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science for a changing world

# Reservoir Habitat Restoration – Nutrient Control

**RFHP Annual Workshop**

**October 5, 2019**

**Reed Green**

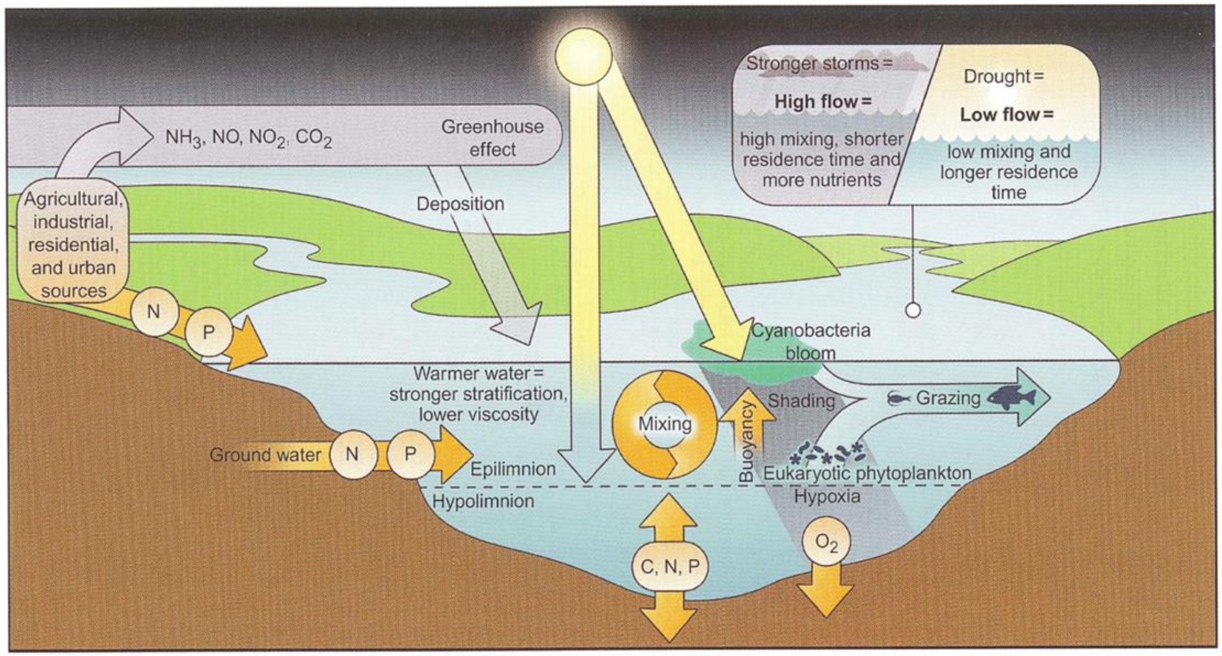


FIGURE 2 Conceptual diagram illustrating external and internal factors controlling growth, accumulation (as blooms), and fate of cHABs in freshwater ecosystems. Factors can act individually or in combined (synergistic, antagonistic) ways.

Wehr, and others, 2015, Freshwater Algae of North America, Chapter 20, figure 2

U.S. Department of the Interior
U.S. Geological Survey

# Nutrients

- **Nitrogen**, needed for plant growth and production
  - Major component of chlorophyll, and
  - Amino acids, the building blocks of proteins
- **Phosphorus**, plays a critical role in cell development
  - Key component of molecules that store energy (ATP),
  - DNA, and
  - Lipids (fats and oils)

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# Commonly known……

## Global phosphorus retention by river damming

Taylor Maavara[a,b,1], Christopher T. Parsons[a,b], Christine Ridenour[a,b], Severin Stojanovic[a,b], Hans H. Dürr[a,b], Helen R. Powley[a,b], and Philippe Van Cappellen[a,b]

[a]Ecohydrology Research Group, Water Institute, University of Waterloo, Waterloo, ON, Canada N2L 3G1; and [b]Department of Earth and Environmental Sciences, University of Waterloo, Waterloo, ON, Canada N2L 3G1

Edited by Andrea Rinaldo, Ecole Polytechnique Federale Lausanne, Lausanne, Switzerland, and accepted by the Editorial Board November 3, 2015 (received for review June 25, 2015)

ECOLOGY LETTERS

Ecology Letters, (2016) doi: 10.1111/ele.12658

LETTER

## Phosphorus accumulates faster than nitrogen globally in freshwater ecosystems under anthropogenic impacts

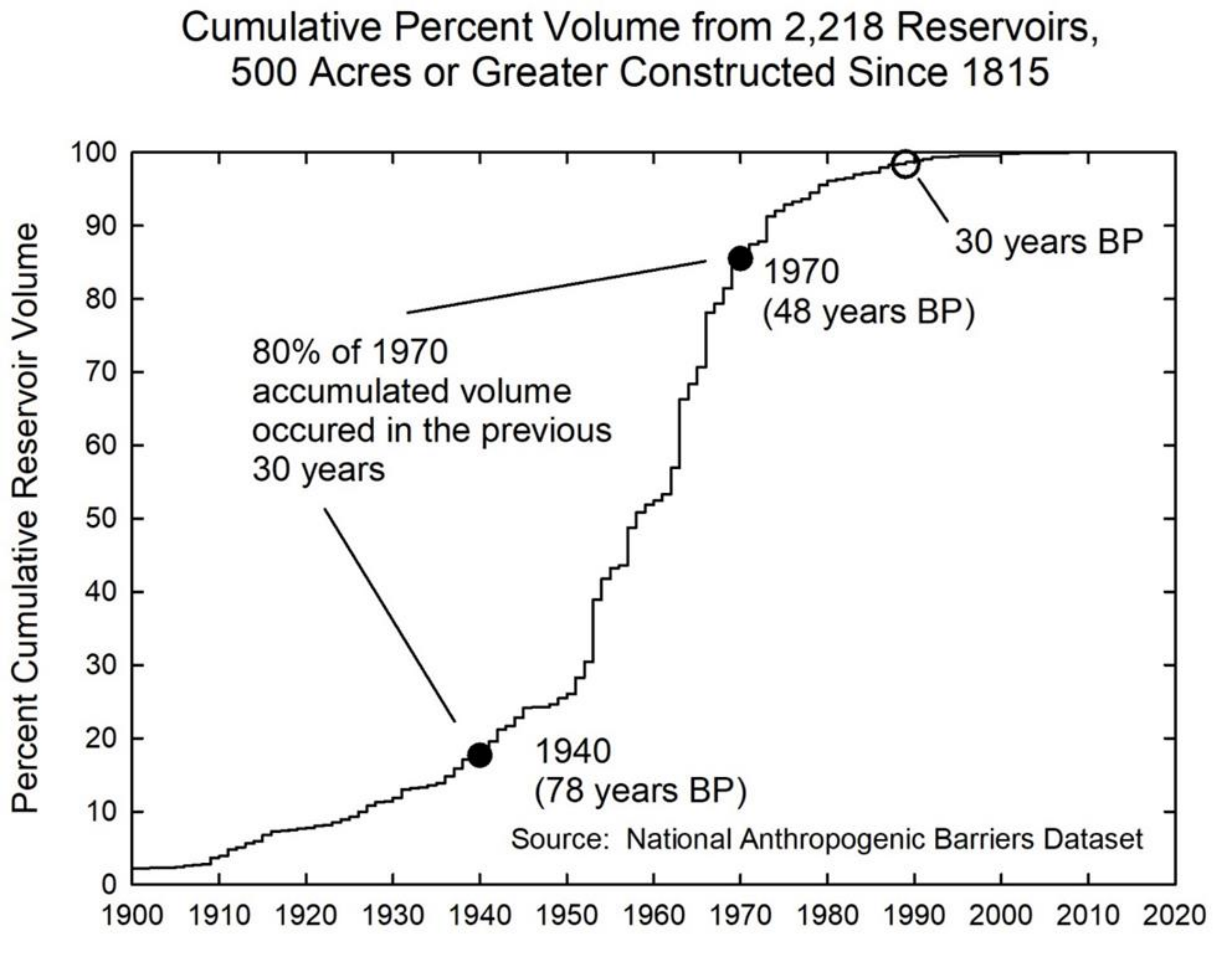
Yan, et al.

# More recently……


Constructed – 1928
Provides 50% of the freshwater to the Chesapeake Bay.
Traps ~ 3.5 million pounds of P and 4 billion pounds of sediment, per year.
Storage capacity has reached equilibrium.
Source: https://www.chesapeakebay.net/news/blog/who_is_responsible_for_the_conowingo_dam (4/9/2018)

**This information is preliminary and is subject to revision.**

# Reservoir aging

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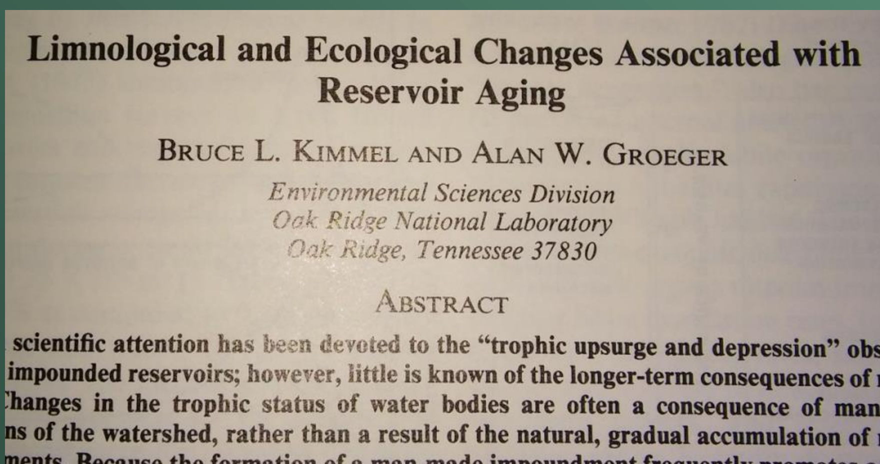
# Reservoir Fisheries Management (1986) brought us, *Limnological and Ecological Changes Associated with Reservoir Aging*



