Phosphorus Forum 2019

April 5, 2019
Barrett and O’Connor Washington Center
at Arizona State University
1800 I Street NW
Washington, DC,
phosphorusalliance.org
#PhosForum19

Made possible by the support of our members:

Founding/Current Members and Strategic Partners

Sustainable Phosphorus Alliance
Welcome!
Thanks to Ostara and to OCP for coffee & lunch sponsorship!

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>8:00 am - 8:30 am</td>
<td>Registration and networking</td>
</tr>
<tr>
<td>8:30 am - 9:00 am</td>
<td>Welcome&lt;br&gt;Dr. Jim Elser, Director, Sustainable Phosphorus Alliance</td>
</tr>
<tr>
<td>9:00 am - 9:45 am</td>
<td>Keynote Address&lt;br&gt;Dr. Bruce Rittmann, Co-Recipient, Stockholm Water Prize</td>
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<tr>
<td>9:45 am - 10:00 am</td>
<td>Coffee&lt;br&gt;Sponsored by Ostara</td>
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<tr>
<td>10:00 am - 10:30 am</td>
<td>Phosphorus Field-to-Watershed Modeling Task Force Report&lt;br&gt;Dr. Peter Vadis, Soil Scientist, USDA-ARS</td>
</tr>
<tr>
<td>10:30 am - 11:00 am</td>
<td>Biosolids and Manure Task Force Report&lt;br&gt;Dr. Rebecca Muenich, Research Scientist, and Dr. Matt Scholz, Program Manager, Sustainable Phosphorus Alliance</td>
</tr>
<tr>
<td>11:00 am - 12:00 pm</td>
<td>Phosphorus Sustainability Challenge and Group Activity&lt;br&gt;Dr. Matt Scholz, Program Manager, Sustainable Phosphorus Alliance</td>
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<tr>
<td>12:00 pm - 1:30 pm</td>
<td>Lunch and Networking&lt;br&gt;Sponsored by OCP</td>
</tr>
<tr>
<td>12:30 pm - 1:00 pm</td>
<td>Lunch Speaker&lt;br&gt;Dr. Kathleen Merrigan, Executive Director, Swette Center for Sustainable Food Systems at Arizona State University</td>
</tr>
<tr>
<td>1:30 pm - 2:00 pm</td>
<td>Cost Effective Method to Remove Phosphorus from Water Bodies&lt;br&gt;Mr. James Gaspard, CEO, Biochar Now</td>
</tr>
<tr>
<td>2:00 pm - 2:15 pm</td>
<td>ReNEW Water Project: Resource Recovery in the US&lt;br&gt;Dr. Patrick Dube, Biosolids Program Manager, WEF</td>
</tr>
<tr>
<td>2:15 pm - 2:30 pm</td>
<td>Closing Comments&lt;br&gt;Dr. Jim Elser, Director, Sustainable Phosphorus Alliance</td>
</tr>
<tr>
<td>2:30 pm - 3:00 pm</td>
<td>Room open for networking</td>
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</table>
2019 is a very special year for phosphorus

Happy 350th Birthday, Phosphorus*!

*actually, it’s our KNOWLEDGE of P that is 350 years old. The P itself is billions of years old!
A recipe (Ingredients: 5000 liters of urine)

• Step 1: Boil urine to reduce it to a thick syrup.
• Step 2: Heat until a red oil distills up from it, and draw that off.
• Step 3: Allow the remainder to cool, where it consists of a black spongy upper part and a salty lower part.
• Step 4: Discard the salt, mix the red oil back into the black material.
• Step 5: Heat that mixture strongly for 16 h.
• Step 6: First white fumes come off, then an oil, then phosphorus.
• Step 7: The phosphorus may be passed into cold water to solidify.
Hennig Brand (1630 – c. 1692 or c. 1710)

Very poor at chemistry
(5000 liters of urine should have produced 550 g of P.
He only got 120 g.)

