Hazen

Monitoring and Management of HABs

Elizabeth Crafton

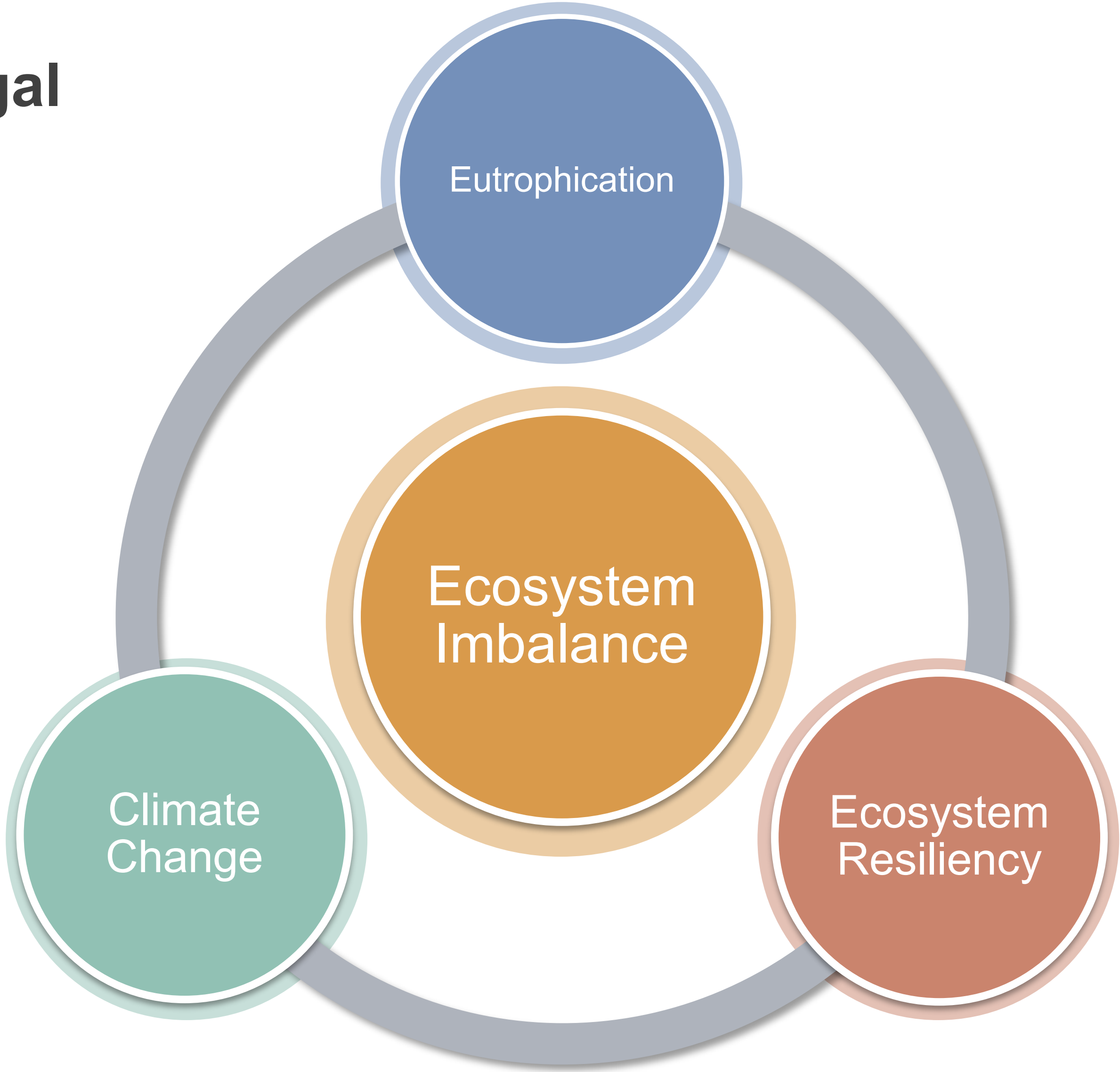
Agenda

- *Overview of harmful algal blooms*
- *Monitoring*
- *Short-term management*
- *Long-term management*
- *Examples*

What Causes Harmful Algal Blooms?

"Harmful Algal Blooms (HABs) are symptomatic of ecosystem imbalance"

caused the by many environmental changes that manifest with the expanding global human footprint and climate change



Wehr et al. 2015

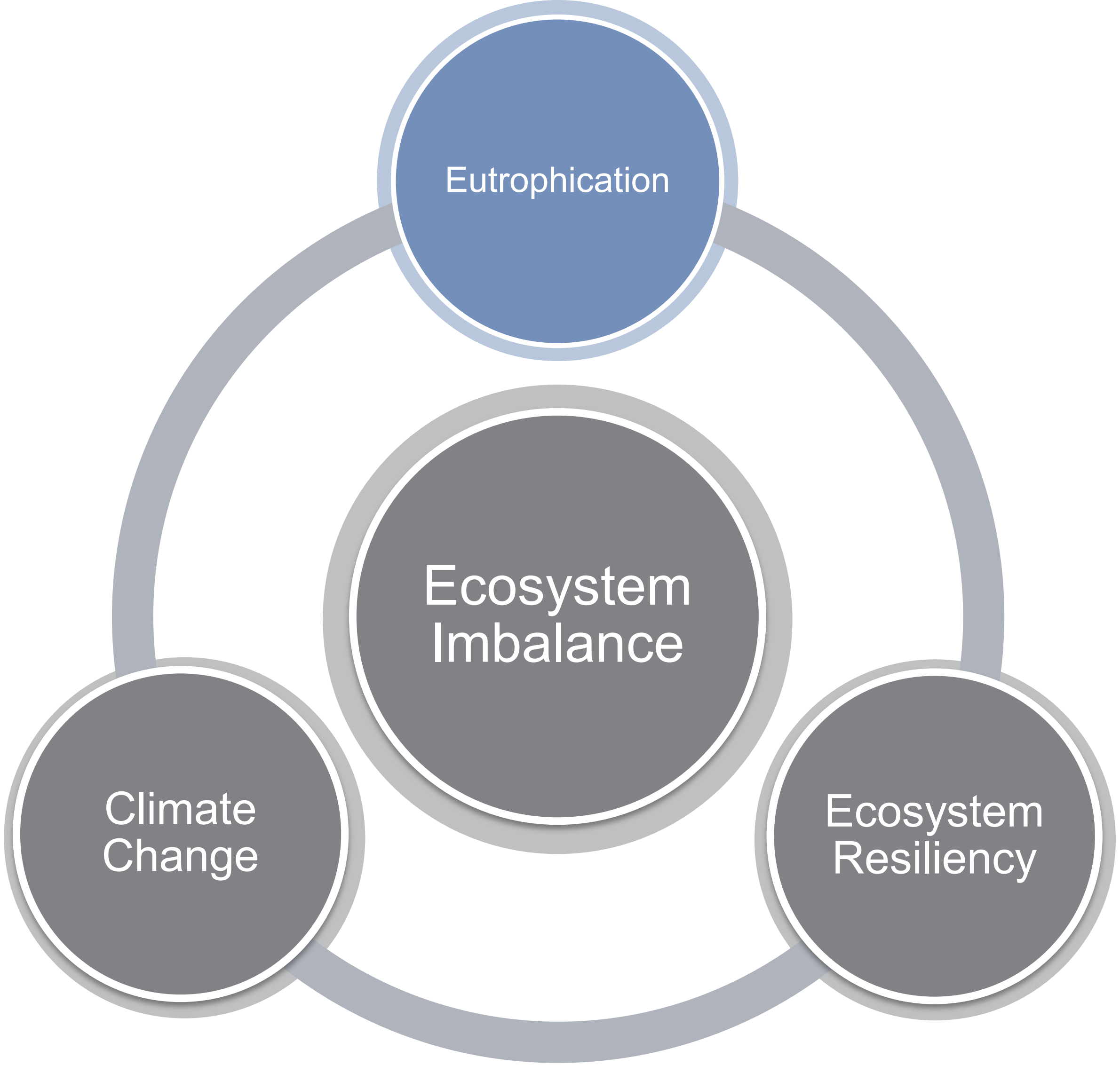
Eutrophication

Nutrient enrichment of water systems

Drives ecosystem changes and increases productivity

Key items to evaluate

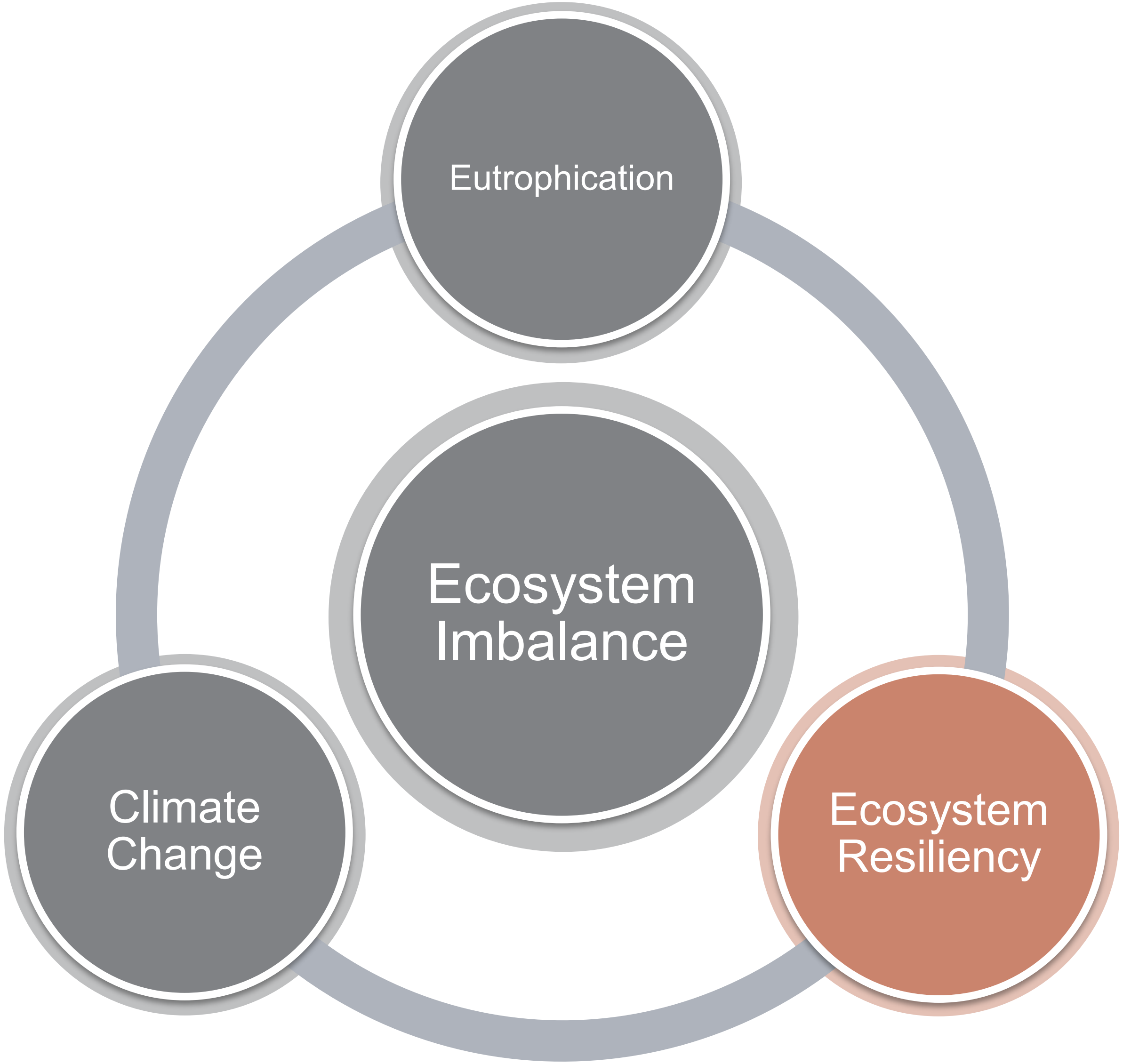
- Urbanization
- Land Use-Land Cover (LULC)
- Watershed size
- Ratio to perimeter and water depth