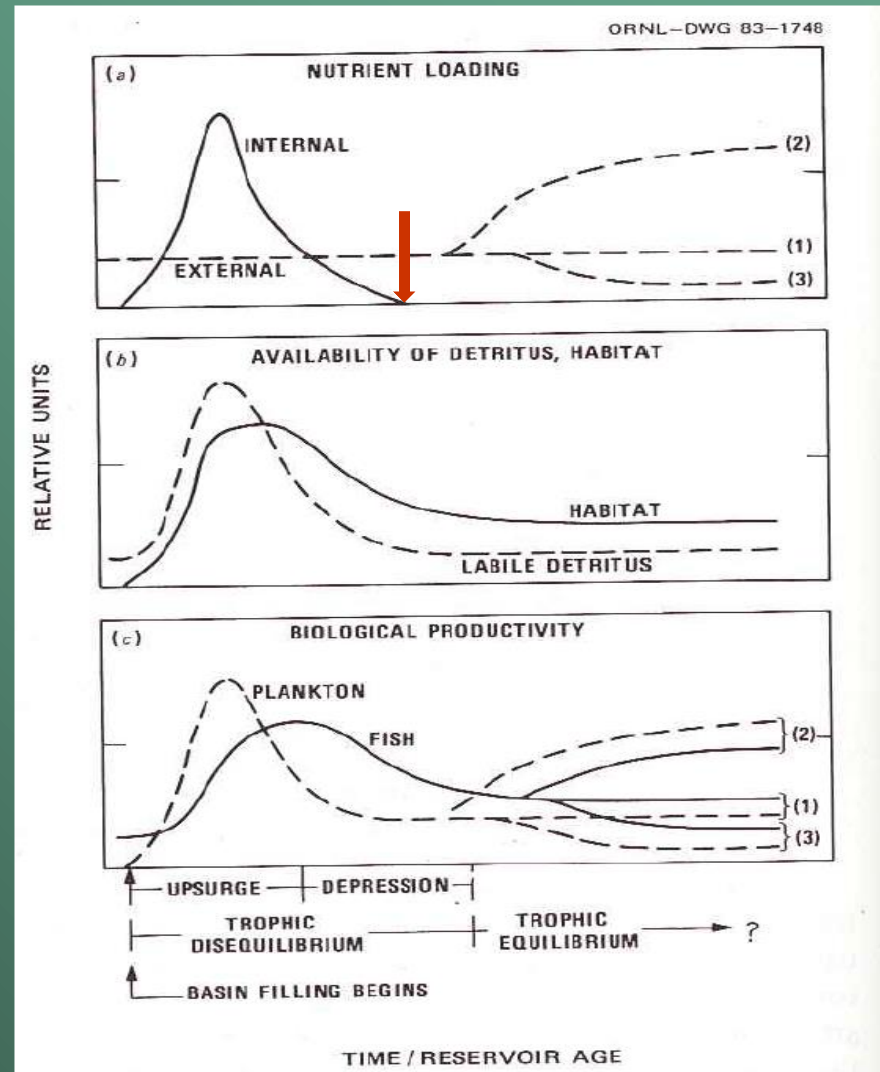
**Limnological and Ecological Changes Associated with Reservoir Aging**

BRUCE L. KIMMEL AND ALAN W. GROEGER

*Environmental Sciences Division*
*Oak Ridge National Laboratory*
*Oak Ridge, Tennessee 37830*

ABSTRACT

scientific attention has been devoted to the "trophic upsurge and depression" obs
impounded reservoirs; however, little is known of the longer-term consequences of r
Changes in the trophic status of water bodies are often a consequence of man-
ns of the watershed, rather than a result of the natural, gradual accumulation of r
ments. Because the formation of a man-made impoundment frequently promotes ac




Source: https://fisheries.org/bookstore/all-titles/afs-unit-publications/x53012xm/

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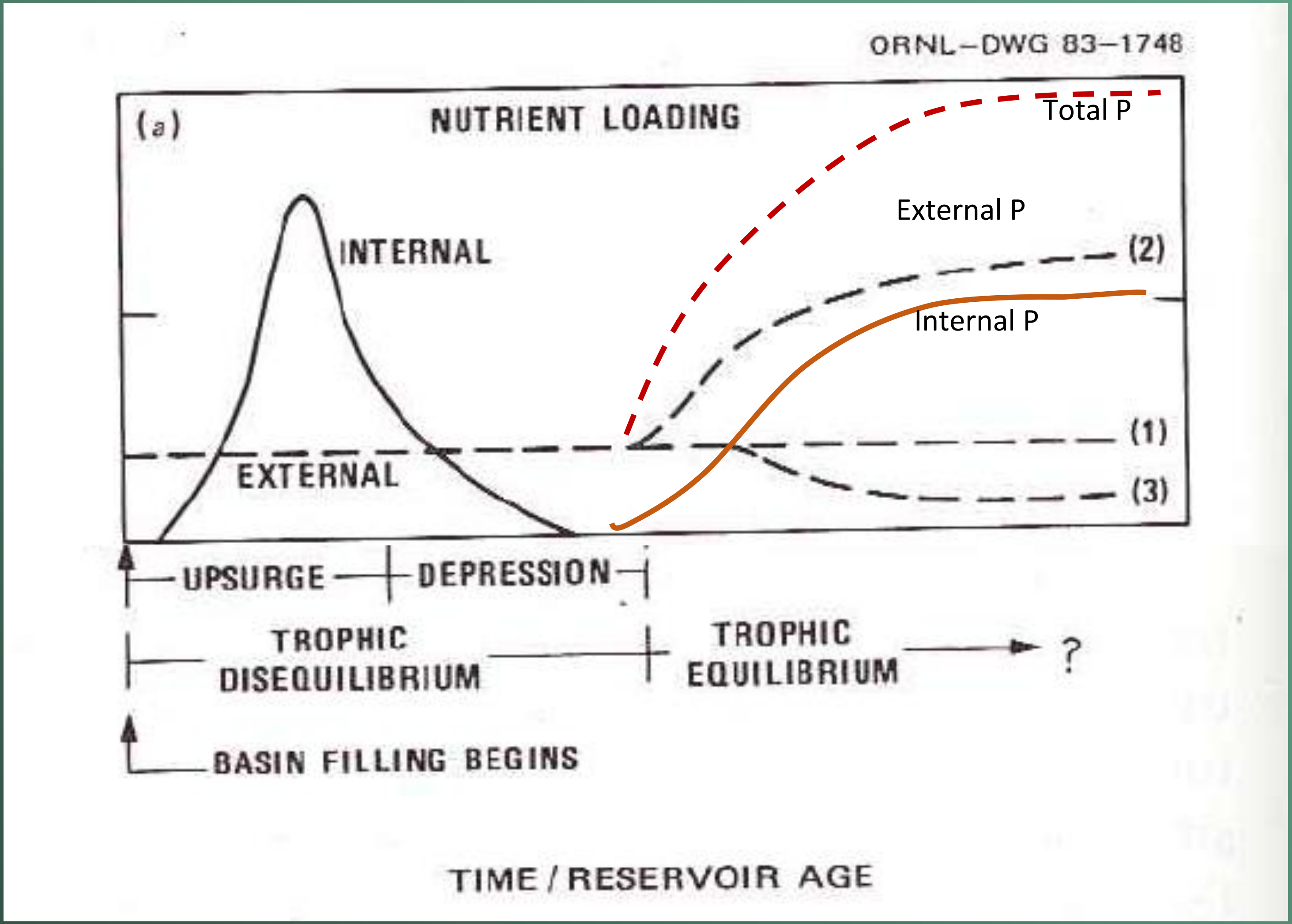


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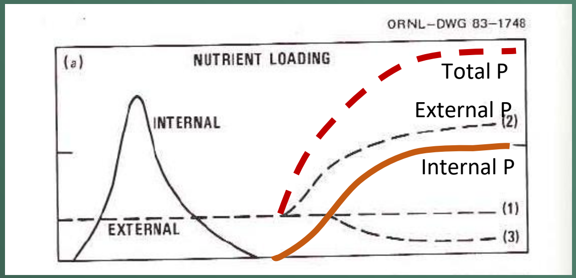


