Utah Lake Water Quality Study Update

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
WATER QUALITY

Utah Lake Steering Committee
March 25, 2021

Erica Brown Gaddis, PhD
Director

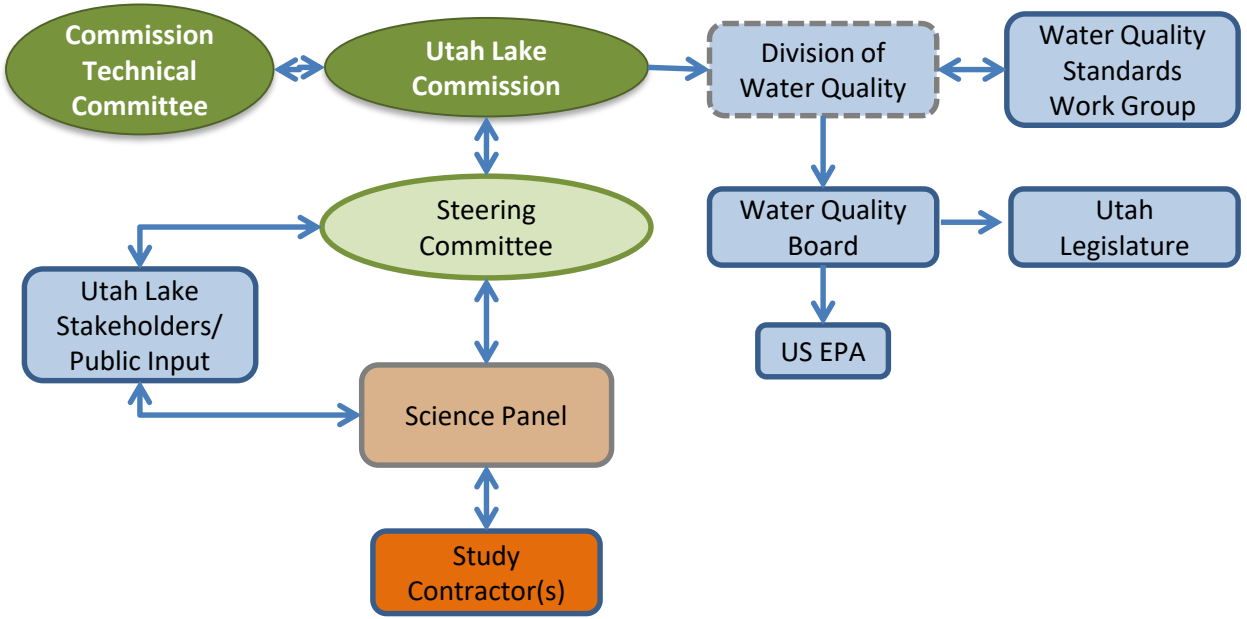
Utah Lake Water Quality Study

Goal: Develop nitrogen and phosphorus criteria that are protective of the lake's designated beneficial uses (recreation, aquatic life, and agricultural)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Phase 1 – Data gathering and characteristics																
Phase 2 – Criteria development																
Phase 3 – Implementation Planning																
Criteria and Implementation Plan Submittal to WQB and EPA																
Nonpoint Source and MS4 Implementation																
POTW Permit Implementation																

Steering Committee Charge to Science Panel

1. What was the historical condition of Utah Lake with respect to nutrients and ecology pre-settlement and along the historical timeline with consideration of trophic state shifts and significant transitions since settlement?
2. What is the current state of the lake with respect to nutrients and ecology?
3. What additional information is needed to define nutrient criteria that support existing beneficial uses?
4. Is there an improved stable state that can be reached under the constraints of current water and fishery management?



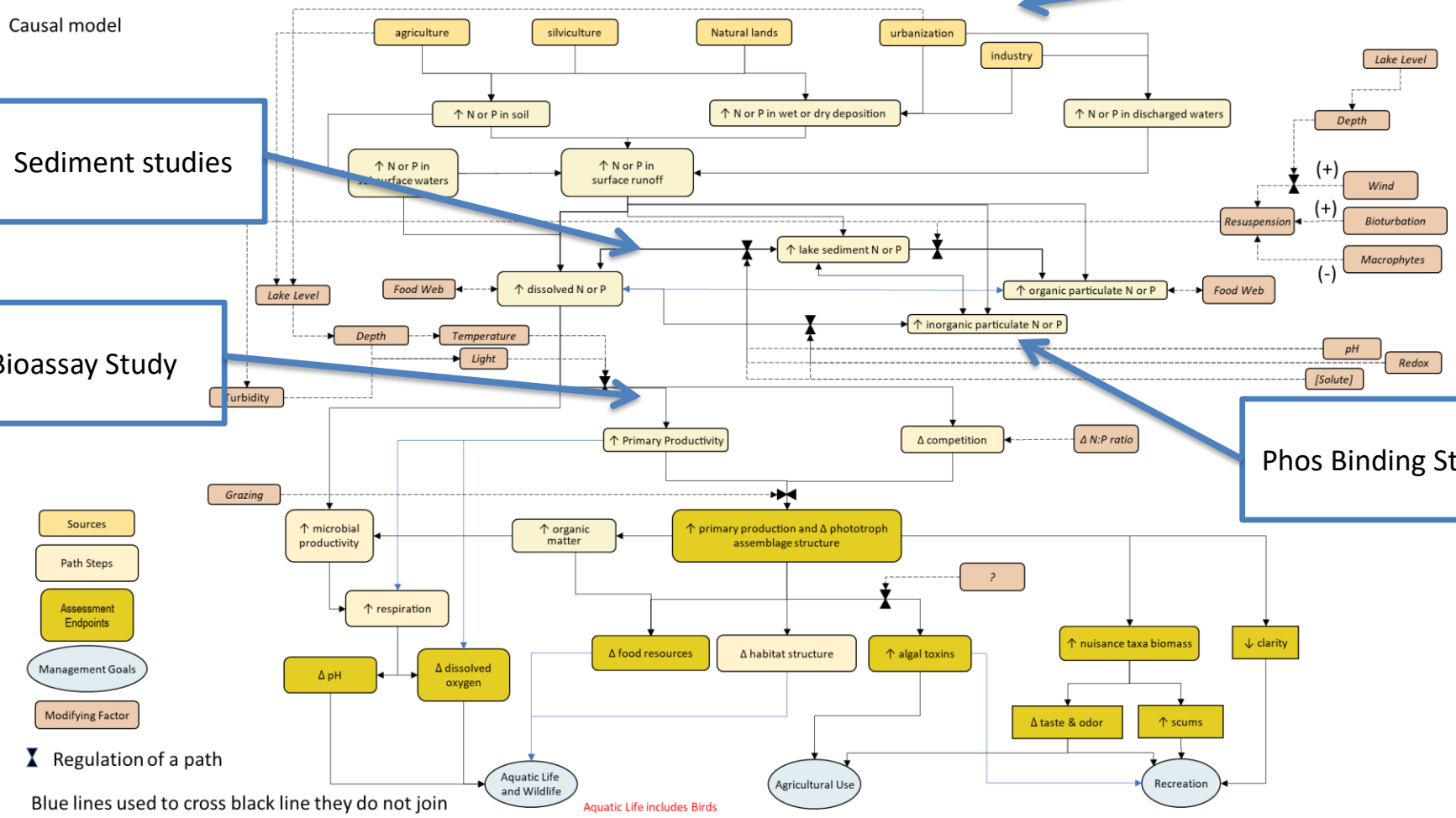
Utah Lake IS complicated!

Watershed Modeling

Sediment studies

Bioassay Study

Phos Binding Study



LEGISLATIVE GENERAL COUNSEL
₵ Approved for Filing: R.H. Rees ₵
₵ 02-24-21 7:21 AM ₵

H.B. 364
1st Sub. (Buff)

Representative Brady Brammer proposes the following substitute bill:

UTAH LAKE AUTHORITY
2021 GENERAL SESSION
STATE OF UTAH
Chief Sponsor: Brady Brammer
Senate Sponsor: _____

(3) (a) The statewide public purpose of the lake authority is to work in concert with applicable federal, state, and local government entities, property owners, owners of water rights, private parties, and stakeholders to encourage, facilitate, and implement:

(i) the rehabilitation of Utah Lake and the waters of Utah Lake; and

(ii) the management of the lake authority land to maximize the long-term viability and health of Utah Lake and to produce economic, aesthetic, recreational, and other benefits for the state, consistent with the strategies, policies, and objectives described in this chapter.

