Phosphorus 101

Sustainable Phosphorus Alliance

P

Matt Scholz, PhD Program Manager Sustainable Phosphorus Alliance

Bill's Marching Orders

- General overview of phosphorus and phosphorus sustainability issues
- Biosolids, manure, and regional balances
- Drivers for change here and abroad
- Models and measurement
- Legacy phosphorus issues



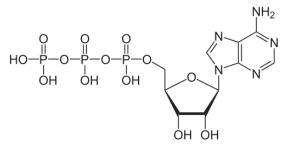
The Bright Side



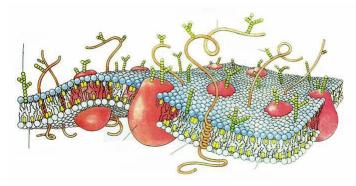
Phosphorus is in the House



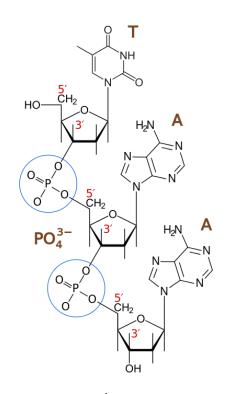
Your Frame: Ca₅(PO₄)₃(OH) Wikimedia Commons



Your Power: Adenosine Triphosphate



Your Bricks: Phospholipid Bilayer William Crochot – NIST



Your Blueprint: DNA



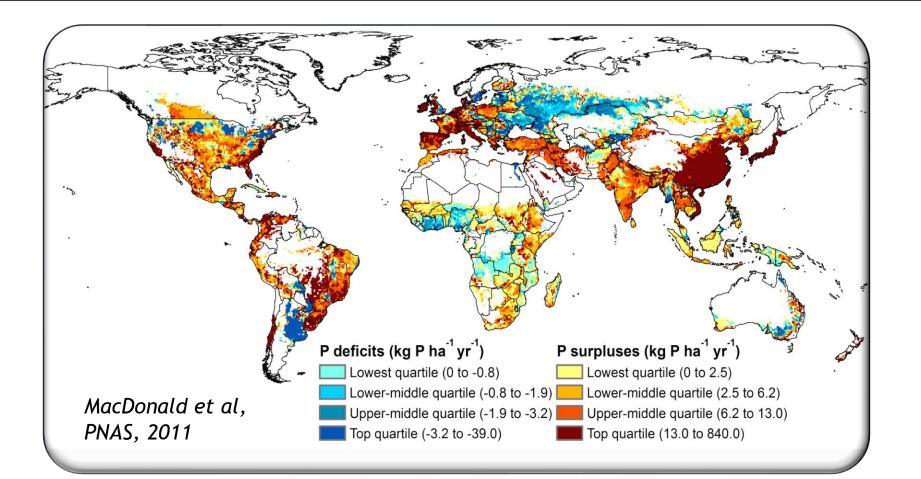
Not All the News Is Bad





Sustainable Phosphorus Alliance

Trash or Treasure?



We often focus on P as a pollutant, but global P deficits beget food insecurity.



The Dark Side



The Supply Problem: NOT Peak Phosphorus

"World resources of phosphate rock are more than 300 billion tons. There are no imminent shortages of phosphate rock." – USGS, Mineral Commodity Summaries 2018

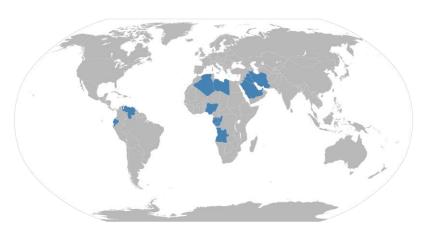
BUT



The Supply Problem

"World resources of phosphate rock are more than 300 billion tons. There are no imminent shortages of phosphate rock." – USGS, Mineral Commodity Summaries 2018

BUT



82% of global crude oil reserves here

71% of global phosphate rock reserves here

AND



The Supply Problem

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BUT



82% of global crude oil reserves here

71% of global phosphate rock reserves here

AND

> 400% increase in the global P flux as a result of mining (Y2K numbers; N increase = 108%, C increase = 13%) Falkowski et al. 2000, Science



