Comprehensive Strategies to Protect Drinking Water from Harmful Algal Blooms

Webinar Series #4: Harmful Algae Management

US Army Corps of Engineers

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Webinar Series #4: Harmful Algae Management

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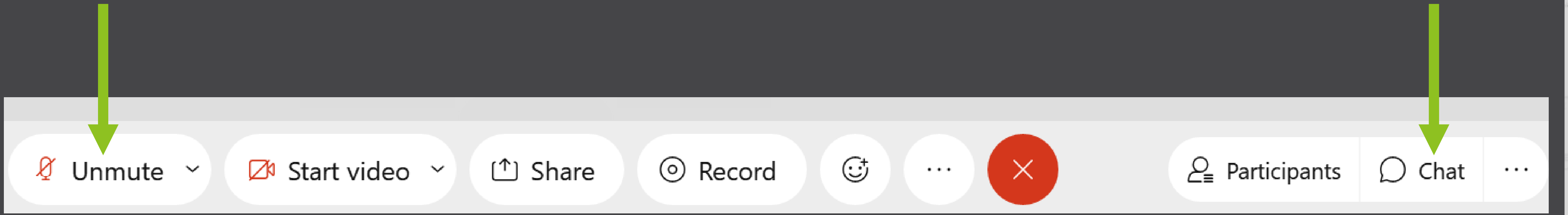

Webinar Series: Comprehensive Strategies to Protect Drinking Water from Harmful Algal Blooms

American Water Works Association

NALMS

NORTH AMERICAN LAKE MANAGEMENT SOCIETY™

APMS

The Aquatic Plant Management Society

1st Presentation

Dr. West Bishop is the Algae Scientist and Water Quality Research Manager at SePRO Corporation, a position he has held for over 10 years.

Dr. Bishop's graduate education consisted of a Masters at Clemson University and Doctorate at NC State University and focused on managing nuisance algae/cyanobacteria.

Dr. Bishop has presented more than 100 professional presentations and published numerous articles in peer-reviewed and other literature and is a certified lake professional through NALMS. His current focus includes inventing, developing and implementing numerous proactive and reactive solutions to improve water quality and control nuisance algae and cyanobacteria. He collaboratively works to solve large-scale algal issues across the country. He is also the Host of AlgaeCorner®, an informational video series on algae, that has over 30 episodes and over 40,000 cumulative views.

Incorporation of algaecides in source water protection

West M. Bishop, Ph.D., CLP
Algae Scientist and Water Quality Research Manager

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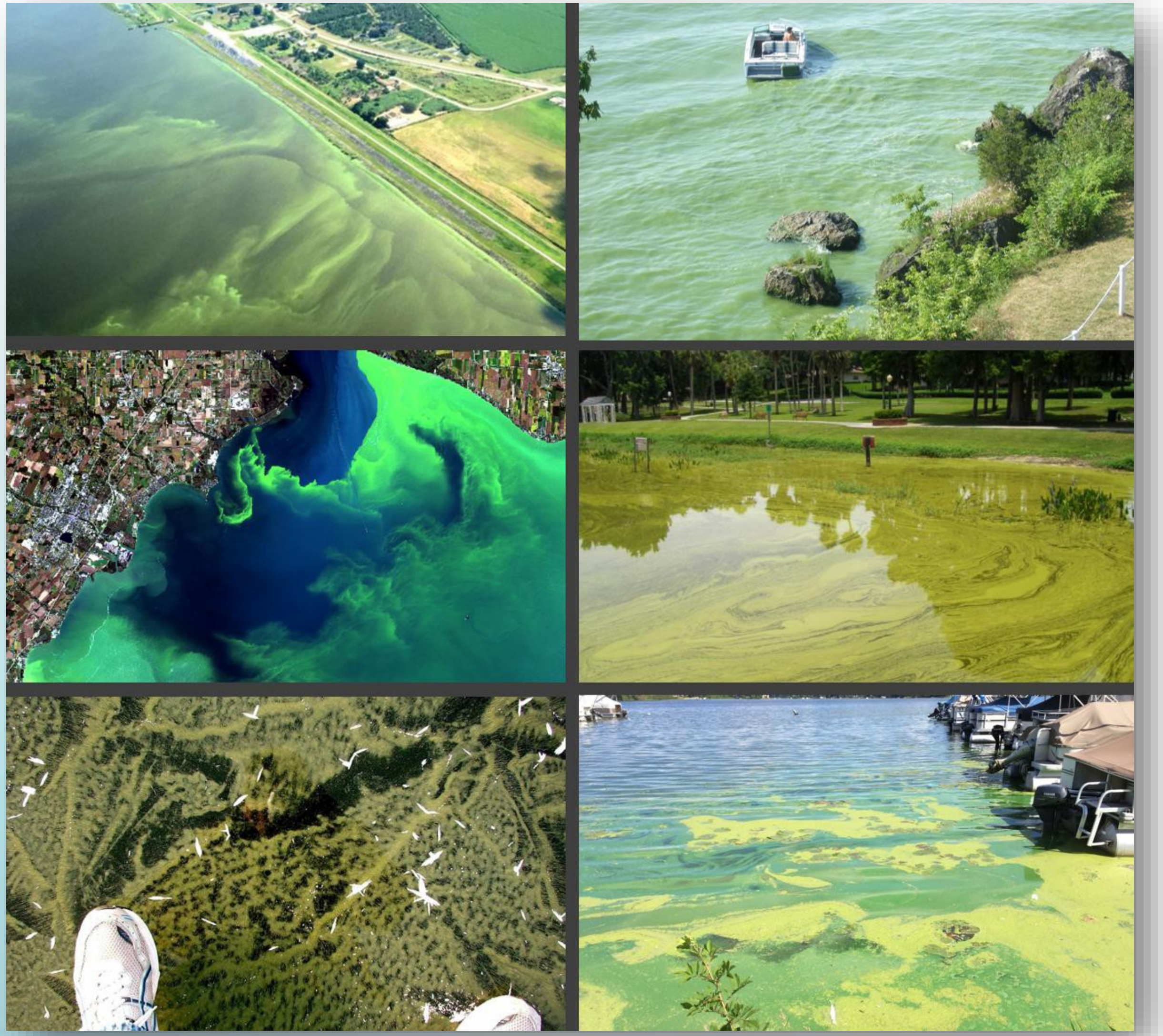
LOOKING FORWARD

Overview

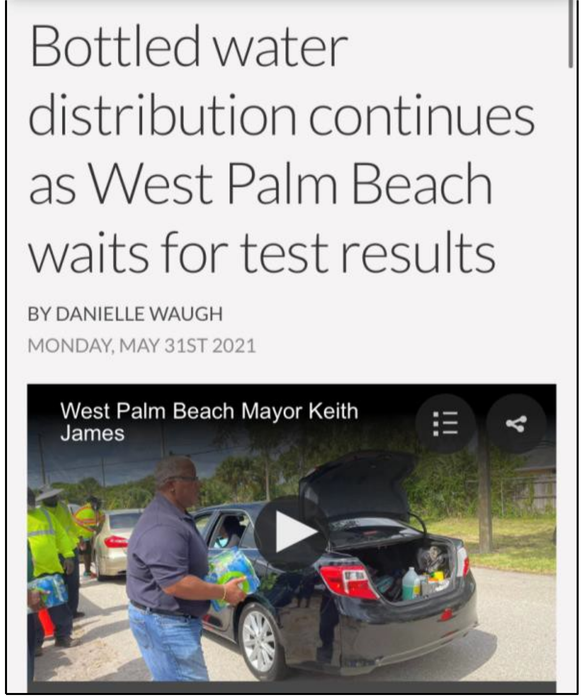
- Why have this talk
- HAB issues in drinking water
- What are Algaecides
  - Strategic need/use
- Action Threshold Approach
- Examples
- Summary/ discussion




TRUTHOUT

NEWS | ENVIRONMENT & HEALTH

Explosive Growth of Toxic Algae Threatens Water Supplies Across US


Bottled water distribution continues as West Palm Beach waits for test results

BY DANIELLE WAUGH

MONDAY, MAY 31ST 2021


IOWA CAPITAL DISPATCH

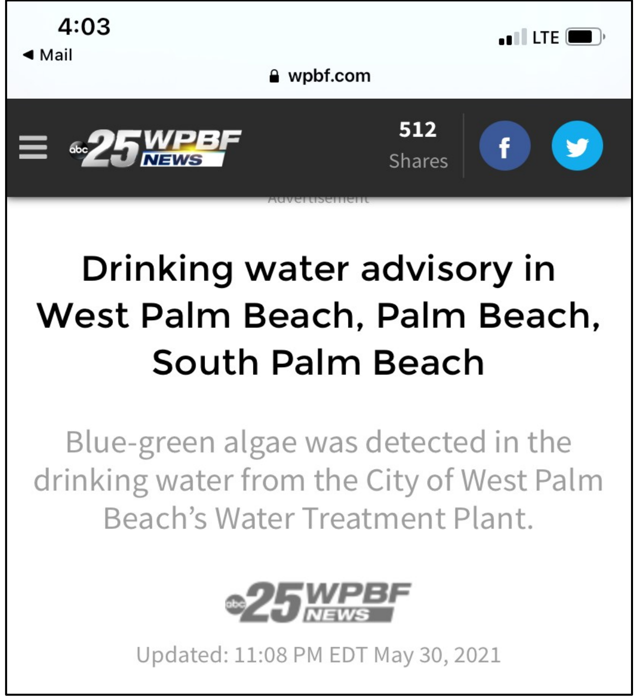
COVID-19 EDUCATION HEALTH CARE JUSTICE AG + ENVIRONMENT GOVERNMEN

PUBLIC INFORMATION COMMENTARY

Ag + Environment

Des Moines River 'essentially unusable' for drinking water due to algae toxins

By Perry Beeman - August 26, 2020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25 WPBF NEWS

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Drinking water advisory in West Palm Beach, Palm Beach, South Palm Beach

Blue-green algae was detected in the drinking water from the City of West Palm Beach's Water Treatment Plant.

25 WPBF NEWS

Updated: 11:08 PM EDT May 30, 2021


circle of blue

where water speaks

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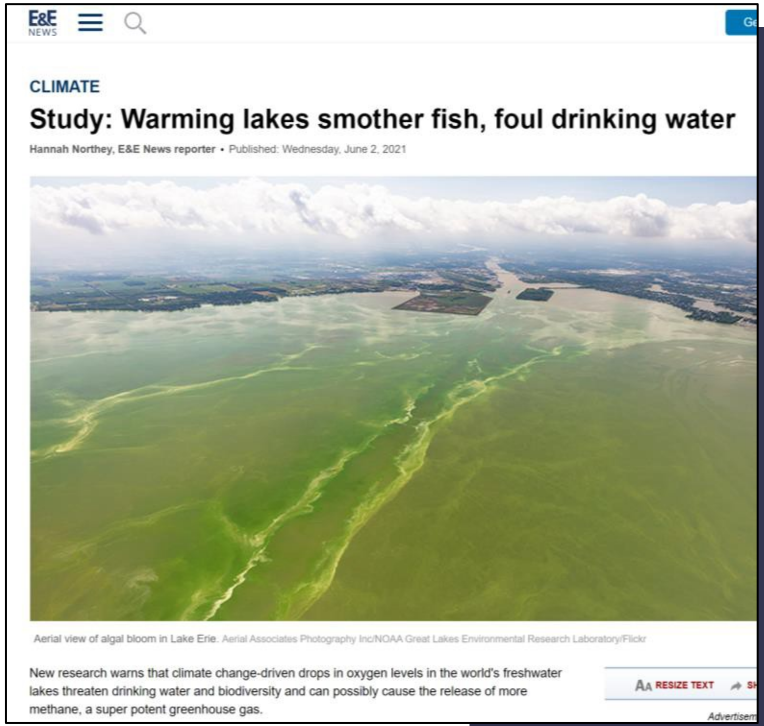
Oregon Capital Battles Algal Toxins in Drinking Water

Toxins result in 'do not drink' advisory for Salem, the latest U.S. city challenged by cyanobacteria.


E&E NEWS

CLIMATE

Study: Warming lakes smother fish, foul drinking water

Hannah Northey, E&E News reporter • Published: Wednesday, June 2, 2021

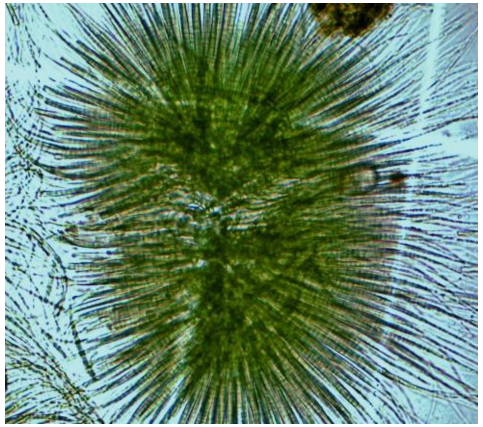
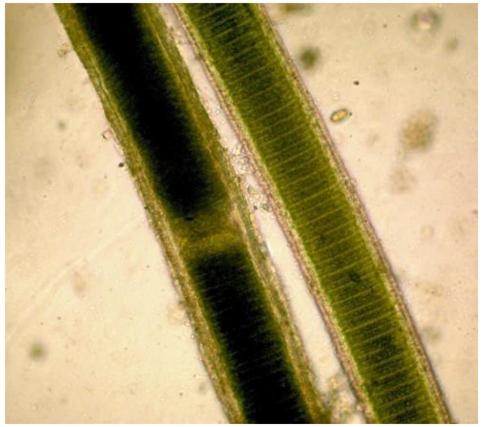
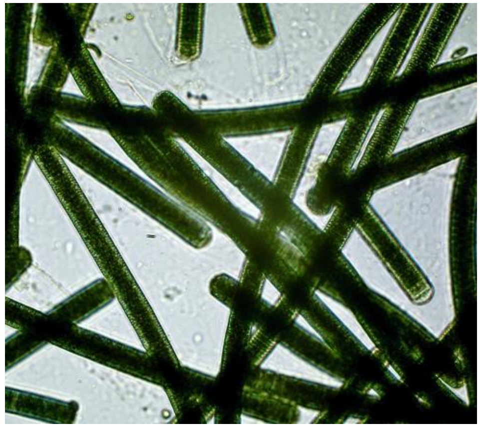
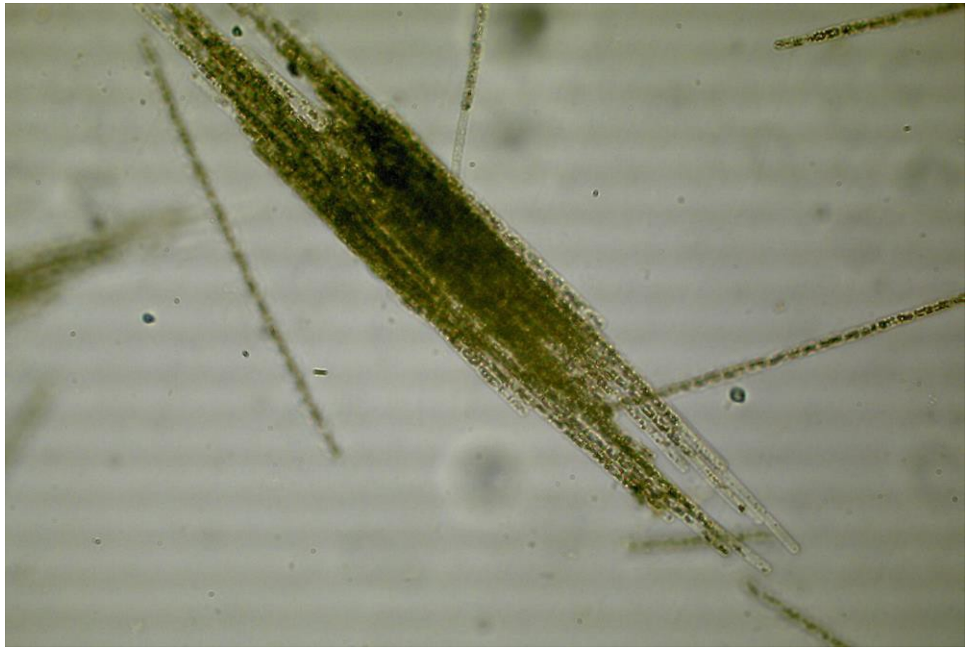
Aerial view of algal bloom in Lake Erie. Aerial Associates Photography Inc/NOAA Great Lakes Environmental Research Laboratory/Flickr

New research warns that climate change-driven drops in oxygen levels in the world's freshwater lakes threaten drinking water and biodiversity and can possibly cause the release of more methane, a super potent greenhouse gas.

Why?

