PASSIVE HARVESTING OF CYANOBACTERIA TO RESTORE WHITE POND'S WATER QUALITY AND PREVENT HEALTH RISKS, CONCORD MASSACHUSETTS

"Before" Photo: HEA 8/26/2021 White Pond, Concord, Mass.
Microcystis Sp. scums and suspensions over 50% of pond

SOURCE: YEAR 2022 SUMMARY REPORT - RESTORATION OF WHITE POND'S WATER QUALITY

RESTORATION METHOD: PASSIVE HARVESTING, SUSTAINABLE REMOVAL AND COMPOSTING OF CYANOBACTERIA USING THE A-POD TECHNOLOGY (U.S. Patent No. 10,745.879)

Project Summary

- As part of ecological restoration activities from August 2021 to December 2022 to improve the water quality of White Pond, HEA utilized a patented (No. 10,745.879) cyanoHAB harvesting and removal technology, called the A-Pod, to passively trap (harvest), concentrate and permanently remove approximately 388.5 dry to moist U.S. pounds of cyanoHAB and similar suspended solids (pollen, and fragments of leaves, pine needles and macroalgae) from White Pond. The A-Pod technology is a physical collection, concentration and separation process for permanently removing suspended solids in water (i.e., cyanoHABs and similar). At White Pond, the A-Pods were used in passive mode, leveraging natural water body currents to trap and remove cyanoHABs without the use of chemicals, biologic substances, or physical alterations such as dredging or covering of sediment.

Credits:

- **Town of Concord, Natural Resources Division**: A majority of funding for work in year 2022 was provided under contract to the Town of Concord, Massachusetts

- **National Science Foundation (NSF):** Additional funding during years 2020-2022 for research and development (R&D) for the A-Pod Technology (U.S. Patent No. 10,745,879) at White Pond and elsewhere was provided by the National Science Foundation (NSF Grant No. 2025679). HEA has additional NSF R&D samples and results for White Pond and other water bodies but this presentation focuses on work completed under contract to the Town of Concord.

Disclaimer:

- Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or Town of Concord.

References and Sources

- Additional references and sources of information are provided at the end of this presentation. If not referenced on slides, information is provided by Higgins Environmental Associates, Inc. (HEA) under contracts noted in Credits.

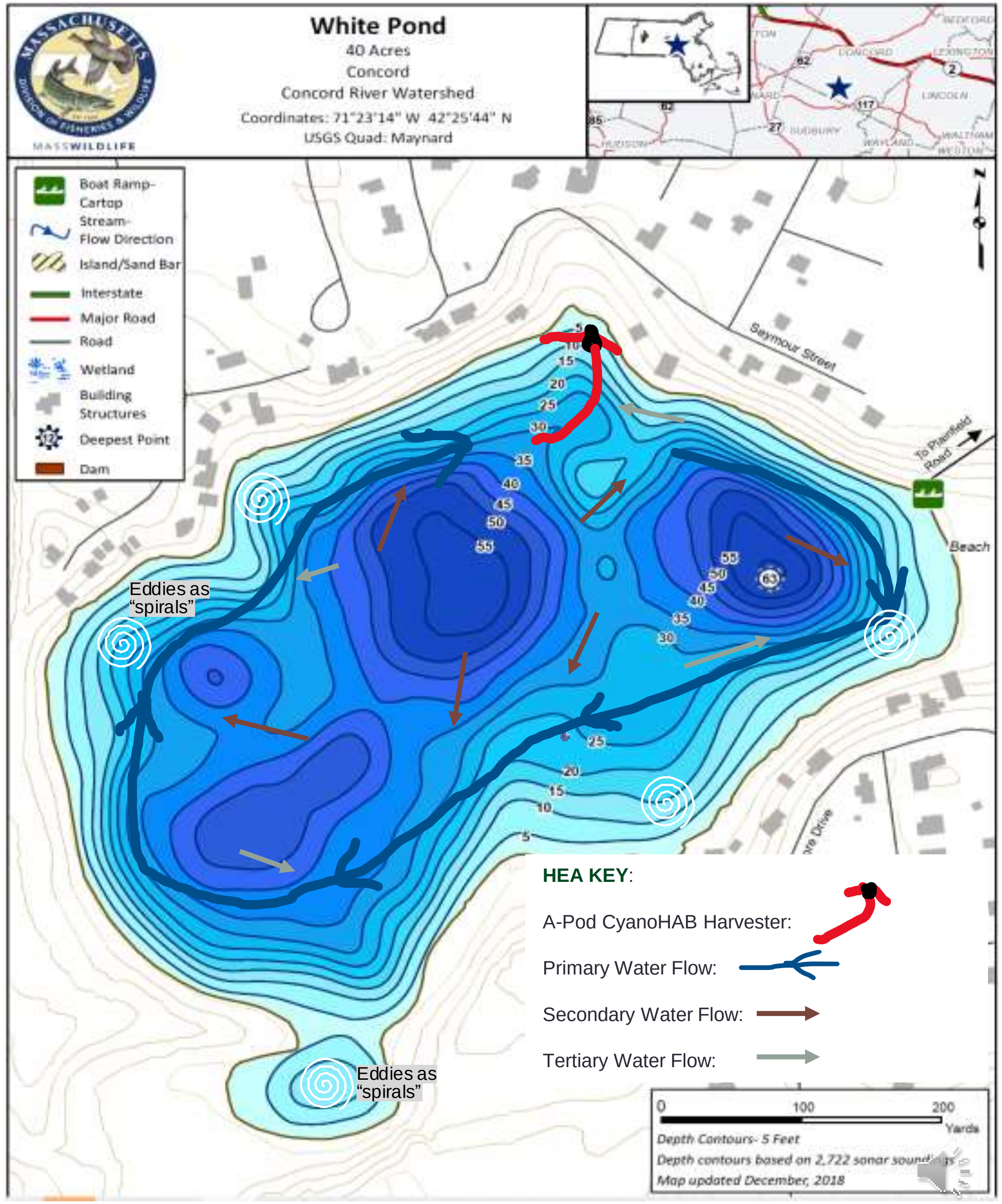
What is Passive Harvesting of CyanoHABs?

- Permanent removal and physical separation of cyanoHABs from water using A-Pods by leveraging naturally-occurring water flow and cyanoHAB characteristics ☺ Power of empirical earth sciences.

- White Pond has no surface water inlets or outlets. However, strong and sustained clockwise water currents (6-8 feet/minute; top 4 feet primarily) are created and driven by wind fetch, water incompressibility, turbulent friction and drag, bathymetry and shoreline morphology. Water current velocity decreases with depth but was measured to 10 feet below the water surface. Ekman Flow (1902) but without the Coriolis affect for small water bodies like White Pond.

