Sustainable P Management in the Age of the Bloom

Nandita Basu

University of Waterloo

Anthropocene: Urban P and Human Impacts

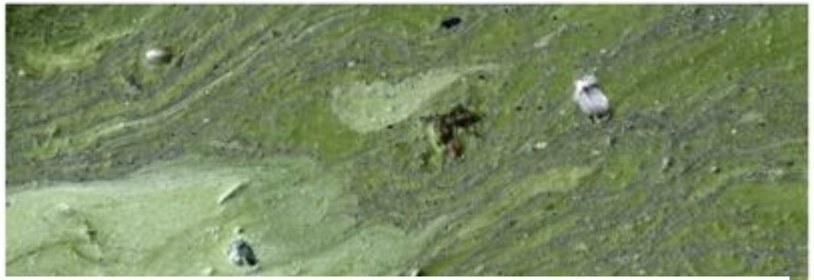
Algae in the News

Florida Fights Giant Algal Bloom in Lake Okeechobee

Governor declares state of emergency as algae covers about 90% of the 730-square-mile lake

Environmental agency: Nearly entire Gulf of Finland overrun with blue-green algae

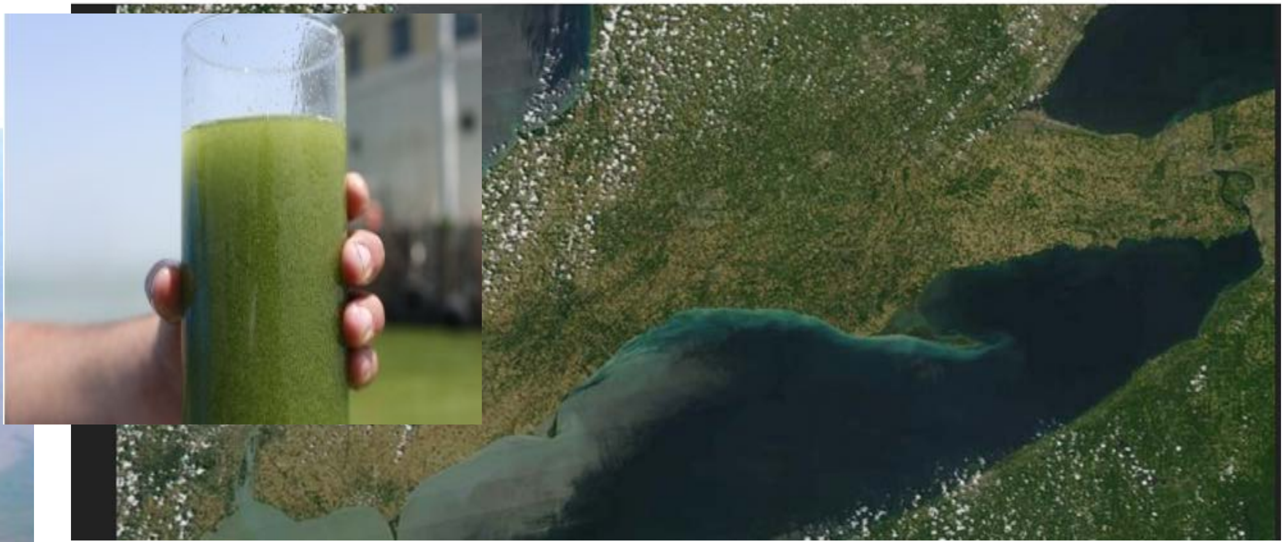
The algal blooms have also invaded many inland lakes and researchers say the situation will only improve in August.



Toxic algae in western Lake Erie makes early arrival because of heat

By Tom Henry | BLADE STAFF WRITER

Published on July 2, 2018 | Updated 1:20 a. m.

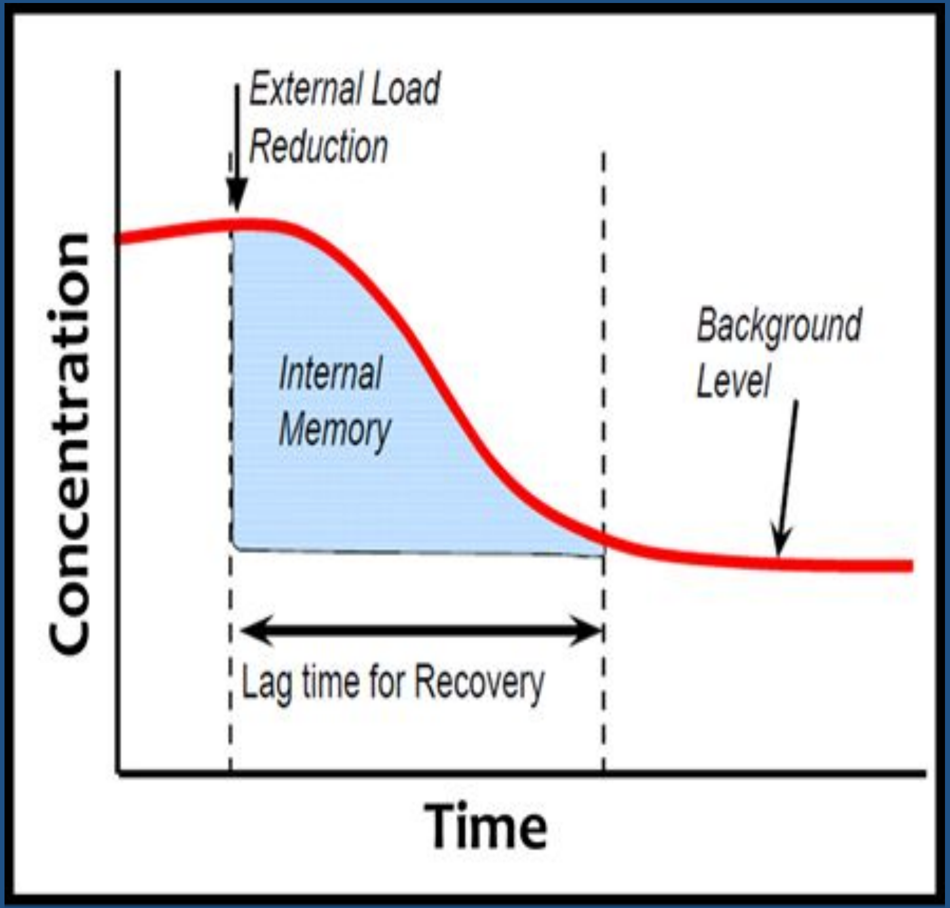


Public health agency warns of blue-green algae in Toronto waters

Phosphorus Legacies



Intensively managed catchments have legacy stores of nutrients that have built up over decades of fertilizer application and contribute to catchment time lags



adapted from Reddy et al.(2011)

Environmental Science & Technology

Viewpoint

pubs.acs.org/est

Sustainable Phosphorus Management and the Need for a Long-Term Perspective: The Legacy Hypothesis

Philip M. Haygarth,*,† Helen P. Jarvie,‡ Steve M. Powers,§ Andrew N. Sharpley,∥ James J. Elser,⊥ Jianbo Shen,# Heidi M. Peterson,∇ Neng-Iong Chan,⊥ Nicholas J. K. Howden,○ Tim Burt,◆ Fred Worrall,¶ Fusuo Zhang,# and Xuejun Liu#

5-year fight removes less than 1% of phosphorus from Lake Winnipeg basin

Targeted action needed against nutrient causing toxic algae blooms, scientists and advocates say

By Cameron MacLean, CBC News Posted: Sep 17, 2017 4:00 AM CT | Last Updated: Sep 17, 2017 11:02 AM CT

1

Quantify Legacies & Lag Times

Adjust expectations

nature geoscience

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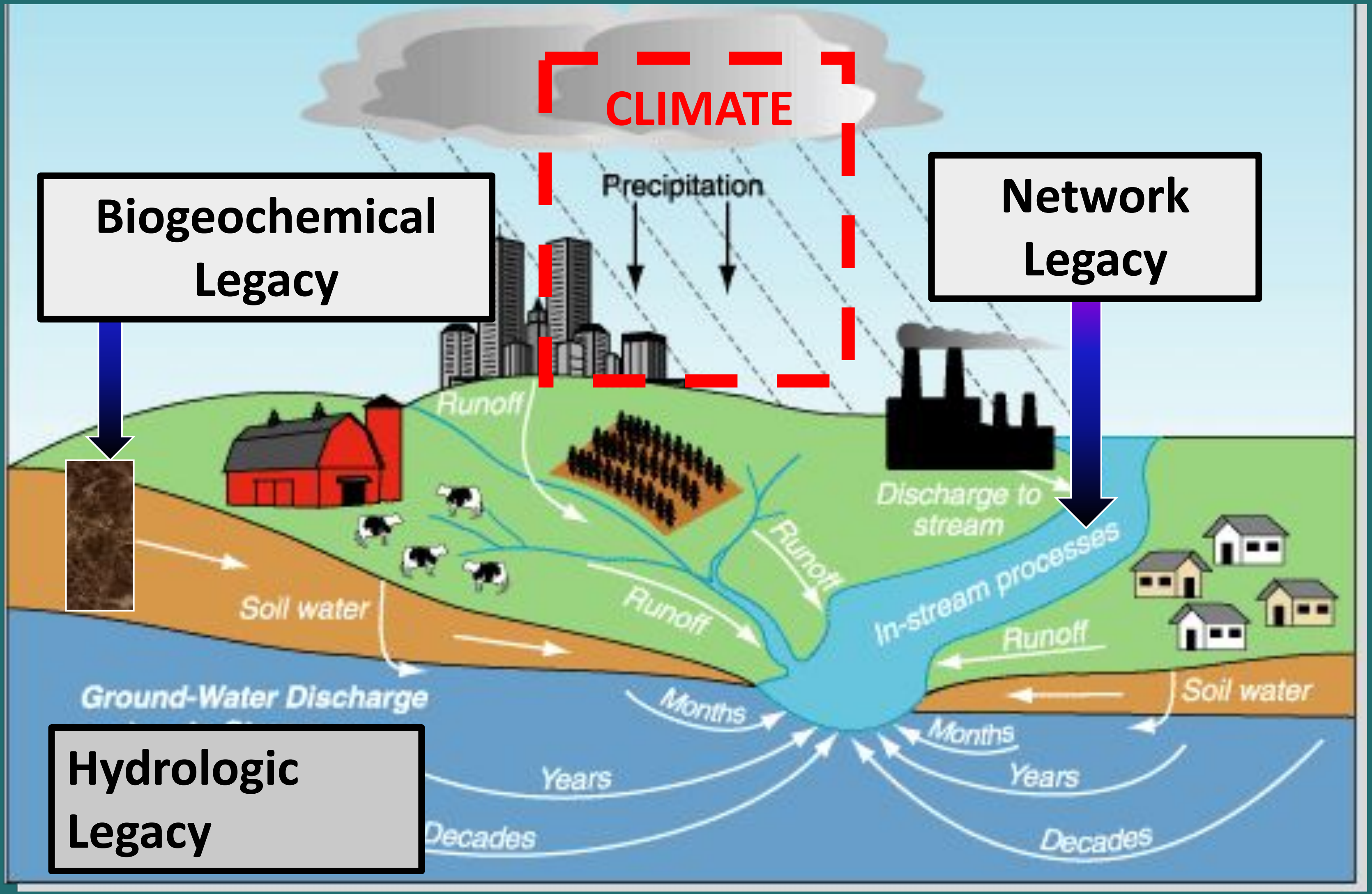
nature > nature geoscience > perspectives > article

Perspective | Published: 10 February 2022

Managing nitrogen legacies to accelerate water quality improvement

Nandita B. Basu, Kimberly J. Van Meter, Danyka K. Byrnes, Philippe Van Cappellen, Roy Brouwer,

How long will it take for water quality to improve?



Stores

How much?

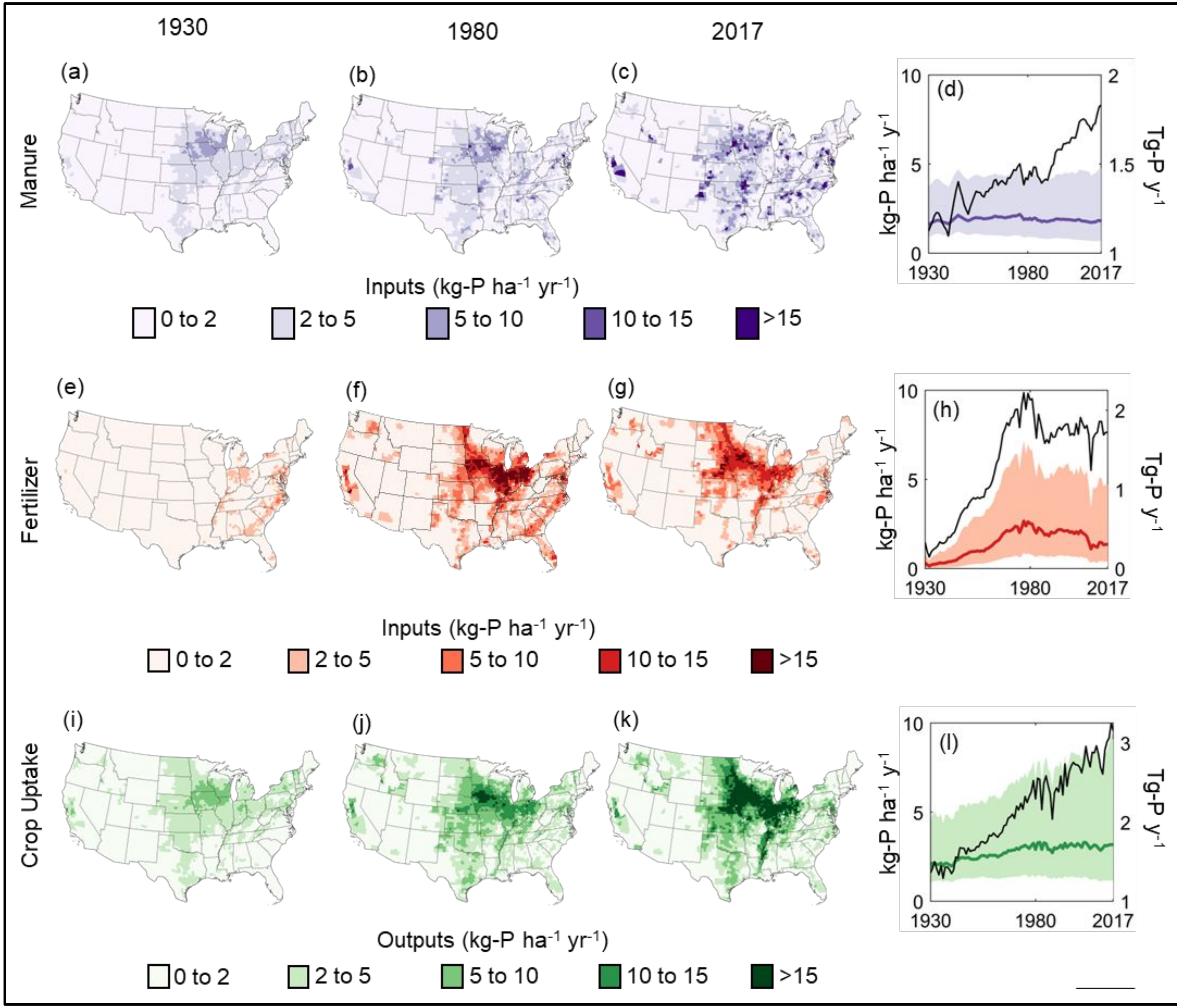
What form?