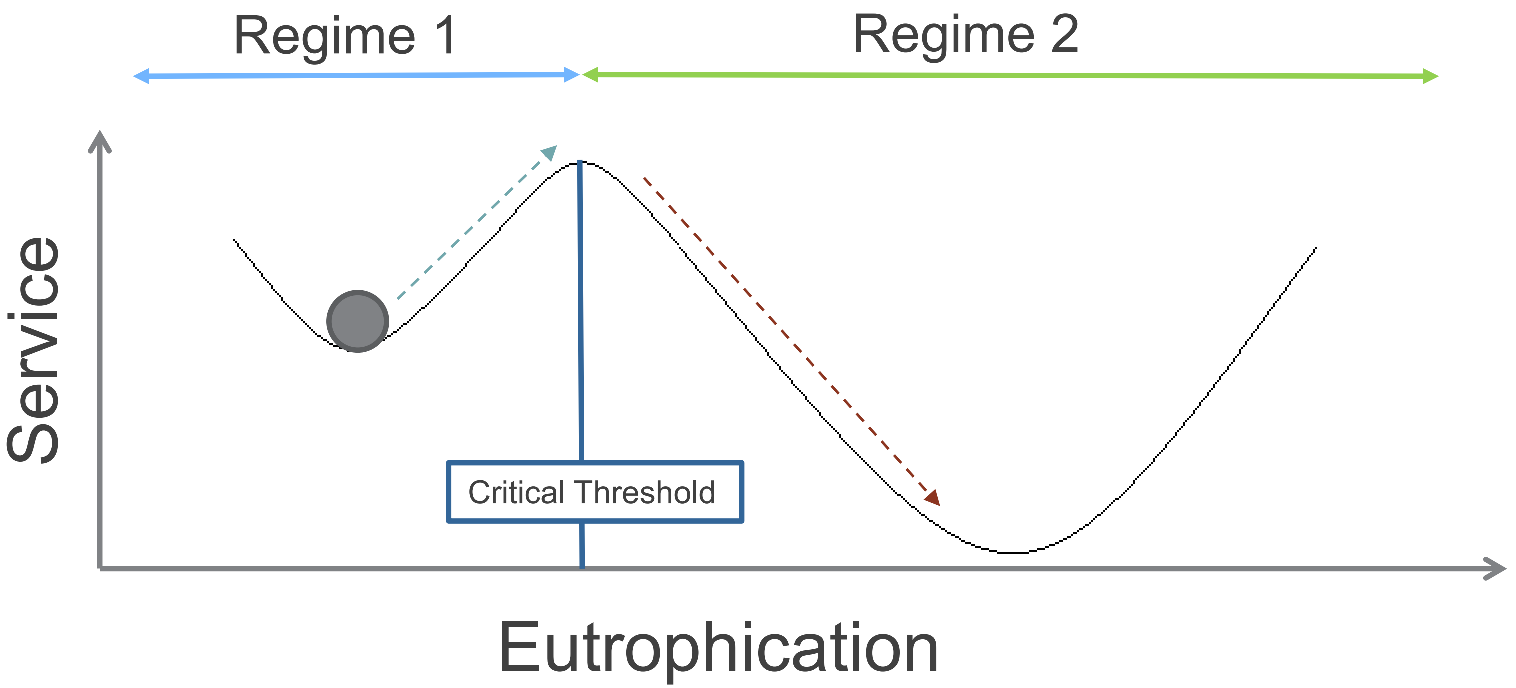
Ecosystem Resiliency

Capacity of an ecosystem to absorb disruption without shifting to alternative state

Ability to maintain normal patterns, nutrient cycling, and biomass production



Ecosystem Resiliency – Regime Shift



"Reorganization in system structure, functions and feedbacks"

Regime 1

Clear state

- *Macrophyte dominated*
- *Mini…*
  ph…
- *P…*
- *Z… g from*
  gra…
- *Suppre… …oplankton growth -competition and allelopathic interaction*

VS

Regime 2

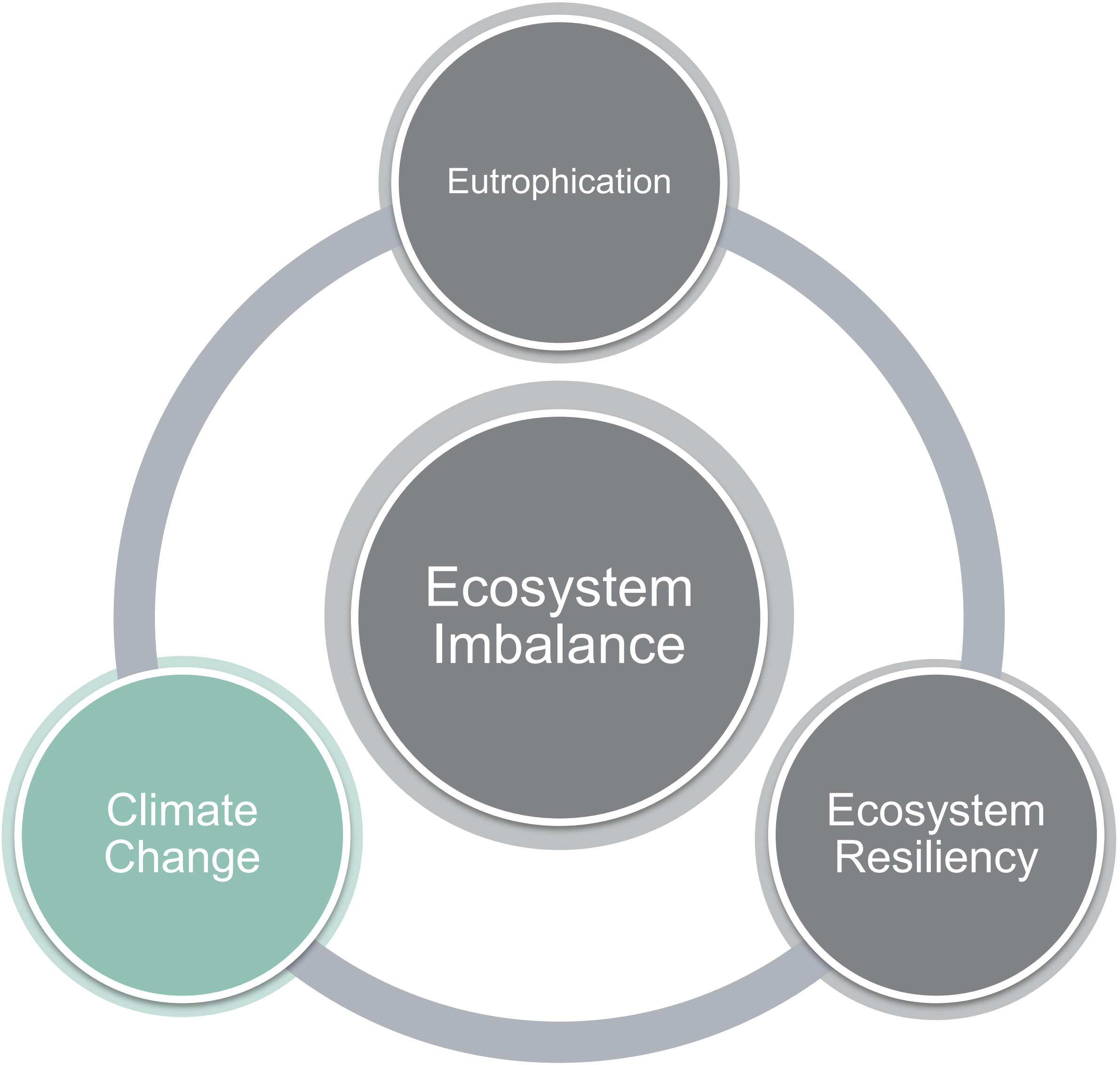
Turbid state

- *Phytoplankton dominated*
- *Interna… …cycle*
- *Bloc… …*
  nutr… …ed
  (imb…
- *Redu… – loss of key ha… …ivorous)*
- *Reduced zooplankton*

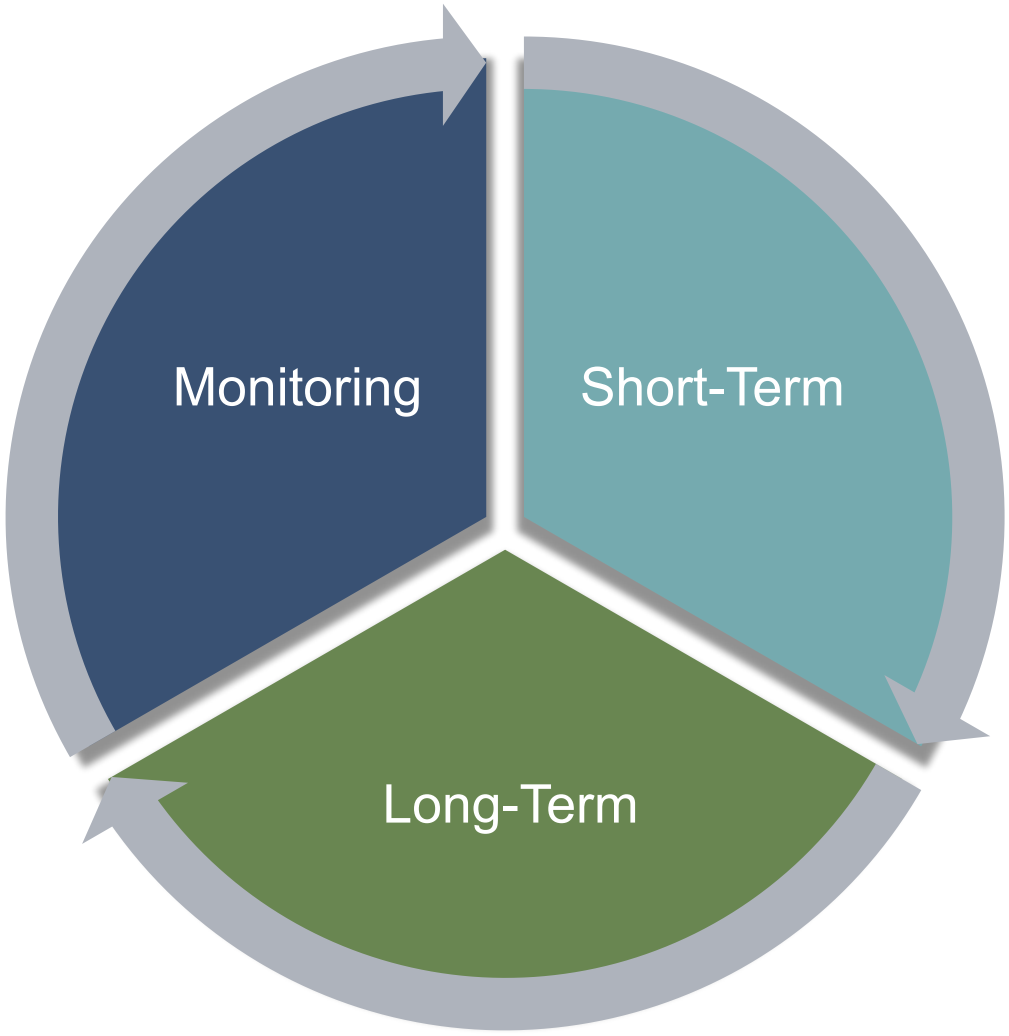
Climate Change

Changes in temperature, weather patterns, and carbon dioxide loading associated with climate change will increase frequency and magnitude of HABs

