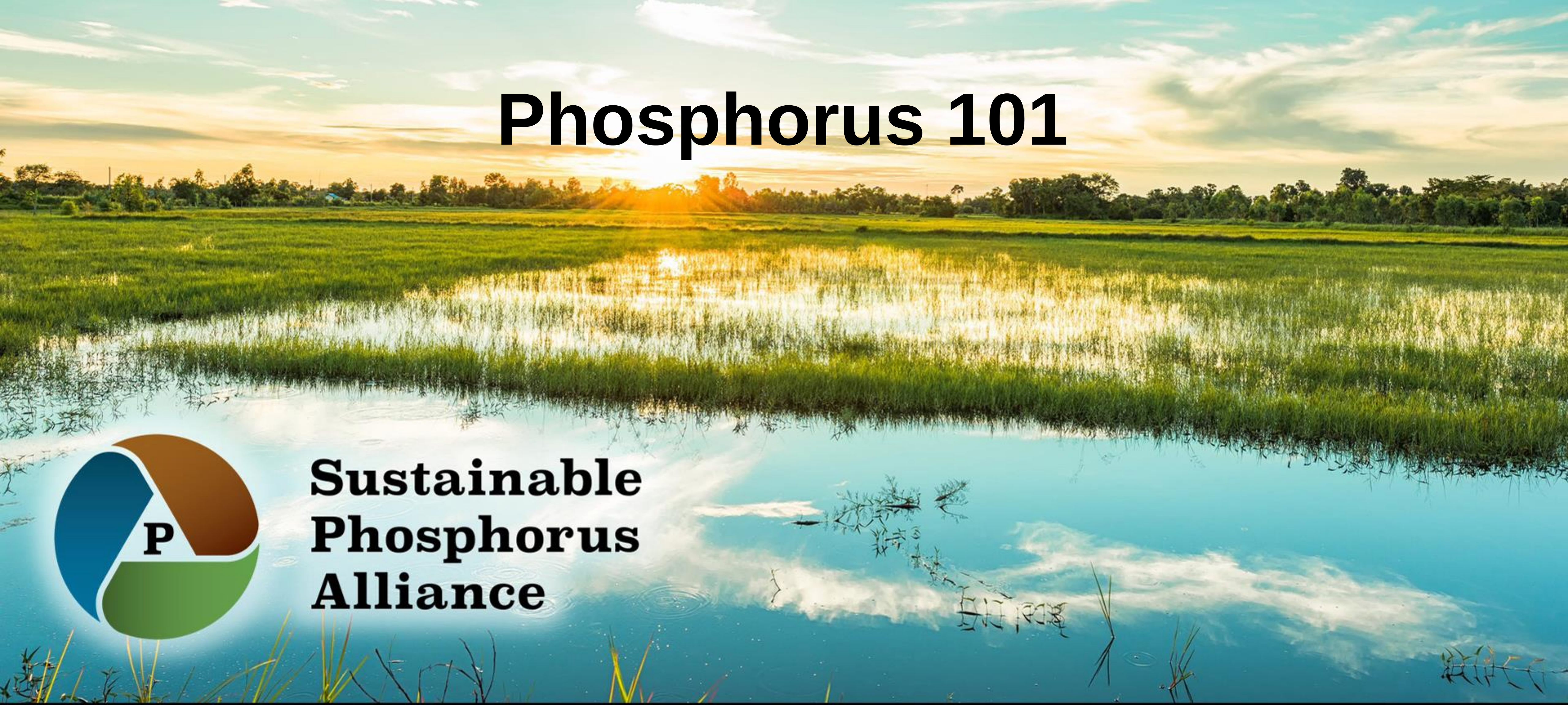
Phosphorus 101



Sustainable Phosphorus Alliance

Matt Scholz, PhD
Program Manager
Sustainable Phosphorus Alliance

Bill's Marching Orders

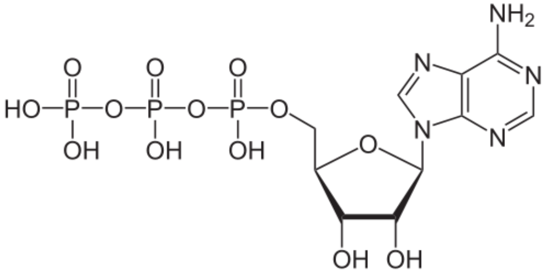
- General overview of phosphorus and phosphorus sustainability issues
- Biosolids, manure, and regional balances
- Drivers for change here and abroad
- Models and measurement
- Legacy phosphorus issues

The Bright Side

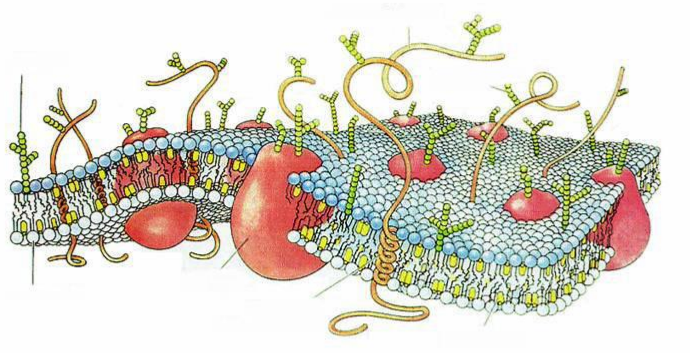
Phosphorus is in the House

Your Frame: $Ca_5(PO_4)_3(OH)$

Wikimedia Commons

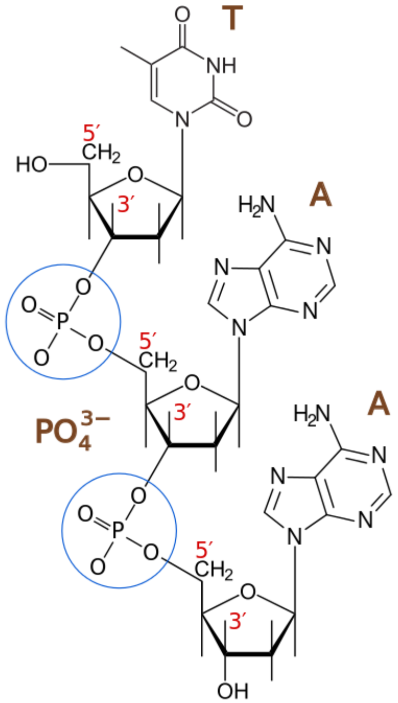


Your Power: Adenosine Triphosphate



Your Bricks: Phospholipid Bilayer

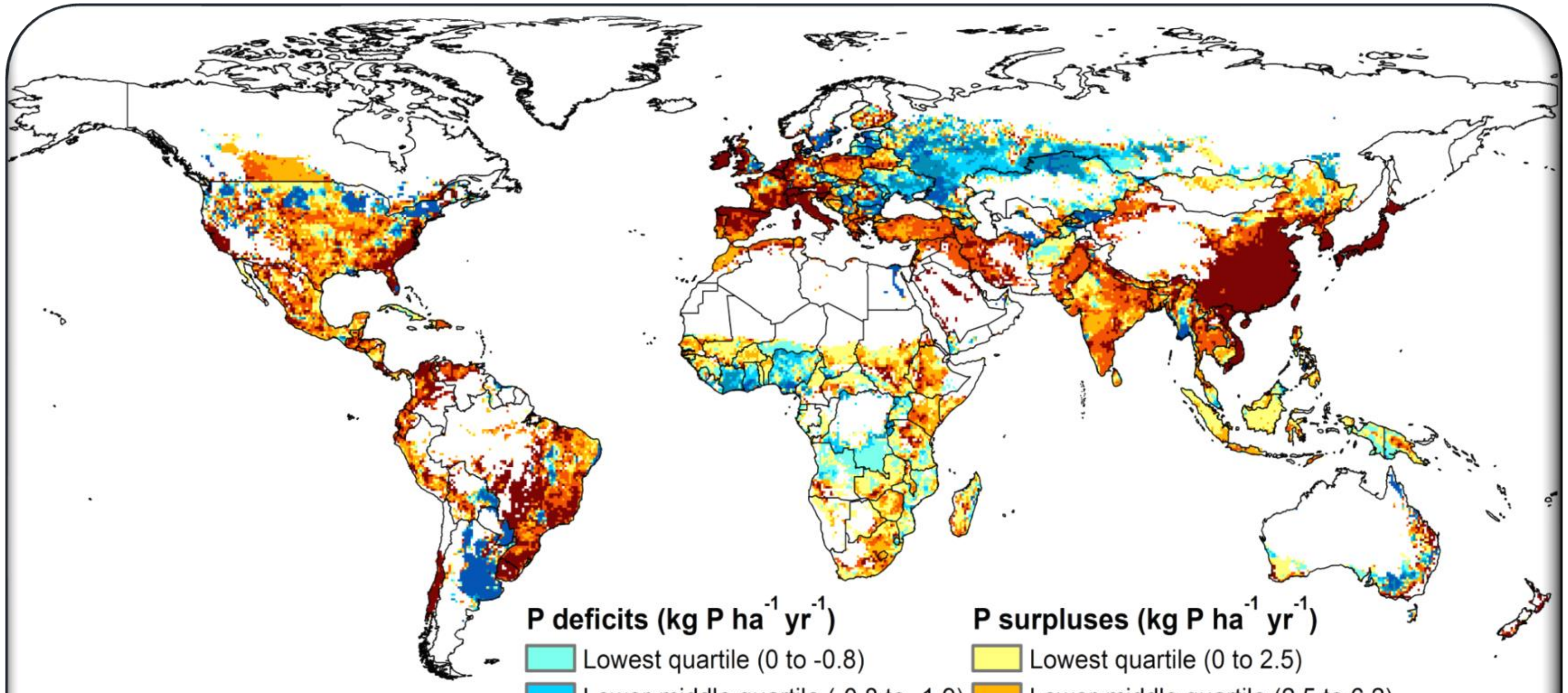
William Crochot – NIST



Your Blueprint: DNA

Not All the News Is Bad

Trash or Treasure?