Where?

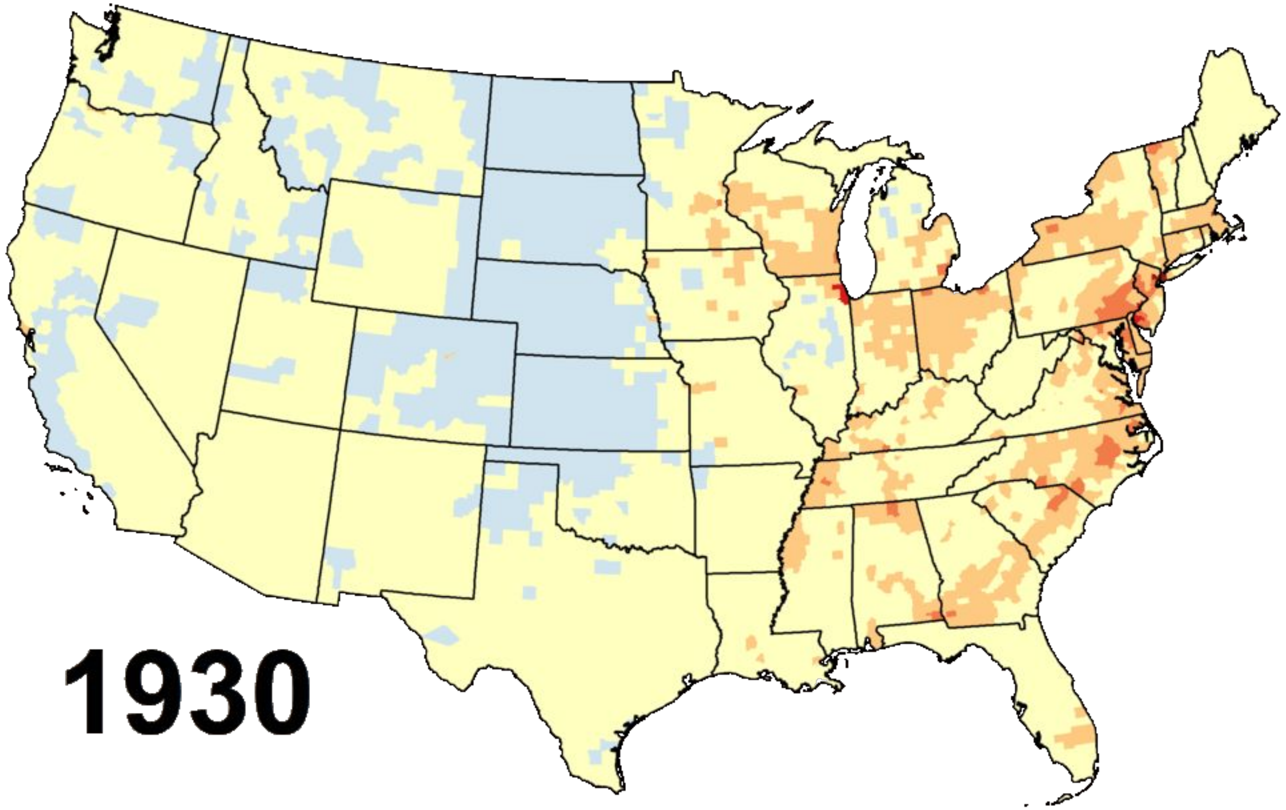
Fluxes

How are these legacies mobilized?

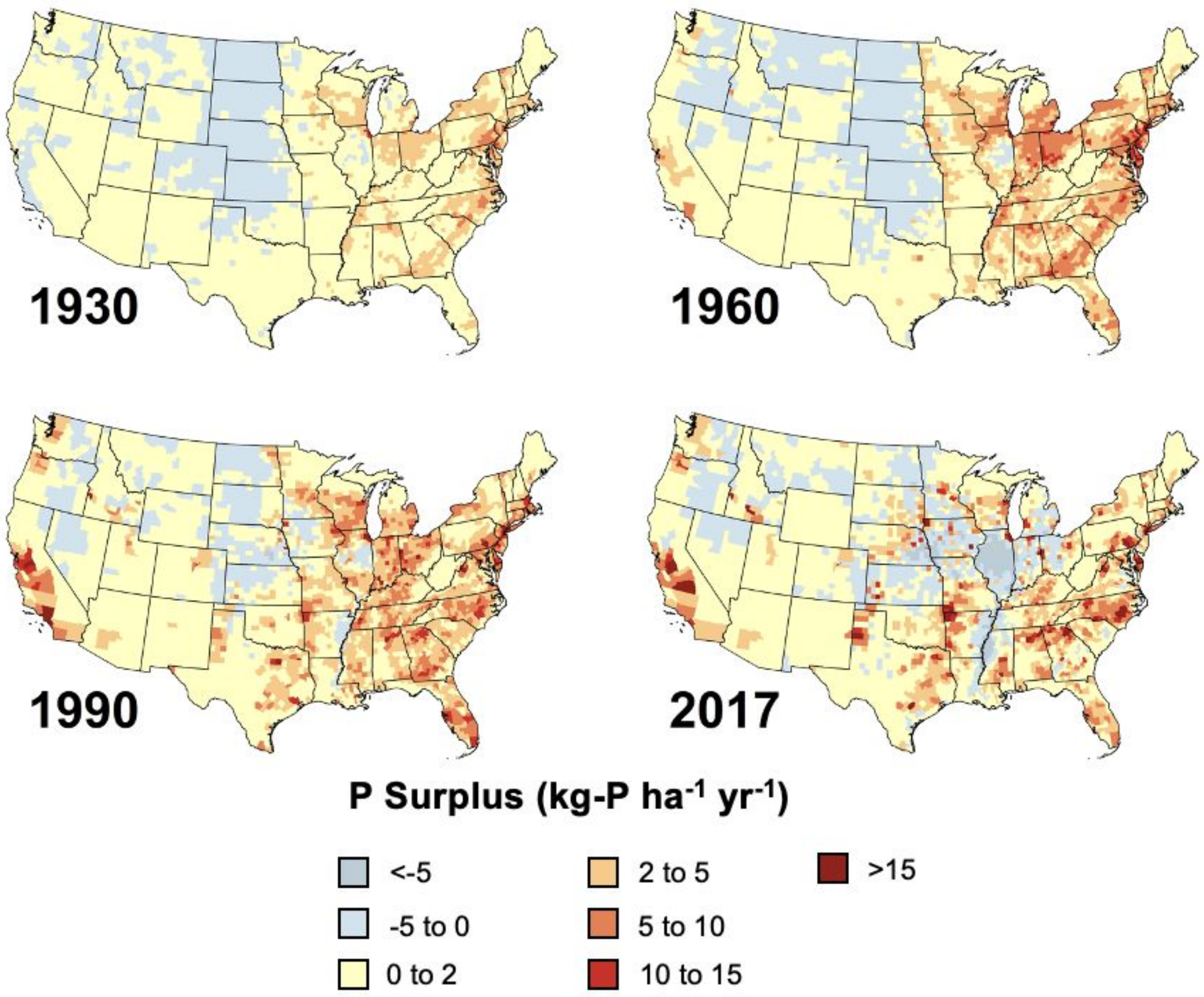
Phosphorus Inputs and Outputs across US (250 m scale)

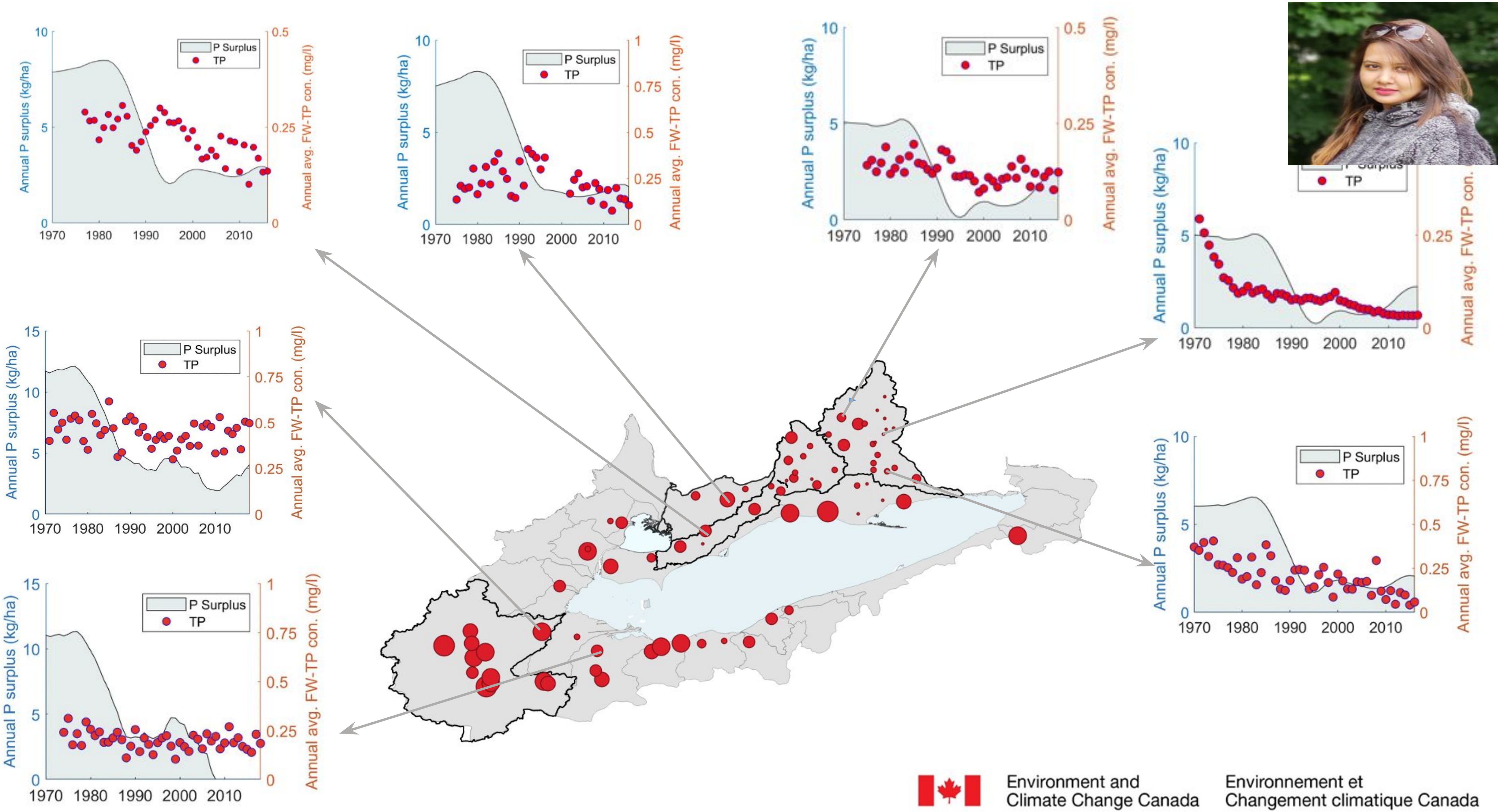


Phosphorus Surplus (Inputs – Outputs) across US



Phosphorus Surplus (Inputs – Outputs) across US



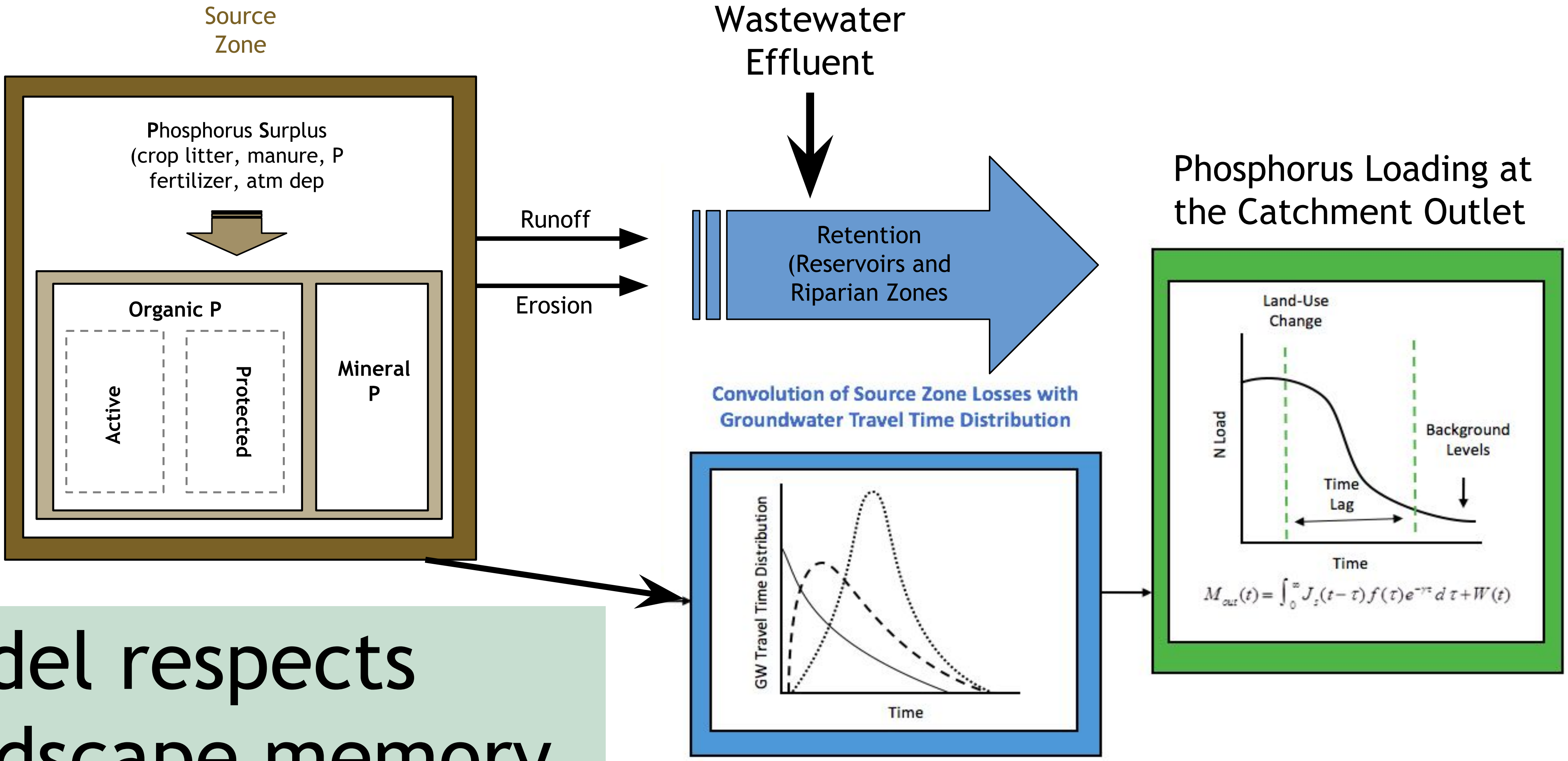


Environment and Climate Change Canada

Environnement et Changement climatique Canada

ELEMeNT Phosphorus

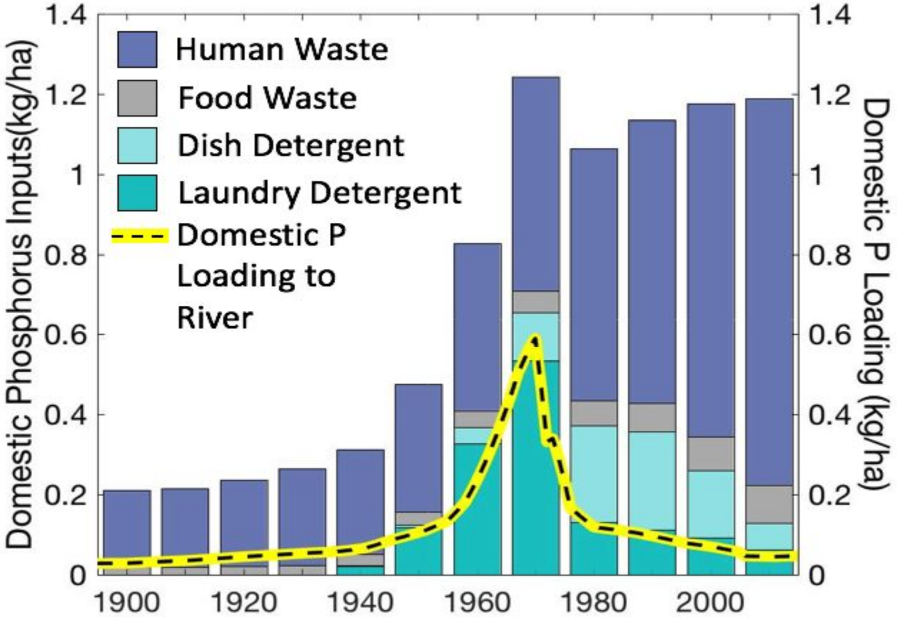
Exploration of Long-tErM NutrienT legacies