Algal Concerns

- **Toxins**
- **Taste and odor compounds**
  - Geosmin, MIB, > 200
- **Disinfection By-Products**
  - Trihalomethanes (THM's), Halo Acetic Acids (HAA's), ADOM
- **In House Chemical Demand**
  - Carbon, Chlorine, Flocculants
- **Clogging of Intakes/ filters/ membranes**


- New Toxin classes
- New analogues
- Toxins you never heard of..
- Unknown toxins/ toxic metabolites

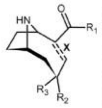
- Lyngbyaureidamides
- Anabaenopeptins
- Jamaicamides
- Aeruginosins
- Nodulopeptins

(Grach-Progrebinsky Carmeli 2008; Zi et al. 2012, Schumacher et al. 2012; Edwards et al. 2004; Ishida et al. 2009)

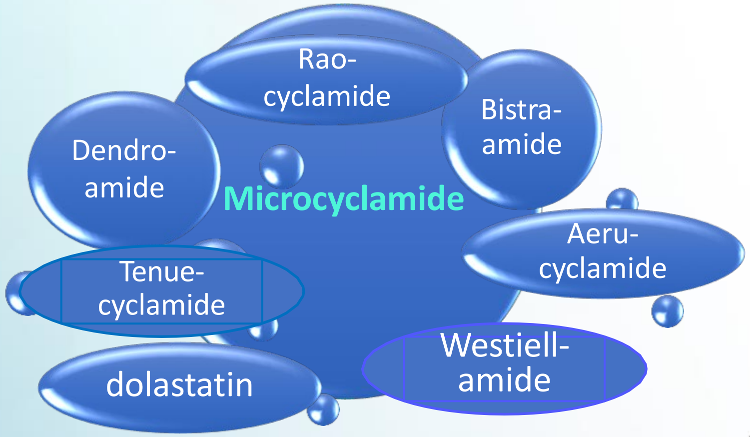
"55 structurally unique bioactive classes"
-Huang and Zimba 2019

Over 250 microcystins

3.2.3. Anatoxin (ANA-Total 10 compounds)



Cpd	M.W.	R_1	R_2	R_3	X-bond
ANA	165.1154	CH_3	H	H	double
homoANA	179.1310	CH_2CH_3	H	H	double
dihydro-ANA	166.1232	CH_3	H	H	single
dihydro-homoANA	180.1388	CH_2CH_3	H	H	single
2,3-epoxy-ANA	181.1103	CH_3	H	H	epoxide
2,3-epoxy-homoANA	195.1259	CH_2CH_3	H	H	epoxide
(*4R*)-4-hydroxy-homoANA	195.1259	CH_2CH_3	H	OH	double
(*4S*)-4-hydroxy-homoANA	195.1259	CH_2CH_3	OH	H	double
4-oxo-homoANA	194.1181	CH_2CH_3	=O		double
11-carboxy-ANA	209.1052	CH_2COOH	H	H	double



C. raciborskii strains can be toxic to mice but do not contain any of the known cyanotoxins
Fastner et al. 2003; Saker et al. 2003

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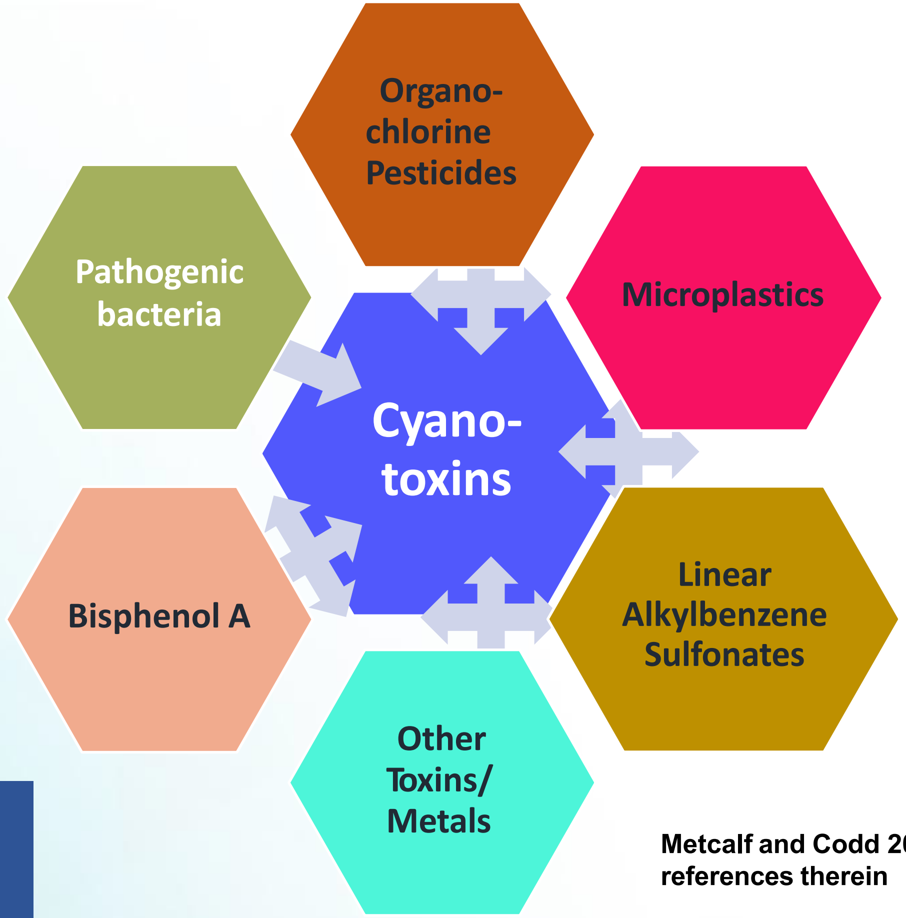
- Synergistic impacts of mixtures of different cyanotoxins and other environmental contaminants
    - Fitzgeorge et al. 1994, Osswald et al. 2009



Metcalf and Codd 2020 and references therein

- Synergistic impacts with drinking water processes
    - Formation of unknown or emerging DBPs
    - 6 by-products formed
        - Merel et al. 2010

chlorination (of microcystins) further enhanced the mammalian cell cytotoxicity and genotoxicity

Liu et al. 2020

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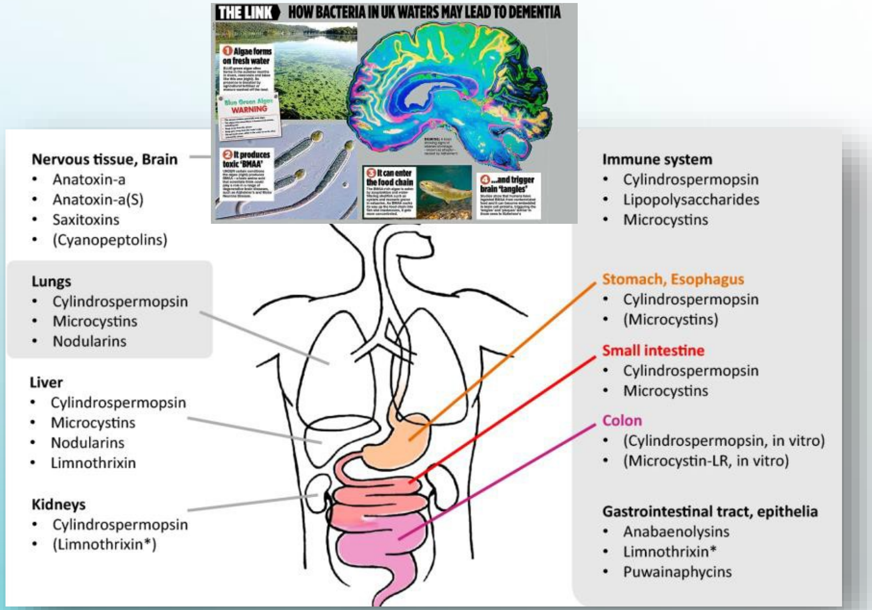
New modes of action

Anatoxin: mimics the neurotransmitter acetylcholine; Binding is irreversible; the sodium channel is locked open, becomes overstimulated, fatigued, and eventually paralyzed

-Botana 2007



Microcystin: causes death from intrahepatic hemorrhage and hypovolemic shock. In animals that live more than a few hours following high level exposure, hyperkalemia or hypoglycemia

-Merck 2008

"….**BMAA** causes the proteins in your brain neurons to get all tangled up, and you see the slow accumulation of tangled up proteins in your neurons until they get completely clogged and the neurons die"

-Dr. Larry Brand

Cylindrospermopsin: induces strand breaks in DNA; Impact kinetochore/spindle function to induce loss of whole chromosomes (aneuploidy)

-Humpage et al 2000

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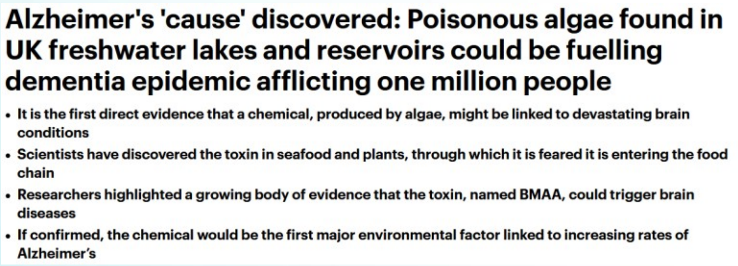
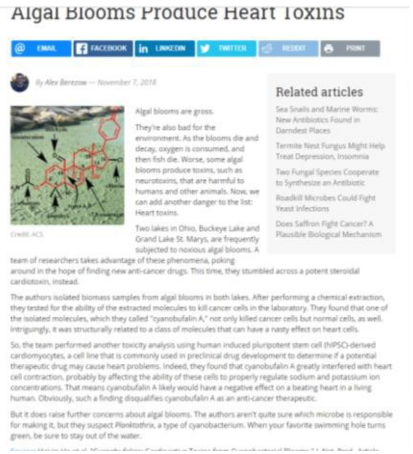
Toxin risks in drinking water?

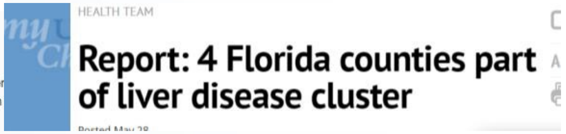
- Cancer
  - Liver cancer: 0.19 pg mcyn per day during 4 summer months (Ueno et al. 1996)
  - Colorectal cancer: mcyn in drinking waters can (Lun et al. 2002)

"A study that analyzed data from Florida determined that there is a significantly higher risk of liver cancer in residents serviced by surface water treatment plants that experience cyanobacterial blooms than those in areas serviced by groundwater."
Fleming et al. 2002

"these bloom-impacted census tracts had a 17.4% higher hepatocellular carcinoma incidence rate as compared to those estimated to receive drinking water from a groundwater source "
Gorham et al. 2020







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Total toxin still a concern in drinking water

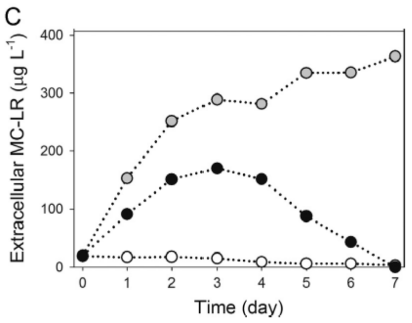
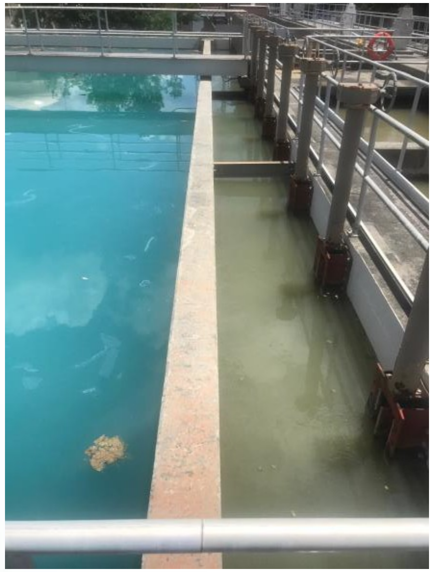


Fig. 1. Variations in the chl.a, intracellular and extracellular MC-LR concentrations following alum treatment in the microcosm experiment. (A): Chl.a concentration, (B): intracellular MC-LR concentration, (C): extracellular MC-LR concentration. White circles: +sediment, gray circles: +alum, black circles: +alum +sediment. Day 0 means before treatment.

- Cells were damaged by alum and subsequently released a large amount of MC-LR
  - Extracellular MC-LR concentration 97 percent of the initial intracellular-LR concentration
    - Han et al. 2013
- Sedimentation sludge: toxin release from decaying cells
- Pass through process
  - Flocculation and filtration: *Aphanizomenon* (Zamyadi et al. 2013)
- Cells can accumulate in filters, potentially lead to a significant amount of extracellular microcystins released to filtered water
  - More backwashes needed, longer durations
- Preoxidation (oxidant prior to filtration) is not recommended because most oxidants will lyse cells and release cyanotoxins
  - EPA, "Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems, July 2012



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Registered Algaecides

- Definition
    - Any substance designed to control, prevent or mitigate a pest (FIFRA)
- Have a place in toolbox
    - Part of integrated program (complement proactive/non-chemical)
- Consistent formulation (QAQC)
- Numerous studies by registrant to support registration
- Label instructions
    - Set for negligible risks to humans and environment
    - Most approved by USEPA/ States for listed use sites (potable sources)
    - Some with NSF ANSI standard 60 certification
- **Rapid-response tool and fast acting**
- **Mostly predictable efficacy**
    - **Can be selective, targeted application**

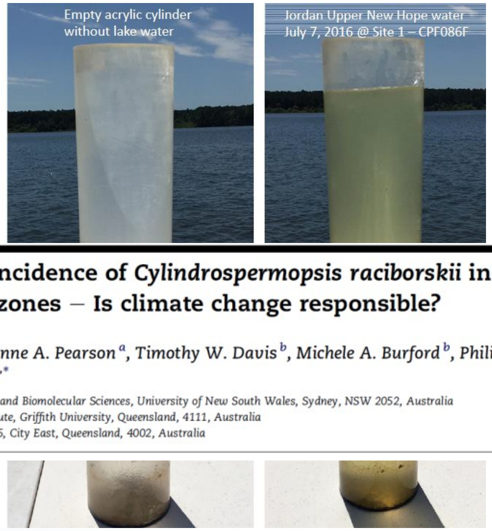
FIFRA

***Read and follow all label instructions**

HAB Physiology

- *Raphidiopsis* grows under both low and high N:P ratios
  - Use multiple forms of nutrients (e.g. organic) (Chislock et al. 2014)
- Grows with no dissolved nitrogen (O'neil et al. 2013)
  - Fixation from atmosphere (Sinha et al. 2012)
- Unique P usage
  - High uptake, affinity, storage, scavenge episodic inputs (Wu et al. 2012)
  - Dominates in low phosphate
- Likes static or mixed conditions, especially to dark zones
  - Kehoe 2010; Antenucci et al. 2005; Burford and O'Donohue 2006

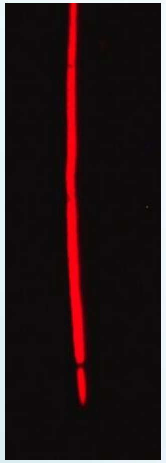
- **Meteorological and chemical factors** were **not** related to the dominance of *C. raciborskii* (Figueredo and Giani 2009)
- "Can tolerate a wider range of P concentrations" and "proliferate in a wide range of N conditions" (Sinha et. al 2012)
- "In summary, the ecological flexibility of this organism means that controlling blooms of *C. raciborskii* is a **difficult undertaking**" (Buford and Davis 2011)

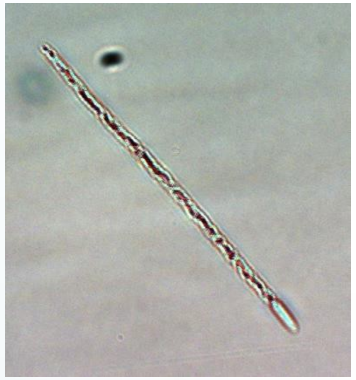


Increased incidence of *Cylindrospermopsis raciborskii* in temperate zones – Is climate change responsible?

Rati Sinha[a], Leanne A. Pearson[a], Timothy W. Davis[b], Michele A. Burford[b], Philip T. Orr[c], Brett A. Neilan[a,*]

[a] School of Biotechnology and Biomolecular Sciences, University of New South Wales, Sydney, NSW 2052, Australia
[b] Australian Rivers Institute, Griffith University, Queensland, 4111, Australia
[c] Sequater, PO Box 16146, City East, Queensland, 4002, Australia





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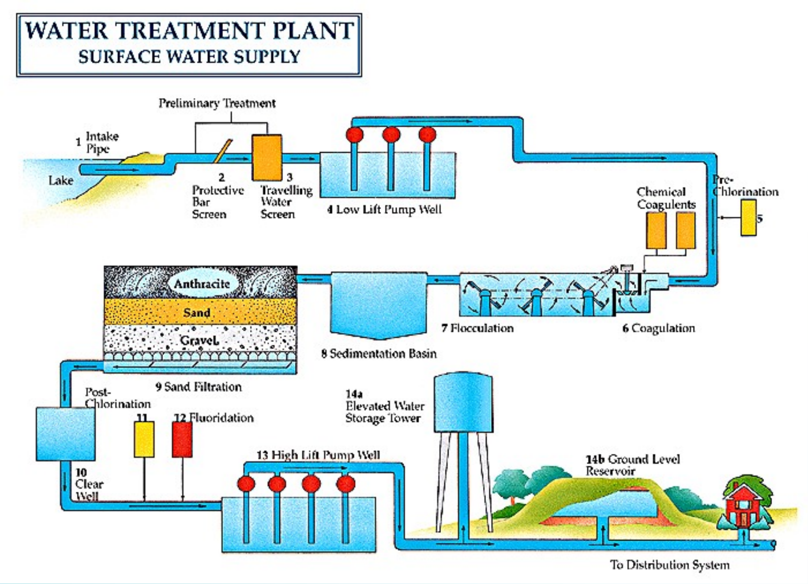
Source Control

Better Water In

Control in supply sources



Better Water Out

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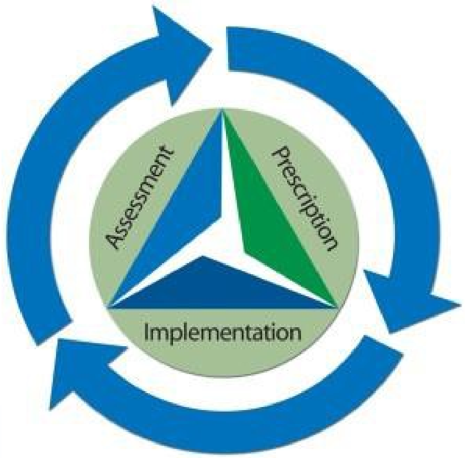
Action Threshold Based Approach

- Justify a treatment
  - Decision trigger
- Set AT levels in accordance with management objectives
  - Adaptable
- Never have levels that cause concern
  - Only treat when needed, but before problematic levels achieved
- Immediate identification of problem/ rapid implementation
  - Avoid public concern over quality
- NPDES 2011 (2.2.2 Weed and Algae pest control)
  - "Applying the pesticide only when the action threshold has been met"



United States Environmental Protection Agency (USEPA) (2011) National Pollutant Discharge Elimination System (NPDES). Pesticide General Permit (PGP) for Discharges from the Application of Pesticides. Washington, DC

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Setting Action Threshold levels?

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Setting AT Levels

- Taste/odor
  - Flavor panel
  - Complaints
- Toxins
- Filter run time
- pH
- Secchi, pigments
- Specific objectives and program

Table 15-5 Critical cell densities estimated for specific VOCs (from measured cell production and OTCs) or from nonspecific sensory detection (SD)*

Taxa	Group	VOC	OTC (μg/L)	CDC Cells (mL⁻¹)	Reference
Anabaena sp.	CYAN	SD		5.E+03	30
Anabaena laxa	CYAN	geosmin	0.004	2.E+02	7
Anabaena sp.	CYAN	β-cyclocitral	19.3	1.E+06	13
Anabaena sp.	CYAN	geosmin	0.004	4.E+01	28
Aphanizomenon	CYAN	SD		7.E+03	30
Microcystis sp.	CYAN	SD		4.E+04	30
Microcystis aeruginosa	CYAN	β-cyclocitral	19.3	2.E+05 - 1.E+06	28, 13
Oscillatoria sp.	CYAN	SD		5.E+04	30
Oscillatoria cf. *chalybea*†	CYAN	MIB	0.029	1.E+02	7
Oscillatoria tenuis‡	CYAN	geosmin	0.004	1.E+03	7
Phormidium cf. *calcicola*	CYAN	geosmin	0.004	3.E+02	7
Phormidium cf. *calcicola*	CYAN	MIB	0.029	5.E+02	7
Dinobryon cylindricum	CHRY	2,4,7-decatrienal	1.5	4.E+03	29
D. cylindricum	CHRY	2,4-heptadienal	3	5.E+04	29
D. divergens	CHRY	2,4,7-decatrienal	1.5	8.E+03	29
Dinobryon sp.	CHRY	SD		3.E+03	30
Dinobryon sp.	CHRY	2,4-heptadienal	3	4.E+05	7
Mallomonas sp.	CHRY	SD		5.E+02	30
Synura sp.	CHRY	SD		3.E+02	30
Synura petersenii	CHRY	2,6 -nonadienal	0.08	3.E+02	7
Synura petersenii	CHRY	2,4,7-decatrienal	1.5	2.E+03	7
Uroglena americana	CHRY	2,4,7-decatrienal	1.5	1.E+05	29
Uroglena americana	CHRY	2,4-heptadienal	3	3.E+04	29
Ceratium sp.	DIN	SD		2.E+02	30
Cryptomonas sp.	CRYP	SD		1.E+03	30
Asterionella formosa	DIAT	2,4,7-octatriene	No data	3.E+03	30
Cyclotella sp.	DIAT	SD		2.E+03	30
Melosira (Aulacoseira) sp.	DIAT	SD		3.E+03	30
Synedra sp.	DIAT	SD		3.E+03	30
Tabellaria sp.	DIAT	SD		8.E+02	30
Euglena sp.	CHLOR	SD		8.E+02	30
Ankistrodesmus sp.	CHLOR	SD		4.E+03	30
Chlamydomonas sp.	CHLOR	SD		4.E+03	30
Eudorina sp. (colonies)	CHLOR	SD		8.E+01	30
Pandorina sp.	CHLOR	SD		2.E+03	30
Scenedesmus sp. (colonies)	CHLOR	SD		2.E+03	30

*Taxonomic group abbreviations as in Table 15-1. References as in Table 15-2. Synonyms for revised species names given in table.
†*Phormidium chalybeum*.
‡*Phormidium tenue*.