Promote cyanobacteria dominance based on physiological characterizes of organisms



Successful management requires a three-prong approach

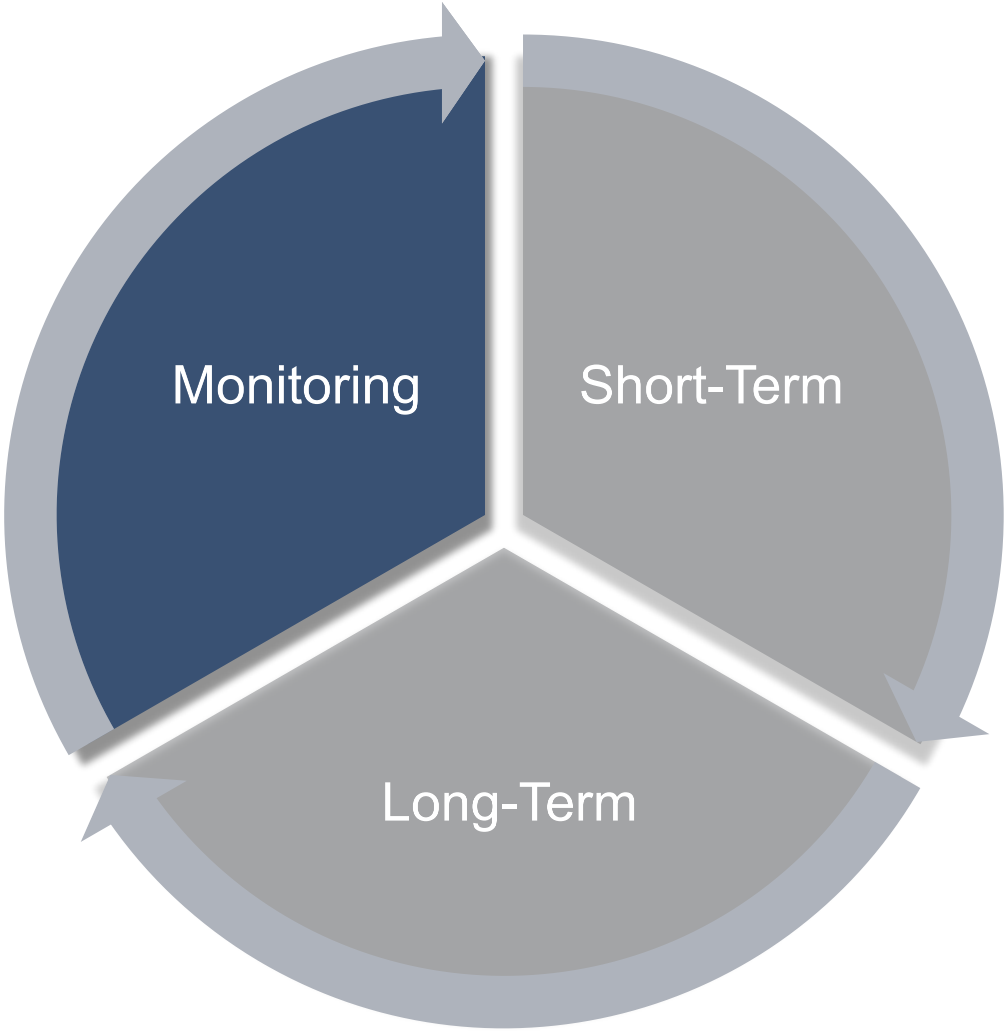


Goals

Seasonal trends

Key biological characteristics

Correlate genera to cyanotoxins and T&O compounds



Key Elements of Comprehensive Monitoring

Monitoring

In-Situ Monitoring

- *Profiles (1-m intervals) of full water column*
- *Standard WQ parameters*
- *Photosynthetic pigments*

Enumerations

- *Grab samples*
- *Microscopic analysis with counting chamber*
- *FlowCAM*

Metabolite Analysis

- *Grab samples*
- *Taste and Odor analysis*
- *Cyanotoxin analysis (analyte and qPCR)*

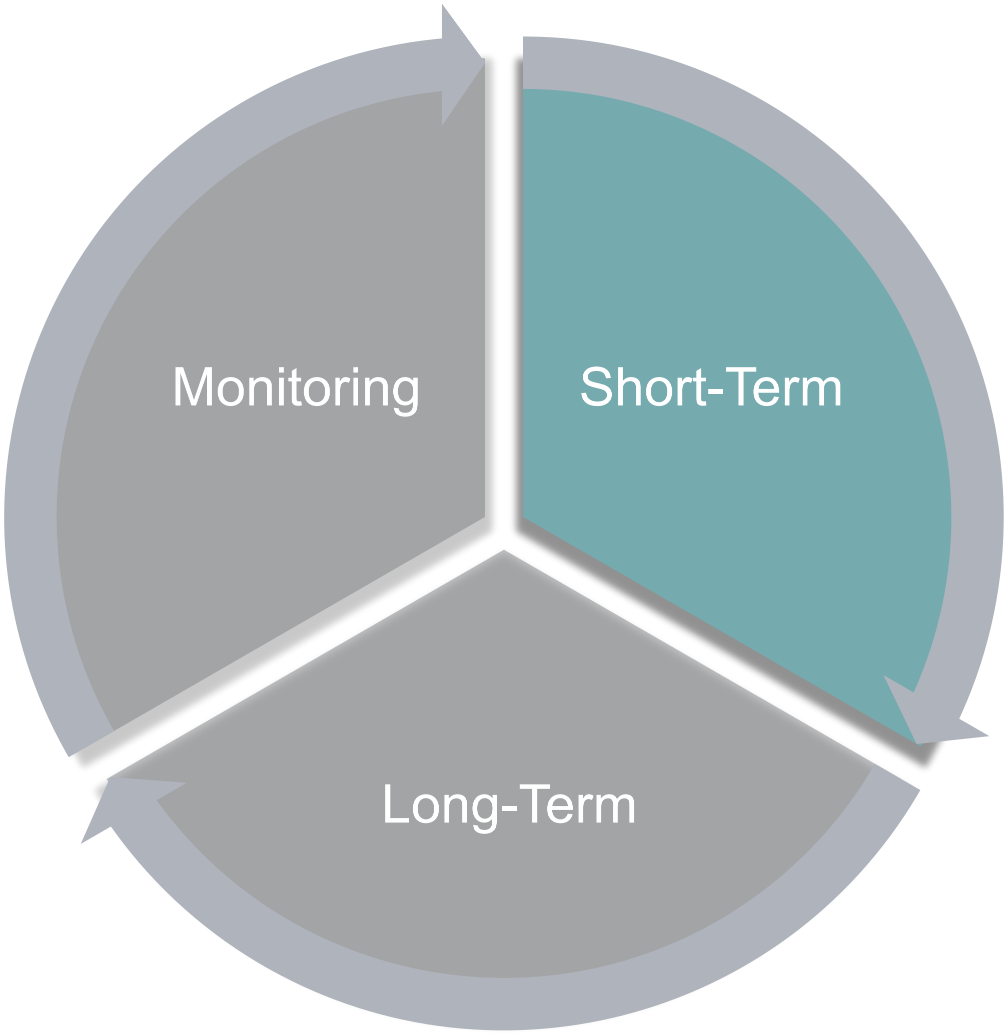
Goals

Maintain current WQ

Limit overproduction of phytoplankton

Reduce risk of cyanotoxin presence

Reduce T&O



Common Strategies for Short-Term Management

Short-term

Ultrasound

- Collapse gas vesicles in cyanobacteria – hypothesis expanded
- On-going research to determine mechanism
- Operation and success dependent on phytoplankton composition

Algaecide

1 Copper-based

- Toxicity-based inactivation mechanism
- Treatments are in response to conditions
- Rebounds are expected (~2 weeks)

2 Peroxide-based

- Selectively targets cyanobacteria
- Oxidative stress inactivation mechanism
- Hinders cellular function for ~4-6 weeks
- Injure not kill
- Timing of first treatment if key

SolarBee

- Solar-powered mixer that targets the upper portion of the photic zone
- Limited area of influence around mixer
- Dilution and dispersion
- Success dependent on phytoplankton composition

SolarBee

Solar-powered

Aeration and mixing

Mixing upper portion of water column

Limited area of influence

Composition of phytoplankton population

Ultrasound

LG Sonic and Sonic Solutions

Collapse of gas vesicles in cyanobacteria

On-going research with OSU

Field study

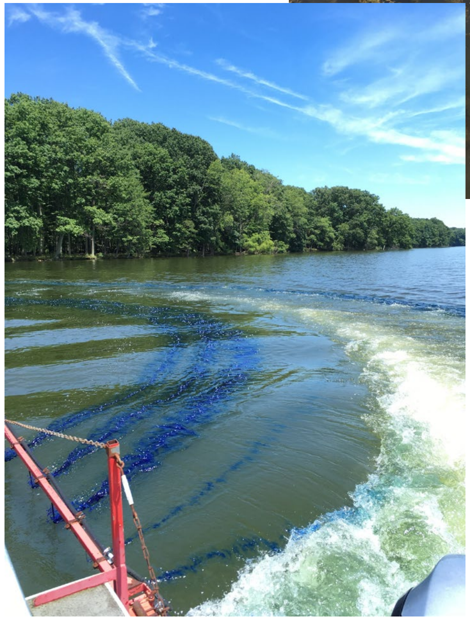
Algaecide

Advances in products

Application approaches and timing of treatment

Minimize risk to non-target organisms

Prolonged suppression



Copper

Toxicity to suppress growth

Liquid products

Chelated

Products that bind available phosphorus (SeClear)