Lousy chemist but a worthy goal:
turn the useless into the valuable.
Phosphoheaven or Phosphogeddon?
Telling the Story of the Opportunities and Challenges to Mend Our Broken Phosphorus Cycle
Elser & Haygarth

*Title TBA*

- Oxford University Press
- Aiming for 2019 – the 350th anniversary
- General audience
- 10 Chapters

<table>
<thead>
<tr>
<th>Name</th>
<th>Chapter 1 - Phosphorus Knowing</th>
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<tbody>
<tr>
<td></td>
<td>Chapter 2 - Phosphorus Becoming</td>
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<tr>
<td></td>
<td>Chapter 3 - Phosphorus Living</td>
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<td></td>
<td>Chapter 4 - Phosphorus Feeding</td>
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<td>Chapter 5 - Phosphorus Growing</td>
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<td>Chapter 6 - Phosphorus Moving</td>
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<td>Chapter 7 - Phosphorus Sustainability Awakening</td>
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<td></td>
<td>Chapter 8 - Phosphorus Transforming: Part 1</td>
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<tr>
<td></td>
<td>Chapter 9 - Phosphorus Transforming: Part 2</td>
</tr>
<tr>
<td></td>
<td>Chapter 10 - Phosphorus Sustaining</td>
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</tbody>
</table>
irrigated agriculture

Liebig’s Law!

Doom vs Abundance

Where to?

moldboard plow

domestication of animals

recycling! (organic agriculture)

Can Planet Earth Feed 10 Billion People?

Humanity has 30 years to find out.

The Atlantic (March 2018)

Charles Mann

Fritz & Karl!
Prophets vs Wizards

Wizards

Prophets

The Atlantic (March 2018)
Charles Mann (Illustrations by Ulises Fariñas)
Can Planet Earth Feed 10 Billion People?

Humanity has 30 years to find out.

The Atlantic (March 2018) Charles Mann

WHAT ABOUT P?
Got phosphorus?

~1.35 pounds, or 0.62 kilograms: that’s how much you have in your body, right now.

~75 pounds, or 34 kilograms: that’s how much you’ll consume in your (average) lifetime.
The evolution of phosphorus in agriculture
(a 3-stage model?)

Stage 1: Prehistoric. Hunter-gatherer.

*Plants take P from indigenous apatite.*

Stage 2: Dawn of agriculture.

*Selected crops close to dwellings, confinement and breeding of animals; use of animal manure and human excrement.*
The evolution of phosphorus in agriculture
(a 3-stage model?)

Stage 3: Today’s agriculture.

Specialized geographic focus, cropping separate from animal production, “spoiled” Fast-Growing Lazy Plants (FGLPs) that rely on easily available P from fertilizer.
Figure 5: Relationship between Olsen P and the yield of three arable crops and of grass. (Johnston, 2001; Johnston et al., 2001a).
Phosphorus and water quality in rivers, lakes, and oceans
(or towards phosphogeddon?)
• Cleaning up phosphorus from point sources in detergents and sewage *(a success story from the last century)*

• The emergence of non-point (diffuse) pollution - a 21st century ‘wicked’ problem
Cleaning up diffuse P water pollution

Complex - but success stories emerging...

Is there an opportunity to redesign the landscape for sustainable intensification?
Climate change to accelerate phosphogeddon?

- Predicted increase in winter P loads due to climate change (up to 30% by 2050s)
- Only large-scale agricultural changes (e.g. 20–80% reduction in P inputs) will limit the projected impacts of climate change on P loads in these catchments
Catastrophic flooding & P release

Amid flooding, Omaha puts 65M gallons of untreated sewage into river

The Associated Press  Apr 1, 2019 Updated 1 hr ago

TRY 1 MONTH FOR FREE
A dark phosphogeddon?

Ocean de-oxygenation, the global phosphorus cycle and the possibility of human-caused large-scale ocean anoxia

Research

Cite this article: Watson AJ, Lenton TM, Mills BJW. 2017 Ocean de-oxygenation, the global phosphorus cycle and the possibility of human-caused large-scale ocean anoxia. Phil. Trans. R. Soc. A 20160318.

http://dx.doi.org/10.1098/rsta.2016.0318

Accepted: 21 June 2017

Andrew J. Watson¹, Timothy M. Lenton¹ and Benjamin J. W. Mills²

¹Earth System Science Group, College of Life and Environmental Sciences, University of Exeter, Exeter EX4 4QE, UK
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The global phosphorus sustainability movement 2003 - now...
A backcasting analysis of global P use to achieve a sustainable target that eliminates reliance on mined phosphate rock by the year 2050. From Cordell et al. (2009).

