

Climate Change Stimulates Freshwater Harmful Algal Blooms (FHABs): A Within Water-Body Management Solution

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Water & Health: Where Science Meets Policy
University of North Carolina at Chapel Hill
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Background



1

Freshwater Harmful Algal Blooms (FHABs)



2

The Interagency, International Symposium on Cyanobacterial HABS: ISOC-HAB



- 1 Hudnell HK [Ed.], 2008. *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. Advances in Experimental Medicine and Biology, Vol. 619, 959 pp
- 2 Lopez CB, Jewett EB, Dortch Q, Walton BT, Hudnell HK, 2007. *Scientific Assessment of Freshwater Harmful Algal Blooms*. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC.

Overview

- Water Quality, Eutrophication & FHABs
 - FHAB Stimulatory Factors & Global Climate Change
 - Solar Powered Circulation (SPC)
 - Planktonic Densities Before & During SPC
 - Crystal Lake, Des Moines, IA
 - East Gravel Lake 4, Thornton, CO
 - Lake Palmdale, Palmdale, CA
 - Falls Lake Watershed Plan - Can we do better?
-
- Possible SPC mechanisms of FHAB Suppression
 - Problematic Applications (Learning Experiences)

Will We Have a Sustainable Supply of Usable Freshwater?

- 44% of river & stream miles, & 64% of lake & reservoir acres are impaired pursuant to section 305(b) of the U.S. Clean Water Act (EPA, 2009)
 - Flux of nutrients, toxic substances & pathogens to receiving waters

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- 1972, 1st EPA Eutrophication Survey: 10-20% of all U.S. lakes & reservoirs eutrophic (Gakstatter & Malone, 1975)

Eutrophic → Harmful Algal Blooms

NATURAL FORCES

HUMAN ACTIVITIES

Habitat Alteration & Environmental Pollutants

Ocean

ECOSYSTEMS

Estuary

Fresh Water

Land

Ecosystem Sustainability

TOXIGENIC CYANOBACTERIA

Human & Animal Health

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- 1972, 1st EPA Eutrophication Survey: 10-20% of all U.S. lakes & reservoirs eutrophic (Gakstatter & Malone, 1975)
- 2009, EPA Eutrophication Survey: 50+% of all U.S. lakes & reservoirs eutrophic or hypereutrophic (EPA, National Lakes Assessment, 2009)

Will We Have a Sustainable Supply of Usable Freshwater?

Toxicol 55 (2010) 1024–1034



Contents lists available at [ScienceDirect](#)

Toxicol

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



Review

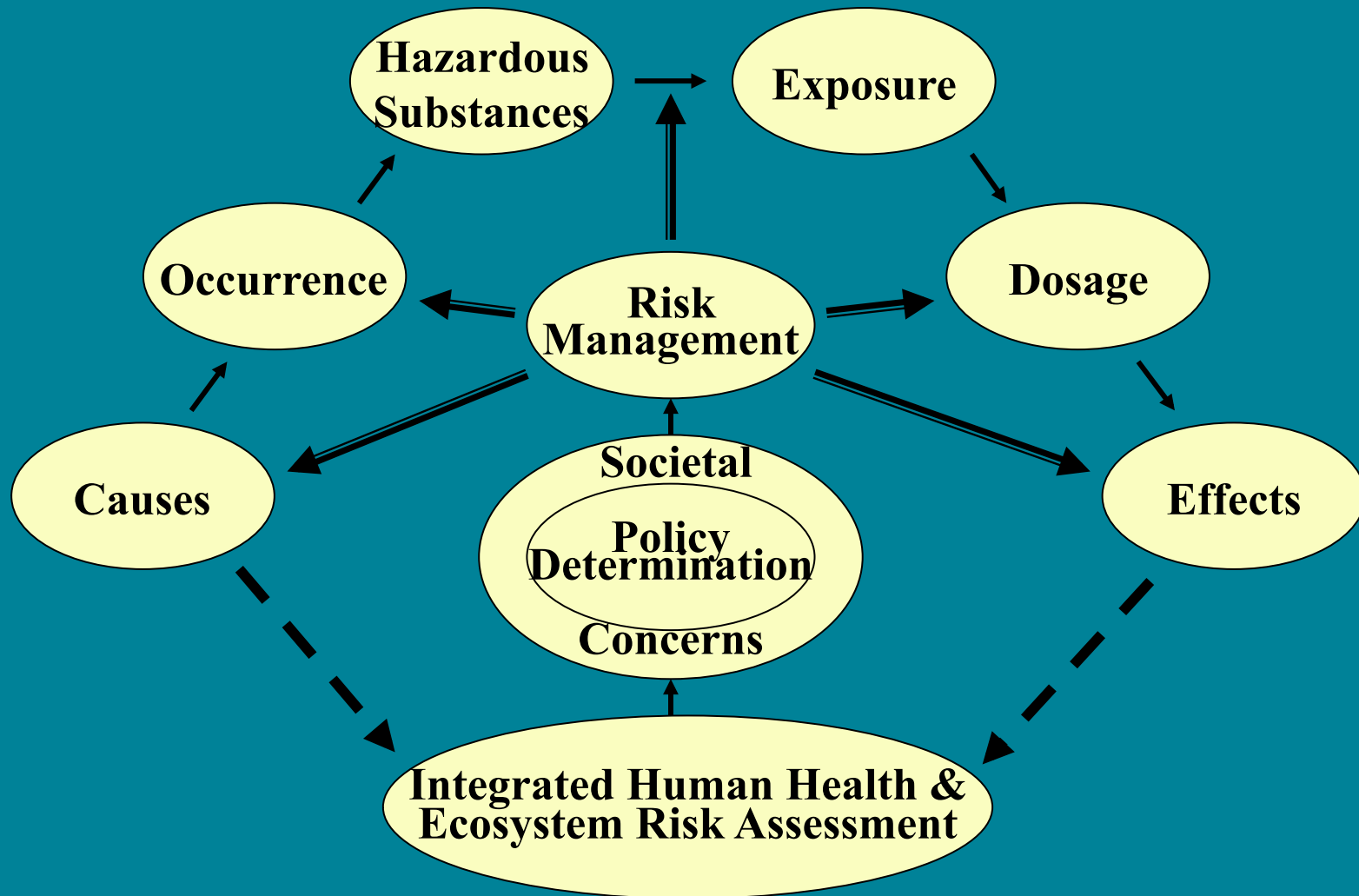
The state of U.S. freshwater harmful algal blooms assessments, policy and legislation

H. Kenneth Hudnell ^{a,b,*} **Toxicol (2010) 55:1024-1034**

Compounds and rodent 24 h intraperitoneal LD₅₀s (µg/kg).

| Cyanotoxins | LD ₅₀ | EPA priority | Comparison | LD ₅₀ |
|---------------------------------|------------------|--------------|--------------------------|------------------|
| Saxitoxins ^a | 10 | Medium/high | Ricin ^f | 22 |
| Anatoxin-a(s) ^b | 20 | Medium/high | Cobra venom ^g | 185 |
| Microcystin-LR ^c | 50 | Highest | Sarin ^h | 218 |
| Anatoxin-a ^d | 200 | Highest | Curare ⁱ | 500 |
| Cylindrospermopsin ^e | 300/180 | Highest | Strychnine ^j | 2500/980 |