Global Governance Needed

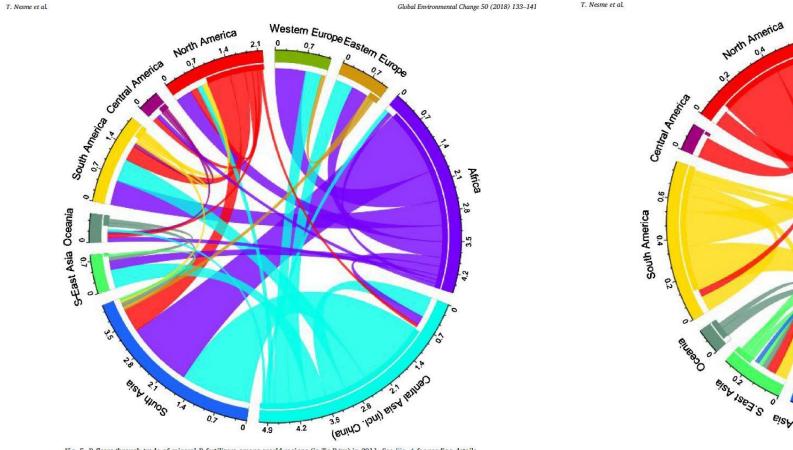


Fig. 5. P flows through trade of mineral P fertilizers among world regions (in Tg P/yr) in 2011. See Fig. 4 for reading details.



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Global Environmental Change 50 (2018) 133-141

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Eastern Europe

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15

Western Europe

0.2

0.4

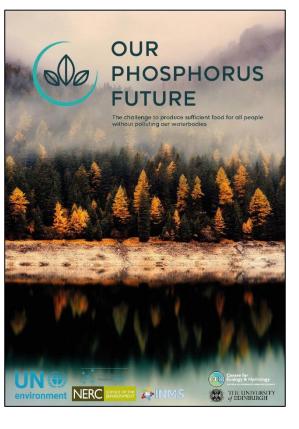
Califial Asia (Incl. China)

Global Governance Needed

Global Environmental Change 50 (2018) 133-141

Western Europe Eastern Europe North America 2.1 Central America South America 2 Africa 2.8 Oceania 3.5 Asia 0.7 Sreast (eulus, ion) siz, ising elsy yinos 7.0 4.2 4.9

T. Nesme et al.



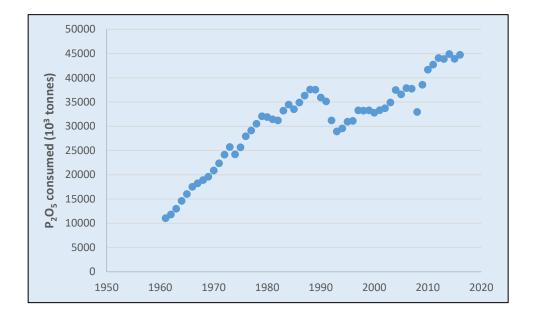
Consensus report by the scientific community to UNEP (and others) due early 2021

Fig. 5. P flows through trade of mineral P fertilizers among world regions (in Tg P/yr) in 2011. See Fig. 4 for reading details.



The Demand Problem

Phosphorus consumption has increased...



and it's wreaking havoc

40% of lakes were in the "most disturbed" condition for total phosphorus (NLA 2012)

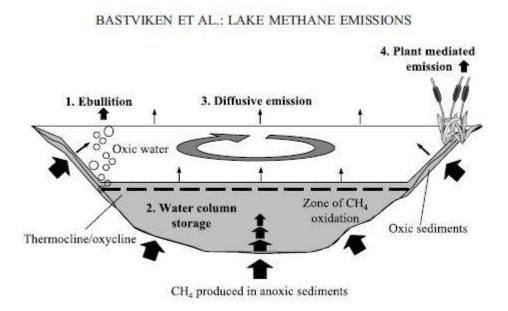
18.2% decline in the percentage of lakes with < 10 ppb P between 2007 and 2012

46% of US rivers and streams (by length) had "high" levels of phosphorus (NRSA, 2009)

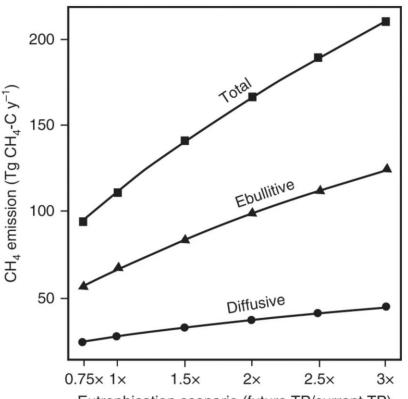
Phosphorus is the most important contaminant of our most important natural resource and commodity.