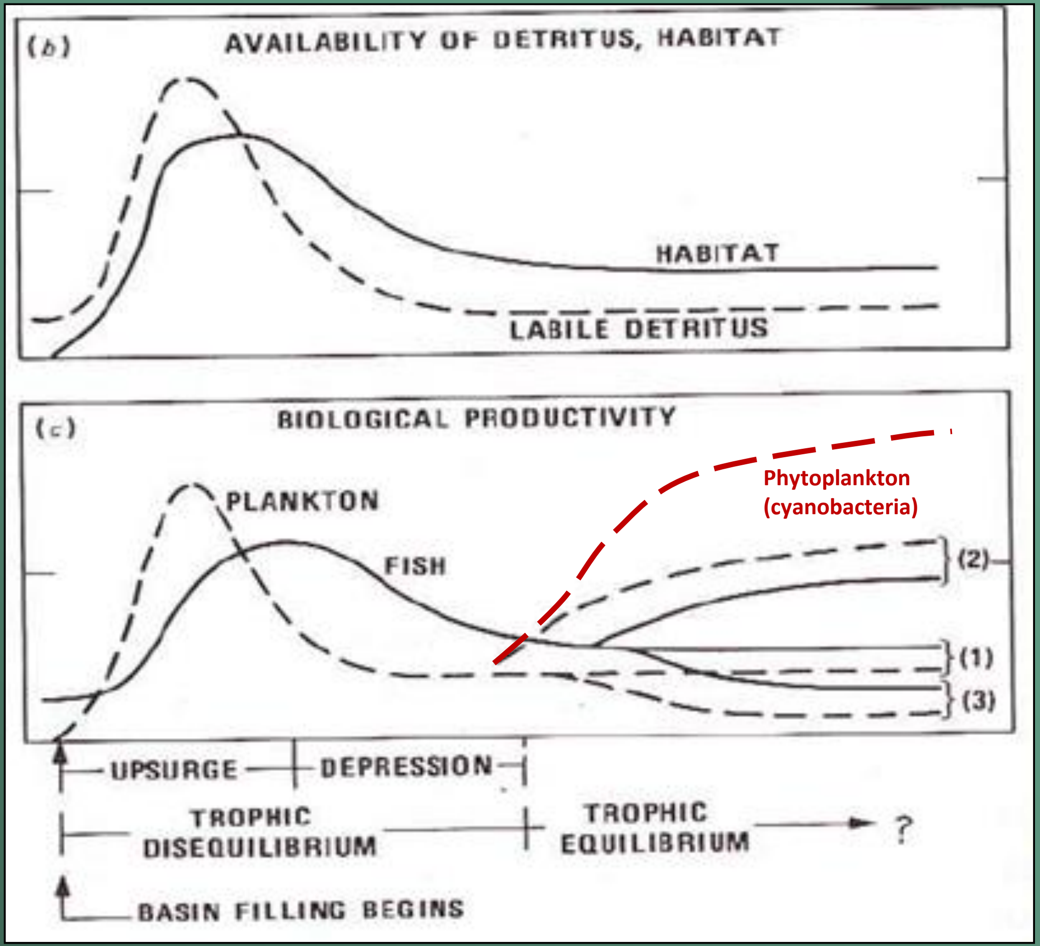


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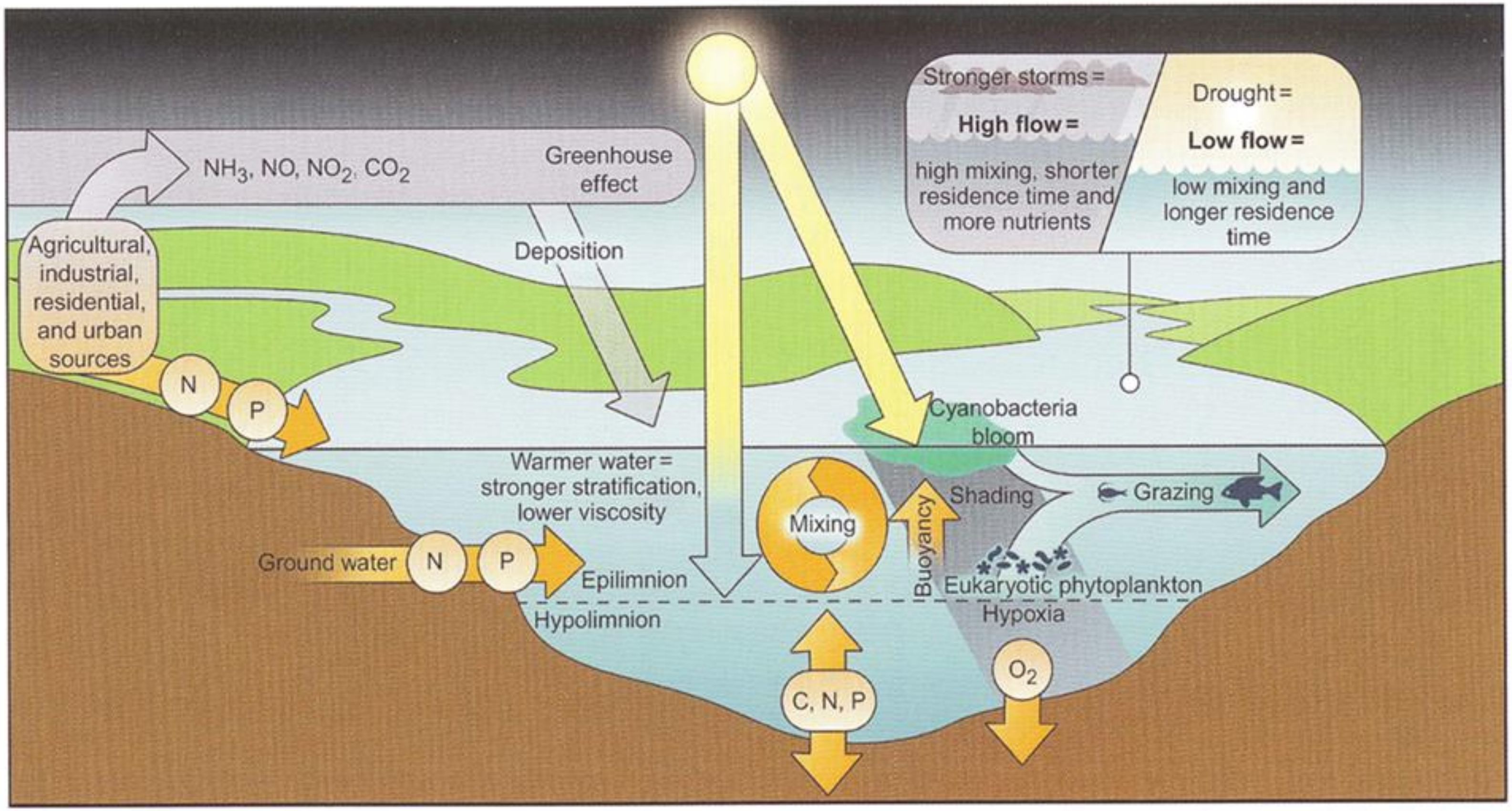
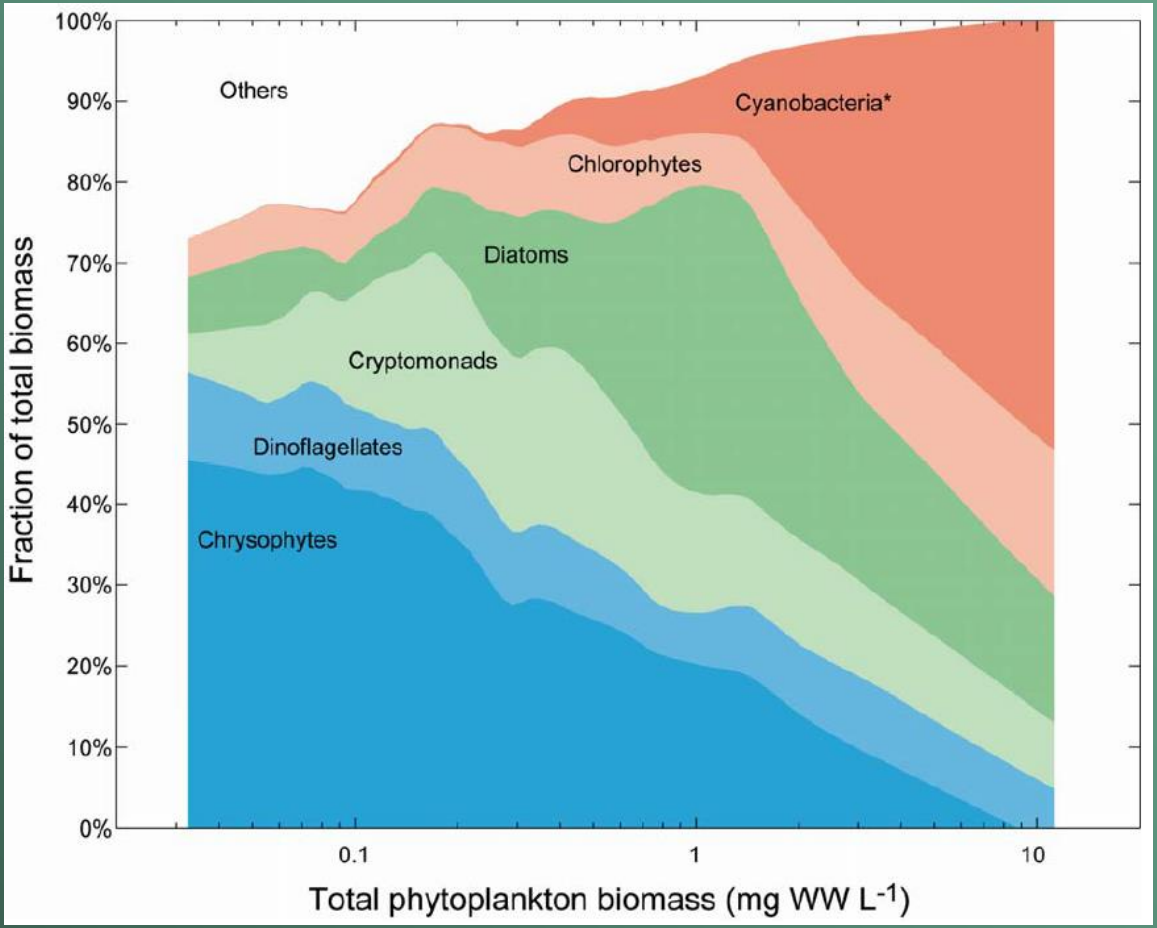



**FIGURE 2** Conceptual diagram illustrating external and internal factors controlling growth, accumulation (as blooms), and fate of cHABs in freshwater ecosystems. Factors can act individually or in combined (synergistic, antagonistic) ways.

# Main algae groups as a fraction of total biomass




Brettum P., and Anderson, T. 2005. *The use of phytoplankton as indicators of water quality. Norwegian Inst. for Water Research.* 33 pp.

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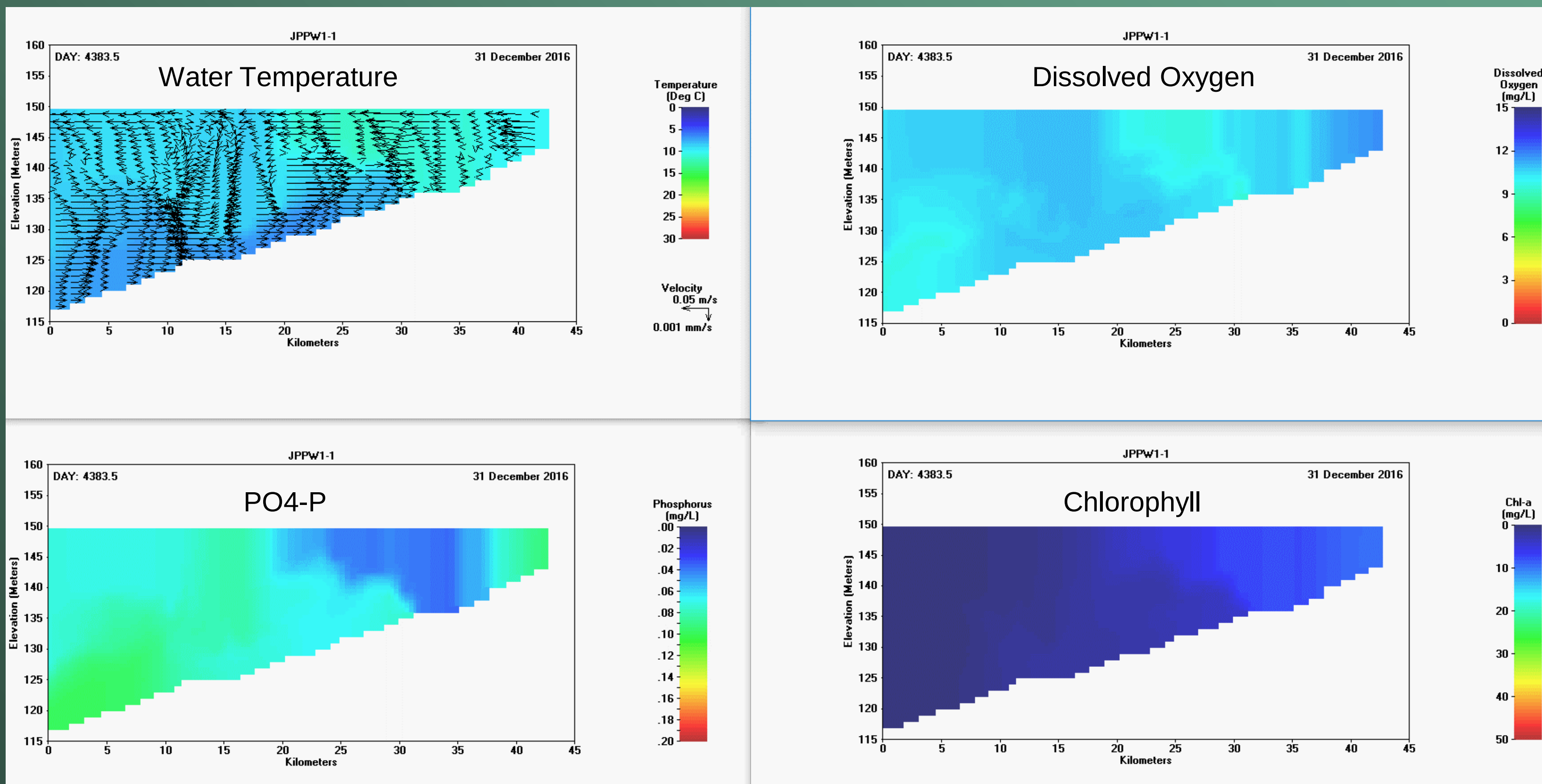
# Annual Cycles