- Population size?
- P use efficiency in crops
  - 4Rs
  - Annualize crops
  - Turn FGSPs into FGIPs (GM, CRISPR-CAS 9)
- Reduce non-human-food agriculture
- P use efficiency in animal production
  - 4Rs for cows?
  - Phytase
- Food chain efficiency
  - Food waste
  - Diets
  - Artificial meat
A backcasting analysis of global P use to achieve a sustainable target that eliminates reliance on mined phosphate rock by the year 2050. From Cordell et al. (2009).
Ch 10: Phosphorus Sustaining

Is it going to be enough? Encouraging? Depressing?

Encouraging?

Annual PV additions: historic data vs IEA WEO predictions
In GW of added capacity per year - source International Energy Agency - World Energy Outlook

Depressing?

Options for keeping the food system within environmental limits

Marco Springmann, Michael Clark, Daniel Mason-D’Croz, Keith Wiebe, Benjamin Leon Bodirsky, Luis Lasaleta, Wim de Vries, Sonja J. Vermeulen, Mario Herrero, Kimberly M. Carlino, Malin Jonell, Max Troell, Fabrice DeClerck, Line J. Gordon, Rami Zurayk, Peter Scarborough, Mike Rayner, Brent Loken, Jess Fanzo, H. Charles J. Godfray, David Tilman, Johan Rockström & Walter Willett
So how do we make the changes that will transform the phosphorus world?
This why we are here today. What systems innovations can be accelerated to achieve “Phospho-heaven”? Thanks for listening!
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Minimizing P Loss, Maximizing Value

Bruce E. Rittmann
Director, Biodesign Swette Center for Environmental Biotechnology
Regents’ Professor of Environmental Engineering
Arizona State University

Rittmann@asu.edu

environmentalbiotechnology.org
Context: Outputs from the Sustainable-P Research Coordination Network

1. Sustainable Phosphorus Alliance (SPA)
What’s the main driver for P sustainability?

- It is not running out of phosphate!
- It is the impact of phosphate discharges on water quality.
  - Eutrophication
  - Hypoxia -- ~ 450 hypoxic zones worldwide

David Schindler (U. Alberta) won the first Stockholm Water Prize for documenting the role of phosphate inputs on eutrophication.
The SWP Award Ceremonies
August 29, 2018, The Blue Room, Stockholm City Hall

Bruce Rittmann
Crown Princess Victoria
Mark van Loosdrecht, Delft Technical University
The “Royal Dinner” in the Gold Room
Context: Outputs from the Sustainable-P Research Coordination Network

1. Sustainable Phosphorus Alliance (SPA)

Global P flows now (million metric tonnes per year)

14
Mined Fertilizer

7.7
Weathered P

7
Soil and Crops

3
Produce and Meat

3.7
Animal and Food Wastes

11
Erosion and Drainage

8
The Environment (21.7)

Illustrations by Elser and Rittmann based on published work by Dana Cordell and co-workers.
Organic Wastes

Address the ~50% of P from organic waste streams

Can get value from ENERGY and P
Recover 100% of animal, food, and human wastes.

This cuts fertilizer use by 48%.

It cuts environmental inputs by 49%.
Context: Outputs from the Sustainable-P Research Coordination Network

1. Sustainable Phosphorus Alliance (SPA)


The BIG ENERGY is in animal wastes

<table>
<thead>
<tr>
<th>Major Sources in the USA today</th>
<th>Million Dry Tons Per Year (USA)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Wastes</td>
<td>335</td>
<td>55*</td>
</tr>
<tr>
<td>Food Processing</td>
<td>113</td>
<td>19</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td>149</td>
<td>25</td>
</tr>
<tr>
<td>Municipal Wastewater</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>604</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

*Equals about 5% of total USA energy demand
# Animal Wastes in the USA

<table>
<thead>
<tr>
<th>Animal Type</th>
<th>Amount, millions dry tons per year</th>
<th>Percentage of all Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>253</td>
<td>42</td>
</tr>
<tr>
<td>Swine</td>
<td>31</td>
<td>5</td>
</tr>
<tr>
<td>Poultry</td>
<td>51</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>335</strong></td>
<td><strong>55</strong></td>
</tr>
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</table>

Only about 3.6 million tons per year (~1%) are subject to energy recovery today – low-hanging fruit.
For animal wastes, anaerobic digestion