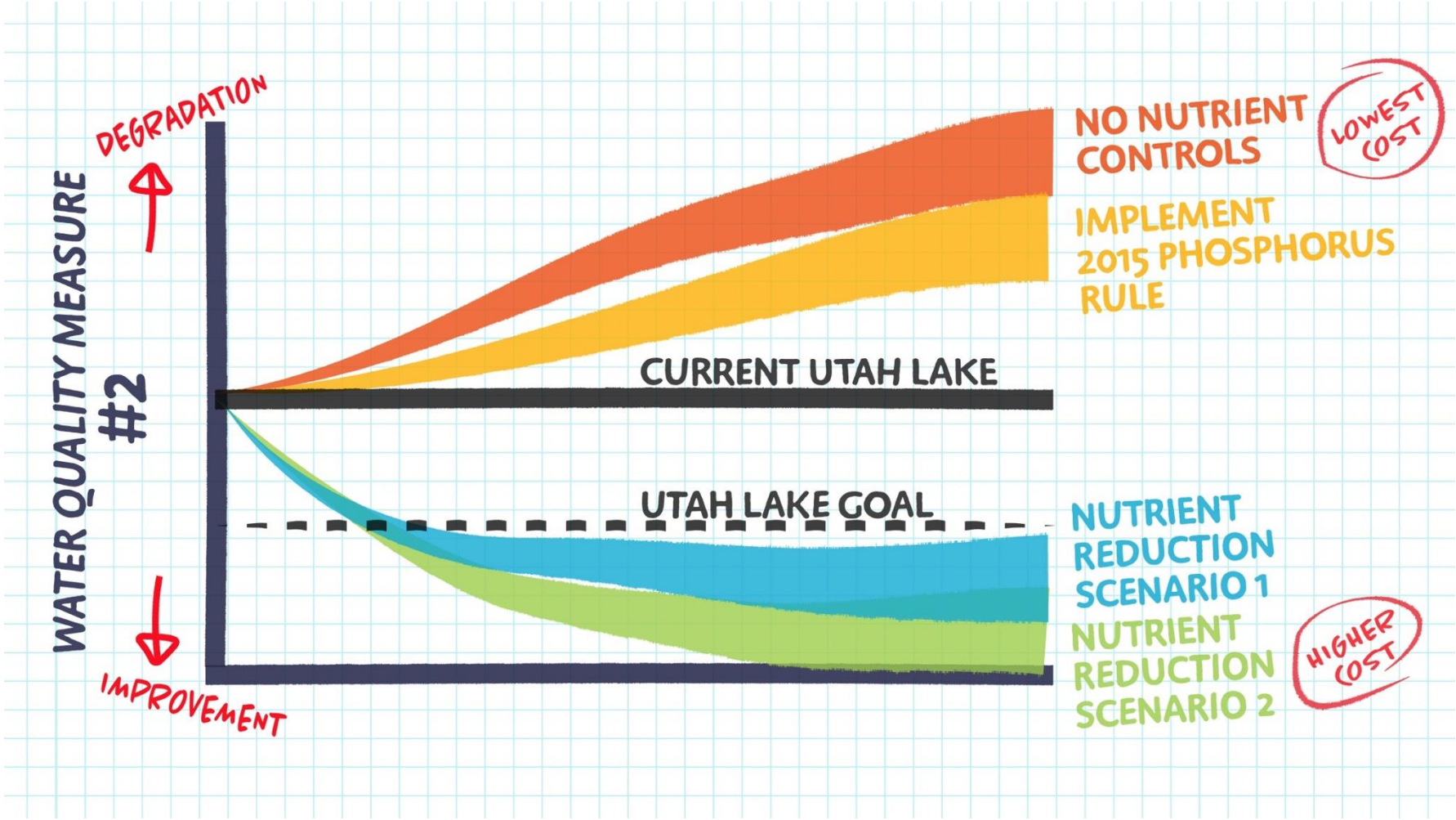
The Legislature intends that the $9.8 million one-time from the General Fund shall be used as follows: 1) $1 million for algae bloom remediation, of which $406,100 is to be used by Utah Valley University; 2) $4.4 million for Walkara Way Phase 2, the development of the trail system between the Provo Airport and Provo River Delta project, to include $850,000 for fencing, $250,000 for a maintenance/staging area, and $3.3 million for the trail system, including environmental considerations where applicable; 3) $800,000 for shoreline restoration; 4) $2.6 million for marina upgrades; 5) $1 million for invasive species remediation (animal feeding operation).

Water Quality Management Goals

Statements about the desired water quality condition for societal, economic, and ecological values of concern including recreation, aquatic life, and agricultural.

Aquatic Life	Recreation	Agricultural Water
		
Warm water fishery **Waterfowl**	**Frequent contact recreation:** **Boating, fishing, swimming, waterskiing**	**Irrigation** **Livestock watering**

Implementation Planning



UTAH DEPARTMENT OF HEALTH

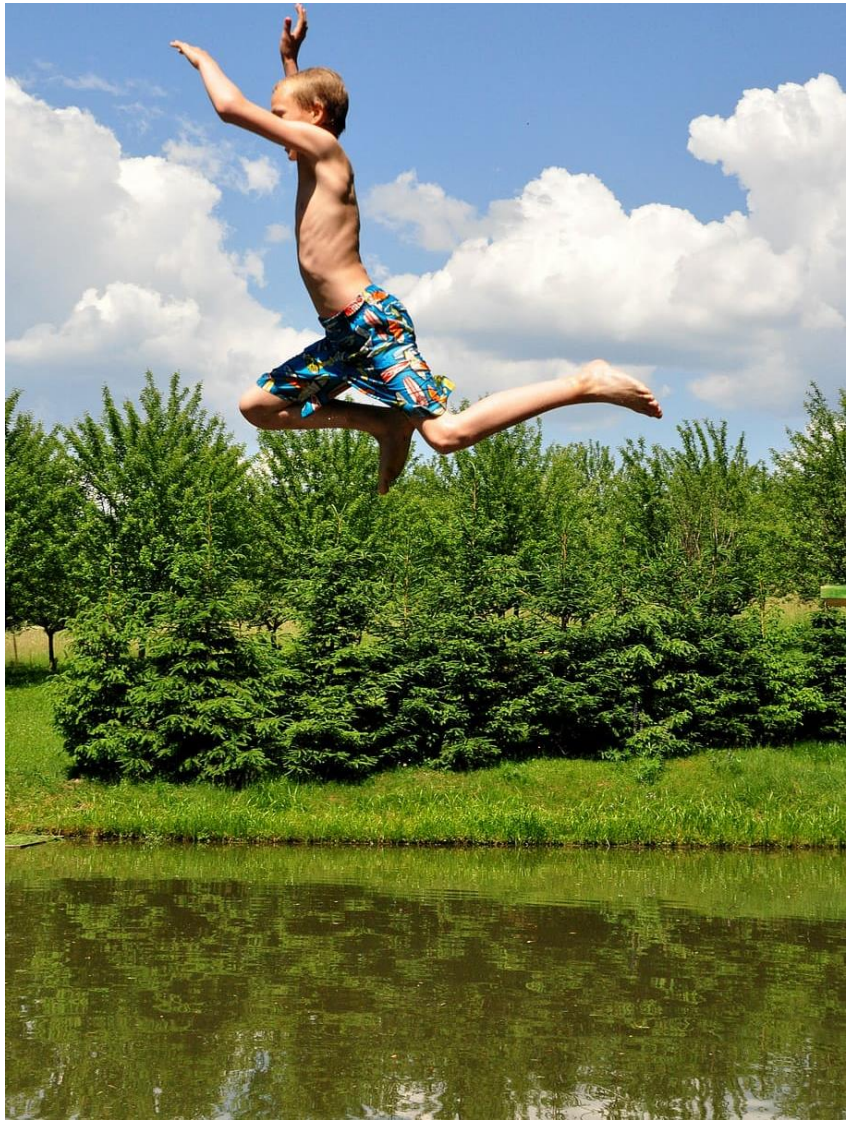
Health Effects Related to Harmful Algal Bloom Exposure

ALEJANDRA MALDONADO, PHD

TOXICOLOGIST

ENVIRONMENTAL EPIDEMIOLOGY PROGRAM

BUREAU OF EPIDEMIOLOGY



Protecting Public Health

UDOH Mission & Vision

- The Utah Department of Health's mission is to protect the public's health through preventing avoidable illness, injury, disability, and premature death; assuring access to affordable, quality health care; and promoting healthy lifestyles.
- Our vision is for Utah to be a place where *all* people can enjoy the best health possible, where *all* can live and thrive in healthy and safe communities.

Lindon Marina, Utah Lake
July 14, 2016
(Photo: Rich Egan, Salt Lake Tribune)

Cyanobacterial Blooms

- Harmful Algal Blooms (HABs) are rapid growths of cyanobacteria or blue-green algae.
- Blooms are mixtures of cyanobacteria communities
- Some cyanobacteria can produce highly potent cyanotoxins.