→

Hydrogen Peroxide

Oxidative stress

Selectively target cyanobacteria

'Injury not kill'

Granular and liquid products

Sodium carbonate peroxyhydrate (27% H_2O_2)

Hydrogen Peroxide

Cyanobacteria prokaryotic

Mehler reaction

ROS-eliminating enzymes

Ascorbate peroxidase (APX)

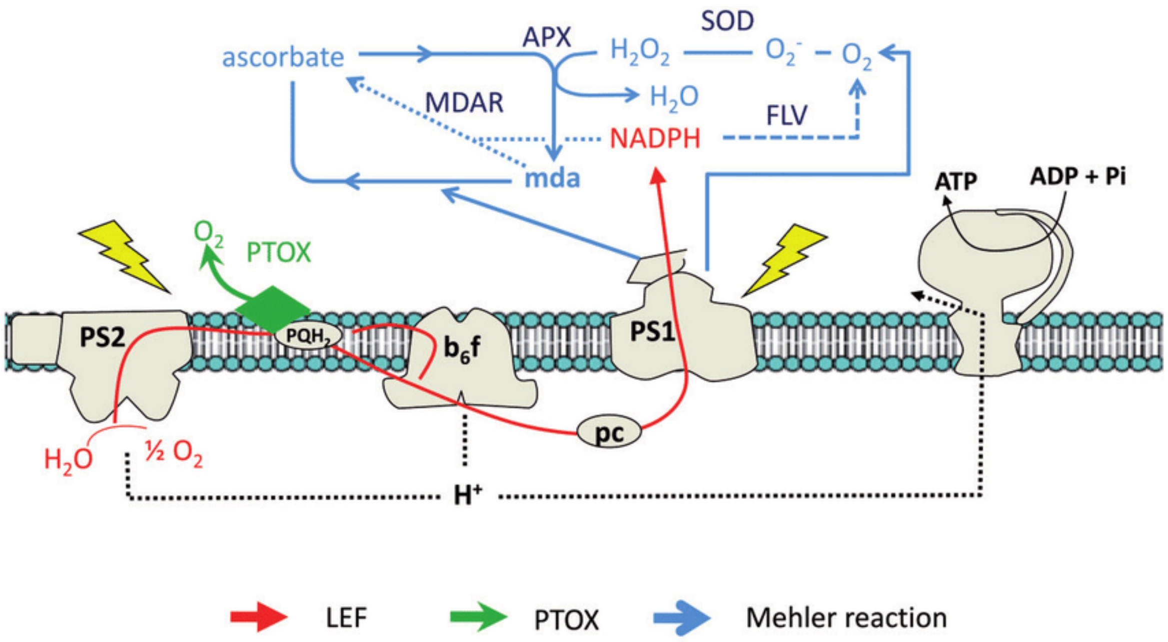


Image: Curien et al. 2016

Hydrogen Peroxide

Disrupts circadian rhythm

Impacts metabolic and physiological function

Reproduction, nitrogen fixation, carbon uptake, synthesis of secondary metabolites, photosynthesis

Downregulates microcystin genes (mcyA, mcyD, mcyH)