• Well-known and proven; simple or sophisticated
• Generates widely useful methane gas (CH$_4$); it’s C-neutral, too.
• Enhanced by effective pre-treatment to digest more solids and make more CH$_4$
• Releases inorganic phosphate for capture
P-recovery strategy (similar for N)

**Sources**
- High P and BOD (animal waste) (40% of mined P)
- Medium P and BOD (sewage) (16% of mined P)
- Low P and BOD (runoff) (46% of mined P)

**Conversions**
- Convert Org-P to Inorg-P simultaneously with anaerobic bioenergy production
- Convert Org-P to Inorg-P with an AOP

**Recovery and Use**
- Energy output, e.g., CH₄
- Separate, concentrate, and recover Inorg-P by selective adsorption or ion exchange
- Water for reuse
- Recovered P for food crops or other uses

*Sources, Conversions, Recovery and Use*
Hydrous Ferric Oxide Filter

BluePRO® technology from Blue Water Technologies
Run-off

Address the ~50% of P from run-off

Much harder to do, but necessary
Future Case 2 – Also capture P in runoff

Recover 100% of animal, food, and human wastes.

Reduce erosion and other losses by 50%.

It cuts mined P use by 86%.

It cuts environmental P loading by 80%.
Context: Outputs from the Sustainable-P Research Coordination Network

1. Sustainable Phosphorus Alliance (SPA)


P sources are many and complex.

Internal loads can be important, i.e., cumulative, legacy run-off.
Relative P loads vary widely

P-form matrix identifies opportunities

Source Color Code
Brown for urban
Green for agriculture
Grey for internal
Tiered system of options for diffuse-P management

Mostly today

Key for internal sources

Needed for full implementation of Future Case 2

Spectrum of management options

- Reduce / Conserve
- Mitigate / RemEDIATE
- Sequester
- Remove
- Reuse
- Recycle

Diffuse, non-point, case study examples

- Increase PUE; draw down soil P surplus; implement BMPs; optimize fertilizer usage (e.g. on-farm and in cities)
- Targeted P-mitigation on-farm; CSAs
- Chemical sequestration of P: e.g. lanthanum-modified clay; alum
- Dredging P-rich aquatic sediments; storm-water sedimentation; re-distribution of organic P-rich wastes (e.g. manures and vegetation)
- Composting (e.g. vegetation; pet excrement); apply P-rich sediment to land
- Future innovations (e.g. reversible adsorption)
Diet

Require less P use by producing less grain for animals

A social issue, not technical
Context: Outputs from the Sustainable-P Research Coordination Network

1. Sustainable Phosphorus Alliance (SPA)


**Future Case 3: Also change diet**

Recover 100% of animal, food, and human wastes.

Reduce erosion and other losses by 50%.

Cut meat consumption by 50%.

This cuts fertilizer use by 95%.

It cuts environmental P discharge by 80%.
Take-home lessons

• The first big step is to capture P and energy from organic waste streams, particularly animal wastes
PARENS = Profitable Agriculture through Recovered Energy, Nutrients, and Solids
Value Proposition for PARENS

EBT = earnings before taxes
Take-home lessons

• The first big step is to capture P and energy from organic waste streams, particularly animal wastes. It is at hand now.

• The second big step to remove and (hopefully) recover P from diffuse sources, such as run-off and sediments. This is hard to do, but we have to start.
Tiered system of options for diffuse-P management

Mostly today

Key for internal sources

Needed for full implementation of Future Case 2

- **Spectrum of management options**
  - Reduce / Conserve
  - Mitigate / Remediate
  - Sequester
  - Remove
  - Reuse
  - Recycle

- **Diffuse, non-point, case study examples**
  - Increase PUE; draw down soil P surplus; implement BMPs; optimize fertilizer usage (e.g. on-farm and in cities)
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  - Future innovations (e.g. reversible adsorption)
Take-home lessons

• The first big step is to capture P and energy from organic waste streams, particularly animal wastes. It is at hand now.

• The second big step to remove and (hopefully) recover ~ 50% of P from diffuse sources, such as run-off and sediments. This is hard to do, but we have to do it.

