ 20 min) :

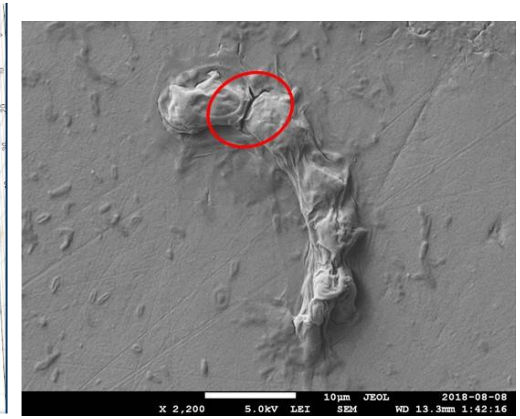
Lab-cultured MA; DOC = 2.5 mg/L

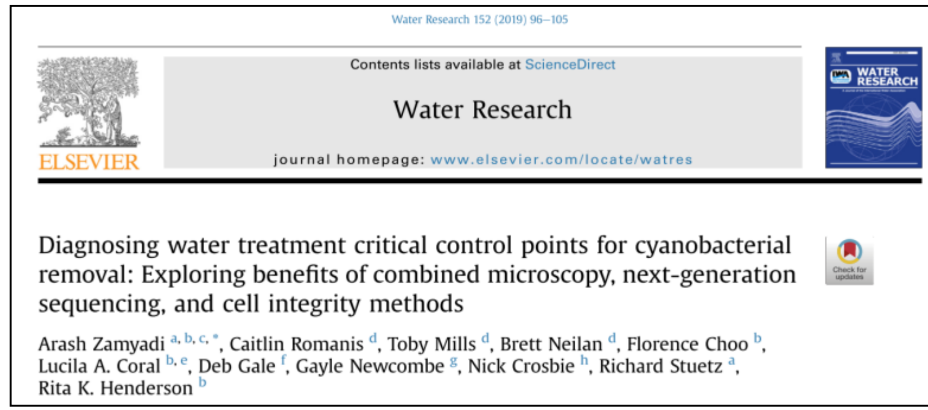


Canadian bloom; DOC = 6.1 mg/L









Water Research 152 (2019) 96–105

Contents lists available at ScienceDirect

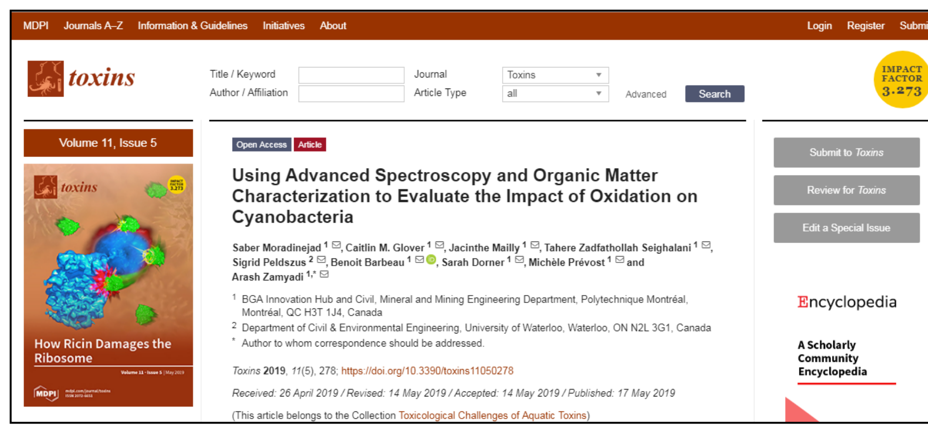
Water Research

journal homepage: www.elsevier.com/locate/watres

ELSEVIER

Diagnosing water treatment critical control points for cyanobacterial removal: Exploring benefits of combined microscopy, next-generation sequencing, and cell integrity methods

Arash Zamyadi [a, b, c, *], Caitlin Romanis [d], Toby Mills [d], Brett Neilan [d], Florence Choo [b], Lucila A. Coral [b, e], Deb Gale [f], Gayle Newcombe [g], Nick Crosbie [h], Richard Stuetz [a], Rita K. Henderson [b]



MDPI Journals A–Z Information & Guidelines Initiatives About Login Register Submit

toxins

Volume 11, Issue 5

Open Access Article

Using Advanced Spectroscopy and Organic Matter Characterization to Evaluate the Impact of Oxidation on Cyanobacteria

Saber Moradinejad [1], Caitlin M. Glover [1], Jacinthe Mailly [1], Tahere Zadfathollah Seighalani [1], Sigrid Peldszus [2], Benoit Barbeau [1], Sarah Dorner [1], Michèle Prévost [1] and Arash Zamyadi [1,*]

[1] BGA Innovation Hub and Civil, Mineral and Mining Engineering Department, Polytechnique Montréal, Montréal, QC H3T 1J4, Canada
[2] Department of Civil & Environmental Engineering, University of Waterloo, Waterloo, ON N2L 3G1, Canada
[*] Author to whom correspondence should be addressed.

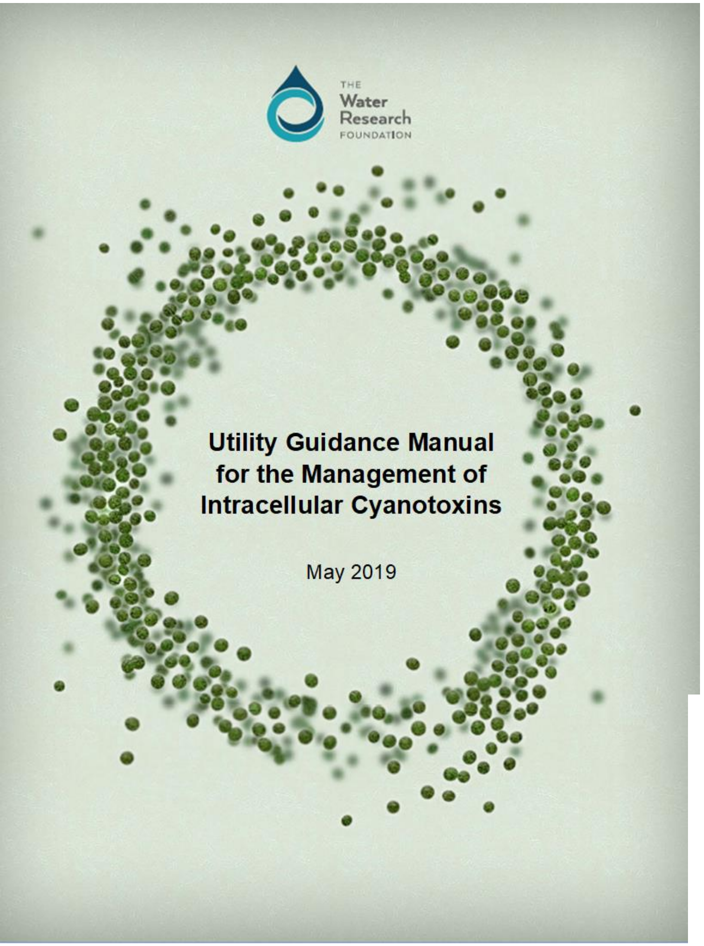
Toxins 2019, 11(5), 278; https://doi.org/10.3390/toxins11050278

Received: 26 April 2019 / Revised: 14 May 2019 / Accepted: 14 May 2019 / Published: 17 May 2019

(This article belongs to the Collection Toxicological Challenges of Aquatic Toxins)

While working on WRF 4692: Release of intracellular cyanotoxins during oxidation of naturally occurring & lab cultured cyanobacteria

Realized the need to: Collect & transfer the scattered (and mostly contradictory) knowledge globally



Impact of morphology?

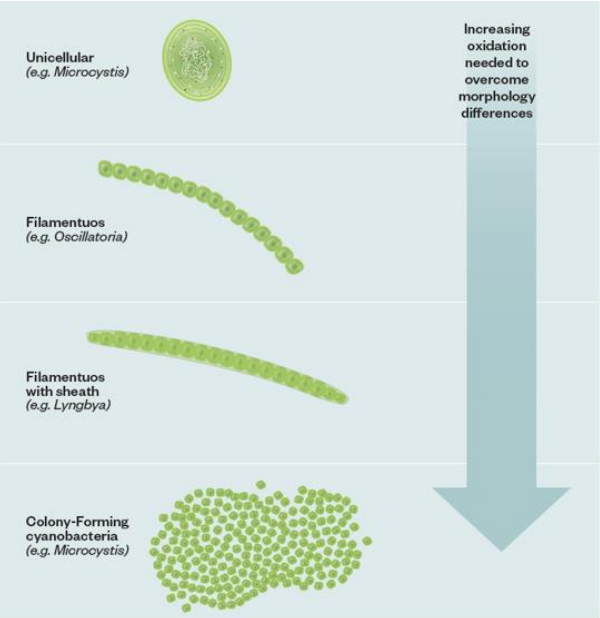


Figure 7: Impact of cyanobacteria cell morphology on resistance to lysing by oxidation

Pre-oxidation?

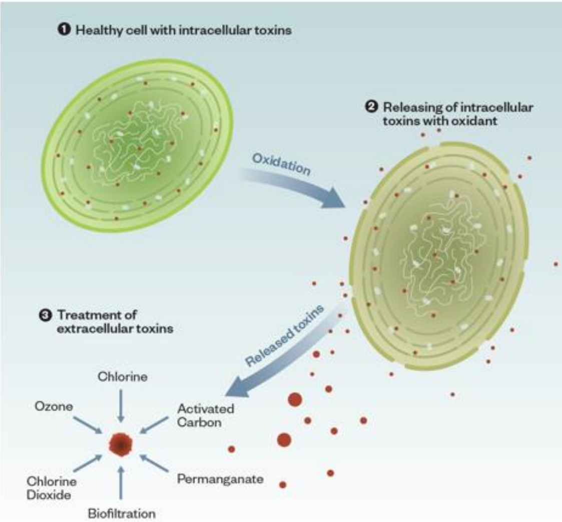


Figure 6: Schematic of the "Release and Treat" approach to cyanotoxin management

Source monitoring & oxidation: Hard to select?