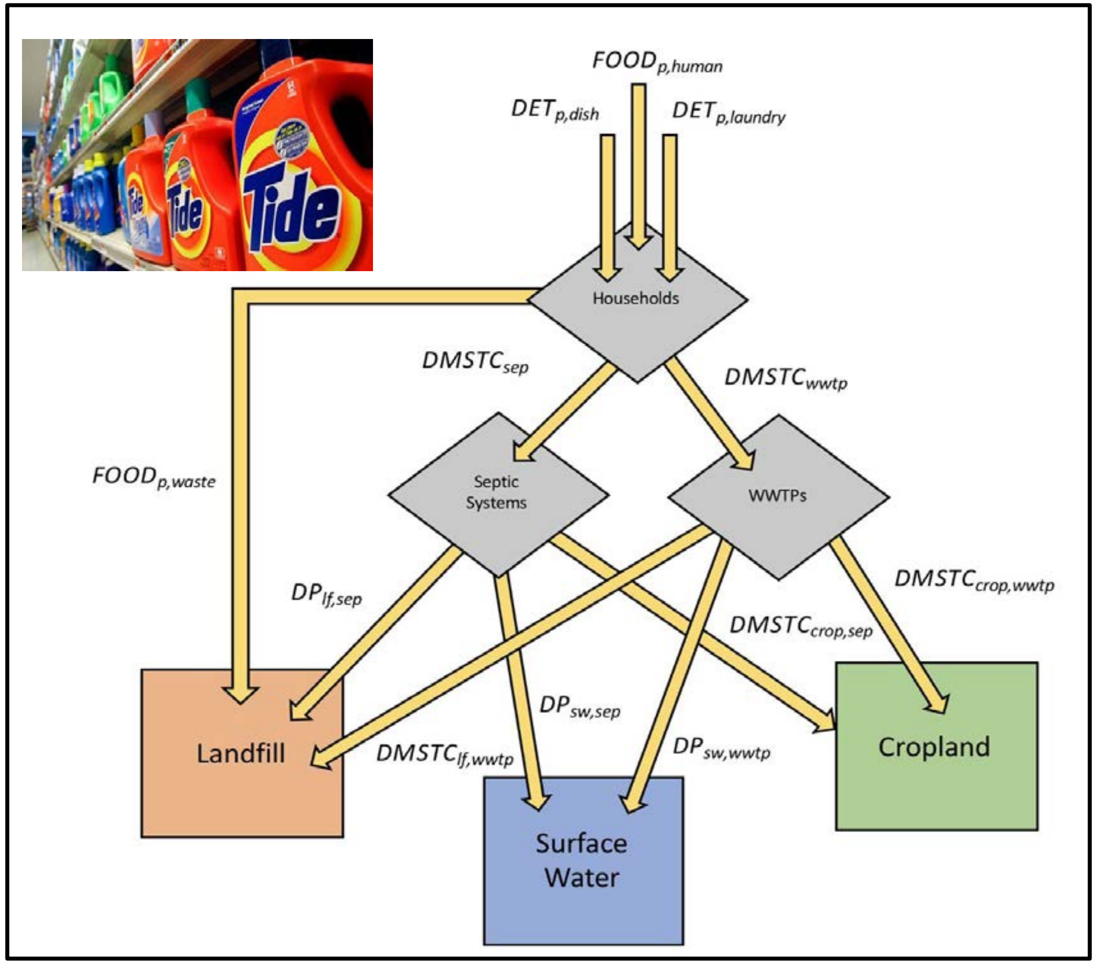


Model respects landscape memory

Beyond the Mass Balance: Watershed Phosphorus Legacies and the Evolution of the Current Water Quality Policy Challenge

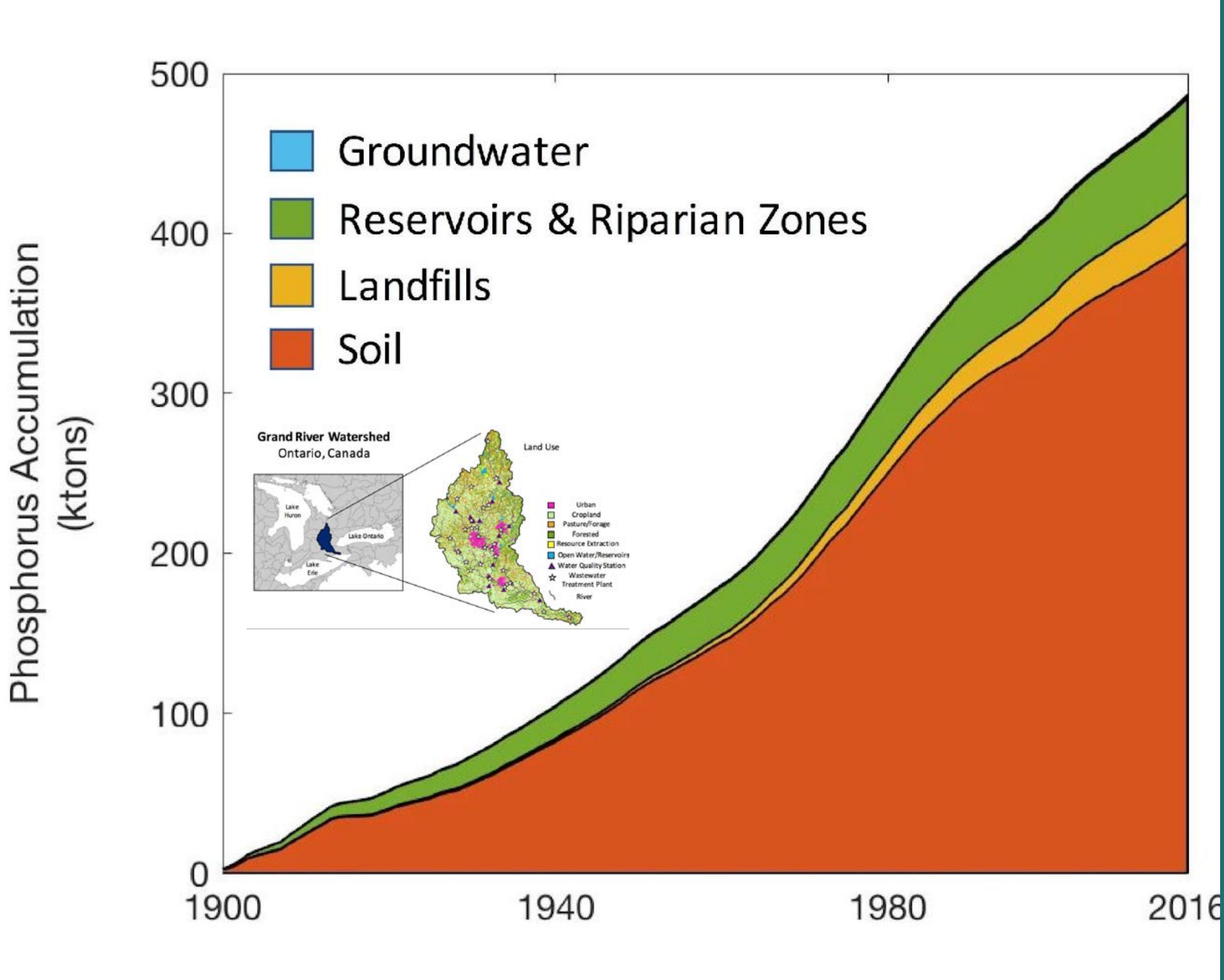
K. J. Van Meter[1], M. M. McLeod[2], J. Liu[3], G. Thierry Tenkouano[4], R. I. Hall[5,6], P. Van Cappellen[4,6], and N. B. Basu[3,4,6]





Representation of the Urban P Component

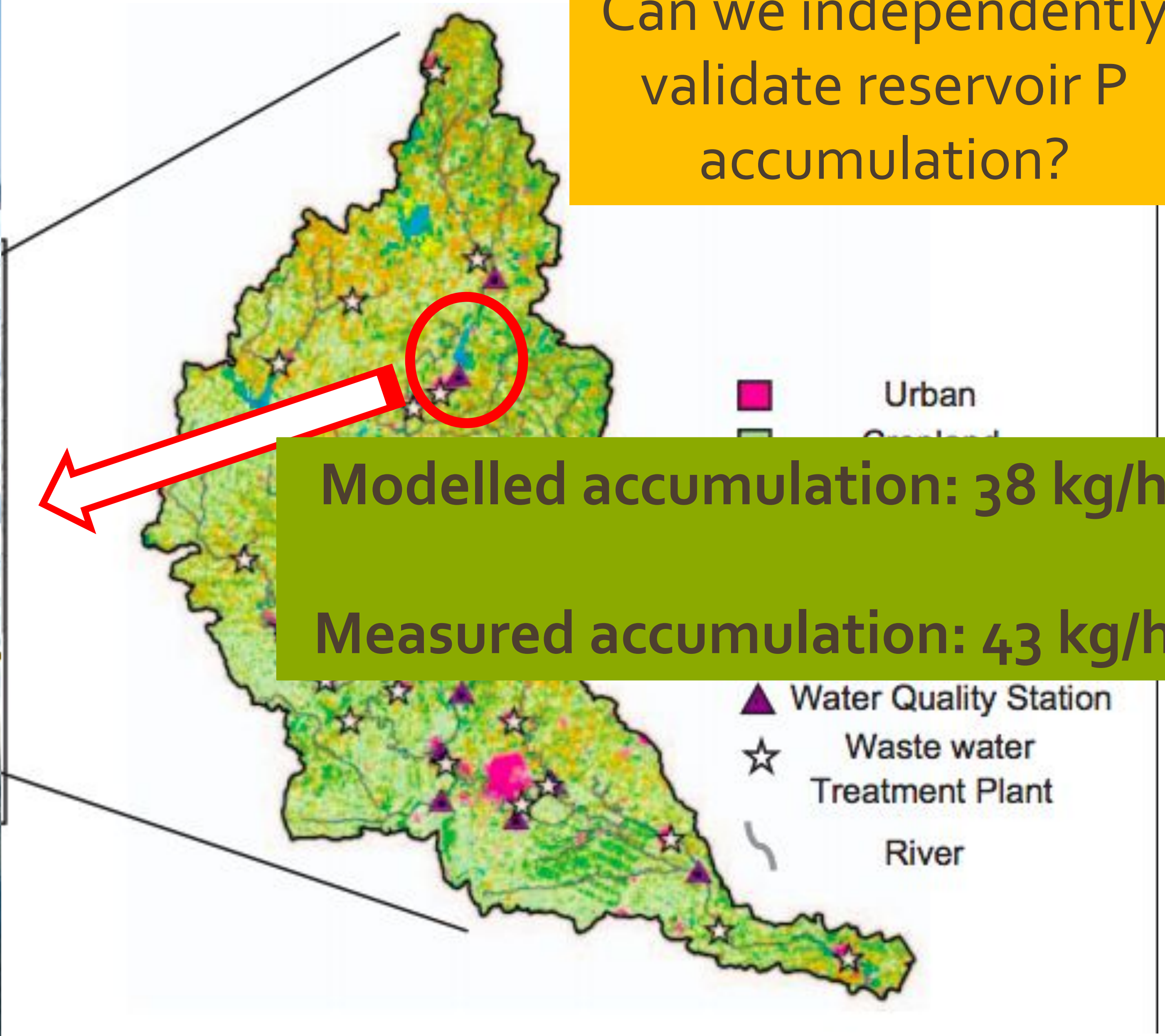
Models tell us where the P is hiding…



For example, a model of the Grand River Watershed showed that most of the legacy P has accumulated in soil

Since 1900, ~4% of net P inputs to the GRW have been exported to downstream waters

Can we independently validate reservoir P accumulation?



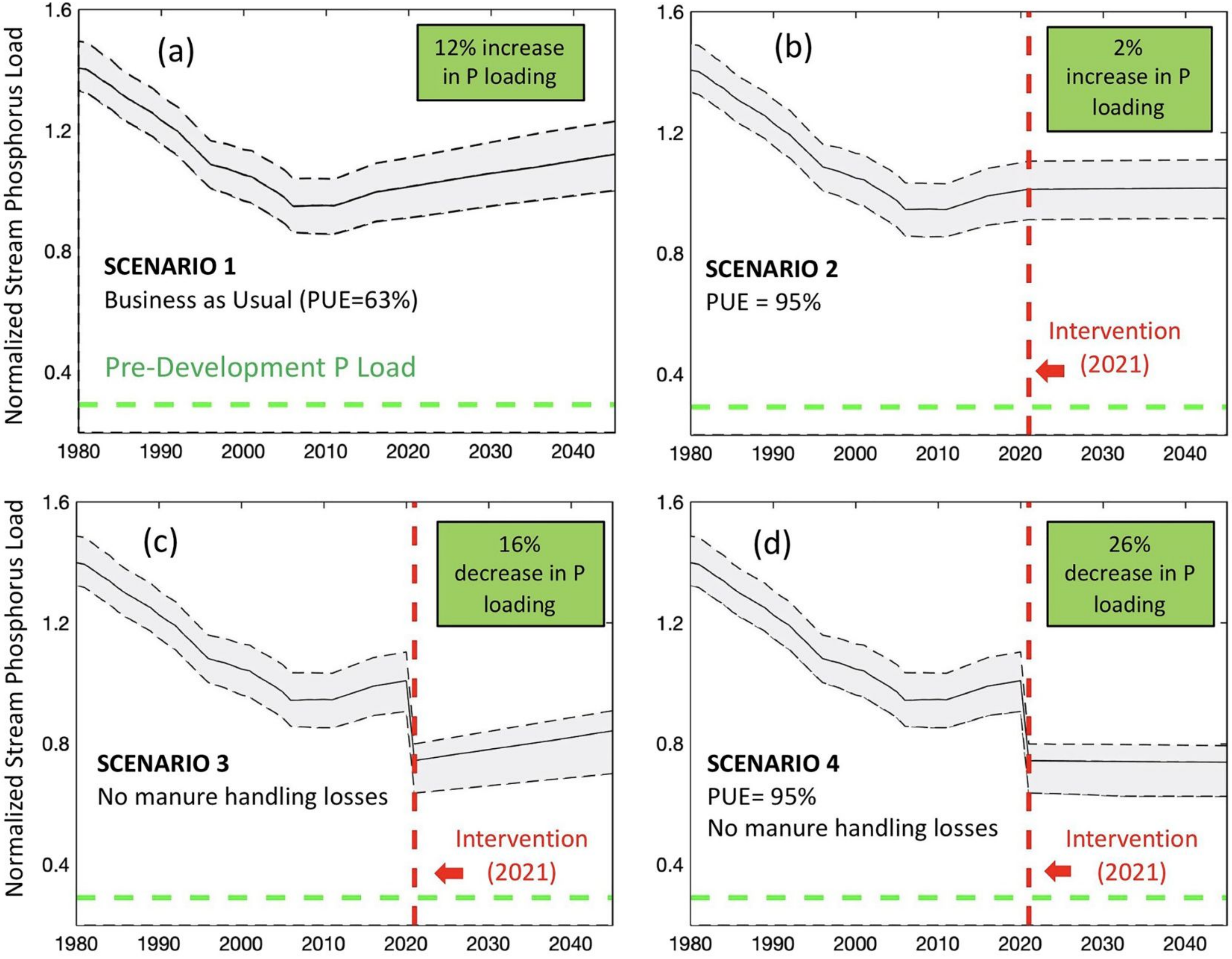
Modelled accumulation: 38 kg/ha

Measured accumulation: 43 kg/ha

Prediction is very difficult… especially if it's about the future.