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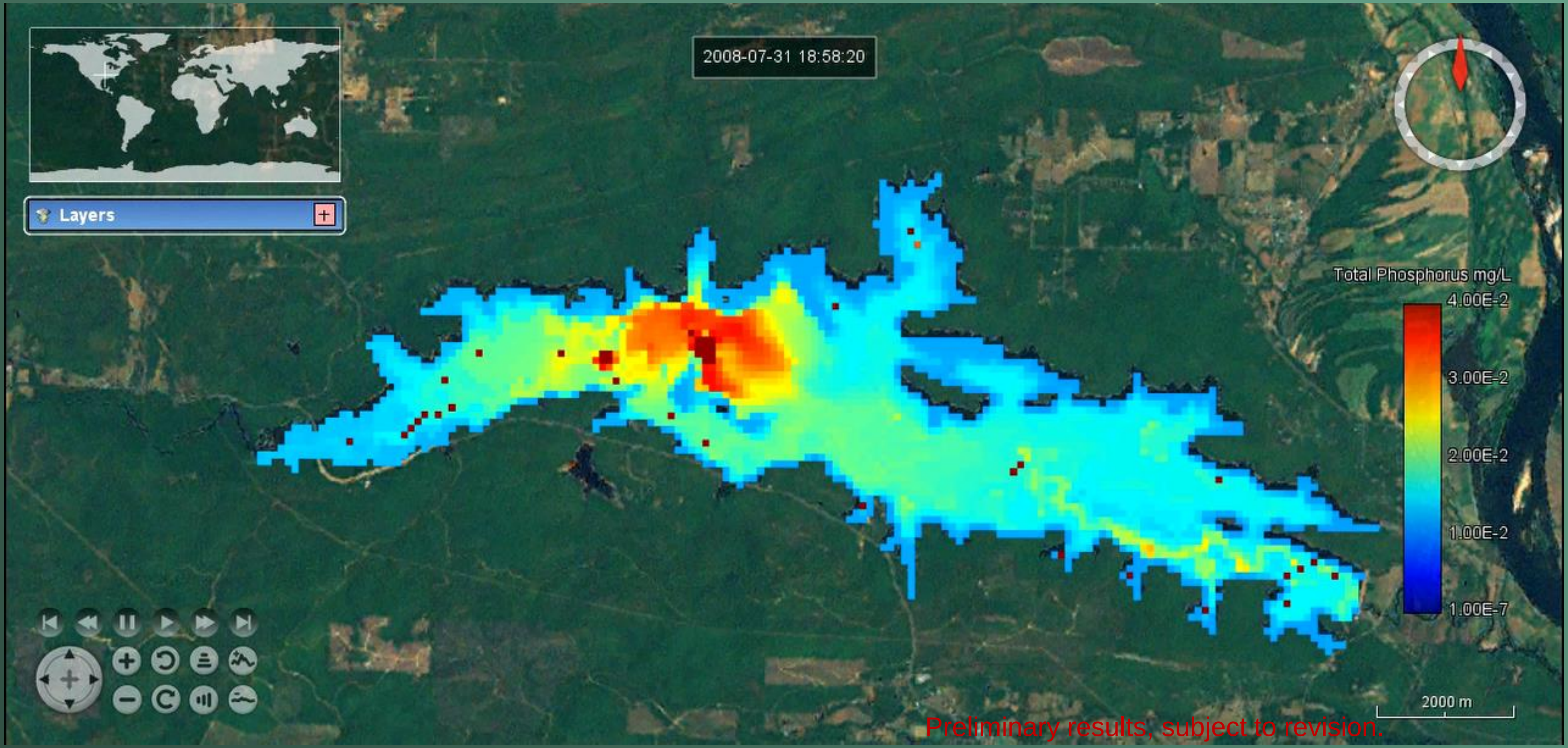
# Total Phosphorus

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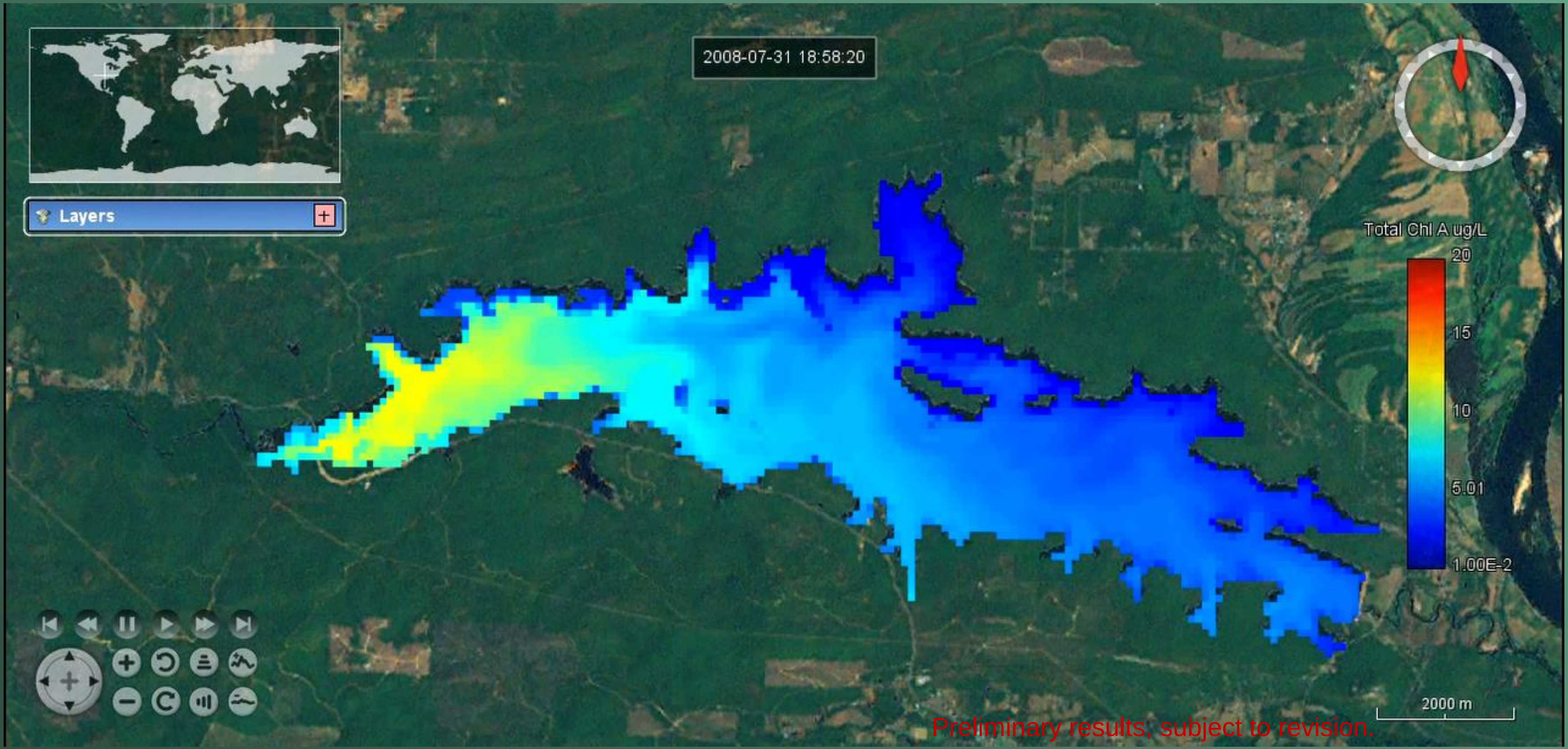
# Chlorophyll