Systems Approach: FHAB Risk Management



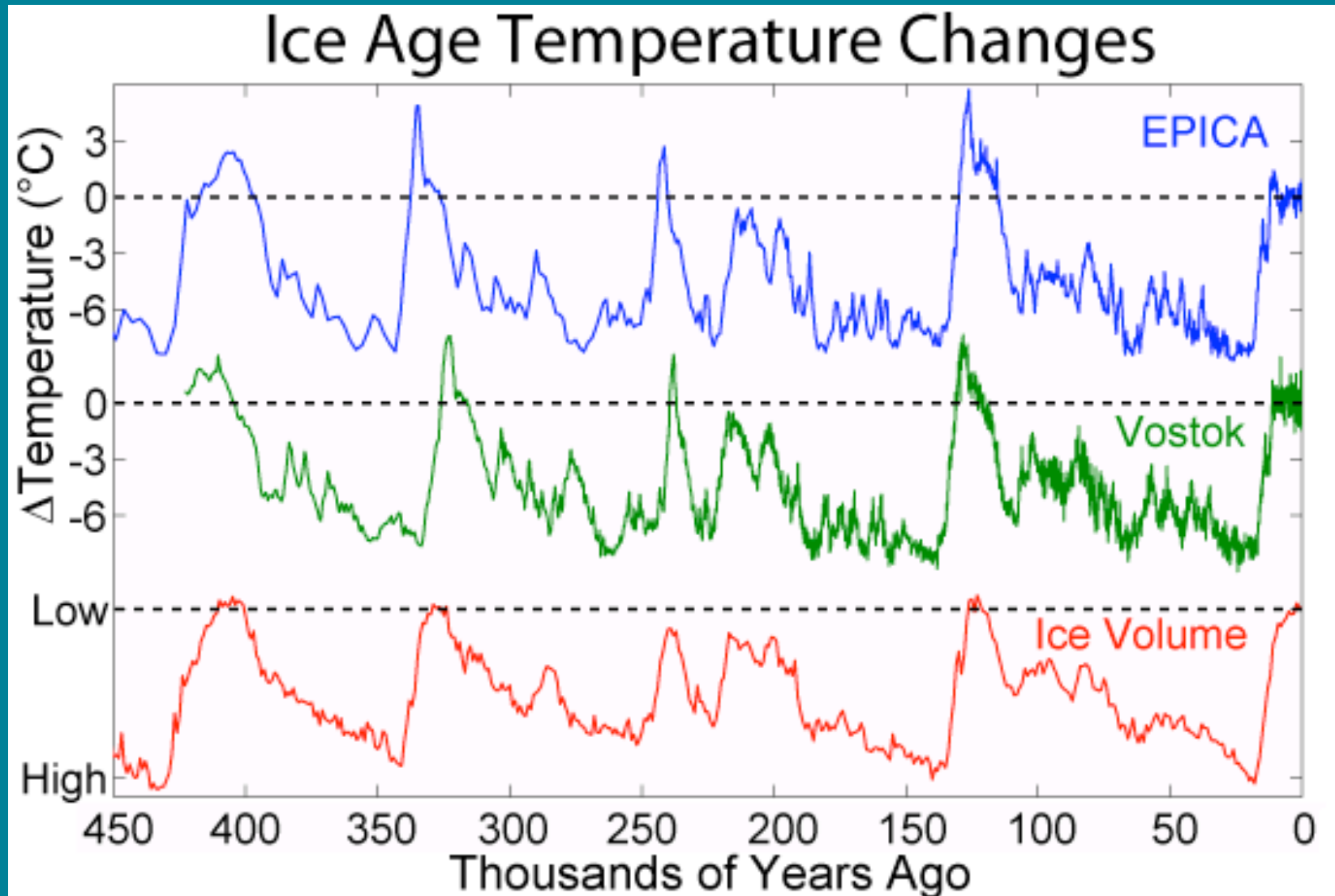
The 4 FHAB Stimulatory Factors & Global Climate Change (GCC)

- **Sunlight: photosynthesis - GCC may increase incident solar irradiation in some areas**

The 4 FHAB Stimulatory Factors & Global Climate Change (GCC)

- **Sunlight: photosynthesis - localized increases?**
- **Temperature: Best > 28° C - Increased by GCC**
 - **Increasing incidence, prevalence & durations**

Based on oxygen isotope ratios in ocean cores



Lisiecki & Raymo (2005) *Paleoceanography* 20:1003

The 4 FHAB Stimulatory Factors & Global Climate Change (GCC)

- **Sunlight: photosynthesis - localized increases?**
- **Temperature: Best > 28° C - Increased by GCC**
- **Nutrients: growth & reproduction - Increased by GCC**
 - **More frequent & severe storms & floods increase the flux of nutrients from watersheds to receiving waters**

The 4 FHAB Stimulatory Factors & Global Climate Change (GCC)

Clean Techn Environ Policy (2010) 12:205–207

DOI 10.1007/s10098-010-0304-6

GUEST COLUMN

Within water-body management: a needed but neglected complement to watershed management

H. Kenneth Hudnell

Clean Techn Environ Policy (2010) 12:205-207

- **Nutrients: growth & reproduction - Increased by GCC**
 - **More frequent & severe storms & floods increase the flux of nutrients from watersheds to receiving waters**
 - **Watershed & land use management policies have proven to be insufficient**
 - **Each receives over \$5B/yr of Federal funds, & much more in state and local funding**

The 4 FHAB Stimulatory Factors & Global Climate Change (GCC)

- **Sunlight: photosynthesis - localized increases?**
- **Temperature: Best > 28° C - Increased by GCC**
 - Increasing incidence, prevalence & durations
- **Nutrients: growth & reproduction - Increased by GCC**
 - More frequent & severe storms & floods
 - Watershed management insufficient
- **Quiescent, stagnant water: outcompete other plankton**
 - Increased by GCC
 - More frequent & severe droughts
 - ◆ Within water-body management needed

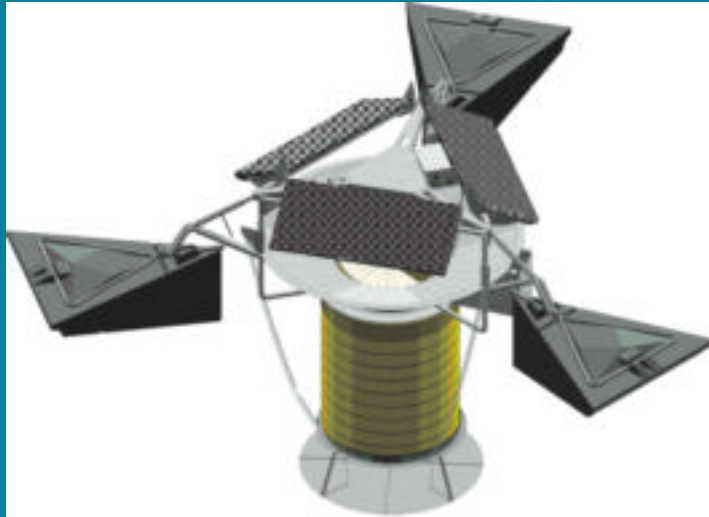
An Environmentally Sustainable, Ecological Approach to FHAB Control



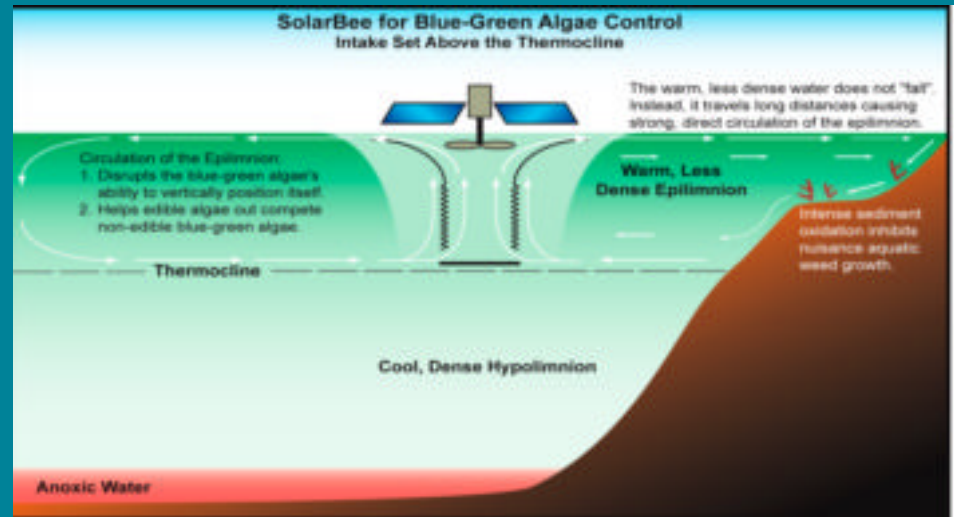
- **Circulating water targets the FHAB stimulatory factor of quiescent, stagnant water**
 - **When FHABs are suppressed & algaecide applications are eliminated or sharply reduced, nutrients move up the trophic levels of the food web creating robust fisheries**

Solar Powered Circulation An Ecological Solution

Only Epilimnion Circulated for FHAB Control



SPC Unit



Three 80 watt solar panels; 18 Volt direct-drive motor & battery;
Continuous day/night operation at 80 RPM; Near-laminar radial inflow; Non-turbulent outflow at surface; 10,000 GPM upflow, 35 acre spacing