-Nils Bohr

Reducing manure losses leads to some of the fastest improvements to water quality




Quantify Lag Times
Adjust expectations
1
Legacy as a Resource?
2

Legacy as a Resource: If P is building up soils can we effectively “harvest” it?

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Feature
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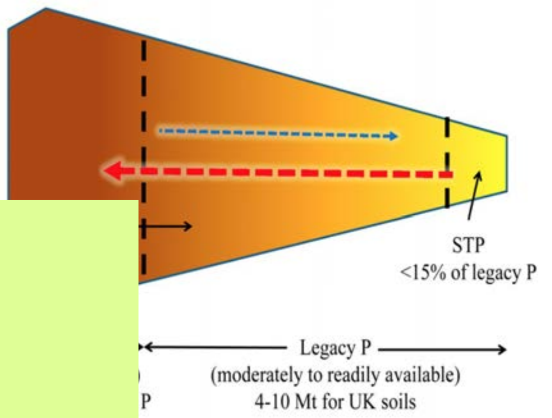
Feed the Crop ... the Food Chain



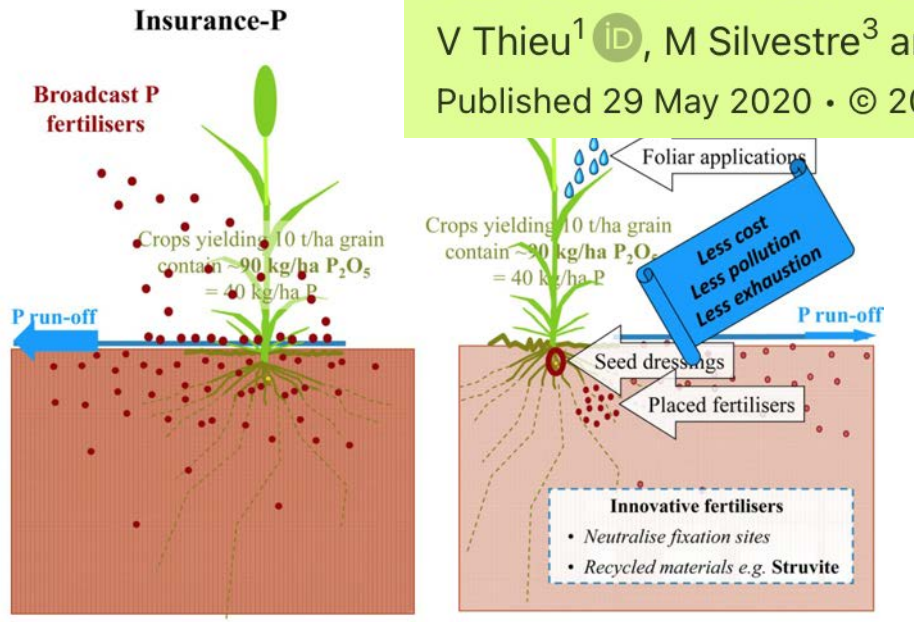
LETTER • OPEN ACCESS

The phosphorus legacy offers opportunities for agro-ecological transition (France 1850–2075)

J Le Noë[1,2], N Roux[1,2], G Billen[1], S Gingrich[2], K -H. Erb[2], F Krausmann[2], V Thieu[1], M Silvestre[3] and J Garnier[1]

Published 29 May 2020 • © 2020 The Author(s). Published by IOP Publishing Ltd

...ection: Agricultural



Impacts of Soil Phosphorus Drawdown on Snowmelt and Rainfall Runoff Water Quality

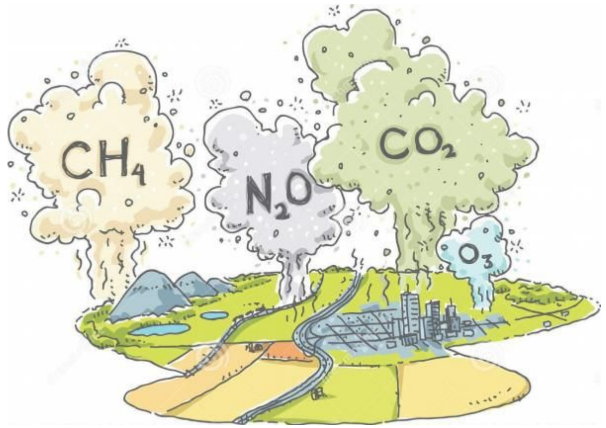
A 60% reduction in fertilizer P application led to a 40-50% reduction in TDP over a 10-year period, with no reduction in crop yield

1
Quantify Lag Times
Adjust expectations
2
Legacy as a Resource?
3
Spatially Targeted Measures
4
Waste Management (Manure + Foodwaste + Domestic Waste)

The planet's prodigious poo problem

Each year, livestock produces billions of tonnes of excrement. It's starting to poison the natural world. So what is to be dung?

by David Cox



How much poo is generated by the world's farms?

Recent research has estimated that by 2030, the planet will be generating at least 5bn tonnes of poo each year, with the vast majority being deposited by livestock. With 80% of farms in the Netherlands already producing more cow dung than they can legally use as fertiliser, and China resorting to drastic measures to try to reduce the amount of manure being discharged into

Intensification of Agriculture

Intensificatio n of Agriculture

Biogeochemistry (2020) 150:139–180
https://doi.org/10.1007/s10533-020-00691-6

REVIEW ARTICLE

From hogs to HABs: impac
on nitrogen and phosphoru

Patricia M. Glibert

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

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Research papers

The spatial organization of CAFOs and its relationship to water quality in the United States

Lorrayne Miralha[a,b], Suraya Sidique[a], Rebecca Logsdon Muenich[a,*]

[a] Arizona State University, Department of Civil Environmental and Sustainable Engineering, Arizona State University School of Sustainable Engineering and the Built Environment Tempe, AZ, United States

te University, Corvallis, OR 97331, United States

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Agricultural Systems

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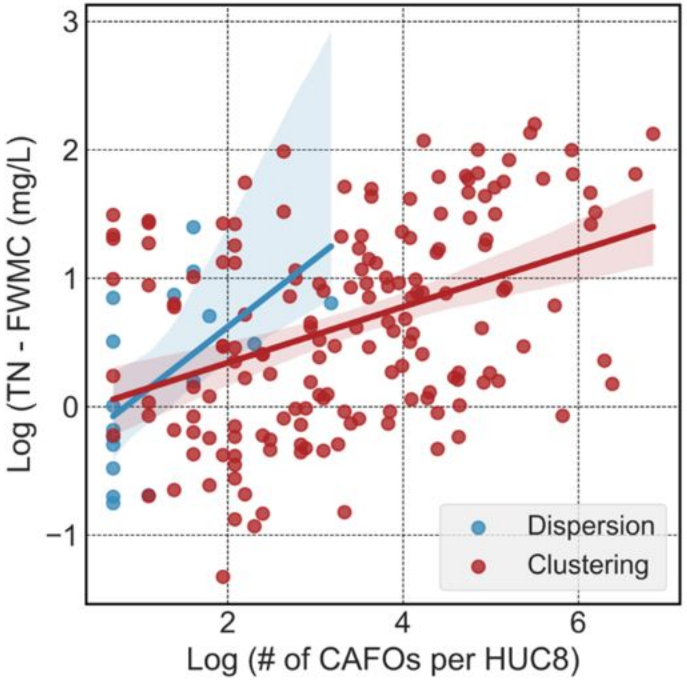
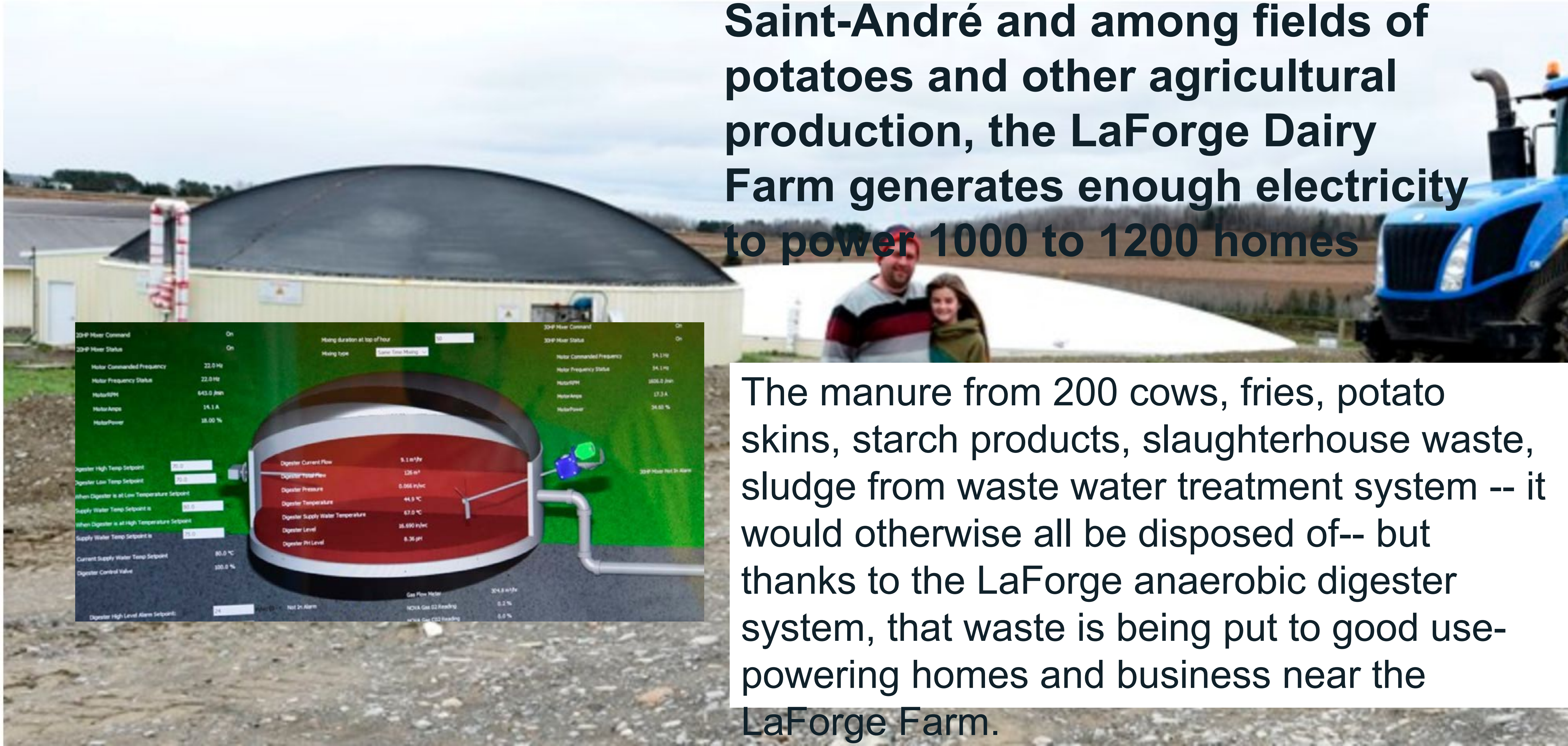
Manuresheds: Advancing nutrient recycling in US agriculture

Sheri Spiegal[a,*], Peter J.A. Kleinman[b], Dinku M. Endale[c], Ray B. Bryant[b], Curtis Dell[b], Sarah Goslee[b], Robert J. Meinen[d], K. Colton Flynn[e], John M. Baker[f], Dawn M. Browning[a], Greg McCarty[g], Shabtai Bittman[h], Jennifer Carter[i], Michel Cavigelli[g], Emily Duncan[j], Prasanna Gowda[k], Xia Li[l], Guillermo E. Ponce-Campos[m], Raj Cibin[n], Maria L. Silveira[o], Doulas R. Smith[e], Dan K. Arthur[b], Qichun Yang[p]



The LaForge Dairy Farm – a Biogas success story

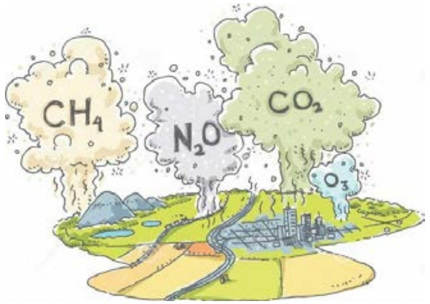
November 1 2016, 15:30 PM



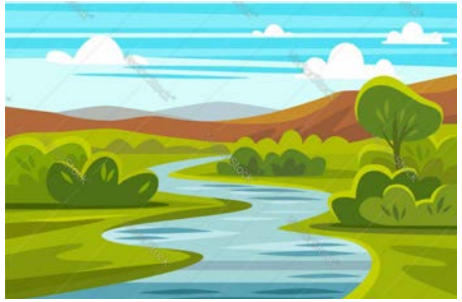
In the rural community of Saint-André and among fields of potatoes and other agricultural production, the LaForge Dairy Farm generates enough electricity to power 1000 to 1200 homes

The manure from 200 cows, fries, potato skins, starch products, slaughterhouse waste, sludge from waste water treatment system -- it would otherwise all be disposed of-- but thanks to the LaForge anaerobic digester system, that waste is being put to good use-powering homes and business near the LaForge Farm.