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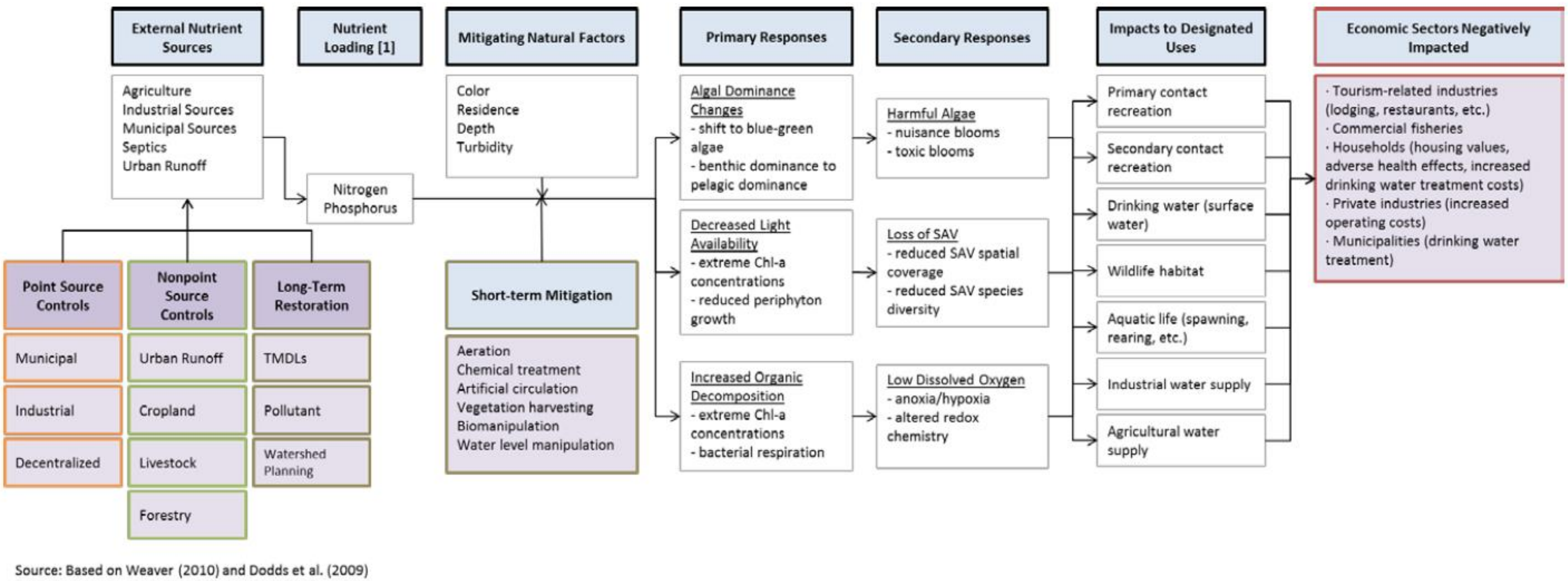
# Relationship of nutrient discharges to economic impacts associated with water quality in lakes and flowing waters.




https://www.epa.gov/nutrient-policy-data/compilation-cost-data-associated-impacts-and-control-nutrient-pollution

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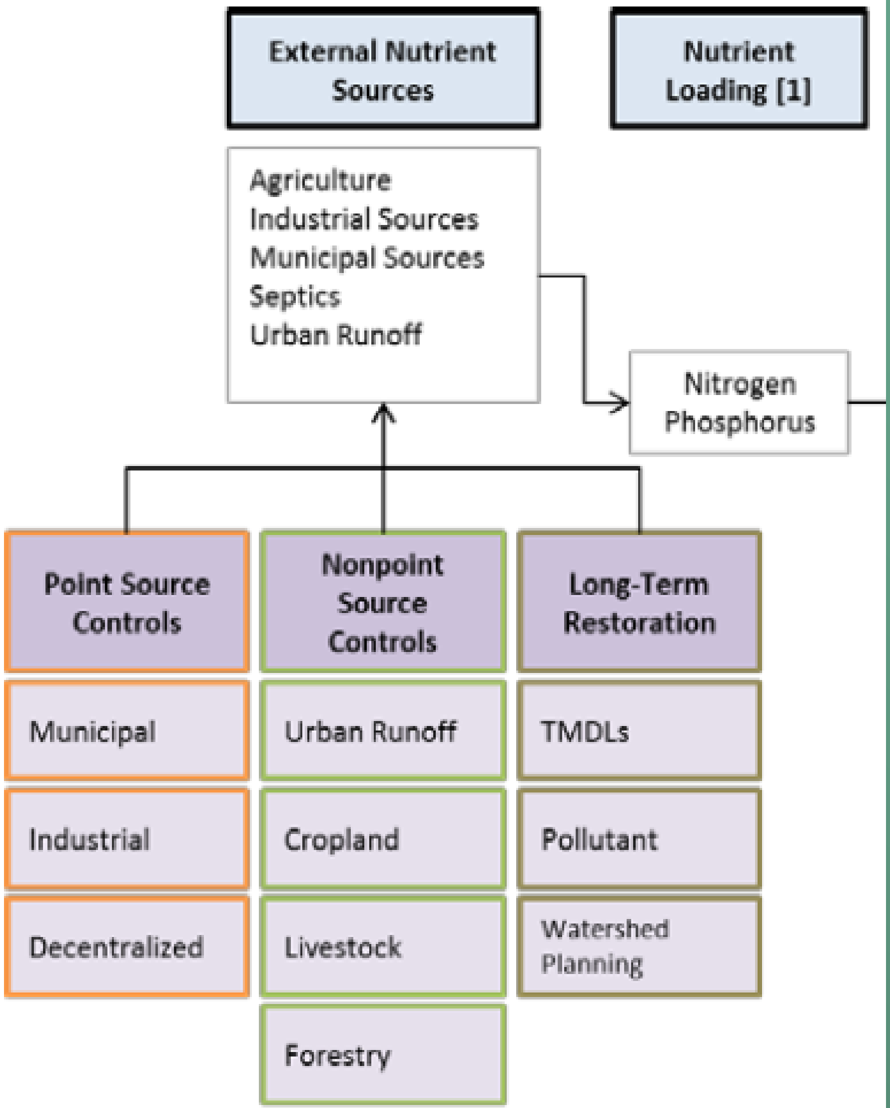
Relationship of nutrient discharges to economic impacts associated with water quality in lakes and flowing waters.




Source: Based on Weaver (2010) and Dodds et al. (2009)

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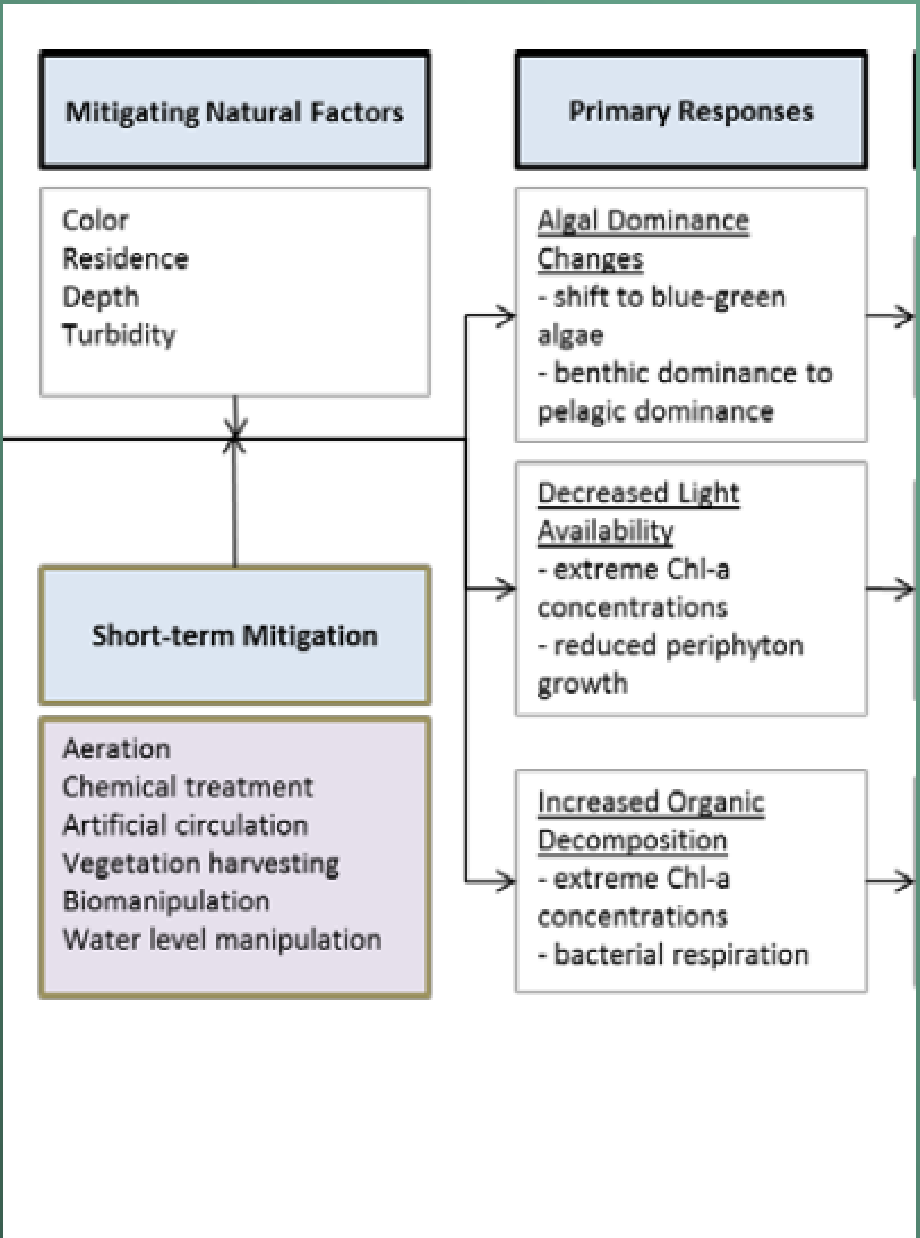
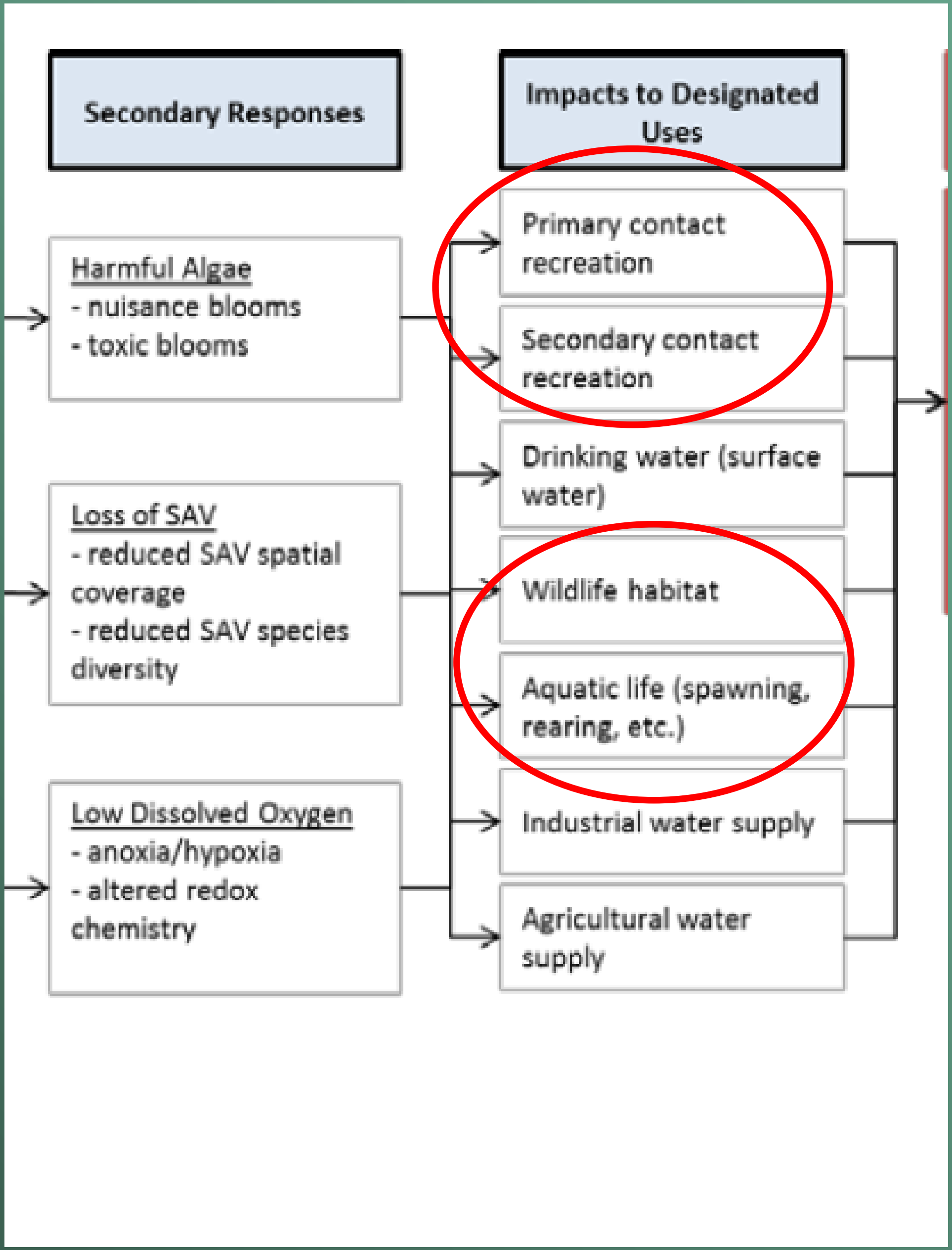
Relationship of nutrient discharges to economic impacts associated with water quality in lakes and flowing waters.