- CyanoHABs, as suspended solids in water, follow vertical and lateral water flow fields i.e., they get pushed to and around the edges, dragged down to the center, then pulled and pushed up again, and repeat, in addition to their own diel vertical migration and separation forces. - includes Coulombs Law, centripetal force and Tea Leaf Paradox flow patterns solved by Einstein (1926).

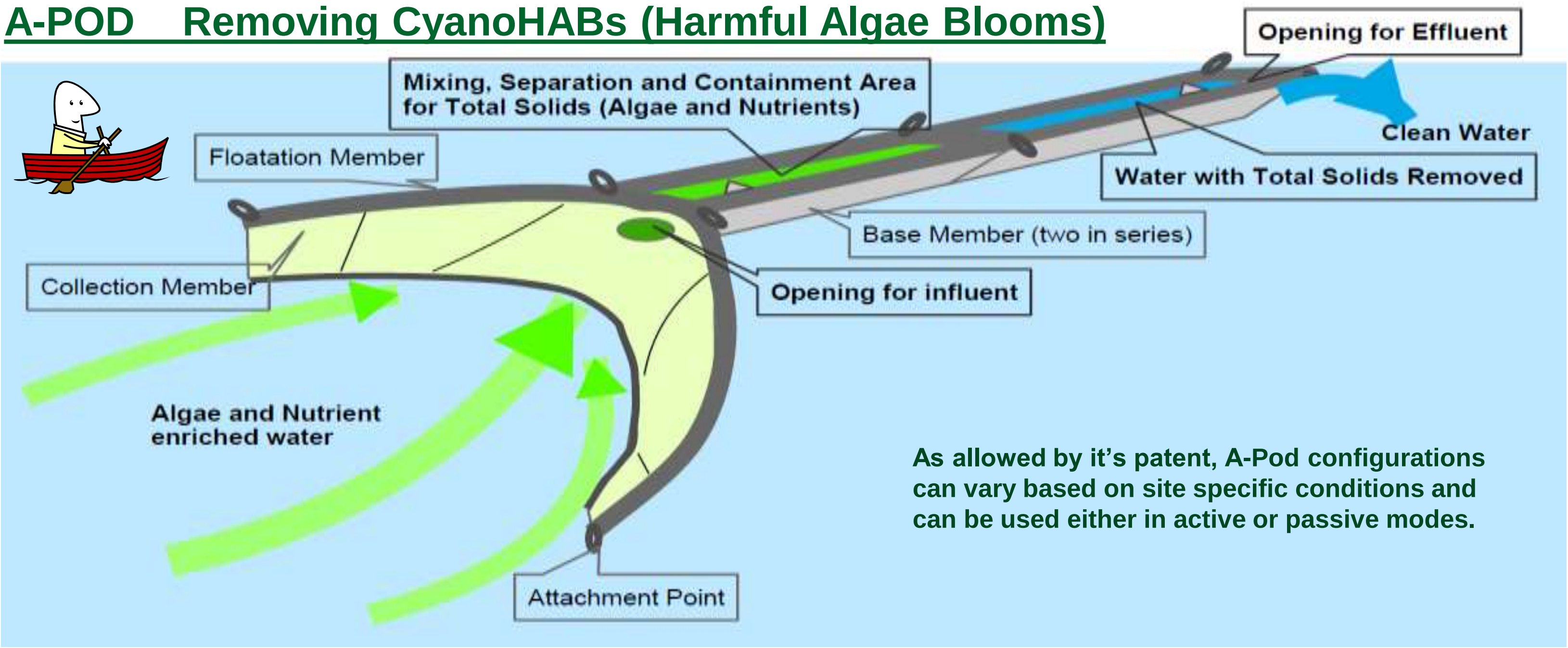
- HEA mapped these natural water and cyanoHAB flow field patterns with hydrological drogues set and tracked on transects across the pond and at different depths (2, 4 and 10 feet) and times of the year.



Summary of the A-Pod Technology

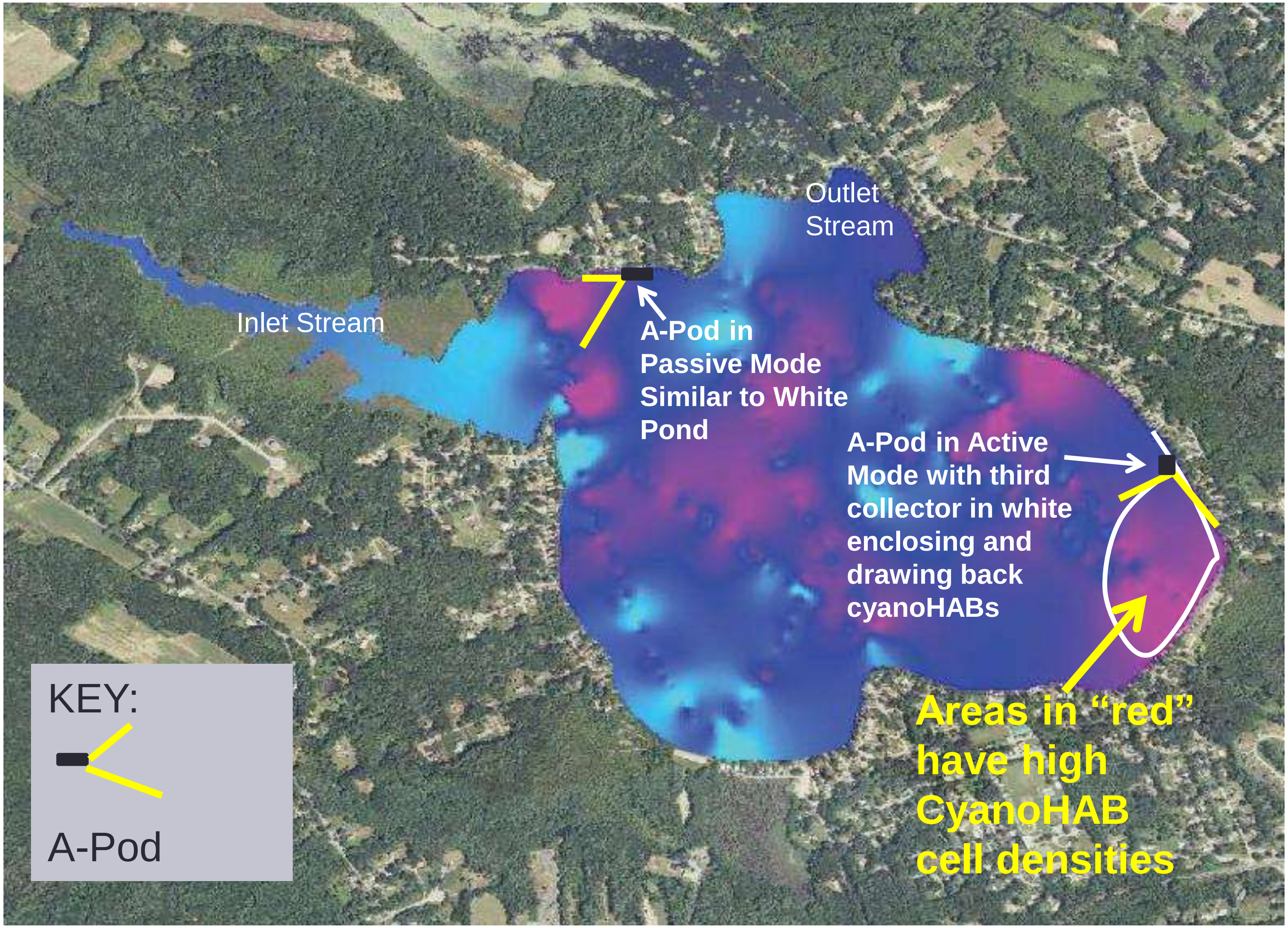
- A-Pods float on water, targets, concentrates and traps suspended cyanoHABs for permanent removal from a water body. Fully scalable and not dependent on heavy infrastructure or related disturbance.
- A-Pods actually work with the cyanoHABs to quickly gather and remove excess nutrients from fresh, estuarine and marine waters and sediment. CyanoHABs are the A-Pod's "eco-miners" and they have evolved over billions of years to gather and retain available nutrients.
- Rapid deployment and efficient at controlling and preventing health and environmental risks posed by cyanoHABs.