Increased Power Generation

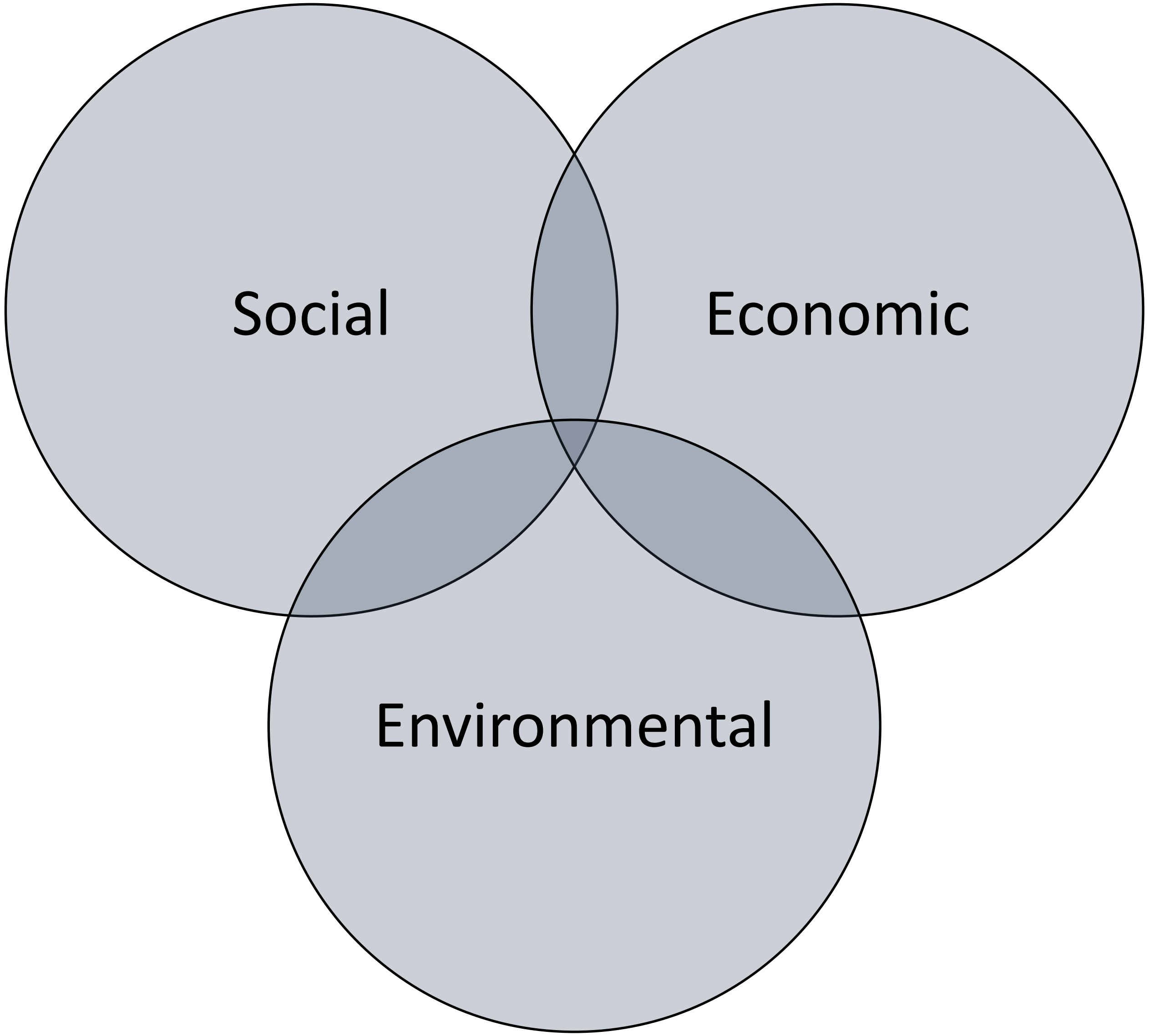


Reduced GHG Emissions



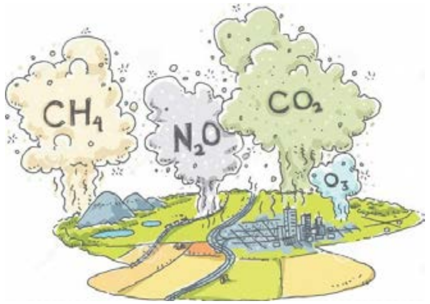
Improved Water Quality

Sustainable Solutions

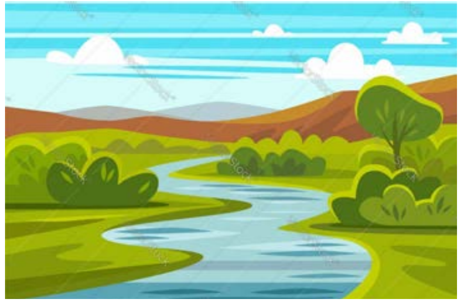


Sustainable Solutions

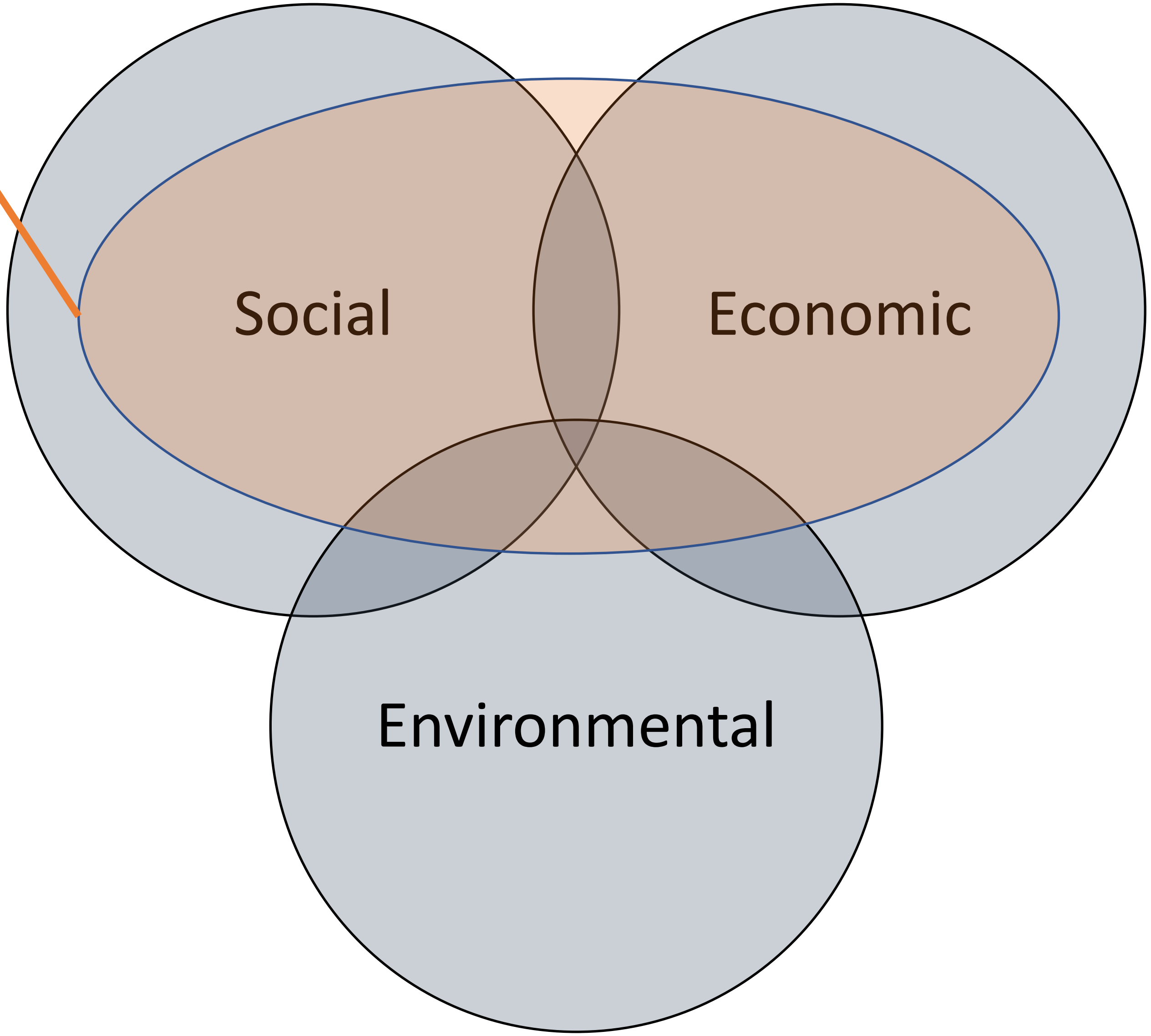
Increased Power Generation

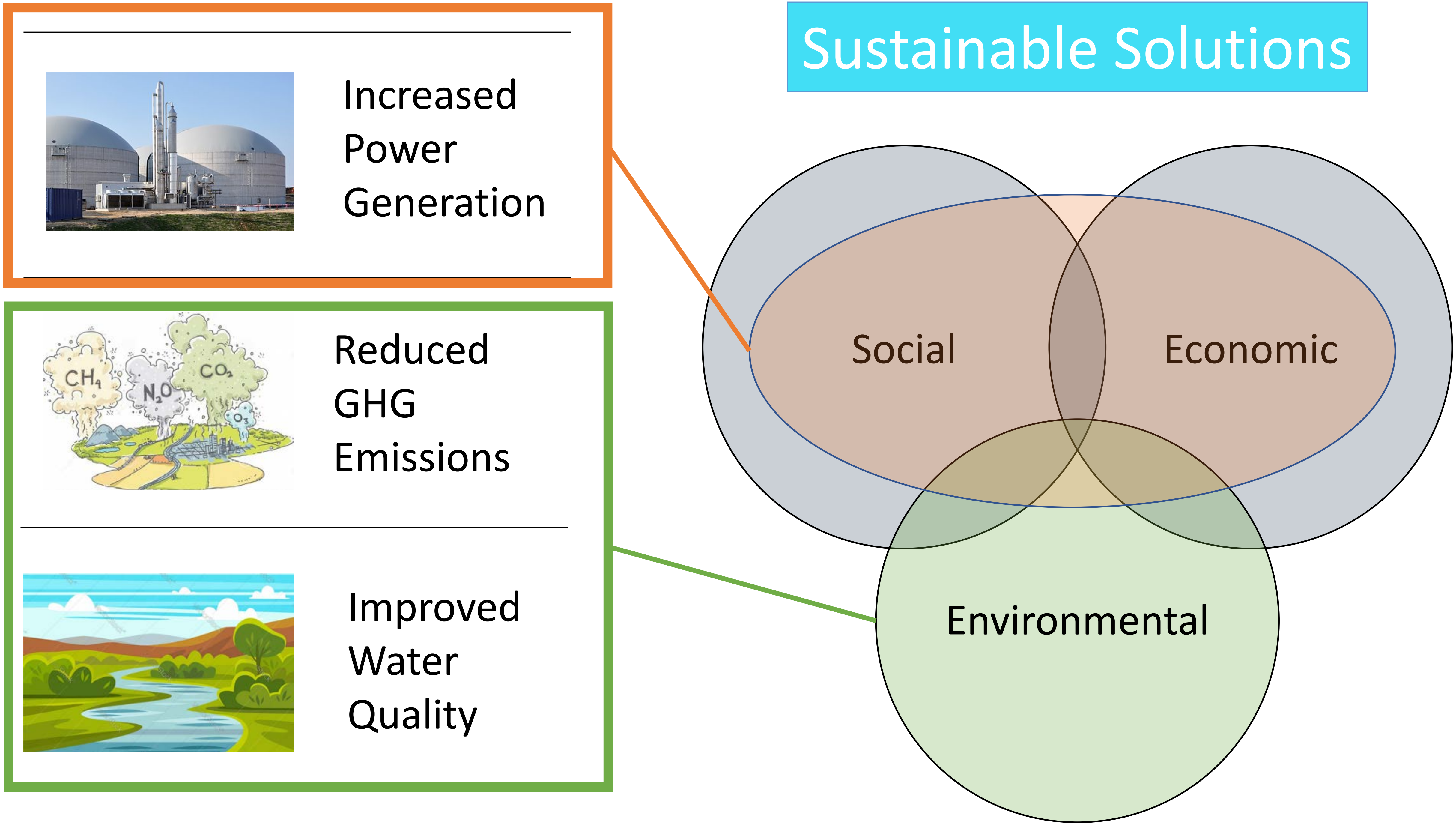


Reduced GHG Emissions



Improved Water Quality




Increased
Power
Generation
Reduced
GHG
Emissions
CH_4
N_2O
CO_2
O_3
Improved
Water
Quality
Sustainable Solutions
Social
Economic
Environmental

California subsidies for dairy cows' biogas are a lose-lose, campaigners say

The state pumps millions into methane produced by manure – but advocates argue it increases greenhouse gas emissions and encourages factory farming

Resources, Conservation & Recycling

Contents lists available a

Resources, Conservatio

journal homepage: www.sciencedirect.com/journa

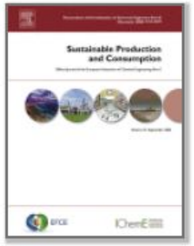
Optimizing transport to maximize nutrient rec
energy recovery

Geneviève S. Metson [*,a], Roozbeh Feiz [b,*], Nils-Hassan Qutt

[a] Theoretical Biology, Department of Physics, Chemistry and Biology, Sweden
[b] Environmental Technology and Management, Department of Management and Engineering, Sweden
[c] Optimization, Department of Mathematics, Sweden
[d] Biology, Department of Physics, Chemistry and Biology Linköping University, Linköping SE-581 83, S

Sustainable Production and Consumption

Volume 29, January 2022, Pages 370-386



Research article

Swedish food system transformations: Rethinking biogas transport logistics to adapt to localized agriculture

Geneviève S. Metson [a], Anton Sundblad [a], Roozbeh Feiz [b], Nils-Hassan Quttineh [c], Steve Mohr [d]

Show more

Spatial Optimization for location of Biogas Plants

Maximize the savings of manure transportation

$$max \sum_{i=1}^{n} \sum_{k=1}^{m} c_{ik} z_{ik} + \sum_{k=1}^{m} \left[-c_0 y_k + (l_1 * r * b * \eta - c_1) \sum_{i=1}^{n} (M_{P,i} z_{ik}) \right]$$

s.t.