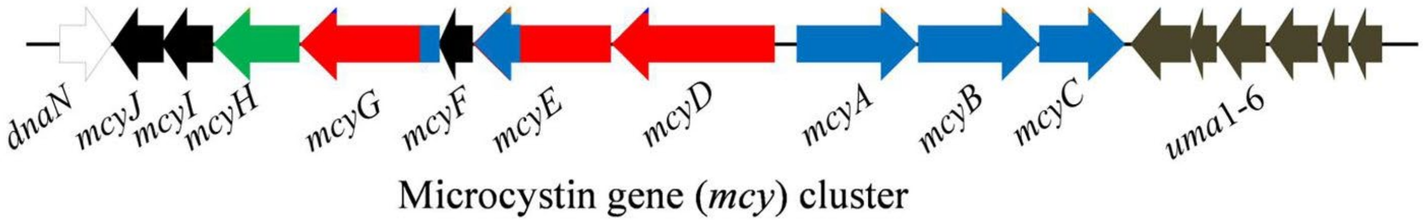


Image: Rastogi et al. 2015

Bench-Scale Assessment of Algaecide Products

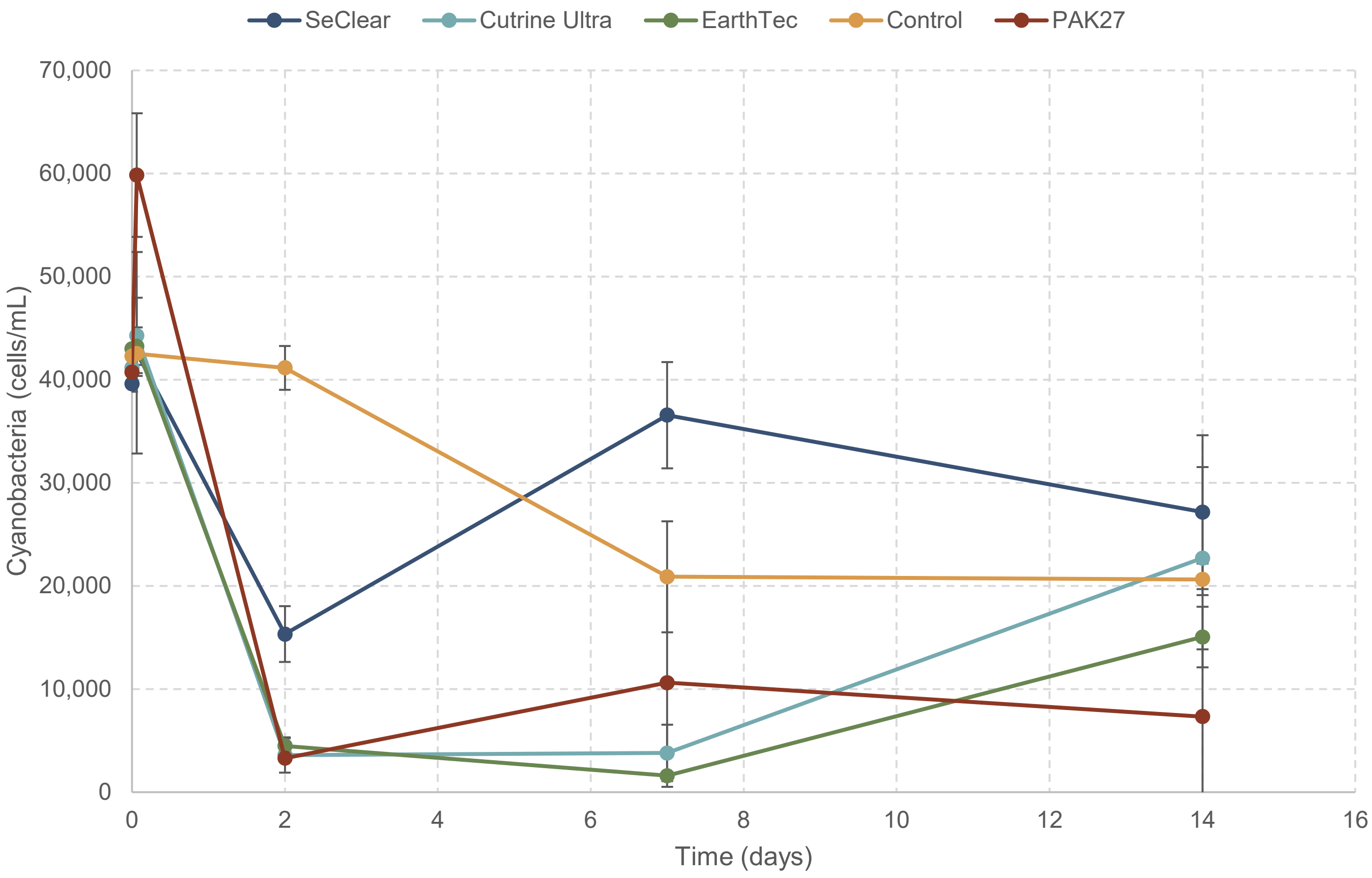
Four products investigated

5 sources waters

Wide variety of cyanobacteria

Tracked cyanotoxins leakage

Cyanotoxin gene synthesis



Application Type and Approach

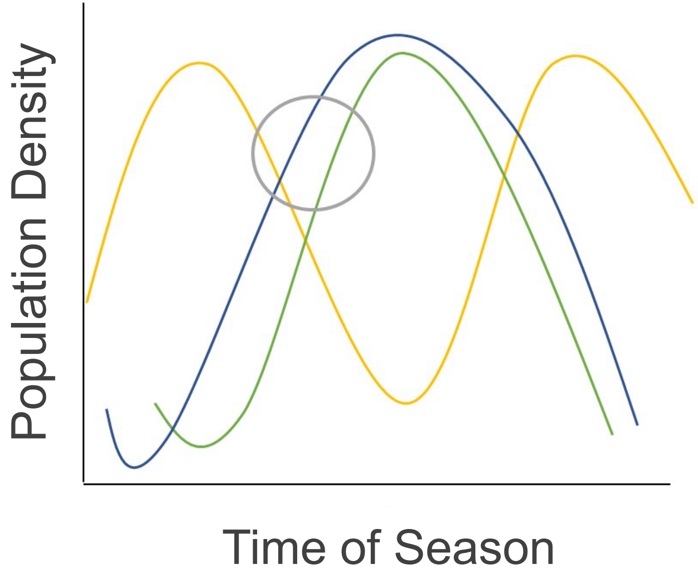
Target sections of the water column

Inject at sediment water interface

Target different section based on product

Hot spots (H_2O_2) vs. accumulation locations

Timing of application



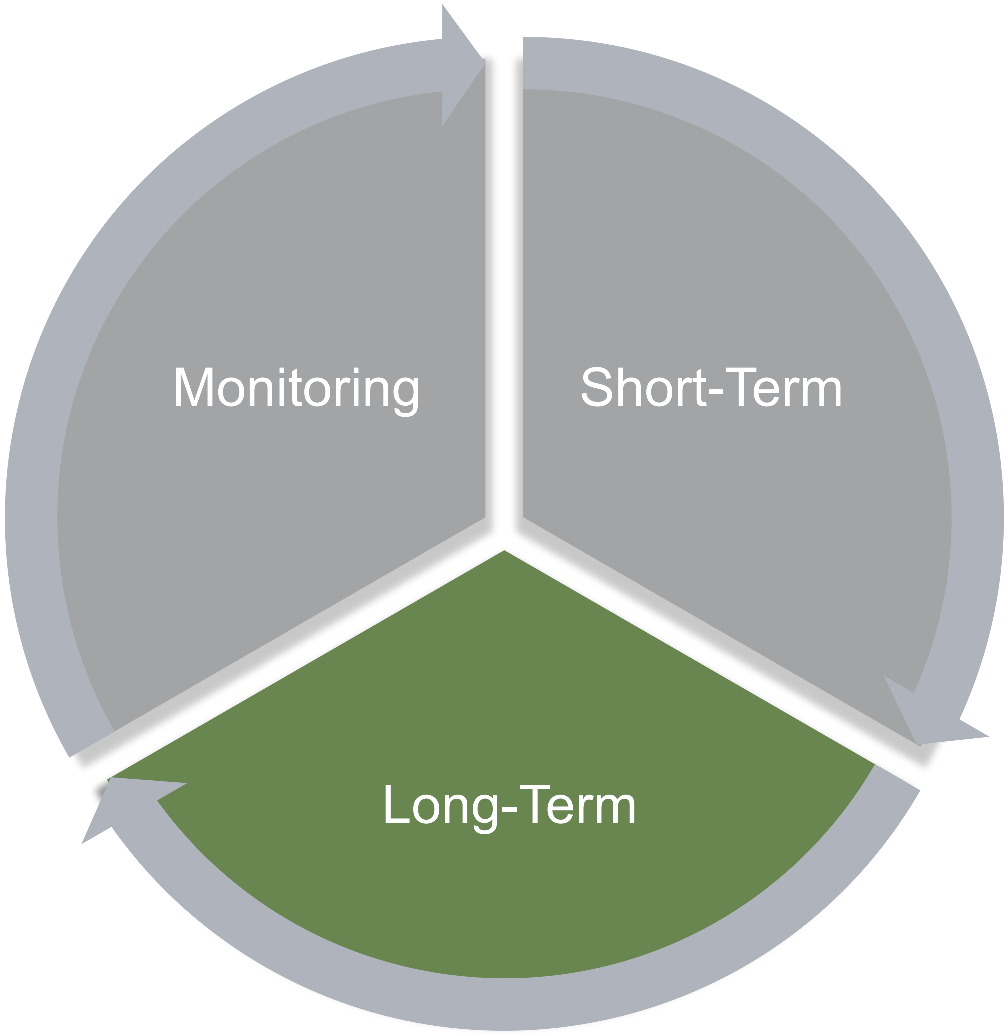
__Goals__

Address nutrient loading

Balance the ecosystem

Increase resiliency

Increase biodiversity



Common Strategies for Long-Term management

Long-term

Watershed Management

- *Key component for long-term success*
- *Targeted BMPs to minimize influent nutrient loads*
- *WTR reuse for phosphorus capture and biochar*
- *Habitat and bank restoration in tributaries*

Aeration & Oxygenation

- *Combat anoxia in hypolimnion*
- *Minimize redox sensitive internal cycling*
- *Reverse impact of increased production*
- *Mixing and destratification (aeration)*
- *Hypolimnetic oxygenation/aeration*

Alum Treatment

- *Inactive phosphorus in sediment*
- *Minimize internal phosphorus cycling*
- *Discrete application or continuous feed point*
- *Applicable in select circumstances*
- *Alternative approach – Phoslock®*

Phytoremediation

- *Nutrient uptake and increased composition*
- *Allelochemical release - allelopathic interaction to benefit management*
- *Key symbiotic relationships*
- *Shift back to regime 1 (recall ecosystem resiliency)*

Watershed Management

Watershed assessment

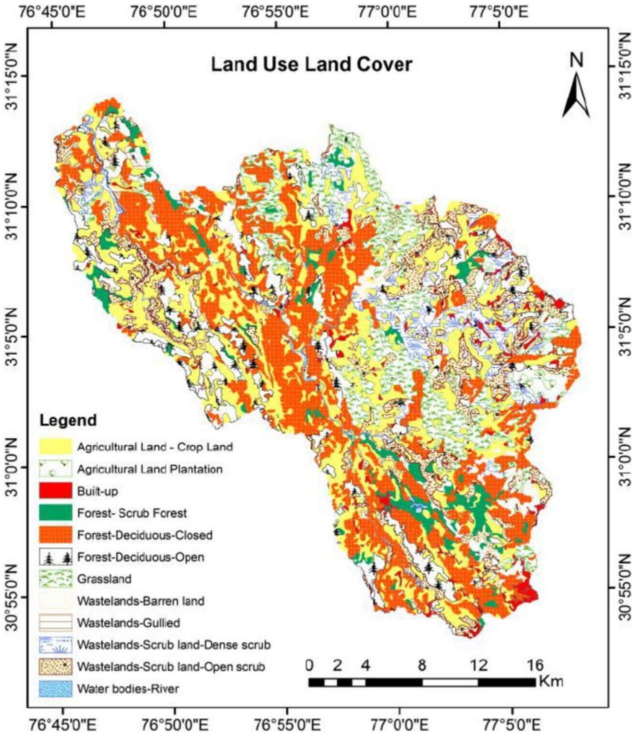
Characterize external sources

Targeted BMPs to minimize input

Stormwater management

Restoration

Key component for long term success



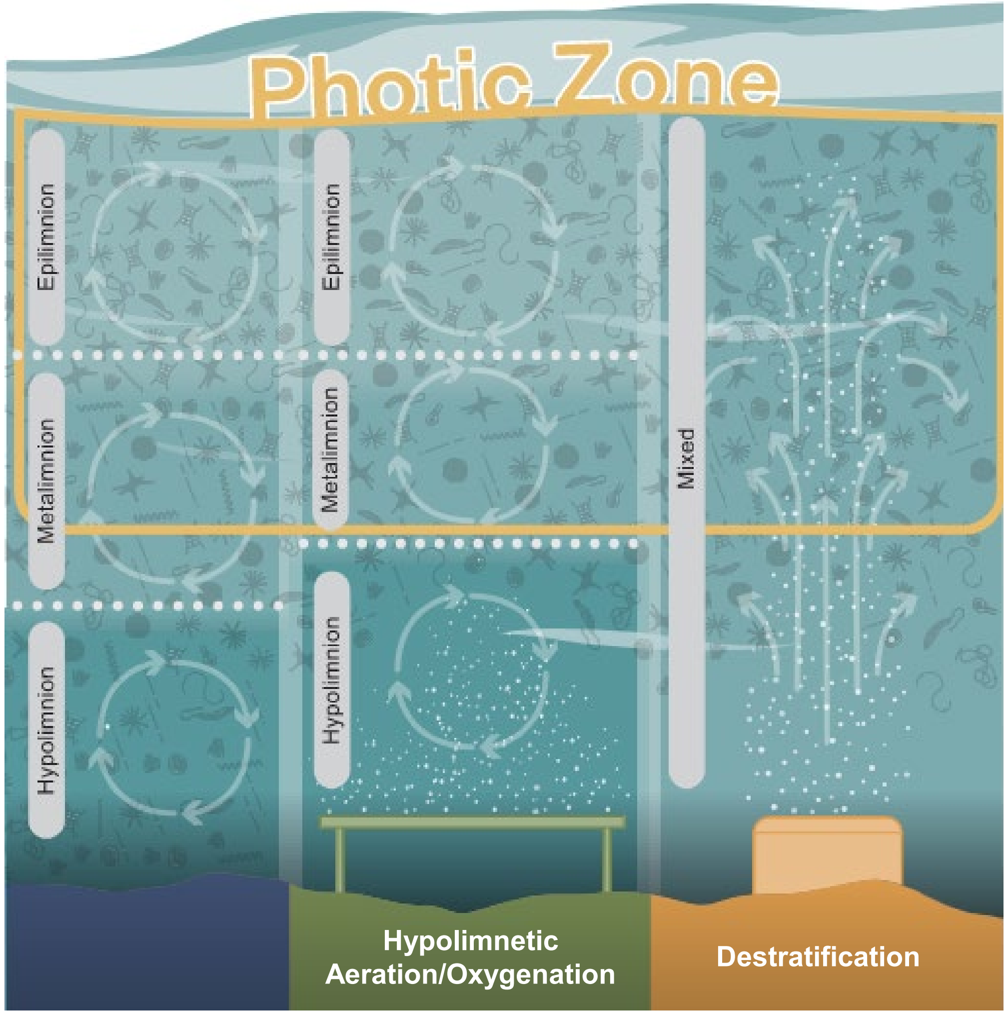
Lilhare et al. 2014

Oxygenation/ Aeration	Circulation/ Destratification
Increases DO without disrupting thermal stratification	Increases DO and mixes the entire water column
Adds O_2 directly via air or oxygen gas (gas-water interface)	Adds O_2 directly via air bubbles (larger diameter, interface transfer)
Minimizes mixing and avoids sediment re-suspension	Adds O_2 indirectly by moving anoxic water to the surface to absorb O_2 from the atmosphere
Increased operation flexibility, can selectively withdrawal water layers	A homogenized water column eliminates buoyancy advantages

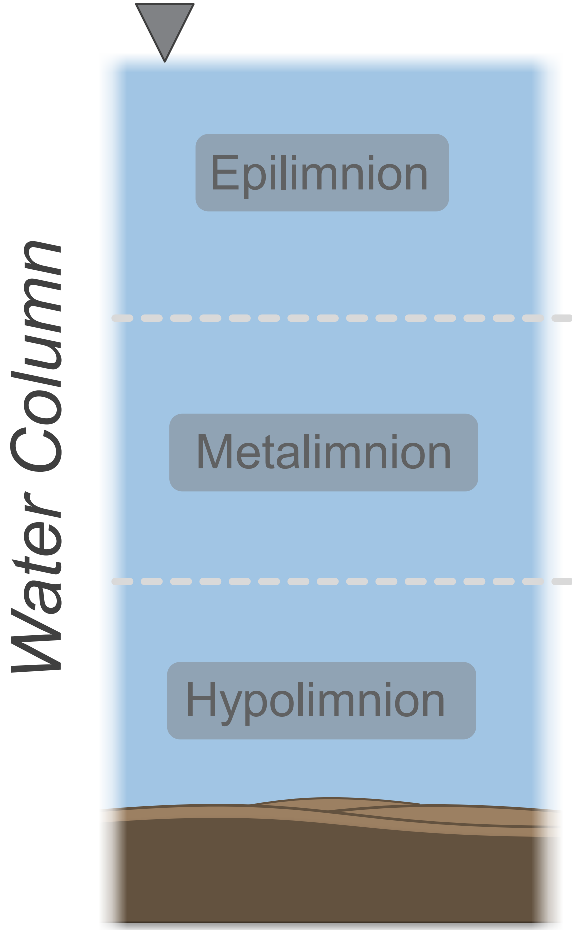
Increases dissolved oxygen concentrations

Induced Vertical Changes

- Nutrient and temperature profiles are altered
- Photic zone is mixed
- Mixing can cause changes in phytoplankton composition
- Changes in phytoplankton compositions are not always favorable



Confounding Effect: Hydrodynamics and Water Quality



Summer

- *Dense biomass*
- *Higher DO*
- *Nutrient limited*

- *Decaying biomass*
- *Lower DO (anoxia)*
- *Higher Fe/Mn*
- *Nutrient rich (flux)*

Winter

- *Higher DO*
- *Diatoms*

- *Well-oxygenated water*
- *Lower Fe/Mn*
- *Flux minimized*

Flow direction of each layer

Project Goals & Objectives

Scope of Work

Cost Benefit	Alternatives	Compare Performance	Improve Conditions
Determine if alternative aeration strategy or upgrades to existing system would provide cost benefit	*Identify alternative strategies for improved aeration*	*Compare performance of new (FL8) and old (LA30PCH) aerators*	*Determine if anoxic conditions and water quality can be improved by changing strategy or technology*