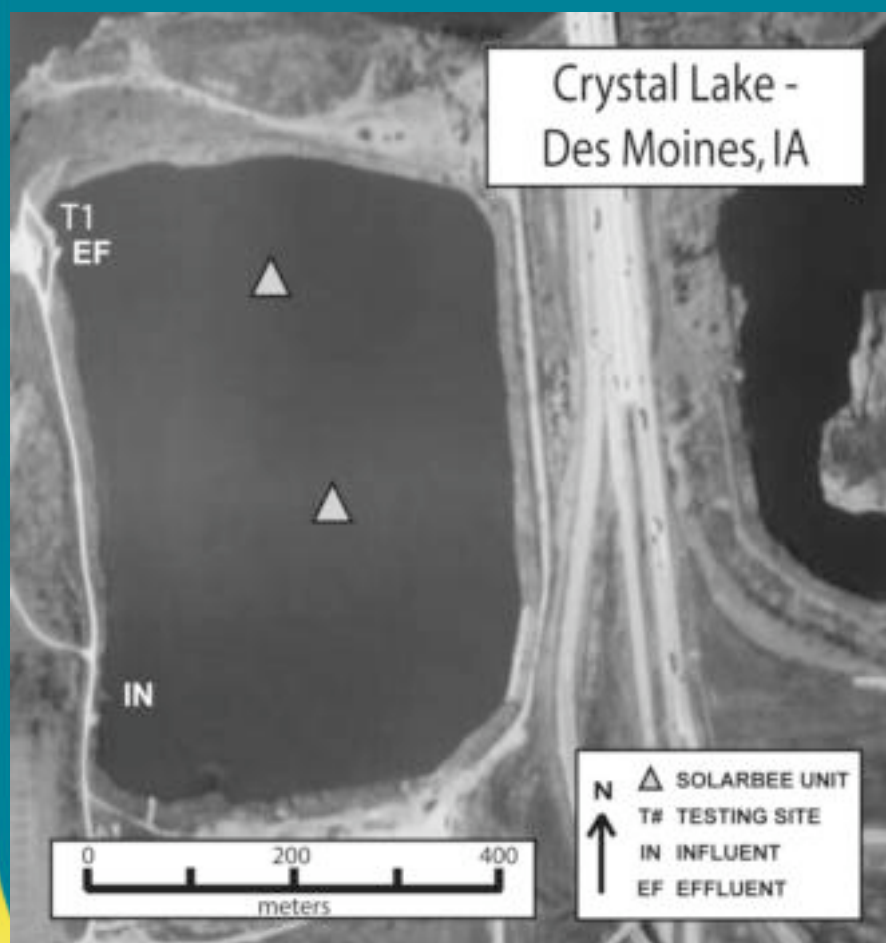
Long Distance Circulation

Site Selection

➤ March 2007, Survey sent to 1st 121 SPC users - 121/83/64: 50 FHAB control, Epilimnetic SPC

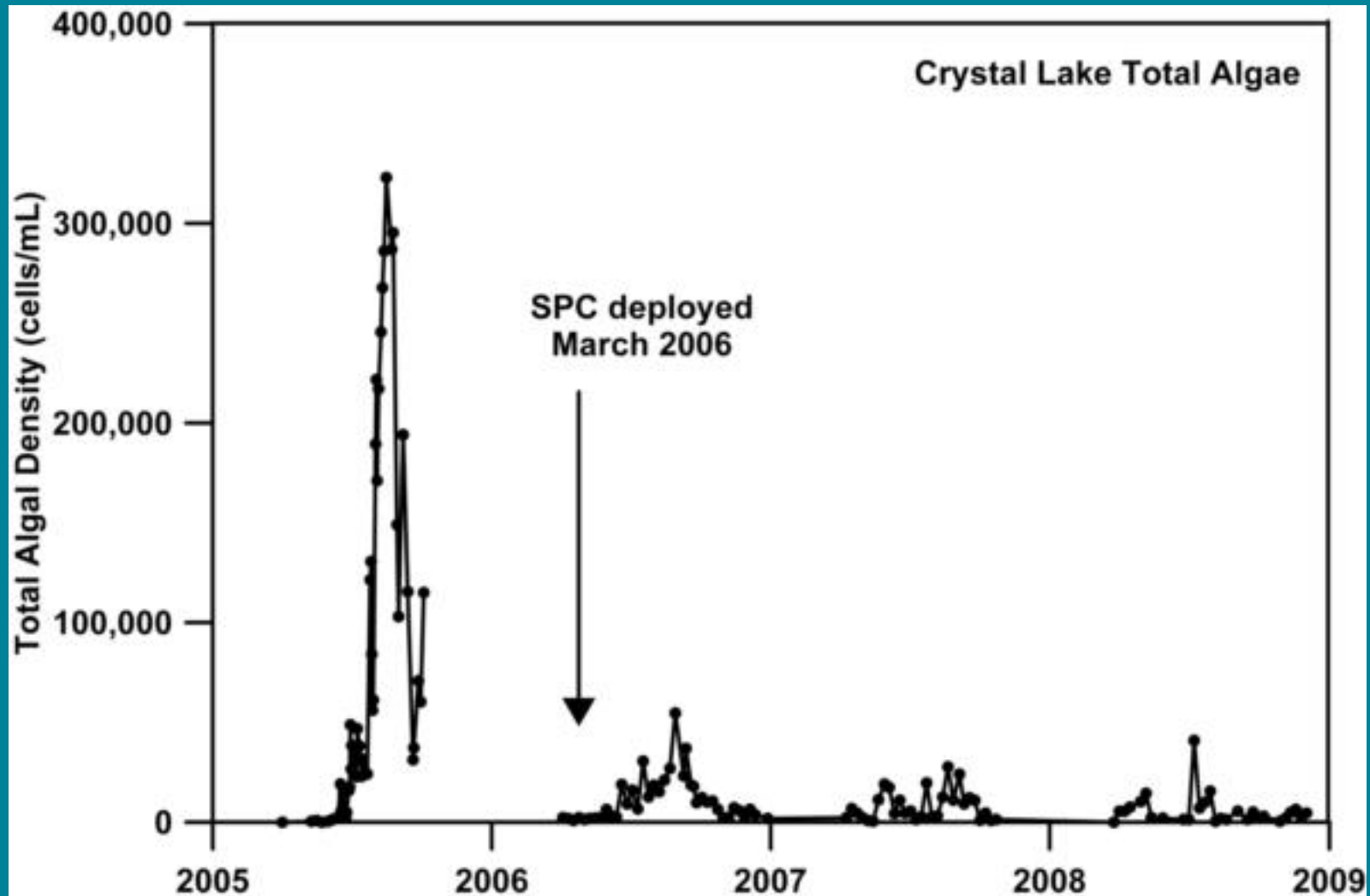
- SPC was deployed for epilimnetic circulation to suppress FHABs
- The whole water body was treated (surface area/SPC unit <16 ha)
- Water body personnel systematically assessed phytoplanktonic density
- Internal analytical methods were validated, standardized and consistent
- Densities of total plankton, cyanobacteria and green algae were available
- Phytoplankton data were available \geq one spring-fall season pre-SPC
- Phytoplankton data were available \geq one spring-fall season during SPC