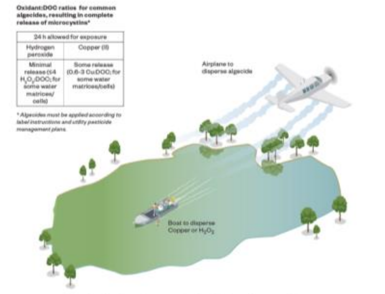
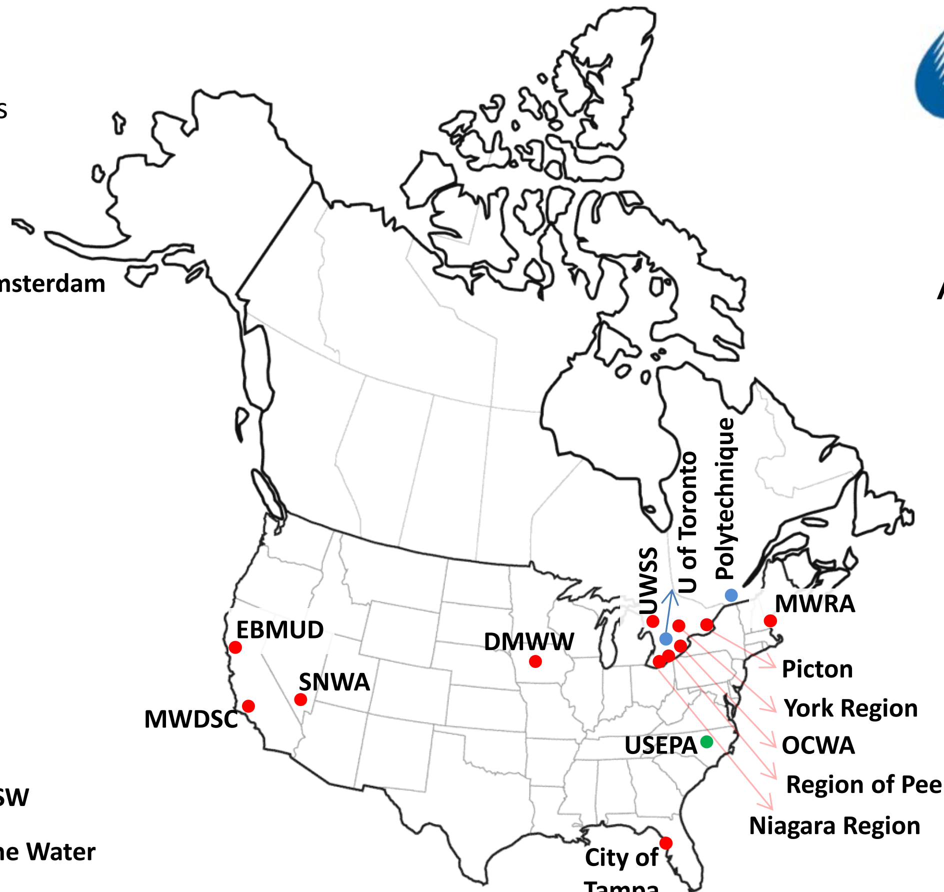


Figure 8: Algacide application methods and effective dosing guidelines

Developing Guidance for Assessment and Evaluation of Harmful Algal Blooms, and Implementation of Control Strategies in Source Water – WRF4912

Project partners

- Participating Water utilities
- Participating Regulatory Agencies
- Participating Universities



Eric Wert

SOUTHERN NEVADA WATER AUTHORITY™

Arash Zamyadi

Water Research AUSTRALIA

Virginie Gaget

THE UNIVERSITY of ADELAIDE

Christine Owen

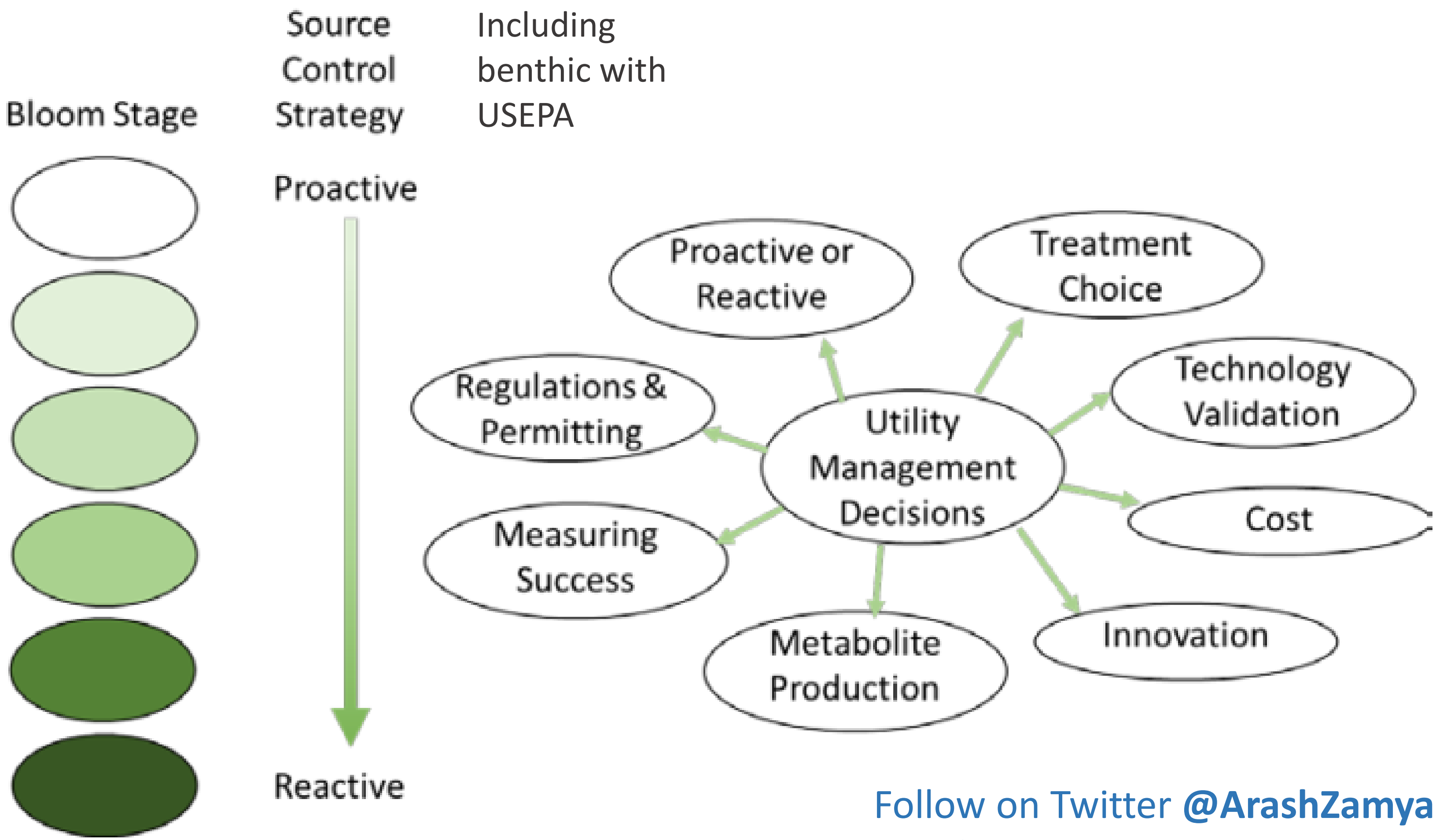
Hazen

Ron Hofmann

UNIVERSITY OF TORONTO

Developing Guidance for Assessment and Evaluation of Harmful Algal Blooms, and Implementation of Control Strategies in Source Water – WRF4912

Including benthic with USEPA



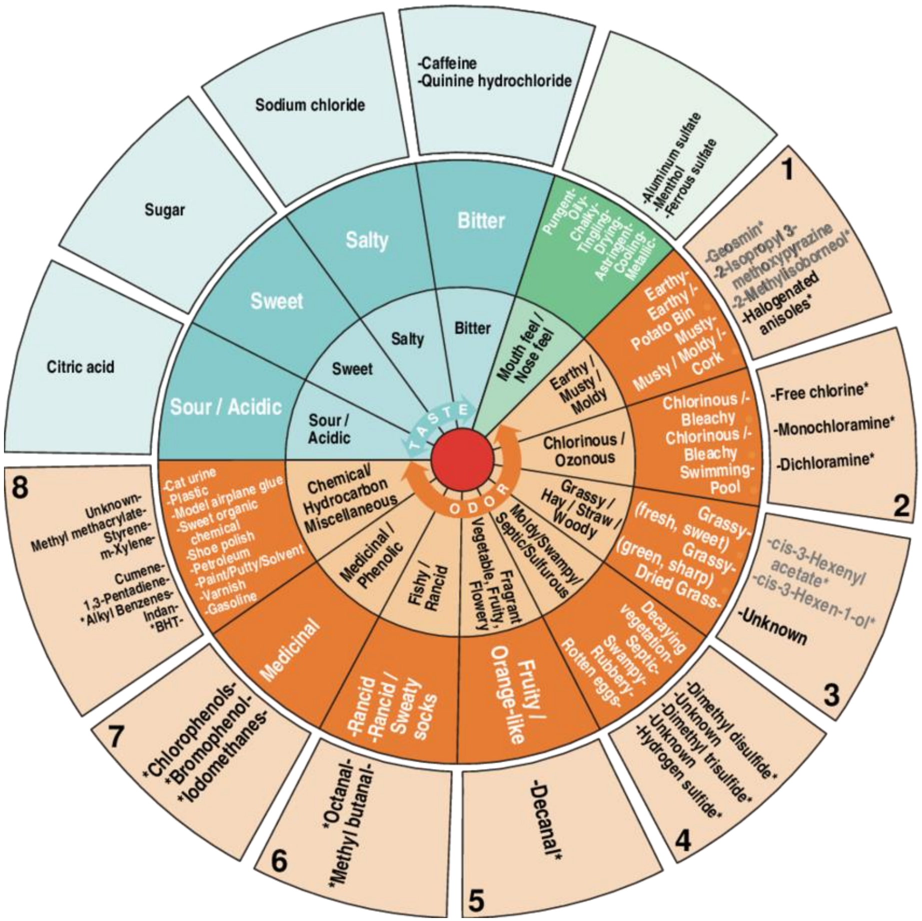
Follow on Twitter **@ArashZamyadi**
Email:

- **arash.zamyadi@waterra.com.au**
- **a.zamyadi@unsw.edu.au**

Guidance Tools

Ron Hofmann, University of Toronto
Husein Almuhtaram, University of Toronto

For taste and odour

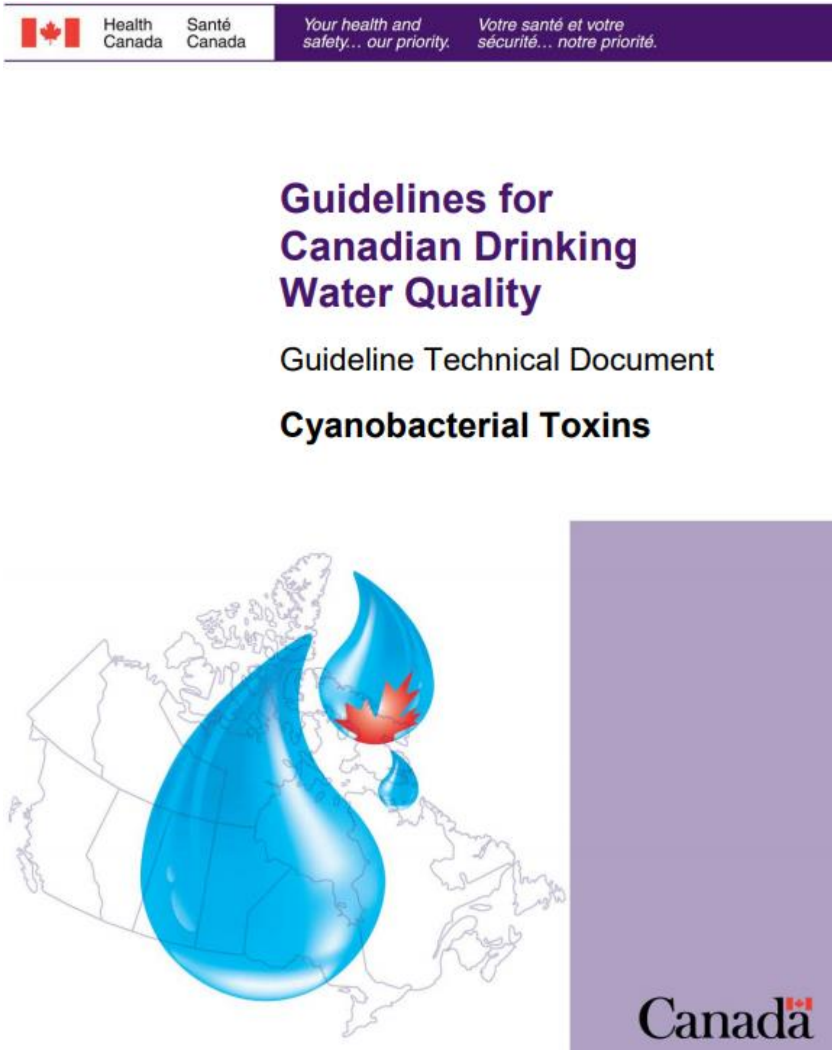


- Tools for utilities to assess preparedness for T&O
- Simple methods to train staff to detect onset of T&O before customer complaints start!

Water Research Foundation website
Project 2614

Cyanobacteria guidance tools: Canada

- Health Canada's cyanotoxin guidance document for utilities
- Covers:
  - Toxins
  - Exposure
  - Monitoring/detection
  - Treatment
  - Kinetics
  - Health effects



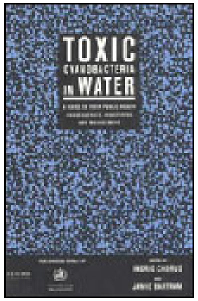
Cyanobacteria guidance tools: International

- World Health Organization cyanobacteria document
- Practical guide for remedial measures, monitoring strategies, and field work

Water sanitation hygiene

Toxic cyanobacteria in water
A guide to their public health consequences, monitoring and management

Authors:
World Health Organization



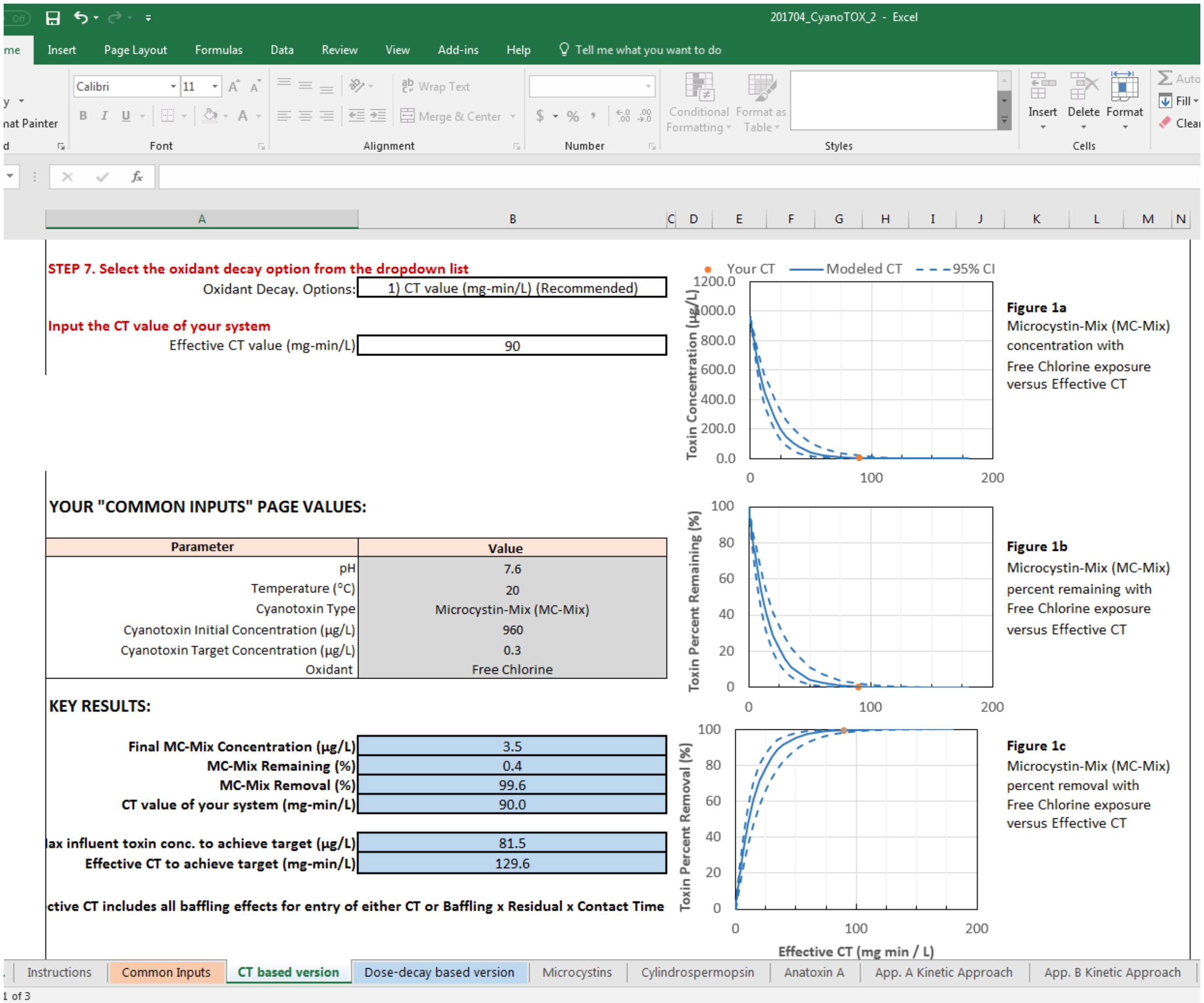
Publication details

Editors: Chorus I, Bartram J
Number of pages: 400
Publication date: 1999
Languages: English
ISBN: 0-419-23930-8

Downloads

– Toxic cyanobacteria in water
pdf 2.32Mb

Cyanobacteria guidance tools: Hazen-Adams CyanoTOX Modeling

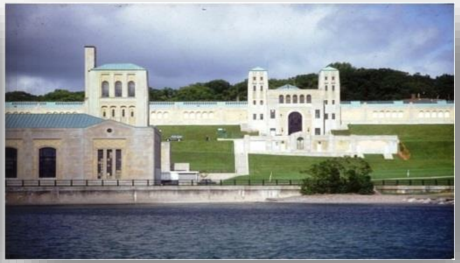


Treatment Strategies in the Plant

1999 City of Toronto response to severe T&O

Powdered activated carbon (PAC) preferred, but…

Plant	T&O control strategy
R.L. Clark	PAC
F.J. Horgan	PAC: direct filtration train Sand/GAC filters: in-line filtration train Ozone in 2009
R.C. Harris	Sand/GAC filters