A-POD Removing CyanoHABs (Harmful Algae Blooms)



As allowed by it's patent, A-Pod configurations can vary based on site specific conditions and can be used either in active or passive modes.

Example of Passive and Active Use of A-Pods for cyanoHAB Removal for Spatially-variable cyanoHABs



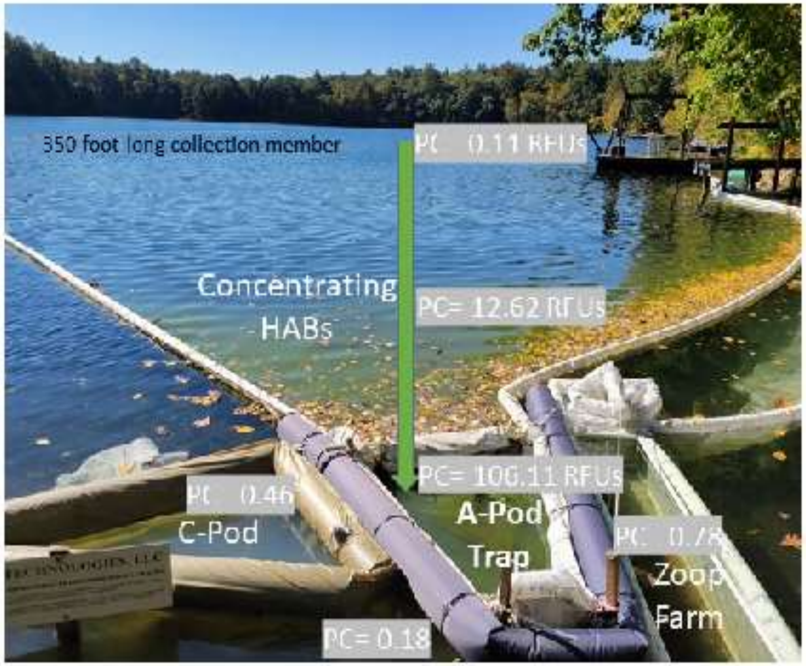
Source for HAB spatial information: 2010 UNH Citizen Cyanobacteria Monitoring Program Report, Lake Attitash – a 300+ acre lake.

Year 2021 White Pond Health Advisory Posting

Year 2021 A-Pods

A-POD HAB TRAP AND REMOVAL PROCESS

Efficient and rapid removal of cyanobacteria, their toxins, excess nutrients and carbon from natural waters.
One Favorable Day of Passive Use = 1,000 fold increase in suspended cyanobacteria biomass (phycocyanin; PC) trapped and removed. Note: these were cyanobacteria dispersed in the water column – not surface scums. Scums formed later in A-Pod trap area due to trapped high cyanobacteria biomass.



October 13, 2021

October 14, 2021

YEAR 2022 A-Pods

October 2022 A-Pod Harvesting CyanoHABs

Initial Approach to Use A-Pod for Harvesting

- Review existing cyanoHAB, water and sediment quality data including reports for historical information.

- Meet with Local Agencies and Community Representatives.

- Check with other local, state and federal agencies and regulations for permitting, species of concern or use restrictions. Obtain approvals and coordinate work as required. The A-Pod was specifically designed to be eco-sensitive so permitting needs may be limited to coordination with agencies having local jurisdiction (e.g., Board of Health, Conservation and Natural Resources, Town/County Administration, and Water body/watershed Associations).

- Start vertical transect and offset multiparameter sonde monitoring to characterize water quality, cyanoHAB biomass, biovolume and seasonal changes. Continuous sonde whole water body, shallow surveys may also be appropriate.

- Complete vertical profile, in-place gravity core sampling of deep basin soft sediments. Test vertical sediment intervals for nutrients (as totals: carbon, iron, nitrogen, phosphorus and sulfur); at minimum of: top 2 inches, middle and bottom of sediment core. Shallow, soft sediment sampling and laboratory analysis for nutrient content may also be appropriate.

- Characterize water flow regime with drogues. Confirm cyanoHAB types and changes over time. Set up a staff gage to monitor seasonal water elevation changes. Weather/Precipitation station also recommended.