Crystal Lake

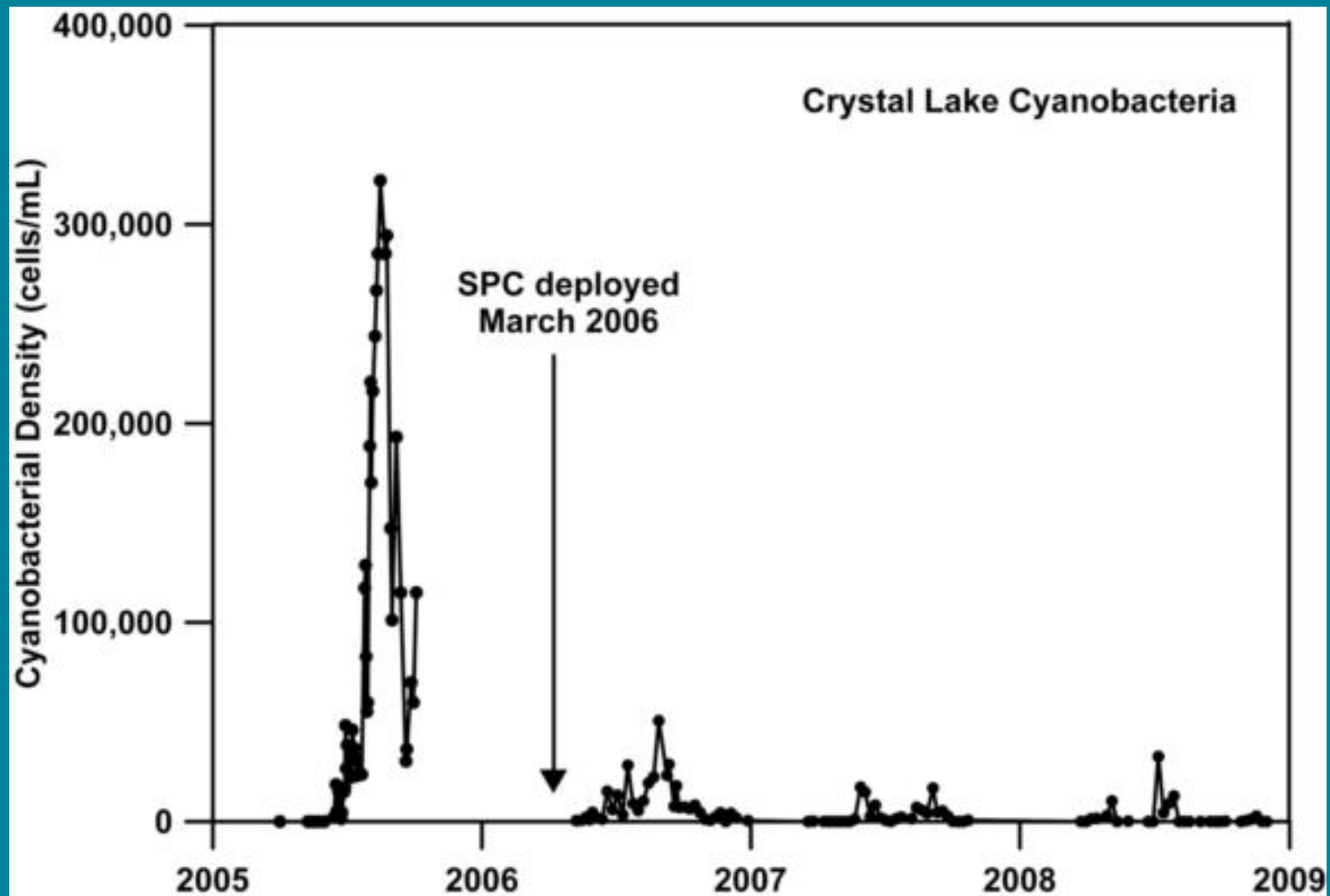


- 63 ac source water
- 25 maximum depth
- 10 ft mean depth
- 7.9 ft SPC mean intake depth
- 5 MGD mean input from Raccoon River
- 40 day mean residence time
- Total N reaches 18 mg/L
- Total P reaches 8 mg/L
- River seeds lake with FHAB cells
- Taste & odor problems
- **Algaecides never used**