PAC experience

Silo system at Clark WTP

From City of Toronto

PAC experience

Supersacs at Horgan WTP

From City of Toronto

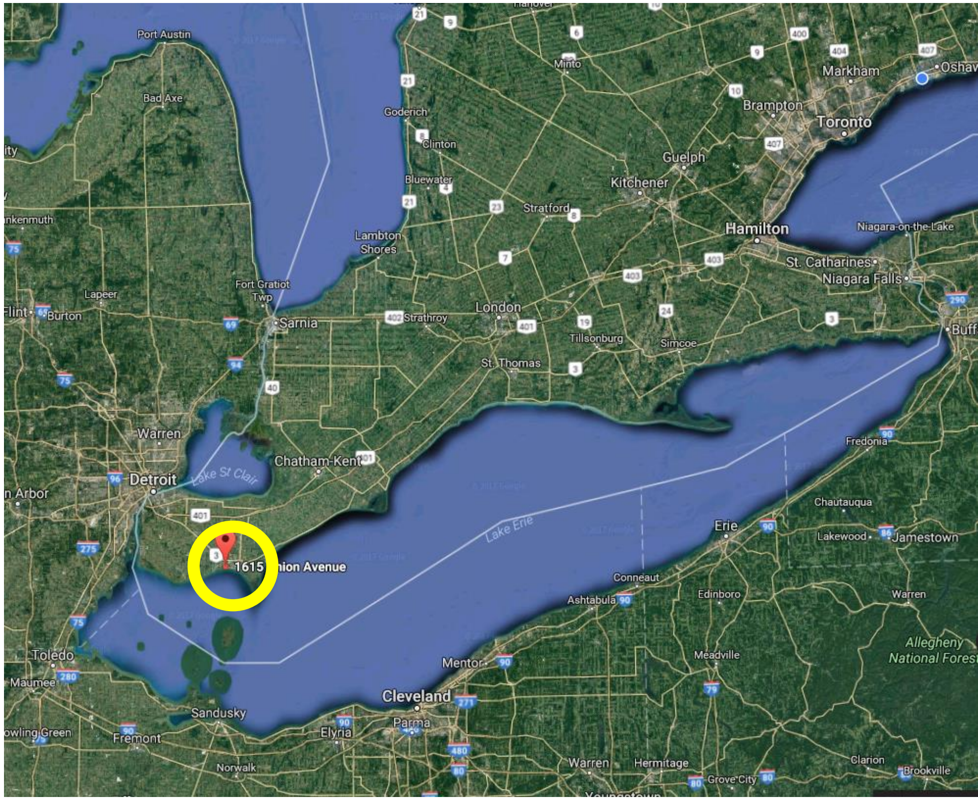
PAC experience

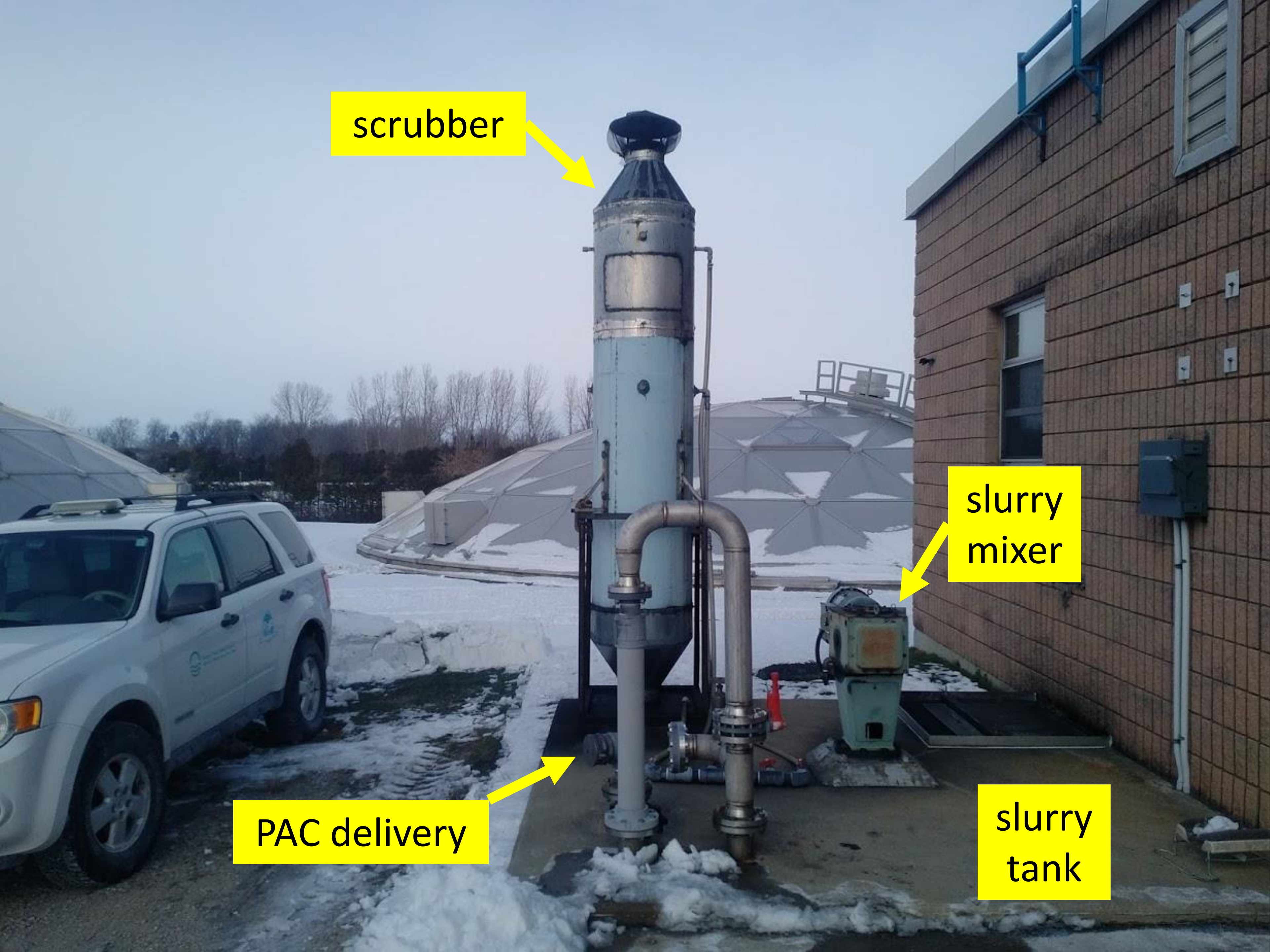
- Clumping in Supersacs, silo slurry flow
- 24 bag changes per day
- 50% more coagulant needed → filter runs < 12 hrs
- 2X treatment cost ($4.50/ML → $10/ML)
- 5X more solids in residue management (upflow clarifier)

…but it worked

PAC experience at Union Water Supply System

- 1.5 mg/L PAC year round
  - Helps to add mass to upflow clarifier
  - Up to 4 mg/L during T&O
- Delivered 3 times/yr, stored in outdoor slurry
- Added to flow with peristaltic pumps

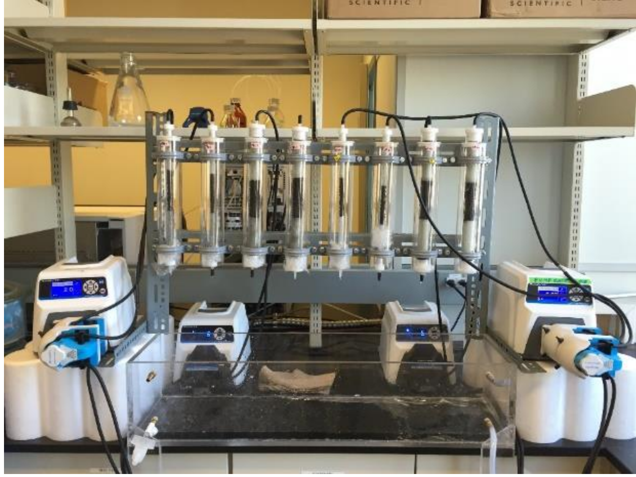



scrubber
slurry mixer
PAC delivery
slurry tank

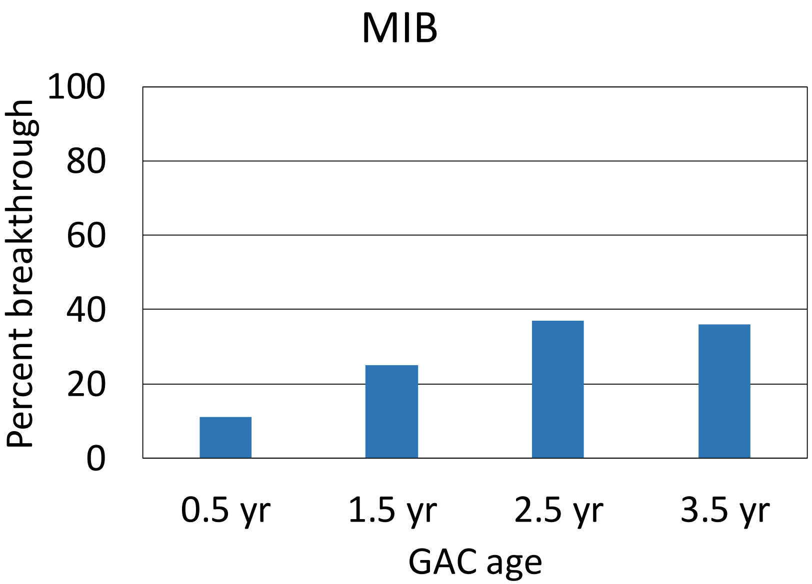
Granular activated carbon (GAC)

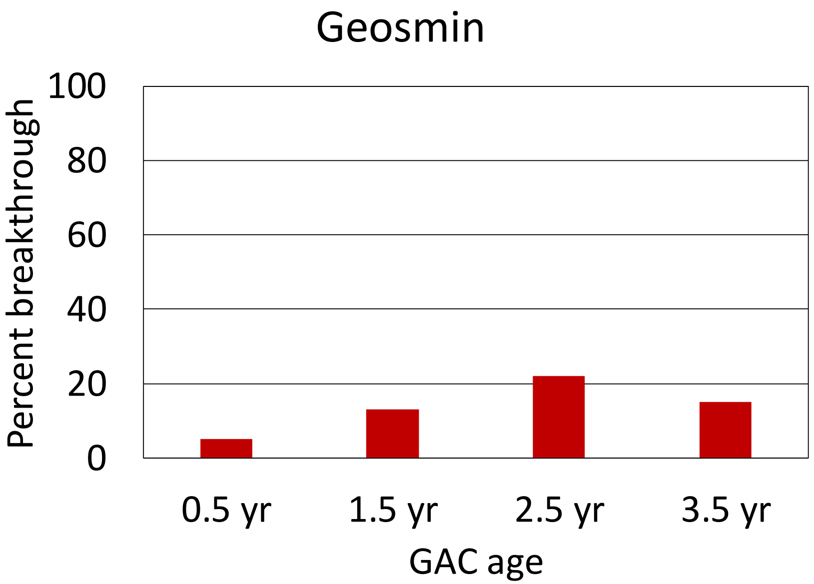
- Often a layer above sand in a conventional filter (retrofit for anthracite)
- Typically 8-12 min empty bed contact time
- Gets saturated even in absence of T&O events due to background organic matter
  - When to replace?