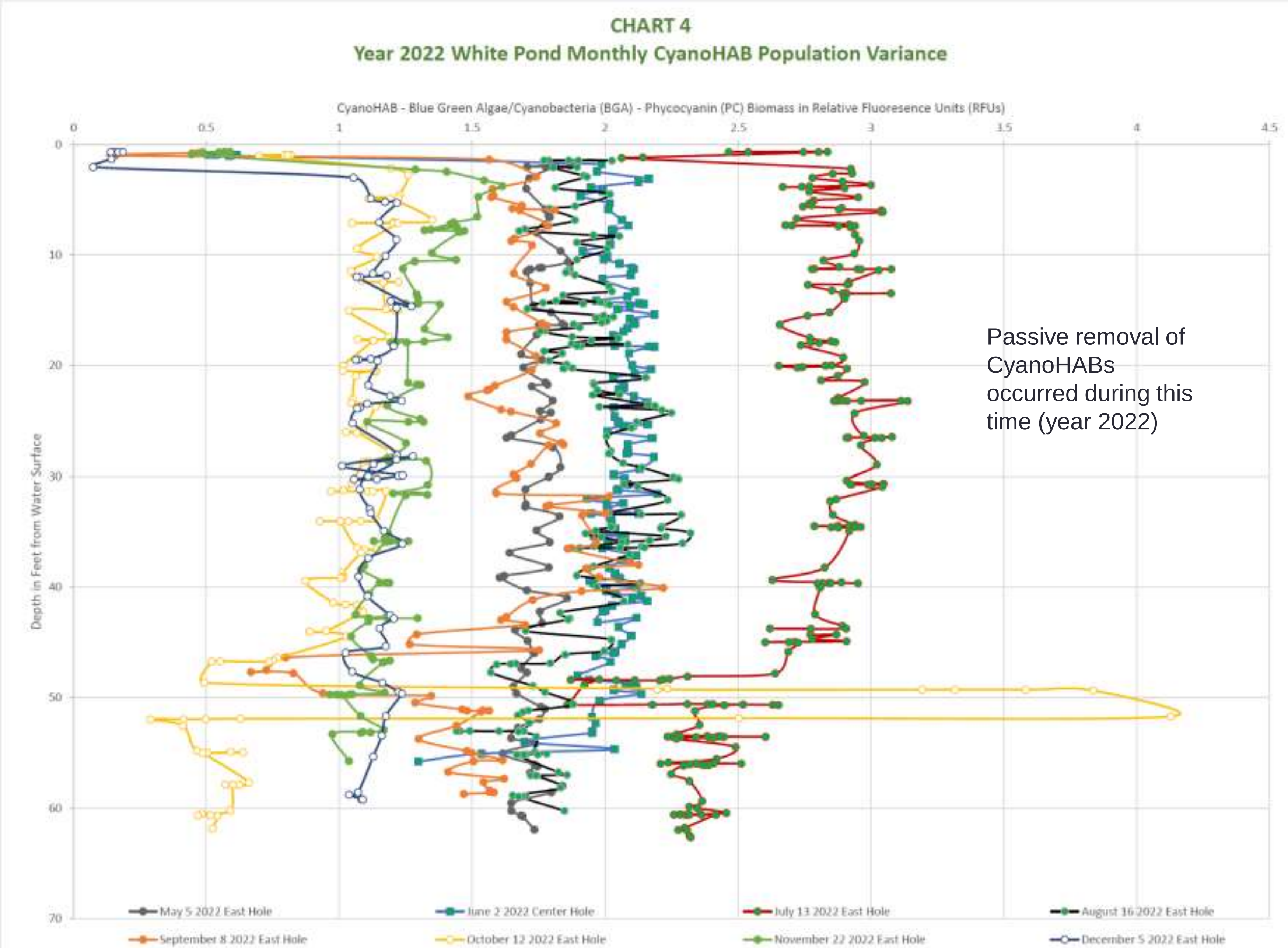


CHART 4
Year 2022 White Pond Monthly CyanoHAB Population Variance
CyanoHAB - Blue Green Algae/Cyanobacteria (BGA) - Phycocyanin (PC) Biomass in Relative Fluoresence Units (RFUs)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Depth in Feet from Water Surface
0
10
20
30
40
50
60
70
May 5 2022 East Hole
June 2 2022 Center Hole
July 13 2022 East Hole
August 16 2022 East Hole
September 8 2022 East Hole
October 12 2022 East Hole
November 22 2022 East Hole
December 5 2022 East Hole
Passive removal of CyanoHABs occurred during this time (year 2022)