Relationship of nutrient discharges to economic impacts associated with water quality in lakes and flowing waters.

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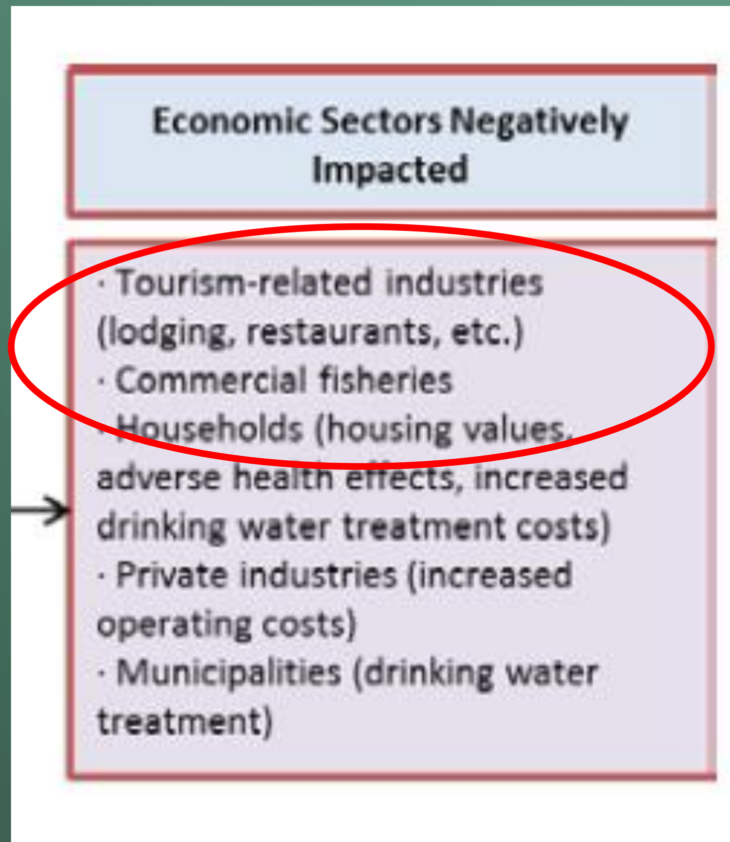


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# Example of the costs of nutrient pollution and eutrophication

| Study | Water Quality Issue | Location | Waterbody or Resource Description | Reported Loss (Original Dollar Years) |
|---|---|---|---|---|
| *National Aggregate* | | | | |
| Dodds, et al. (2009) | Eutrophication | National | Freshwaters throughout the United States | • Fishing and boating trip-related expenditure annual losses of $189 million–$589 million and $182 million–$567 million, respectively (2001$).<br>• Property value annual losses (scaled over 50 years) of $0.3 billion, $1.4 billion, and $2.8 billion for the low (5% private), intermediate (25% private), and high (50% private) assumed land availabilities, respectively.<br>• Aquatic biodiversity impacts of $44 million per year to develop 60 plans for the species that are at least partially imperiled due to eutrophication.<br>• Drinking water impacts of $813 million per year for bottled water because of taste and odor problems potentially linked to eutrophication (2001 dollars). |

https://www.epa.gov/nutrient-policy-data/compilation-cost-data-associated-impacts-and-control-nutrient-pollution

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# So, how do we control nutrients in our reservoirs?

- Watershed remediation (pg. 66*)
- Constructed wetlands (pg. 67)
- Pre-dams (pg. 70)
- In lake remediation (pg. 71)
  - Guide curve revision (pg. 72)
  - Inflow routing (pg. 72)
  - Dilution (pg. 72)
  - Flushing (pg. 72)
  - Selective withdrawal (pg. 72)
  - Hypolimnetic aeration and oxygen (pg. 74)
  - Sediment removal (pg. 74)
  - Sediment drying (pg. 75)
  - Phosphorus precipitation and inactivation (pg. 75)
- Biomanipulation (pg. 79)
  - Fish populations (pg. 79)
  - Fish harvesting (pg. 80)
  - Macrophytes (pg. 81)
  - Floating wetland islands (pg. 81)

* Page numbers are for Miranda's BMP manual.

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# Mitigation Costs Associated with Excess Phosphorus in Lakes

| Study | State | Waterbody | Description | Capital Costs (2012$)[1] | Annual O&M Costs (2012$/yr)[1] |
|---|---|---|---|---|---|
| | | | ***Aeration System*** | | |
| Berkshire Regional Planning Commission (2004) | MA | Onota Lake | Deep-hole system. | $355,621–$411,772 | $49,912 |
| ENSR Corporation (2008) | MA | Lovers Lake and Stillwater Pond | Hypolimnetic aeration only. Based on vendor quote. | $94,907 | $5,260 |
| ENSR Corporation (2008) | MA | Lovers Lake & Stillwater Pond | Artificial circulation | $117,195 | $7,990 |
| Chandler (2013) | MN | Twin Lake | Solar powered system. | $139,157 | $4,945 |
| Chandler (2013) | MN | Twin Lake | Bubbler system. | $232,424 | $34,616 |
| City of Lake Stevens (2013) | WA | Lake Stevens | Actual costs over 6 years, includes power consumption, staffing, and repairs. | Not reported | $35,000–$110,000 |

https://www.epa.gov/nutrient-policy-data/compilation-cost-data-associated-impacts-and-control-nutrient-pollution

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# Mitigation Costs Associated with Excess Phosphorus in Lakes

| Study | State | Waterbody | Description | Capital Costs (2012$)[1] | Annual O&M Costs (2012$/yr)[1] |
|---|---|---|---|---|---|
| *Alum Treatment* | | | | | |
| ENSR Corporation (2008) | MA | Lovers Lake and Stillwater Pond | Treatment to last 15 years for application area of 19 acres for Lovers Lake and 9.25 acres for Stillwater Pond. | $211,676–$243,667 | $0 |
| Barr (2005) | MN | Keller Lake | Treatment for the whole lake, based on lake-specific data. | $58,780 | $0 |
| Barr (2005) | MN | Kohlman Lake | Treatment for the whole lake, based on lake-specific data. | $165,759 | $0 |
| Barr (2012) | MN | Spring Lake | Treatment for the whole lake, based on lake-specific data; intended to last 10–32 years. | $986,000–$1,086,000 | $0 |
| Chandler (2013) | MN | Twin Lake | Alum addition to 19 of the 20 acres of the lake twice in 3 years (intended to last 10–20 years). | $146,377 | $0 |
| The LA Group (2001) | NY | Cossayuna Lake | Partial lake treatment (35 of 776 acres); intended to last 5 years. | $22,687 | $0 |
| Osgood (2002) | SD | Lake Mitchell | Based on $150,000 in the first year, $120,000 for 2 years after, and $100,000 per year thereafter. | $127,623–$238,246 | $0 |

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# Mitigation Costs Associated with Excess Phosphorus in Lakes

| Study | State | Waterbody | Description | Capital Costs (2012$)[1] | Annual O&M Costs (2012$/yr)[1] |
|---|---|---|---|---|---|
| ***Biomanipulation*** | | | | | |
| Chandler (2013) | MN | Twin Lake | Costs based on a total of four stockings conducted in years 1, 2, 4, and 6 over a 10-year period. | $279,403 | $0 |
| ***Dredging*** | | | | | |
| ENSR Corporation (2008) | MA | Lovers Lake and Stillwater Pond | Removal of 32,850 cubic yards from Lovers Lake and 28,500 cubic yards from Stillwater Pond; intended to last 10 years or less. | $1,546,246 | $0 |
| Barr (2005) | MN | Keller Lake | Dredging for the whole lake. | $628,944–$1,390,731 | $0 |
| Barr (2005) | MN | Kohlman Lake | Dredging for the whole lake. | $968,692–$2,143,112 | $0 |
| Chandler (2013) | MN | Twin Lake | Dredging for the whole lake. | $2,541,824 | $0 |
| The LA Group (2001) | NY | Cossayuna Lake | Partial lake treatment (300 out of 776 acres). | $5,905,143–$9,794,369 | $0 |
| Tetra Tech (2004) | WA | Lake Lawrence | Includes alum treatment; intended to last >50 years. | $28,124,132 | $1,404,218 |

https://www.epa.gov/nutrient-policy-data/compilation-cost-data-associated-impacts-and-control-nutrient-pollution