Minicolumn (lab) test



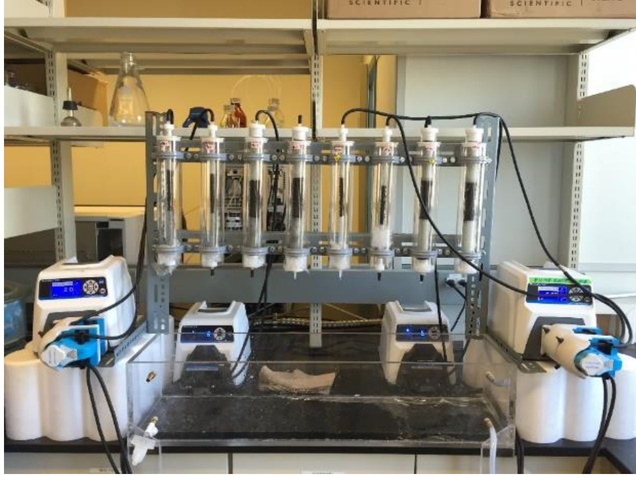
Lake Ontario WTP

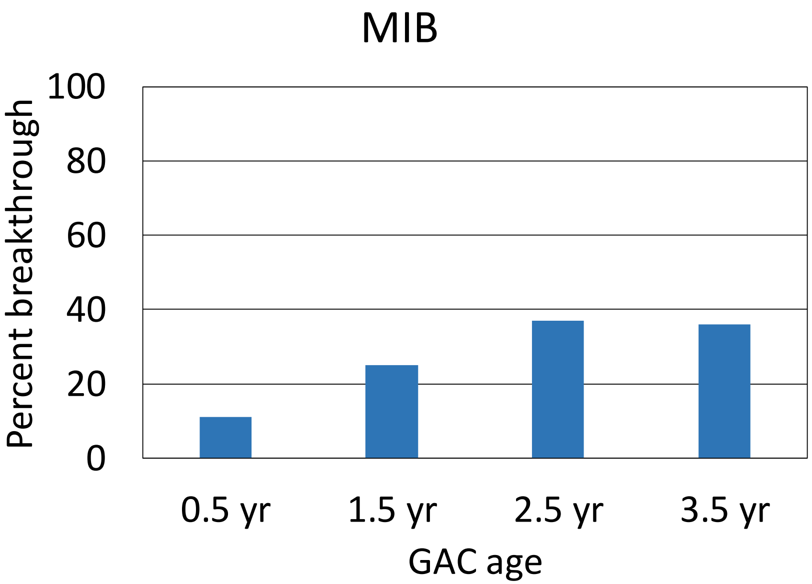


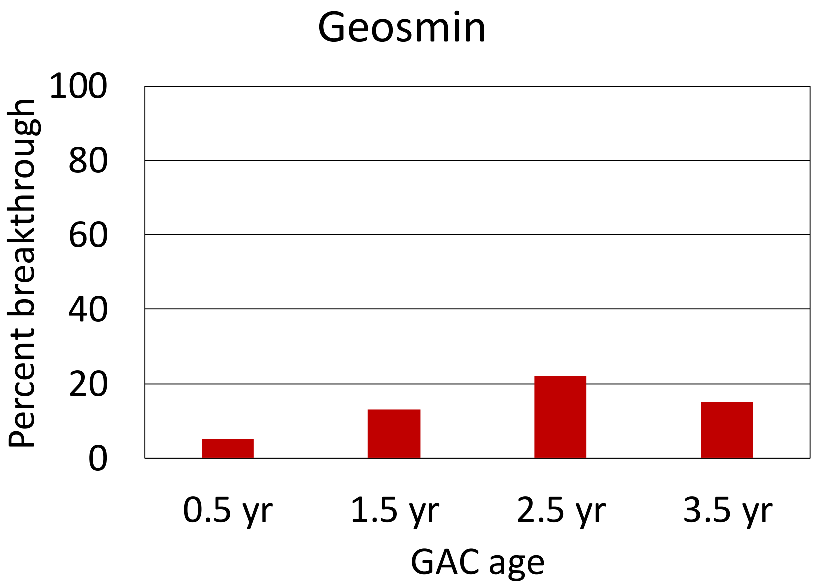


Lake Ontario WTP

Minicolumn (lab) test







Reaching steady-state: biodegradation?

Does GAC/PAC remove cyanotoxins?

- Yes, but…
  - performance mostly assessed during research and not during normal operations
  - most data for microcystin: little for other cyanotoxins (anatoxin-a, cylindrospermopsin, etc.)

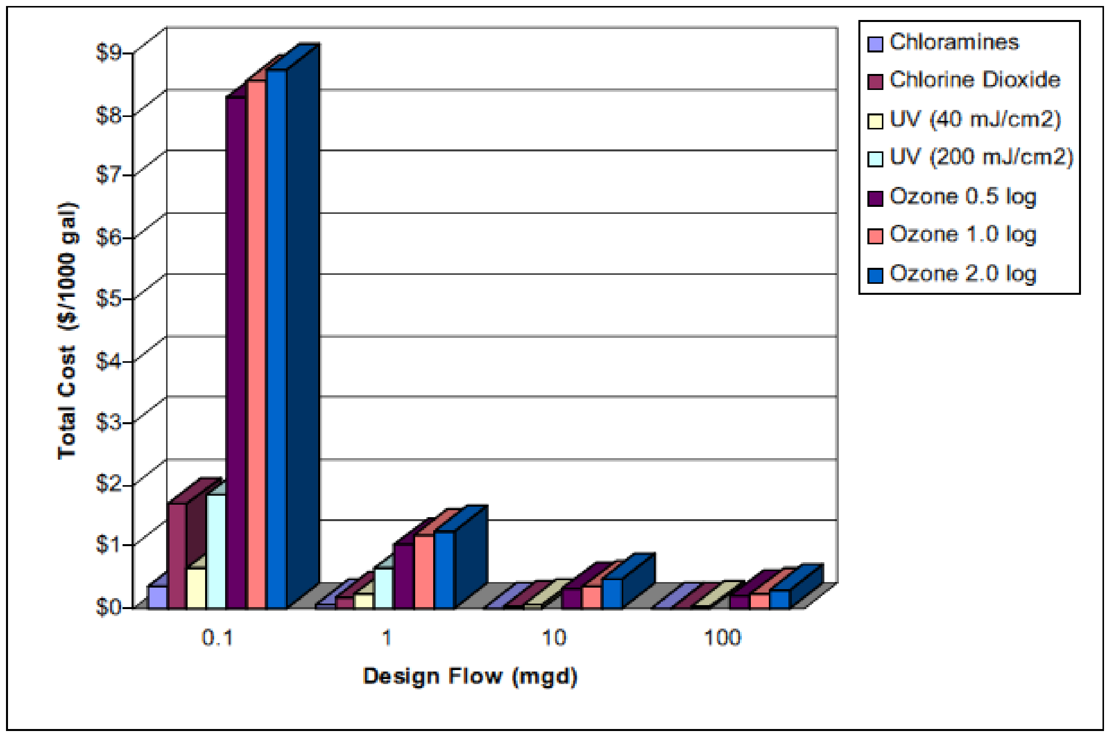
Ozone

- Effective against cyanotoxins
- Often used for concurrent T&O control and *Cryptosporidium* control

USEPA cost document for *Cryptosporidium* (2005)

- Assumed design ozone doses around 4-8 mg/L
- Since then: doses typically around 2-4 mg/L work well
  (IOA Municipal Committee)

Figure ES.1 Cost Comparison for Alternative Chemical Disinfection Strategies[1]



Courtesy IOA Municipal Committee

Consider other benefits of ozone

5. "Gwinnett County's First Ozone Experience: Rationale, Design, Start-up, and Lessons Learned" presented at the IOA-PAG 2005 Annual Conference *Resolving Emerging Issues*, Lake Lanier Islands, Georgia, October 9-12, 2005

Courtesy IOA Municipal Committee

Ozone may provide other benefits and cost savings

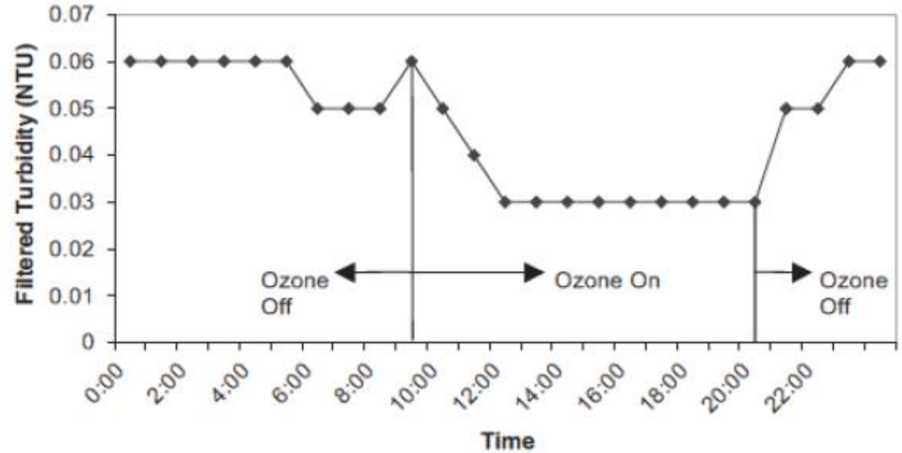


TABLE II Chemical Cost for the Year Before Ozone and After Ozone Implementation

Chemical	Prior to ozone cost June 2000–May 2001 ($)	After ozone cost June 2001–May 2002 ($)	Difference in cost ($)
Alum	573,445	693,503	+120,058
Poly aluminum chloride	126,806	0	–126,806
Total coagulant cost	700,251	693,503	–6,748
Magnafloc LT-22	30,454	24,150	–6,304
Chlorine	[illegible]	109,34[illegible]	+7,194
Powder activated carbon	493,500	0	–493,500
Ozone	0	251,394	+251,394
Total	1,326,[illegible]	[illegible]	–247,964
Water flow (ML/year)	59,814	61,188	+1374
Unit volume cost ($/ML)	22.17	17.62	–4.55

21% reduction of total chemical cost including ozone operation for ~1 log crypto inactivation.

9. Mazloum, S, et al., "Improvement and Optimization of the A. H. Weeks Water Treatment Plant Processes, Windsor, ON, Canada", Ozone Science and Engineering, 26:2, 125 – 140, April 2004.

Bottom line

Many different ways to treat HAB byproducts

(Ozone, PAC, GAC, AOP, permanganate, chlorine, etc.)

Best solution includes site-specific considerations/testing

Contact information

Ron Hofmann, Dept. Civil & Mineral Engineering
University of Toronto
ron.hofmann@utoronto.ca, 416-946-7508

Managing Algal Blooms in Drinking Water Sources - Treatment Plant Approaches

Scott Bindner

October 16, 2019

Agenda

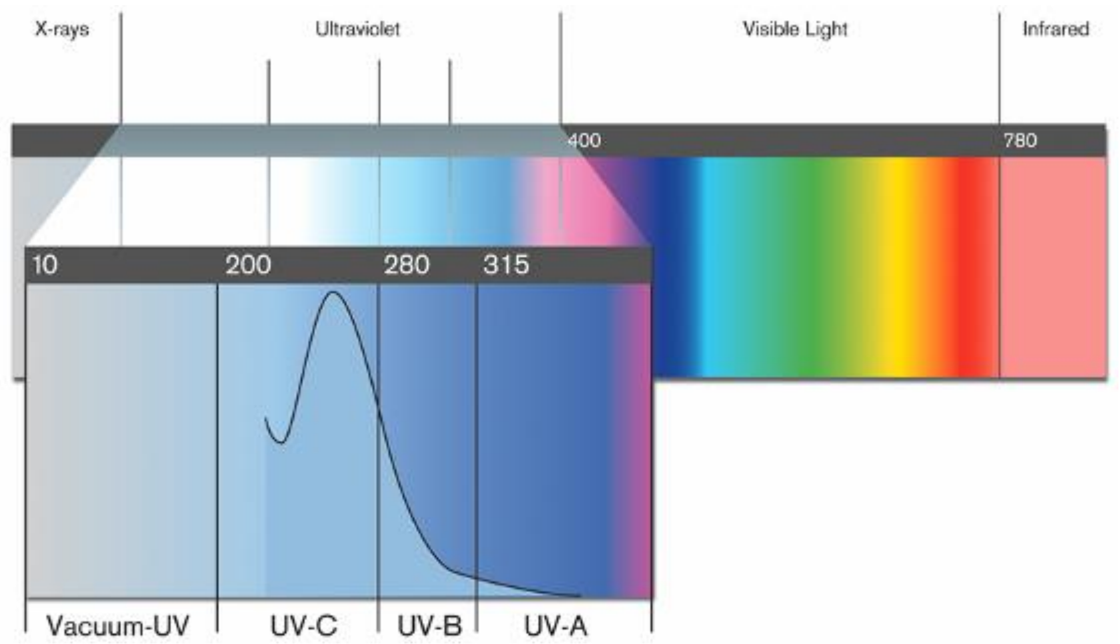
- Review of UV Advanced Oxidation Science
- Applications for Taste and Odor and Algal Toxin Treatment
- Life-Cycle
- Case Studies
- Summary
- Other UV AOP Applications

UV Advanced Oxidation Process (UV AOP)