MacDonald et al, PNAS, 2011

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

The Dark Side

The Supply Problem: NOT Peak Phosphorus

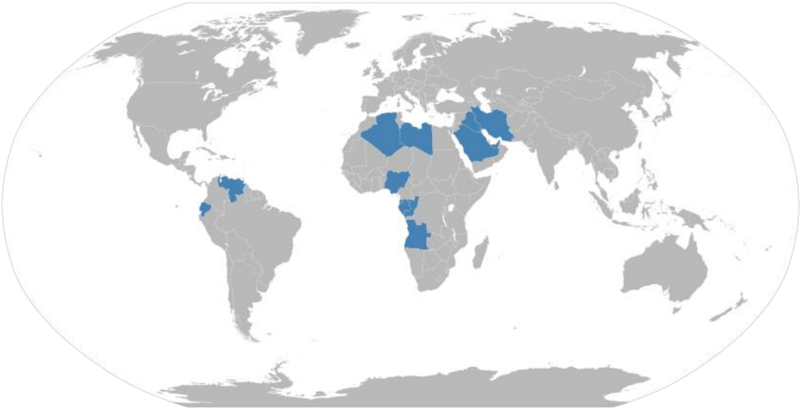
"World resources of phosphate rock are more than 300 billion tons. There are no imminent shortages of phosphate rock." – USGS, Mineral Commodity Summaries 2018

BUT

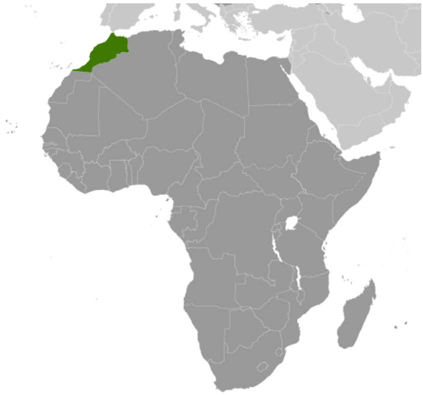
The Supply Problem

"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

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The Supply Problem

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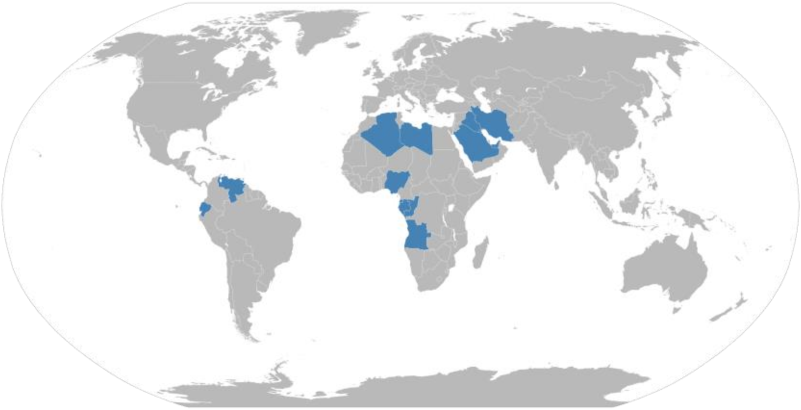


82% of global crude oil reserves here

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

T. Nesme et al. Global Environmental Change 50 (2018) 133–141

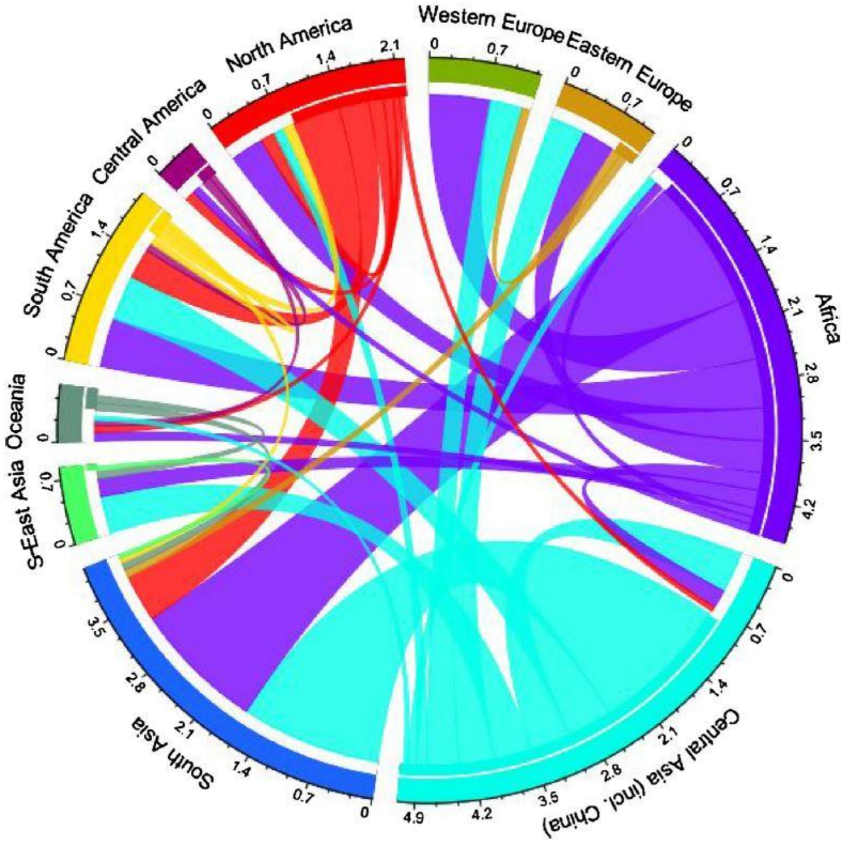
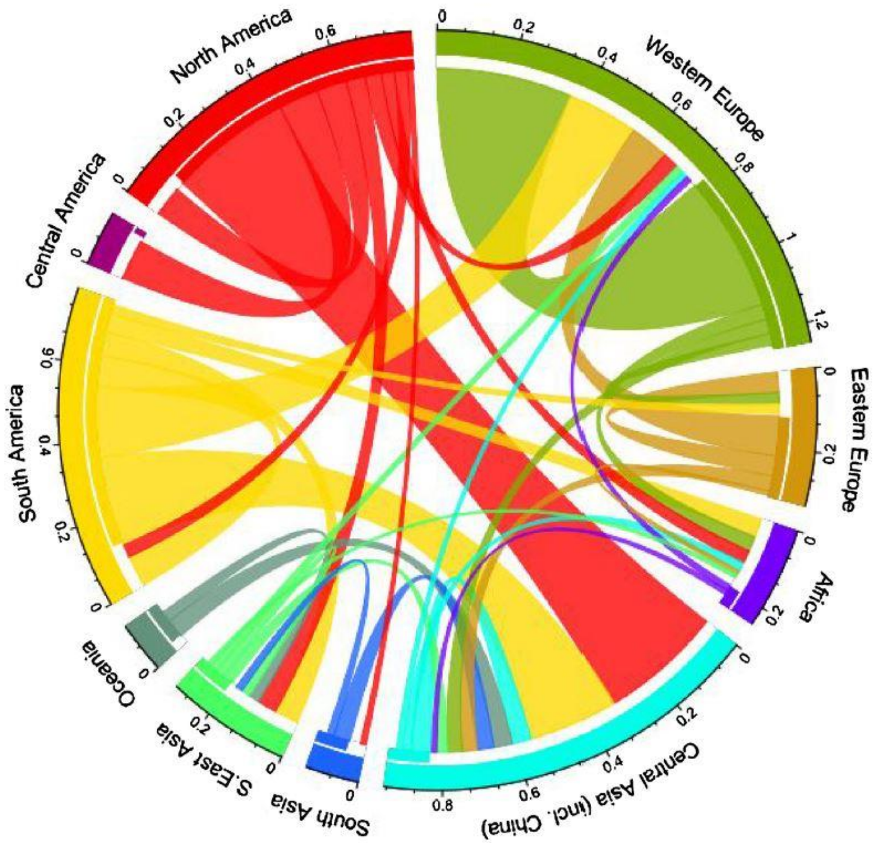


Fig. 5. P flows through trade of mineral P fertilizers among world regions (in Tg P/yr) in 2011. See Fig. 4 for reading details.