Watson, S.B. 2010. Algal Taste and Odor Chapter 15 in: Algae: Source to Treatment, M57 (American Water Works Association Manual).

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Toxins: ~5,000 cells/mL

an algaecide it is important to closely read the pesticide label and be fully aware of both the environmental impact and practical problems with its use. Water systems must also follow the conditions outlined in the pesticide general permit. Treatment should be applied at the early stages of a bloom when cyanobacteria cell counts are low (<10,000 cells/ml) because: 1) this is when the potential for cyanotoxin release is not probable or low, and 2) if the treatment is applied at the early stages of a bloom, then the toxic compounds if released into the water can be removed effectively during the treatment processes. To keep the algae under control for extended periods of time, the algaecide applications should be performed at specific intervals based upon the pesticide label.

American Water Works Association
Ohio Section Technology Committee

Ohio Environmental Protection Agency

DRAFT WHITE PAPER ON CYANOTOXIN TREATMENT
August, 2015

Box 5.2 Epidemiological evidence for low-level cyanobacterial hazard

The epidemiological data of Pilotto *et al.* (1997) can be used as a basis for guideline derivation for acute, non-cumulative health effects which are more likely to result in discomfort rather than serious health outcomes. These data encompass the health effects on humans of intact cyanobacterial cells and colonies and thus include effects of currently unknown substances and bacteria associated with cyanobacterial colonies. The effects measured were eye irritation, ear irritation, skin rash, as well as vomiting, diarrhoea, cold/flu symptoms, mouth ulcers and fever. An elevated "Odds Ratio" for symptoms (3.44) was shown by the people who were in water contact for more than one hour, at above 5,000 cyanobacterial cells per ml. Similar Odds Ratios were seen for symptoms in people bathing in water with 5,000-20,000 cells per ml (2.71) and above 80,000 cells per ml (2.90).

WHO 1999

cyanobacteria, molecular tools or quick testing for cyanotoxin concentrations should be applied in parallel. A cyanobacterial cell density of 4,000 cells/mL was found to be a cost-effective threshold for commencing microcystin analysis.

The HAB treatments include removal of

Koreivienė et al. 2014

in order to maximize public health safety while maintaining cost considerations, we advocate for an adaptive management framework that incorporates toxin measurements only after potentially toxigenic cell densities exceed <u>2000 cells/mL</u>.

Paerl and Otten 2015

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Examples

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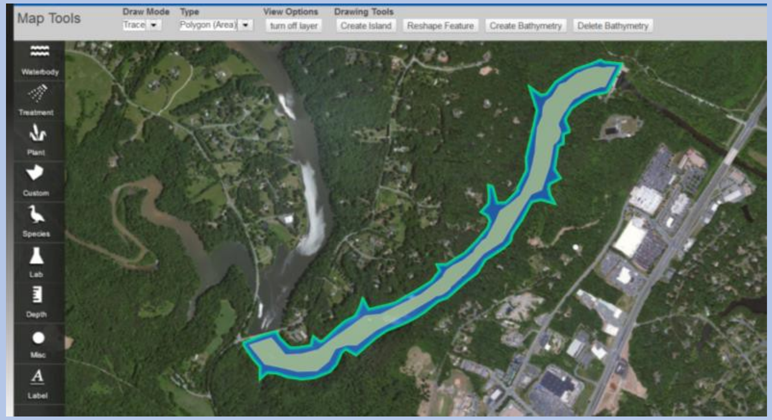
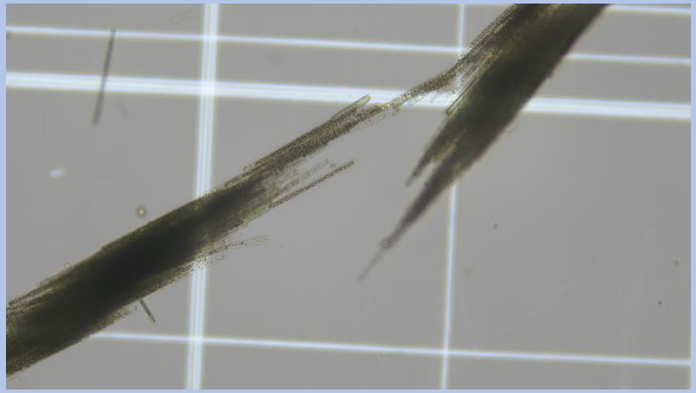
Example 1: Action Threshold program VA Reservoirs

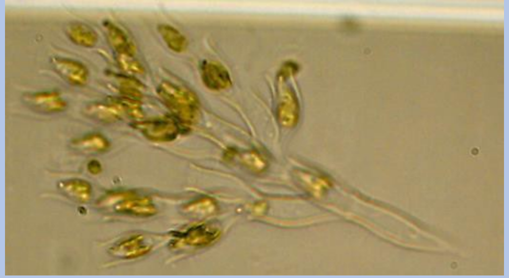


Parameter	Action Threshold level	Units
Overall Cyanobacterial cell density	**5,000**	**cells/mL**
***Dinobryon* spp. cell density**	**1,000**	**cells/mL**

Others: Visible scum formation, mat formation, panel detection

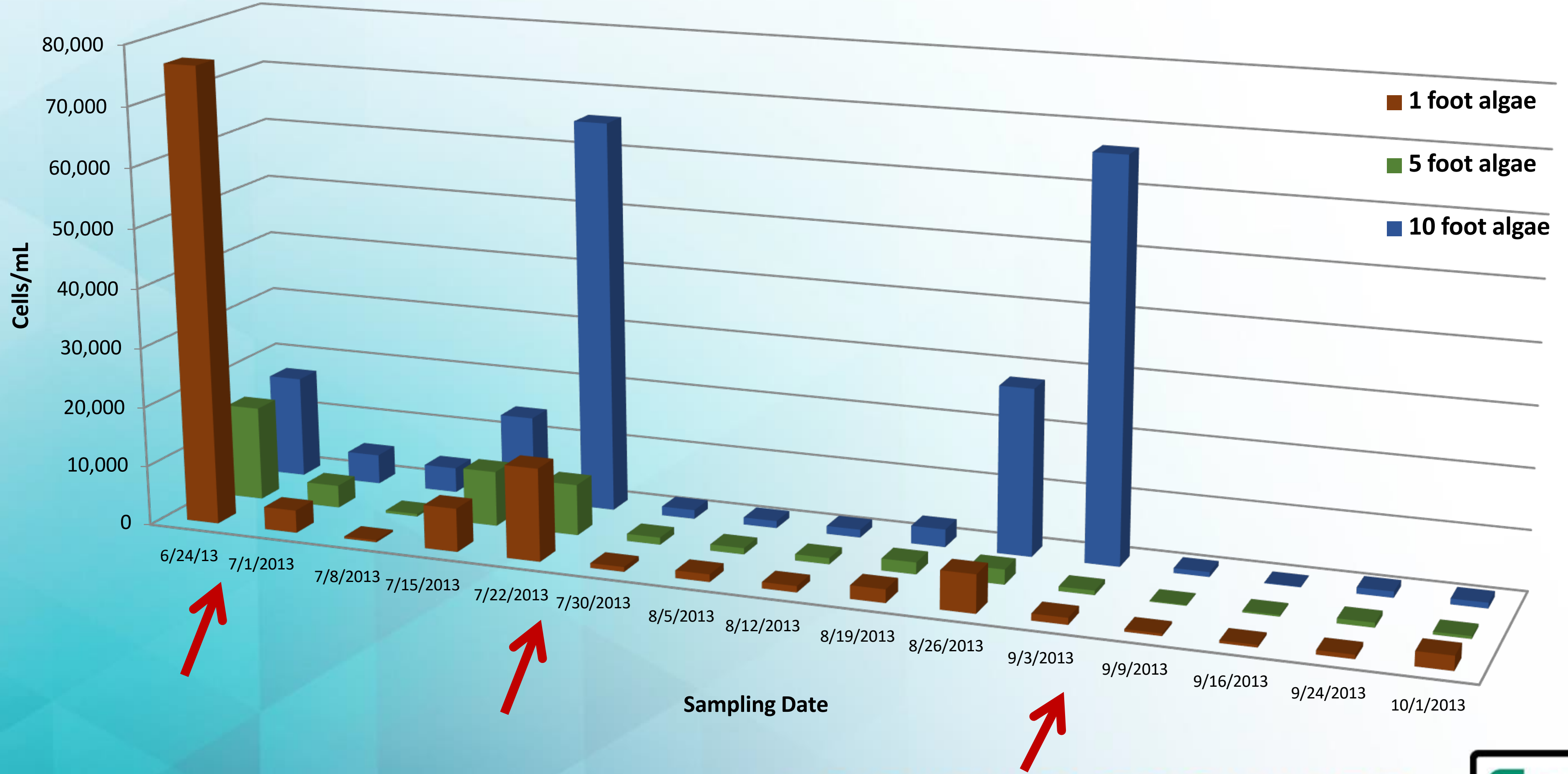
Newly added: (pH swing, filter run time)





Total Algal Densities

Arrows indicate threshold exceeded and subsequent Copper Algaecide and Water Quality Enhancer application



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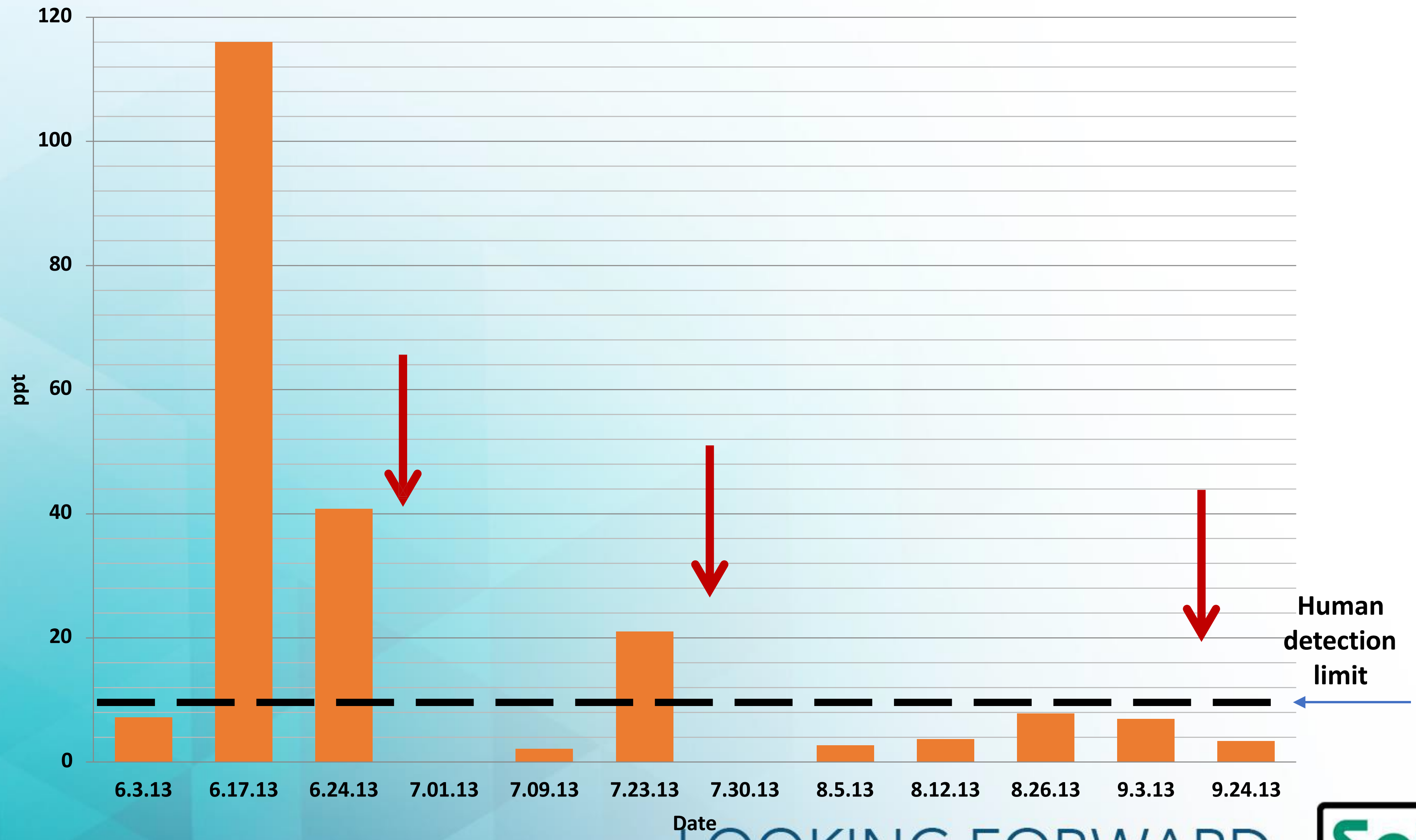
Geosmin Analysis



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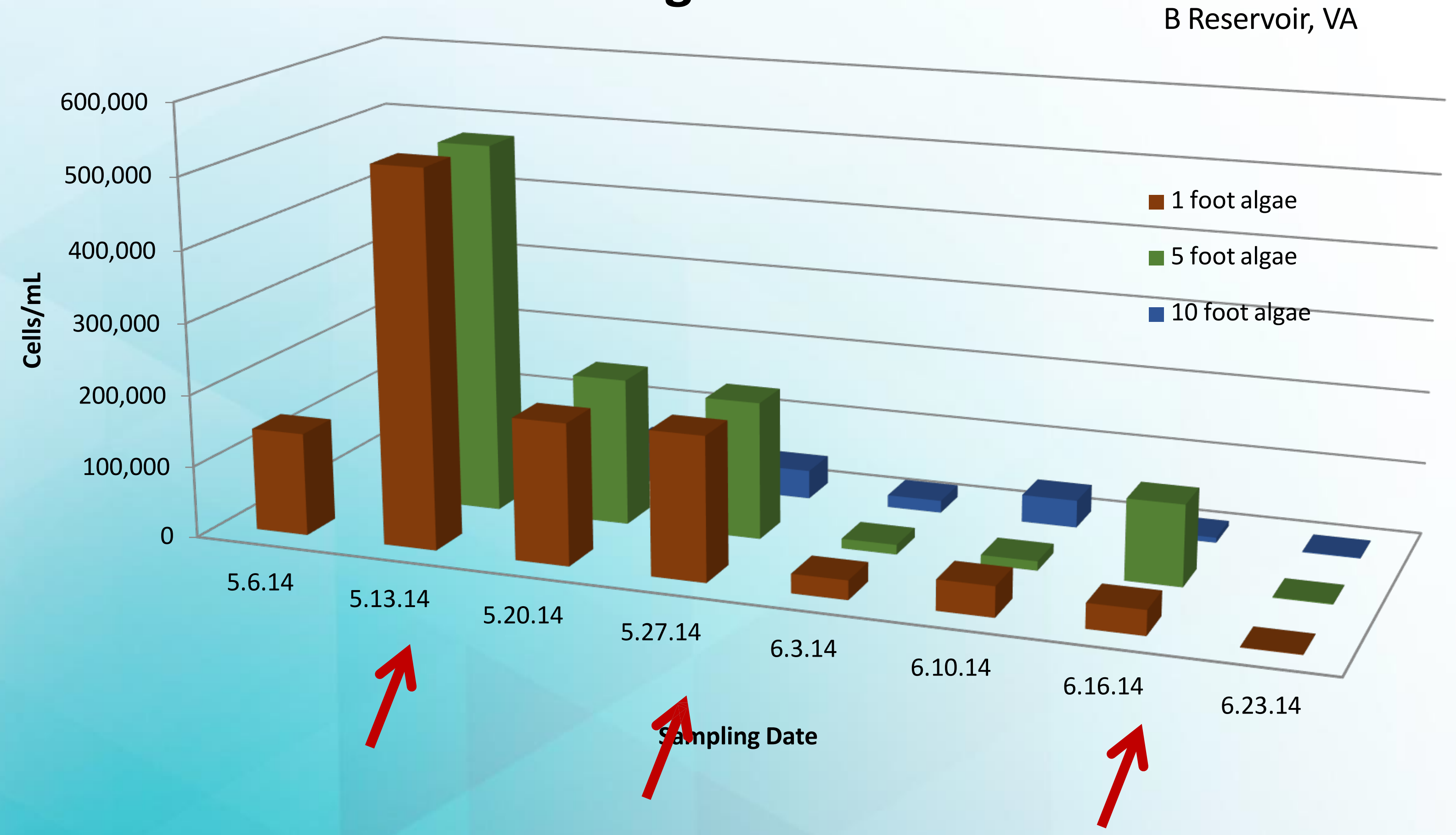
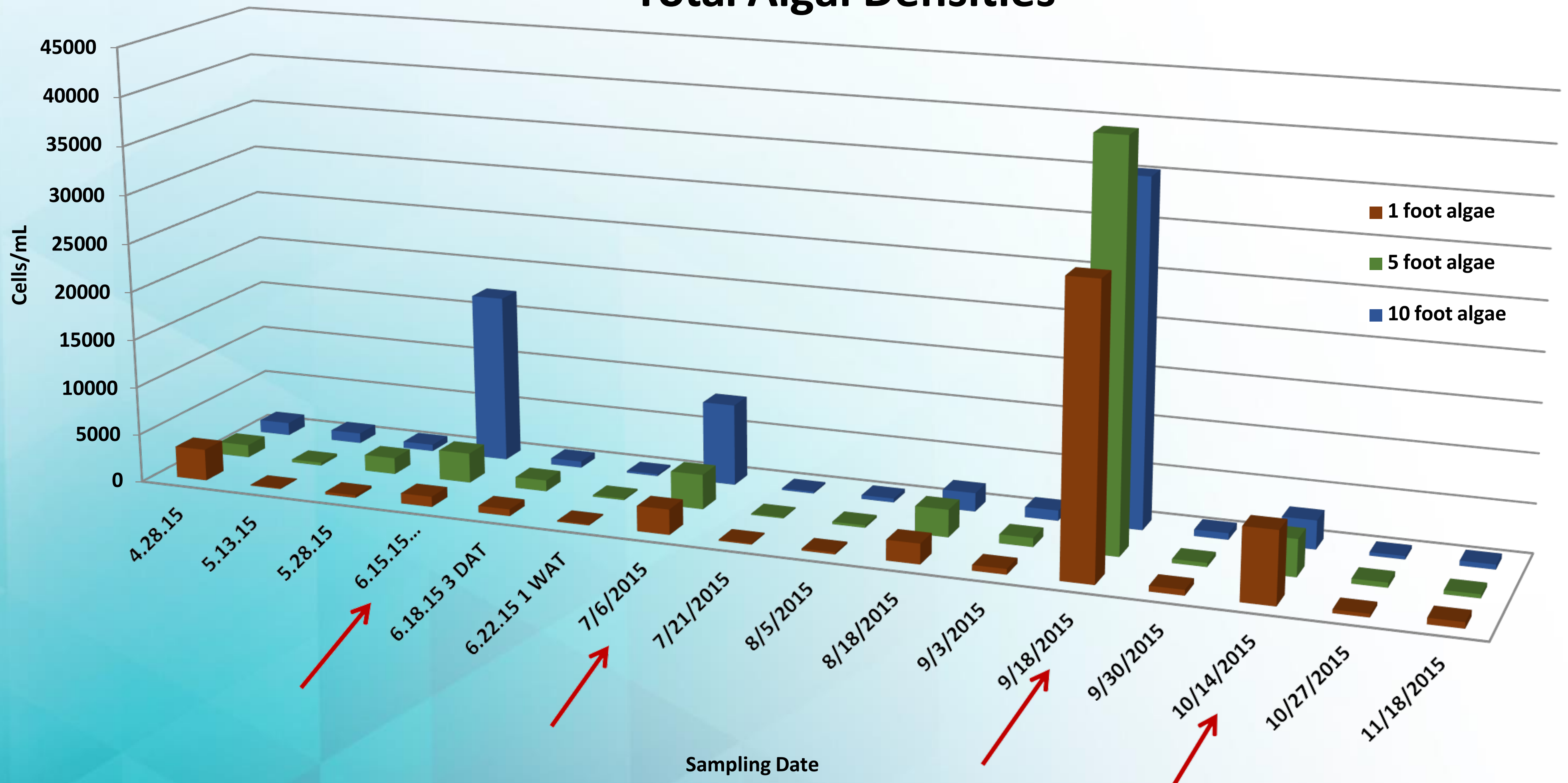
Total Algal Densities