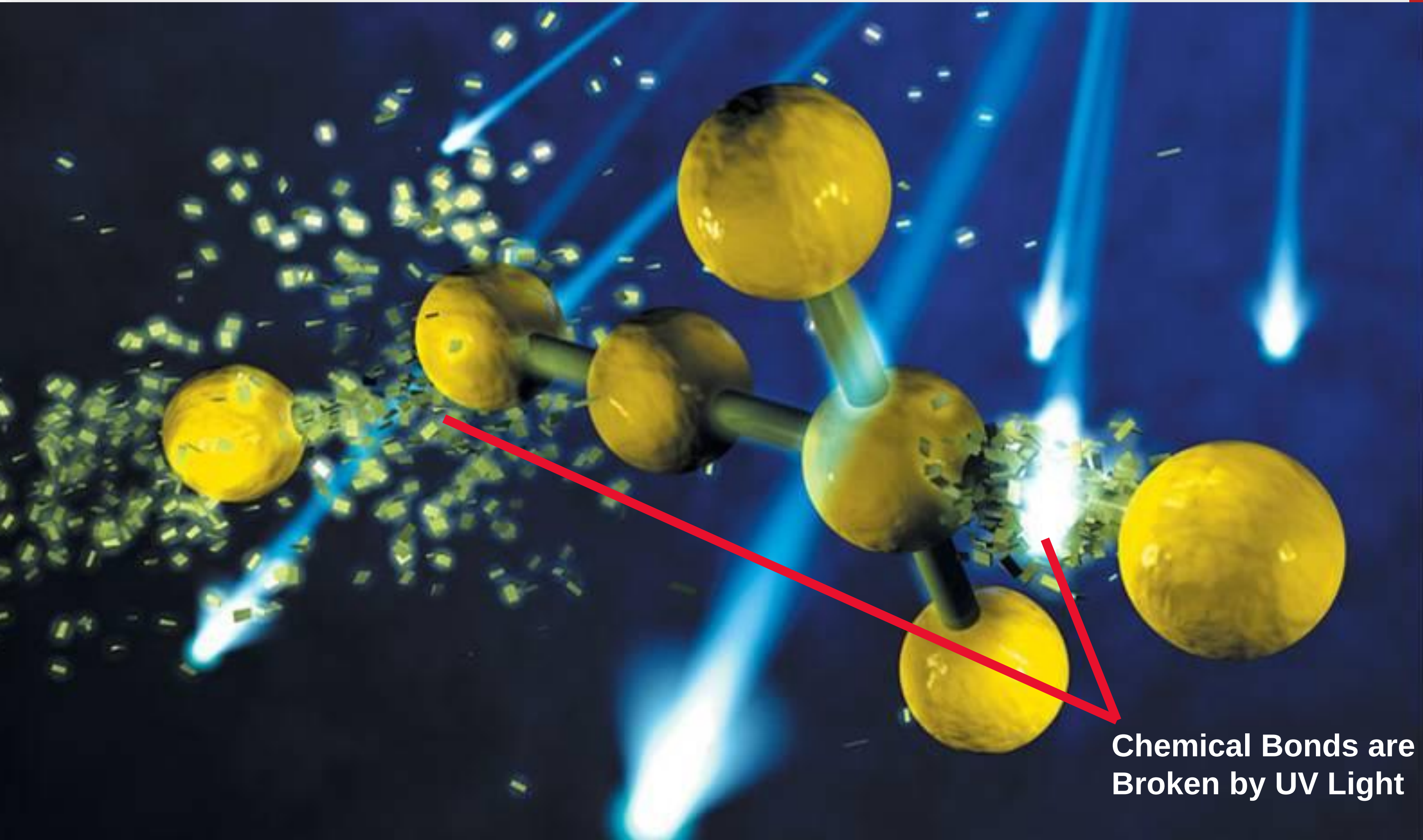
Using UV and hydrogen peroxide to destroy trace organic contaminants in water by:

UV-Photolysis

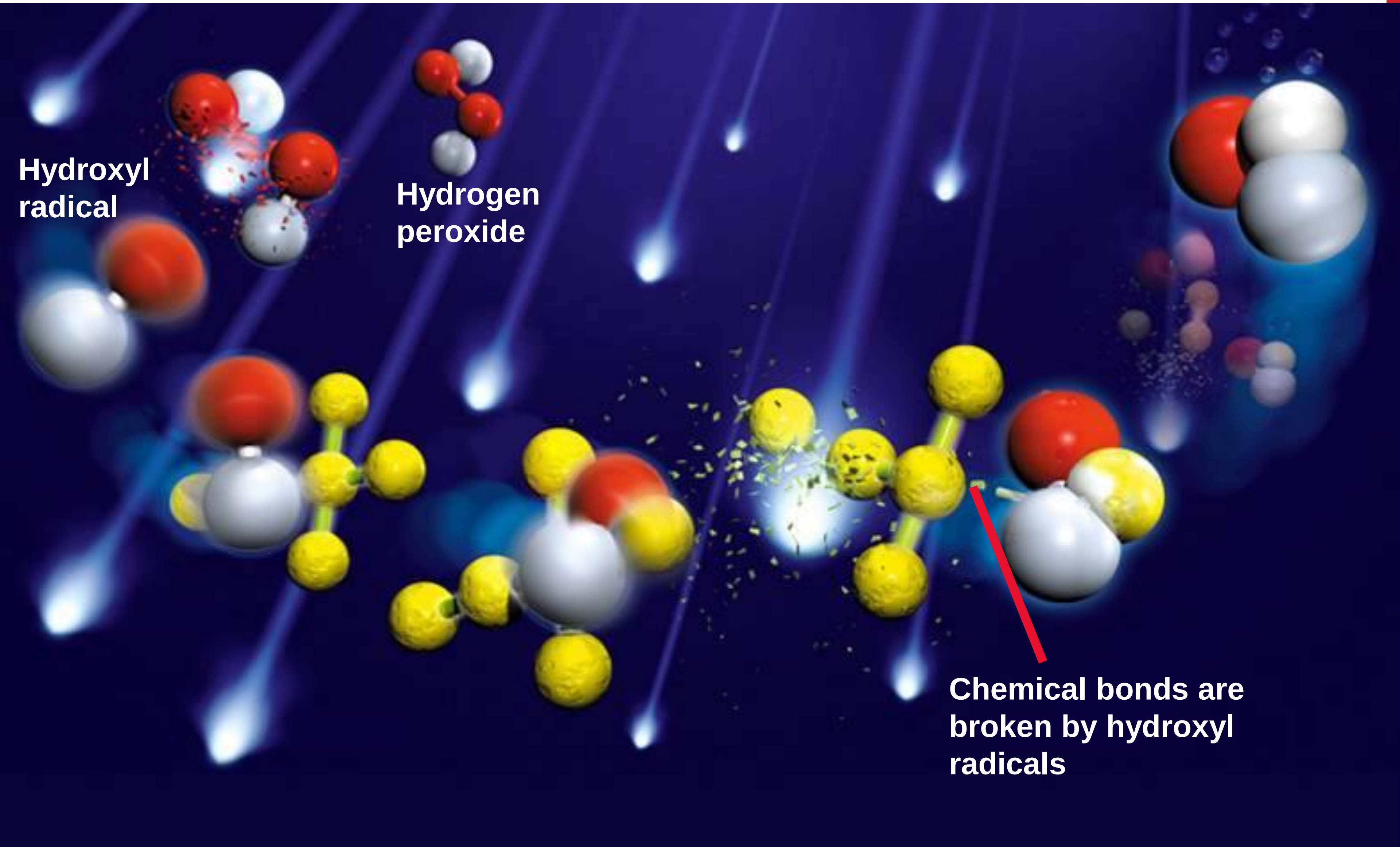
UV-Oxidation



UV-Photolysis



UV-Oxidation



UV-Oxidation Reaction Mechanisms

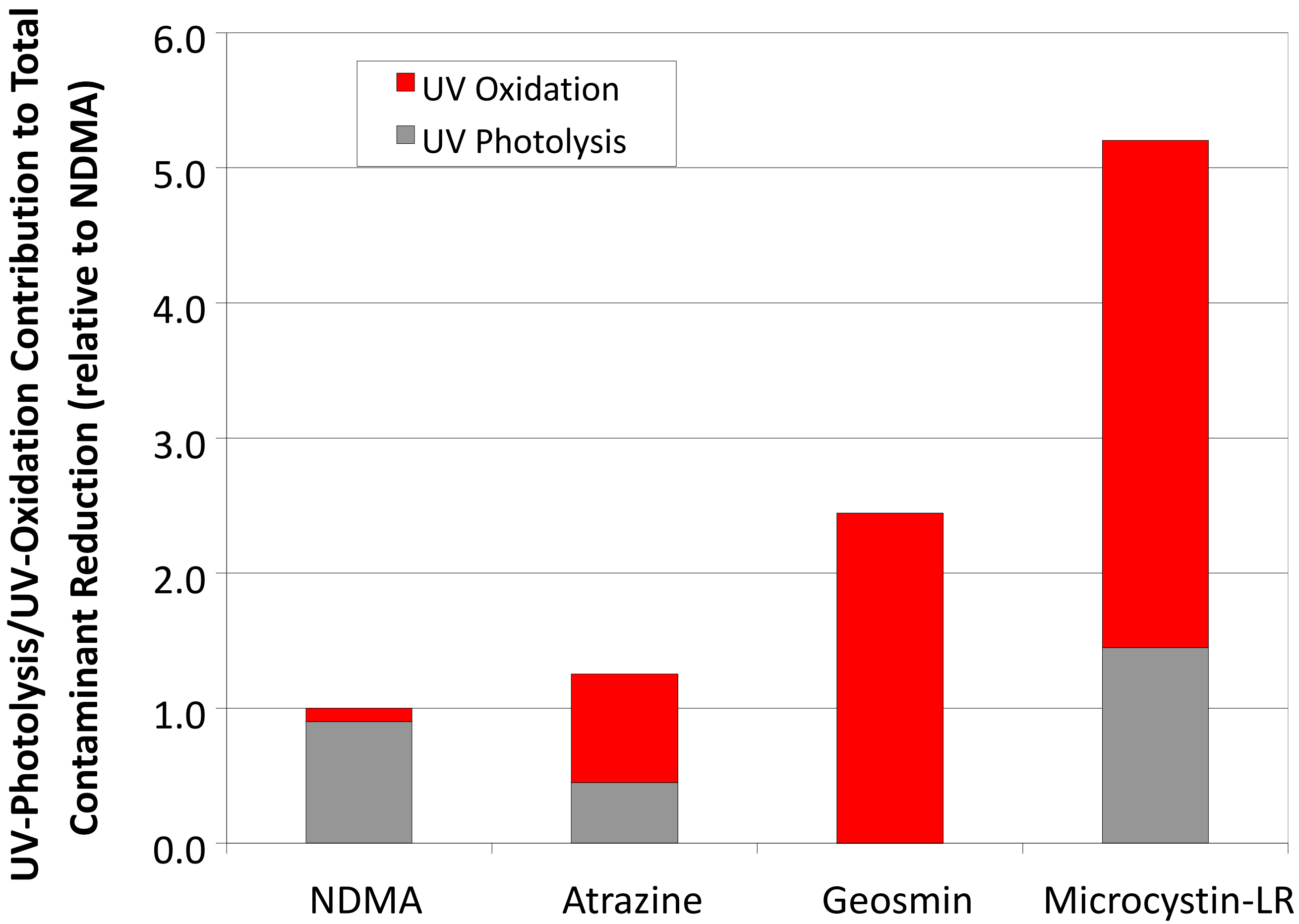
- UV light is absorbed by hydrogen peroxide:

$$H_2O_2 \xrightarrow{h\nu\,\text{(energy)}} 2\,\bullet OH$$

$$C + \bullet OH \xrightarrow{k_{OH,P}} \text{[radical species]} \xrightarrow{O_2} \text{Products}$$