Crystal Lake Total Algal Densities

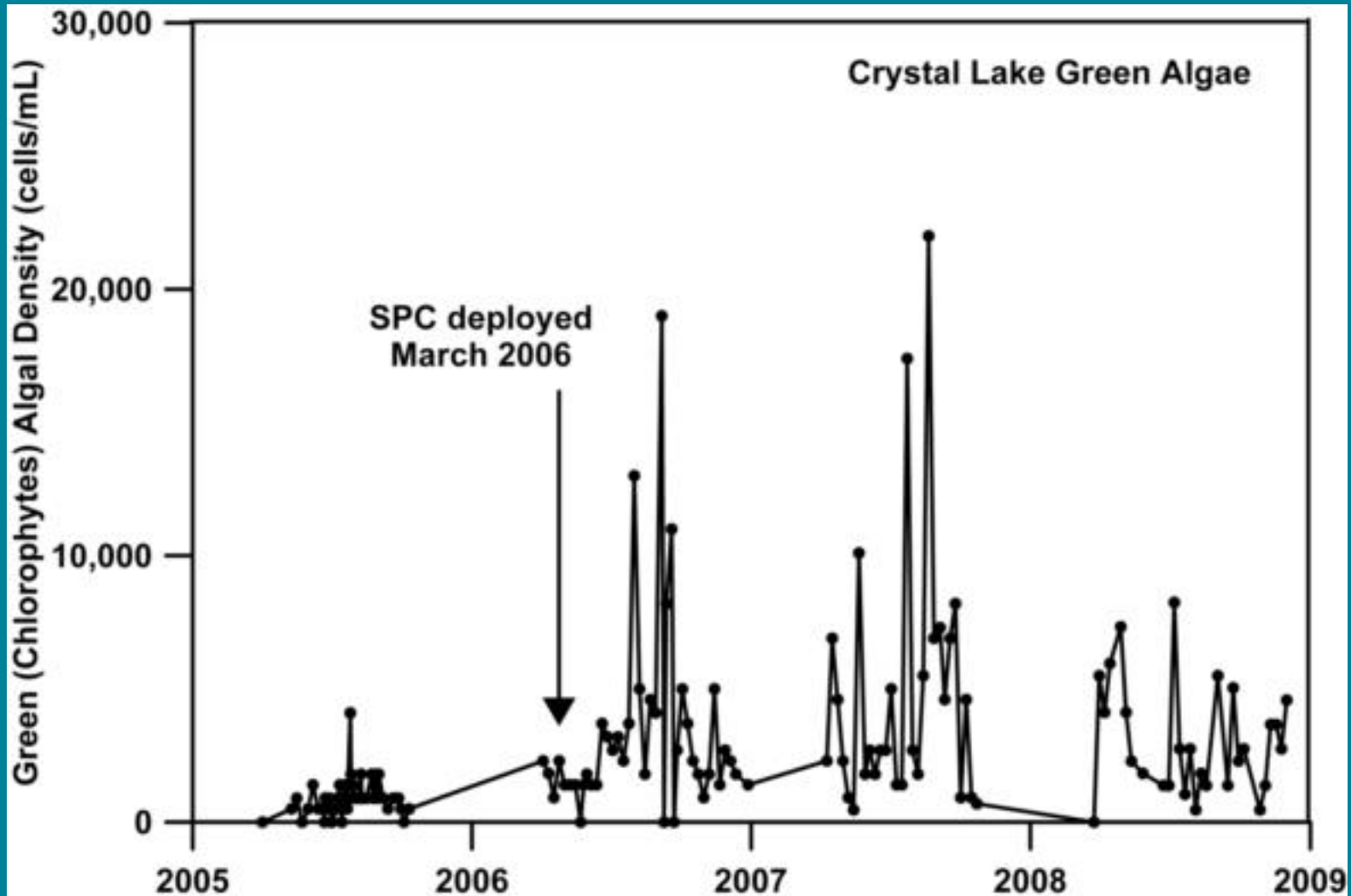


Crystal Lake Cyanobacterial Density



Algaecides never used

Crystal Lake Green Algal Densities



Crystal Lake Data Summary

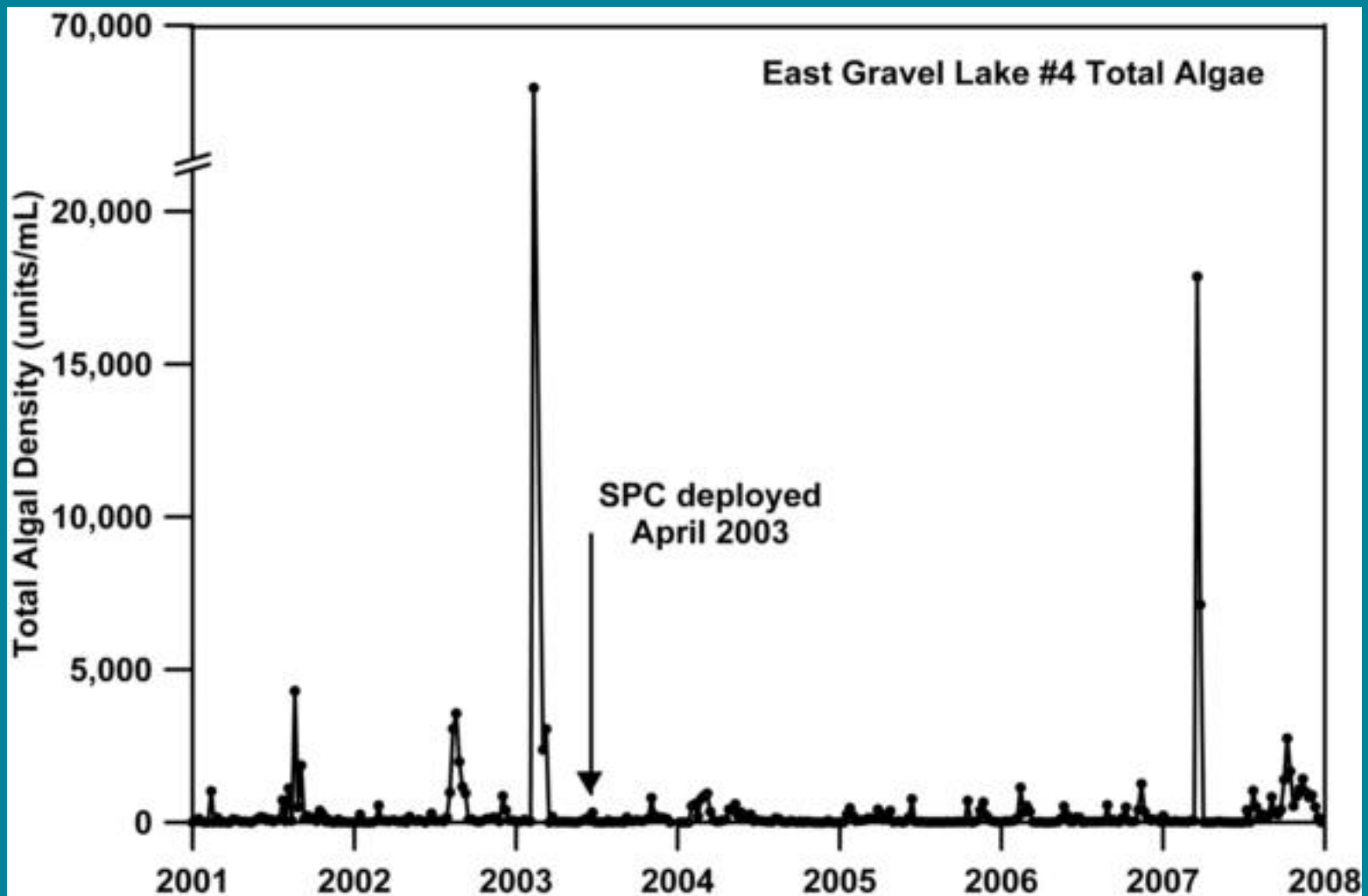
- High densities of total algae were dominated by cyanobacteria prior to SPC
- Total algal & cyanobacterial densities decreased significantly during SPC
 - Indication that FHAB suppression strengthened over time
- Green algal densities increased significantly during SPC

East Gravel Lake 4 (EGL 4)

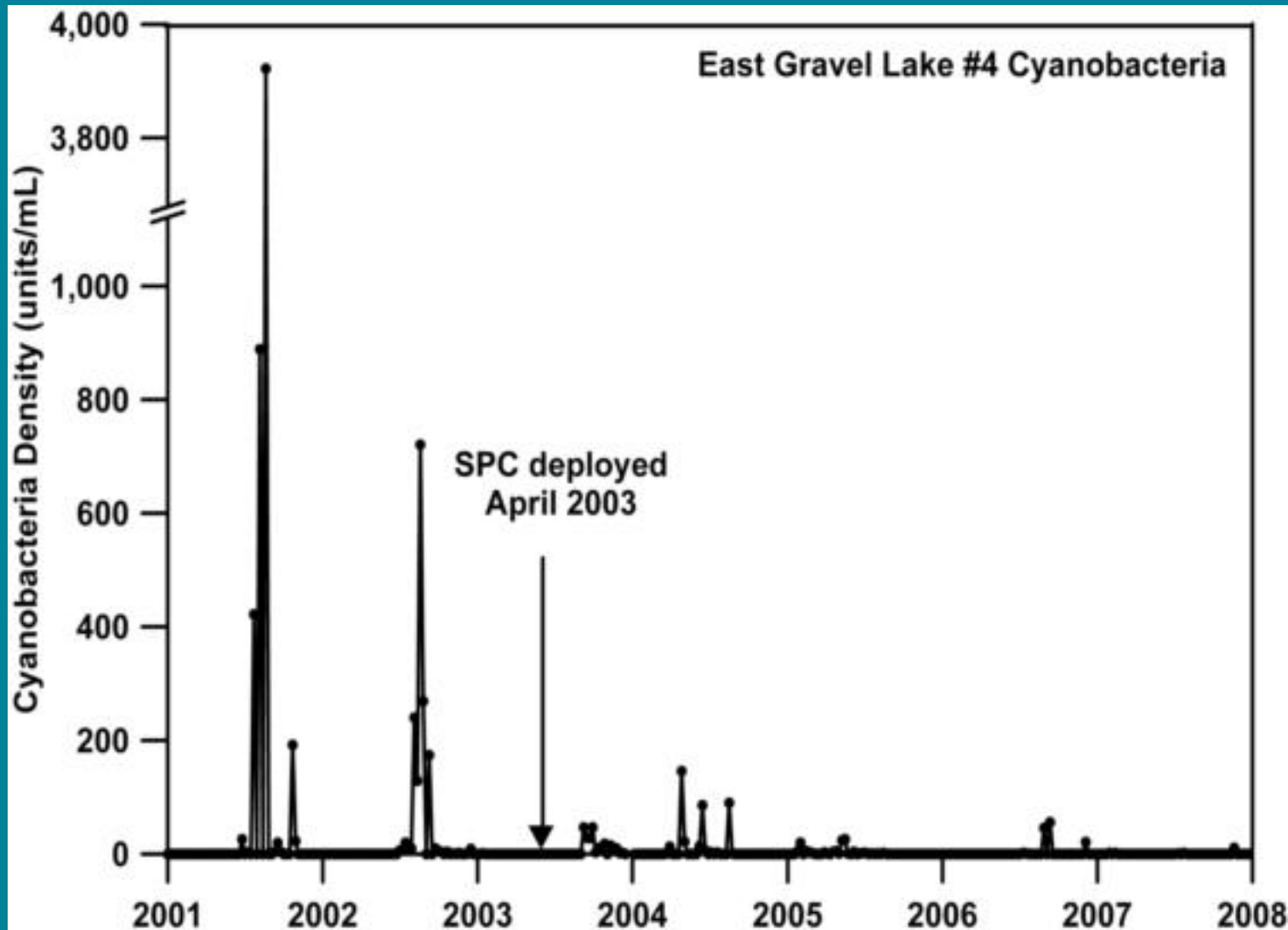


- 115 ac source water
- 35 maximum depth
- 25 ft mean depth
- 22-14.1 ft mean SPC intake depth
- 3.4 MGD mean input from Burlington Ditch (carries Denver effluent)
- 270 day mean residence time
- Nitrate reaches 10 mg/L
- Total P reaches 1.3 mg/L
- Ditch seeds lake with FHAB cells
- Taste & odor problems
- **Algaecides used**