Phosphorus Drives Major GHG Emissions



Greenhouse gas emissions from lakes and reservoirs represent around 1/5th of those from fossil fuel combustion, and 75% of this impact is from methane.



Eutrophication scenario (future TP/current TP)

Beaulieu, J.J., DelSontro, T., Downing, J.A., 2019. Eutrophication will increase methane emissions from lakes and impoundments during the 21st century. Nature Communications 10.



Phosphorus meets methane at 2021 AAAS meeting!



UNDERSTANDING DYNNMC ECOSYSTEMS MAAAS ANNUAL MEETING

RESEARCH TOPICS

- COVID-19
- Toxins and pollution remediation
- Artificial intelligence, robotics, nanotechnology, and human-machine interface applications
- Modeling—traditional methods to quantum computing
- Weathering extreme climate and geological changes
- Microbiomes
- Genetic engineering challenges
- Social ecosystems
- Systems of interaction and community-building both in-person and virtually
- Invasive species

This list highlights issues we believe are particularly timely, but we welcome submissions on other relevant topics.

#AAASmtg

Symposium

"Phosphorus and Climate Change: A Vicious Circle"

Featuring

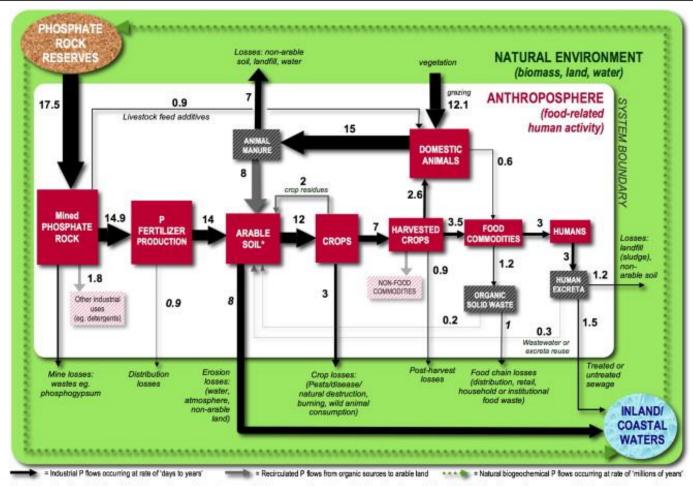
Moderators Jim Elser & Matt Scholz (SPA)

Speakers

John Downing (NOAA) Laura Johnson (Heidelberg U.) Ahren Britton (Ostara, Inc.)



Global P Flows Estimates



Cordell, Drangert, & White, 2009. Units are millions of tonnes of phosphorus per year.

* only a fraction of applied mineral P is taken up by crope in a given yeer, the balance comes from the soil stocks, either from natural soil P, or build up from previous years and decades of fertilizer application.



Holistic Approach

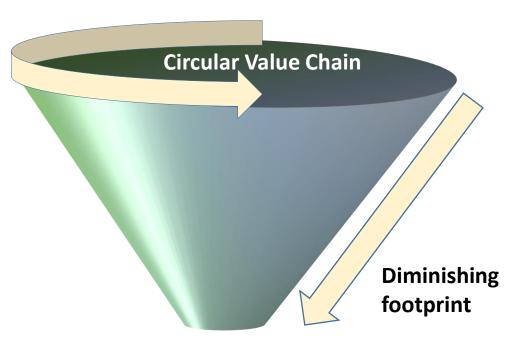
The Sustainable Phosphorus Alliance is a members organization that serves as North America's central forum and advocate for the sustainable use, recovery, and recycling of phosphorus in the food system.





