

All Phosphorus Is Not Created Equal - Why Bioavailability Matters



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Upstate Freshwater Institute

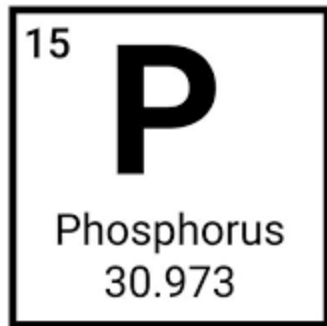


Preview

- 1.** Phosphorus and its many forms
- 2.** Significance of phosphorus in lakes
- 3.** What is bioavailability and how is it measured?
- 4.** Survey of the science
- 5.** Implications for water quality management



What is Phosphorus and Why is it Important?



1																		18	
H	2													13	14	15	16	17	He
Li	Be													B	C	N	O	F	Ne
Na	Mg													Al	Si	P	S	Cl	Ar
K	Ca		3	4	5	6	7	8	9	10	11	12		Ga	Ge	As	Se	Br	Kr
Rb	Sr		Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd		In	Sn	Sb	Te	I	Xe
Cs	Ba		Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg		Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn		Nh	Fl	Mc	Lv	Ts	Og

		La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb																	
		Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No																	

- DNA, RNA
- Cellular energy transfer
- Cell membranes
- Bones, teeth
- Commonly phosphates (PO_4^{3-})

Phosphorus: Sources and Uses

- Sources: bone ash→guano→phosphate rock
- Moroccan desert contains 75% of the world's phosphate reserves
- 17 million tons applied to crops annually
- Uses: fertilizer, detergents, pesticides