EGL 4 Total Algal Densities

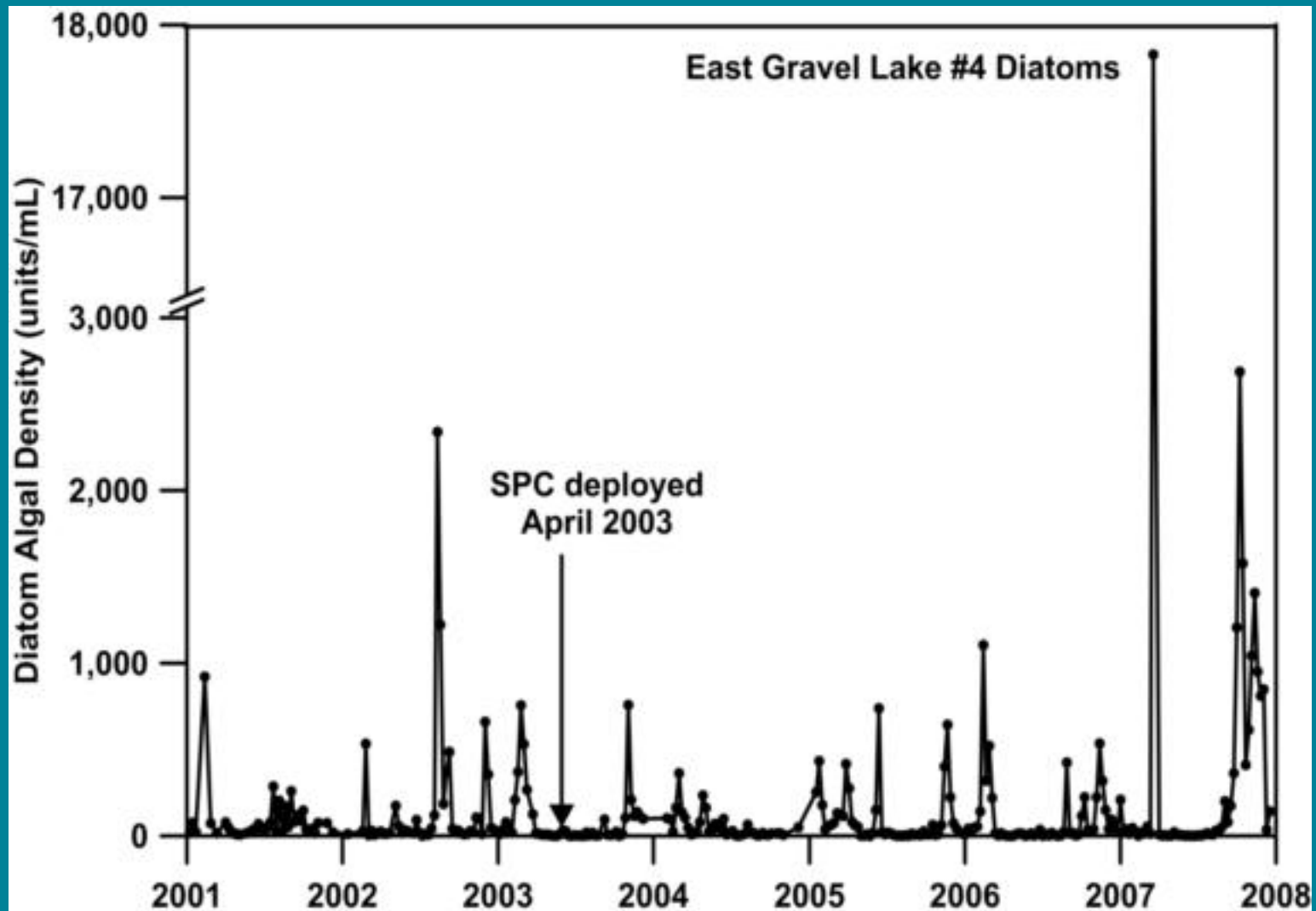


EGL 4 Cyanobacterial Densities



Algaecide usage: 1-2/mth pre- to 1-2/yr during-SPC

EGL 4 Diatom Densities

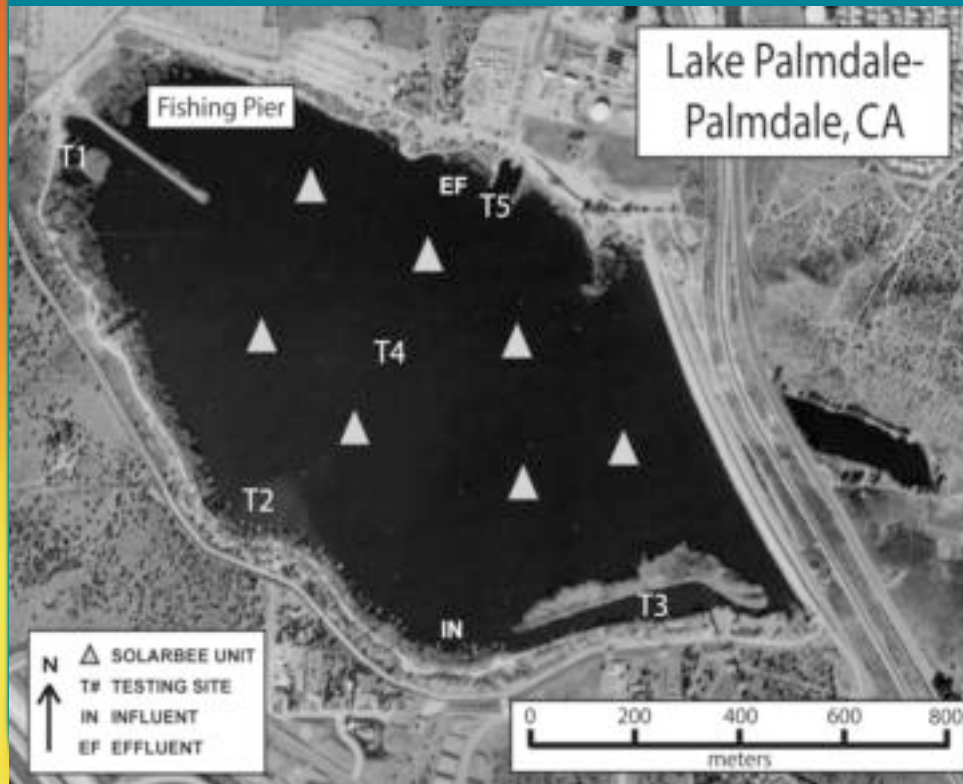


EGL 4 Data Summary

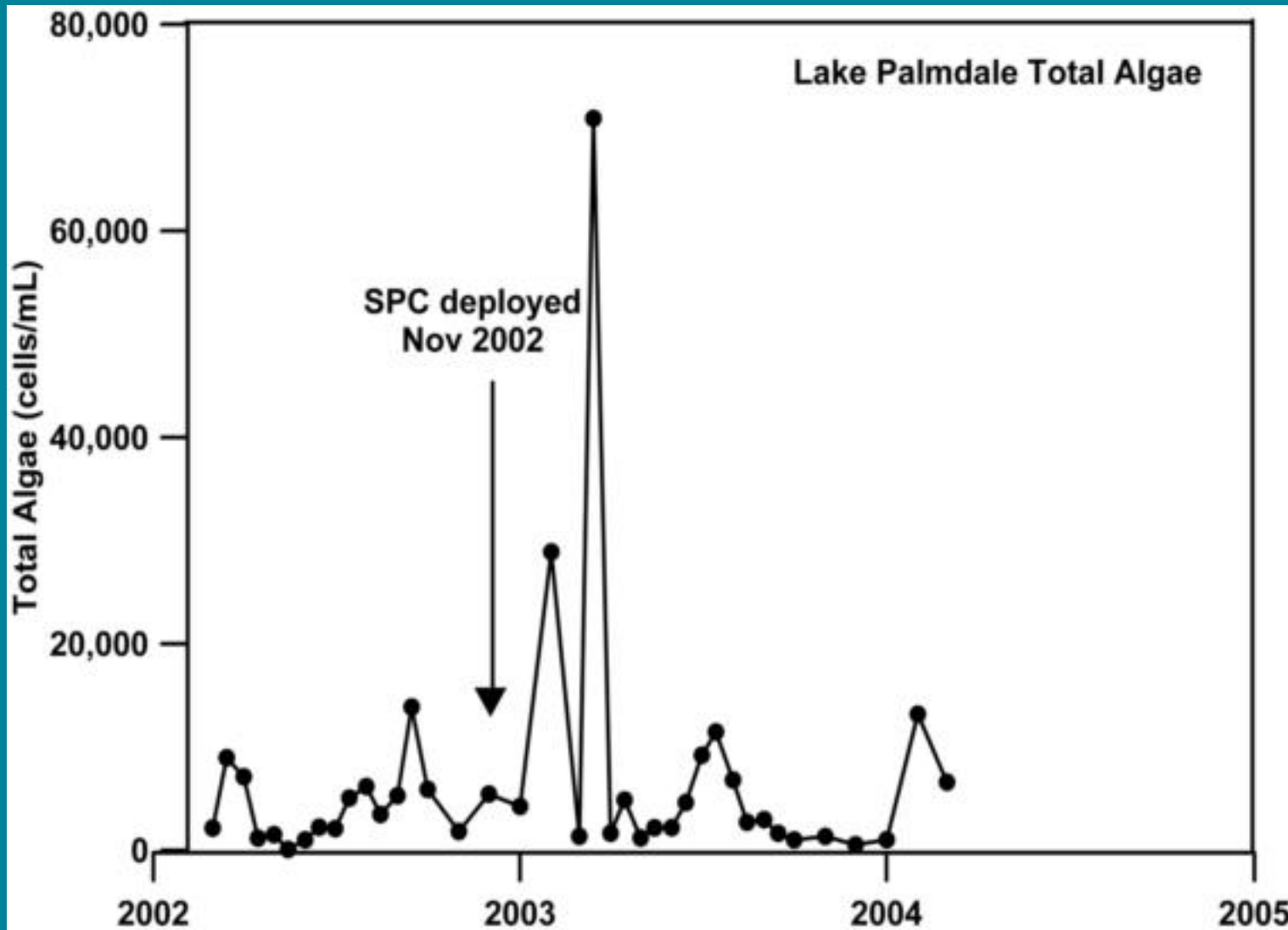
- High densities of total algae were dominated by cyanobacteria prior to SPC
- Total algal & cyanobacterial densities decreased significantly during SPC
 - Indication that FHAB suppression strengthened over time
- Little change in green algal density
- Diatom densities increased significantly during SPC
- Algaecide applications declined from 1-2/mth to 1-2/yr during SPC