Aeration system Audit: Approach & Key Findings

- Records were provided
- Operating costs include energy and diving
- Maintenance costs include preventative and corrective
- Immediate upgrades required:
  - Airline repairs
  - New compressors
- Annual average costs were used for Lifecycle Cost analysis

22 Years of Operation

Costs	Cumulative
Maintenance	$697K
Operating	$4.9M
Total O&M Costs	$5.6M

Annual O&M costs

Costs	Average	Maximum
Maintenance	$30K	$79K
Operating	$221K	$281K
Total O&M Costs	$251K	$360K

Field Study

Determine:

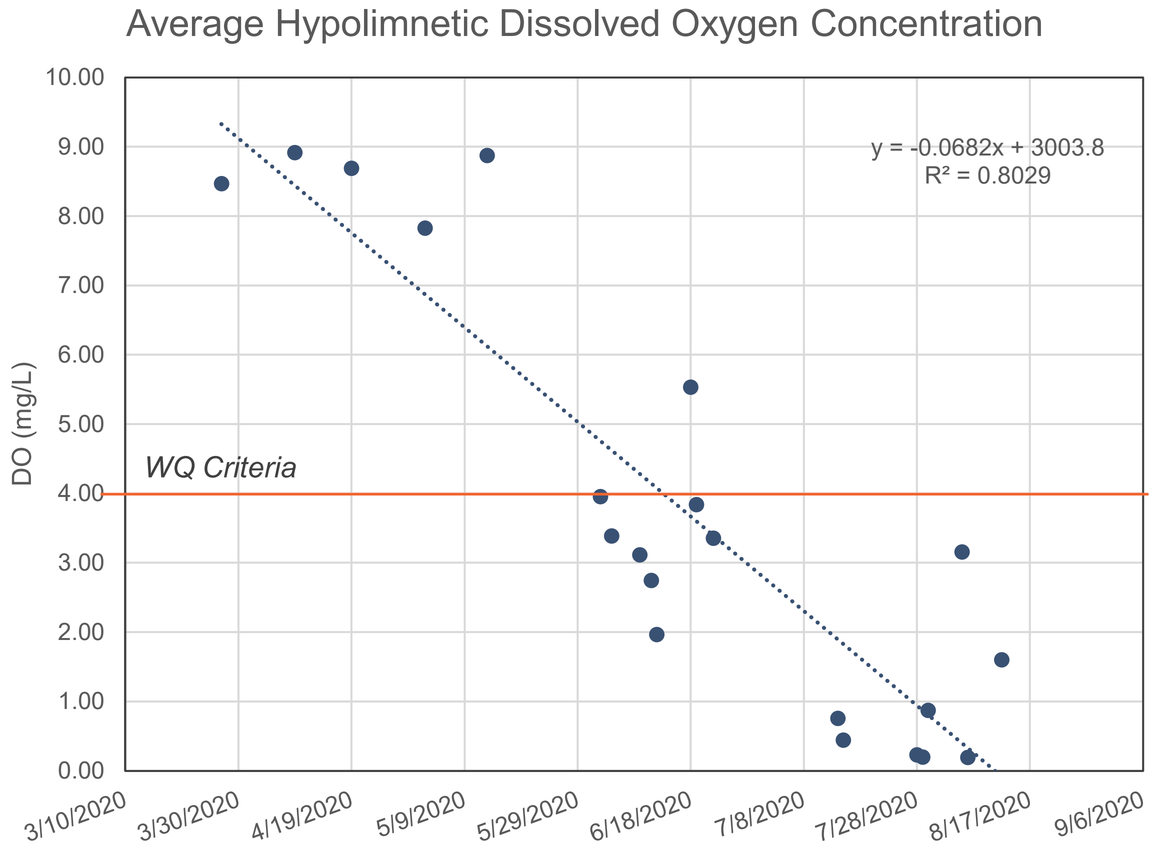
- Aerator operating conditions
- Oxygen transfer characteristics
- Seasonal variation in performance
- Performance of each aerator model

Images: Dr. Schafran (ODU)

Field Study: Key Findings

- Average DO was 3.72 mg/L (season)
- 72% of field observations were below WQ criteria
- Dropped below WQ criteria after 74 days
  - Extended by 49 days
- Residual demand of 2,152 kg/day DO
  - Target DO addition 9,000 kg/day
- System cannot recover after oxygen depletion (addition < demand)
- Similar performance between new (FL8) and old (LA30PCH) aerator

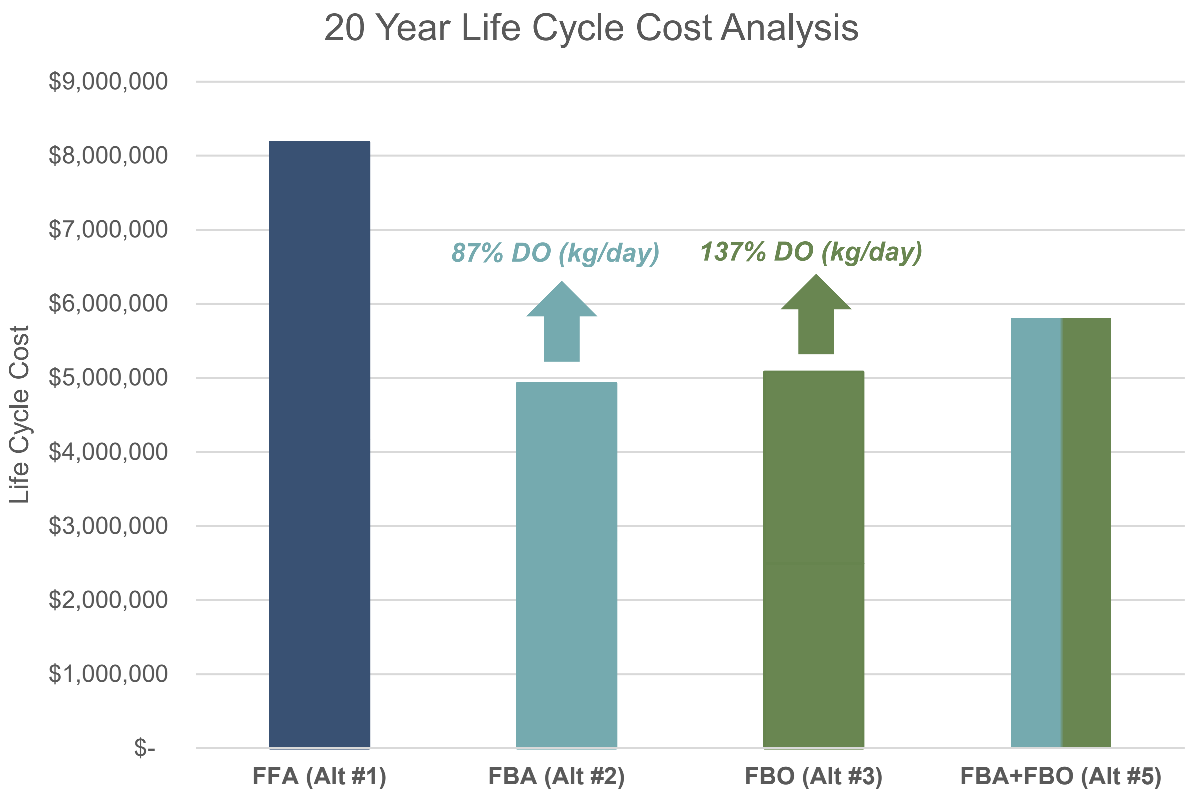
Operating below minimum performance



Life Cycle Analysis: Findings

20-Year Lifecycle Cost

Alternative	Capital Cost	O&M Cost	Total Cost
FAA	$4.2 M	$4.0 M	$8.2 M
FBA	$2.8 M	$2.1 M	$4.9 M
FBO	$2.5 M	$2.6 M	$5.1 M
FBA+FBO	$3.1 M	$2.7 M	$5.8 M