**Want to Learn
More about
Phosphorus?**



**THE
DEVIL'S
ELEMENT**

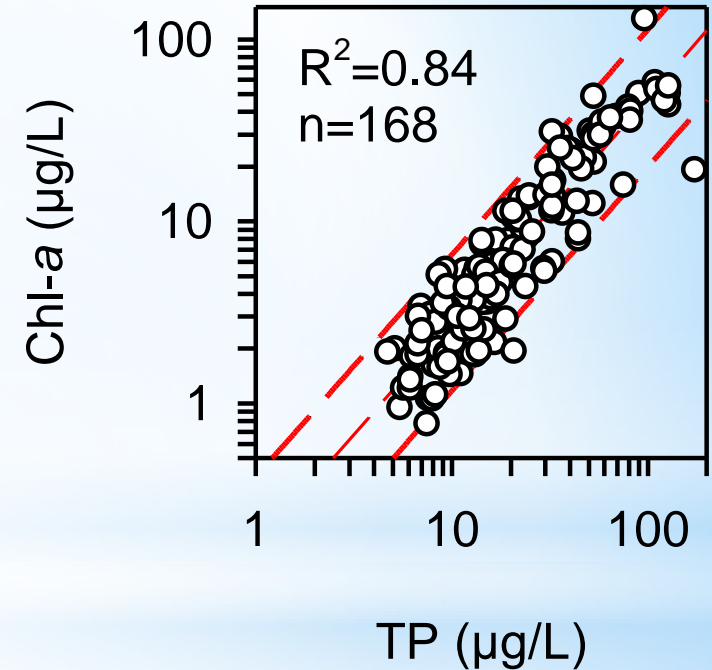
PHOSPHORUS AND A
WORLD OUT OF BALANCE

DAN EGAN

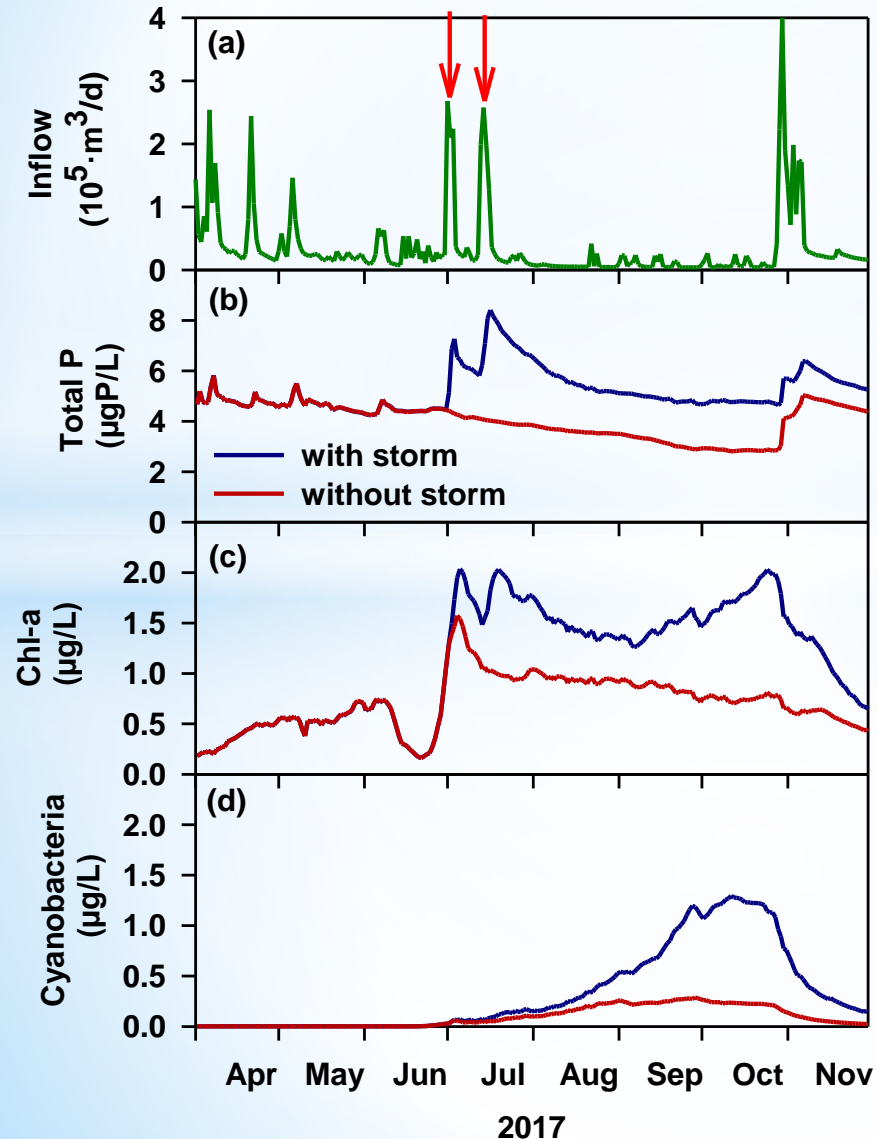
BEST-SELLING AUTHOR OF
THE DEATH AND LIFE OF THE GREAT LAKES

Significance of Phosphorus in Lakes

- Often the growth-limiting nutrient for algae in lakes
 - Liebig's law of the minimum
- New York State guidance value - 20 $\mu\text{g/L}$
- Focus of TMDLs and 9EPs in NYS
- Reducing P is the only proven remedy for eutrophication and HABs



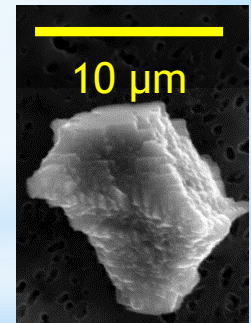
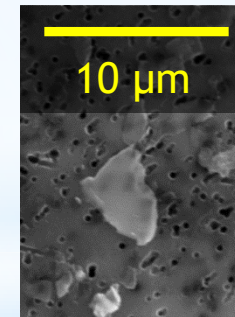
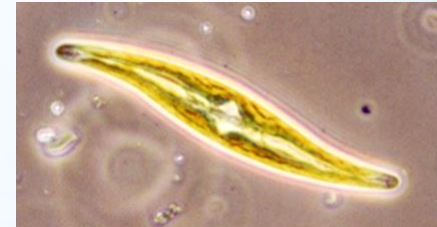
Impact of P Loading on HABs