Excess cell can only move the excess P available

$$\sum_{k=1}^{m} z_{ik} \leq S_i; \ \forall\, i$$

Fraction *f* of the total excess P must be moved

$$\sum_{i=1}^{n} \sum_{k=1}^{m} z_{ij} \geq f * \sum_{i=1}^{n} S_i$$

Limit the amount of manure a biogas plant can receive to *b* tons &
Prevent manure from moving to locations without biogas plants

$$\sum_{i=1}^{n} (M_{P,i} z_{ik}) \leq b y_k; \ \forall\, k$$

$$z_{ik} \geq 0; \ \forall\, i, k$$

$$y_k = 0{,}1; \ \forall\, k$$

Parameters:

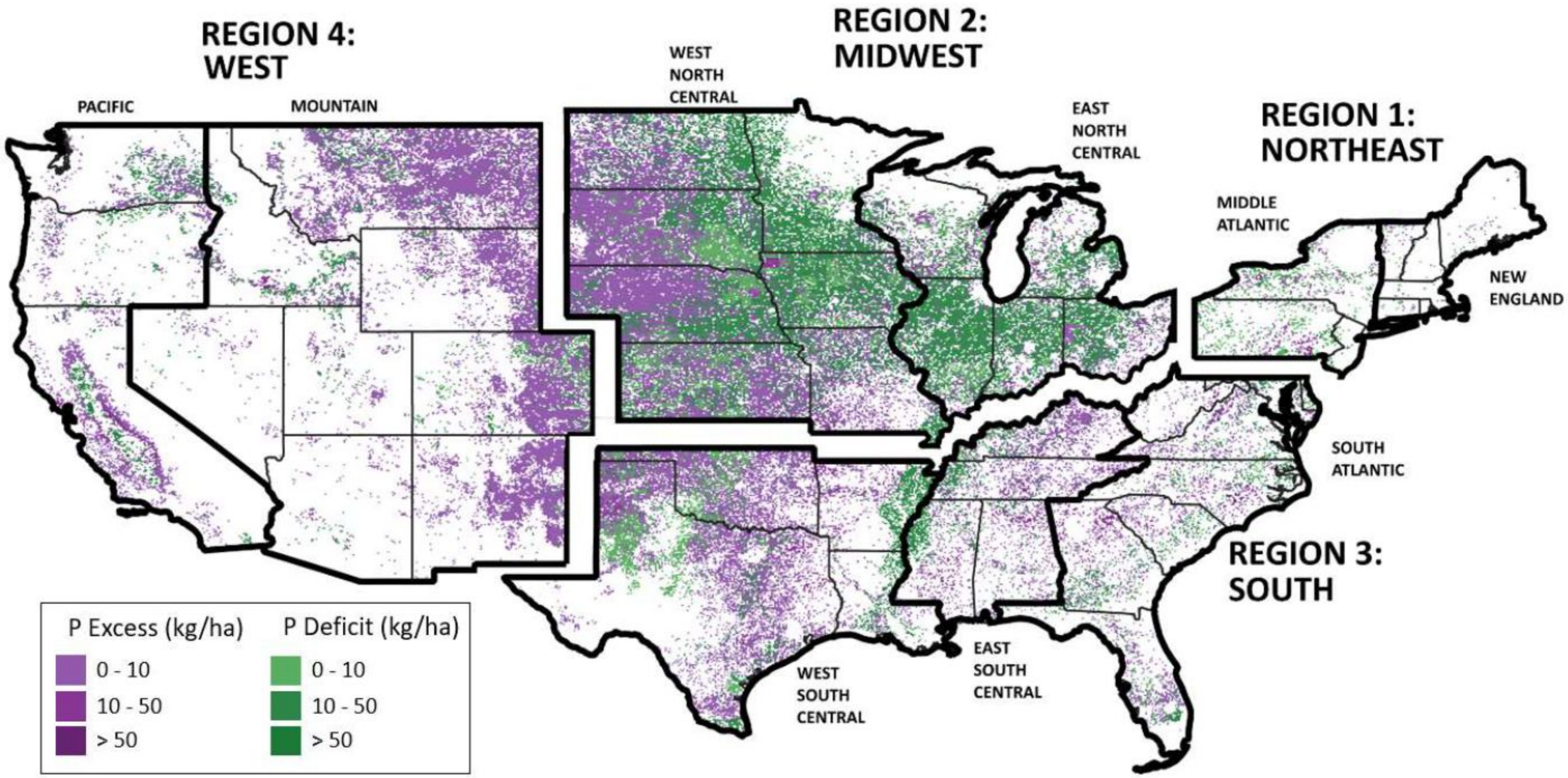
- i = Index of net P supply locations
- k = Index of potential biogas locations
- n = Number of P excess locations
- m = Number of potential biogas locations
- c_{ik} = Savings from moving manure from cell i to biogas plant j [$/ton P]
- c_0 = Fixed costs from building and operating a biogas plant [$]
- c_1 = Variable costs from building and operating a biogas plant [$/kWh]
- l_1 = Variable benefits from building and operating a biogas plant [$/Btu]
- r = Energy produced per volume of gas produced [Btu/m3 methane]
- b = Volume of gas produced per mas of manure used [m3 methane/ton manure]
- η = Efficiency of electrical energy generation [-]
- $M_{P,i}$ = Manure to phosphorus ratio in cell i [ton M/tonP]
- S_i = total phosphorus supply at cell i [ton P]
- f = minimum fraction of excess manure to be transported [-]
- b = Maximum manure capacity of a biogas plant [tons M]

Variables:

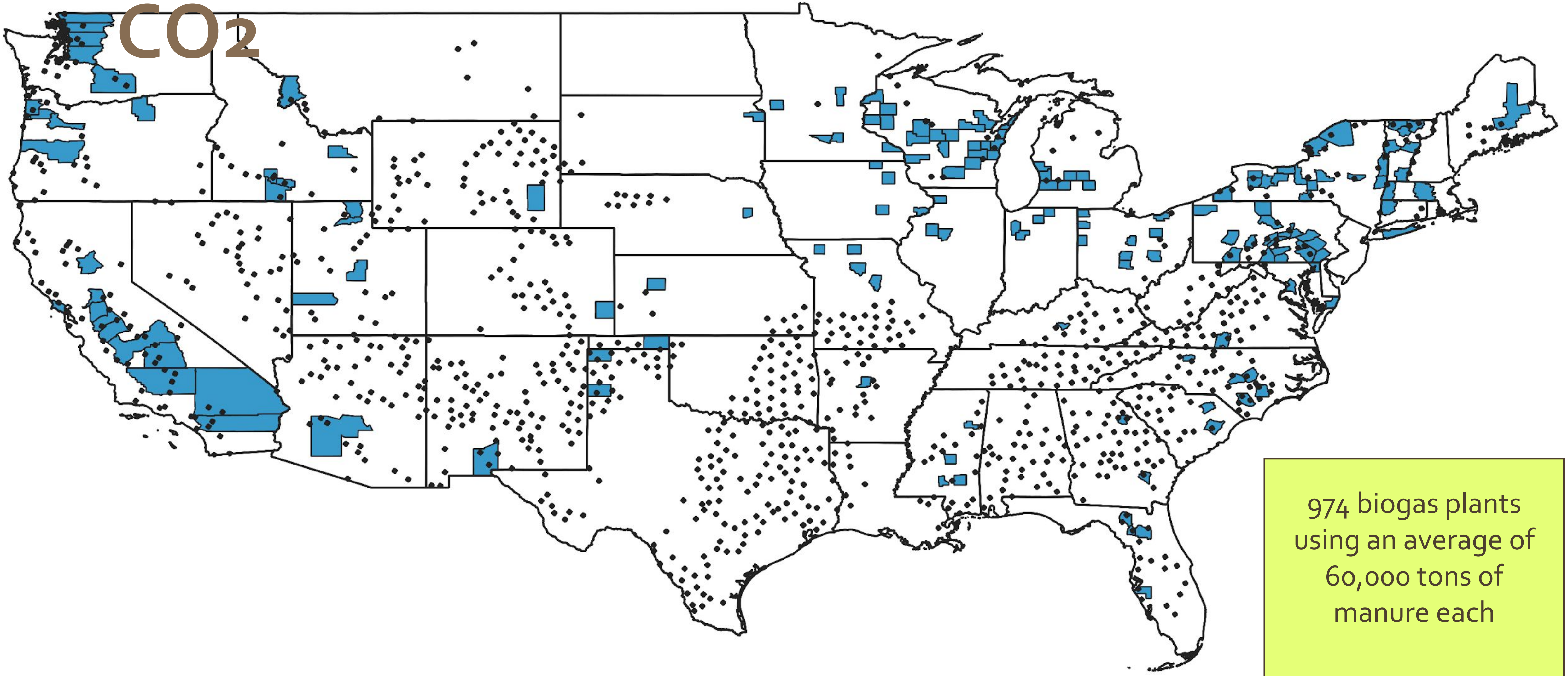
- z_{ik} = amount of phosphorus transported from cell i to cell j [ton P]
- y_k = Is 1 of a biogas plant is built at location j, 0 otherwise

P balance across US:

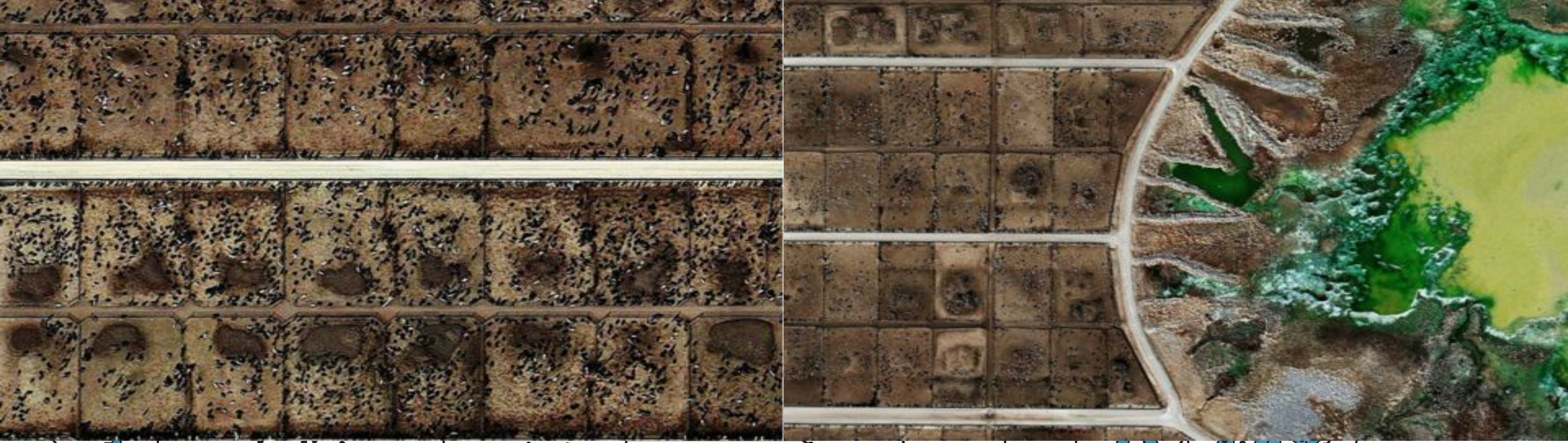
- Manure is only able to meet 22% of the P needs at location where it is produced
- 1 million ton of manure P remains as excess --- 144 ug/L P in runoff (49 ug/L)