LOOKING FORWARD

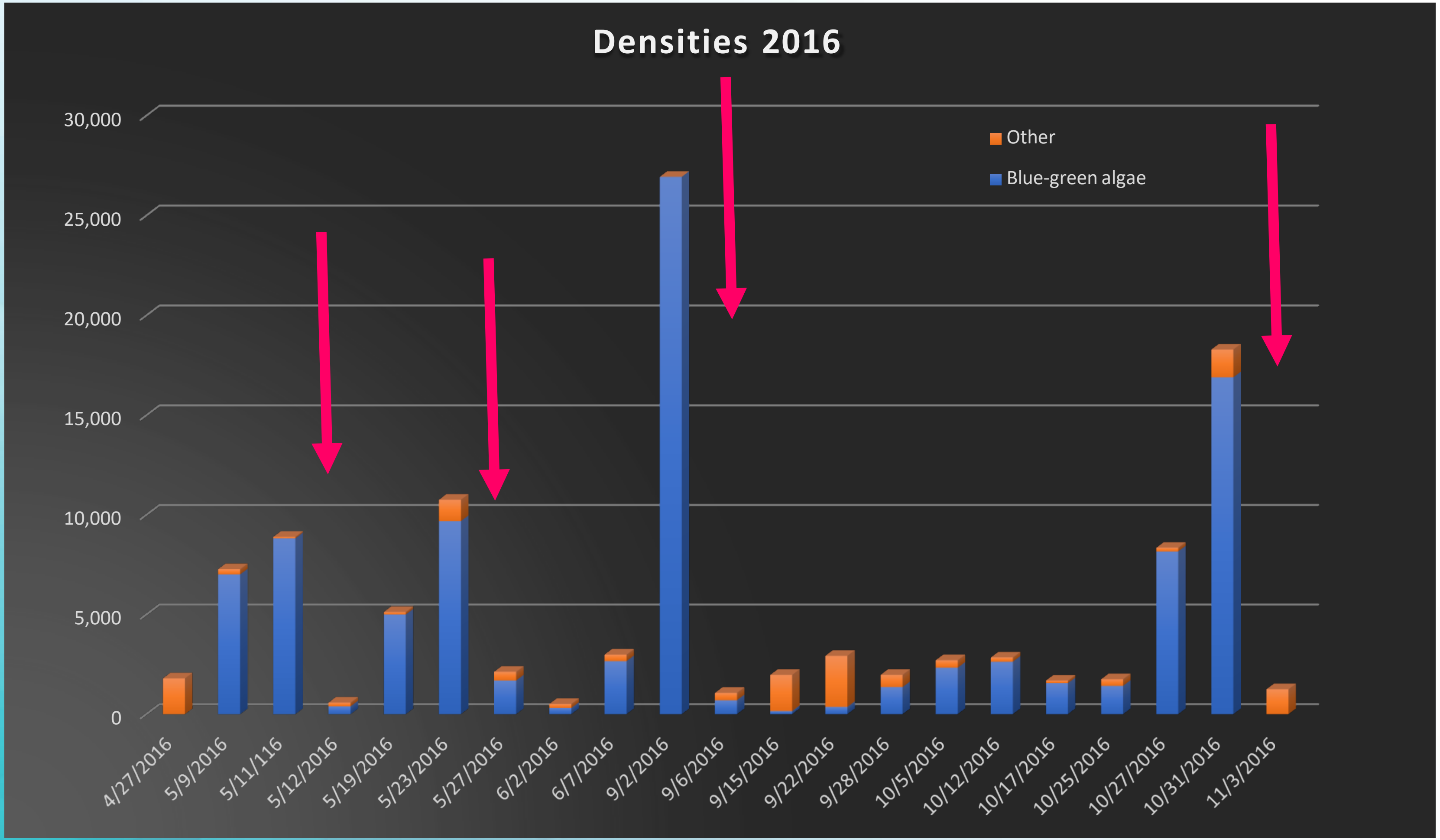
Total Algal Densities

B Reservoir, VA



LOOKING FORWARD

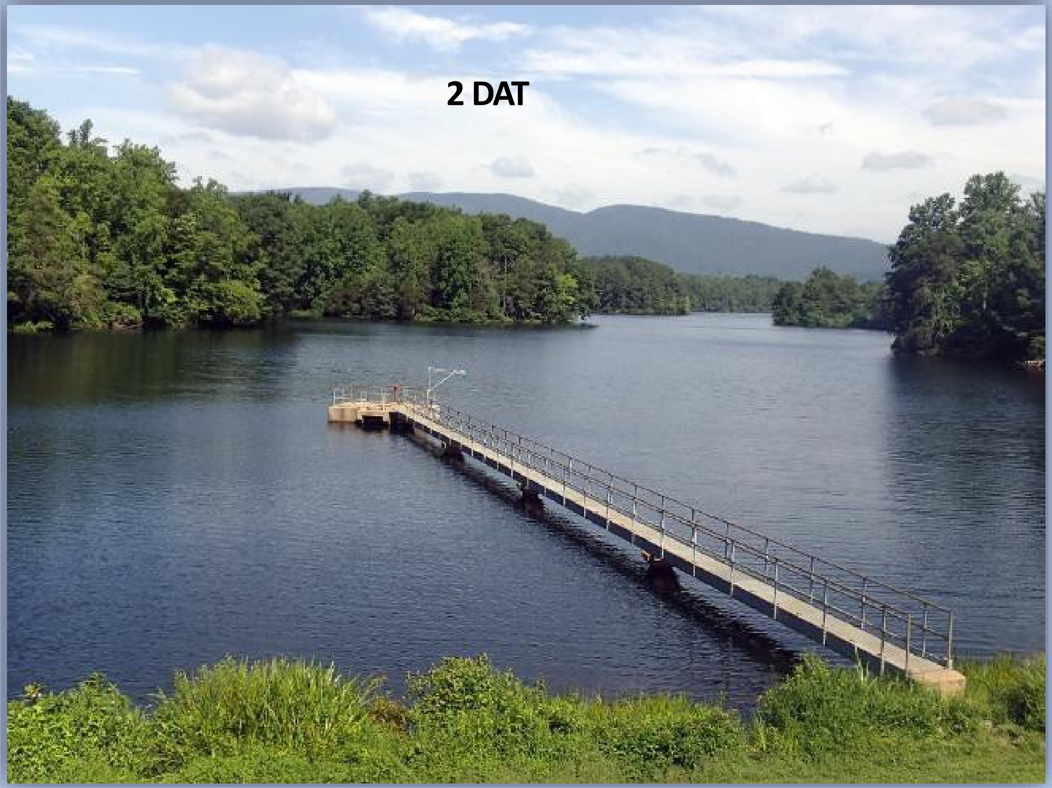
SePRO



LOOKING FORWARD

Problem: cyanobacteria at multiple depths, taste/odor issues

Solution: Low-dose copper-based algaecide/water quality enhancer



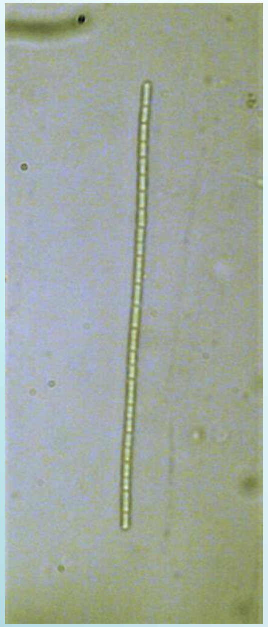
Example 2: Southern canal and reservoir system

- Action Thresholds Established
  1) Geos/MIB exceed 10 ng/L

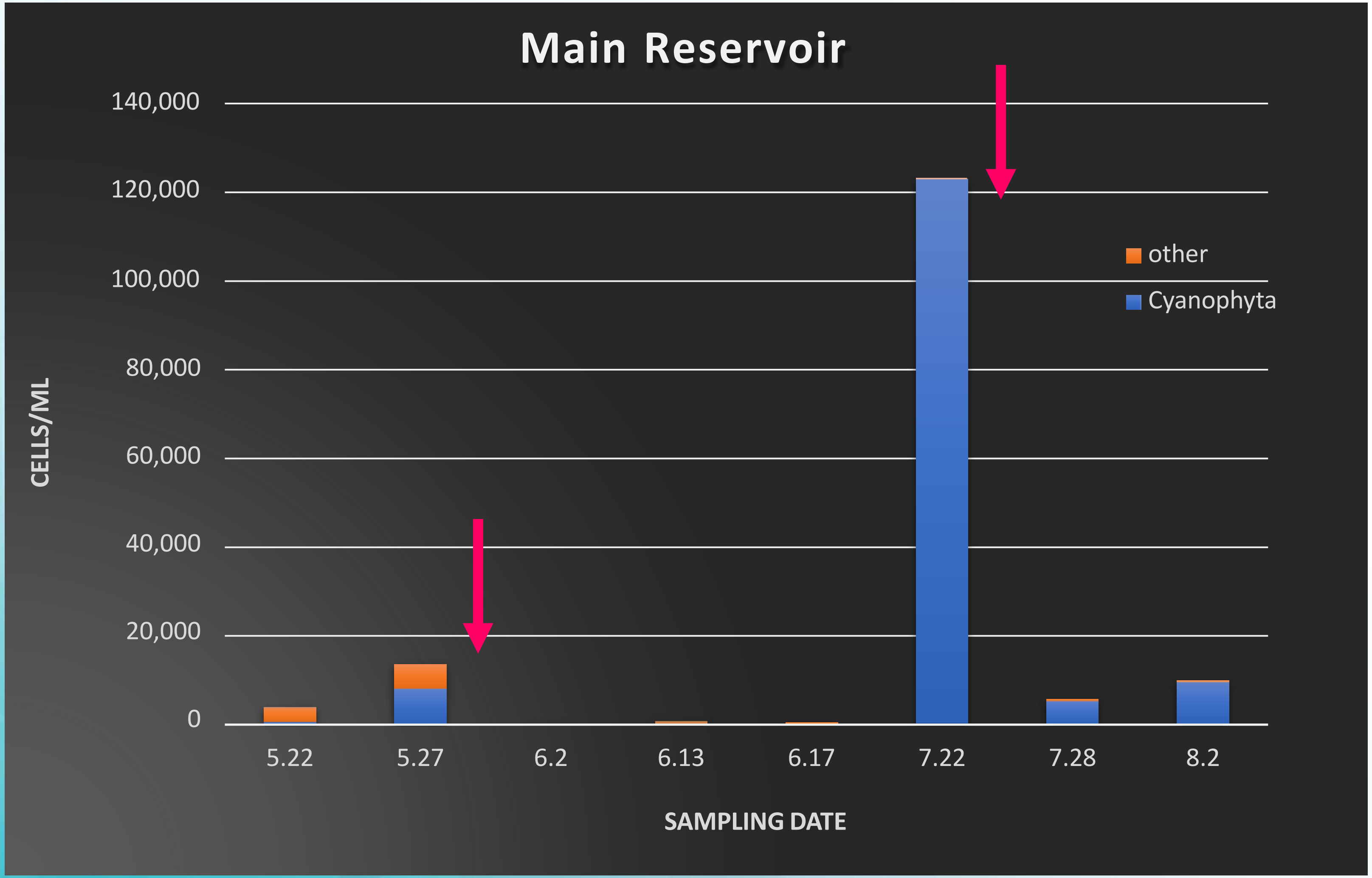
     or

  2) T&O producing algae > 5,000 cell/mL

- Target 55-acre (180MG) storage reservoir



LOOKING FORWARD SePRO



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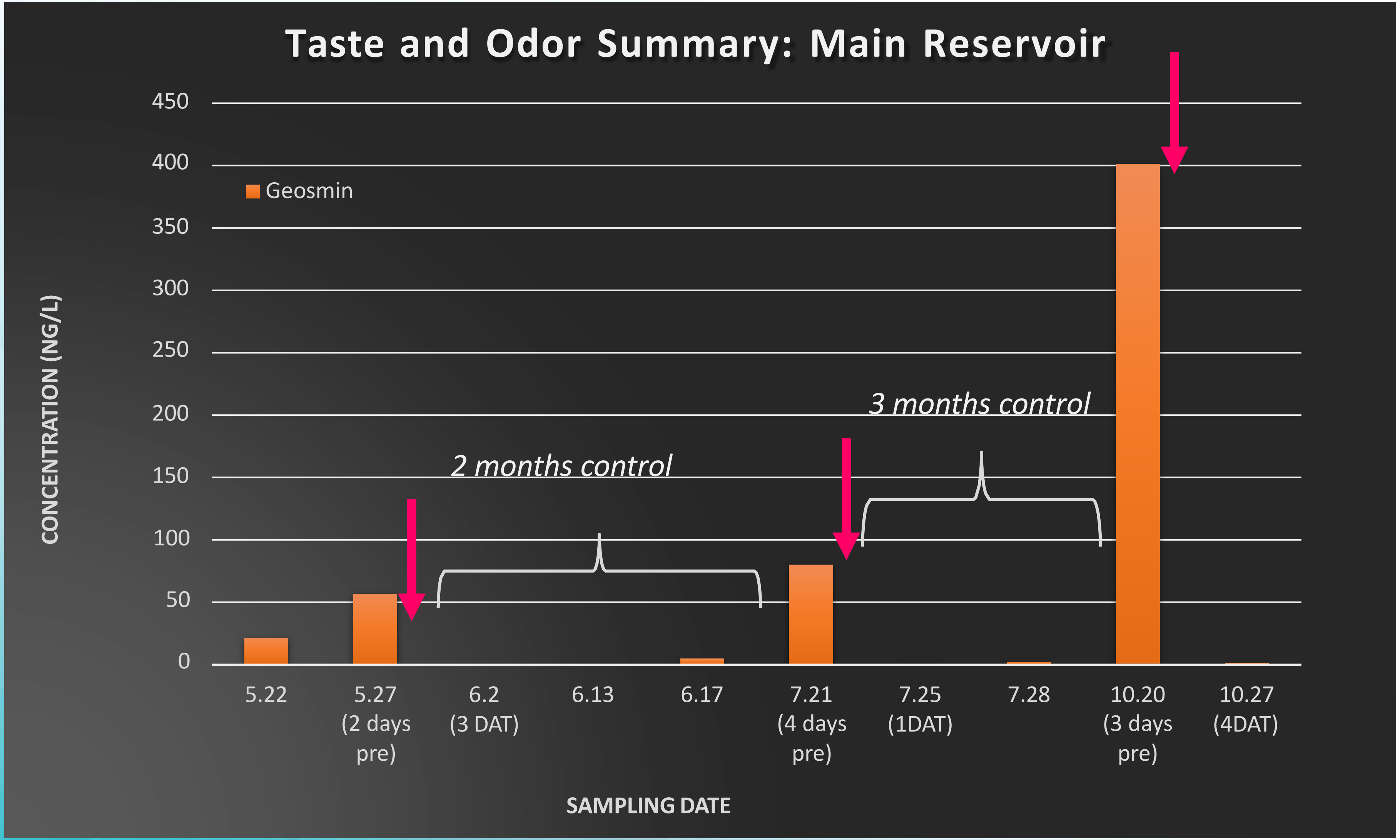

LOOKING FORWARD

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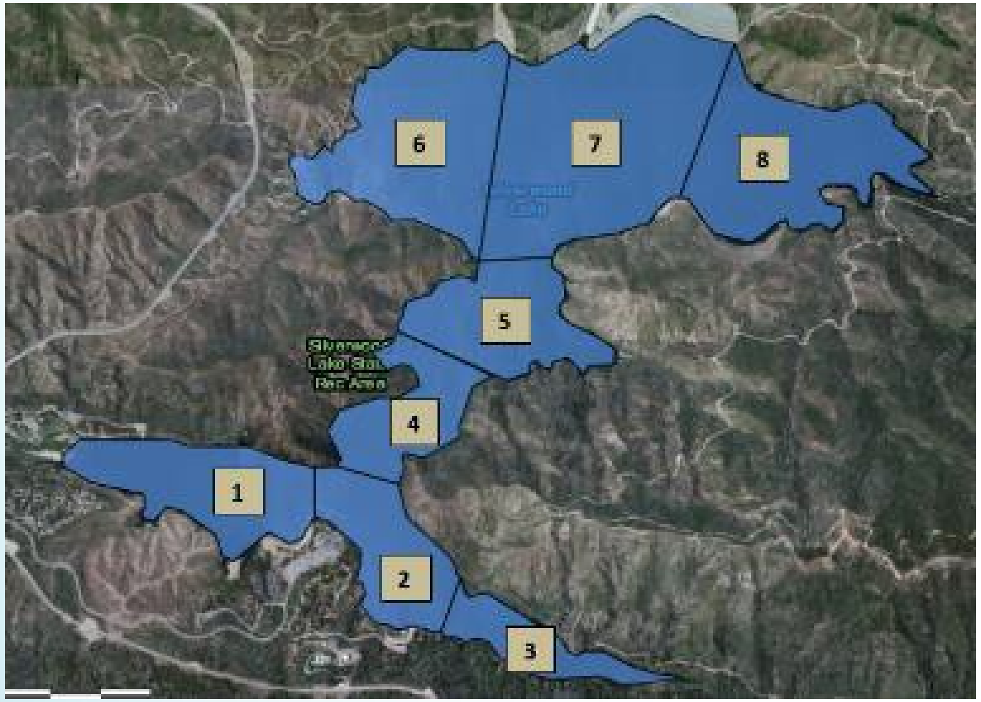
Example 3: Silverwood Lake, CA