- Model simulation
- Skaneateles Lake
 - big lake
 - small watershed
- Water residence time of about 12 years
- A few major storms contribute most of the annual P load

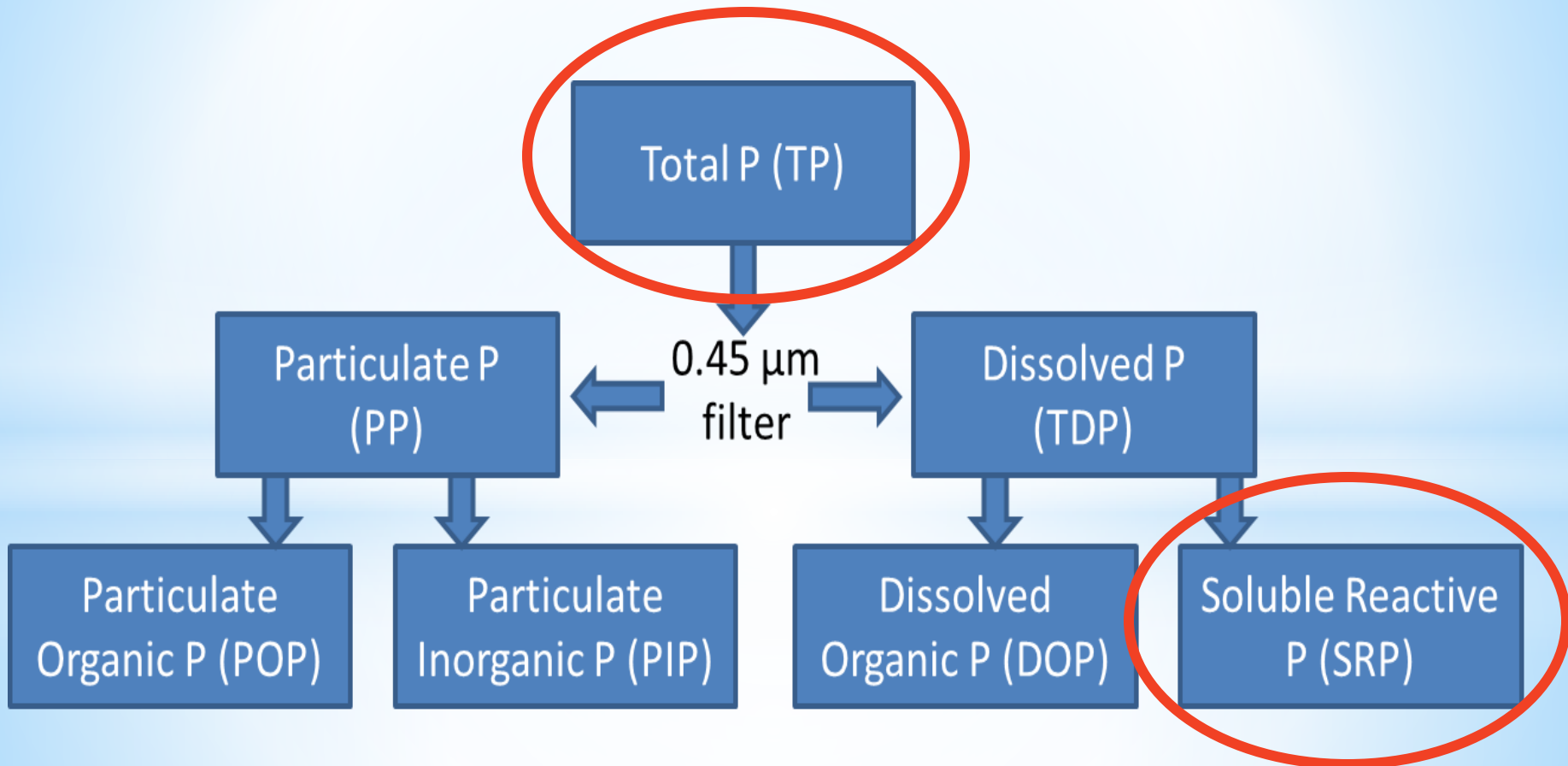
The Many Forms of Phosphorus

- Organic-Inorganic
- Particulate-Dissolved
- Labile-Refractory
- Sorbed to minerals - Al-P, Ca-P, Fe-P



**Some forms are available to algae,
some are not**

Forms of P Measured in the Lab



Further fractionation - NaOH extractable P, acid hydrolysable P

Forms are operationally defined!