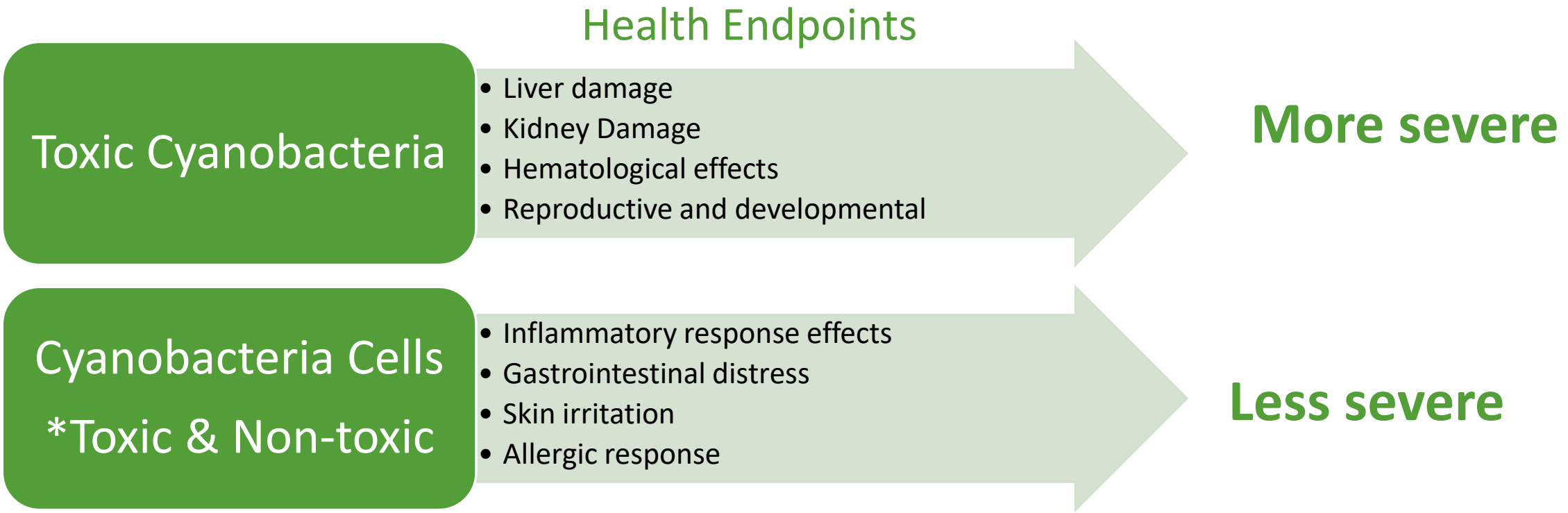
Cyanobacteria Toxicology

	Freshwater Cyanotoxins	Type of Toxin	Causative organism
*	Anatoxin-a	Neurotoxin	*Anabaena spp.* *Aphanizomenon spp.* *Planktothrix spp.*
*	Cylindrospermopsin	Hepatotoxin	*Cylindrospermopsis raciborskii,* *Aphanizomenon ovalisporum*
	Lyngbyatoxin	Dermal toxin	*Lyngbya spp.*
*	Microcystins	Hepatotoxin	*M. Aeruginosa* *Anabaena spp.* *Planktothrix spp.*
	Saxitoxins	Neurotoxins	*Anabaena circinalis* *Lyngbya wollei*

- **Toxigenic** cyanobacteria can produce multiple toxins and toxins can be produced by several different species.
- Toxins can either reside inside the cell (intracellular) or be released into the water (extracellular).
- **Main Target Organs:**
  - Liver (hepatotoxic)
  - Nervous system (neurotoxic)
  - Skin (dermatoxic)

Comparing Severity of Health Effects

Non-toxic cyanobacteria vs Toxic Cyanobacteria



Potential Exposure Pathways

Incidental Ingestion

Inhalation of aerosols

Skin contact

Exposure to Cyanobacteria and Human Health Effects

- Information about human health effects from exposure to cyanobacteria and cyanotoxins is primarily derived from studies of:
  - recreational exposures;
  - studies with laboratory animals;
  - reports of extreme human exposure events; and
  - animal exposures.

References are available at: **https://www.cdc.gov/habs/publications/html**.

Health Effects: Ingestion

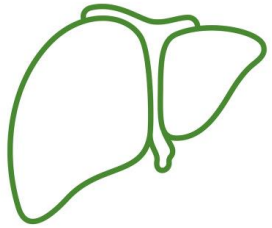
Nausea

Headache

Neurological Symptoms

Muscle Cramps

Kidney Damage



Liver Damage

Health Effects: Skin Contact

Eye Irritation

Rash

Hives

Blisters or Sores

Health Effects: Inhalation

Nose Irritation

Sore Throat

Coughing

Difficulty Breathing

Why are toxigenic cyanobacteria cell counts included in Utah HAB Advisory Guidance?

1. **Exposure to cyanobacterial cells alone, even in the absence of analyzed toxins, has adverse inflammatory health effects.**
   - Rashes
   - Respiratory and GI distress
   - Ear and eye irritation

Epidemiological Studies

Cyanobacteria Cell Densities	Health Effects Reported	Reference
> 5,000 cells/mL	Skin rashes, eye irritation, ear irritation, GI* distress, fever, respiratory symptoms	Pilotto et al. 1997

*GI = gastrointestinal
** Follow-up study of Levesque et al. 2014

Why are **toxigenic** cyanobacteria cell counts included in Utah HAB Advisory Guidance?

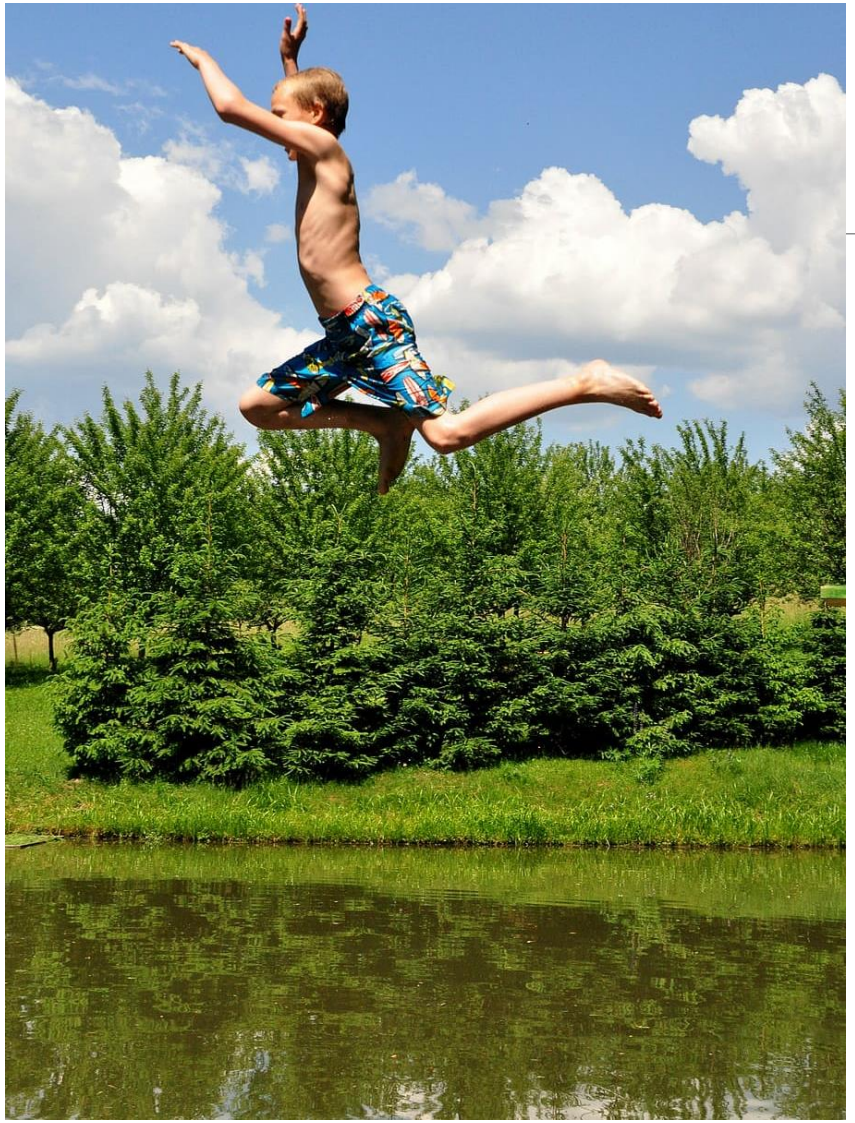
2. **Elevated cell counts are currently the most important early and integrative indicator for local health departments (LHD's) to act appropriately to warn the public about a public health threat.**

Protecting Vulnerable Populations

Children may be more likely to become ill:

- Drink more water in recreational settings.
- May be in the water longer.
- Have more skin exposure.
- Smaller size → larger doses compared to adults.

August 30, 2019
Starvation Reservoir
Image from UDEQ



Protecting Public Health

UDOH Mission & Vision

- The use of **toxigenic** cell counts in addition to toxin levels helps to ensure that UDOH is meeting our mission and vision in protecting public health.

Summary

- People can become ill from cyanobacteria or their toxins through ingestion, direct skin contact, or inhalation.
- Children may be more vulnerable to cyanobacteria and cyanotoxins.
- Exposure to cyanobacteria cells in ambient waters is associated with numerous inflammatory health endpoints.
- Toxigenic cyanobacteria cell counts can be an indicator of the potential of a bloom to produce cyanotoxins.
- The use of toxic cell counts in addition to toxin data provides an integrative approach to protecting public health from exposures to HABs.