The Conical Economy for Phosphorus

A conical economy is a circular economy that emphasizes reducing the consumptive footprint of the value chain (i.e. sustainable *use* and *sustainable* recycling).





Recycling



Recycling: Heavy Poo, Cheap P

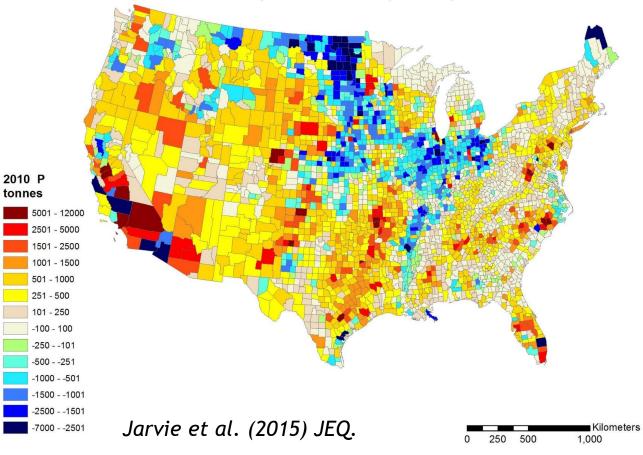
US P Fertilizer Consumption¹ 1.9 Mtonnes/yr US Manure P Recovered^{2*} US Manure P Produced² US Biosolids P Generation³

1.3 Mtonnes/yr 3.3 Mtonnes/yr 0.4-1 Mtonnes/yr

*i.e. animals pooping in fields don't count

¹ IFASTAT 2016 ² IPNI NuGIS 2014 ³ Phosphorus Forum 2017; Toffey 2015

Phosphorus Produced (human and manure) Minus Phosphorus Demand (fertilizer)





Recycling: Heavy Poo, Cheap P

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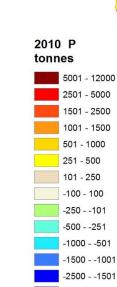
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Chesapeake Bay

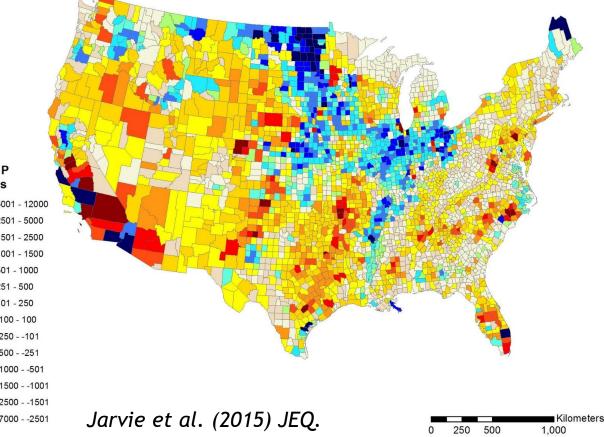
Manure P Produced Biosolids P Produced Fertilizer Applied

Kleinman et al. 2012 J Soil Water Conservation *Biosolids number = 3.6 Mt waste * 3.5% P

70 ktonnes/yr 126 ktonnes/yr* 47 ktonnes/yr



Phosphorus Produced (human and manure) Minus Phosphorus Demand (fertilizer)





Recycling: Heavy Poo, Cheap P

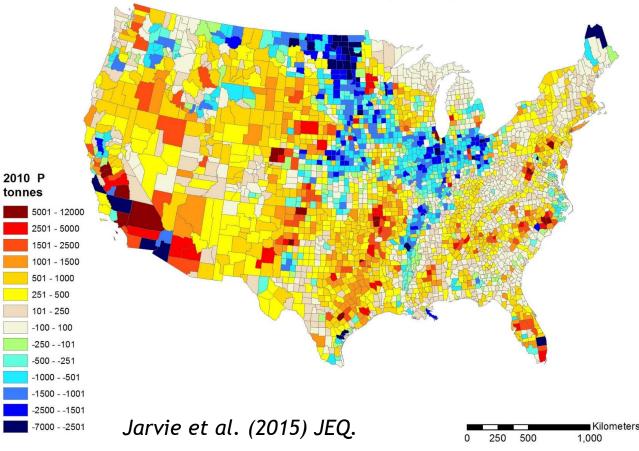
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However, N:P ratios of residuals aren't well balanced (but have C!) and:

Price of Triple Superphosphate Fertilizer: \$0.35/lb (market price, USDA 2014, <100 lb/acre needed)

Advancing tech for P capture would help, especially at small scale, as would policy incentives. Phosphorus Produced (human and manure) Minus Phosphorus Demand (fertilizer)





Land Application Regulations Tool

GIS-P A Tool for Sustainable Phosphorus Management	Sustainable Phosphorus Alliance 🛐 🎔 🕫
Project Overview Manure Regulations	Biosolid Regulations Full Data Map Sources
	Alabama 👳
	Alabama
Regulations	Regulator
	Agency(ies) involved in regulation enforcement: Alabama Department of Environmental Management (ADEM)
You'll notice two tabs at the bottom of this panel for "Regulations" and "State Maps". The current Regulations tab provides a text summary of state-level manure land application regulations. A pulldown menu in the upper right	Links to regulations: ADEM CAFO program: http://www.adem.state.al.us/programs/water/cafo.cnt Chapter 335-6-7. AL NPDES http://www.adem.state.al.us/programs/water/waterforms/CAFORule12-1-00.pdf Which departmental category is the regulating agency? ENV = environmental; NR = natural resources; AG = agriculture; COMB = more than one agency; OTH = other
of the pane permits you to select a state of interest.	Combined
Please note that the intent here is not to summarize all manure land application regulations, but rather to	Other regulatory info: Not Applicable Definitions
focus on those that pertain to how nutrients flow through the environment. For most states, these summary data were used of hus toto resultation.	How CAFOs are defined or categorized: 335-6-7-02 (h) "Animal Feeding Operation" (AFO) means a lot or facility (other than an aquatic animal production facility) where animals (does not have to be the same animals) have been are as will be stabled confined, extended or concentrated and fed or maintained (watered, closed, closed, concentrated are Ver a Last watered, closed, concentrated and fed or maintained (watered, closed, concentrated are Ver a Last watered, closed, concentrated are Ver a

https://phosphorusalliance.org/gis-p

Rauh E, Muenich RL, Scholz M. Policy Landscape for Recycled Fertilizers in the US: Implications for land application of biosolids and CAFO manure. In review.

How to regulations vary across states?

How do biosolids and manure regulations compare?

What is the broader context for the regulations that exist?



Circularization Efforts Underway

- Ostara: Crystal Green
- Renewable Nutrients: CaP to feed and fertilizer
- Green Technologies: GreenEdge
- DC Water: Bloom
- Lystek: Lystegro
- Midwest Bioag: TerraNu
- Anuvia: SymTRX
- Upcycle & Co: Native Plant Fertilizer (brewer's yeast, algae, biosolids)

Plus over 80 P-recovery facilities operating or under construction in the global wastewater industry (Kabbe, 2018, Isle Utilities)





Change Drivers



Drivers of a Conical P Economy - North America

• Legislative

Binational agreements: e.g. Great Lakes Water Quality Agreement
Federal laws: e.g. US Clean Water Act & Canada Water Act
Multi-state/provincial agreements: e.g. Chesapeake Clean Water Blueprint
State & Provincial regulations: e.g. Ontario Nutrient Management Act (NMS/P)
Local/state regulations: e.g. organics diversion laws, municipal P fertilizer bans

- Incentives programs for farmers (e.g. USDA EQIP program, nutrient trading)
- Legal threats (e.g. potential regulation of dairy manure as a hazardous waste)
- Growth constraints (e.g. N. Carolina ban on new lagoons for swine waste)
- Corporate supply chain sustainability efforts (e.g. Field to Market)
- Dietary changes (e.g. Impossible Burgers)





Additional Drivers in the EU

- Listing of P as a critical material (not in US)
- Mandates for recovery of P from sewage sludge \rightarrow P-recovery from ash
- Swiss ban on biosolids land application
- Danish taxes/restrictions on P
 - 22 Euro/kg P at outlet from WRRFs
 - 63 Euro/ton residuals sent to landfill
 - limit of 140-170 kg N/ha/y for the entire Danish territory
 - Tax on P in animal feed
- Other EU strategies/plans
 - Farm-to-Fork strategy: reduce nutrient losses by 50% by 2030
 - Circular Economy Action Plan II -- Integrated Nutrient Management Action Plan
 - The US lacks national level policies such as these