- 935 acres (73,000 AF)
- Supplies 3 Million people in Los Angeles area
- Severe taste/odor issues
- *Dolichospermum* sp. culprit



Summer Algae Bloom Stinks Up Southern California's Water

LOOKING FORWARD SePRO

The Objective

1) treat source – cyanobacteria
2) reduce taste & odor compounds

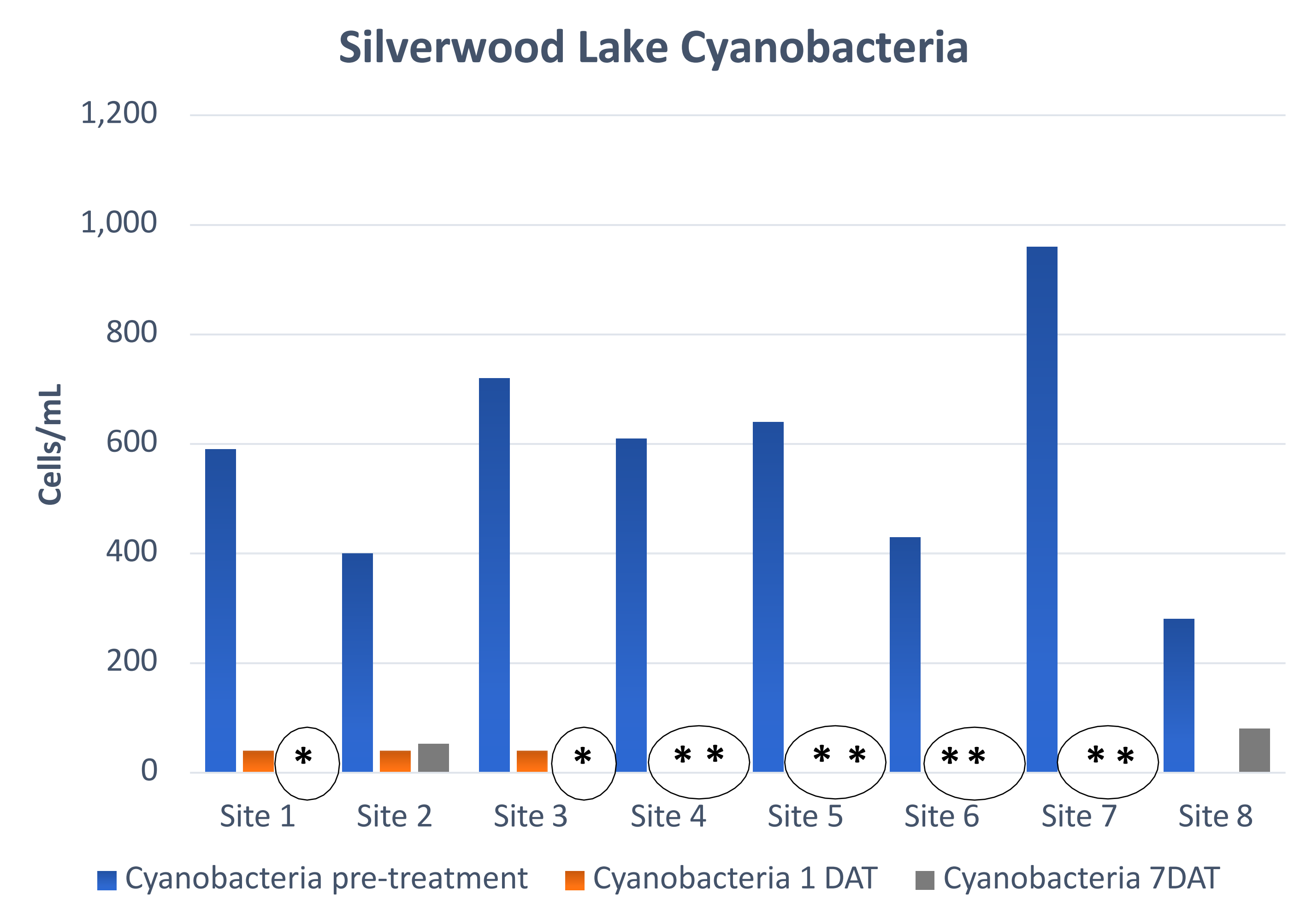
LOOKING FORWARD SePRO

Implementation (SCP)

AquaTechnex

LOOKING FORWARD

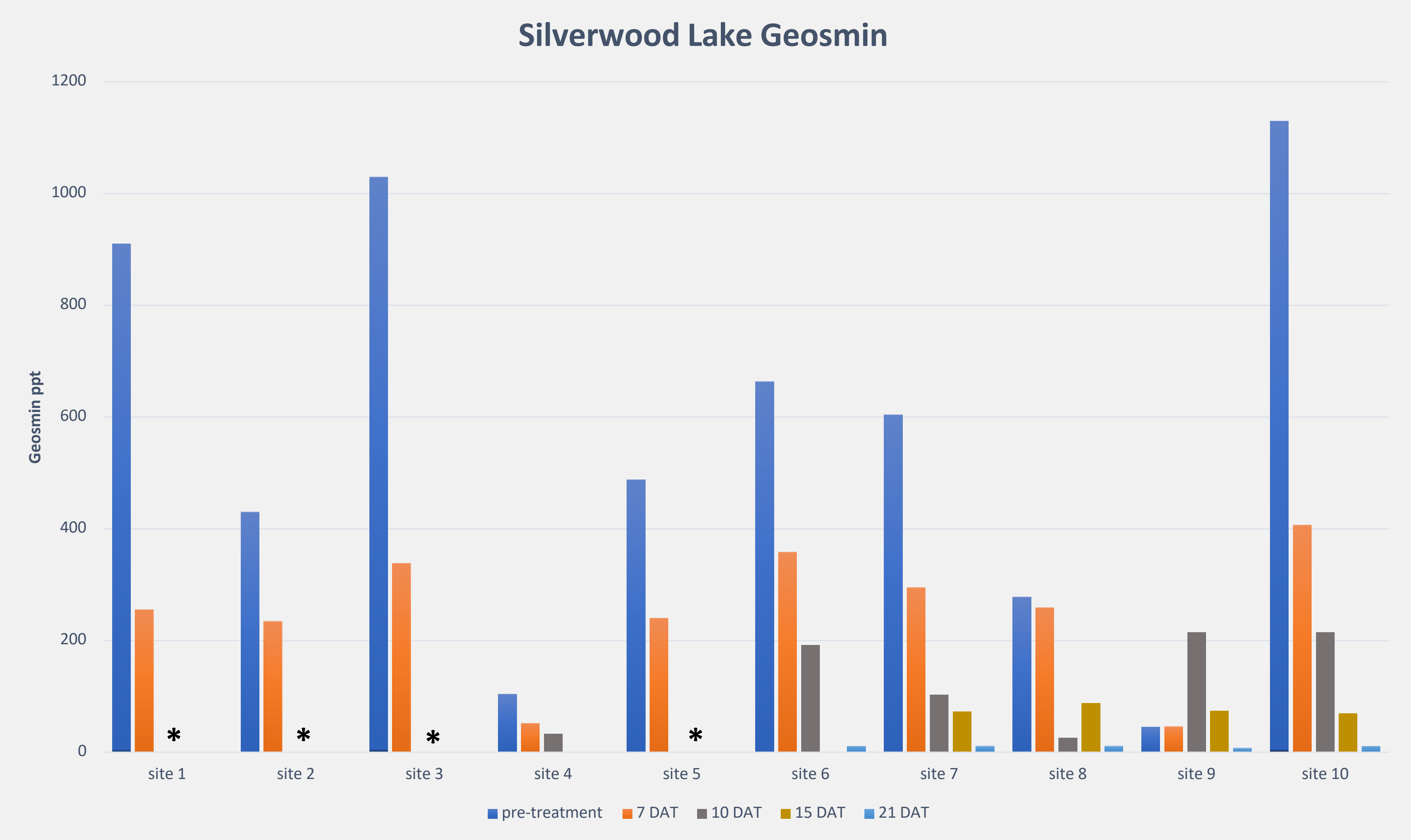
SePRO



Cyanobacteria **significantly decreased**

- **Non-detect at most sites 1 and 7 DAT**
- *Anabaena* (*Dolichospermum*) dominant taxa, with exception of some *Microcystis* in site 8, 7 DAT

LOOKING FORWARD



- **Immediate and significant decrease after treatment**
- **~4 WAT = non-detect geosmin**

LOOKING FORWARD SePRO

Geosmin Summary - Silverwood Lake

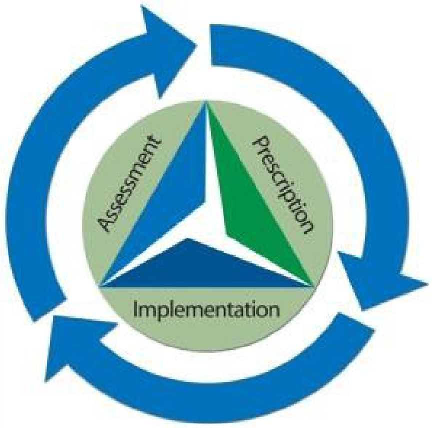
Collection Date	Geosmin (ng/L) Average from 10 sites	Percent Decrease From Initial
6/30 Initial	568.3	----
7/7 (7 DAT)	248.6	56%
7/10 (10 DAT)	130.7	77%
7/15 (15 DAT)	76.3	87%
7/21 (21 DAT)	9.5	98%
8/4	Non - detect	>99%

LOOKING FORWARD SePRO

Conclusion

- Action Threshold approach is effective
- Need to have program in place independent of/ complementary to other integrated approaches

- Source water Action Threshold Management Program
  - Set action threshold levels for your system (multiple/adaptable)
  - Intervene early
  - Alleviate immediate risks from HAB's
  - Offset removal concerns



- Pre-treatment samples from source water for algal location/densities
- Rapid/strategic implementation of registered/ NSF certified product
- Continue to monitor post-treatment, document effectiveness, adapt

LOOKING FORWARD

The Stewards of Water

Algae Corner

SePRO

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A DIVISION OF SePRO

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2nd Presentation

Dr. Kaytee Pokrzywinski-Boyd is Chief of the Harmful Algal Bloom (HAB) Forecasting Branch at NOAA's National Centers for Coastal Ocean Science (NCCOS).

Dr. Pokrzywinski-Boyd received her PhD in Marine Biosciences from the University of Delaware in 2014, with a specific focus on characterizing a novel, environmentally benign, bacterial algicide for the control of harmful dinoflagellates (red-tides).

Prior to joining NCCOS in 2020, Dr. Pokrzywinski-Boyd served as a Research Biologist at the US Army Engineer Research and Development Center where she led interdisciplinary teams from diverse technical backgrounds in the areas of HAB monitoring, detection and management; water quality monitoring and historic data analysis; and algal biomaterials development.

2nd Presentation

Dr. Mandy Michalsen is the U.S. Army Engineer Research Development Center's (ERDC's) Harmful Algal Bloom Program Coordinator, currently stationed in Seattle, WA.

Dr. Michalsen's research interests have included novel applications of groundwater remediation technologies to accelerate cleanup of explosives- and chlorinated solvent-contaminated aquifers, as well as use of polymeric samplers for measuring freely-dissolved contaminants in sediment porewater.

She received her bachelor's degree in Civil Engineering from University of Iowa in Iowa City, IA and both her master's and doctorate degrees in Civil Engineering from Oregon State University in Corvallis, OR. Prior to joining ERDC in November 2014, Mandy was Chief of Soils at Seattle District USACE.

Non-Traditional HAB Management Strategies

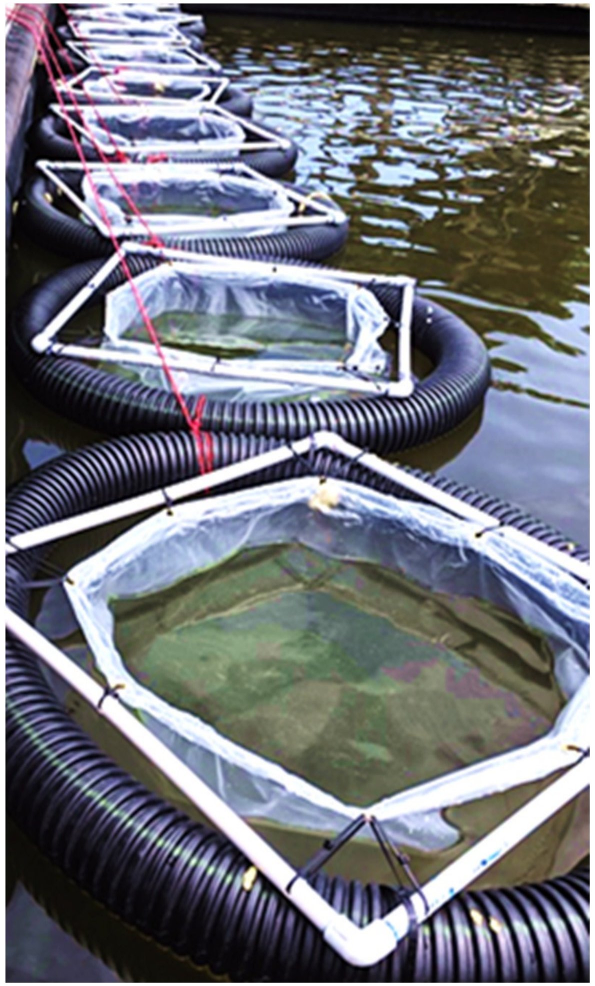
Physical, Chemical, and Biological Control Techniques for Cells and Toxins

Kaytee Pokrzywinski, PhD
Chief, HAB Forecasting Branch
NOAA-NCCOS

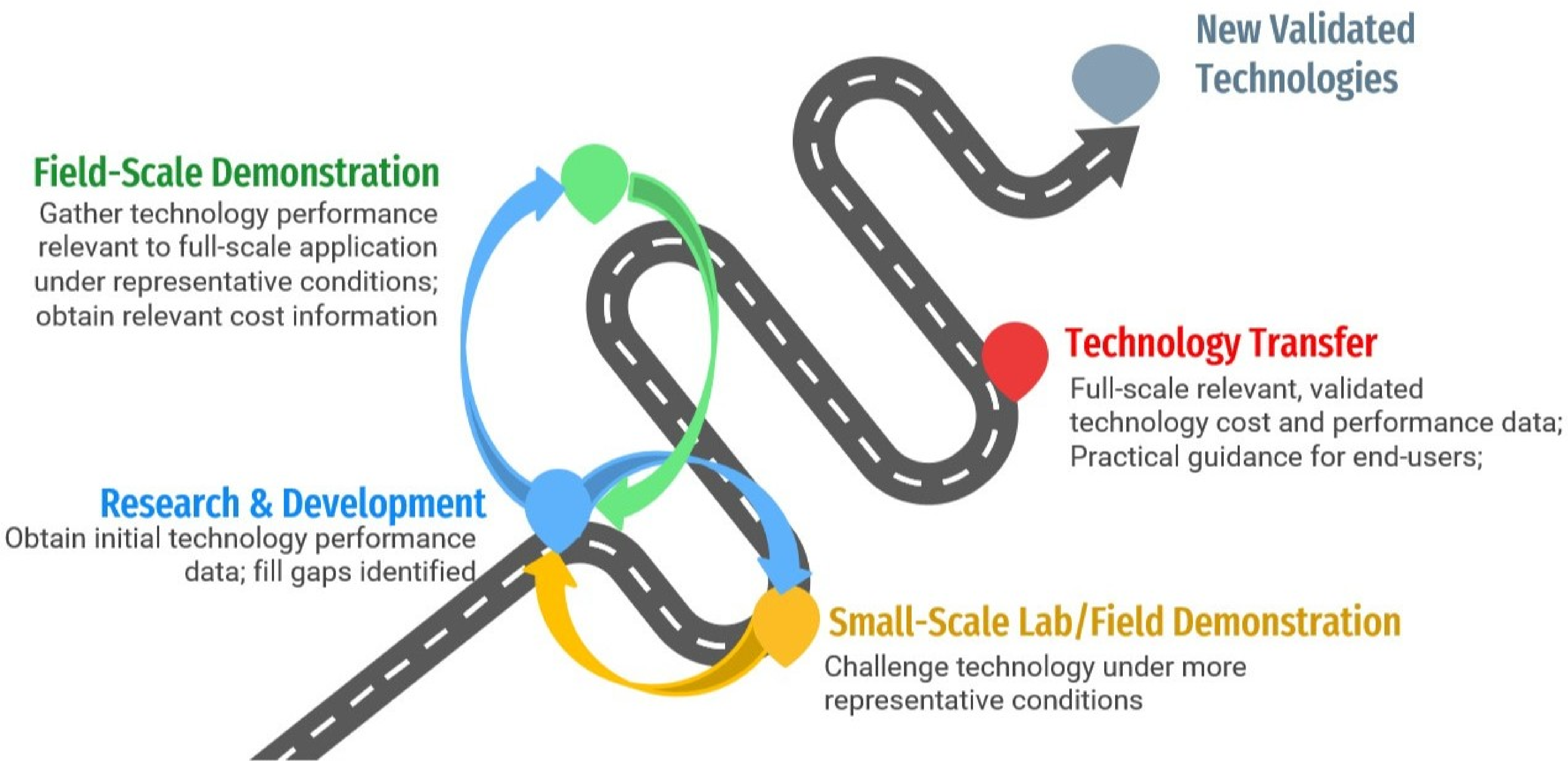
Mandy Michalsen, PhD, P.E.
Strategic Initiatives Program Manager
USACE-ERDC-EL

Problem Statement

- HABs cause a wide variety of environmental, economic, and human health problems
- The growing frequency and magnitude of HABs has created a pressing need for in situ control strategies in both freshwater and marine environments
- Field demonstrations of HAB control technologies are needed to fill the gap between laboratory research and operational scale use
- Field ready technologies need to be properly transitioned to resource managers for implementation in operational programs



HAB Technology R&D Roadmap



HAB Directives

U.S. Army Engineer Research Development Center – USACE-ERDC

- **WRDA 2018** (The Water Resources Development Act of 2018)
  - Authorized five-year HAB technology demonstration program (FY19-FY22)
  - Deliver scalable HAB prevention, detection and management technologies
- **WRDA 2020**
  - Directed continued implementation of HAB research/technology development
  - Authorized HAB technology demonstration program

National Centers for Coastal Ocean Science – NOAA

- **HABHRCA** (The HAB and Hypoxia Research and Control Act 1998, 2014, 2017)
  - Identify research, development, and demonstration activities needed to minimize the occurrence of HABs
  - Improve capabilities to detect, predict, monitor, control, mitigate, respond to, and remediate HABs
  - Identify ways to reduce the duration and intensity of HABs

HAB Control and Mitigation

Response Time

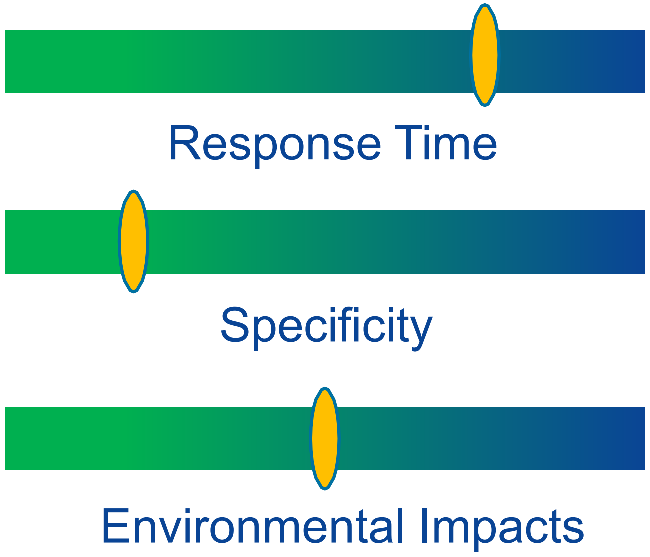
- Time to elicit a substantial response
- Duration of efficacy

Specificity

- Specific to a single HAB species/class
- Non-specific, targeting all phytoplankton/broader communities

Environmental Impacts

- Positive, negative, or neutral impacts
- Impact duration
- Consequences of taking no action



Physical/Mechanical Control Strategies

Methods that…

- Physically remove algal cells from the water column
- Limit spatial extent of a bloom by a physical barrier, or
- Neutralize algal cells through a physical means

Examples

- Skimmers/harvesters
- Flocculants
- Sonication
- Aeration
- Curtains

HABITATS: Technology & Benefits

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INTERCEPTION

Selectively remove algae from the water, rather than treating all the water.