Contact

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Utah Department of Health

Toxigenic Cell Count Densities in Utah DWQ/DOH Recreational HAB Advisory Program

Kate Fickas, PhD
Recreational Water Quality Health Program Coordinator
Utah Division of Water Quality
Department of Environmental Quality

ENVIRONMENTAL QUALITY
WATER QUALITY

Goals of DWQ HABs Advisory Program

Identify and quantify toxic cyanobacteria blooms in the state of Utah to protect public health in recreational waterbodies

- Prioritize waterbodies
- Collect and summarize data
- Coordinate analysis
- Make action and advisory recommendations to local health departments
- Communicate emerging science and information to all stakeholders

Recreation Season Advisory Process

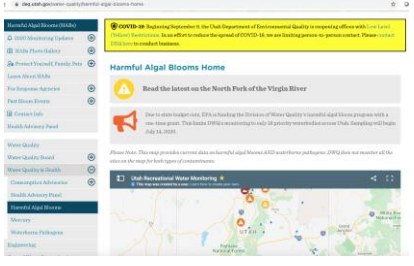
Detection

Advisory

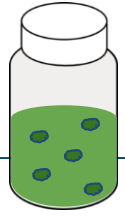
HAB Advisory Program

Testing

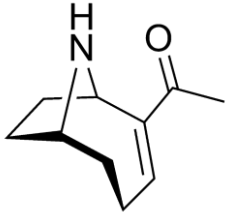
Communication



Monitoring

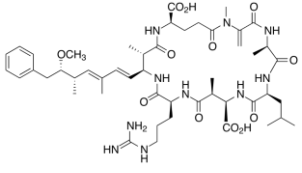


Cyanotoxins - ELISA & LCMS Analysis



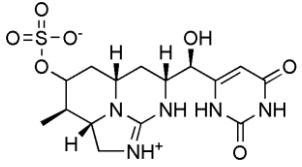
Anatoxin-a

- Neurotoxin
- Also known as Very Fast Death Factor (VFDF)
- Produced by many cyanobacteria species, including those found in Utah waterbodies



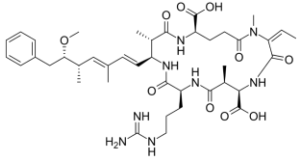
Microcystin

- Hepatotoxin
- Produced by many cyanobacteria species, including those found in Utah waterbodies



Cylindrospermopsin

- Hepatotoxin
- Nephrotoxin
- Produced by many cyanobacteria species, including those found in Utah waterbodies



Nodularin

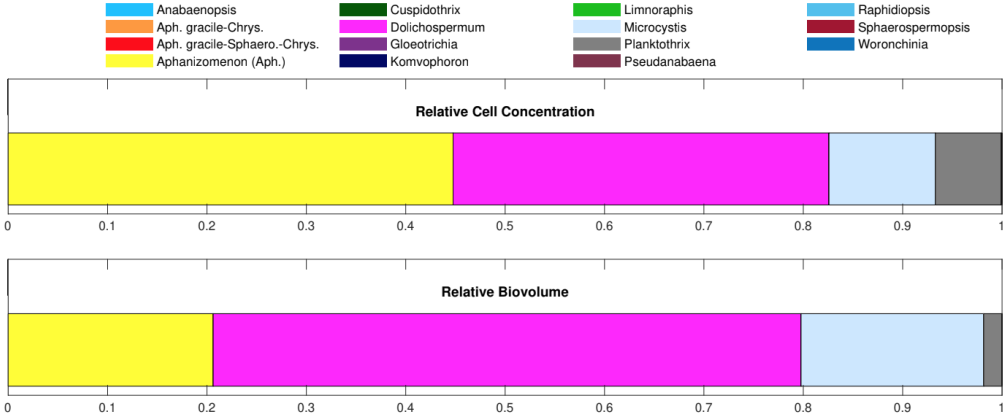
- Hepatotoxin
- Very similar to microcystin
- **Not** produced by many cyanobacteria species rarely found in Utah waterbodies***

Toxigenic Cell Density and Taxonomy

Sample ID: D20201002T192643
Customer ID: 336
Tracking Code: 200228-336
Sample Info: UTA-7-093020-C

System: Utah Lake
Site: UTA-7-093020-C
Station: 4917708
Level: Composite

Date Sampled: 9/30/2020
Date Received: 10/1/2020
Date Analyzed: 10/2/2020



Total Algal Concentration: 582928 cells/mL
HAB Concentration: 561280 cells/mL
HAB Relative Concentration: 96%

Total Biovolume: 175532625 um^3/mL
HAB Biovolume: 158258837 um^3/mL
HAB Relative Biovolume: 90%

! WARNING !

HAB concentration is high - Toxin testing recommended.

2020 Guidance

- Developed collaboratively with Utah Department of Health
- Benchmarked with EPA guidance and other States
- Not inclusive of all cyanotoxins
  - Not all toxins have been researched enough for developing guidance
  - UDOH/DWQ treats “new” cyanotoxins as binary presence/absence
- Only local health departments and UDOH have authority to issue public advisory
  - DWQ only makes recommendation

Health Watch		Warning Advisory	Danger Advisory
This is not a formal advisory level. Rather, these are indicators that a bloom may exist or may become more severe. Increased monitoring and surveillance are strongly recommended. Indicators may include: • Visual reports • Reports of animal or human illness • Detection of cyanotoxins or toxigenic cyannobacterial cell density below thresholds • Detectable levels should be defined using appropriate QA/QC procedures Consider cautioning users of the waterbody depending on specifics of the event and waterbody.	**Toxigenic Cyanobacterial Cell Density (cells/mL)** [1, 2, 3]	100,000 [A]	10,000,000
	Microcystins (µg/L) [1, 2]	8	2,000
	Cylindrospermopsin (µg/L) [3]	15 [B]	
	Anatoxin-a (µg/L) [3, 4, 5]	15	90
	Health Risks [1, 2, 3]	Potential for long-term illness Short-term effects (e.g., skin and eye irritation, nausea, vomiting, diarrhea)	Potential for acute poisoning Potential for long-term illness Short-term effects (e.g., skin and eye irritation, nausea, vomiting, diarrhea)
	Recommended Actions	Issue **WARNING** advisory to avoid primary contact recreation Post **WARNING** signs Sampling recommended at least weekly	Issue **DANGER** advisory to stay away from the waterbody Post **DANGER** signs Consider **CLOSURE** Sampling recommended at least weekly

[1] WHO, 1999. Toxic cyanobacteria in water.
[2] WHO, 2003. Guidelines for safe recreational water environments, Volume 1, Chapter 8: Algae and cyanobacteria in fresh water.
[3] EPA, 2019. Recommended human health recreational ambient water quality criteria or swimming advisories for microcystins and cylindrospermopsin.
[4] OHA, 2019. Oregon Health Authority. Recreational use public advisory guidelines: cyanobacterial blooms in freshwater bodies.
[5] CWQMC, 2016. California Water Quality Monitoring Council. Cyanobacteria guidance for recreational and related water uses (2016 update).
[A] Human symptoms have been reported between 5,000 – 100,000 cells ml (EPA 2019). At 5,000 – 100,000 cells/mL, LHDs should take into account contextual information and consider issuing an advisory.
[B] Data are sparse on where cylindrospermopsin advisory break points should be. Consult with UDEQ and UDOH as needed on this issue.

2020 Advisory Threshold Changes

Parameter	2019	2020	Benchmarks	
Microcystin	4 ug/L	8 ug/L	2019 EPA Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin	
Cylindrospermopsin	8 ug/L	15 ug/L	2019 EPA Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin	
Anatoxin-a	>0.0 ug/L	15 ug/L	2019 EPA Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin	State of Oregon
Toxigenic Cyanobacteria Cell Density	20,000 cells/mL	100,000 cells/mL	2019 EPA Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin	World Health Organization, 2003. Guidelines for safe recreational water environments, Volume 1, Chapter 8: Algae and cyanobacteria in freshwater.

Why are toxigenic cyanobacteria cell counts included in the Utah HAB advisory guidance?

Why are toxigenic cyanobacteria cell counts included in the Utah HAB advisory guidance?

1. Exposure to cyanobacteria cells alone, even in the absence of analyzed toxins, has adverse inflammatory health effects.

- *"Various health studies, described in more detail in Appendix D, relate recreational exposure to increasing densities of cyanobacterial cells with increased incidence of specific health endpoints that can be described as acute inflammatory or allergenic reactions."*

Why are toxigenic cyanobacteria cell counts included in the Utah HAB advisory guidance?

2. Toxigenic cyanobacteria cell counts provide a proxy measure of cyanotoxins, both those that are measurable and those that are not currently suitable for analysis.

- *"Although there can be large variation in the number of toxigenic cyanobacteria present relative to non- toxigenic cyanobacteria in any given body of water, measures of the total cyanobacterial biomass, such as cell counts, chlorophyll, or even visual assessments, can be used effectively in decision-making as early warnings of potential HAB-associated hazards (Loftin et al. 2016b). Pacheco et al. (2016) stated that these measurements can be good indicators of the potential risk of cyanotoxin exposure and useful when access to more sophisticated approaches, resources, or expertise may be limiting. Measurements of total cyanobacteria may also be particularly useful in waters with a history of HAB occurrence and the presence of elevated cyanotoxins."*

Why are toxigenic cyanobacteria cell counts included in the Utah HAB advisory guidance?

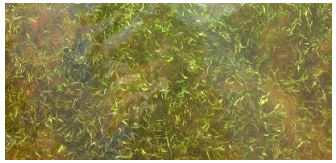
2. Toxigenic cyanobacteria cell counts provide a proxy measure of cyanotoxins, both those that are measurable and those that are not currently suitable for analysis.

- With existing resources, DWQ staff can visit affected waterbodies weekly at best
  - Cyanobacteria and associated toxins are variable and episodic over the course of a day, becoming elevated quickly.
  - Elevated cell counts are currently the most important early and integrative indicator for Local Health Departments (LHDs) to act appropriately to warn the public about a public health threat.
- Several cyanotoxins such as anatoxin-a/s, lyngbyatoxins, lipopolysaccharides, and anabaenopeptins
  - Not currently suitable for routine laboratory analysis.
  - In the absence of a reliable laboratory measure for these emerging toxins, toxigenic cyanobacteria cell counts provide a proxy to the potential for their presence and associated health effects.