• To finish the job, we probably will need to shift the human diet away from so much meat. This is bucking international trends, but it has good P-mitigation leverage.
Future Case 3: Also change diet

- Recover 100% of animal, food, and human wastes. Reduce erosion and drainage losses by 50%.
- Cut meat consumption by 50%.
- This cuts fertilizer use by 95%.
- It cuts environmental P discharge by 80%.
Bonus: a spiffy animation for Slate
Auxiliary Slides
# Biomass pre-treatment technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description/Scale</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>High-temperature treatment (150-220°C)</td>
<td>- Achieve solids reduction</td>
</tr>
<tr>
<td></td>
<td>Full-scale success</td>
<td>- Capital intensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Energy neutral/negative</td>
</tr>
<tr>
<td>Mechanical (including ultrasound)</td>
<td>Shear, pressure, homogenization, or ultrasonic physical attack of membrane</td>
<td>- Achieve benefits of cell lysis at small scale</td>
</tr>
<tr>
<td></td>
<td>Pilot scale success</td>
<td>- High energy consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Restricted to WAS only</td>
</tr>
<tr>
<td>Chemical</td>
<td>Addition of acids/bases/enzymes/oxidants to attack membrane</td>
<td>- Achieve benefits of lysis</td>
</tr>
<tr>
<td></td>
<td>Lab/pilot scale success</td>
<td>- High chemical/capital costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Chemical removal/neutralization</td>
</tr>
<tr>
<td>Electrical</td>
<td>Generation of free radicals by electrolysis of water</td>
<td>- High energy consumption</td>
</tr>
<tr>
<td></td>
<td>Pilot scale demonstrations</td>
<td>- Discontinued technology</td>
</tr>
<tr>
<td>Electromechanical</td>
<td>Electroporation of cell membranes resulting in osmotic lysing; disruption and fragmentation</td>
<td>- Demonstrated in multiple labs and at full scale</td>
</tr>
<tr>
<td>Pulsed electric fields (PEF)</td>
<td></td>
<td>- Energy positive</td>
</tr>
</tbody>
</table>

**R&D Issues**

- Pulsed electric fields (PEF)

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**Notes:**
- Thermal technology is noted for achieving solids reduction, being capital intensive, and possibly energy neutral/negative.
- Mechanical technology involves shearing, pressure, homogenization, or ultrasonic physical attack of membranes, with successful lab/pilot scale demonstrations.
- Chemical methods include adding acids/bases/enzymes/oxidants to attack membranes, with lab/pilot scale success and high chemical/capital costs.
- Electrical methods generate free radicals by electrolysis of water, with lab/pilot scale demonstrations and high energy consumption.
- Electromechanical methods use electroporation of cell membranes, demonstrated in multiple labs and at full scale, with energy positive.

---

**Biodesign Swette Center Environmental Biotechnology**

www.biodesign.seu.edu
The Microbial Fuel Cell (MFC) for generating electrical power

\[ \text{e}^- \text{ donor half reaction: } \text{CH}_3\text{COO}^- + 3 \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{HCO}_3^- + 8\text{H}^+ + 8e^- \quad -0.29 \text{ V} \]

\[ \text{e}^- \text{ acceptor half reaction: } 2 \text{O}_2 + 8\text{H}^+ + 8e^- \rightarrow 4 \text{H}_2\text{O} \quad 0.81 \text{ V} \]

Net reaction: \[ \text{CH}_3\text{COO}^- + 2\text{O}_2 \rightarrow \text{CO}_2 + \text{HCO}_3^- + \text{H}_2\text{O} \quad 1.10 \text{ V} \]

Electrical power generation in an MFC

The reaction potential drives all biological, chemical, and electrochemical processes in MFC => typical recovered potentials are 0.3 - 0.6 V
Modifying the MFC to an MEC to Produce \( \text{H}_2 \)

- e\(^-\) donor half reaction: \( \text{CH}_3\text{COO}^- + 3 \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{HCO}_3^- + 8\text{H}^+ + 8\text{e}^- \) - 0.29 V
- e\(^-\) acceptor half reaction: \( 8\text{H}^+ + 8\text{e}^- \rightarrow 4 \text{H}_2 \) - 0.41 V

Net reaction: \( \text{CH}_3\text{COO}^- + 3\text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{HCO}_3^- + 4 \text{H}_2 \) - 0.12 V

In a **Microbial Electrolysis Cell (MEC)**, we exclude \( \text{O}_2 \) and add power (applied voltage) to have a low enough cathode potential to produce \( \text{H}_2 \).
H₂ from an MEC or CH₄?

• H₂ can be used to power chemical fuel cells, say to drive your car of the future.