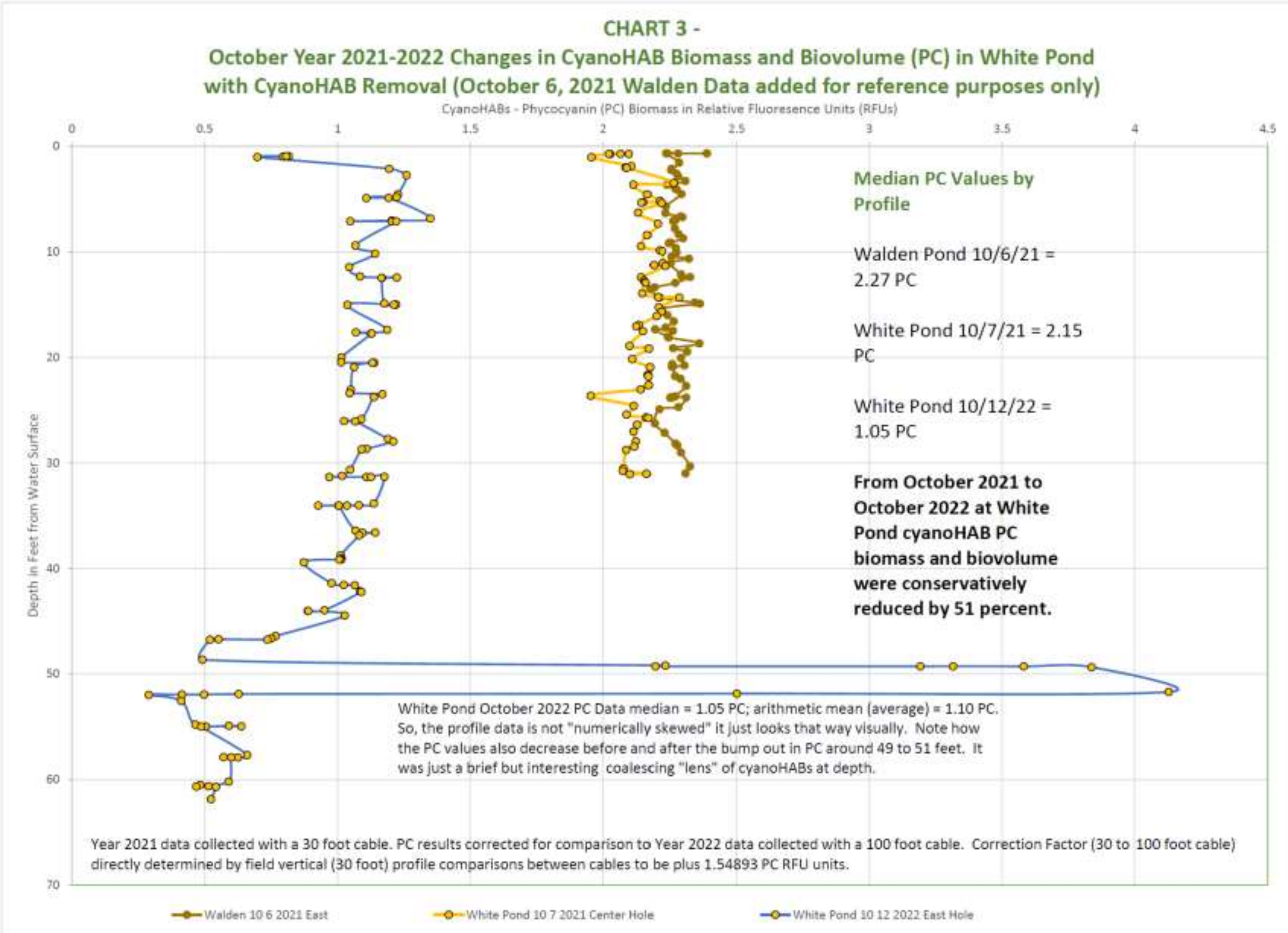


CHART 3 -
October Year 2021-2022 Changes in CyanoHAB Biomass and Biovolume (PC) in White Pond with CyanoHAB Removal (October 6, 2021 Walden Data added for reference purposes only)
CyanoHABs - Phycocyanin (PC) Biomass in Relative Fluoresence Units (RFUs)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
10
20
30
40
50
60
70
Depth in Feet from Water Surface
Median PC Values by Profile
Walden Pond 10/6/21 = 2.27 PC
White Pond 10/7/21 = 2.15 PC
White Pond 10/12/22 = 1.05 PC
From October 2021 to October 2022 at White Pond cyanoHAB PC biomass and biovolume were conservatively reduced by 51 percent.
White Pond October 2022 PC Data median = 1.05 PC; arithmetic mean (average) = 1.10 PC. So, the profile data is not "numerically skewed" it just looks that way visually. Note how the PC values also decrease before and after the bump out in PC around 49 to 51 feet. It was just a brief but interesting coalescing "lens" of cyanoHABs at depth.
Year 2021 data collected with a 30 foot cable. PC results corrected for comparison to Year 2022 data collected with a 100 foot cable. Correction Factor (30 to 100 foot cable) directly determined by field vertical (30 foot) profile comparisons between cables to be plus 1.54893 PC RFU units.
Walden 10 6 2021 East
White Pond 10 7 2021 Center Hole
White Pond 10 12 2022 East Hole

Lab Data for Nutrients in Surface Water (“Trap”, “IN” and “OUT”)

Table 2 - Surface Water Sample Results - White Pond, Concord, MA

Sample ID:	WP-Trap		WP-Trap		WP-Trap		
Lab Sample Number:	2F03025-01		2H17031-01		2J13028-01		
Date Sampled:	6/2/2022		8/16/2022		10/12/2022		
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Units
General Chemistry							
Nitrate and Nitrite as N	ND	0.03	ND	0.03	ND	0.03	mg/L
Total Nitrogen	**0.6**	0.1	**0.8**	0.1	**1.1**	0.1	mg/L
Kjeldahl Nitrogen	**0.6**	0.1	**0.8**	0.1	**1.1**	0.1	mg/L
Total Phosphorous	**0.05**	0.02	ND	0.02	ND	0.02	mg/L
Total Organic Carbon	**3.7**	0.5	**3.1**	0.2	**4**	0.2	mg/L
Total Metals							
Iron	**0.17**	0.05	**0.49**	0.05	**0.4**	0.05	mg/L
Sulfur	**1.5**	0.5	**1.3**	0.5	**1.2**	0.5	mg/L
Field Measured Phycocyanin at Sampling							
Phycocyanin	**1.87**		**1.95**		**4.02**		RFUs
Phycocyanin and Cyanotoxins by Laboratory Analysis							
Phycocyanin	**7.23**		**17.2**		**113.2**		ug/L
Cyanotoxin	**ND**		see below		see below		ug/L
Microcystin					**0.802**		ug/L
Anatoxin			**0.08**				ug/L

Sample ID:	WP-In		WP-In		WP-In		
Lab Sample Number:	2F03025-02		2H17031-02		2J13028-02		
Date Sampled:	6/2/2022		8/16/2022		10/12/2022		
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Units
General Chemistry							
Nitrate and Nitrite as N	**0.03**	0.03	**0.08**	0.03	**0.04**	0.03	mg/L
Total Nitrogen	**0.23**	0.1	**0.38**	0.1	**0.54**	0.1	mg/L
Kjeldahl Nitrogen	**0.2**	0.1	**0.3**	0.1	**0.5**	0.1	mg/L
Total Phosphorous	ND	0.02	ND	0.02	ND	0.02	mg/L
Total Organic Carbon	**2.7**	0.5	**2.7**	0.2	**2.4**	0.2	mg/L
Total Metals							
Iron	ND	0.05	ND	0.05	**0.08**	0.05	mg/L
Sulfur	**1.4**	0.5	**1.3**	0.5	**1.2**	0.5	mg/L
Field Measured Phycocyanin at Sampling							
Phycocyanin	**0.251**		**1.91**		**0.87**		RFUs
Phycocyanin and Cyanotoxins by Laboratory Analysis							
Phycocyanin	**4.46**		**2.51**		**1.69**		ug/L
Cyanotoxin	**ND**		see below		**ND**		ug/L
Microcystin							ug/L
Anatoxin			**0.11**				ug/L

Sample ID:	WP-Out		WP-Out		WP-Out		
Lab Sample Number:	2F03025-03		2H17031-03		2J13028-03		
Date Sampled:	6/2/2022		8/16/2022		10/12/2022		
Parameter	Result	Reporting Limit	Result	Reporting Limit	Result	Reporting Limit	Units
General Chemistry							
Nitrate and Nitrite as N	**0.03**	0.03	**0.04**	0.03	ND	0.03	mg/L
Total Nitrogen	**0.13**	0.1	**0.34**	0.1	**0.5**	0.1	mg/L
Kjeldahl Nitrogen	**0.1**	0.1	**0.3**	0.1	**0.5**	0.1	mg/L
Total Phosphorous	ND	0.02	ND	0.02	ND	0.02	mg/L
Total Organic Carbon	**2.7**	0.5	**2.7**	0.2	**2.5**	0.2	mg/L
Total Metals							
Iron	ND	0.05	ND	0.05	**0.05**	0.05	mg/L
Sulfur	**1.3**	0.5	**1.4**	0.5	**1.2**	0.5	mg/L
Field Measured Phycocyanin at Sampling							
Phycocyanin	**2.09**		**1.74**		**1.1**		RFUs
Phycocyanin and Cyanotoxins by Laboratory Analysis							
Phycocyanin	**1.92**		**2.38**		**2.61**		ug/L
Cyanotoxin	**ND**		**ND**		**ND**		ug/L
Microcystin							ug/L
Anatoxin							ug/L

Notes for Table 2:

1. All samples collected as discrete (grab) samples.
2. All results reported as total on a wet weight basis. mg/L = milligrams per liter; RFUs = relative fluoresence units; ug/L = micrograms per liter.
3. ND = not detected at or above reporting limit noted.
4. Detected results are highlighted in yellow with bold typeface. Cyanotoxin non-detect data also highlighted in yellow and bold typeface given its importance.
5. Preservatives - laboratory pre-preserved bottles per Standard Methods and Analytes (HNO3 for Fe, S; H2SO4 for N and C; none for P and N; all cooled to less than 4 degrees Celcius from collection to analysis).