Why are toxigenic cyanobacteria cell counts included in the Utah HAB advisory guidance?

3. Through implementation of the Utah HAB Recreational Advisory program, UDOH/UDWQ has learned that it is much easier to communicate quantitative measures (cells/ml) of a bloom to LHDs and the public rather than describe a visible surface scum, which many states rely upon as an indicator to recommend swimming advisories.

- *"Decision points contingent on visually confirmed blooms may miss or delay the identification of the hazardous condition associated with exposure to elevated cyanotoxins, especially in water bodies with a previous history of HAB events or toxin detections and the downstream waters potentially affected by the HAB."*



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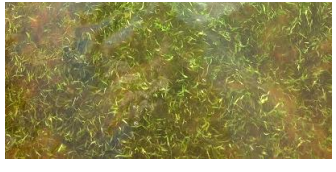
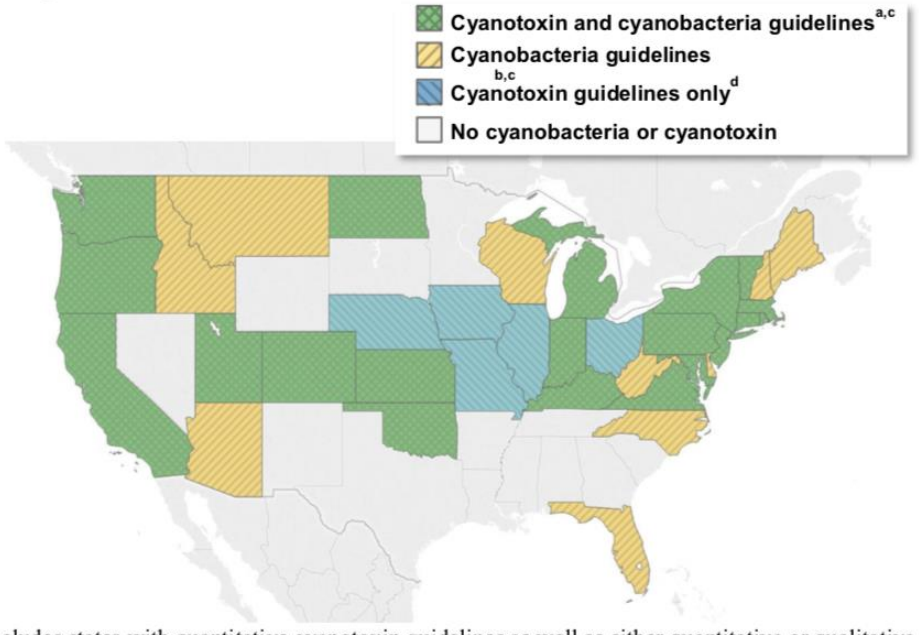
3. Through implementation of the Utah HAB Recreational Advisory program, UDOH/UDWQ has learned that it is much easier to communicate quantitative measures (cells/ml) of a bloom to LHDs and the public rather than describe a visible surface scum, which many states rely upon as an indicator to recommend swimming advisories.

- “150,000 cells/mL were observed in the water column”
  vs
- “It looks really green and scummy”



Are other states using cell counts in their advisory guidance?

Are other states using cell counts in their advisory guidance?



[a] Includes states with quantitative cyanotoxin guidelines as well as either quantitative or qualitative cyanobacteria guidelines.

[b] Includes states that either have quantitative cyanobacteria guidelines only or qualitative guidelines only.

[c] The EPA found that Texas and North Carolina published guidelines in the past, but the guidelines were no longer on their websites.

[d] Missouri has presence/absence testing for cyanotoxins and quantitative thresholds.

Utah advisories, cell counts, and toxins

Utah advisories, cell counts, and toxins

- From 2017 to 2019, there were **62 HAB advisories** issued by LHDs across Utah.
  - Of those, **only 4 advisories (6%)** occurred where cyanotoxins did not preceed, accompany concurrently, or follow elevated cyanobacteria cell counts.
- Utah Lake specifically has never had a recreational season in this time period in which cyanotoxins did not preceed, accompany concurrently, or follow elevated cyanobacteria cell counts.

Recreational Ambient Water Quality Criteria and/or Swimming Advisories (AWQC/SA) for Cyanotoxins

John Ravenscroft

Office of Water, Office of Science and Technology

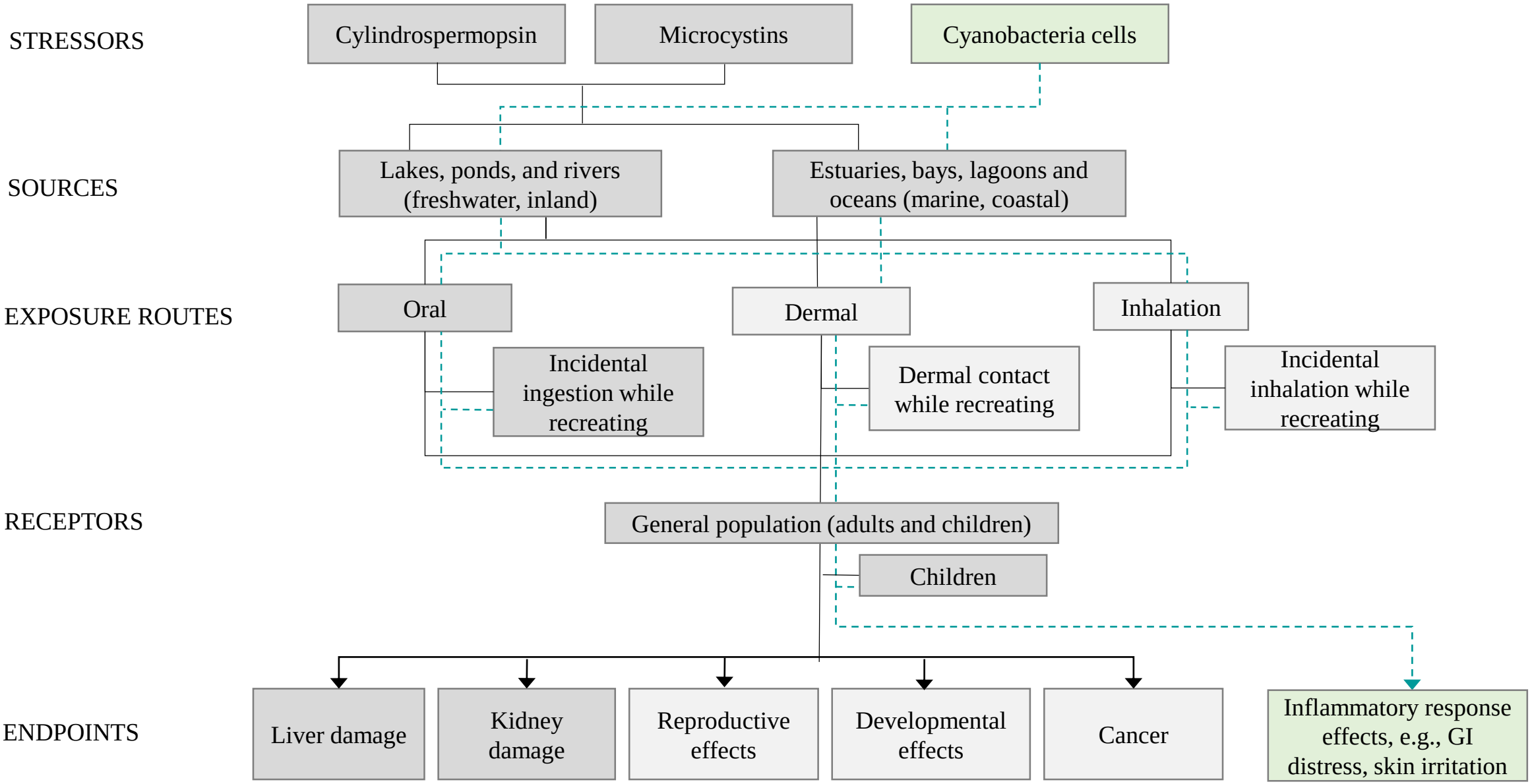
Development of AWQC/SA and Stakeholder Engagement

- EPA initiated development of values that reflect the latest science to protect the primary contact recreational use.
- EPA worked with a variety of stakeholders in the development of the document.
- Used as either §304(a) recreational criteria or as swimming advisories, or both.
  - Adopted as WQS and approved by EPA under §303(c) and used for CWA purposes.
  - Use as basis for swimming advisories for notification purposes.