- Degradation rate depends on:
  - Lamp type
  - Absorption of water background (UVT)
  - Hydroxyl radical (●OH) rate constant $k_{OH,C}$
  - H_2O_2 concentration
  - Hydroxyl radical scavenging demand

Contaminant Destruction Balance

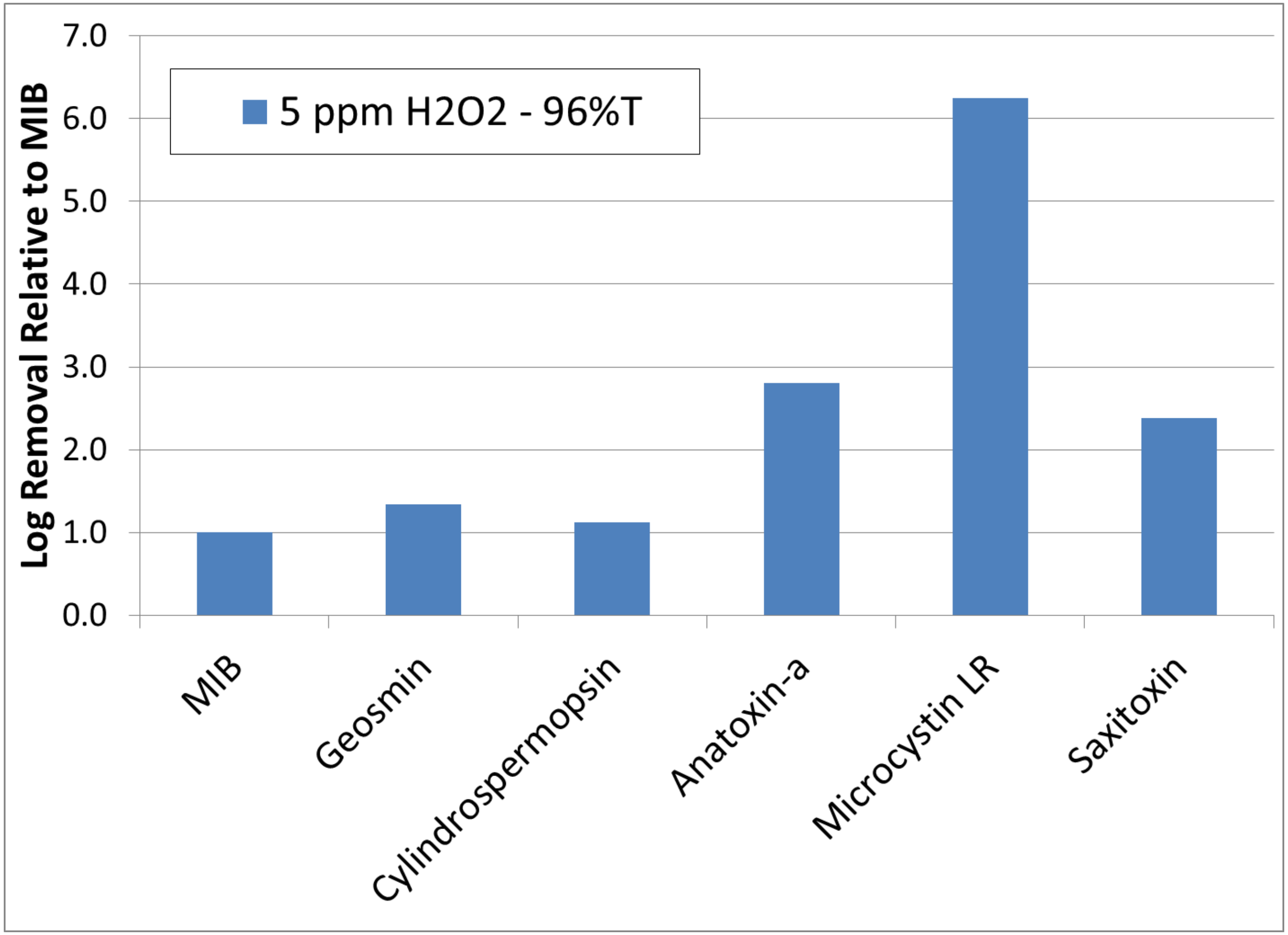


Algal Toxins

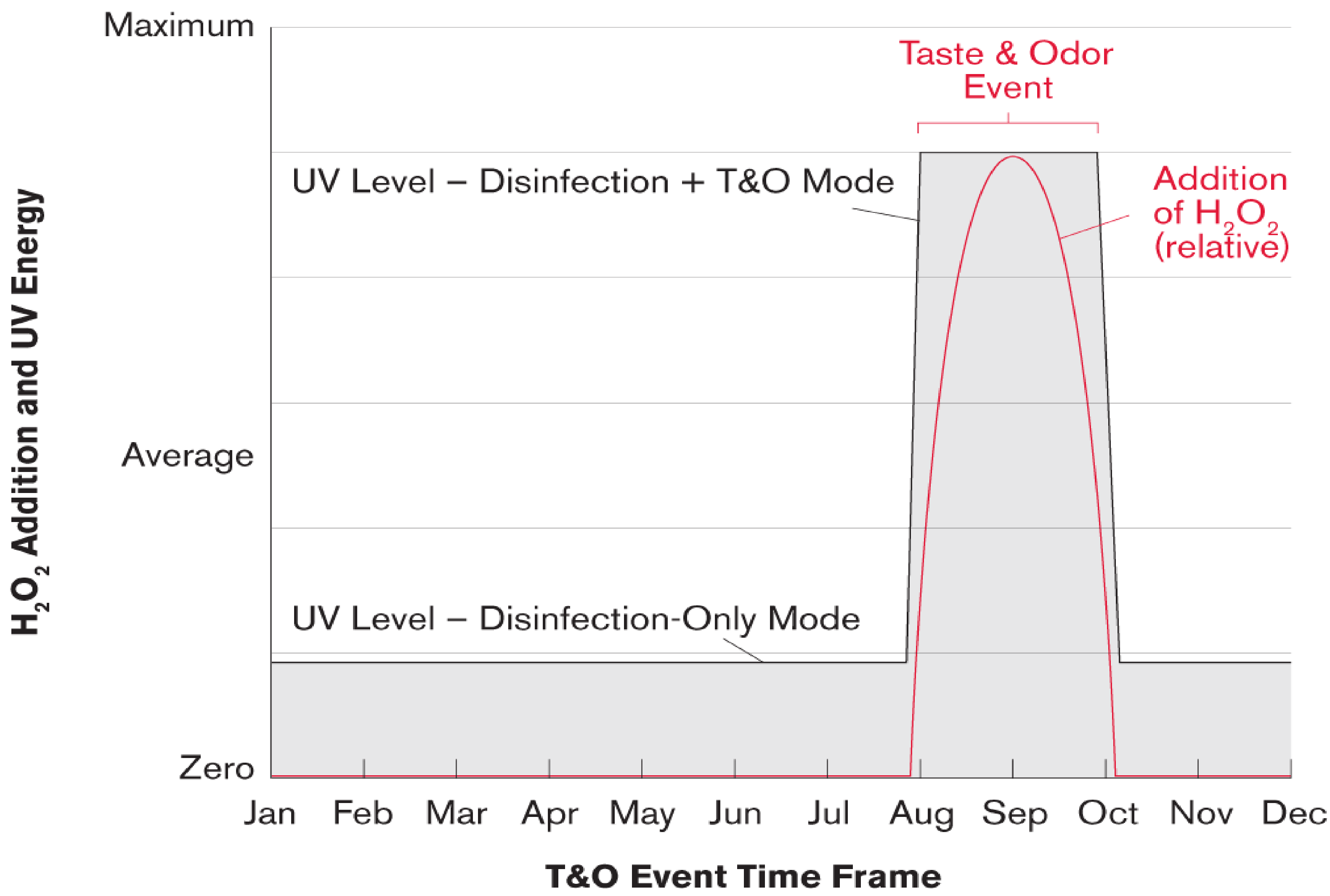
- Algal toxins and their toxicity mode:

Name of Toxin	Type of Toxin	Affected Area
Cylindrospermopsin	Cytotoxin	Liver, Kidney
Microcystin	Hepatotoxin	Liver
Saxitoxin	Neurotoxin	Nervous System
Anatoxin	Neurotoxin	Nervous System
Lipopolysaccharides	Endotoxin	Skin

Algal Toxins Oxidize more Easily than T&O Molecules



Dual-Mode Operation



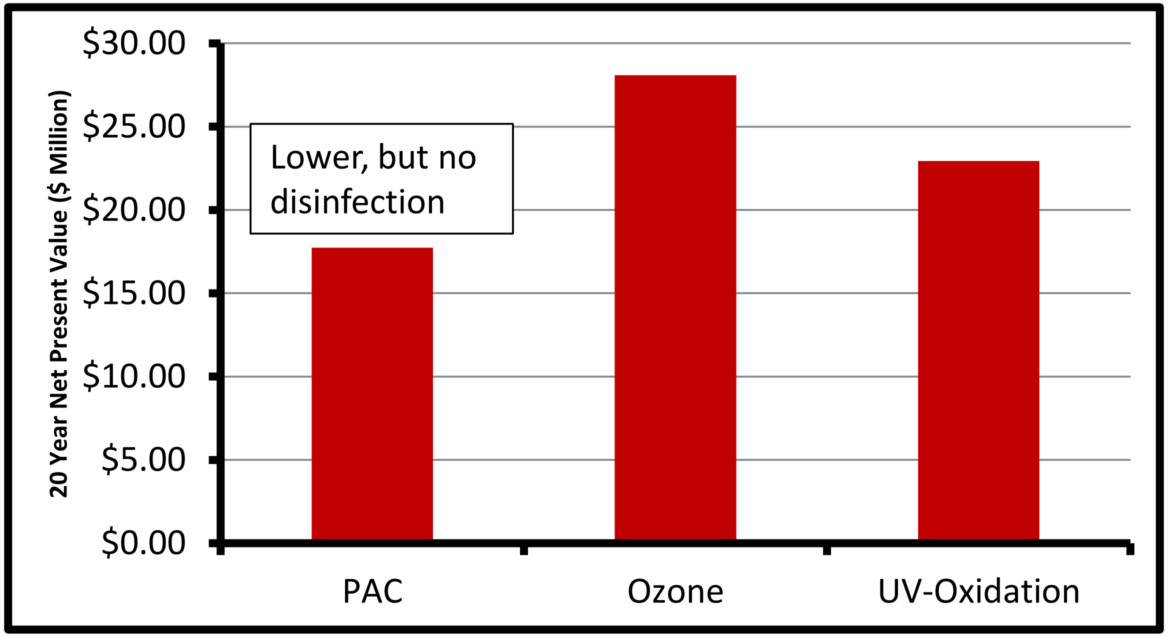
Quenching

- H_2O_2 is not a highly efficient absorber of UV-light
- Most H_2O_2 dosed into a UV-AOP system is not converted to radicals
- Quenching residual H_2O_2 typically needed for most municipal facilities