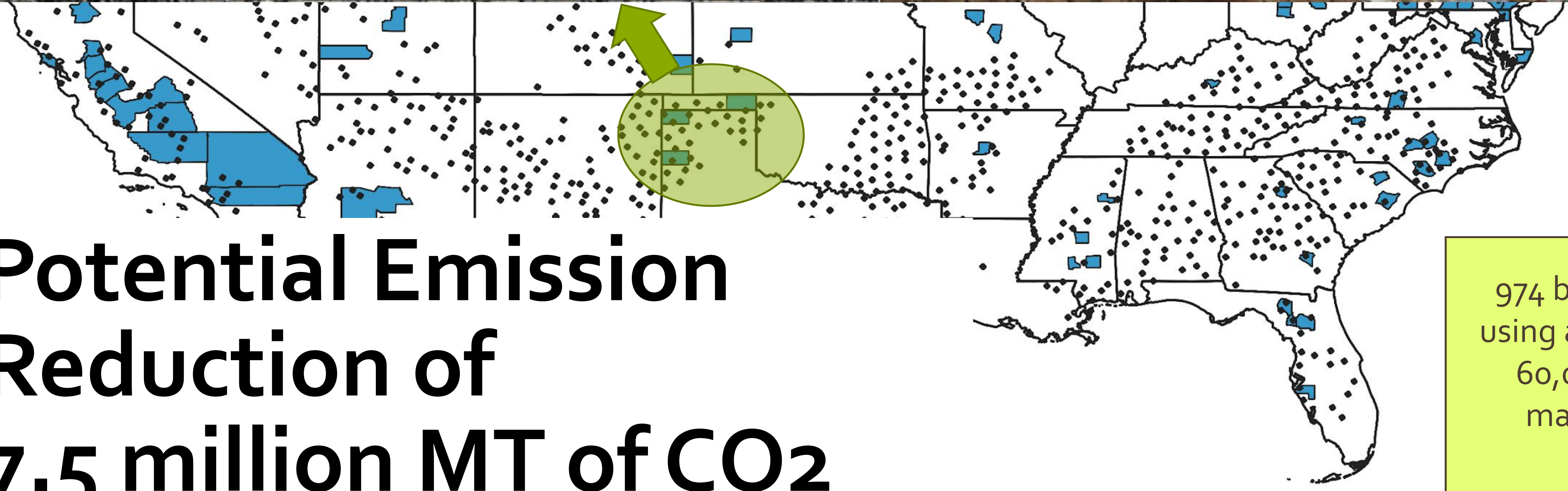


Currently 260 plants in operation reduce emissions by 2 million MT of CO_2



974 biogas plants using an average of 60,000 tons of manure each

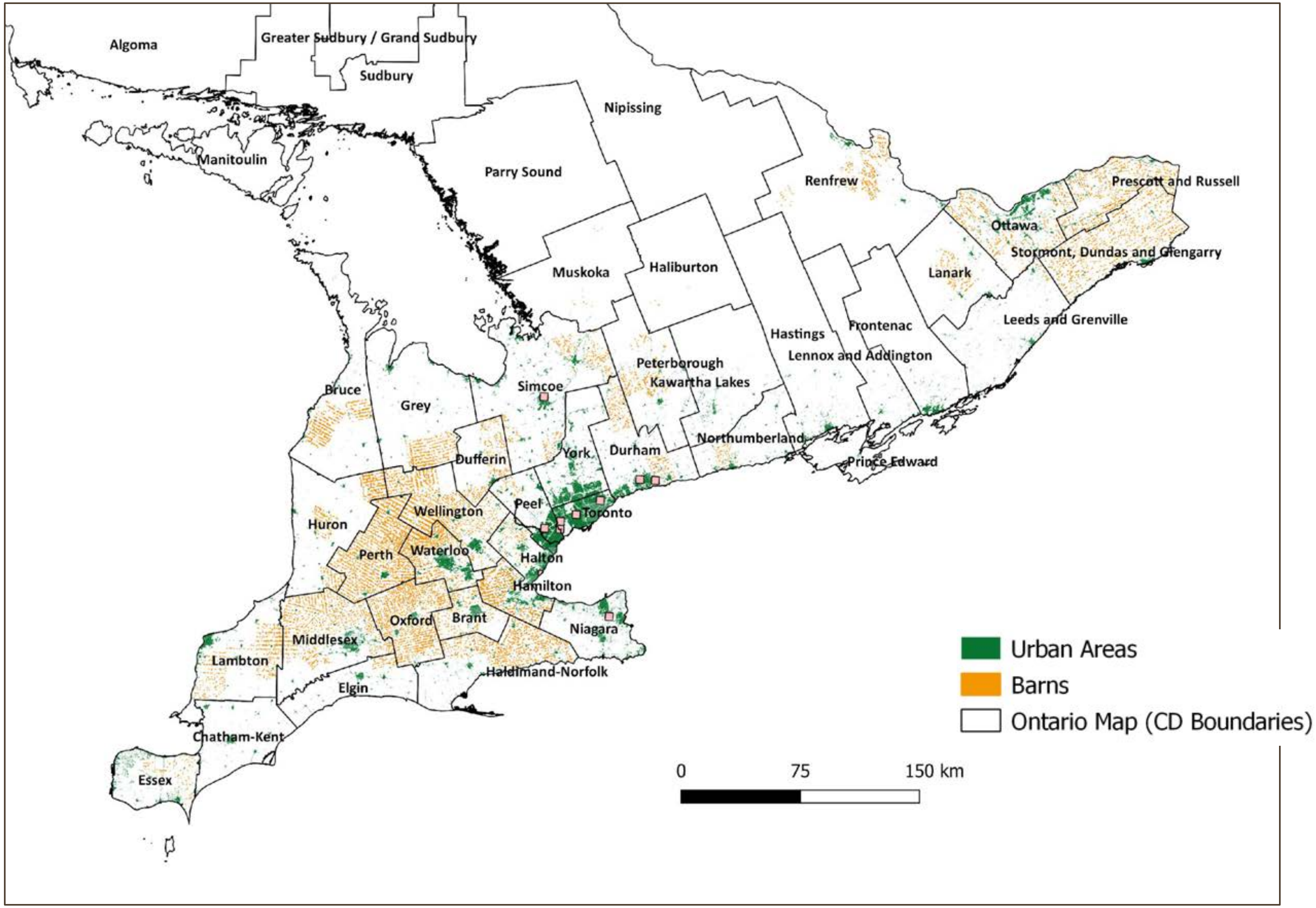




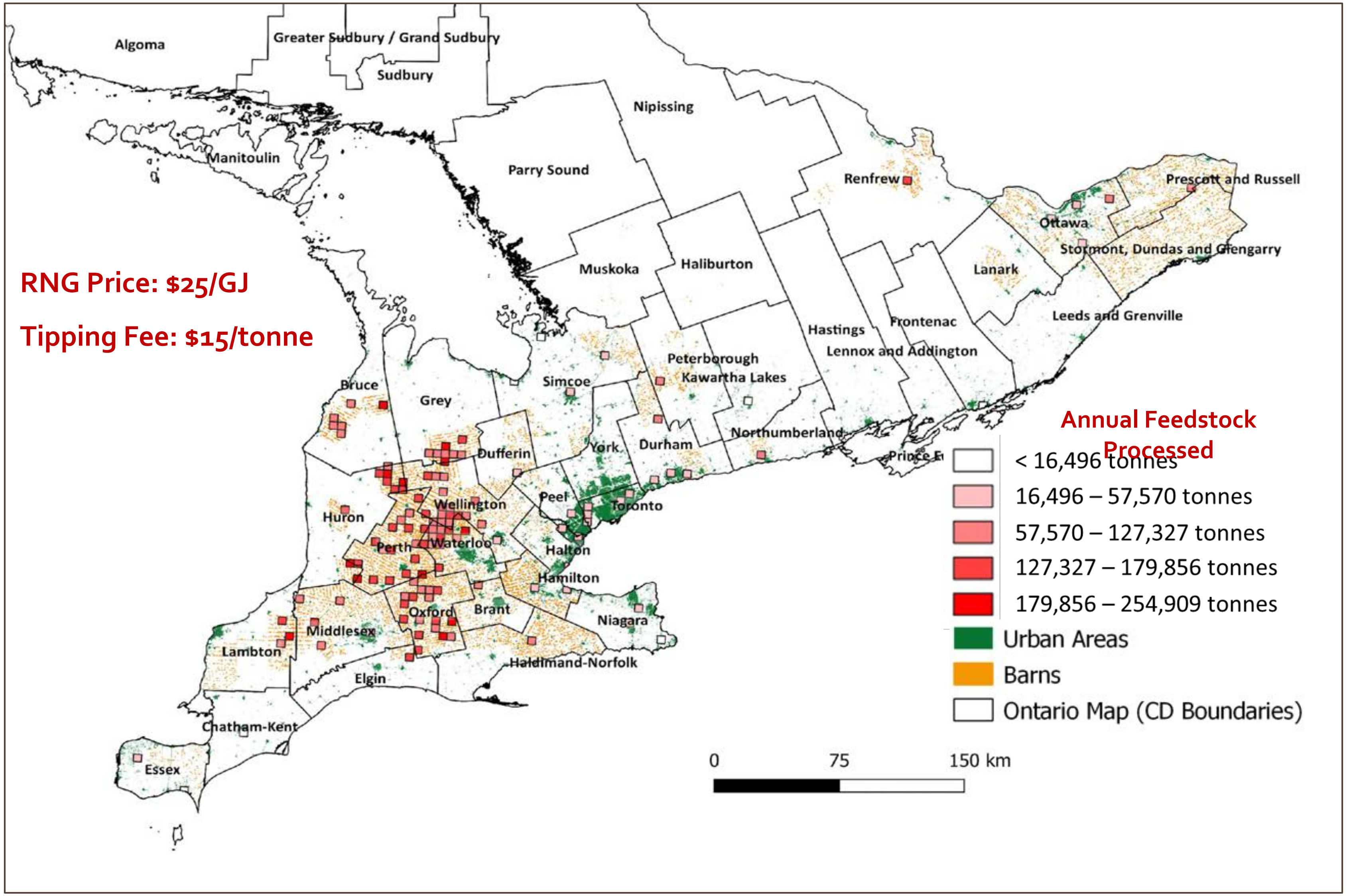
Potential Emission Reduction of 7.5 million MT of CO_2

974 biogas plants using an average of 60,000 tons of manure each

Similar analysis in Southern Ontario highlights food waste critical for cost-effectiveness of biodigesters



Similar analysis in Southern Ontario highlights food waste critical for cost-effectiveness of biodigesters



Thank you and Questions

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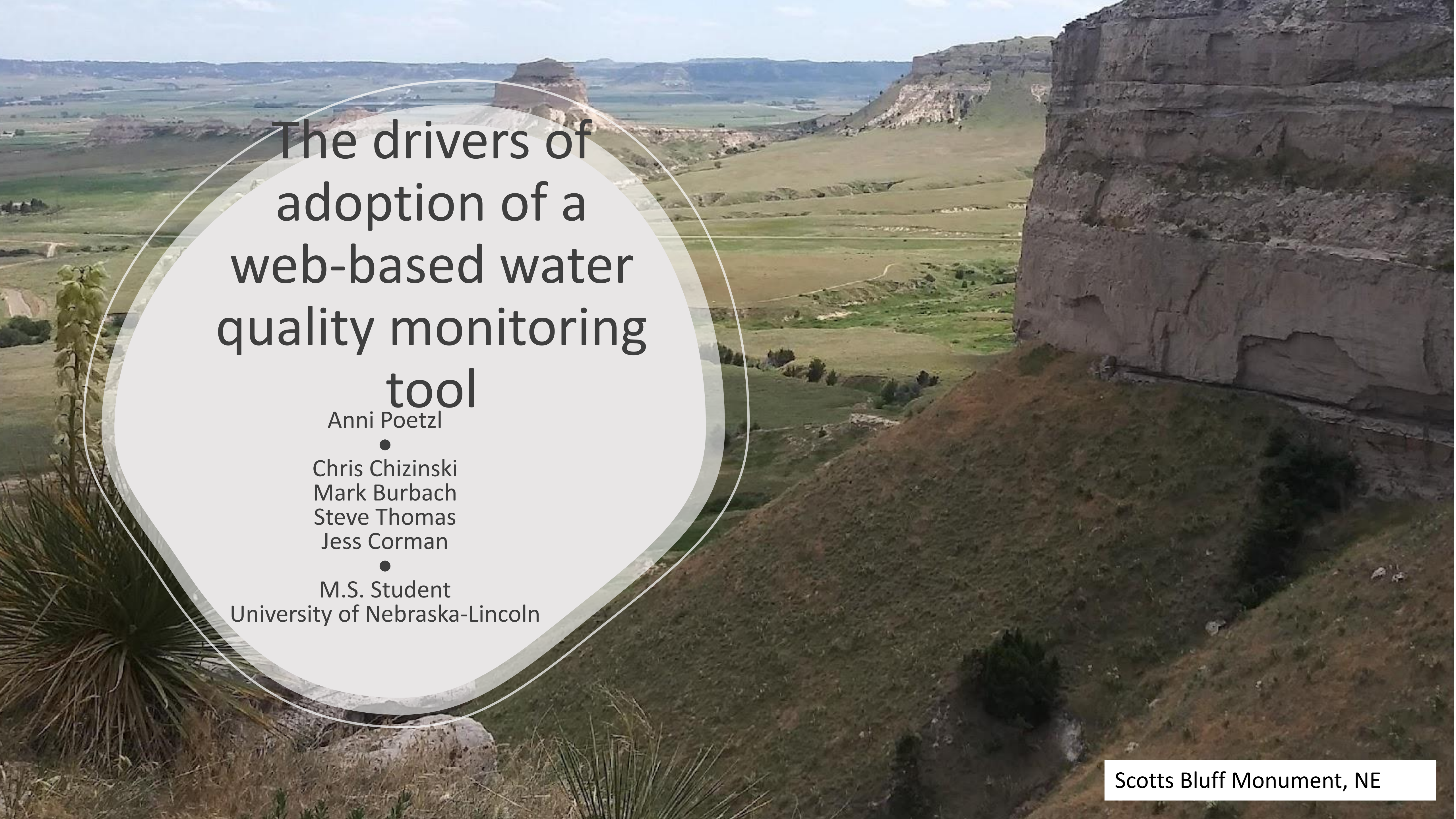
Email: nandita.basu@uwaterloo.ca

The drivers of adoption of a web-based water quality monitoring tool

Anni Poetzl
●
Chris Chizinski
Mark Burbach
Steve Thomas
Jess Corman
●
M.S. Student
University of Nebraska-Lincoln



Scotts Bluff Monument, NE

Acknowledgements

- North Platte – Natural Resource District
- Nebraska Environmental Trust
- The University of Nebraska Panhandle Research and Extension Center
- The Chizinski Lab
- The community members of the North Platte River Valley

Introduction

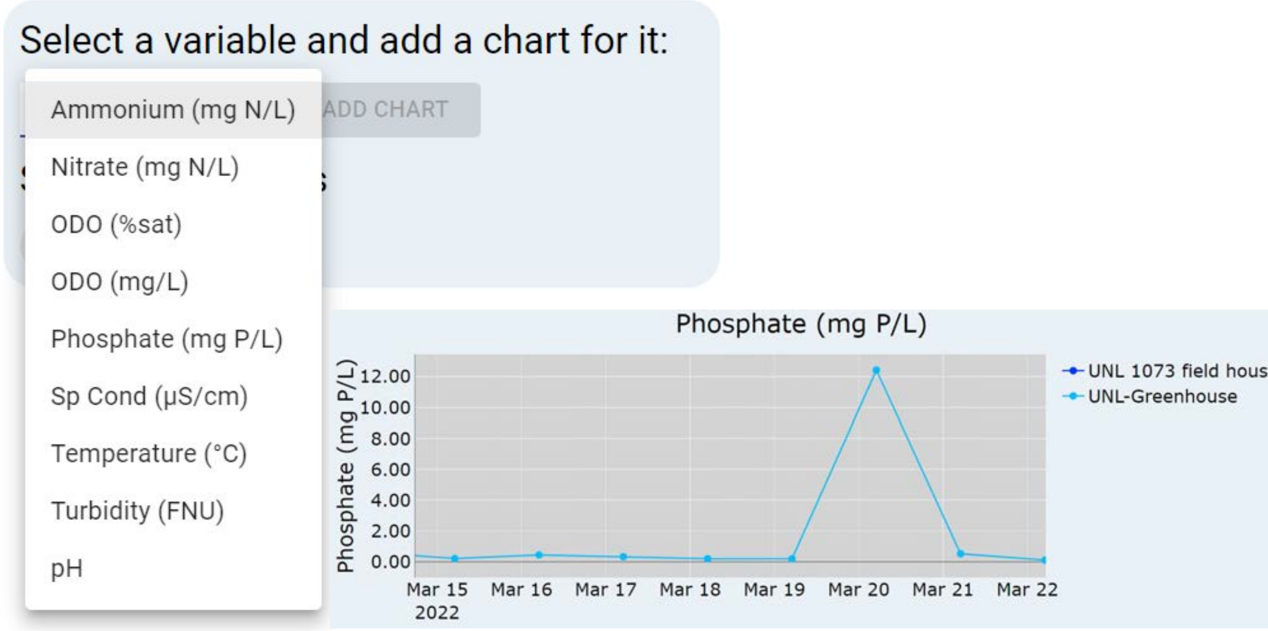
- Water quality management (WQM) depends on the reduction of nutrient inputs, yet sampling frequency and coverage do not reliably represent changing systems, such as rivers.
  - Frequency = temporal
  - Coverage = spatial

Sampling a canal in the North Platte River Valley

Introduction

- Water quality management (WQM) depends on the reduction of nutrient inputs, yet sampling frequency and coverage do not reliably represent changing systems, such as rivers.
- The development of near-real time sensors allow users to visually monitor water quality using web-based technology (~15 min).

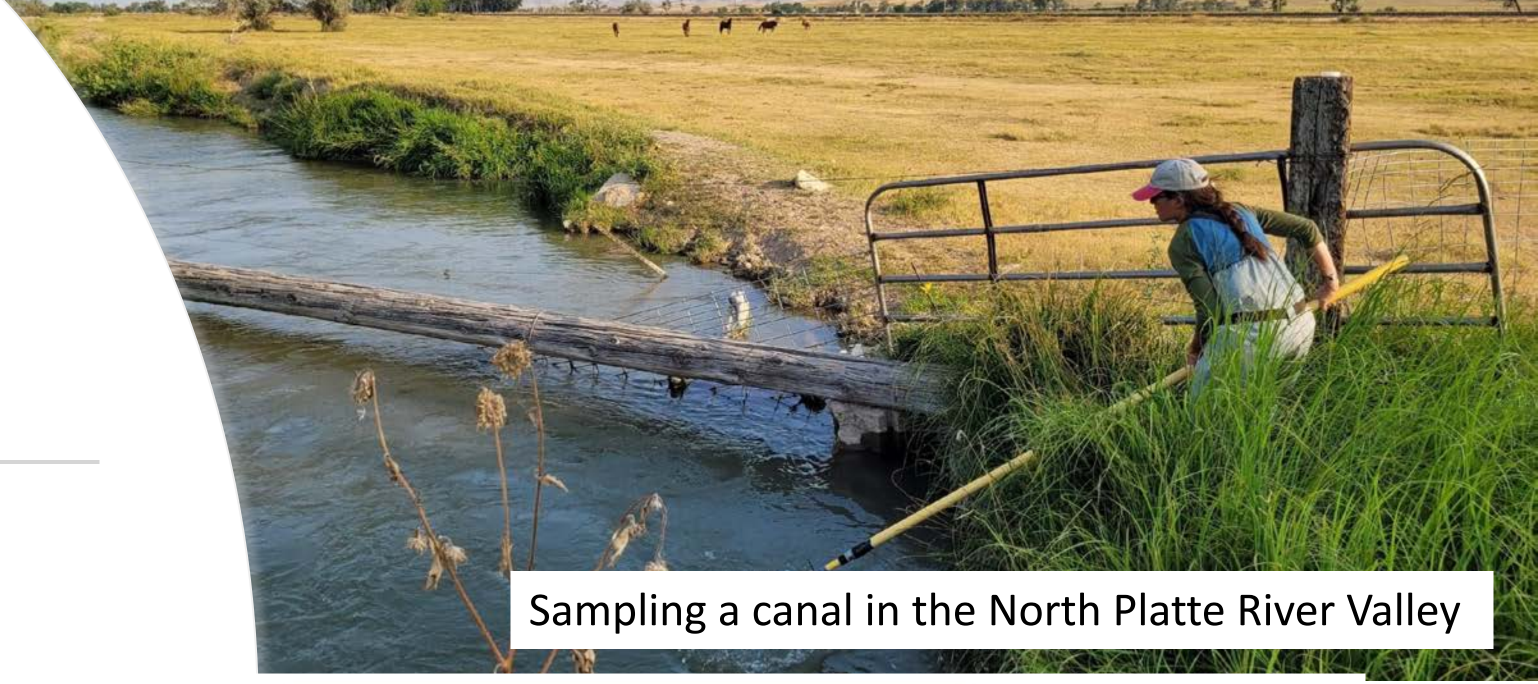
Sampling a canal in the North Platte River Valley