“TRAP” Nutrients June-October 2022

- 0.05 to ND for Phosphorus
- 83% increase in Nitrogen
- 20% reduction in Sulfur
- 135% increase in Iron
- 0.08 anatoxin to 0.802 microcystin

“IN” Nutrients June-October 2022

- ND (0.02) for Phosphorus
- 135% increase in Nitrogen
- 14% reduction in Sulfur
- ND to 0.08 for Iron
- 0.11 anatoxin to ND microcystin

“OUT” Nutrients June-October 202

- ND (0.02) for Phosphorus
- 285% increase in Nitrogen
- 8% reduction in Sulfur
- ND to 0.05 for Iron
- ND for anatoxin and microcystin
- Mass Recreational Water Health Advisory Limit for microcystin = 8 ug/l

Lab Data for Nutrients in CyanoHABs and Sediment

Table 3 - Benthic Macroalgae (Nitella), Recovered CyanoHAB and Sediment Sample Results - White Pond

	Benthic Algae		Cyanobacteria (HAB) Samples						
Sample ID:	BPLNT-1		APOD HAB		HAB1-22		HAB-2-22		
Lab Sample Number:	1I15020-03		1J15038-04		2H17029-06		2J13027-01		
Date Sampled:	9/14/2021		10/14/2021		7/5/2022		10/7/22		
Parameter	Sample Result	Reporting Limit	Sample Result	Reporting Limit	Sample Result	Reporting Limit	Sample Result	Reporting Limit	Units
General Chemistry									
Nitrate and Nitrite as N	Not Tested		Not Tested		**492**	23	ND	7	mg/kg
Total Nitrogen	**3050**	10	**5860**	0.1	**12400**	10	**18200**	10	mg/kg
Kjeldahl Nitrogen	Not Tested		Not Tested		**11900**	440	**18200**	1490	mg/kg
Total Phosphorous	**1570**	1.39	**3630**	2.39	**2200**	1.62	**2040**	2.53	mg/kg
Total Organic Carbon	**46**	0	**40**	0	**36**	0	**40**	0	Percent (%)
Total Metals									
Iron	**9550**	14	**12000**	24.1	**9360**	16.3	**7320**	25.6	mg/kg
Sulfur	**3970**	140	**3680**	241	**3230**	163	**2690**	256	mg/kg

CyanoHABs 2021-2022

- 44% reduction in Phosphorus
- 211% increase in Nitrogen
- 27% reduction in Sulfur
- 39% reduction in Iron

	Sediment Samples													
Sample ID:	SED1 WHTS		SED2 WP		SED 3 -WPS	WP-ED-6"		WP-CD-6"		WP-WD-6"		WP-EH-62'		
Lab Sample Number:	1G21034-01		1H31016-01		1K10047-01	2H17028-03		2H17028-04		2H17028-05		2K10018-03		
Date Sampled:	7/16/2021		8/26/2021		11/9/21	8/10/2022		8/10/2022		8/10/2022		11/7/2022		
Parameter	Sample Result	Reporting Limit	Sample Result	Reporting Limit	Sample Results East Hole	Sample Result	Reporting Limit	Sample Result	Reporting Limit	Sample Result	Reporting Limit	Sample Result	Reporting Limit	Units
General Chemistry	East Hole top 6"		Thoreaus Cove 6"		EH Vert Profile to 24" Top 2"/4-8"/16-24"	East Hole to 6"		Center Hole to 6"		West Hole to 6"		East Hole Top 2"		
Nitrate and Nitrite as N	Not Tested		Not Tested		Not Tested	**153**	7	**224**	11	**504**	24	**204**	10	mg/kg
Total Nitrogen	**7620**	0.1	**229**	10	**1130/1680/1650**	**10500**	10	**14500**	10	**22400**	10	**8840**	10	mg/kg
Kjeldahl Nitrogen	Not Tested		Not Tested		Not Tested	**10300**	154	**14300**	236	**21900**	443	**8640**	985	mg/kg
Total Phosphorous	**580**	2.39	**899**	1.47	**2250/2740/2460**	**2100**	0.55	**2410**	0.91	**2390**	1.22	**1990**	1.6	mg/kg
Total Organic Carbon	**3**	0	**10**	0	**16/30/29**	**16**	0	**23**	0	**26**	0	**16**	0	Percent (%)
Total Metals														
Iron	**8600**	24.1	**10500**	14.8	**27300/10100/9280**	**18100**	5.5	**10500**	9.1	**11000**	12.3	**25700**	16.2	mg/kg
Sulfur	**2370**	241	**3030**	148	**9870/4790/4470**	**6000**	55.4	**5280**	91.4	**6180**	123	**11400**	162	mg/kg

Sediment 2021-2022 (top 2")

- 12% reduction in Phosphorus
- 682% increase in Nitrogen
- 15% increase in Sulfur
- 6% reduction in Iron

Notes for Table 3:

1. HAB = harmful algae bloom; HAB1-22 sample is a composite of 35 pounds of partially-dried HAB removed from main A-Pod Trap "A" on June 29, 2022; HAB2-22 is a composite of 40 pounds of partially-dried HABs removed from A-Pod "A" in Oct 2022.
2. All HAB samples collected as composite samples on date sampled. Sediment samples collected as discrete samples over specified interval (either top 2 inches; top 6 inches; or at 6 inch intervals at SED3-WPS from a 0 to 24 inch core sample).
3. All results reported as total on a dry weight basis.
4. ND = not detected at or above reporting limit noted.
5. Detected results are highlighted in yellow with bold typeface.
6. Preservatives - samples frozen after collection until laboratory analysis.
7. APOD HAB sample from 10/14/21 was part of our NSF funded work; and serves as a Year 2021 year end "background sample" for Concord's Year 2022 work and results for HAB solids.
8. Most sediment samples were collected and analyzed as part of HEA's National Science Foundation (NSF) work; presented results are summarized for informational purposes only.
9. Sample SED3-WPS was collected using a gravity corer with intact recovery of 24 inches (60 centimeters) of soft sediment. Discrete sediment samples were collected and results reported from the core as follows: top 2 inches/ 4 to 8 inches / 16 to 24 inches.
10. Sample WP-EH-62 was collected in the east hole (deep basin off beach) using a discrete water sampler which is helpful for collecting the very loose, almost smoke-like top 2 inches of sediment. This sample was primarily green-colored detritus with active microbial populations.
11. BPLNT1 = benthic macroalgae (Nitella) sample collected as part of HEA's NSF work from a grab sample approximately 30 feet deep south of Thoreau's cove.