• H₂ is a major feedstock to the chemical industry for reductions, or hydrogenations.

• H₂ can be used for water-pollution control to reduce oxidized contaminants, like nitrate, perchlorate, selenate, and TCE ➔ The MBfR technology.

• The economic value of H₂ is 5 - 10 times greater than CH₄ on an e⁻ (or BOD) basis!
Agenda

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Phosphorus Field-to-Watershed Modeling Task Force Report

Peter Vadas
USDA-ARS, Madison, WI
August 2018 Meeting – Columbus, OH

• 16 researchers and policy experts to discuss how to dovetail in-field P measurements and modeled P fate and transport to more effectively reduce agricultural P loss to water bodies.

• Topics
  • Soil test P measurements and fertilizer recommendations relationships
  • Trends of edge-field and in-stream water quality observations for Maumee River basin
  • Existing models to simulate soil P fate and transport in Maumee basin

• Areas for collaborative research
  • Legacy vs Incidental P loss – relative importance to P loading to Lake Erie
  • Identifying “hotspots” of elevated P export
  • Coupling models for production of organic residuals with watershed models to account for P recycling
Task Force Participants

*Legacy and Incidental P Losses*
- Lead: Peter Vadas (USDA)
- Team: Margaret Kalcic (OSU); Laura Johnson (Heidelberg Univ.), Rebecca Muenich (ASU); Tan Zou (UMd); Kevin King, Chad Penn (USDA); Josh McGrath (UKY)

*Identifying P Loss Hotspots with Hydrologic Models*
- Lead: Rem Confessor (Heidelberg Univ.)
- Team: Peter Vadas (USDA), Margaret Kalcic (OSU); Rebecca Muenich (ASU); Grey Evenson (OSU); Carl Bolster (USDA)

*Coupling Process and Hydrologic Models*
- Lead: Céline Vaneeckhaute (Université Laval)
- Team: Rebecca Muenich (ASU); Rem Confessor (Heidelberg Univ.)
Legacy vs Incidental P loss

- Legacy – loss of P already in the soil from historical P applications
- Incidental – loss of P from newly applied fertilizer and manure

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- What is relative contribution of each?
- How long does incidental signal last?
- How does better information help set priorities and targets?
Legacy vs Incidental P loss

• Use field data and simulation models to tell us how best to manage these two P sources

• Suite of \textit{harmonized} models available
  
  • \textbf{APLE} – annual time step, field scale, rapid, user friendly to explore broad scenarios
  
  • \textbf{SurPhos} – daily time step, field scale, user-friendly to explore event based dynamics
  
  • \textbf{SWAT} – daily time step, basin scale, more data intensive to explore spatial and transport dynamics

• Use field data to test models – use models to expand scenarios and details
**APLE application**: How much can reducing legacy soil P decrease P loss from MD ag land to Chesapeake Bay

![Graph showing total P loss from MD Ag Land over years with current, drawdown, and optimum scenarios. The graph indicates a 42% decrease in P loss over 30 years.]
**SurPhos application**: How does day of year manure is applied change P loss

<table>
<thead>
<tr>
<th>Runoff Group</th>
<th>Winter P Loss (kg/ha/y)</th>
<th>Non-Winter P Loss (kg/ha/y)</th>
<th>Season Diff.</th>
<th>Runoff Diff. over Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.28</td>
<td>0.11</td>
<td>2.5x</td>
<td>--</td>
</tr>
<tr>
<td>Med.</td>
<td>1.01</td>
<td>0.35</td>
<td>2.9x</td>
<td>3.4x</td>
</tr>
<tr>
<td>High</td>
<td>2.40</td>
<td>0.67</td>
<td>3.6x</td>
<td>7.5x</td>
</tr>
</tbody>
</table>

**SWAT Application**: Scale analysis to watershed and find out where this makes the most difference and the impact at the final waterbody.
Identifying P hotspot with hydrologic models

Hotspots
Fields with high P loss due to high legacy soil P or excessive P application

**APLE application**: Legacy P hotspot quantification in Chesapeake Bay watershed

Only 19% of land (>150 ppm STP) falls under P Index regulations, but responsible for 37% of legacy P loss