Measurement, Models, and Communication



Incentives for P Sustainability in Ag

- Nutrient Management Planning (NRCS 590): Includes biosolids and manure!
- Pay for Practice: Farmers reimbursed to implement certain BMPs
 - Advantage: avoid having to measure P (difficult)
 - Disadvantage: action driven, BMP performance is highly variable
- Pay for Performance: Farmers reimbursed for modeled reductions
 - Advantage: result driven, actions tailored to fields
 - Disadvantage: models may not reflect reality, information intensive (transaction costs)
- Nutrient Trading Programs (our webinar: https://youtu.be/NFci0_HIDDY)
- Corporate Incentives



The Role of Models

Currently impossible to measure P flows at scale

- Diffuse in nature, landscapes are immense
- No cheap, reliable sensors

Hydrological models required to simulate data



Models Diverge

Nitrogen

2012

0

25

Agriculture

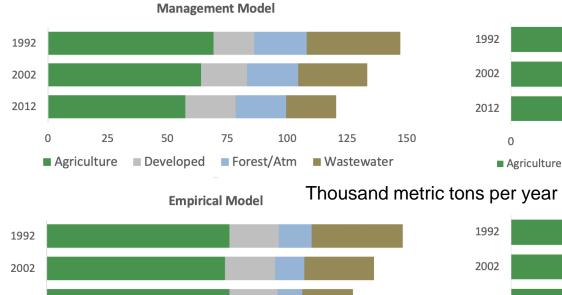
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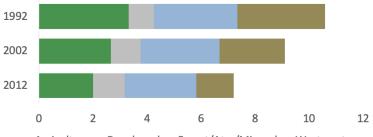
Developed Forest/Atm Wastewater

100

125

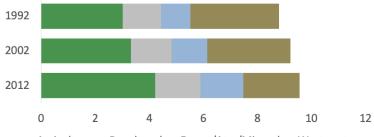


Phosphorus **Management Model**



■ Agriculture ■ Developed ■ Forest/Atm/Mineral ■ Wastewater





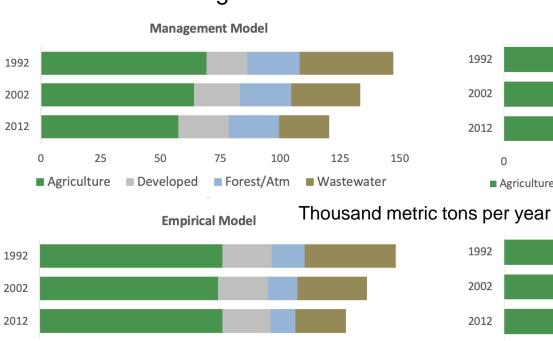
■ Agriculture ■ Developed ■ Forest/Atm/Mineral ■ Wastewater

Chesapeake Bay watershed management model v. SPARROW empirical model (Ator et al. 2020. JEQ) And Dr. Don Boesch, U Maryland

150



Models Diverge



75

Developed Forest/Atm Wastewater

100

125

150

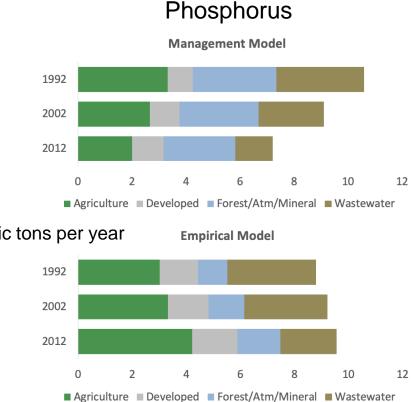
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Agriculture