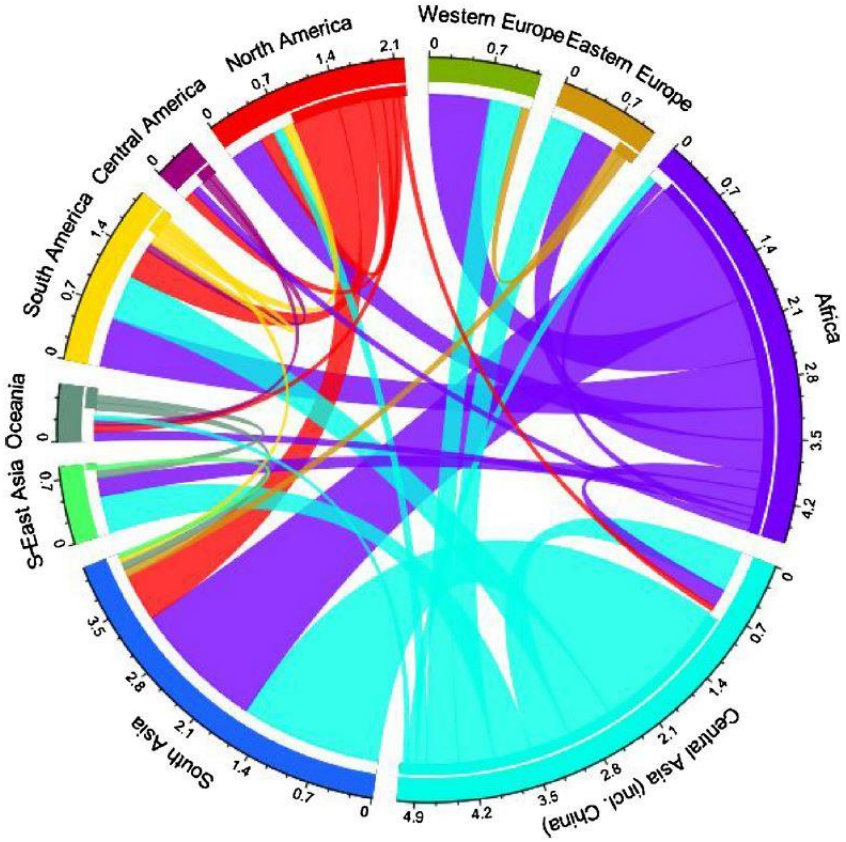
T. Nesme et al. Global Environmental Change 50 (2018) 133–141



Sustainable Phosphorus Alliance

Global Governance Needed

T. Nesme et al. Global Environmental Change 50 (2018) 133–141



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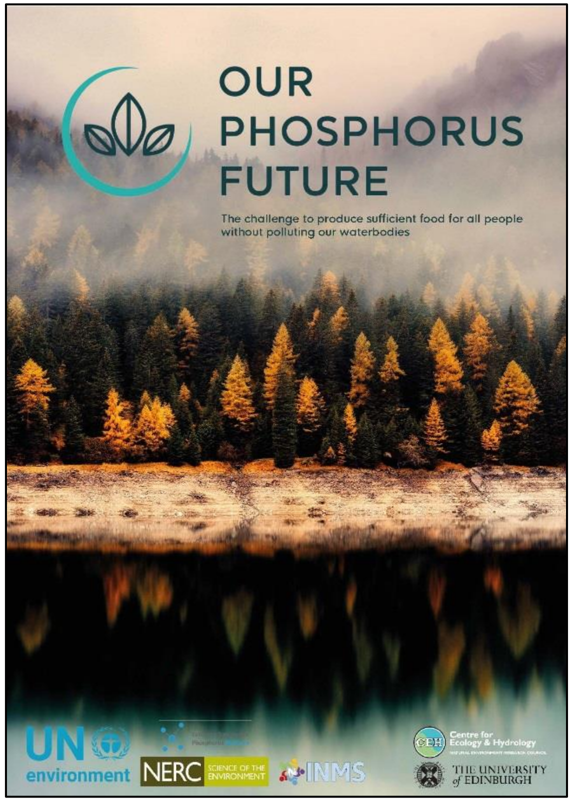
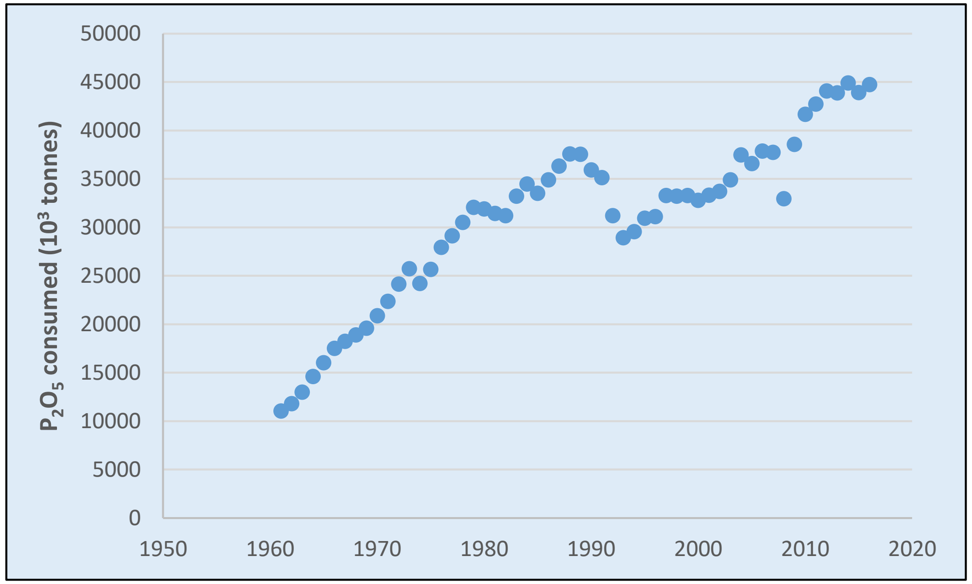


Consensus report by the scientific community to UNEP (and others) due early 2021

The Demand Problem

Phosphorus consumption has increased…



and it's wreaking havoc

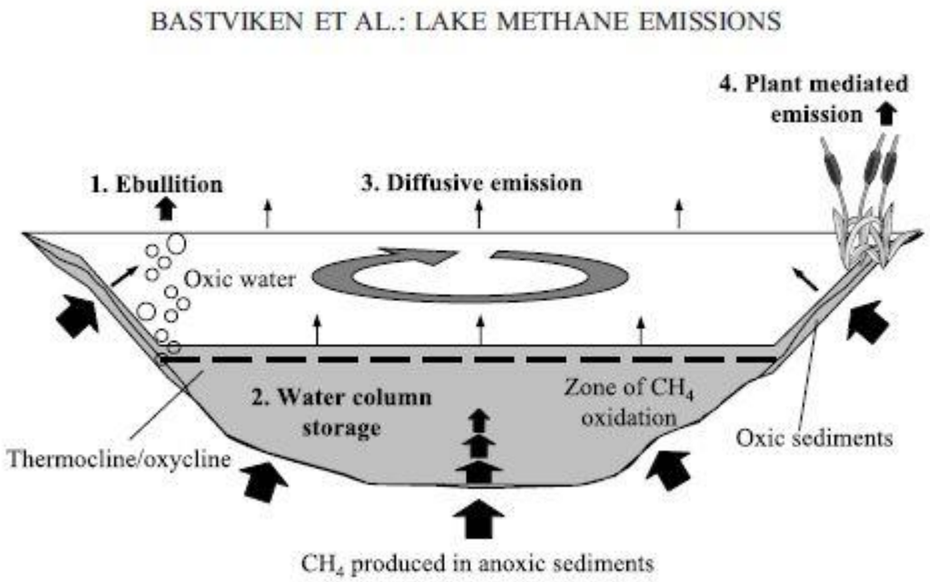
40% of lakes were in the "most disturbed" condition for total phosphorus (NLA 2012)