Nutrient Patterns in Aquatic Media

- CyanoHAB nutrient concentrations and biovolume reflect the availability of nutrients to them each season in a water body.

- Sediment in-place core vertical profile data provides both a current (top 2 inches) and historical record of biogeochemical conditions affecting nutrient availability, deposition and reuse patterns over time.

- Surface water nutrient concentrations provide a snapshot of short term spatial and temporal variances in water quality.


CHART 1
Years 2021-2022 - Benefit of CyanoHAB Removal on Reducing CyanoHAB (PC) Biovolume and Health Risks
Pounds of CyanoHABs and Suspended Solids Removed from White Pond
Phycocyanin in Relative Fluoresence Units (RFUs)
120
100
80
60
40
20
0
3
2.5
2
1.5
1
0.5
0
Risk +
Risk -
Less Risk from
HAB scums when
PC < 1.71 RFUs
Jul-21
Aug-21
Sep-21
Oct-21
Nov-21
Dec-21
Jan-22
Feb-22
Mar-22
Apr-22
May-22
Jun-22
Jul-22
Aug-22
Sep-22
Oct-22
Nov-22
Dec-22
Pounds cyanoHABs and SS Removed
PC Biovolume in RFUs
Linear (PC Biovolume in RFUs)

Year 2022 Composting of CyanoHABs

Years 2021-2022 Benefit of CyanoHAB Passive Harvesting and Removal

- Board of Health closures for water contact were not required or issued in Year 2022 during use of the A-Pods. A "use at your own risk" advisory was posted briefly in June during the start of the 2022 passive cyanoHAB removal season.

- Water clarity improved to a Year 2022 (May to November) median of 24.2 feet versus the historic 30-year (1987-2017, typically June to August) median of 19.6 feet. Maximum year 2022 water clarity at 32.6 feet.

- A fifty one percent (51 %) reduction in cyanoHAB biovolume from October 2021 to October 2022.

- Excess nutrients (carbon, iron, nitrogen, phosphorus and sulfur) and cyanotoxins were sustainable removed as cyanoHAB removal progressed.

- 388.5 pounds of cyanoHAB and suspended solids were permanently removed in years 2021-2022 and composted on land in a controlled manner.

Feedback from the Community

- The Concord Bridge, January 1, 2023: *The A-POD is the only commercial remediation treatment WPAC (White Pond Advisory Committee) has found that adds no additives to pond water and shows immediate results at a reasonable price point," the WPAC memo notes.* https://theconcordbridge.org/index.php/2022/11/09/white-pond-committee-focuses-on-water-quality/

- What Would Henry Do? Essays for the 21st Century, Volume II (2022): A long- time member of the Friends of White Pond, imagines in her essay what Henry David Thoreau might think of the A-Pod:
  - *Henry gazed into Walden's crystalline waters. "I apologize. Sometimes my imagination runs away with me. Perhaps in the future someone will invent a machine that collects algal blooms and converts them into fertilizer. Just as I envision educational programs for children and adults to encourage responsible usage of the ponds and their environs, and foster coordination among the advocacy groups, government agencies, and individuals."*
  - *https://thoreaufarm.org/what-would-henry-do/*

- *"White Pond has not been this clear since the 1970s."* WPAC Member
- *"Thanks for saving White Pond, we really appreciate it"* abutter

Sources and References for Additional Information

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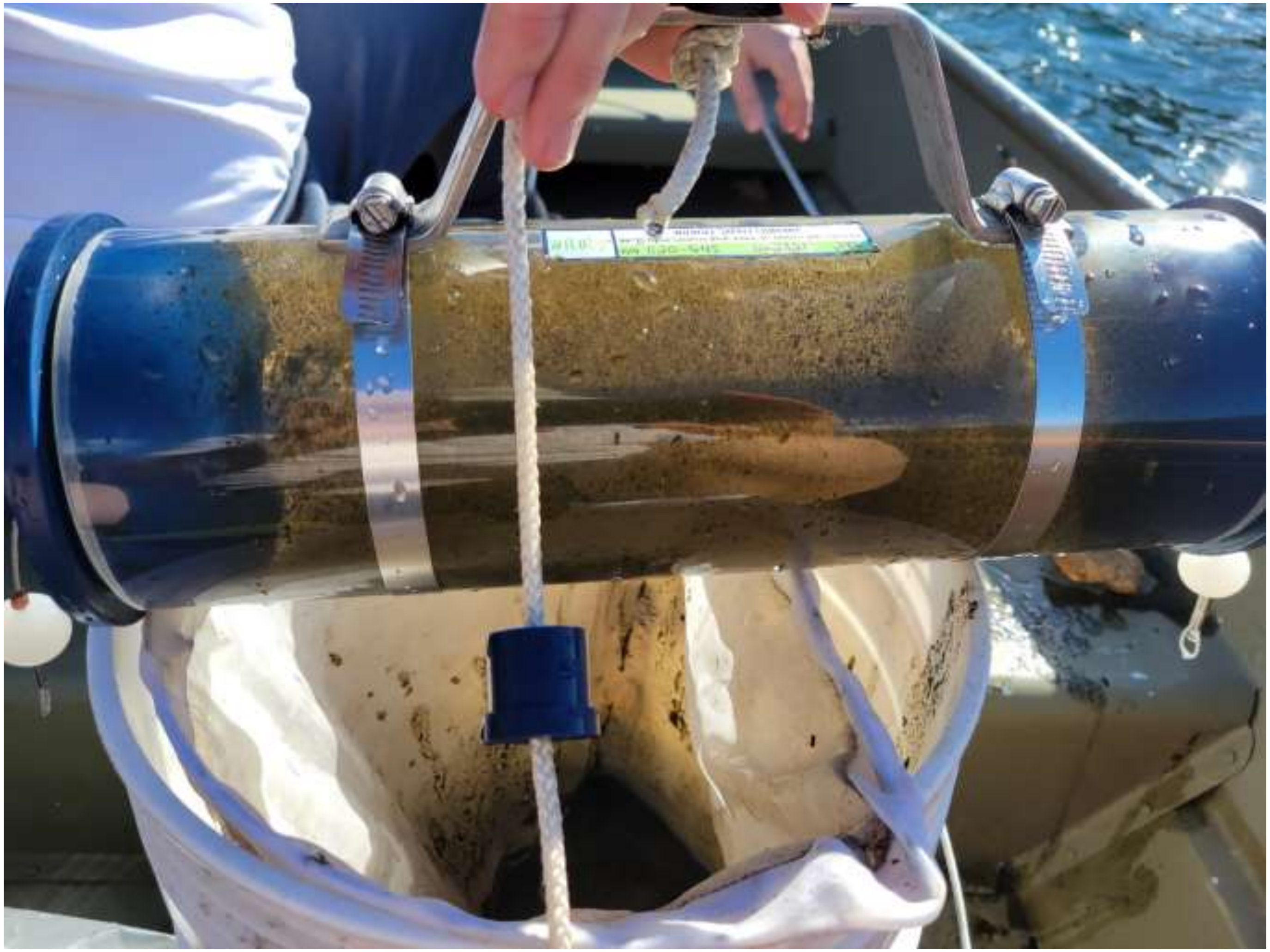
Jon Higgins holding a Nova Scotian lake iron nodule. My doctoral research on these led to the development of the A-Pod and P-Pod Technologies. Ask me about what I've learned about them.