What Forms of P are Available to Algae?

- Orthophosphate (PO_4^{3-})
- Soluble Reactive Phosphorus (SRP)
 - Immediately and almost entirely available
- Dissolved Organic Phosphorus (DOP)
 - Mostly available
- Particulate Phosphorus (PP)
 - Variable, but mostly unavailable



Quantifying Bioavailability – DCDA

Dual
Culture
Diffusion
Apparatus



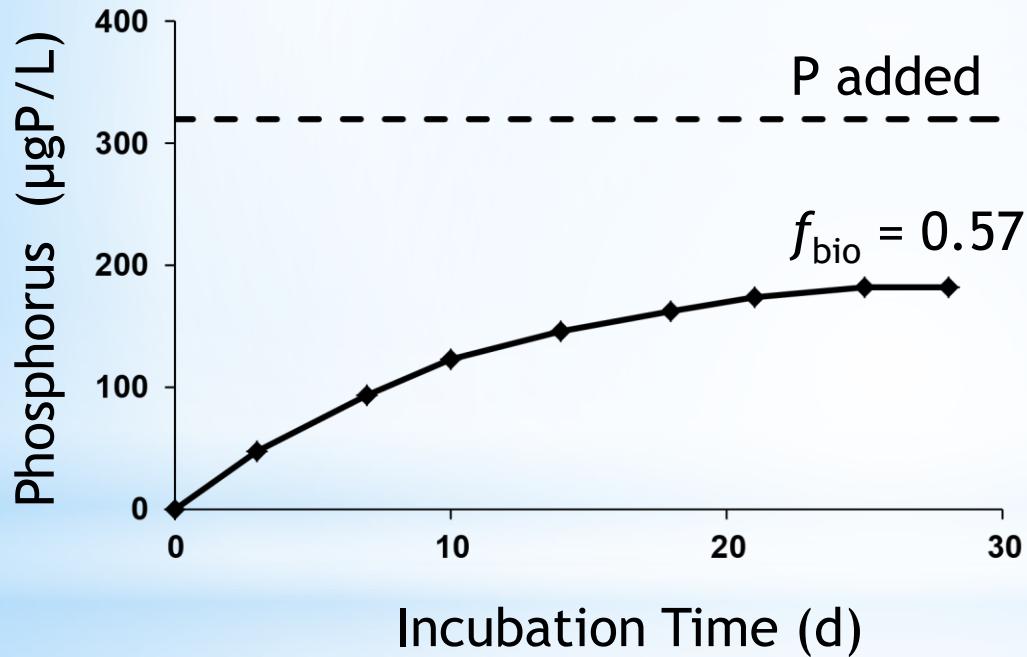
**Particulate-P
sample**



**P-starved
algal culture**

Young, T.C., DePinto, J.V., Flint, S.E., Switzenbaum, M.S. and Edzwald, J.K. 1982. Algal availability of phosphorus in municipal wastewater. *Journal of the Water Pollution Control Federation*, 54: 1505-16.