TREATMENT *AND* ***TRANSFORMATION***

Clarify and oxidize the water to allow for safe discharge back into the environment, and concentrate the algae into a thick paste to minimize waste volumes.

Recover resources from the concentrated algae while destroying any potential toxins.

physically removes algae as well as nutrients and toxins that are contained within the algae; destroys cyanotoxins; relatively high throughput; potentially energy neutral; resource recovery can offset costs.

HABITATS: Field Demonstrations

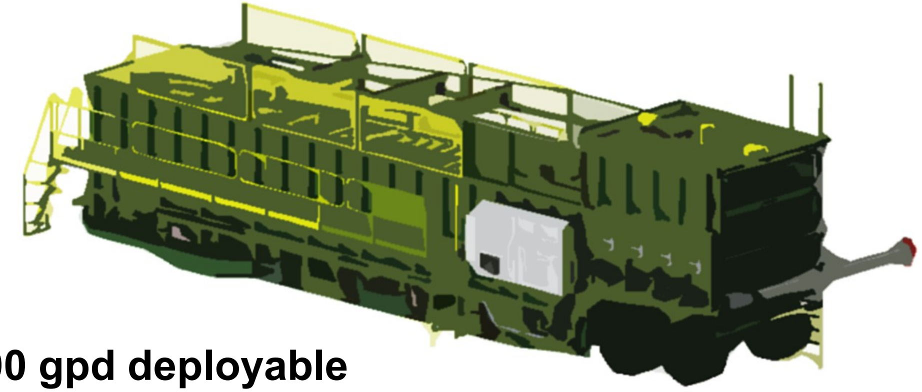
FY20: Pilot scale validation studies of integrated system

- 90% removal of algae and phosphorus and 55% removal of nitrogen from water passing through the system; > 99% microcystin removal
- Demonstrated onshore systems in FL and NY(130 gpm)
- Pilot tested hydrothermal liquefaction with 20% fuel yield and 99.5% microcystin destruction
- Development, assembly and preliminary testing of shipboard system.

FY21: Increasing physical and economic scalability

- Research to improve algae dewatering and energy recovery
- Developing *in-situ* flotation capability to concentrate the target
- Executing controlled shipboard demonstration (pending, NY)
- Acquire the first full scale onshore HABITATS module (1500 gpm)

First shipboard HABITATS prototype on Chautauqua Lake, NY (2020)



1500 gpd deployable dissolved air flotation system

HABITATS: Full-Scale Projections

Spillway Scenario, Water Depth = 10’

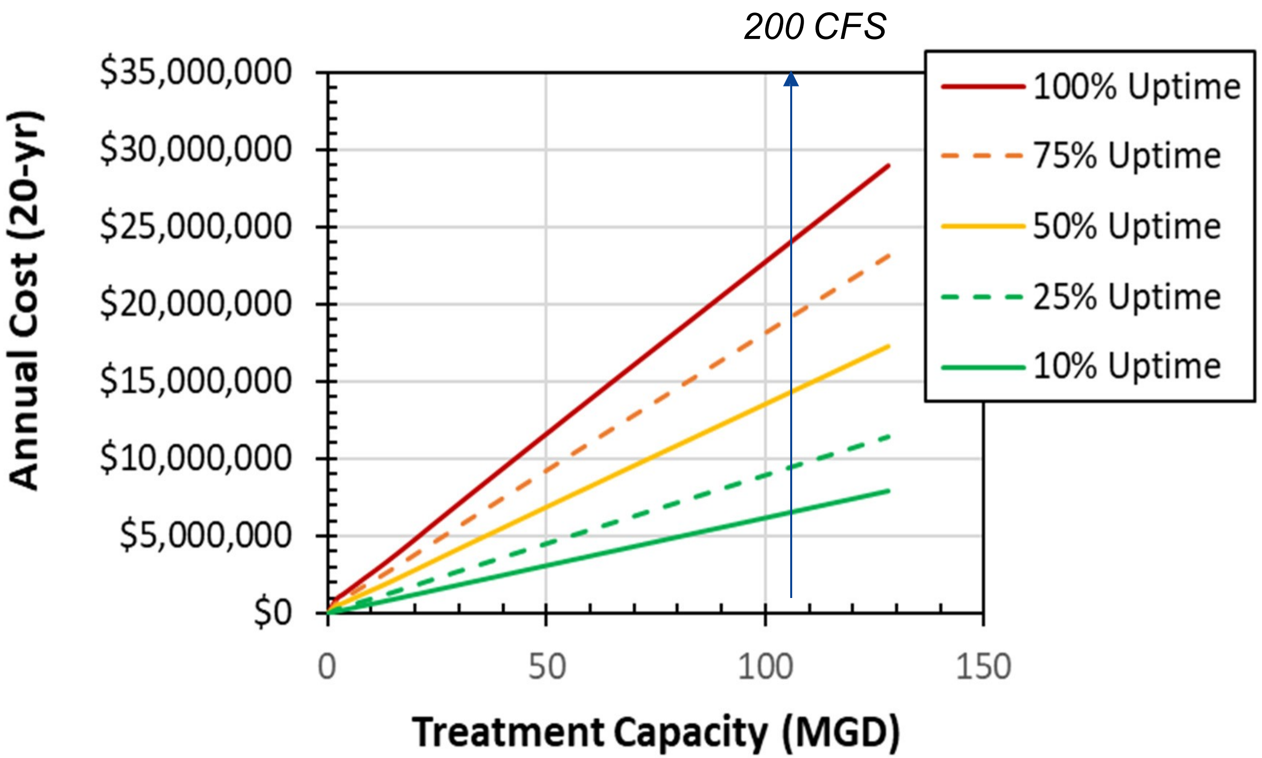


Figure 1. Projected annual cost of a HABITATS system over a 20-yr period as a function of treatment capacity with varying uptimes.

DDC is Depth-Dilution Coefficient
DDC = 0.17 → 35% of algae in upper 2’ of water column
DDC = 1 → 85% of algae in upper 2’ of water column

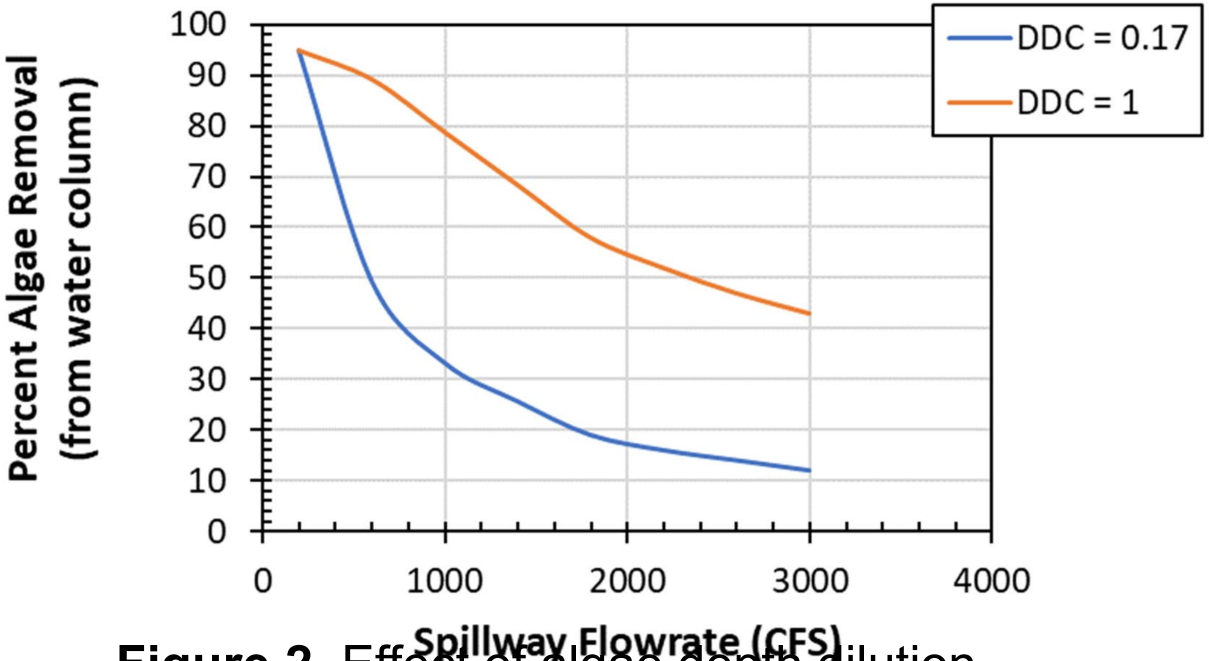
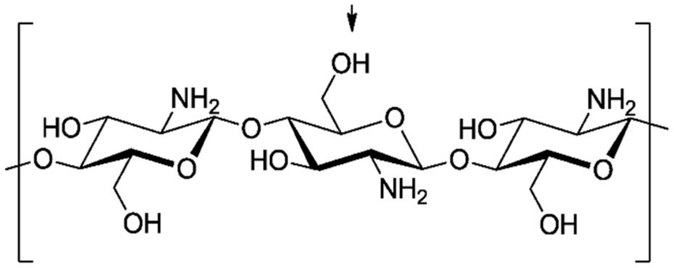
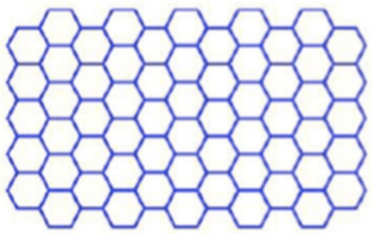


Figure 2. Effect of algae depth dilution coefficient on algae removal (from water column) by a ***200 CFS*** (108 MGD) HABITATS system as a function of spillway flowrate.

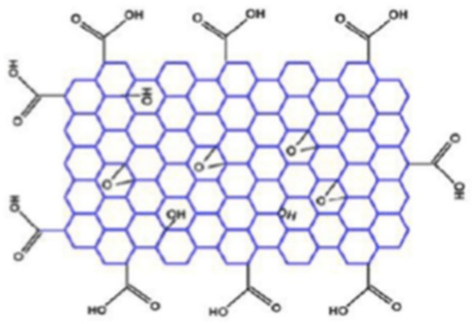
Novel Sorbents: Chitosan and Graphene
e



chitosan (CS)



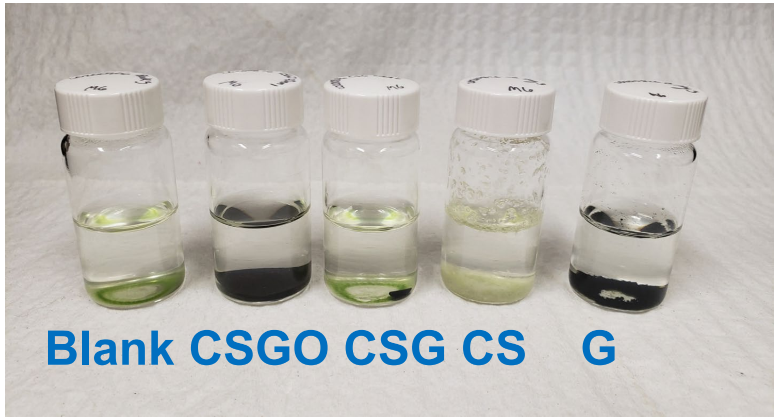
graphene (G)

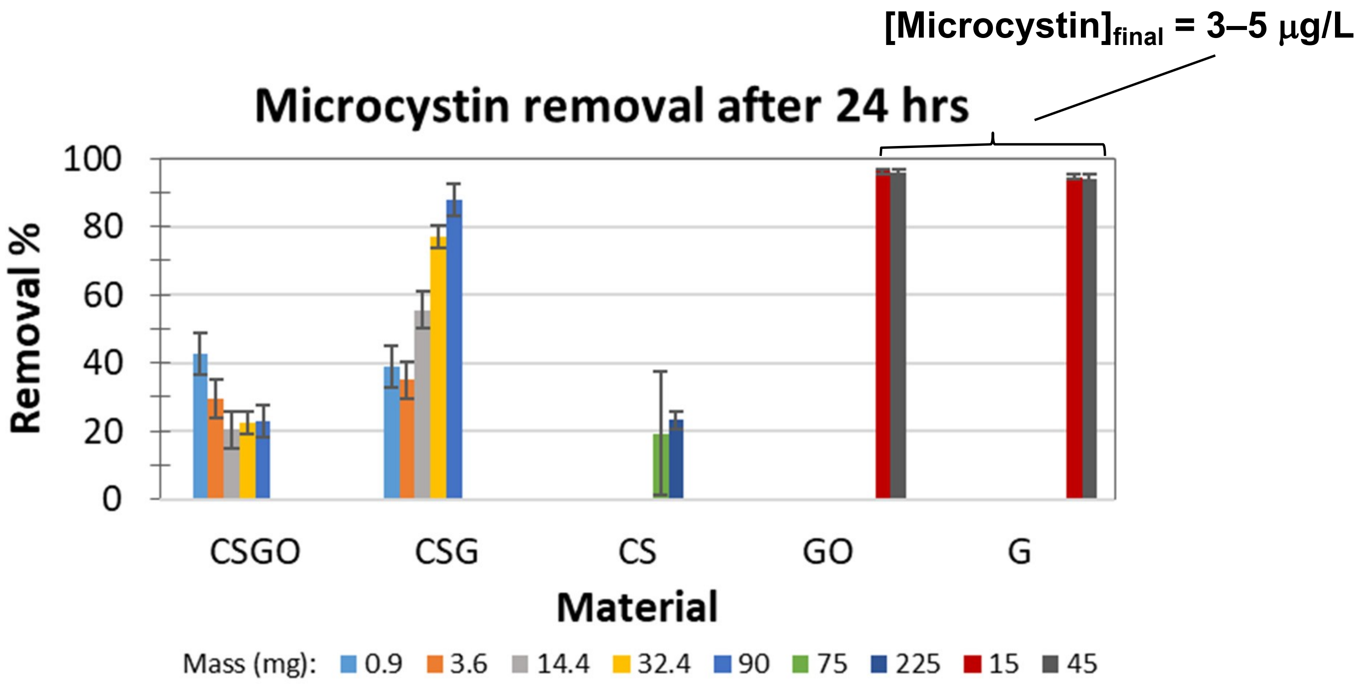


graphene oxide (GO)

chitosan-graphene (CSG)

Initial small-volume (16 mL) batch testing results:
G and GO, and CSG reduced microcystin significantly – final microcystin concentration in GO and G treatments was < 8 µg/L recreational standard after 24 hours





Novel Sorbents: Chitosan and Graphene

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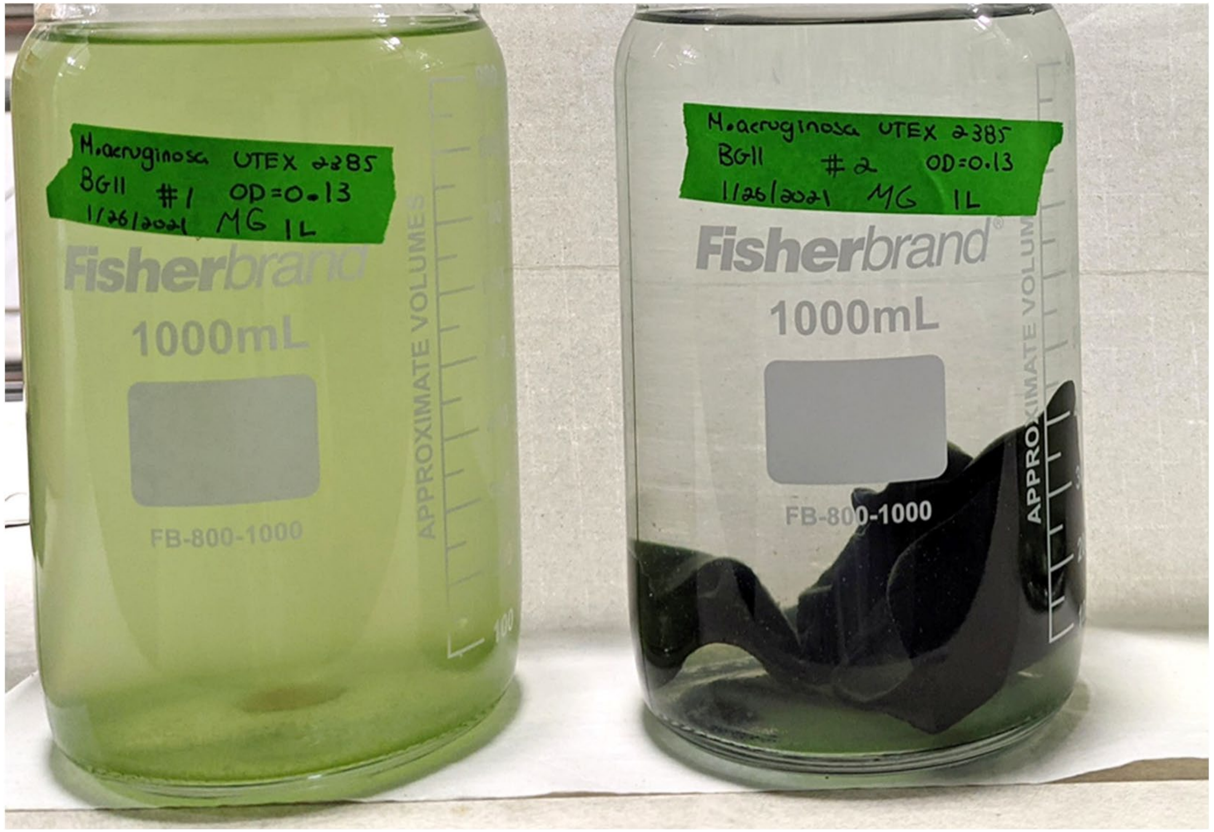