0

Nitrogen



Possible Explanations

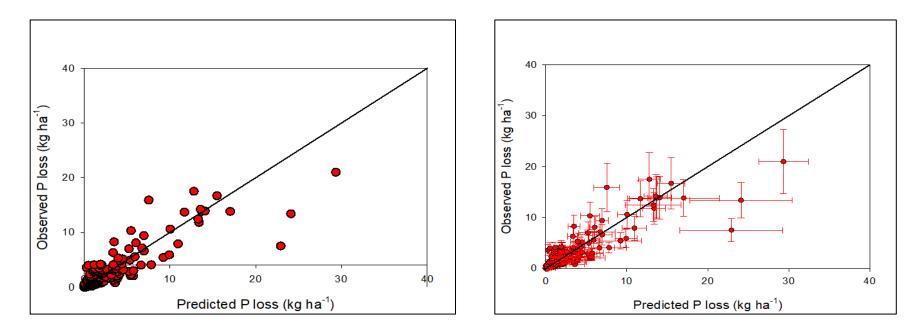
- Lag times
- Uncertainty
- User error
- Model differences
- Assumptions of effects of actions.
 - Ag BMPs less effective
 - More urban nutrient retention

Chesapeake Bay watershed management model v. SPARROW empirical model (Ator et al. 2020. JEQ)



Modeling Performance

Need to build public trust in the face of uncertainty



Images stolen from Dr. Carl Bolster, USDA-ARS



A Phosphorus Legacy



Complications in Messaging

Messaging can appear to be mixed

• Soil Erosion P: has been helped greatly by conservation practice (no-till, cover crops, etc.)



Further Complications in Messaging

Messaging can appear to be mixed

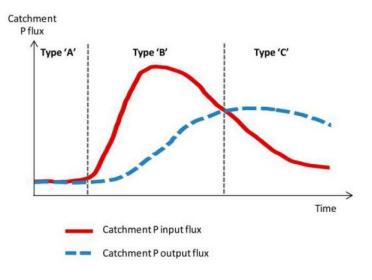
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- Dissolved P: can be made worse by same conservation practices (no-till, cover crops, etc.)



Complications in Messaging

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- Soil Erosion P: has been helped greatly by conservation practice (no-till, cover crops, etc.)
- Dissolved P: can be made worse by same conservation practices (no-till, cover crops, etc.)
- Legacy P: largely unaffected by conservation practice



For fertilizer applied in a year: <25% plant uptake <10% lost to runoff

The rest: Legacy P!

Haygarth et al. ES&T 2014



Legacy Phosphorus in Vermont

	Contents lists available at ScienceDirect	
2 2 2 2 1 2 1 2 2 2 2 2 2 2 2 2 2 2 2 2	Global Environmental Change	
ELSEVIER	journal homepage: www.elsevier.com/locate/gloenvcha	

Phosphorus flows and legacy accumulation in an animal-dominated agricultural region from 1925 to 2012 Michael B. Wironen^{a,b,*}, Elena M. Bennett^c, Jon D. Erickson^{a,b}

Current Lake Champlain TMDL: Ag must reduce P contribution by 53% over next few decades

Legacy P built from 1925-2012 = 240 ktonnes

(Largest import now: animal feed = 3x fertilizer)

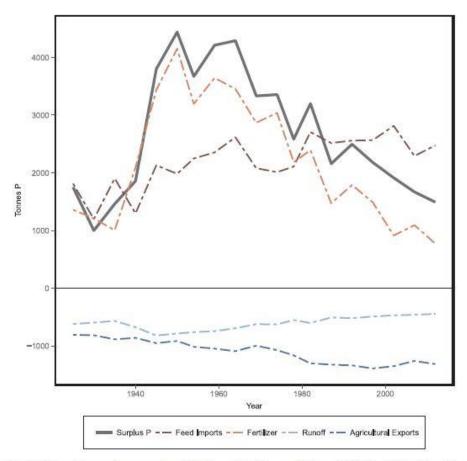


Fig. 5. Phosphorus flows and net balance in Vermont from 1925 to 2012. Negative flows (values below zero) indicate outflows from Vermont's agricultural system.



Some Concluding Questions

- How can we incentivize recycling when virgin P is so cheap?
- How do we move recycled phosphorus to places of scarcity?
- What kinds of national goals and policy could we set to drive P sustainability?
- How do we improve models and guide their implementation?
- How do we communicate complex messages about P sustainability effectively?





Sustainable Phosphorus Alliance

PhosphorusAlliance.org

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