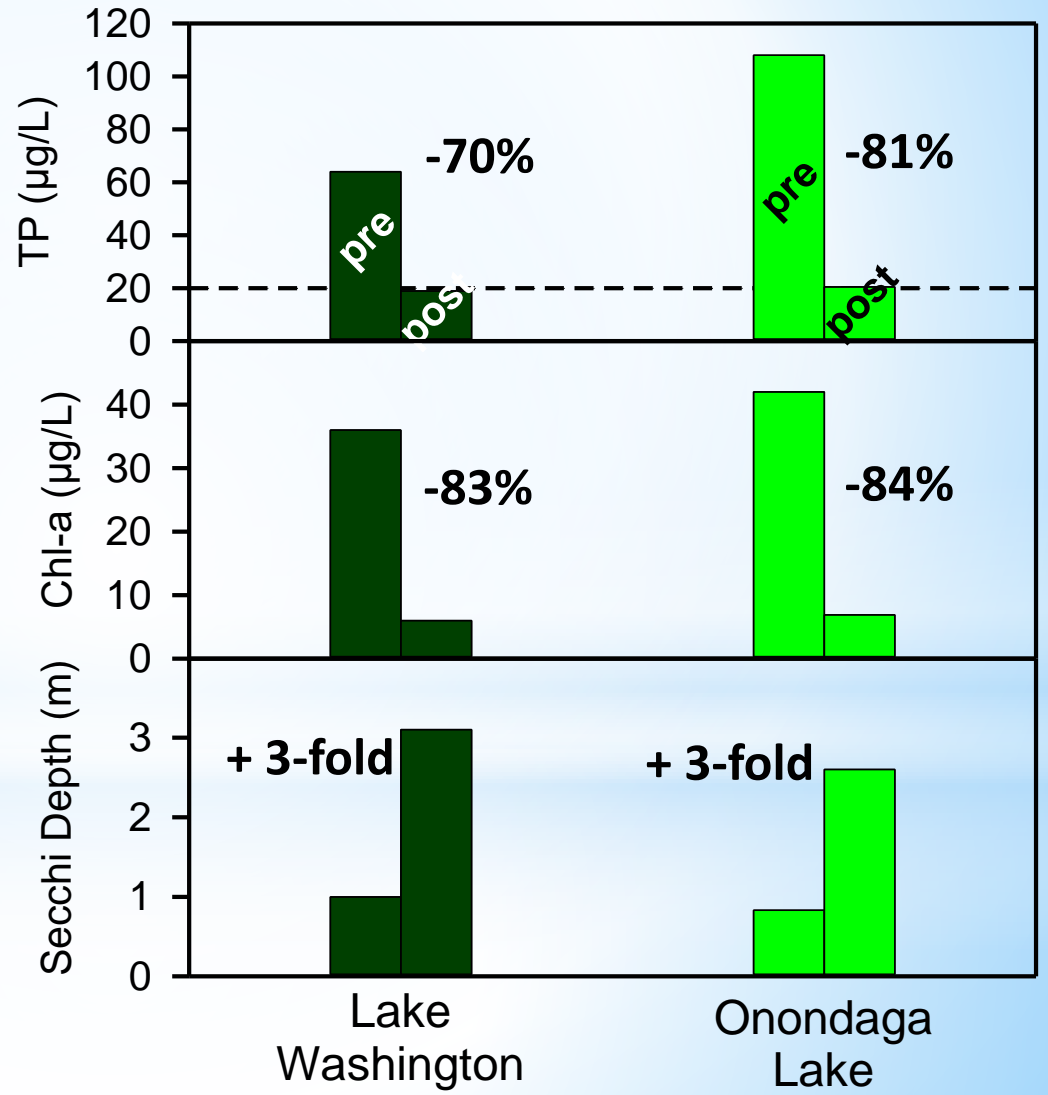
Quantifying Bioavailability – DCDA



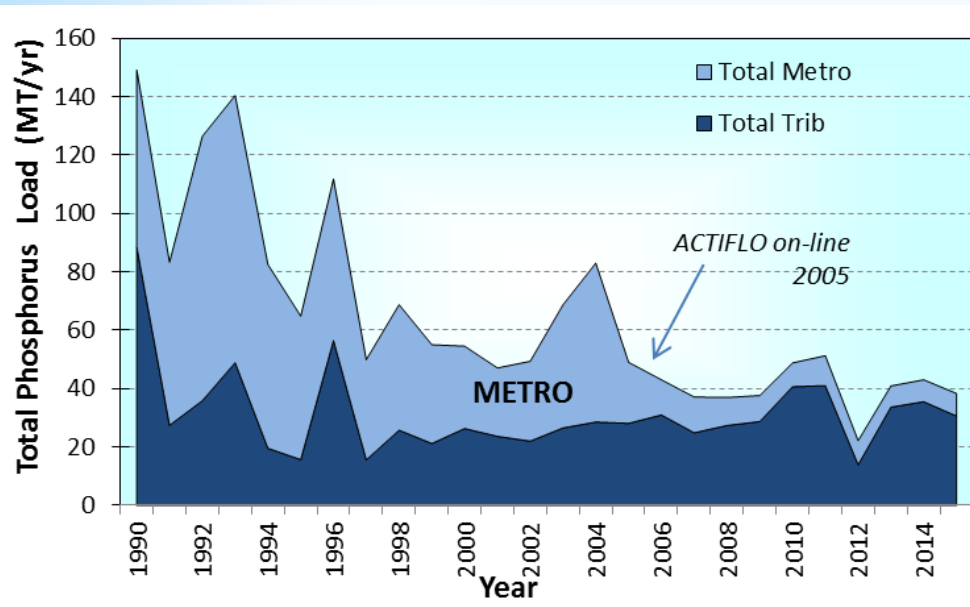
Comparing the Recoveries of Onondaga Lake and Lake Washington



- the pinnacle of lake restoration



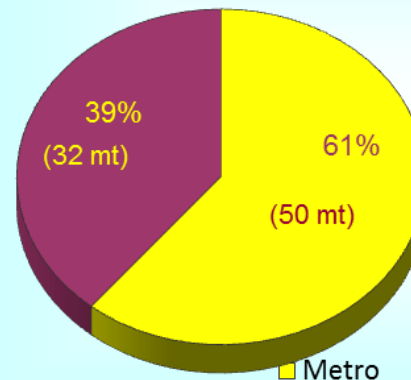
Phosphorus Loading to Onondaga Lake: Wastewater versus Watershed



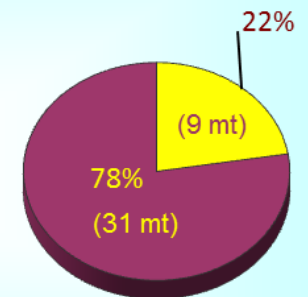
- Wastewater TP loading reduced by 80%
- Watershed TP loading unchanged