# Mitigation Costs Associated with Excess Phosphorus in Lakes

| Study | State | Waterbody | Description | Capital Costs (2012$)[1] | Annual O&M Costs (2012$/yr)[1] |
|---|---|---|---|---|---|
| | | | ***Herbicide Treatment*** | | |
| Berkshire Regional Planning Commission (2004) | MA | Onota Lake | Represents actual costs for application of the herbicide SONAR over the whole lake, with follow-up spot treatment. | $172,264 | $0 |
| The LA Group (2001) | NY | Cossayuna Lake | Partial lake treatment (35 out of 776 acres); intended to last 5 years. | $29,169 | $0 |
| | | | ***Hypolimnetic Withdrawal*** | | |
| Chandler (2013) | MN | Twin Lake | Lasts 20 years. | $583,532 | $39,561 |

https://www.epa.gov/nutrient-policy-data/compilation-cost-data-associated-impacts-and-control-nutrient-pollution

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# Summary of Costs to Administer Nutrient Trading and Offset Programs

| Program Name (Location) | Type of Program | Nutrient(s) Involved | Description of Costs (2012$) |
|---|---|---|---|
| Boulder Creek Trading Program (CO) | Offset | Nitrogen | The total cost was estimated at $1.58–$1.70 million. Costs included the costs of gathering data for planning and evaluation, construction, materials, labor, and time. The overall cost was brought down by the donation of volunteer labor, time, materials, and land easements from landowners. |
| Chatfield Reservoir Trading Program (CO) | Trading | Phosphorus | A $122 application fee to cover administrative costs is required for point sources to apply for increased discharge through trading. Credits that enter the pool are sold at a price that reflects the cost of nonpoint-source reduction projects, costs associated with the pooling program, and costs incurred by the Authority to administer the trading program. Exact costs are unknown, but the monitoring program was estimated to cost $71,000/year. |
| Cherry Creek Basin (CO) | Trading | Phosphorus | Coming from a combination of property taxes and user fees, the budget for 2003 was $1.7 million, of which at least 60% had to be spent on the construction and maintenance of pollution reduction facilities. The remaining 40% is used in research, planning documents, technical reports, and administrative costs. State grants finance a smaller portion of the work, particularly that involving educational campaigns about nonpoint-source pollution and construction of pollution reduction facilities. |

https://www.epa.gov/nutrient-policy-data/compilation-cost-data-associated-impacts-and-control-nutrient-pollution

# Summary of Costs to Administer Nutrient Trading and Offset Programs

| Program Name (Location) | Type of Program | Nutrient(s) Involved | Description of Costs (2012$) |
|---|---|---|---|
| New York City Watershed Program (NY) | Offset | Phosphorus | For development of the comprehensive strategies in the Croton System, the New York City Department of Environmental Protection allocated up to $1.2 million to each county required to develop a water quality protection plan. |
| Tar-Pamlico Nutrient Reduction Trading Program (NC) | Trading | Nitrogen and phosphorus | The Tar-Pamlico Basin Association gave $182,000 to the state Department of Environmental Management during Phase I to fund a staff position, and the trading ratio includes 10% for administrative costs. |
| Great Miami River Watershed Water Quality Credit Trading Pilot Program (OH) | Trading | Nitrogen and phosphorus | Estimated 3-year project cost of $2,430,810 including $607,000 to fund BMPs. The program receives in-kind support primarily in the form of water quality monitoring, and the training of soil and water conservation professionals by other organizations. |

*Source: Breetz et al. (2004)*

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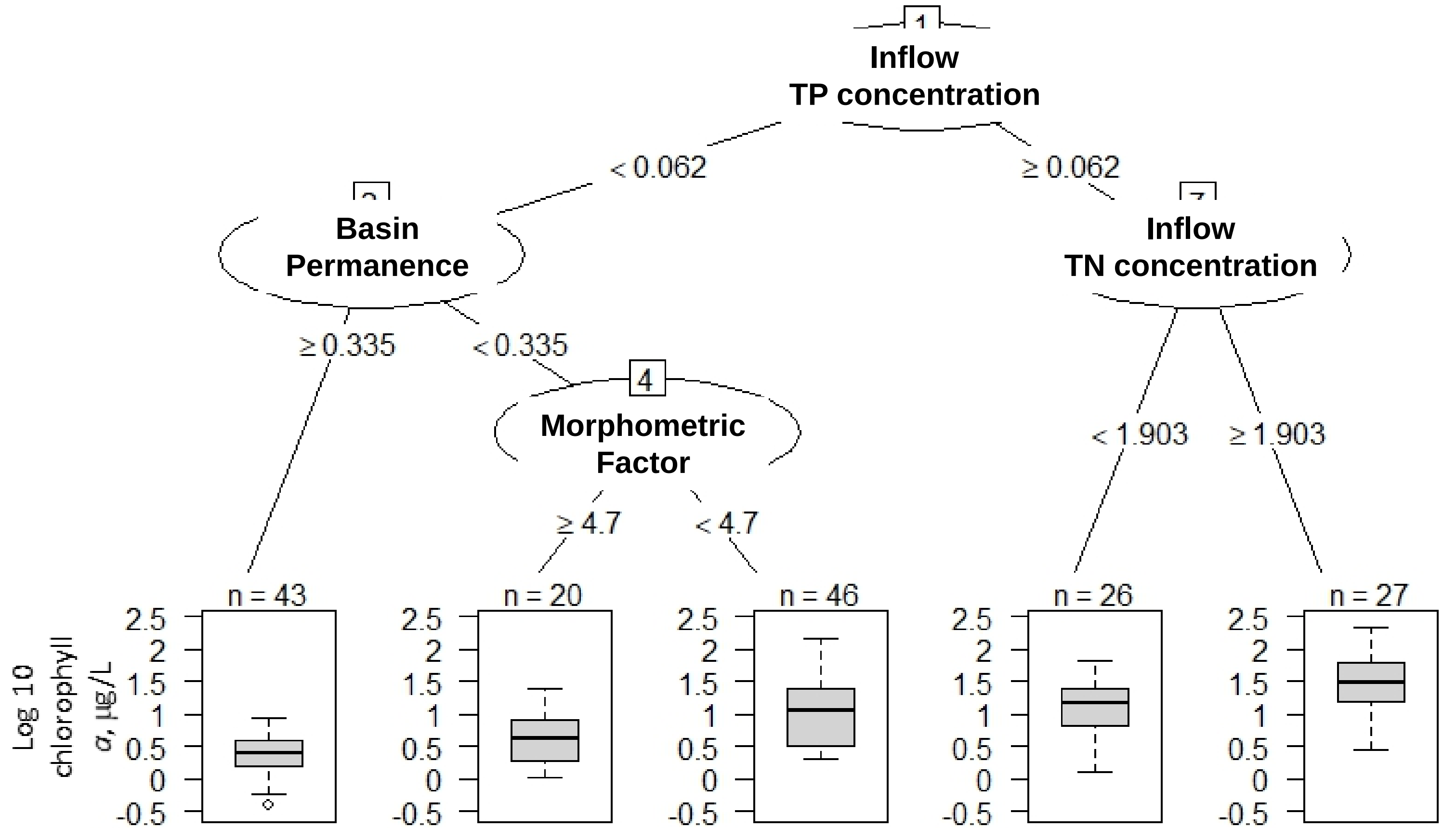
# Chlorophyll




| | | | | | |
|---|---|---|---|---|---|
| mean | 3.1 µg/L | 6.2 µg/L | 19.7 µg/L | 18.9 µg/L | 47.1 µg/L |
| median | 2.6 µg/L | 4.3 µg/L | 11.4 µg/L | 14.9 µg/L | 28.0 µg/L |
| #WBs | 30 | 18 | 31 | 23 | 21 |
| CTSI | M | M | E | E | E/H |
| Endpoint | 1 | 2 | 3 | 4 | 5 |

**This information is preliminary and is subject to revision.**

# Case Study, Aroura Reservoir

Hypolimnetic oxygenation of water supply reservoirs using bubble plume diffusers

Mark Mobley, Paul Gantzer, Pam Benskin, Imad Hannoun, Susan McMahon, David Austin & Roger Scharf (2019) Hypolimnetic oxygenation of water supply reservoirs using bubble plume diffusers, Lake and Reservoir Management, 35:3, 247-265

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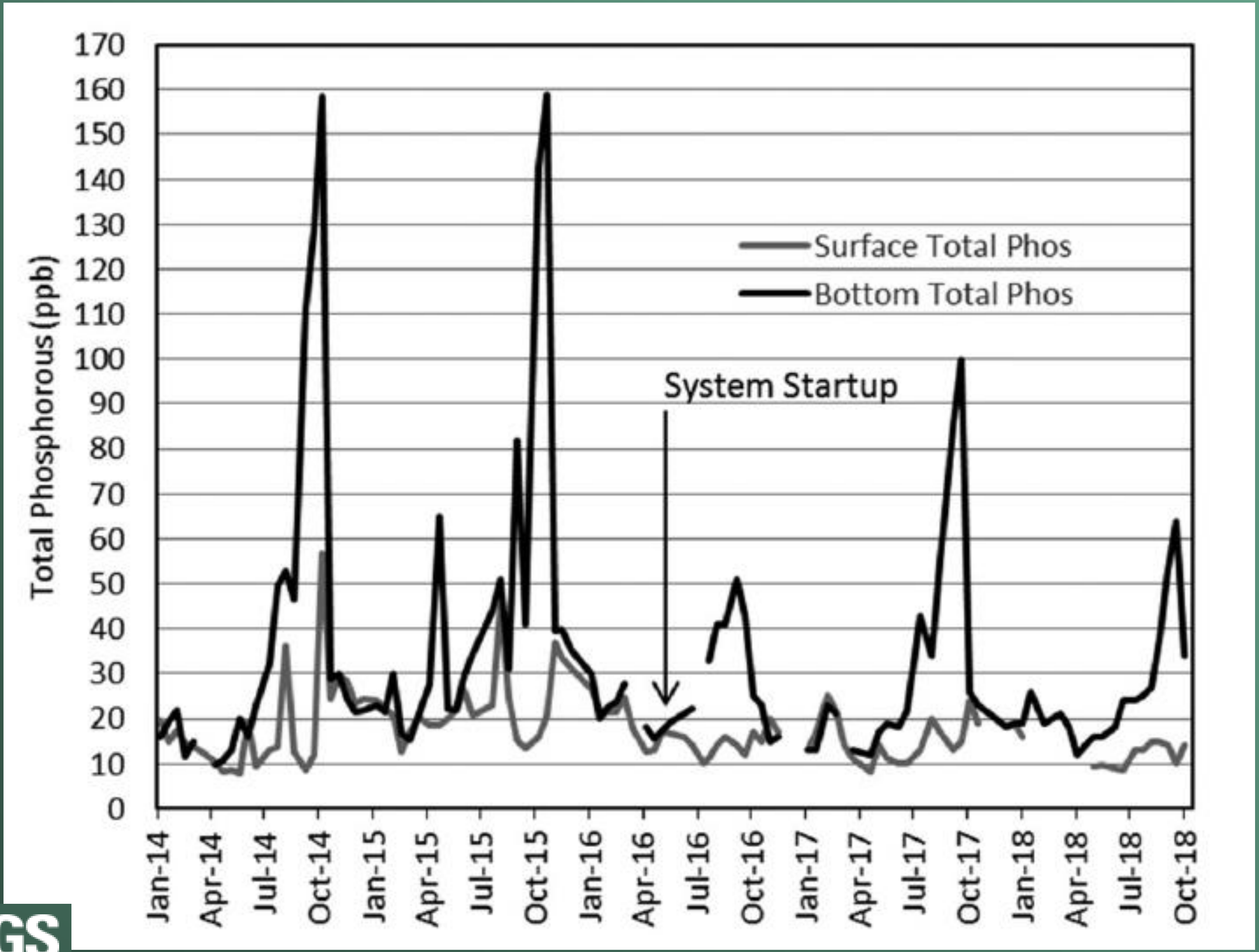
# Total Phosphorus