<table>
<thead>
<tr>
<th>Soil test P (ppm)</th>
<th>% Land</th>
<th>% P Loss</th>
<th>Ratio P Loss to Land</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low runoff and erosion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-150</td>
<td>32.3</td>
<td>8.1</td>
<td>0.3</td>
</tr>
<tr>
<td>150-300</td>
<td>2.9</td>
<td>1.4</td>
<td>0.5</td>
</tr>
<tr>
<td>300-450</td>
<td>2.4</td>
<td>1.8</td>
<td>0.8</td>
</tr>
<tr>
<td>450-500</td>
<td>1.9</td>
<td>1.8</td>
<td>0.9</td>
</tr>
<tr>
<td>&gt;500</td>
<td>0.6</td>
<td>0.8</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Medium runoff and erosion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-150</td>
<td>44.4</td>
<td>45.4</td>
<td>1.0</td>
</tr>
<tr>
<td>150-300</td>
<td>3.9</td>
<td>6.8</td>
<td>1.7</td>
</tr>
<tr>
<td>300-450</td>
<td>3.2</td>
<td>8.0</td>
<td>2.5</td>
</tr>
<tr>
<td>450-500</td>
<td>2.7</td>
<td>7.7</td>
<td>2.9</td>
</tr>
<tr>
<td>&gt;500</td>
<td>0.8</td>
<td>3.2</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>High runoff and erosion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-150</td>
<td>4.0</td>
<td>9.6</td>
<td>2.4</td>
</tr>
<tr>
<td>150-300</td>
<td>0.4</td>
<td>1.4</td>
<td>4.0</td>
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<tr>
<td>300-450</td>
<td>0.3</td>
<td>1.7</td>
<td>5.6</td>
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<tr>
<td>450-500</td>
<td>0.2</td>
<td>1.6</td>
<td>6.6</td>
</tr>
<tr>
<td>&gt;500</td>
<td>0.1</td>
<td>0.7</td>
<td>9.2</td>
</tr>
</tbody>
</table>
**Identifying Incidental P hotspots**

**SurPhos Application:** How much can we reduce P loss by avoiding temporal P hotspots (runoff soon after P application) during 30 years of simulated manure application?

<table>
<thead>
<tr>
<th>Number of Runoff-free days after Application</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average annual P Loss (kg ha⁻¹)</td>
<td>1.25</td>
<td>1.20</td>
<td>1.14</td>
<td>1.11</td>
</tr>
<tr>
<td>% of days (n=12,275) when application delay reduced P loss by more than 0.1 kg ha⁻¹</td>
<td>--</td>
<td>3.6</td>
<td>6.9</td>
<td>9.1</td>
</tr>
<tr>
<td>Average decrease in P loss (kg ha⁻¹), max in parentheses, when delay decreased P loss by more than 0.1 kg ha⁻¹</td>
<td>--</td>
<td>1.48 (5.97)</td>
<td>1.69 (5.97)</td>
<td>1.73 (5.97)</td>
</tr>
<tr>
<td>% of days when delay increased P loss by more than 0.1 kg ha⁻¹</td>
<td>--</td>
<td>1.2</td>
<td>2.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Average increase in P loss (kg ha⁻¹), max in parentheses, when delay increased P loss by more than 0.1 kg ha⁻¹</td>
<td>--</td>
<td>0.35 (2.13)</td>
<td>0.45 (2.34)</td>
<td>0.47 (2.35)</td>
</tr>
</tbody>
</table>

**SWAT Application:** Scale analysis to watershed and find out where this makes the most difference and the impact at the final waterbody.
Coupling P production models to watershed models

**Objective:** To couple nutrient recovery process models used in wastewater treatment (e.g., NRM) with SWAT hydrologic model

**Expected benefits:**
- Potential to simulate and optimize nutrient behavior over the whole fertilizer production and application chain
- Potential to adjust the fertilizer quality to the watershed or river basin quality
Concept

**NRM**
- Nutrient recovery process modelling
- Target fertilizer characteristics

**SWAT**
- Watershed modelling
- Soil characteristics
- Water characteristics
- Crop nutrient uptake

**SIMULATION**

**OPTIMIZATION**

**INTERFACE**

- Fertilizer characteristics
Research Needs

• Development of SWAT routines to allow for more advanced physicochemical representation of fertilizer materials and runoff of fertilizer applied to soil surface.

• Development of an interface between NRM and SWAT to allow for easy data exchange and to calculate target fertilizer characteristics based on the soil and water quality and crop nutrient uptake.