Alum Treatment

Target

Water column

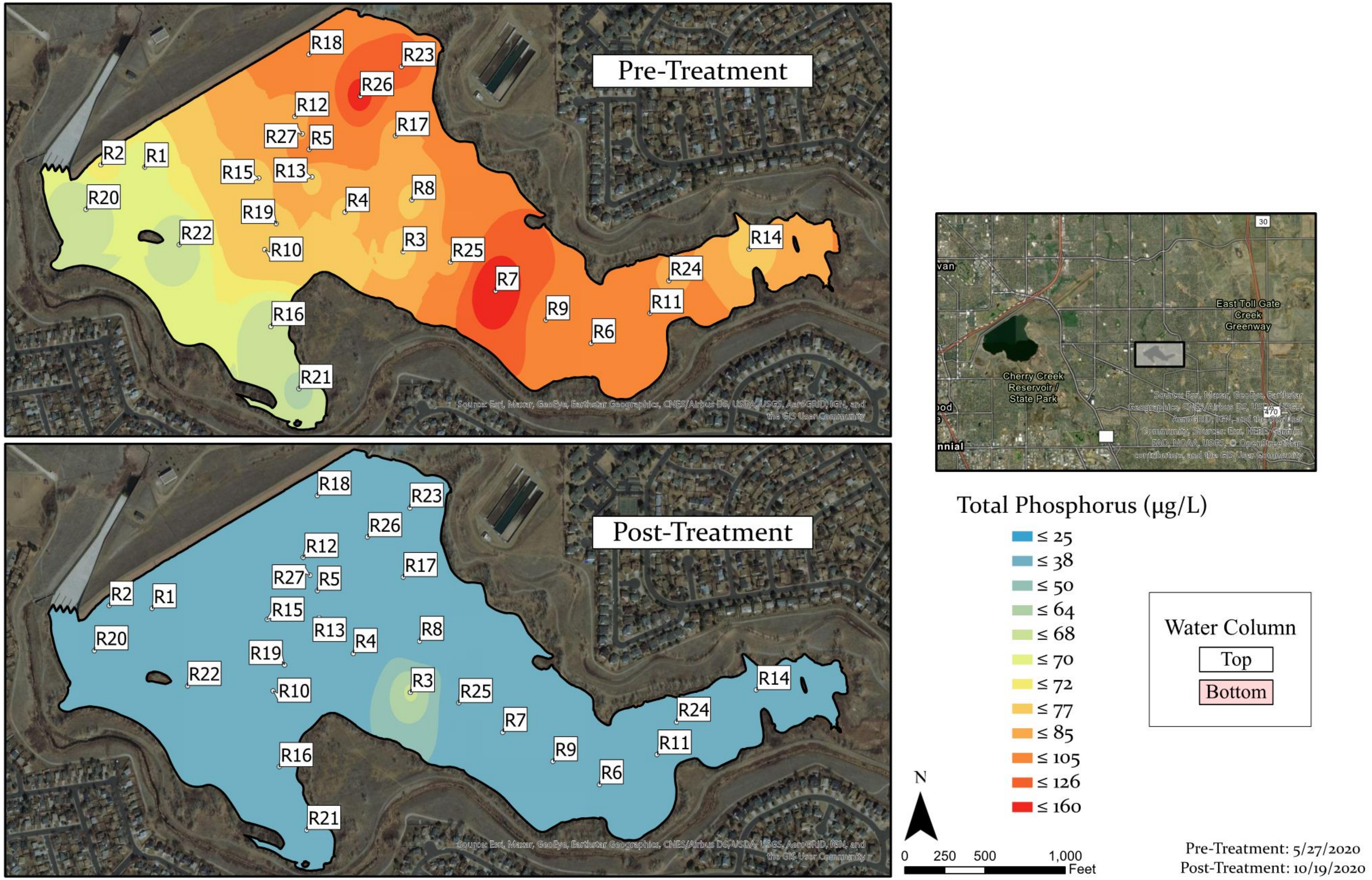
Sediment inactivation

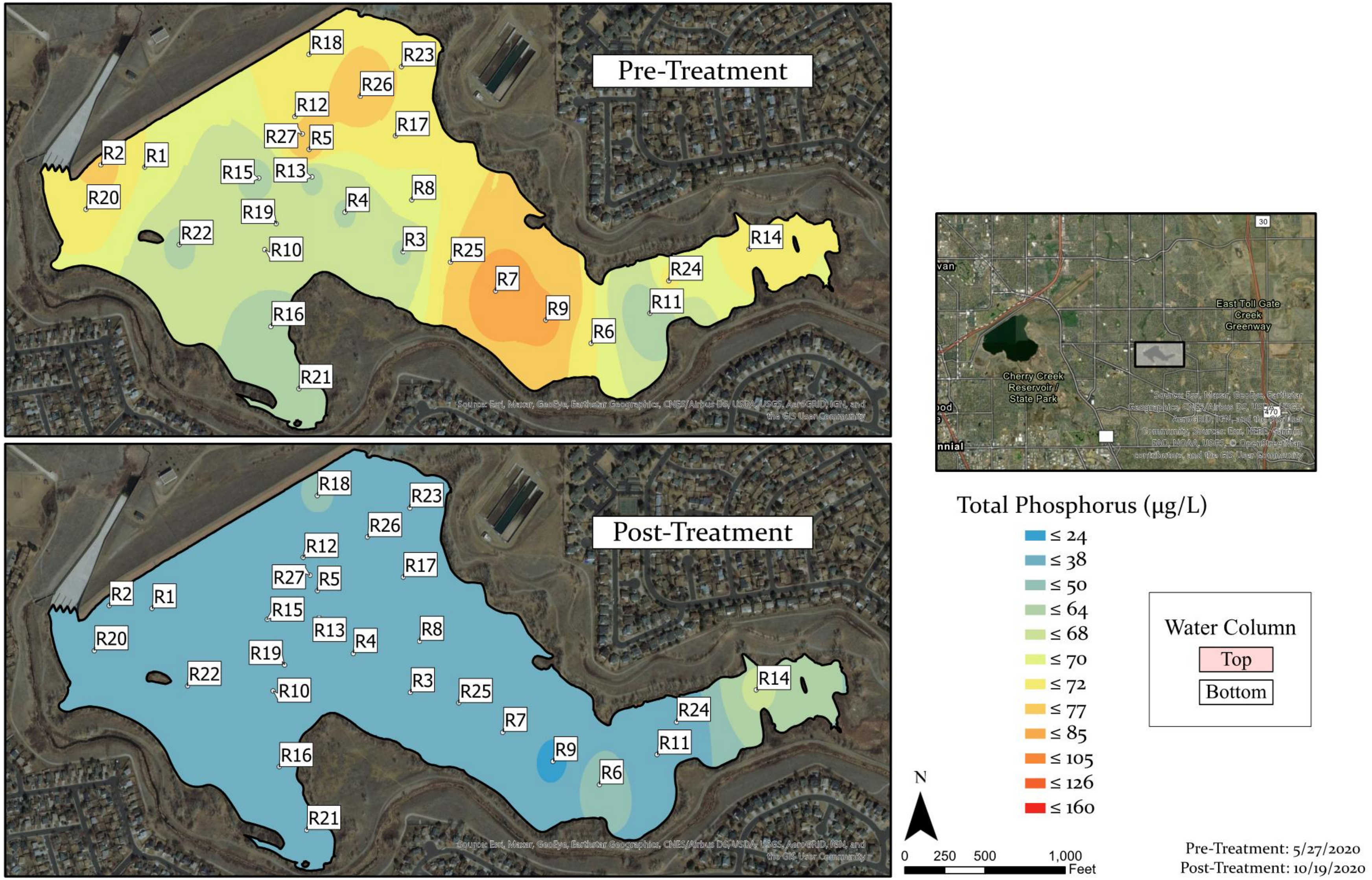
Application

Continuous feed point

Discrete application

Buffered


Pre-Treatment
R18
R23
R26
R12
R17
R27
R5
R2
R1
R15
R13
R8
R20
R4
R19
R3
R22
R10
R25
R14
R24
R7
R11
R9
R6
R16
R21
Post-Treatment
East Toll Gate Creek Greenway
Cherry Creek Reservoir / State Park
Total Phosphorus (µg/L)
≤ 25
≤ 38
≤ 50
≤ 64
≤ 68
≤ 70
≤ 72
≤ 77
≤ 85
≤ 105
≤ 126
≤ 160
Water Column
Top
Bottom
N
0 250 500 1,000 Feet
Pre-Treatment: 5/27/2020
Post-Treatment: 10/19/2020


Pre-Treatment
Post-Treatment
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 R25 R26 R27
East Toll Gate Creek Greenway
Cherry Creek Reservoir / State Park
Total Phosphorus (μg/L)
≤ 24
≤ 38
≤ 50
≤ 64
≤ 68
≤ 70
≤ 72
≤ 77
≤ 85
≤ 105
≤ 126
≤ 160
Water Column
Top
Bottom
N
0 250 500 1,000
Feet
Pre-Treatment: 5/27/2020
Post-Treatment: 10/19/2020

Alum Alternative

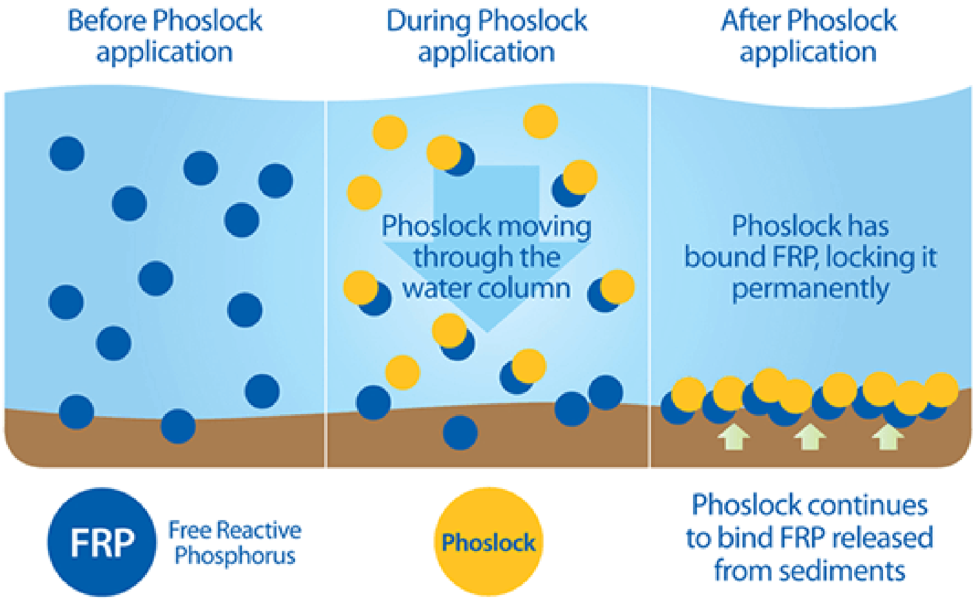
Phoslock

Lanthanum-modified bentonite clay

Similar approach

Water column

Sediment inactivation



Picture: https://www.sepro.com/aquatics/phoslock

Nutrient Removal

Biochar

Biochar + metal salt

Nutrient removal pellets

Mimic passive reactive barriers

Socks

In-reservoir

Tributaries

Picture: https://www.solitudelakemanagement.com

Phytoremediation

<u>*Littoral zone restoration*</u>

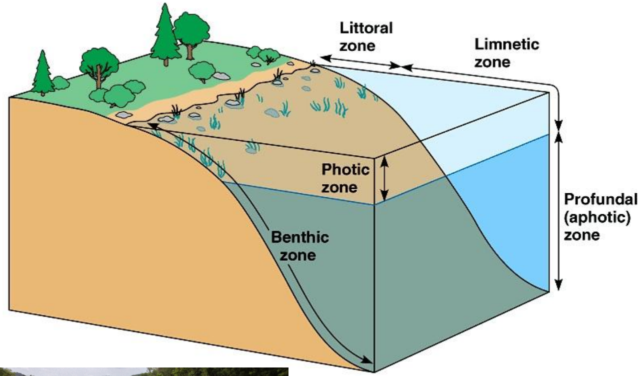
Internal buffer

Provide key habitats

Nutrient uptake and competition

Stabilize internal cycling

Regime shift



Phytoremediation

Hydroponic systems

Optimized floating wetland

Roots directly exposed in photic zone

Nutrient uptake and competition

Allelochemical release

Positive symbiotic relationship

Examples

EXAMPLE #1 - Water Quality Challenges

The Problem

1. **Frequent blooms**
   Dense population are frequently observed with visible surface scums

2. **Cyanobacteria-dominated**
   Phytoplankton comprised of Dolichospermum, Microcystis, and Limnoraphis

3. **Cyanotoxins**
   Consistent microcystin synthesis is observed

4. **Taste & Odor**
   Frequent challenges presented by MIB/geosmin

5. **Limited use**
   Biomass and T&O have limited use as DUWS and recreational closures

6. **Bypassed tributaries**
   During original construction of reservoir tributaries were bypassed but frequent overflow events

7. **Reduced influent**
   Additional stormwater management and optimized bypass to reduce overflow (~70% reduction – 12 years)

EXAMPLE #1 – Why didn’t it work?