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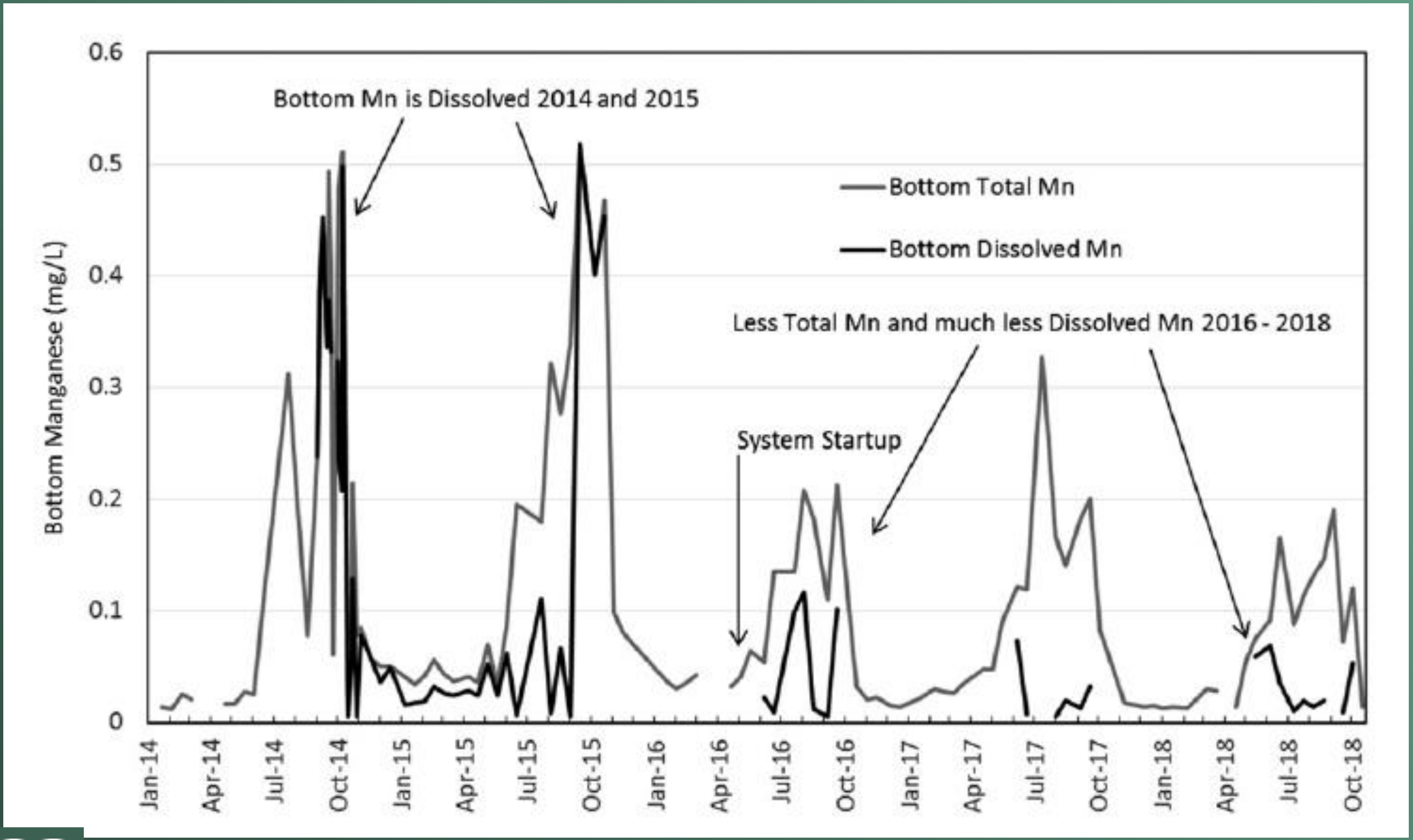
# Manganese

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# Canyon Lake, CA
# Alum Treatment

Alum treatments twice a year since 2013


Source: Terry McNabb, NALMS Certified Lake Manager

# Outcome:

- Strips phosphorus out of the water column.
- Reduces internal phosphorus loading.
- Effectively treats external loads, as well.
- Met their TMDL phosphorus target three years early.

https://www.youtube.com/watch?v=D0iUtkTVGnc

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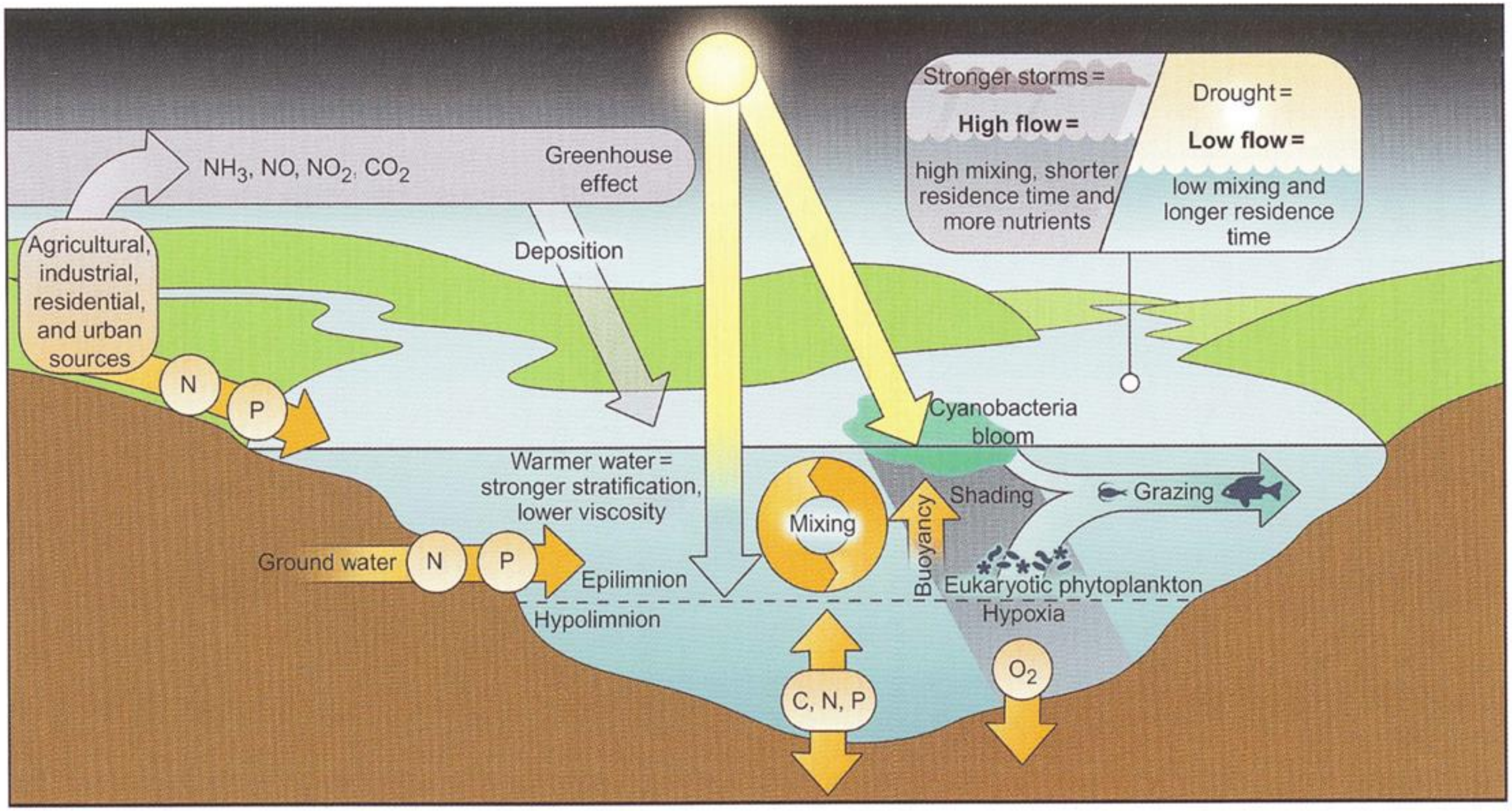


**FIGURE 2** Conceptual diagram illustrating external and internal factors controlling growth, accumulation (as blooms), and fate of cHABs in freshwater ecosystems. Factors can act individually or in combined (synergistic, antagonistic) ways.

# NALMS Position Statements

https://www.nalms.org/nalms-position-papers/

- Source Water Protection
- Use of Alum
- Climate Change
- Herbicides
- Watercraft Safety
- Invasive Species
- Harmful Algal Toxins
- Clean Water Act

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