	Free Chlorine	Activated Carbon
Advantages	•Less expensive •Maintain secondary residual	•Simple and efficient •Low EBCT and infrequent replacement (catalysis)
Disadvantages	•Challenging to manage dose	•More costly

UV AOP Cost Comparison

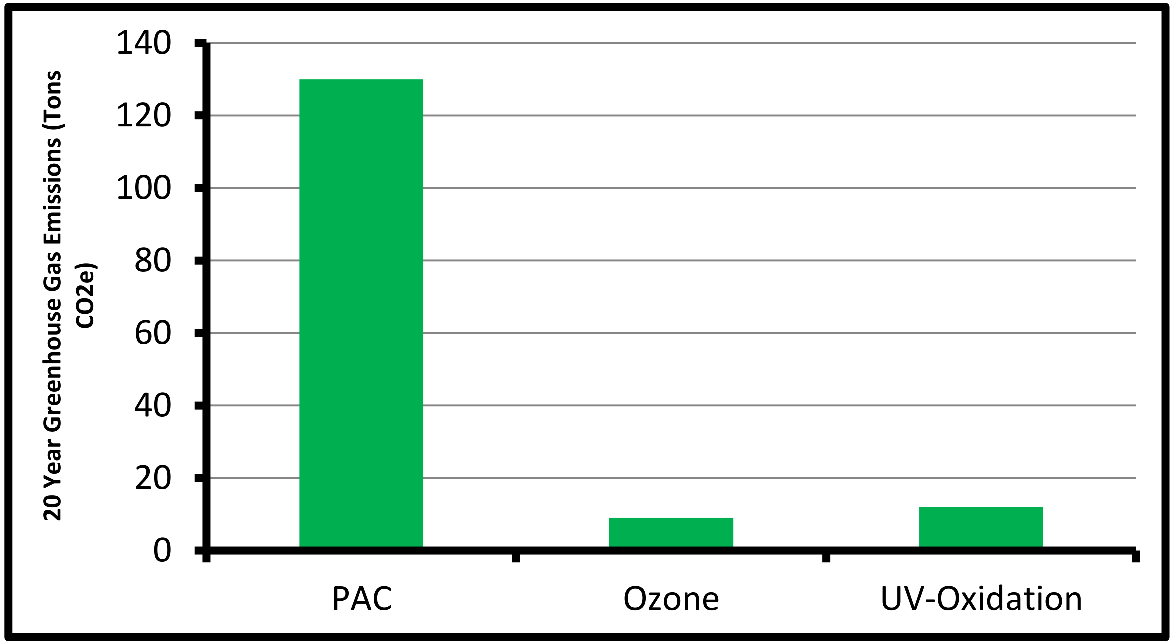
- Design Flow: 30 MGD
- Length of T&O Event: 16 Weeks
- T&O Target: 1-Log Geosmin (During Event Only)
- Disinfection Target: 3-Log *Cryptosporidium* (All Year)
- Facility Lifetime: 20 Years



Swaim, et al., 2011

UV AOP Carbon Footprint

- Design Flow: 30 MGD
- Length of T&O Event: 16 Weeks
- T&O Target: 1-Log Geosmin (During Event Only)
- Disinfection Target: 3-Log *Cryptosporidium* (All Year)
- Facility Lifetime: 20 Years



Swaim, et al., 2011

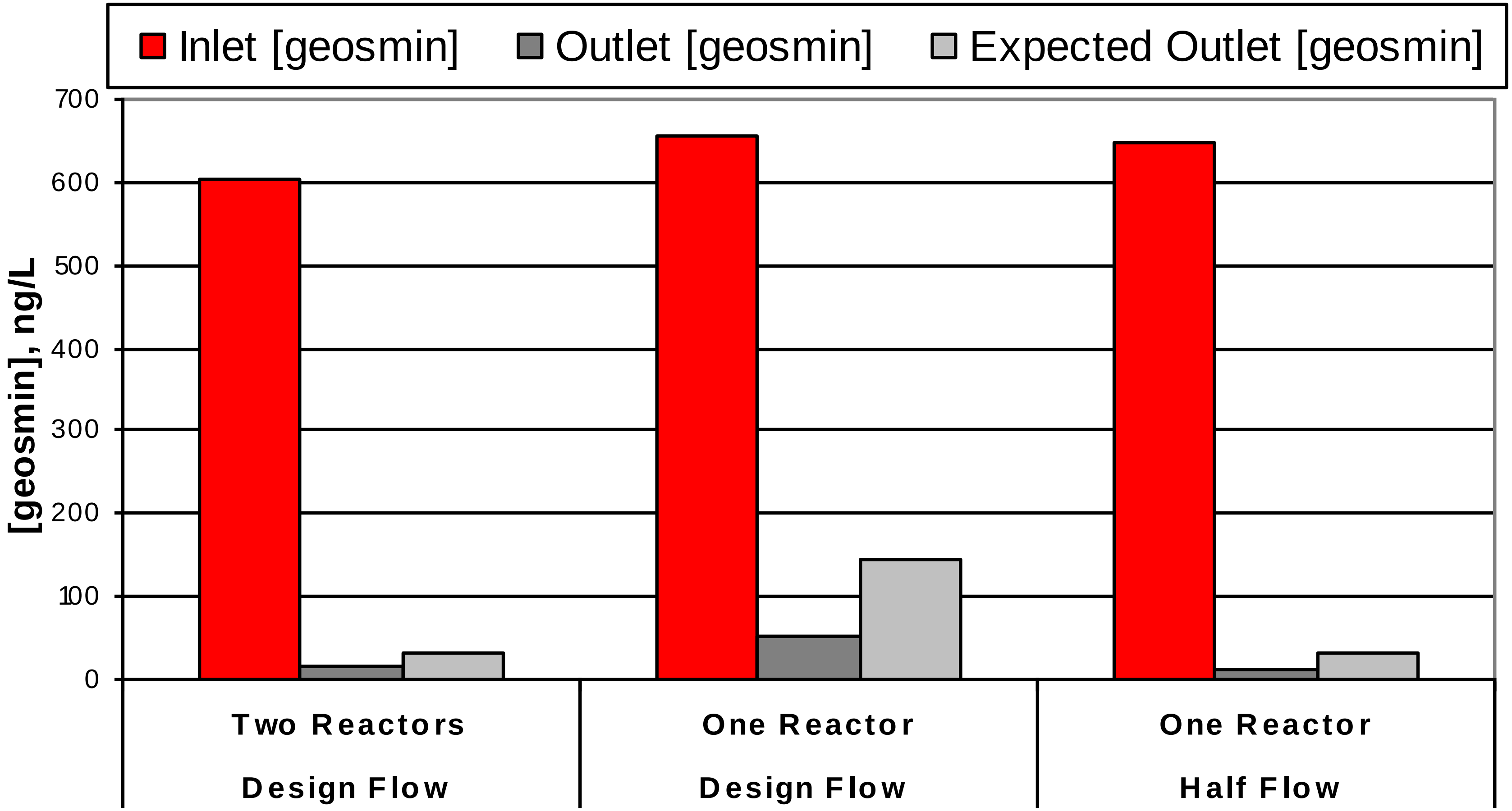
CASE STUDY
Lorne Park WTP, Peel Region

- Flow rate = 103 MGD
- Algal blooms in late summer/early autumn
- Designed for 0.7 log reduction of geosmin
- System provides disinfection in addition to UV AOP (*Cryptosporidium* barrier)
- Both UV-oxidation and ozone technologies were evaluated
- UV-oxidation was ultimately selected due to its:
    - Smaller footprint
    - Safety (no liquid oxygen required on site)
    - Simplicity

CASE STUDY
Regional Municipality of West Elgin

- Source water is Lake Erie
- Flow rate 3.8 MGD (14.4 MLD)
- Treatment train: Screen filtration → Microfiltration → UV-oxidation → final disinfection (Chlorine Quenching)
- Algal blooms in late summer/early fall
- Previously used Powder Activated Carbon for T&O
- Designed for 1.3-log geosmin and 1.0-log MIB
- Operates September through October

CASE STUDY
Regional Municipality of West Elgin



Plants Recently Selecting UV AOP

Treatment Plant Location	Design Flow (MGD)	Target
Groesbeck, TX	2	1-Log Geosmin
Waxahachie, TX	14	1.4-Log Geosmin
Mansfield, TX	7.5	1-Log Geosmin
Patoka Lake, IN	10	1.5-Log Geosmin
Neshaminy, PA	15	1.0-Log Geosmin
Lucerne, CA	1	1.3-Log Geosmin
Lorne Park, ON (Canada)	103	3-Log Geosmin & 1-Log MIB
Chicoutimi Nord, QC (Canada)	2	1-Log Geosmin
PWN (The Netherlands)	63	0.7-Log Atrazine (Pesticide)
Aurora Reservoir, CO	50	Various Contaminants

Benefits Summary

- Small physical footprint
- Less expensive than ozone
- Provides superior third-party validated disinfection
- Always ready: can't be exhausted or degraded (as GAC can be)
- Flexible: if no T&O event, O&M costs are ~1 cent/1,000 gallons
- Can be retrofitted into existing plants
- No bromate formation
- Also capable of removing algal toxins in addition to T&O

THANK YOU

Scott Bindner

Vertical Market Manager – Advanced Oxidation Systems

Trojan Technologies

Office: 519-457-3400 x 2253

Telephone: 905-516-4346

Email: sbindner@trojantechnolgies.com

For more information on UV AOP fill-out a form at:
https://info.trojanuv.com/remediation-ppc2

TROJAN technologies™

Aquafine™ TROJANUV™ VIQUA™ TROJAN marinex™ salsnes Filter™