6 Bypassed tributaries

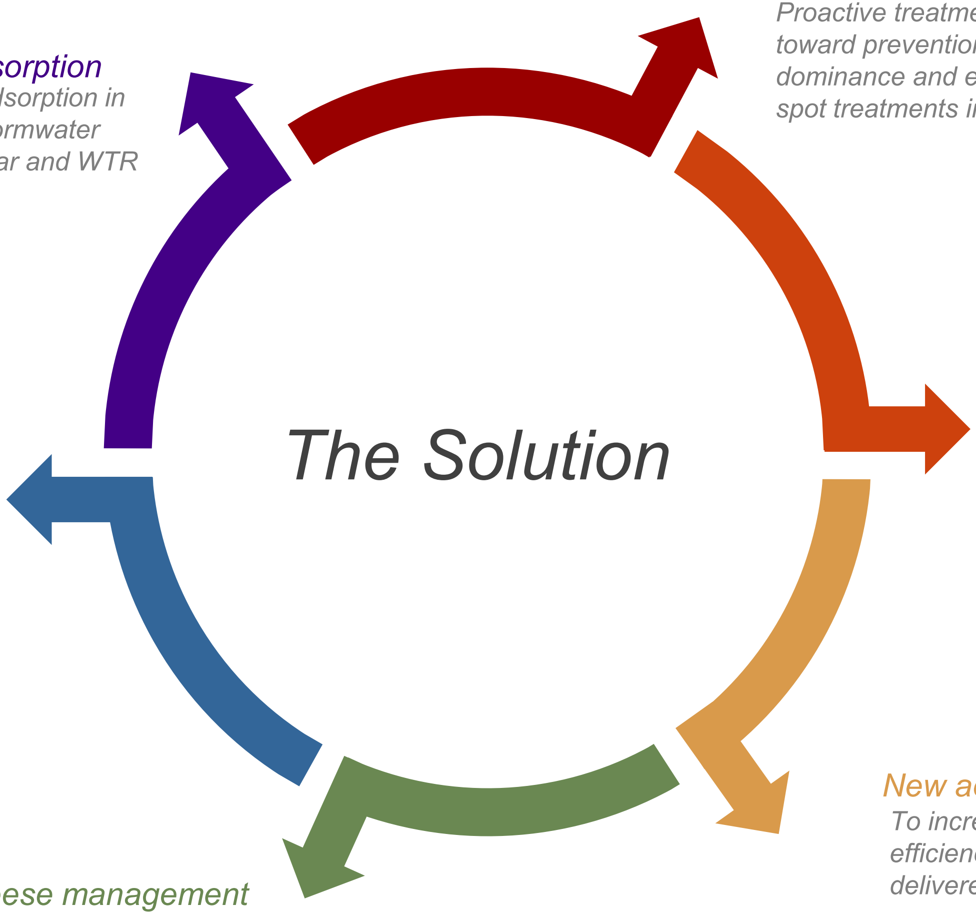
- Tributaries were bypassed during construction of reservoir
- Overflows during precipitation events
- Crucial action that slowed the rate of eutrophication and delayed degradation
- Overflow events began more frequent and larger magnitude
- Sediment accumulation
- Increase in runoff from development

7 Reduced influent

- To minimize overflow events bypass was optimized
- Implemented stormwater management
- Two retention basins by reservoir with biological treatment
- Reduced overflow events and influent nutrients by ~70%
- 12 years ago, but issues worsened
- Internal cycling and legacy nutrients

Correcting ecosystem imbalance extends past reducing influent loads

EXAMPLE #1



Nutrient Adsorption

Phosphorus adsorption in bypass and stormwater basins – biochar and WTR

Peroxide Treatments

Proactive treatment plan geared toward prevention of cyanobacteria dominance and elevated growth; spot treatments in hot spots

Alum treatment

Address internal cycling of nutrient a full reservoir sampling effort used to develop alum treatment plan (60% TP, 83% RP)

New aeration system

To increase operational efficiency as well as DO delivered

Geese management

Resident geese population management to limit input

Phytoremediation

Littoral zone restoration and hydroponic system for nutrient removal and allelopathic interaction

EXAMPLE #2 - Water Quality Challenges

The Problem

1. ***Taste & Odor***
   High concentrations of MIB/geosmin occur frequently

2. ***Benthic Cyanobacteria***
   Dominate source of T&O issues; dense and diverse population

3. ***Watershed development***
   Rapid and widespread development; silt fences are poorly maintained

4. ***Minimal stormwater management***
   Stormwater is not sufficiently managed and has not been expanded to account for development

5. ***Sediment transport***
   Excessive sediment transport as a result of development and poor stormwater management; transport terrestrial source of T&O

6. ***Aeration & Chemical feed***
   Installed aeration system equipped with ferric feed point to overcome challenged but issues persisted

7. ***Copper use limited***
   Low alkalinity, relatively low pH, and low DOC make using copper products risky

EXAMPLE #2 – Why didn't it work?

6 *Aeration & Chemical feed*

Installed an aeration system (FBP) with continuous ferric feed points

Issues persisted and no significant reduction in phosphorus or productivity

Too many outstanding issues in the watershed

Influent sediment and nutrients

Too much influent to overcome internally

Iron is a key micronutrient for cyanobacteria growth

7 *Copper Limitation*

Could not combat issues with copper

Unique water chemistry presents challenges

The alkalinity, pH, and DO are unfavorable for copper use

Heightened toxicity

High risk treatments

Fish kills were problematic

EXAMPLE #2

Benthic Monitoring

Monitoring program was expanded as it was previous tailored for phytoplanktonic

Stormwater management

Multiple retention and treatment (wetland) systems were designed (319 grant)

Watershed BMPs

Targeted BMPs were outlined for the watershed; focused on agriculturally heavy areas

Peroxide Treatments

Targeted benthic treatments to suppress reproduction and reduce T&O synthesis

Change chemical feed

Chemical feed was changed from ferric to alum; aeration system control was adjusted to T&O

Phytoremediation

Littoral zone restoration to buffer near-shore activity (heavy residential) and hydroponic systems for shallow areas

EXAMPLE #3 - Water Quality Challenges

The Problem

1. **Frequent blooms**
Dense population are frequently observed with visible surface scums

2. **Cyanobacteria dominated**
Phytoplankton comprised of Dolichospermum, Microcystis, and Planktothrix

3. **Cyanotoxins**
Consistent microcystin and saxitoxin synthesis is observed

4. **Taste & Odor**
Frequent challenges presented by MIB/geosmin

5. **Alum feed station**
Furthest upstream location of reservoir where largest tributary enters (10 year) but issues worsened

6. **Aeration & mixing**
Aeration system was installed to achieve mixing as well as DO addition; costly with no benefit

7. **Low-dose Copper**
Main barrier against cyanobacteria HABs; frequent treatments with minimal control and worsening by year

EXAMPLE #3 – Why didn't it work?

5 Alum feed station

- Continuous alum feed at upstream location where largest tributary enters
- Operational for 10 years with no benefit
- Presented additional challenges
- Location of feed station was key factor in lack of success

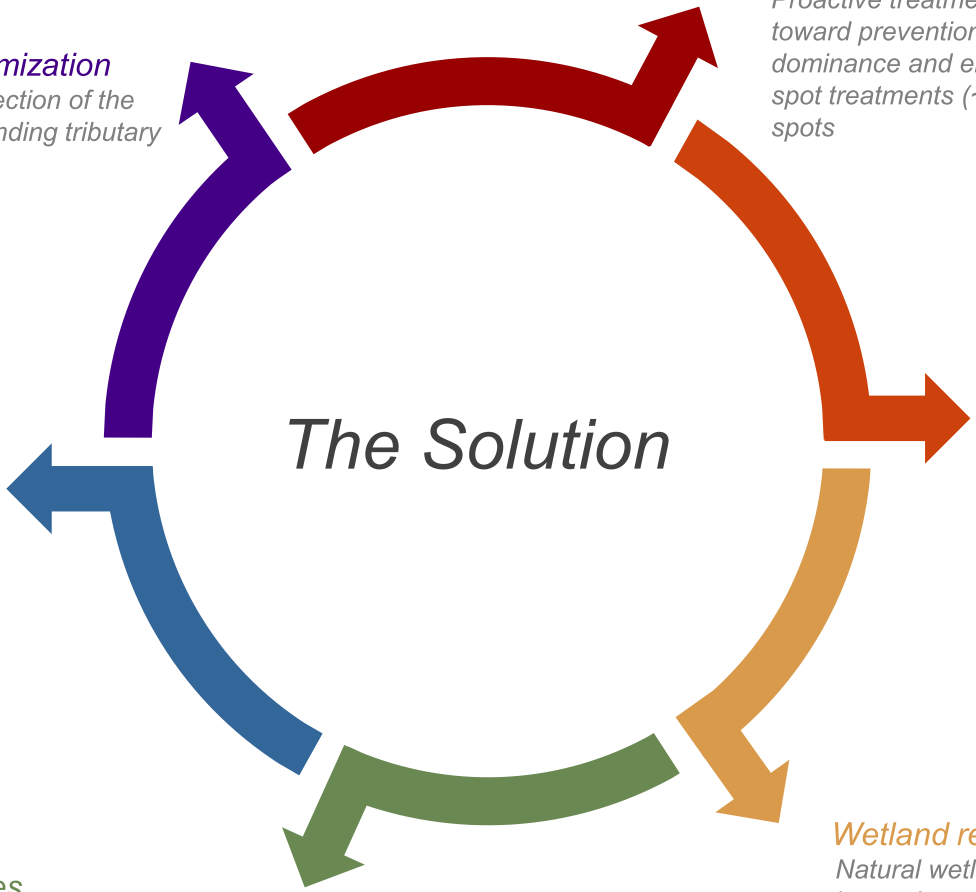
6 Aeration & Mixing

- The location of aeration system was problematic
- Costly to operated and maintain
- Minimal benefit observed

7 Low-dose copper

- Relied on to combat issues
- Treatment demand continuously increased
- 'higher' dose treatment did not meet demand and were frequently required

EXAMPLE #3



Peroxide treatments

Proactive treatment plan geared toward prevention of cyanobacteria dominance and elevated growth; spot treatments (~10 – 16% SA); hot spots

Land acquisition

Significant influent source of nutrients was identified; land was purchased for restoration

Wetland restoration

Natural wetland was restored and expanded; located upstream (primary headwaters) of tributary in agriculturally heavy area

Phos-boxes

WTR reuse to phosphorus adsorption in nutrient landed tributary; mimic PRB; baffled

Phytoremediation

Littoral zone restoration, hydroponic systems, and FTW in key locations

Hydrodynamic optimization

Stagnant area in key section of the reservoir and corresponding tributary

Key Takeaways

- *There is no silver bullet*
- *One strategy or technology will not solve the multidimensional problem*
- *Algin strategies with WQ goals and biotic characteristic*
- *Each system is unique and requires an equally unique approach and coupling of management technologies*

Comprehensive Source Water Management

Services

Source Water Monitoring Program

- *Construct multi-objective monitoring program*
- *Obtain key biological information for management*
- *In-house identification and enumeration for assessments*
- *FlowCAM calibration and library development*

Microscope (Alan)

Source Water Assessment

- *Comprehensive analysis*
- *Annual and total nutrient budget*
- *Phytoplankton composition*

Short-Term Management

- *Proactive use of hydrogen peroxide*
- *Low-powered ultrasound application*
- *Flushing and mixing (SolarBee ®)*

Long-Term Management

- *Watershed-based nutrient management*
- *Targeted BMPs (e.g. biochar, adsorption methods, WTR)*
- *In-situ phytoremediation (e.g. floating wetland, hydroponics)*
- *Aluminum addition and sediment phosphorus fractionation*
- *Oxygenation and aeration application and modeling*

NLA Gravity Corer

Thank you!

Questions?

Password: Algae