• Development of an appropriate optimization algorithm for the integrated tool.
Questions?
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Biosolids and Manure Task Force Report

Sustainable Phosphorus Alliance

Rebecca Muenich, Eleanor Rauh, Carl Churchill, Matt Scholz
Project Motivation

Nutrient runoff leads to increased eutrophication which can lead to negative environmental impacts.

Photo credit: Tom Archer
Organic residuals like biosolids and manure offer a potentially low-cost alternative to inorganic fertilizers.
There are almost 500,000 Wastewater Facilities in the United States and Puerto Rico. 1 dot = 1 facility.
Biosolids are federally regulated under 40 CFR Part 503, “Standards for the Use or Disposal of Sewage Sludge”

Concentrated Animal Feeding Operations (CAFO) are regulated under the National Pollutant Discharge Elimination System (NPDES) in 40 CFR Part 122 and 40 CFR Part 412
Project Motivation

The patchwork of state regulations are **cumbersome and confusing**.

There is **little guidance** for states on developing regulations.

This **impairs** the development of recycled fertilizer markets.
The Biosolids and Manure Task Force work will let practitioners, agencies, and researchers easily study state and federal regulations on biosolids and manure by providing a user-friendly clearinghouse for land application regulations for industry, regulators, and others with vested interests.
Data Gathering

• May 2018-August 2018: Collect all state-level regulations governing the land application of biosolids and manures from CAFOs
• August 2018-March 2019: QA’d with state regulators
Tool Development

Translate Compendium information into a readable database

<table>
<thead>
<tr>
<th>Column ID</th>
<th>Description</th>
<th>Data Type</th>
<th>Mappable</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATE_NAME</td>
<td>State name</td>
<td>Text</td>
<td>N</td>
</tr>
<tr>
<td>STATE_FIPS</td>
<td>Federal information processing standard (FIPS) state code</td>
<td>Integer</td>
<td>N</td>
</tr>
<tr>
<td>SUB_REGION</td>
<td>Subregion state belongs to</td>
<td>Text</td>
<td>N</td>
</tr>
<tr>
<td>STATE_ABBR</td>
<td>Alphabet code for state</td>
<td>Text</td>
<td>N</td>
</tr>
<tr>
<td>REG_AGEN</td>
<td>Name of regulatory agency</td>
<td>Text</td>
<td>N</td>
</tr>
<tr>
<td>REG_AGEN_CAT</td>
<td>Regulatory agency category: state epa, state ag, nat resour, health, combo, other</td>
<td>Text</td>
<td>Y</td>
</tr>
<tr>
<td>REG_LINKS</td>
<td>URL links to regulations</td>
<td>Text</td>
<td>N</td>
</tr>
<tr>
<td>DEL_ST</td>
<td>Is state delegated for biosolids? : yes, no</td>
<td>Text</td>
<td>Y</td>
</tr>
<tr>
<td>OTHER</td>
<td>Other important details to highlight</td>
<td>Text</td>
<td>N</td>
</tr>
</tbody>
</table>
Uses for GIS-P

• Scenario planning
• Comparisons across states
• Allows regulators to compare with nearby states
• Contextualization of regulations with related data
Data Collection Challenges

• Inconsistent Terminology & Approaches to Regulations

• “Gray” Areas of Regulations

• Some states still not QA’d
States That Still Need QA

**Biosolids**
- California
- Connecticut
- Georgia
- Missouri
- Nebraska
- New Hampshire
- New Mexico
- Rhode Island
- Tennessee
- West Virginia
- Some California Regions

**Manure**
- Alaska
- Some California RWQBs
- Florida
- Hawaii
- Idaho
- Missouri
- Montana
- New Jersey
- North Carolina
- Rhode Island
- Tennessee
- Texas
- Vermont
- West Virginia
- Wisconsin

Also Consider…
- Other supplemental data you’d like to see
- Thoughts on “ease of use”
- Continuing to work on Canada
• We translated difficult to review/compare regulations into a user-friendly tool

• Makes comparison across states easy

• Allows for incorporation of other, related data sources for context

• Allows for multiple kinds of visualizations of complex data

For more information

Rebecca Muenich (Rebecca.Muenich@asu.edu or muenichlab.com)

Matthew Scholz (scholz@phosphorusalliance.org)
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