- Rehabilitation guided by high bioavailability of wastewater effluent

1990-2004
82 metric tons per year



2007-2015
40 metric tons per year



■ Metro ■ Watershed

Cannonsville Reservoir

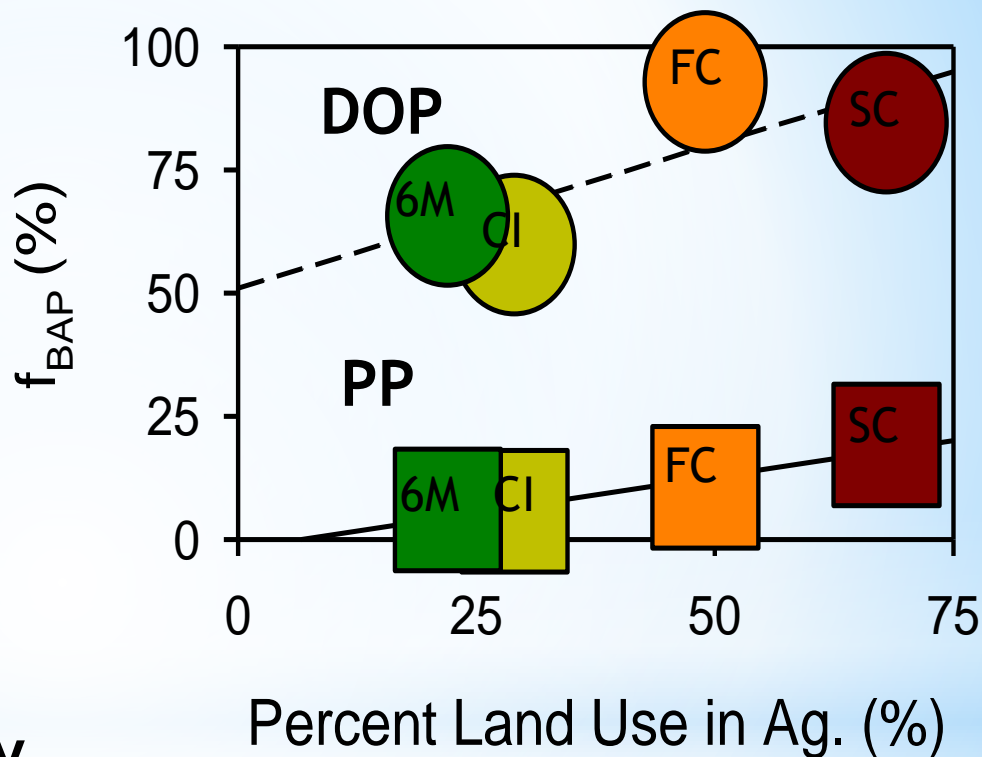
- West Branch of the Delaware River
- Dissolved P - 100% bioavailable
- Particulate P - 25% bioavailable (wet weather), 48% bioavailable (dry weather) - wastewater influence
- Dissolved P accounted for 91-97% of algal P