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

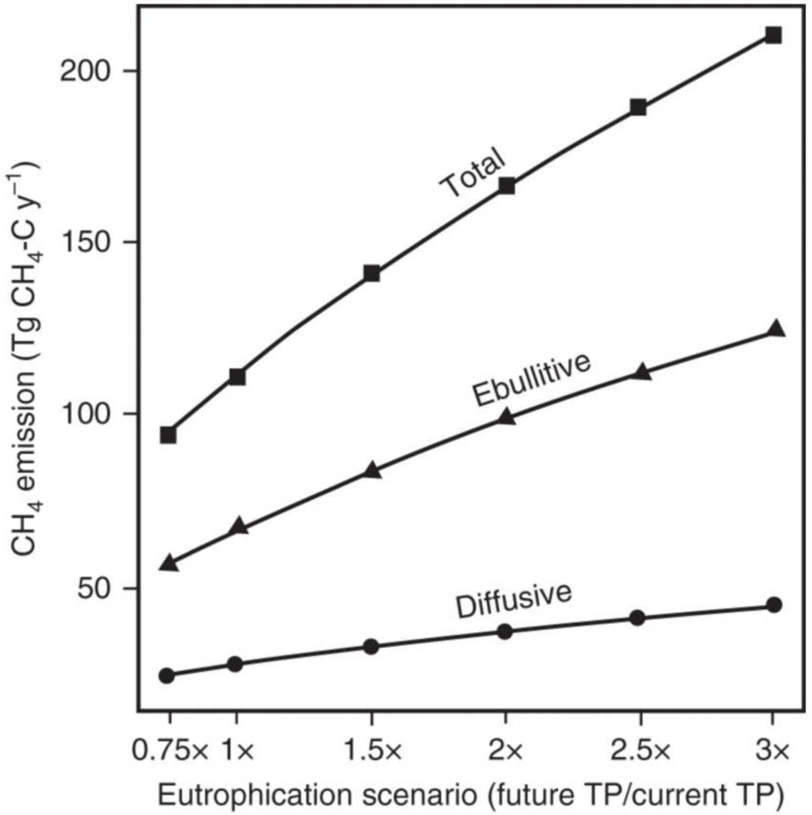
46% of US rivers and streams (by length) had "high" levels of phosphorus (NRSA, 2009)

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

Phosphorus Drives Major GHG Emissions

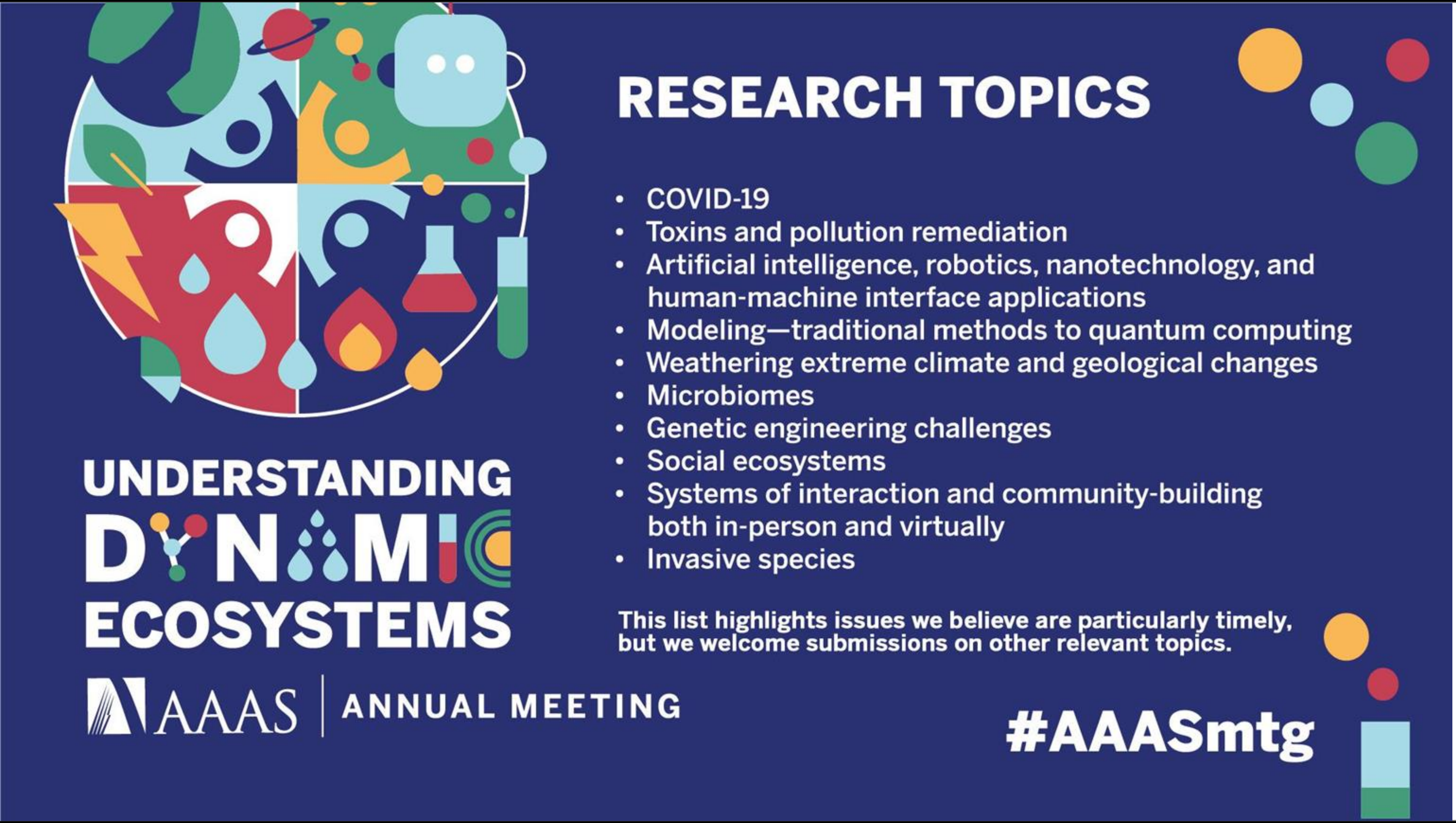


Greenhouse gas emissions from lakes and reservoirs represent around 1/5th of those from fossil fuel combustion, and 75% of this impact is from methane.



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!



Symposium

"Phosphorus and Climate Change: A Vicious Circle"

Featuring

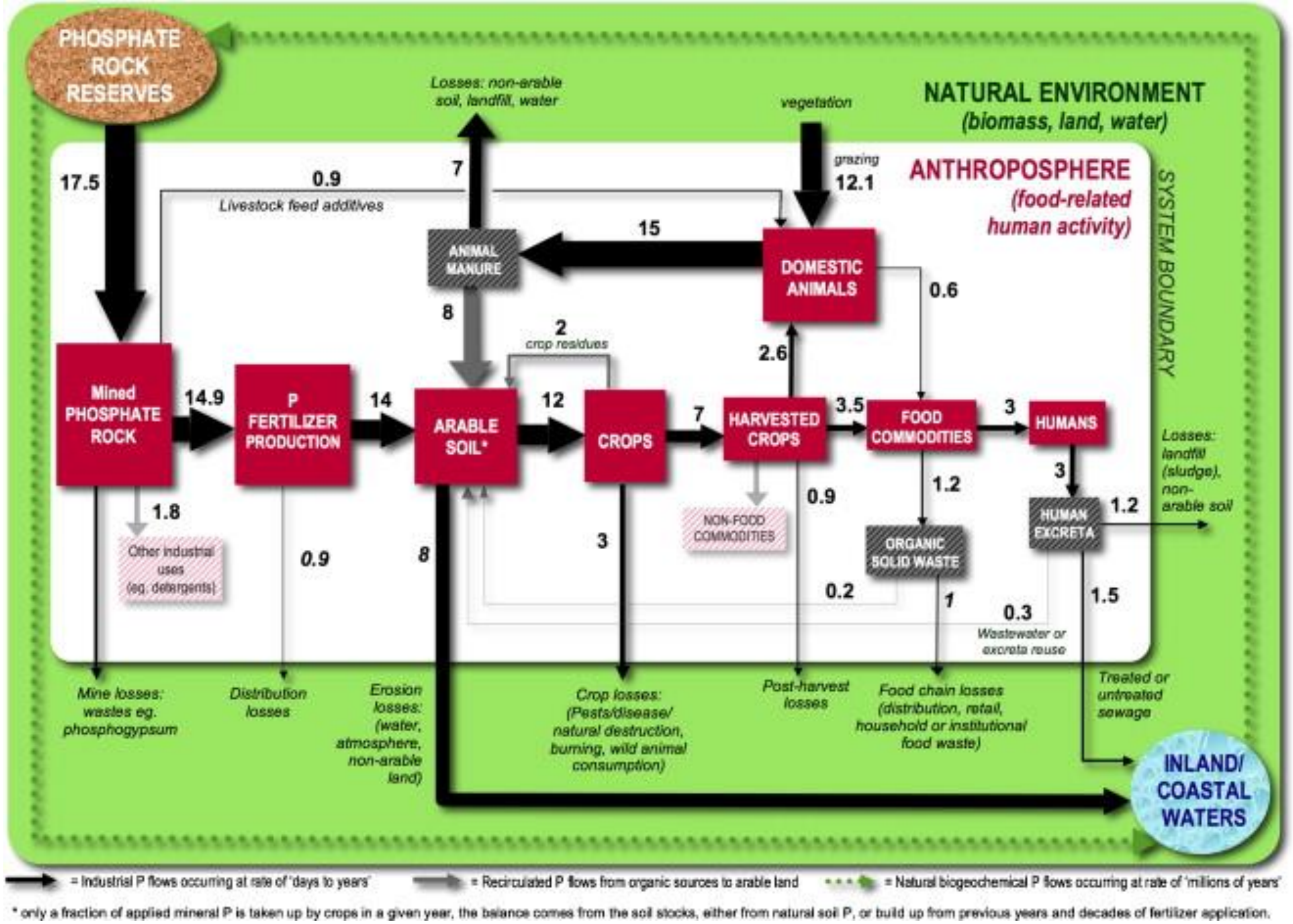
Moderators

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.