Lake Palmdale

- 234 ac source water
- 25 maximum depth
- 18 ft mean depth
- 15.1 ft mean SPC intake depth
- 14.2 MGD mean input from California Aqueduct
- 270 day mean residence time
- Nitrate reaches 6 mg/L
- Total P reaches 0.22 mg/L
- Aqueduct seeds lake with FHAB cells
- Taste & odor problems
- **Algaecides used**



Lake Palmdale Total Algal Densities



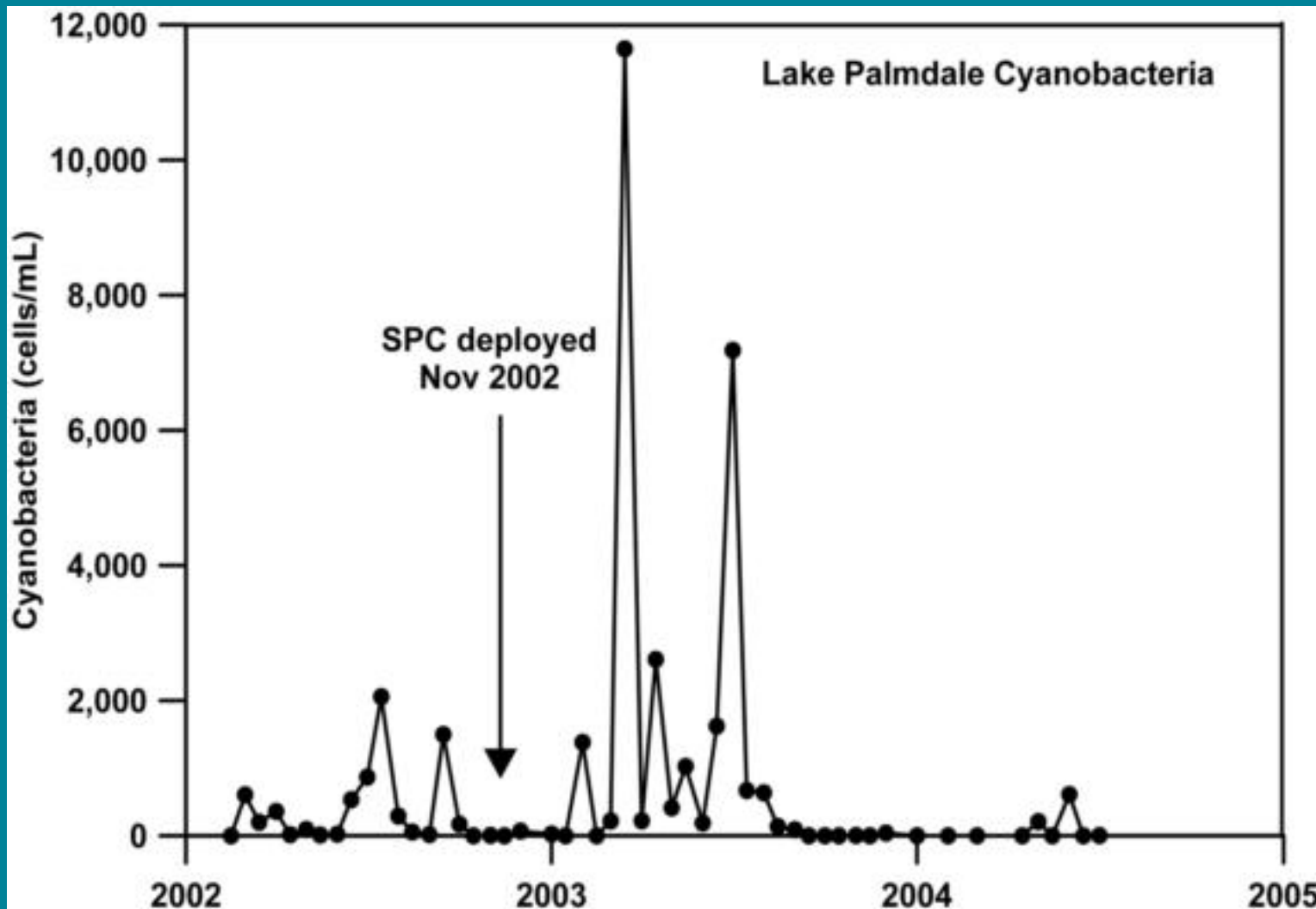
26,070 kg

3,922 kg

3,753 kg

CuSO₄

L Palmdale Cyanobacterial Densities



26,070 kg

3,922 kg

3,753 kg

CuSO₄

Lake Palmdale Data Summary

- Total algal mean density significantly higher during SPC
- Large FHAB during 1st year of SPC, cyanobacterial density significantly lower in 2nd year than pre-SPC
- No significant change in green algal or diatom densities during SPC
- Zooplankton densities increased significantly during SPC
- Algaecide usage declined by approximately 85% during SPC

Study Conclusion & Discussion

- **SPC is a Sustainable, Ecologically-based Approach to FHAB Suppression**
- **Waters with high N & P supplied each reservoir**
 - Each had a watershed management, nutrient reduction plan
 - Nutrient levels remained high throughout the study
 - ◆ Watershed management is a long-term approach
 - Anecdotal reports of “best ever” fisheries when FHABs suppressed with little or no algaecides
 - ◆ Nutrients were channeled up the food web

SPC complements watershed management

Falls Lake Watershed

Is there a quicker, more affordable solution using watershed & within water-body management?

- **2005 - NC Legislature requires nutrient reduction plan**
- **2010 - NC DWQ proposed rules to reduce N&P inputs**
 - **Stage 1 - Meet goals in lower lake by 2020**
 - **Stage 2 - Meet goals in upper lake by 2040**
 - **Total cost estimated at \$1.5-3.3 B**
- **Drinking water utility in lower lake plans to upgrade in 2016 if nutrients not reduced**
 - **\$115 M for FHAB cyanotoxins, taste & odor**
 - **\$200 M for organic carbons THMs, HAAs,**

Thank You!