Auer et al. 1998. Phosphorus bioavailability and P-Cycling in Cannonsville Reservoir Lake and Reservoir Management 14:278-289.

Cayuga Lake Tributaries

Tributary	PP f_{BAP} (%)	DOP f_{BAP} (%)
Fall Cr.	11	93
Cayuga Inlet	6	60
Salmon Cr.	19	84
Six Mile Cr.	6	66



- **SRP was nearly completely bioavailable (> 93%)**

Prestigiacomio et al. 2015. Apportionment of bioavailable phosphorus loads entering Cayuga Lake, NY

Journal of the American Water Resources Association 52:31-47.

Phosphorus Loading to Western Lake Erie

- Re-eutrophication despite reduced TP loading
- TSS and PP↓, but SRP↑
- 26-30% of PP bioavailable, 100% of SRP bioavailable
- Erosion reduction efforts (e.g., conservation tillage) caused buildup of P at soil surface
- Recommended separate loading goals for particulate and dissolved forms of P



*Baker et al. 2014. Phosphorus loading to Lake Erie from the Maumee, Sandusky and Cuyahoga rivers: The importance of bioavailability
Journal of Great Lakes Research 40:502-517.*

Model Simulations for Owasco Lake - Phosphorus Reduction Scenarios

Scenario	% change	
	TP	Chl-a
30% TP load (particulate only)	-7	-3%
30% TP load (dissolved only)	-28%	-26%

“BMPs intended to address phytoplankton growth and HABs should focus on dissolved forms of phosphorus”

Land Cover, Phosphorus Cycling and Water Quality

More than 90% forested



Less than 40% forested



Bioavailable P is scarce in the absence of human activities - human waste, concentrated animal waste, over-fertilization

Prioritizing Water Quality Improvement Projects

- Septic system improvements
- Streambank stabilization
- Agricultural best management practices
- Water and Sediment Control Basins (WASCOBs)
- Ditch and culvert projects
- Filter strips
- Grassed waterways
- Wetland construction



How Do We Choose?



- Opportunity
- Cost
- Funding
- Nutrient and sediment loading reductions (total)
- **Bioavailability**

Recommendations

- Consider bioavailability in BMP selection
- Preserve forested lands
- Prioritize water quality improvement projects
 - Septic system maintenance
 - Sewer projects
 - Reduce/eliminate residential fertilizer
 - Agricultural best management practices
 - Manure management
 - Minimize P fertilizer

What About Erosion?



Photo by
Bill Hecht



Photo by
Bill Hecht

- Conspicuous and becoming more frequent
- Navigation, drinking water supplies
- Not the best target for eutrophication control

Questions?