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.

Founding/Current Members and Strategic Partners

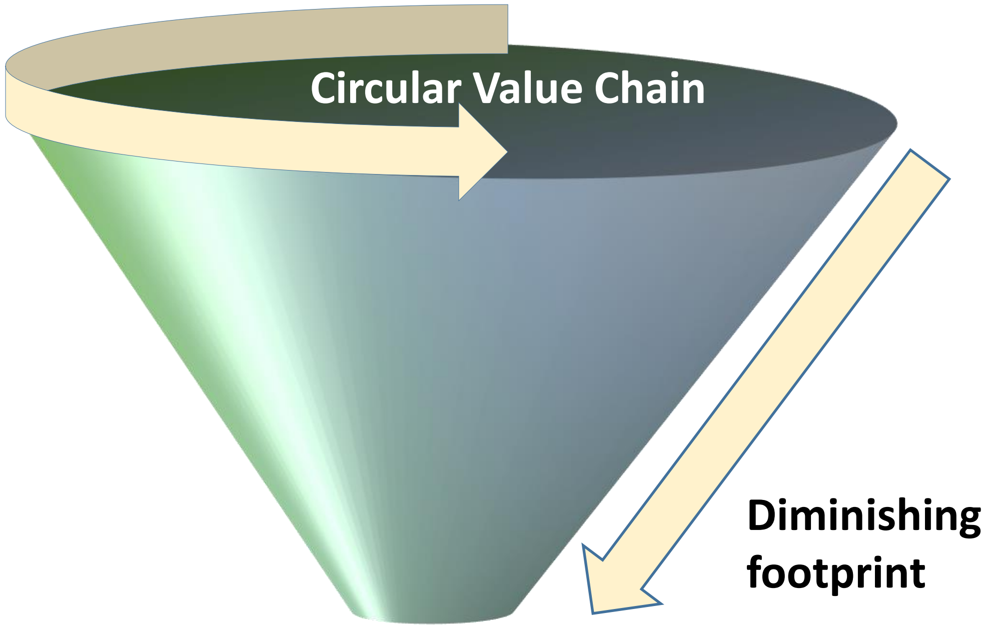
OCP
OSTARA
NACWA
RENEWABLE NUTRIENTS
GreenEdge® GreenTechnologies, LLC
THE Water Research FOUNDATION
Biochar Now
THE SUSTAINABILITY CONSORTIUM™
FEECO INTERNATIONAL
CAB Consultants Associated With Brookside

Strategic Partners

AgSTAR
Water Environment Federation the water quality people®
nebra North East Biosolids & Residuals Association

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).



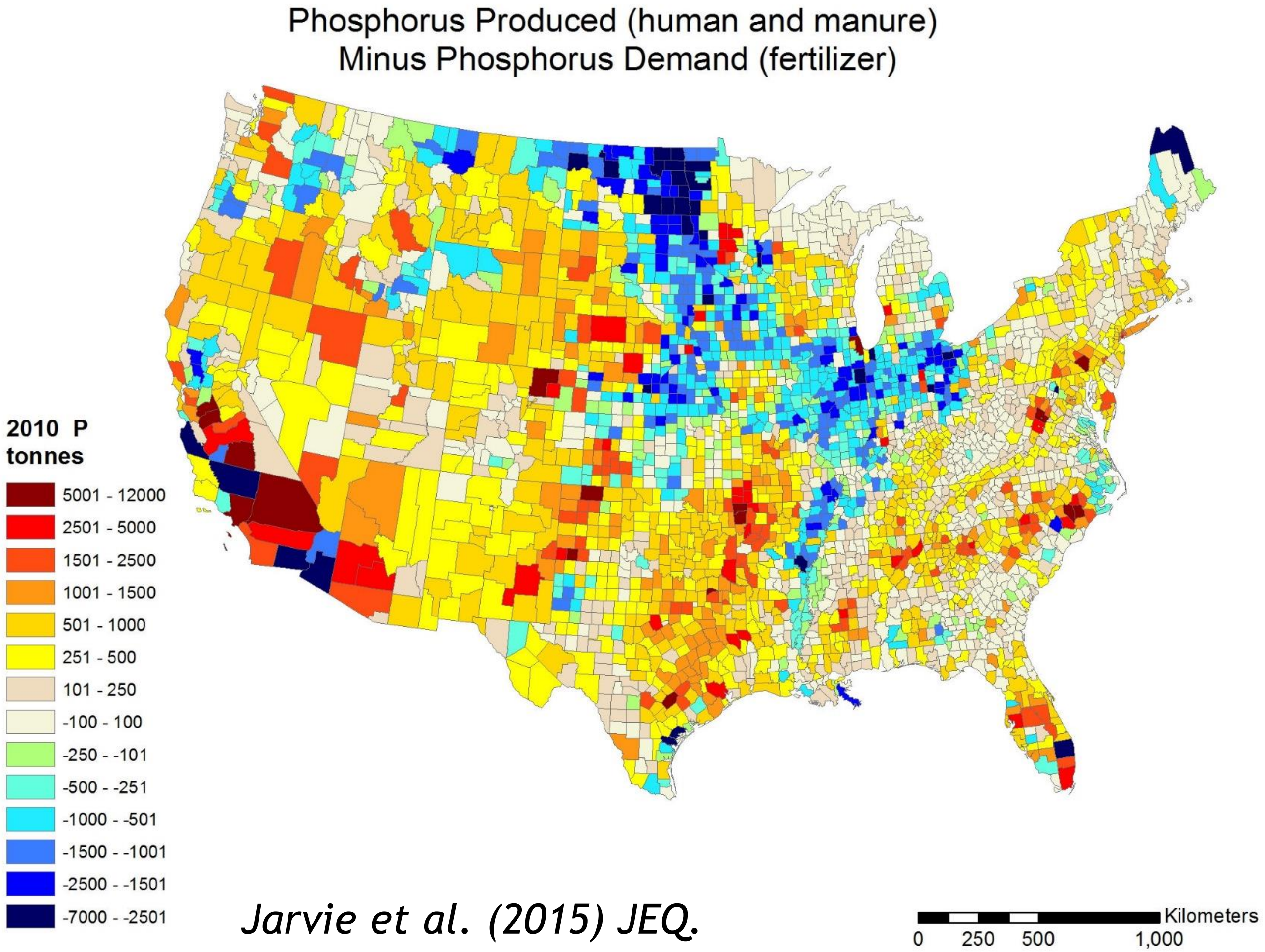
Recycling

Recycling: Heavy Poo, Cheap P

US P Fertilizer Consumption[1]	1.9 Mtonnes/yr
US Manure P Recovered[2]*	1.3 Mtonnes/yr
US Manure P Produced[2]	3.3 Mtonnes/yr
US Biosolids P Generation[3]	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



Jarvie et al. (2015) JEQ.