Takeaways

- Small-scale monoculture lab trial results show graphene-based materials are promising for HAB management applications

Next steps

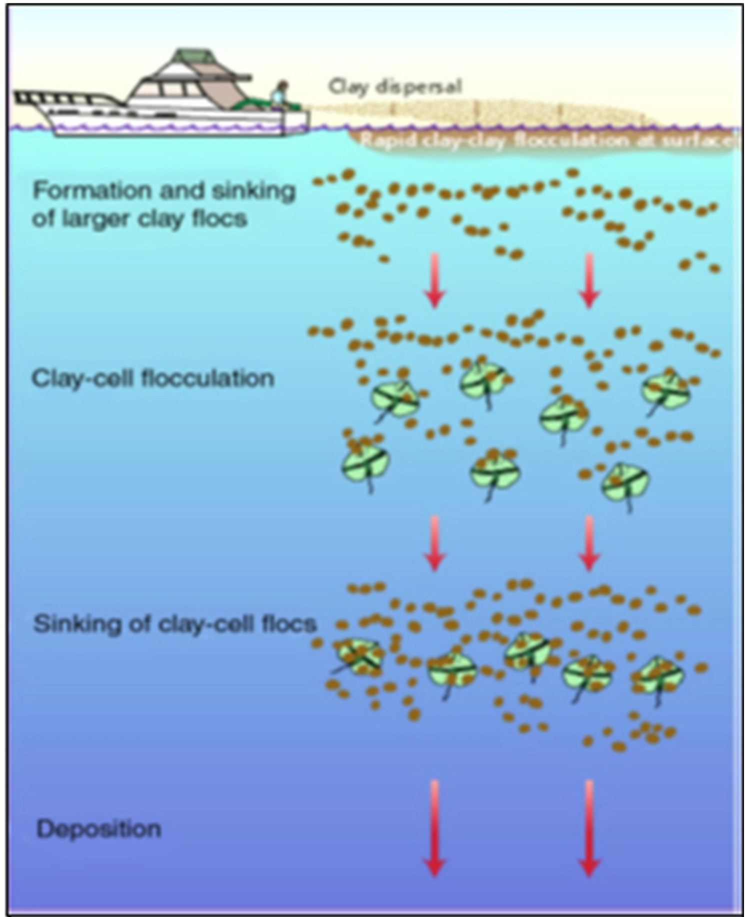
- Sorption capacity, kinetics
- Test against toxins without algae
- Scalability studies
- Study field sample algae

Conceptual Material Costs

Lab-scale:	Conceptual swim beach:
55-gallon drum	Assume football field size, 6’ deep
\$3 graphene chitosan	$2.6x10^6$ gallon
	\$140K graphene chitosan

Clay Flocculation

- Clay particles bind to each other and algal cells forming flocs or rapidly sinking aggregates that naturally deposit in the benthos
- Benign minerals can be used to modify clay formulations without adverse environmental impacts
- Modifying clay with safe inorganic polymers proven to increase efficiency and reduces cost.



Clay dispersal and flocculation, leading to removal of HAB cells (credit: D. Anderson, adapted from Sengco, 2005)

Clay Flocculation

Takeaways

- Increased efficiency and reduced cost
- Location specific formulation design

Next steps

- Test for effectiveness against *Karenia brevis*
- Assess impacts to benthos
- Determine scalability to size of affected areas
- Conduct a cost-benefit analysis including social component, as method for HAB control.

Implications

- Novel clay-based formulations that can be adapted to each environmental setting offer a valuable rapid control technology

Testing to be carried in laboratory, mesocosm and field site conditions. (photo credit: D. Anderson)

Chemical Control Strategies

Methods that rely on the release of chemicals or minerals that kill, inhibit, or remove algal species and toxins, through a variety of mechanisms.

Examples

- Algaecides (e.g. peroxides and copper)
- Nanobubbles
- Biosurfactants
- Purified plant, algal, and bacterial extracts (e.g. barley straw)

NBOT: Nanobubble Ozone Technology

NOAA NCCOS

Caption. NBOT pump cabinets at Lake Newport, OH. Credit WKBN27, Youngstown, OH.

Lake Newport, OH, before and after treatment with NBOT. Credit P Moeller, NOAA.

NCCOS research designed ozone and nanobubbles parameters together in a safe way that way did not release ozone into air. Through a Cooperative Research and Development Agreement (CRADA) multiple companies design increasingly efficient and higher capacity NBOT components as we continuously test and demonstrate the best proprietary components the industry can engineer.

NBOT: Nanobubble Ozone Technology

2020 Independent Laboratory Testing

"The NBOT-2.5HP is highly effective at controlling concentrations of algae, bacteria and motile zooplankton in both low and high water quality challenge conditions in time frames less than Great Lakes trade voyages. These promising results in varying challenge conditions at the bench scale, provide support for further research into determining the effectiveness of this technology as an in-tank treatment system at larger scales for the potential treatment of Great Lakes ballast water on board Great Lakes vessels."

Lake Superior Research Institute Testing Laboratory

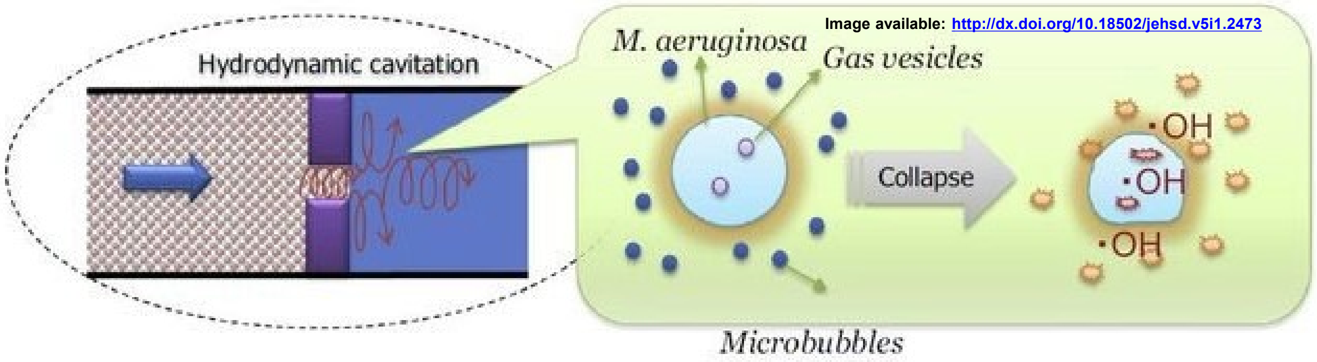
2021 Technology Scaleup

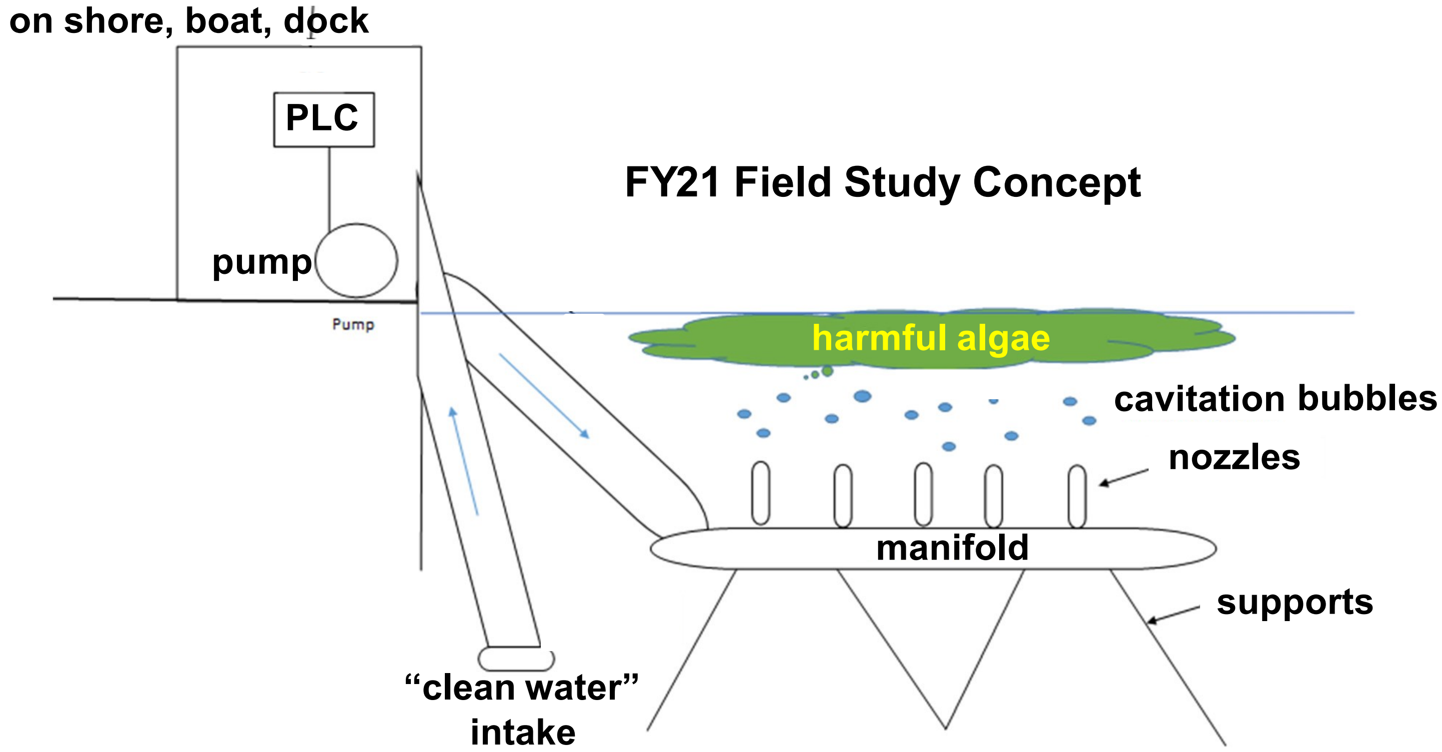
Working with CRADA partners and USCG to engineer NBOT scale up for use Ballast Water applications addressing invasive species.

NanoBOT 7.5 HP-60 Treatment Technology as Installed at Montreal Pier Facility. Univ. Wisconsin LSRI/Great Waters Research Collaborative

POC: Peter Moller, peter.moller@noaa.gov

Cavitation





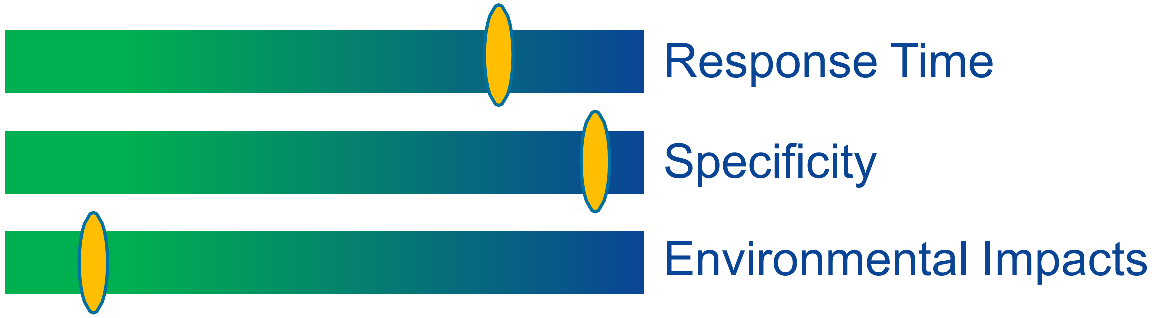
- Cavitation forms short-lived reactive oxygen species (ROS, e.g. superoxide, hydroxyl radical) in water without addition of harsh chemicals
- ROS can neutralize cyanobacteria cells and degrade their toxins
- FY21 laboratory and field studies will assess cavitation effectiveness for treating cyanobacteria and toxins (*Microcystis aeruginosa* and microcystin, respectively)

Biological Control Strategies

Methods that use biological organisms or pathogens to kill, inhibit, or remove HAB cells or toxins using a variety of mechanisms

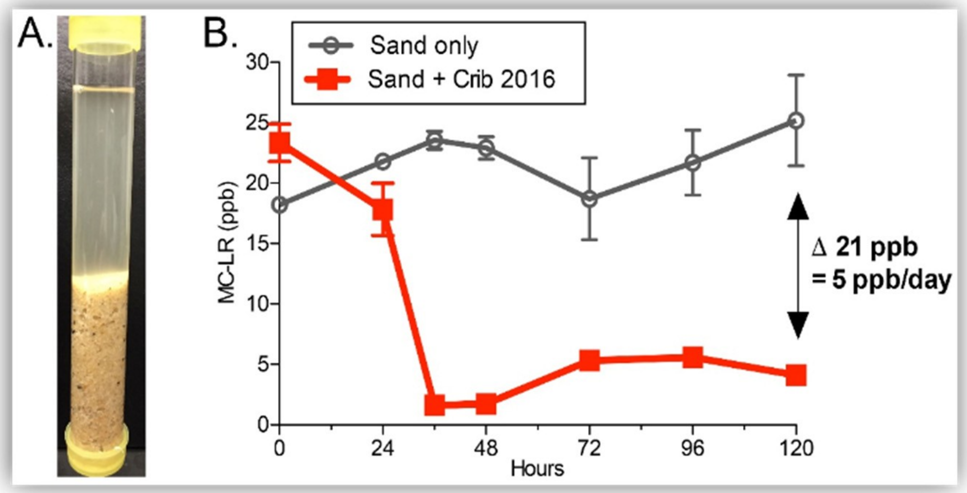
Examples

- Algicidal bacteria/toxin degrading bacteria
- Cyanophages and viruses
- Parasites
- Macroalgae



Microcystin-Degrading Bacteria

- Treatment processes available to treat microcystin-contaminated waters
  - Chlorination, powdered activated charcoal, and ozonation
  - Expensive and generate waste products and byproducts that require additional treatment
- Bacteria have been isolated from Lake Erie that have been shown to degrade microcystins into non-toxic fragments
- These bacteria have been prepared in biofilters and evaluated on water contaminated with microcystins



Microcystin-Degrading Bacteria

Takeaways

- Bacteria-inoculated sand filters (biofilters) have been shown to remove microcystins from contaminated water

Next steps

- Develop and test biofilters to degrade microcystins in water treatment waste products
- Identify toxin degrading enzymes to supplement biofilters

Implications

- Reduce water treatment costs
- Provide safer alternative to conventional water treatment processes
- Point-of-use water treatment method