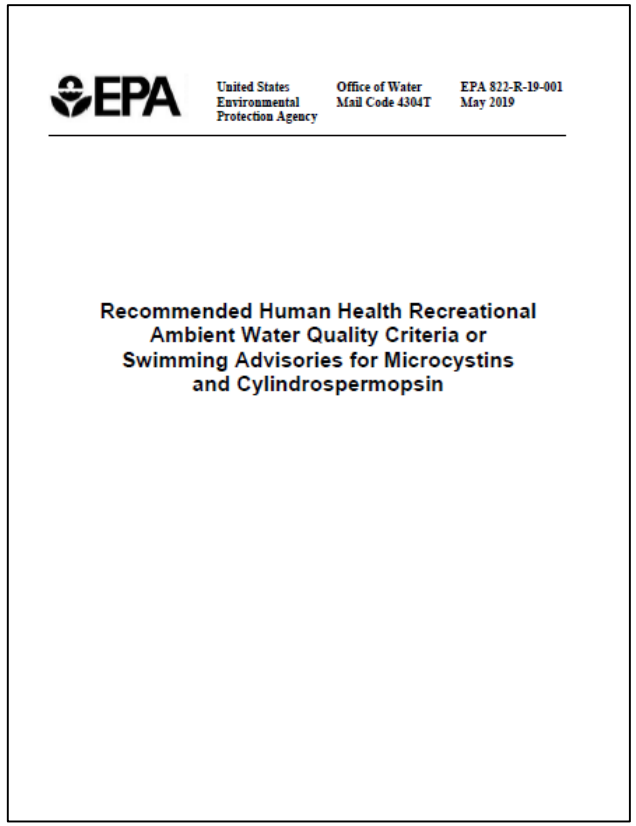
Development Approach

- Used peer-reviewed information to develop recommended values for microcystins and cylindrospermopsin.
- Used Agency-recommended recreational exposure values in a scenario which includes immersion and incidental ingestion of ambient water.
- Evaluated science describing health effects from exposure to cyanobacteria cells.

Conceptual Model of Cyanotoxin and Cyanobacteria Exposure Pathways While Recreating



EPA's FINAL Recommended Recreational AWQC/SA


EPA United States Environmental Protection Agency | Office of Water Mail Code 4304T | EPA 822-R-19-001 May 2019

Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin

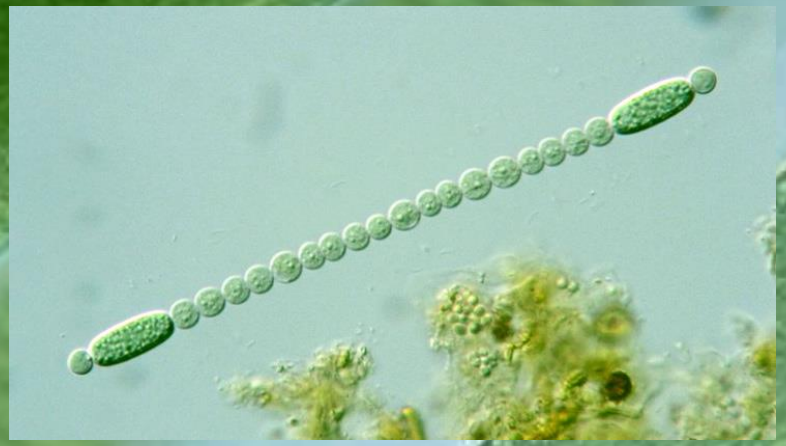
Application of Recommended Values	Microcystins			Cylindrospermopsin		
	Magnitude (µg/L)	Duration	Frequency	Magnitude (µg/L)	Duration	Frequency
Recreational Water Quality Criteria	8	1 in 10-day assessment period across a recreational season	More than 3 excursions in a recreational season, not to be exceeded in more than one year	15	1 in 10-day assessment period across a recreational season	More than 3 excursions in a recreational season, not to be exceeded in more than one year
Swimming Advisory		One day	Not to be exceeded		One day	Not to be exceeded

https://www.epa.gov/wqc/recommended-human-health-recreational-ambient-water-quality-criteria-or-swimming-advisories

Cyanobacterial Cells Characterization

- Many states indicated they use cell density to manage water quality and were interested in information characterizing the inflammatory effects resulting from exposure to cells
- EPA provided a summary of available information on health effects associated with cyanobacterial cells but did not derive criteria associated with cell density due to data uncertainties. It includes:
  - tables of cell density guidelines used by states, countries and international organizations,
  - information available demonstrating a link between total cyanobacterial cell exposure and inflammatory illness,
  - a toxigenic microcystin-producing cell density of 40,000 cells/mL based on the recommended AWQC/SA for microcystins

Contact Information:



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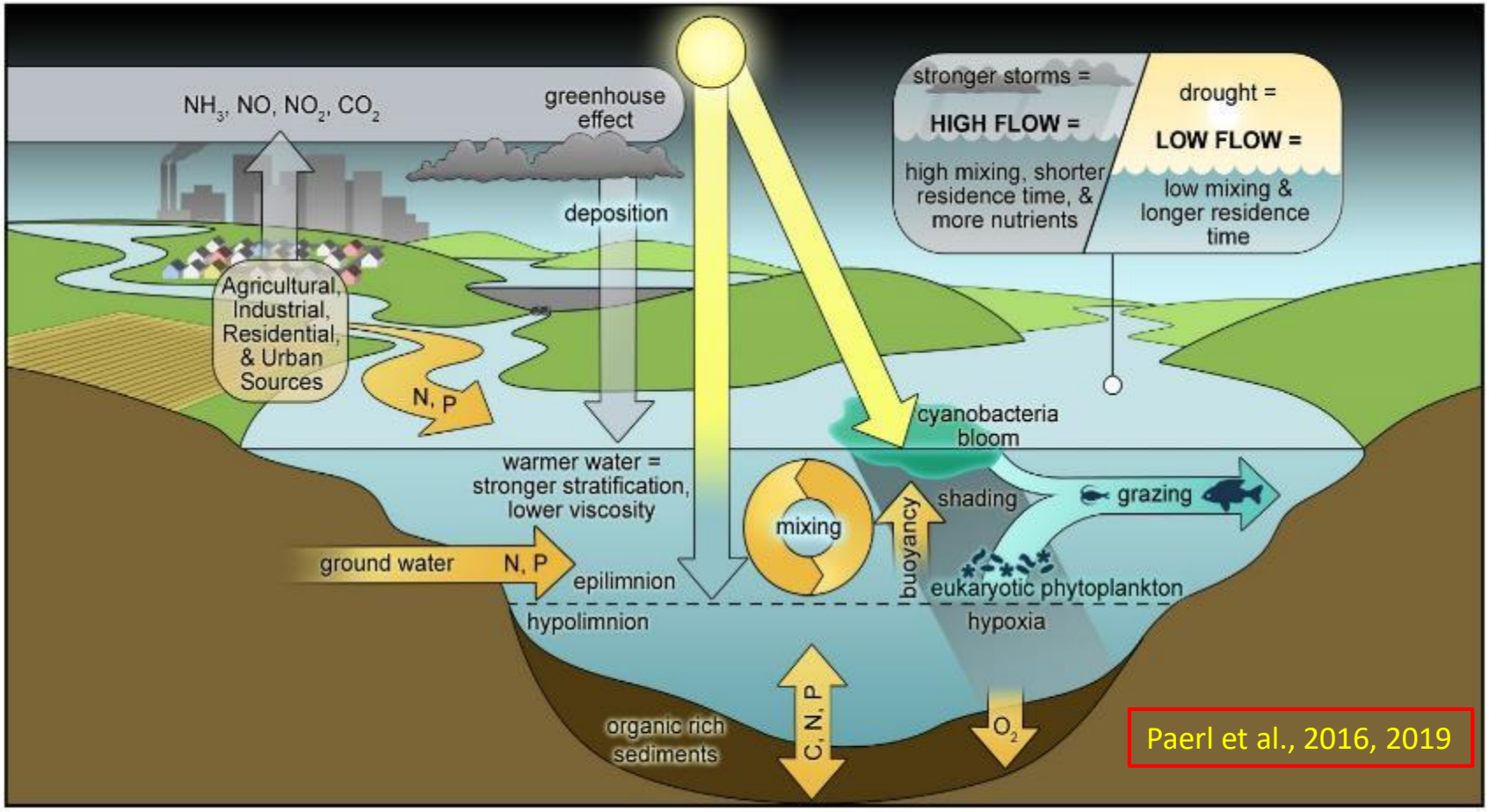
EPA's CyanoHABs Website

www.epa.gov/cyanohabs

What drives CyanoHABs? Interactive physical, chemical and biotic factors

The nutrient (N and P) "knob" is the most feasible one to "tweek"