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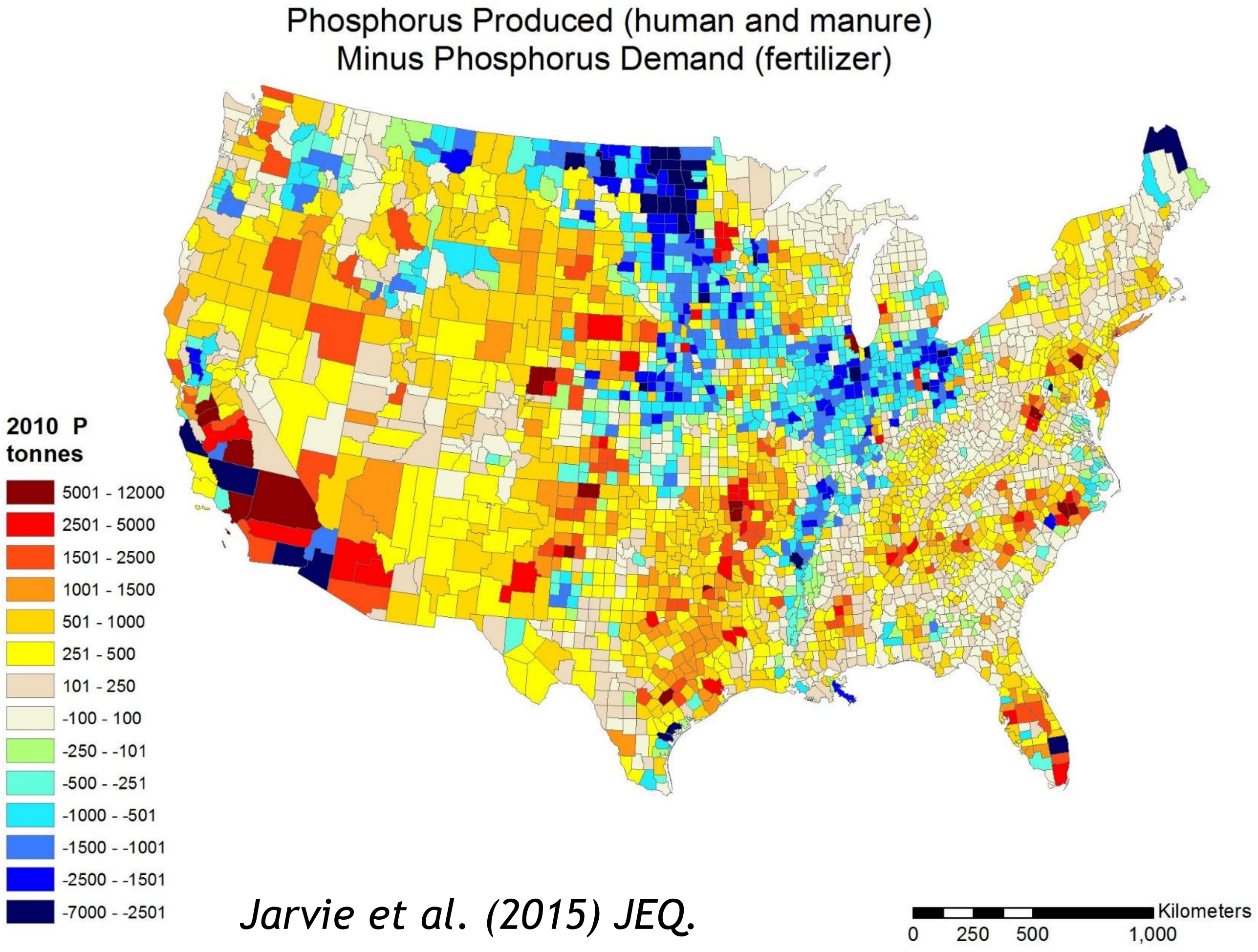
Chesapeake Bay

Manure P Produced	70 ktonnes/yr
Biosolids P Produced	126 ktonnes/yr*
Fertilizer Applied	47 ktonnes/yr

Kleinman et al. 2012 J Soil Water Conservation

**Biosolids number = 3.6 Mt waste * 3.5% P*



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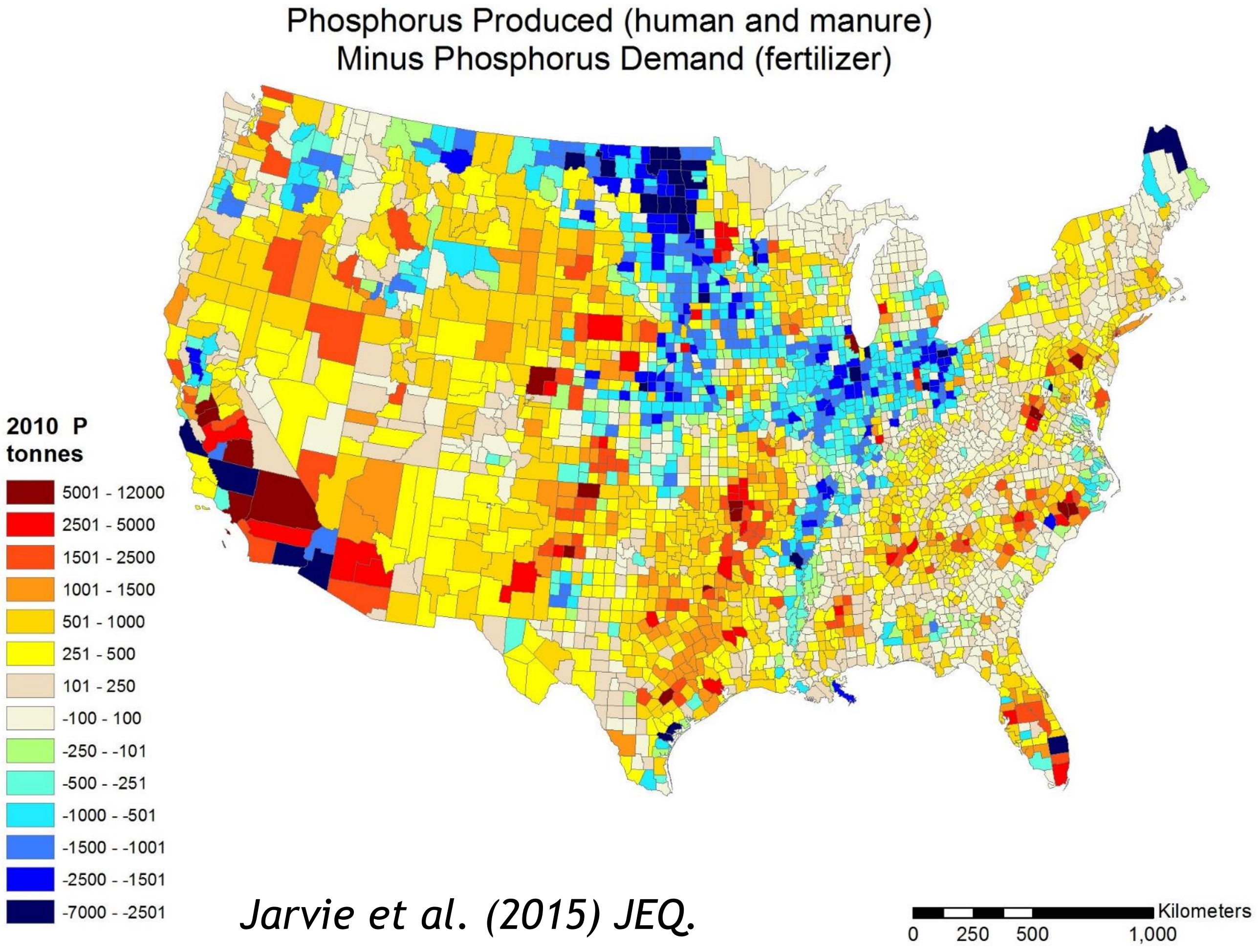
However, N:P ratios of residuals aren't well balanced (but have C!) and:

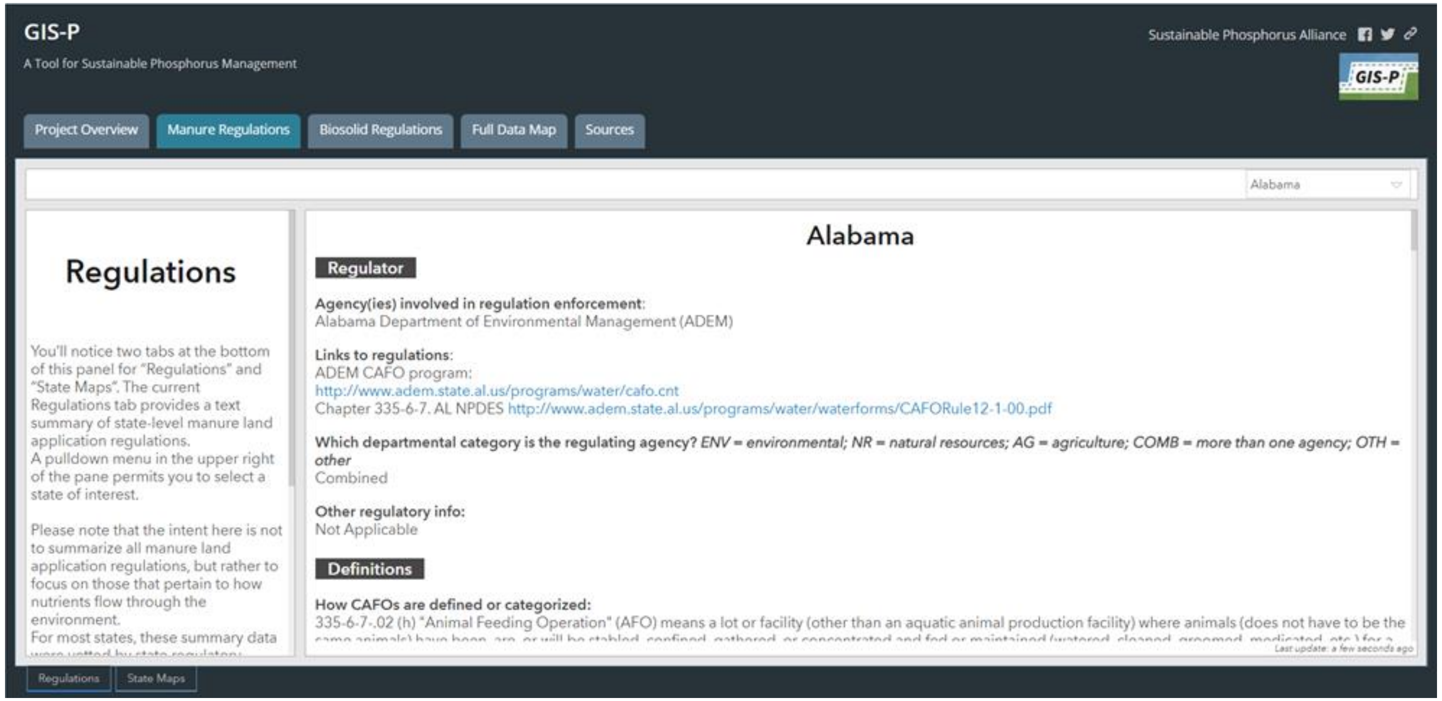
Price of Triple Superphosphate Fertilizer: $0.35/lb (market price, USDA 2014, <100 lb/acre needed)