POC: Felix Martinez, felix.martinez@noaa.gov

Bacterial remediation of HAB toxins

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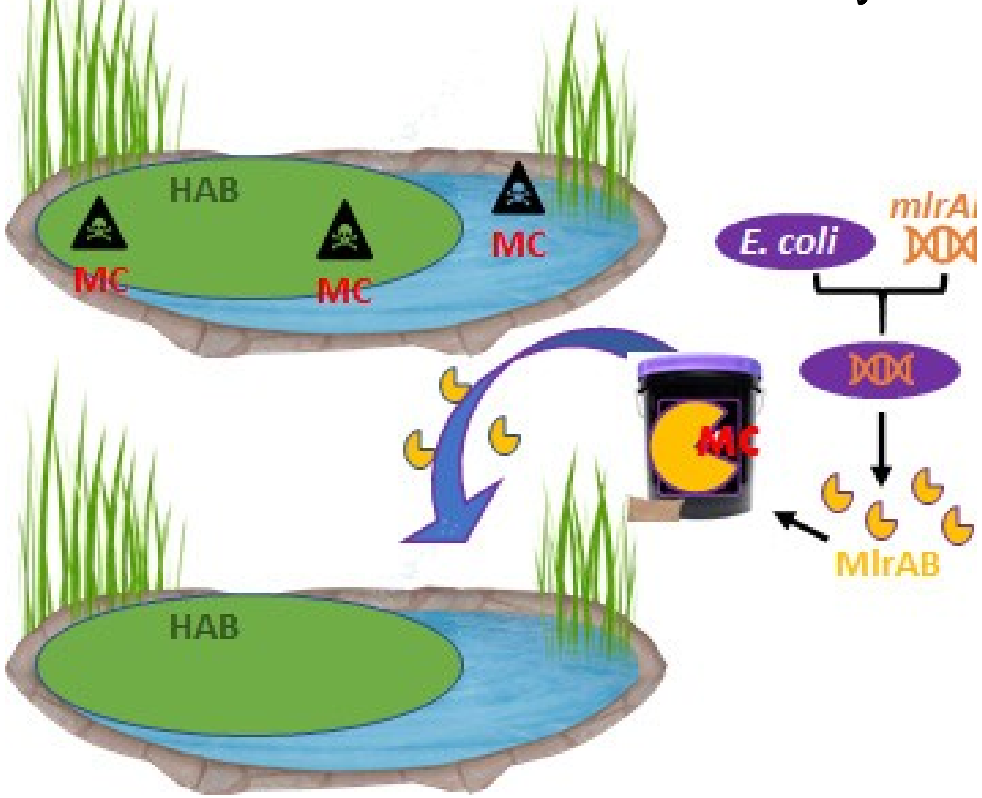
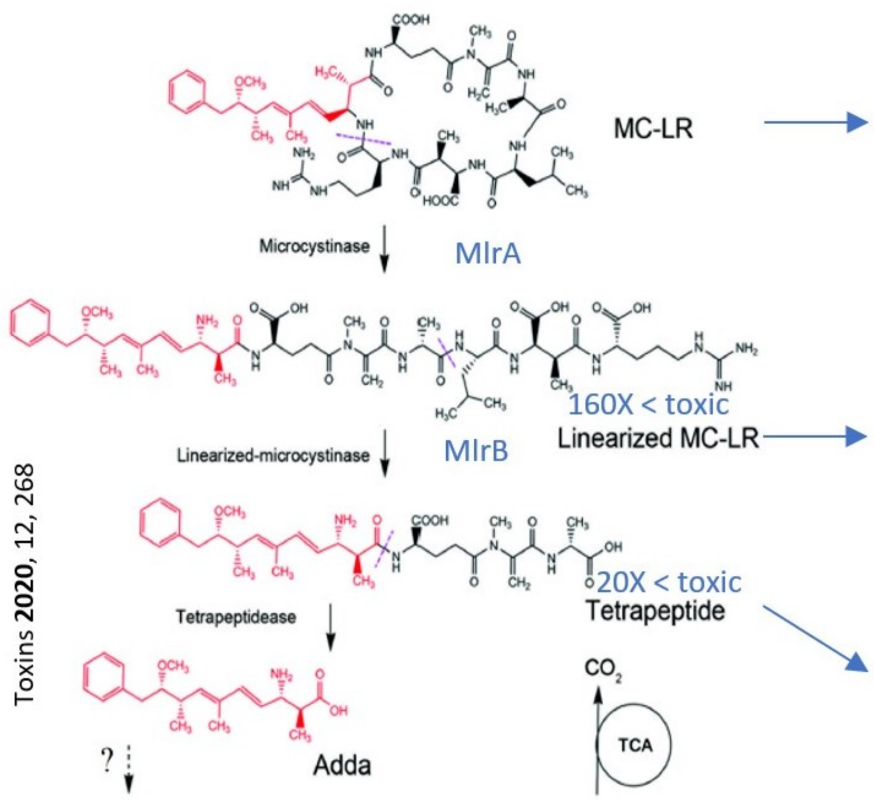
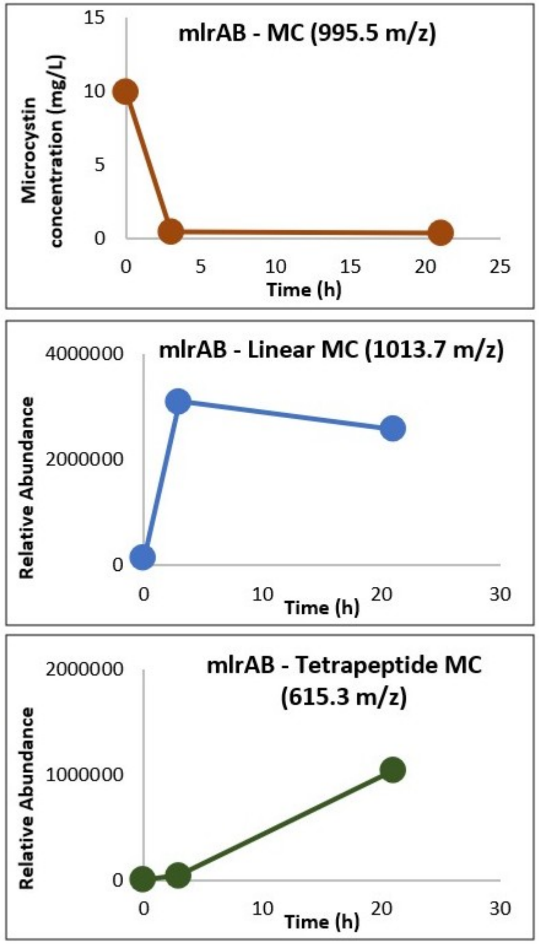
Objective: a shelf-stable MC-degrading enzyme that can be used in the field to deactivate harmful toxins a remediate MC-HAB events safely



Initial Results:



Toxins **2020**, 12, 268

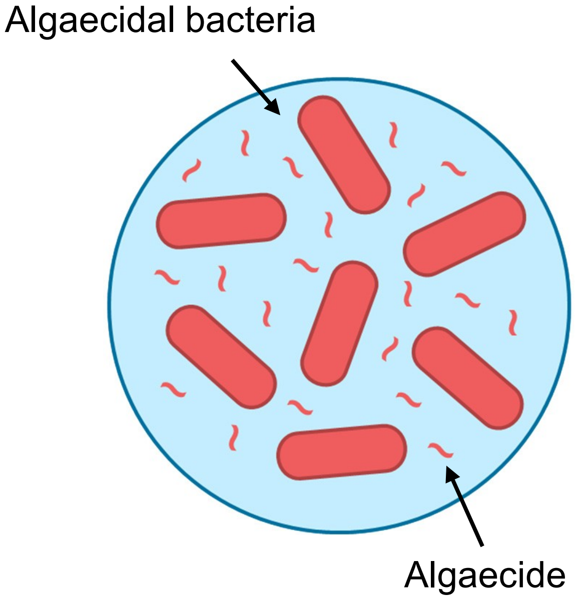


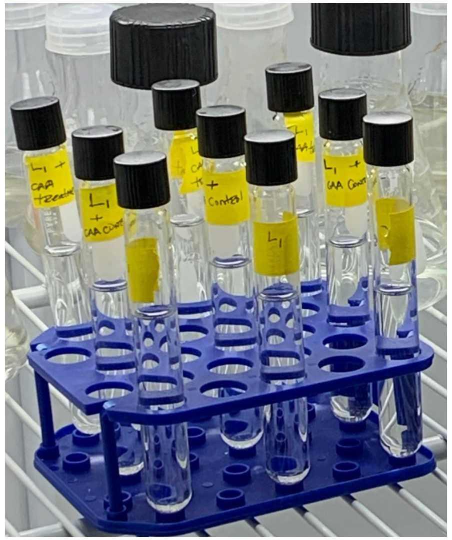
NCCOS

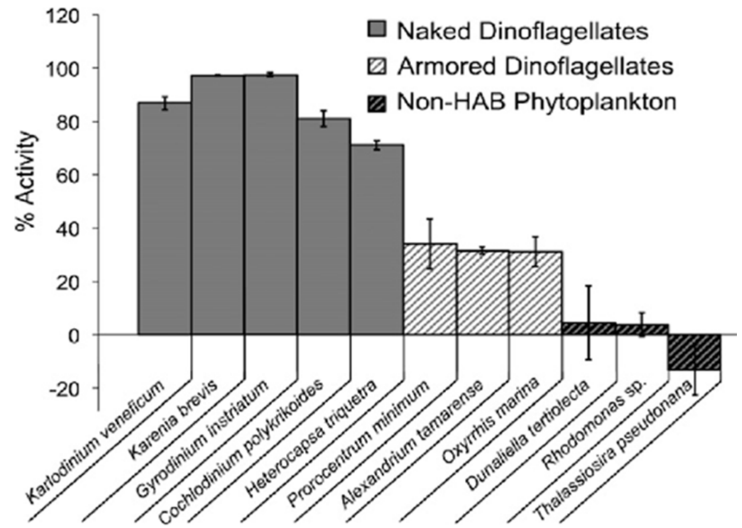
DinoSHIELD: Algaecidal Bacteria

Shewanella sp. IRI-160, a novel algaecidal bacterium

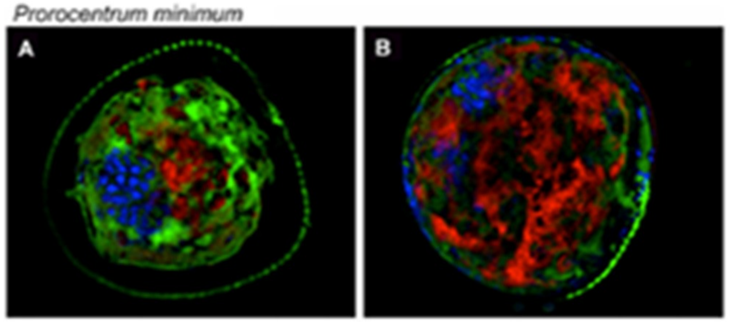
- Secretes a bioactive compound
- Selectively targets dinoflagellates
- No negative impacts on metazoan species
- Programmed cell-death pathway







Pokrzywinski et al. 2012 Harmful Algae

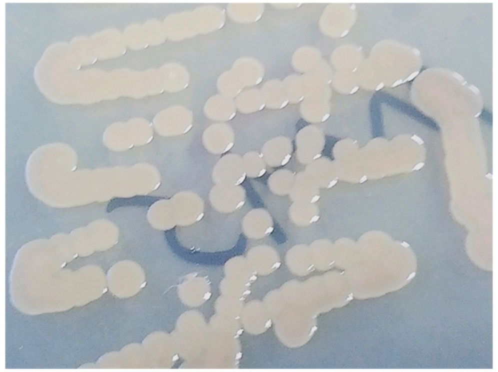


Pokrzywinski et al. 2017 Harmful Algae

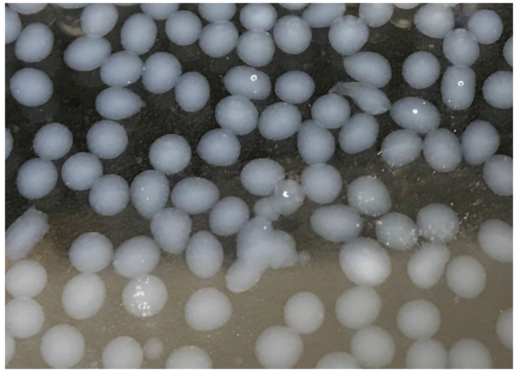
DinoSHIELD: Immobilized Algaecidal Bacteria

- Algaecidal bacteria have unpredictable environmental impacts
- Even high-dose applications of free bacteria or cell-free algaecide may be ineffective for long-term control
- The use of micro-bioreactors would ensure the algaecide is dispersed over a longer period at a consistent rate

Shewanella sp. IRI-160 algicidal bacteria



Embed bacteria in alginate hydrogels: DinoSHIELD



Apply DinoSHIELDs to treat *Karenia brevis* bloom in FL

Demonstrate the utility of slow-release alginate hydrogels containing immobilized algaecidal bacteria for red tide management

DinoSHIELD: Immobilized Algaecidal Bacteria

Takeaways

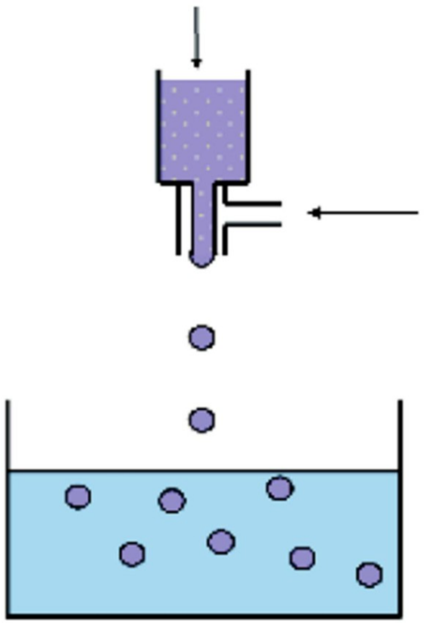
- Easy to prepare
- Prevents dispersion
- Protects from environmental stress
- Biodegradable/environmentally benign

Next steps

- Demonstrate technology in the field
- Engage management community

Implications

- Results of this work will stimulate research on algaecidal bacteria or derived compounds as effective means to prevent or mitigate HABs.



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Leveraging approach for freshwater systems for cyanobacteria

POC: Felix Martinez, felix.martinez@noaa.gov

Technology Maturity Level

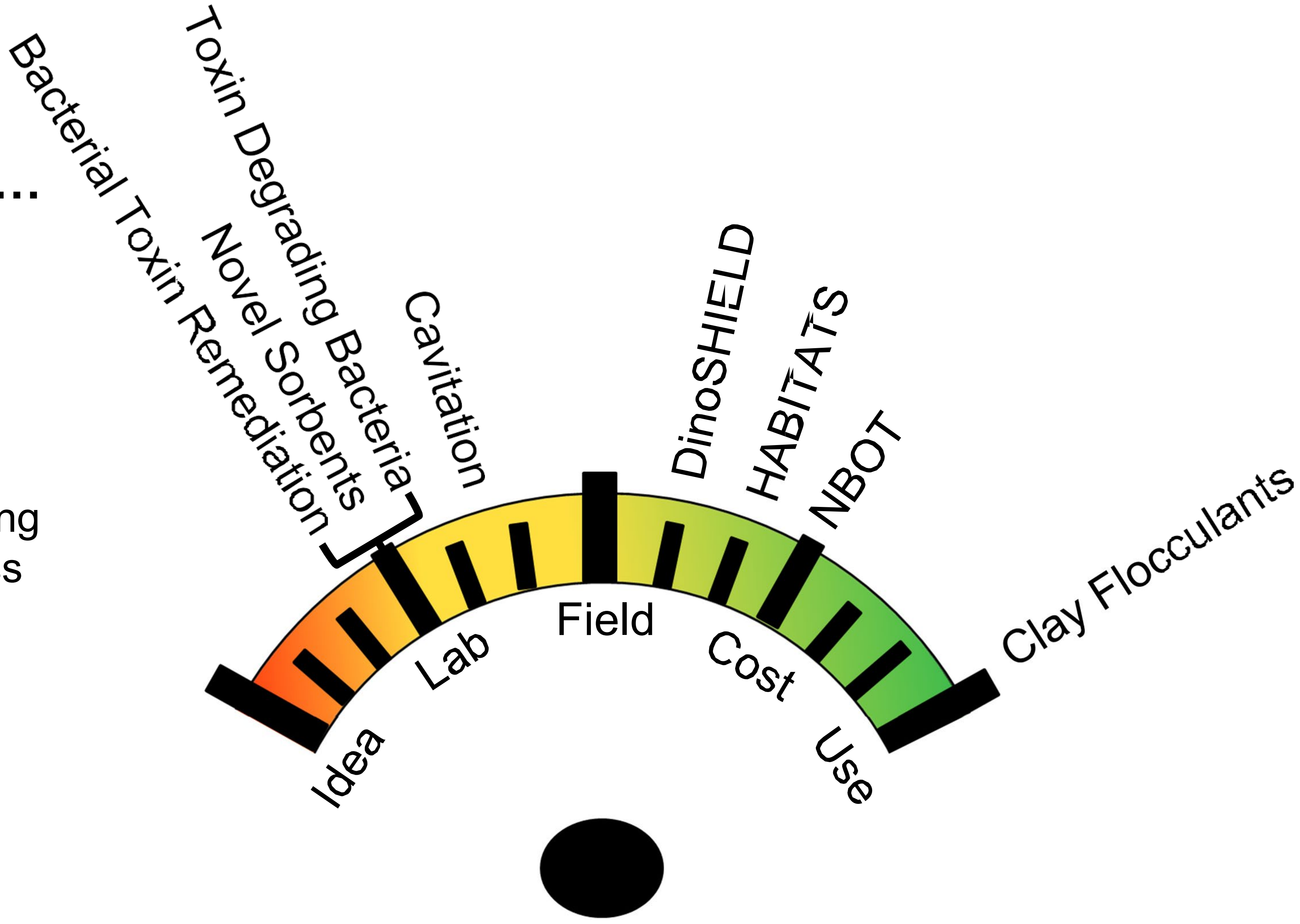
Research takes time!

Quality products require…

- Validation
- User guidance
- Training materials

Allows for…

- Data-driven decision making
- Greater chance for success
- Reduced impacts to environment



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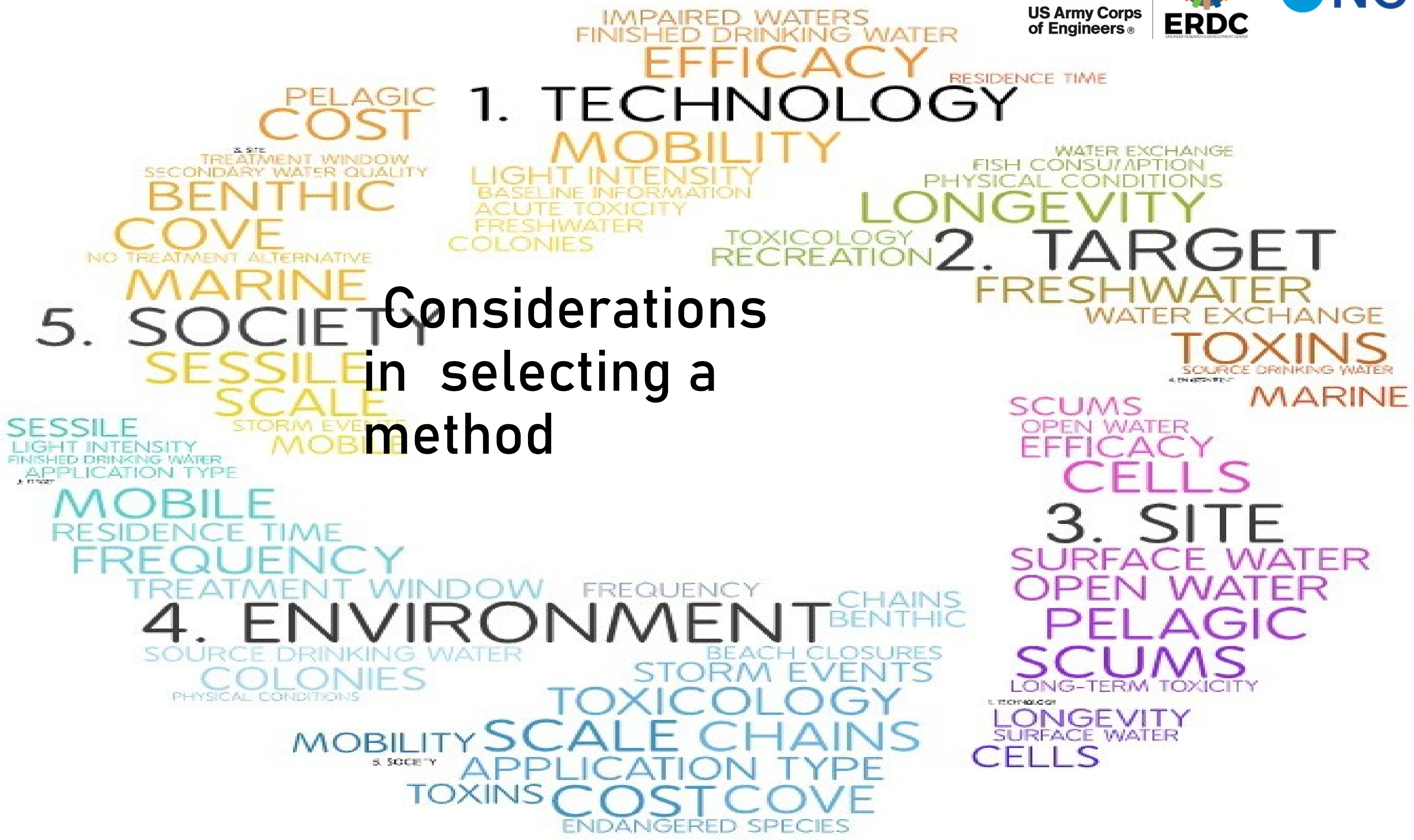
Considerations in selecting a method



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https://ansrp.el.erdc.dren.mil/HAB.html

https://coastalscience.noaa.gov/research/stressor-impacts-mitigation/pcmhab/

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Questions & Answers

Please post any questions to the "CHAT".

Please join us next week!