Year 2022 A-Pod in Passive Use
Note water flow bowed collection member

Year 2022 50 foot depth White Pond

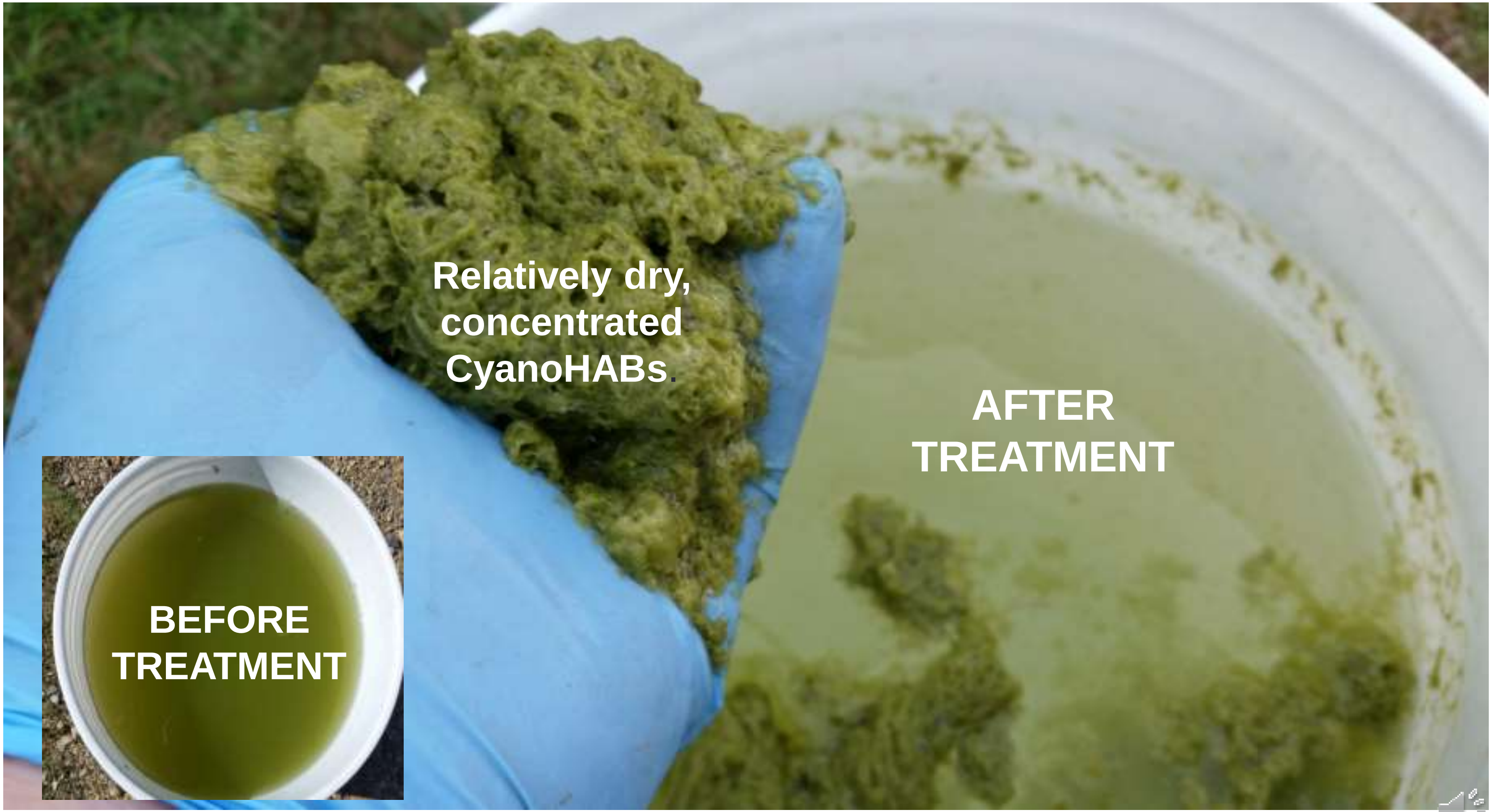
November 2022 62 foot deep sediment sample (top 2 Inches) WP-EH-62’



Community Awareness Labelling

Hydrologic Drogue with GPS and Label

CyanoHABs Removed from A-Pod by flotation



Early Prototype A-Pod Field Trial Location No. 1 – Park Pond

Park Pond - Field Trial Location No. 1 Results through 2020

Trial Location No. 1: Park Pond, 4 feet deep by 0.4 acres. Previously dense cyanoHAB scums and mats despite years of biannual use of management chemicals (Flocculant: aluminum sulfate; Algaecide: copper sulfate; and a Herbicide)

A-Pod HAB Trap and Removal Process Results (one year of use)

- Captured and removed 320 dry-weight pounds of cyanoHABs. CyanoHAB occurrence and nutrient content diminished during removal operations.
- Reduced total phosphorus content of sediment by 85% a change from Eutrophic to Oligotrophic for this pond.
- Reduction of phosphorus content of recovered cyanoHABs over time by 98% (e.g., from luxury uptake to growth limited).