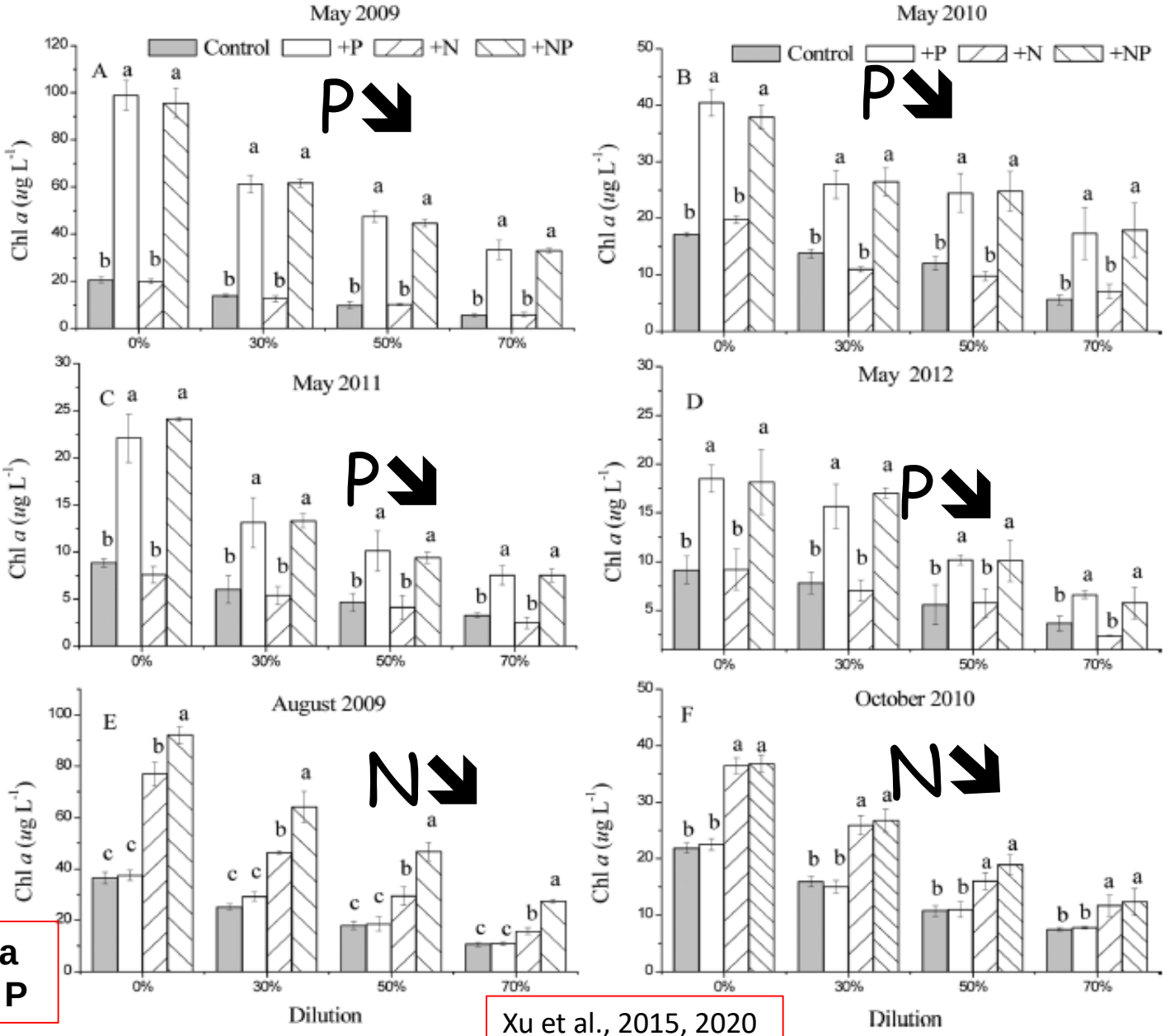
Scientific Consensus on HABs in Utah Lake

- Increased nutrient pollution promotes development and persistence of harmful algal blooms (mostly cyanobacteria)
- Large HABs require external sources of nutrients to be sustained
- Reduction of nutrient inputs from watershed sources can significantly reduce HAB frequency and magnitude
- Important to distinguish CyanoHABs from non-harmful algal taxa (i.e. I.D. and counts)
- Conditions for blooms: Nutrients, warm temperatures, good light, and low wind speed (stagnant conditions)

Heisler et al., 2008. Eutrophication and harmful algal blooms: A scientific consensus. Harmful Algae 8:3-13

Paerl et al., 2016. Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. Harmful Algae 54:213-222.

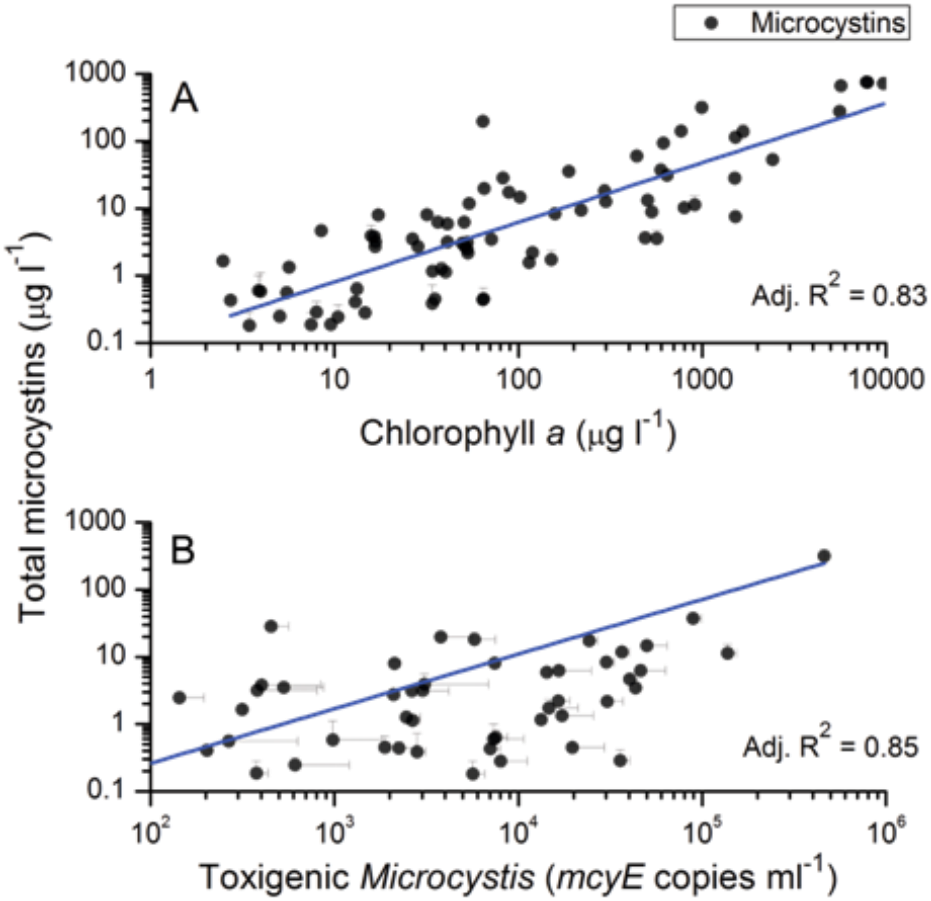
How much to reduce nutrient inputs?
Using Nutrient Dilution Bioassays to set N & P reduction targets for CyanoHAB control

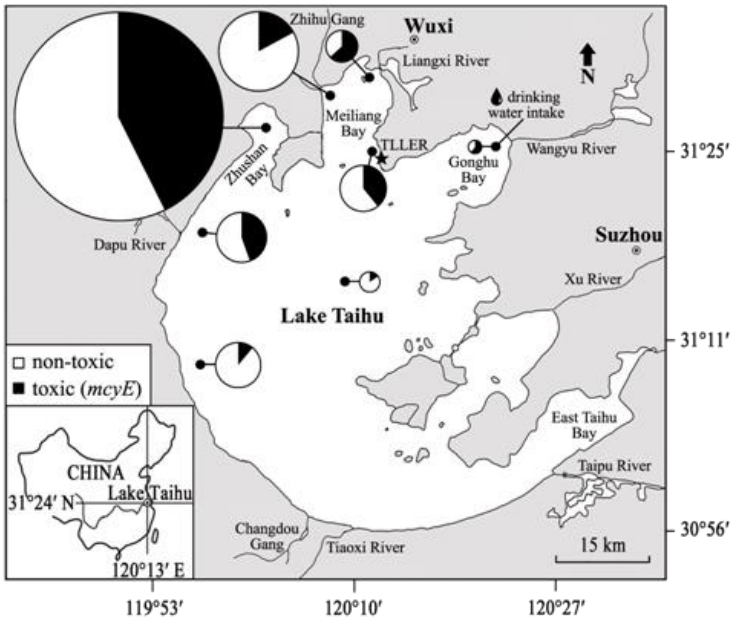


For Lake Taihu, China
>30% for both N and P

Xu et al., 2015, 2020

CyanoHAB Toxicity
Related to nutrient inputs and biomass
Chlorophyll a is a sensitive, relevant and easy to use indicator