Advancing tech for P capture would help, especially at small scale, as would policy incentives.



Jarvie et al. (2015) JEQ.

Land Application Regulations Tool



How to regulations vary across states?

How do biosolids and manure regulations compare?

What is the broader context for the regulations that exist?

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.

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 → 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

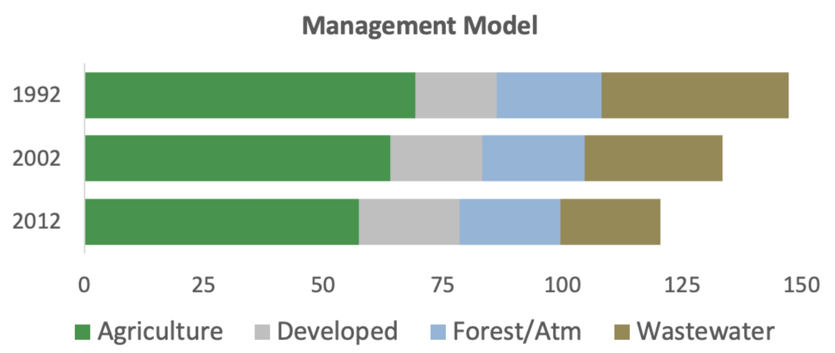
Currently impossible to measure P flows at scale

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

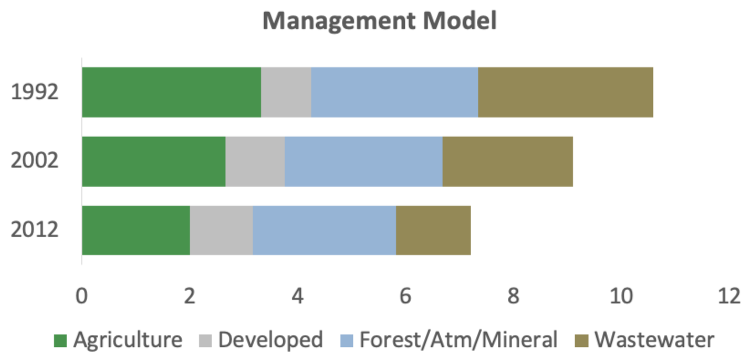
Hydrological models required to simulate data