**Please Consider Joining the Informal Coalition for
Improved FHAB Federal Research & Control
Legislation (FHAB ACT)**

Now Folded into the HABHRCRA Reauthorization

<http://www.HABlegislation.com>

<http://www.CleanWaterAmericaAlliance.org/index.php>

Possible Mechanisms

- **Disruption of cyanobacterial buoyancy control**
 - **Non-optimal positioning for light & nutrients**
- **Distribution of non-motile cyanobacterial pathogens**
 - **Cyanophage (viruses), cell lysing bacteria, fungi**
- **Distribution of non-motile beneficial algae & bacteria**
 - **Higher reproduction rates, limit available nutrients**
- **Enhance iron oxidation rate, making it less available**
 - **Cyanobacteria require much more iron than others**
- **Promote zooplankton & grazing**

May be multifactorial or vary with conditions

Problematic Applications

- **Small, shallow (< 1 m) aquaculture ponds**
 - High fish density & nutrient levels, low zooplankton density
- **Other small, shallow ponds, particularly when adjacent to wetlands that seed cyanobacteria**
- **Lakes with residence time < 5 days and frequent seeding from inflows**
- **Some partial-lake applications**
 - High nutrient & seeding rate, leeward side of prevailing wind, photic zone beyond thermocline

Reservoirs & Treatment

| | Crystal Lake | EGL 4 | Lake Palmdale |
|---|-----------------------------|--|---|
| Algaecides Used | No | Yes | Yes |
| Surface Area (km ²) | 0.26 | 0.47 | 0.89 |
| Max Depth (m) | 7.6 | 10.7 | 7.6 |
| Mean Depth (m) | 3.0 | 7.6 | 5.5 |
| Water Volume (km ³) | 7.65x10 ⁻⁴ | 3.53x10 ⁻³ | 4.90x10 ⁻³ |
| Water Mean Residence Time (days) | 40 | 270 | 91 |
| Data Collection Period | March-December 2005-2008 | January-December 2001-2007 | January-December 2002-2004 |
| SPC Initiation Date | March 2006 | April 2003 | November 2002 |
| # SPC Units | 2 | 3 | 6-7 ^a |
| Surface Area km ² /SPC unit | 0.13 | 0.16 | 0.15-0.13 ^a |
| Mean Intake Depth (m) | 2.4 | 6.7-4.3 ^b | 4.6 |
| Water Volume Circulated (km ³) | 6.1x10 ⁻⁴ | 3.1x10 ⁻³ -2.0x10 ^{-3b} | 4.1x10 ⁻³ |
| Water km ³ Circulated/SPC unit | 3.05x10 ⁻⁴ | 1.04x10 ⁻³ -6.67x10 ^{-47b} | 6.82x10 ⁻⁴ -5.85x10 ^{-4a} |
| SPC Circulation Rate (km ³ /day) | 5.5x10 ⁻² | 5.5x10 ⁻² | 5.5x10 ⁻² |
| Total Circulation Rate (km ³ /day) | 0.11 | 0.17 | 0.33-0.39 ^a |
| Turnover Duration (days) ^c | 5.6 | 19.0-12.2 ^b | 12.4-10.6 ^a |

^a A seventh SPC unit was installed in June 2003

^b Water intake depths were varied as the reservoir surface elevation and water clarity varied over time

^c The duration required for the SPC units to circulate all the water between the surface and mean intake depths one time

Pre- v During-SPC Data Summary

| | Total Algae | Cyanobacteria | Green Algae | Diatoms | Zooplankton |
|---------------|---------------------------|---------------------------|-----------------------|-------------------------|---------------------------|
| Crystal Pre | 86,302 _{+13,834} | 85,447 _{+13,799} | 871 ₊₉₀ | NA | NA |
| Crystal Post | 8,668 ₊₉₇₂ | 5,161 ₊₅₂₄ | 3,665 ₊₃₈₀ | NA | NA |
| EGL 4 Pre | 1,796 ₊₈₆₂ | 72 ₊₄₁ | 1,534 ₊₈₅₀ | 135 ₊₃₀ | NA |
| EGL 4 Post | 306 ₊₈₇ | 3.9 ₊₁ | 45 ₊₈ | 232 ₊₈₆ | NA |
| Palmdale Pre | 4,228 ₊₈₄₈ | 426 ₊₁₄₈ | 1,528 ₊₄₂₃ | 2,216 ₊₇₆₉ | 169₊₅₆ |
| Palmdale Post | 7,977 _{+2,449} | 967 ₊₄₄₆ | 888 ₊₂₁₄ | 4,436 _{+2,211} | 984₊₂₇₂ |

Numbers are means \pm standard errors of the means; NA = not available

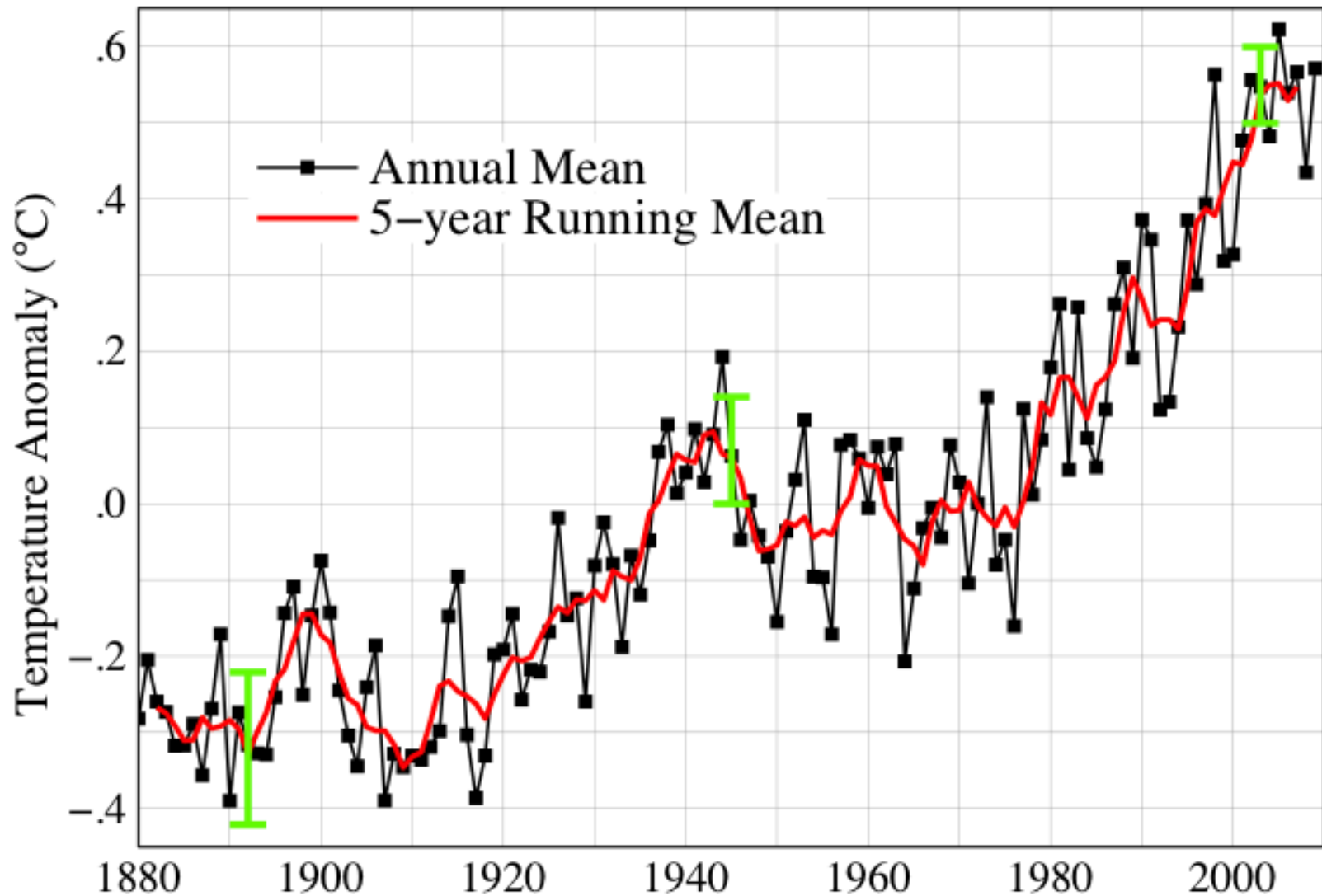
Units are cell/mL at Crystal and Palmdale, and units/mL at EGL 4

Bolded values are statistically significant at $p \leq 0.05$; Between-site comparisons are inappropriate

Algaecides were never used at Crystal, whereas copper sulfate usage declined by 85% at Palmdale and from 1-2/mth to 1-2/yr at EGL 4 after SPC initiation

**SPC provides an Ecological Approach to
FHAB Suppression**

Global Land–Ocean Temperature Index



NASA Goddard Institute for Space Science, April 2010