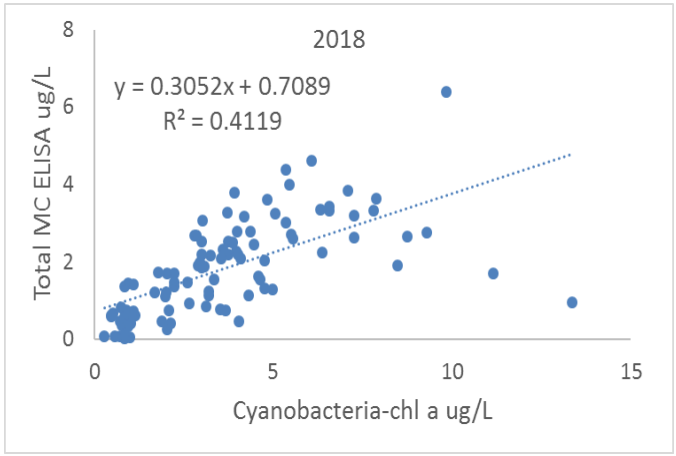


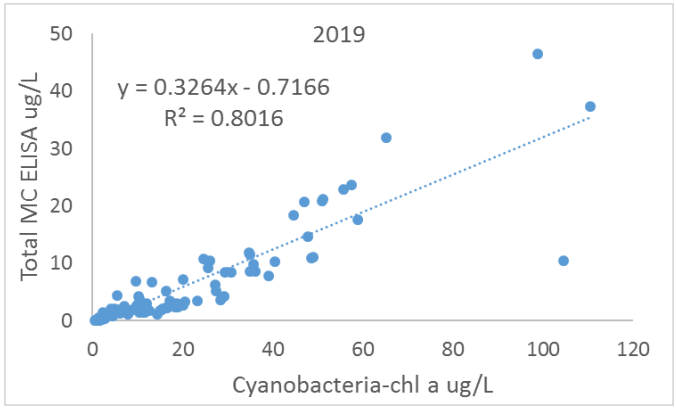


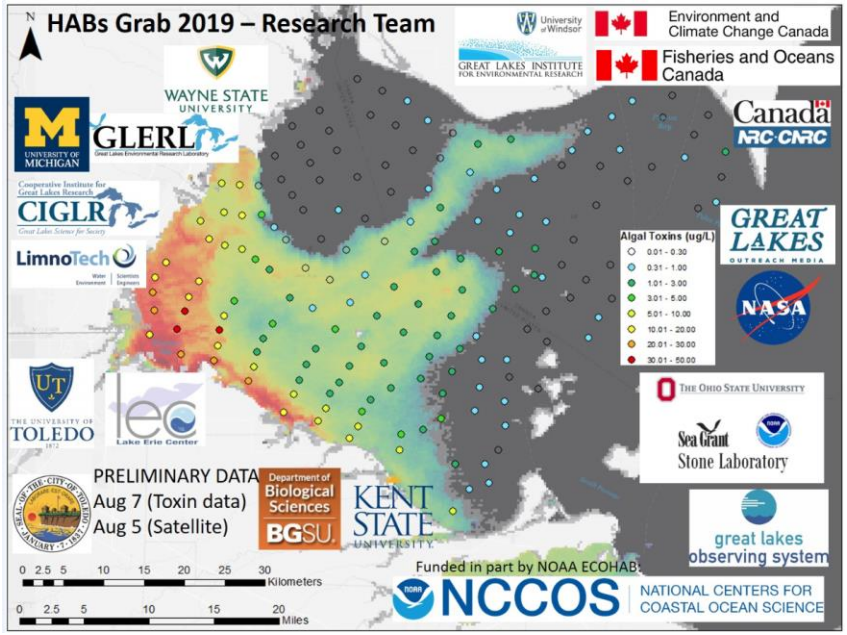
Otten et al., 2011, 2012; Wilhelm et al., 2011

In Western Lake Erie, microcystin correlated with cyanobacteria biomass in 2019, less so in 2018.

Variability due to multiple sources and drivers of toxins







GREAT LAKES CENTER
FOR FRESH WATERS AND HUMAN HEALTH
AT BOWLING GREEN STATE UNIVERSITY
BGSU

Why are algal I.D. and counts important?

Source of variability: multiple CyanoHAB "players" in Utah Lake can produce toxins In varying amounts under varying environmental conditions

				Salinity Range		
Genus	**Group**	**Potential toxin(s)**	**Characteristics**	**Low (0-4)**	**Mod. (4-16)**	**High (16+)**
Anabaena	Cyanobacteria	ATX, CYN, MC, STX	B,D,F	X	X	
Anabaenopsis	Cyanobacteria	MC	P,D,F	X	X	X
Aphanizomenon	Cyanobacteria	ATX, CYN, STX	P,D,F	X	X	
Cylindrospermopsis	Cyanobacteria	ATX, CYN, STX	P,D,F	X		
Cylindrospermum	Cyanobacteria	ATX, MC	B,D,F	X		
Dolichospermum	Cyanobacteria	ATX, CYN, MC, STX	P,D,F	X	X	
Fischerella	Cyanobacteria	MC	B,D,F	X	X	X
Haplosiphon	Cyanobacteria	MC	B,D,F	X		
Lyngbya	Cyanobacteria	CYN, LYN, STX	B,F	X	X	X
Microcystis	Cyanobacteria	MC	P,C	X		
Nodularia	Cyanobacteria	NOD	B/P,D,F	X	X	X
Nostoc	Cyanobacteria	ATX, MC	B,D,F	X	X	
Oscillatoria	Cyanobacteria	ATX, CYN, MC, STX	B/P,D,F	X	X	X
Phormidium	Cyanobacteria	ATX, MC	B,F	X	X	X
Planktothrix	Cyanobacteria	ATX, MC	P,F	X	X	
Raphidiopsis	Cyanobacteria	ATX, CYN, MC	P,F	X	X	
Scytonema	Cyanobacteria	MC, STX	B,D,F	X	X	X
Umezakia	Cyanobacteria	CYN, MC	P,D,F	X		

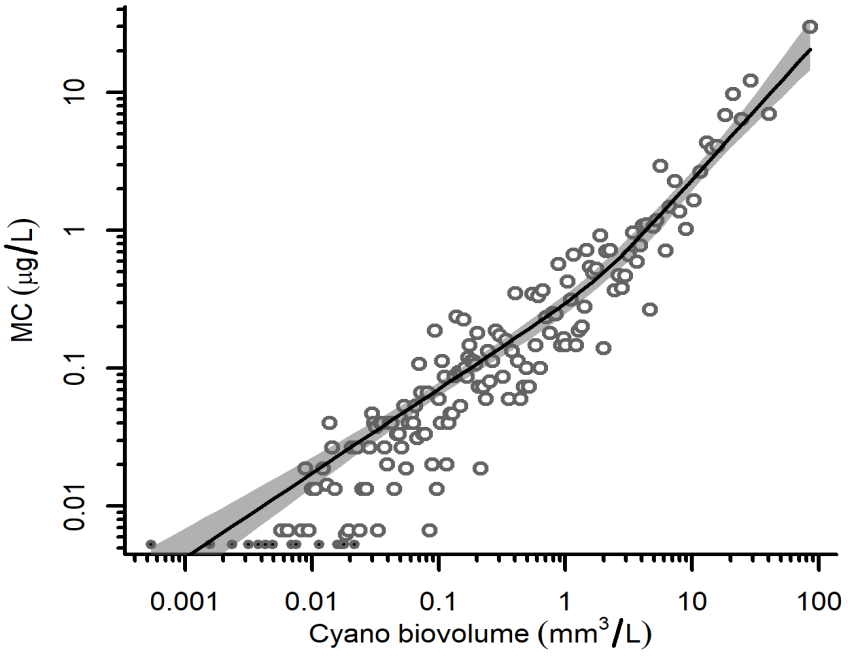
Toxin abbreviations: ATX = Anatoxin-a; BRV = Brevetoxin; CYN = Cylindrospermopsin; DA = Domoic acid; ICX = Ichthyotoxins; LYN = Lyngbyatoxin; MC = Microcystin; NOD = Nodularin; STX = Saxitoxin

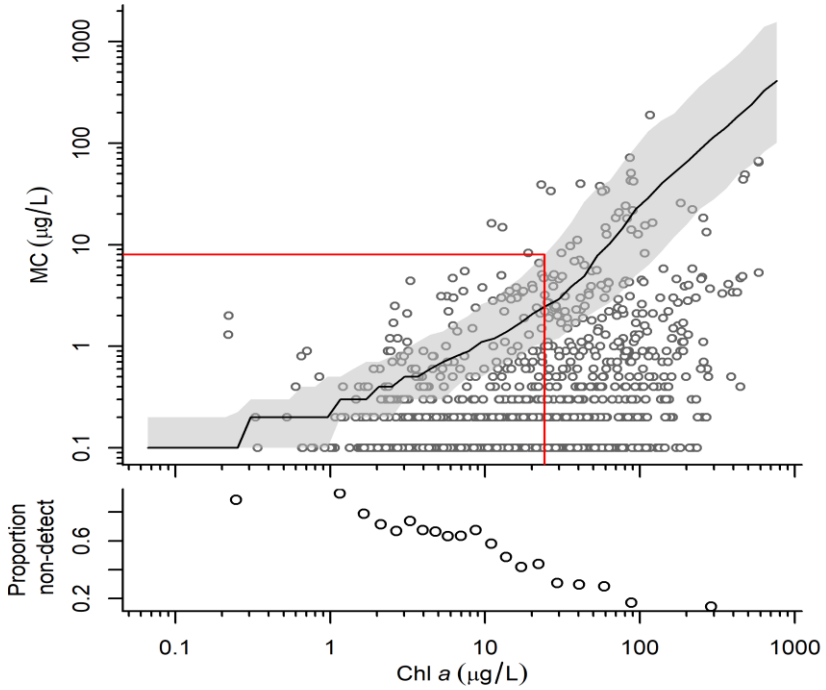
Characteristics abbreviations: B = Benthic; C = Coccoid; D = Diazotrophic; F = Filamentous; P = Planktonic

Paerl et al. 2018, ES&T 52:5519−5529

Utah Lake Nutrient Criteria Development

- Relating nutrients to potential toxin production
  - Water quality models
  - Empirical models
  - EPA lake criteria recommendation
- Toxin producers vs. non-toxin producers





EPA draft criteria recommendations for lakes and reservoirs (2020).