Models Diverge

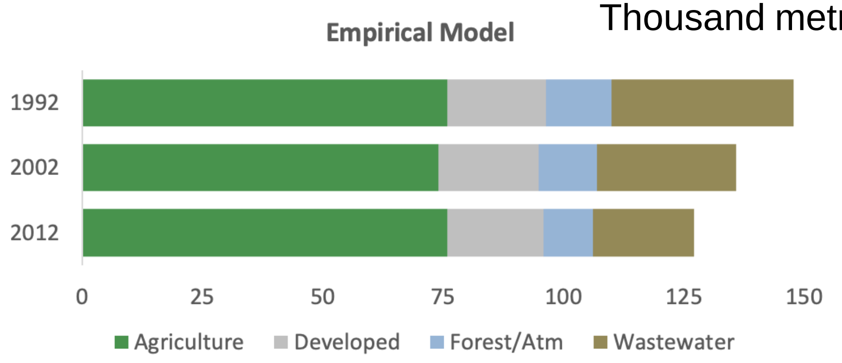
Nitrogen

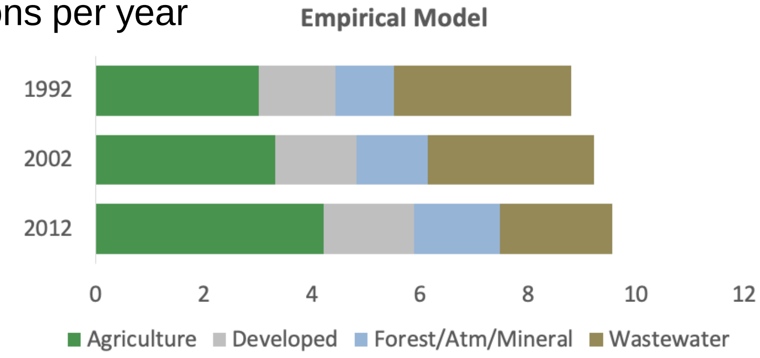


Phosphorus



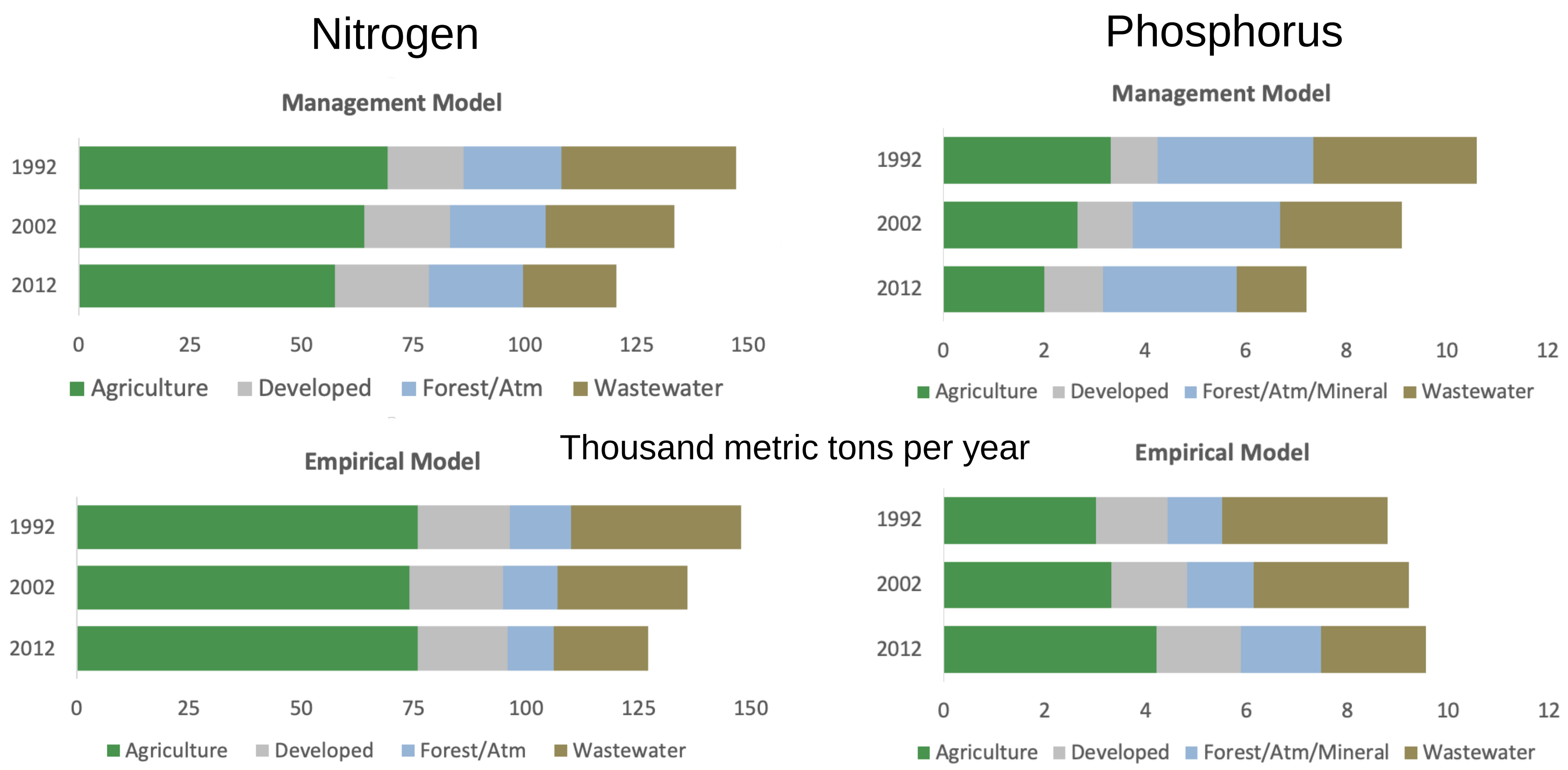
Thousand metric tons per year





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

Models Diverge



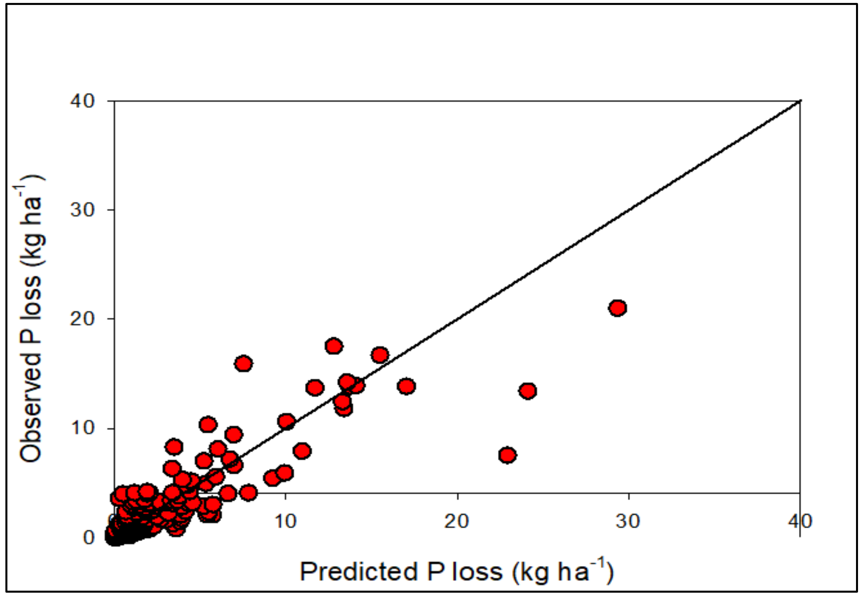
Possible Explanations

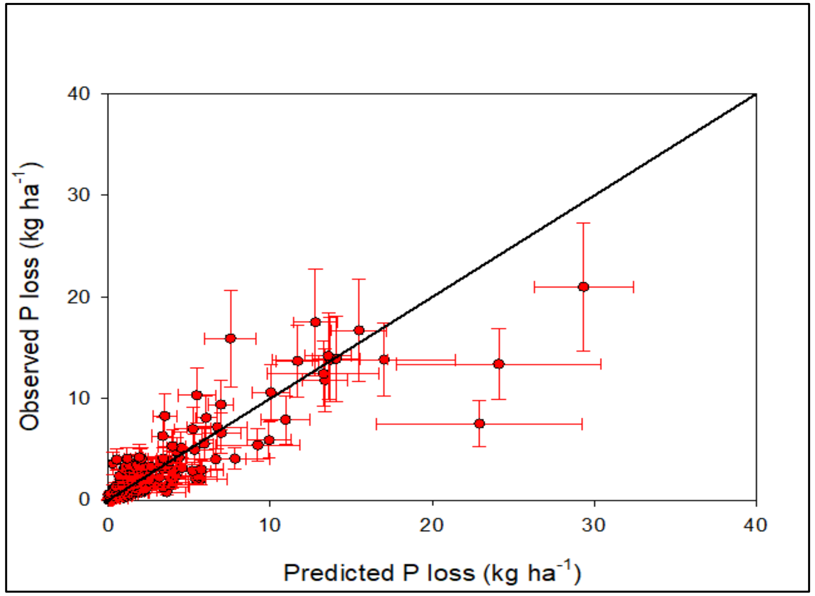
- Lag times
- Uncertainty
- User error
- Model differences
- Assumptions of effects of actions.
  - Ag BMPs less effective
  - More urban nutrient retention

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

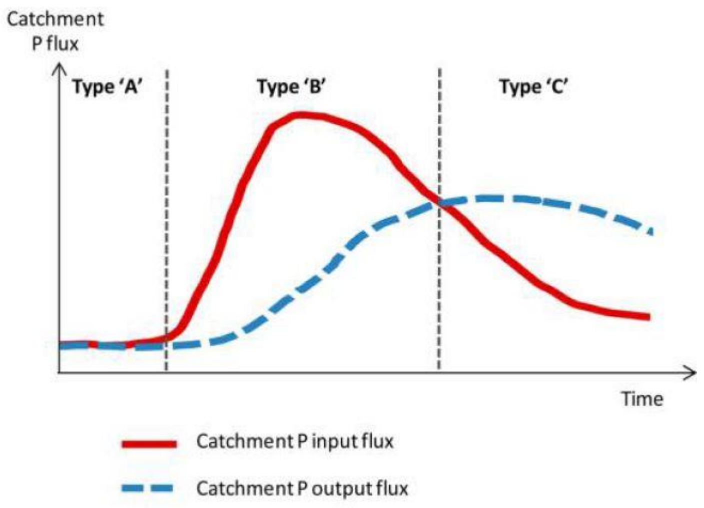
Messaging can appear to be mixed

- **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.)

Complications in Messaging

Messaging can appear to be mixed

- **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



Haygarth et al. ES&T 2014

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

The rest: Legacy P!

Legacy Phosphorus in Vermont

Contents lists available at ScienceDirect

Global Environmental Change

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)

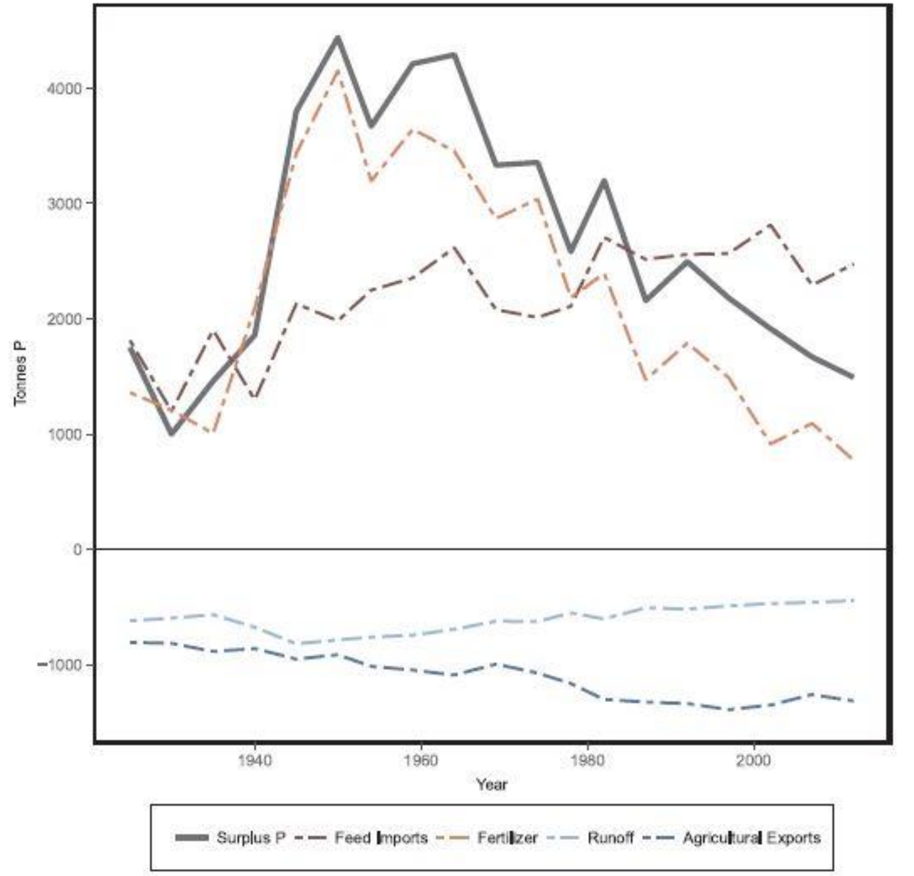


Fig. 5. Phosphorus flows and net balance in Vermont from 1925 to 2012. Negative flows (values below zero) indicate outflows from Vermont's agricultural system.

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