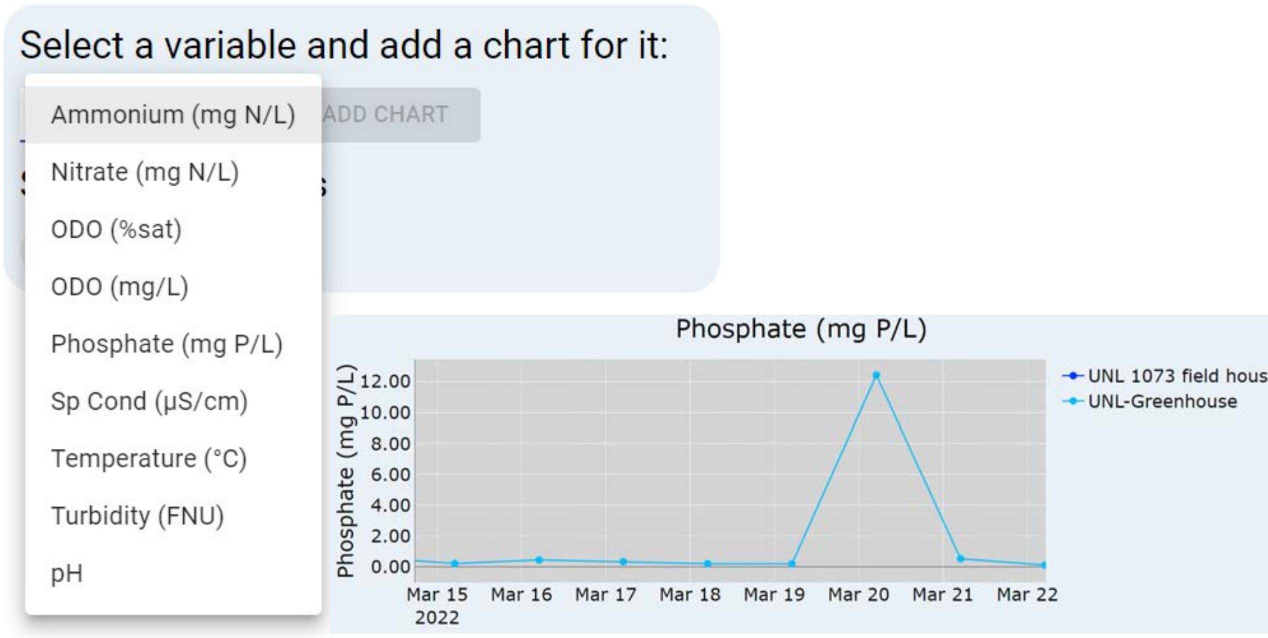
StreamNet, a WQM tool

Introduction

- Public accessibility to water quality data can:
  - decentralize decision-making
  - facilitate collaboration between diverse water user groups
  - lead to human health, economic, ecological, and recreational benefits



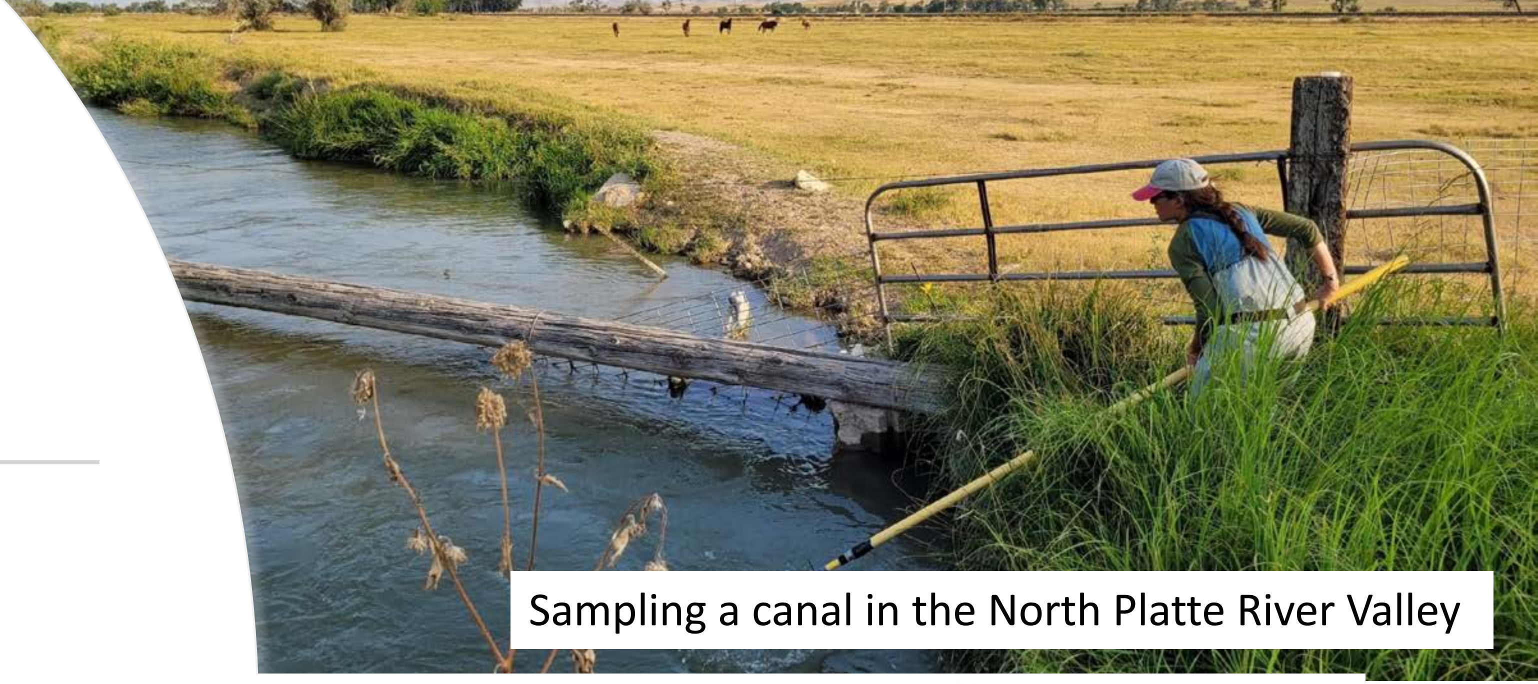
Sampling a canal in the North Platte River Valley



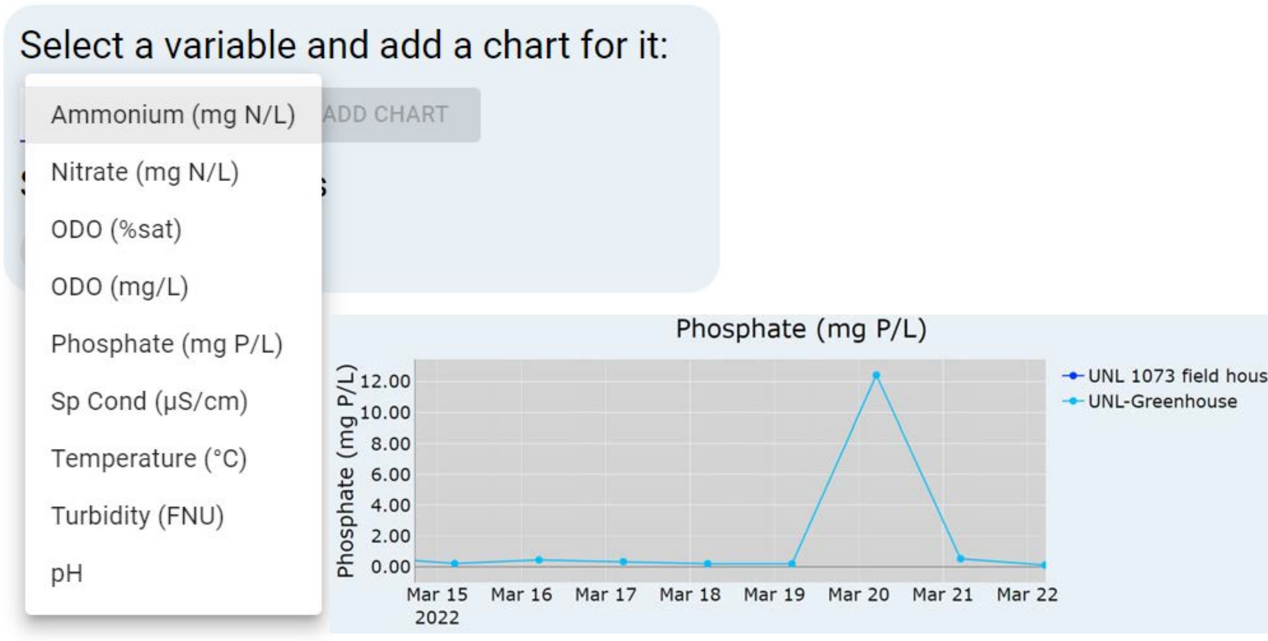
StreamNet, a WQM tool

Introduction

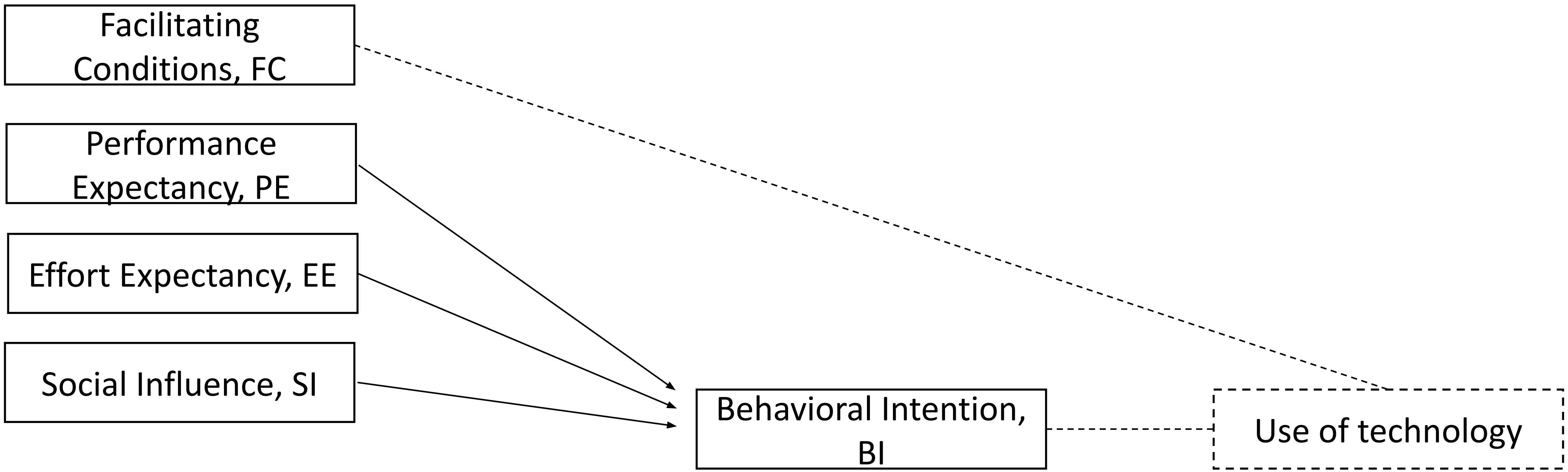
- Public accessibility to water quality data can:
  - decentralize decision-making
  - facilitate collaboration between diverse water user groups
  - lead to human health, economic, ecological, and recreational benefits
- However, access to WQM tools and their data does not automatically influence the use of the tool or data.
  - Norms, attitudes, beliefs, and values can be associated with the intention to use a tool.



Sampling a canal in the North Platte River Valley



StreamNet, a WQM tool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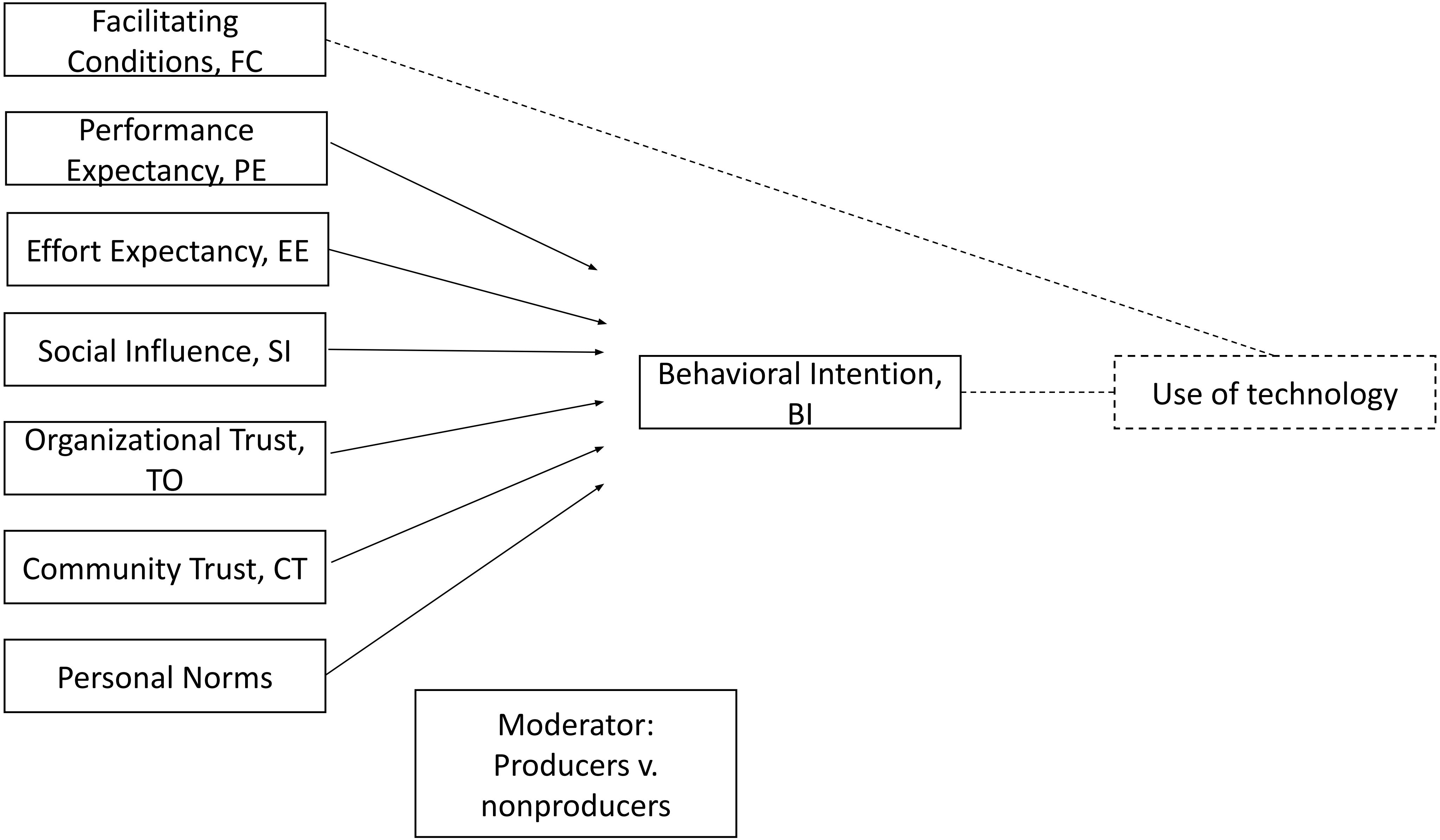
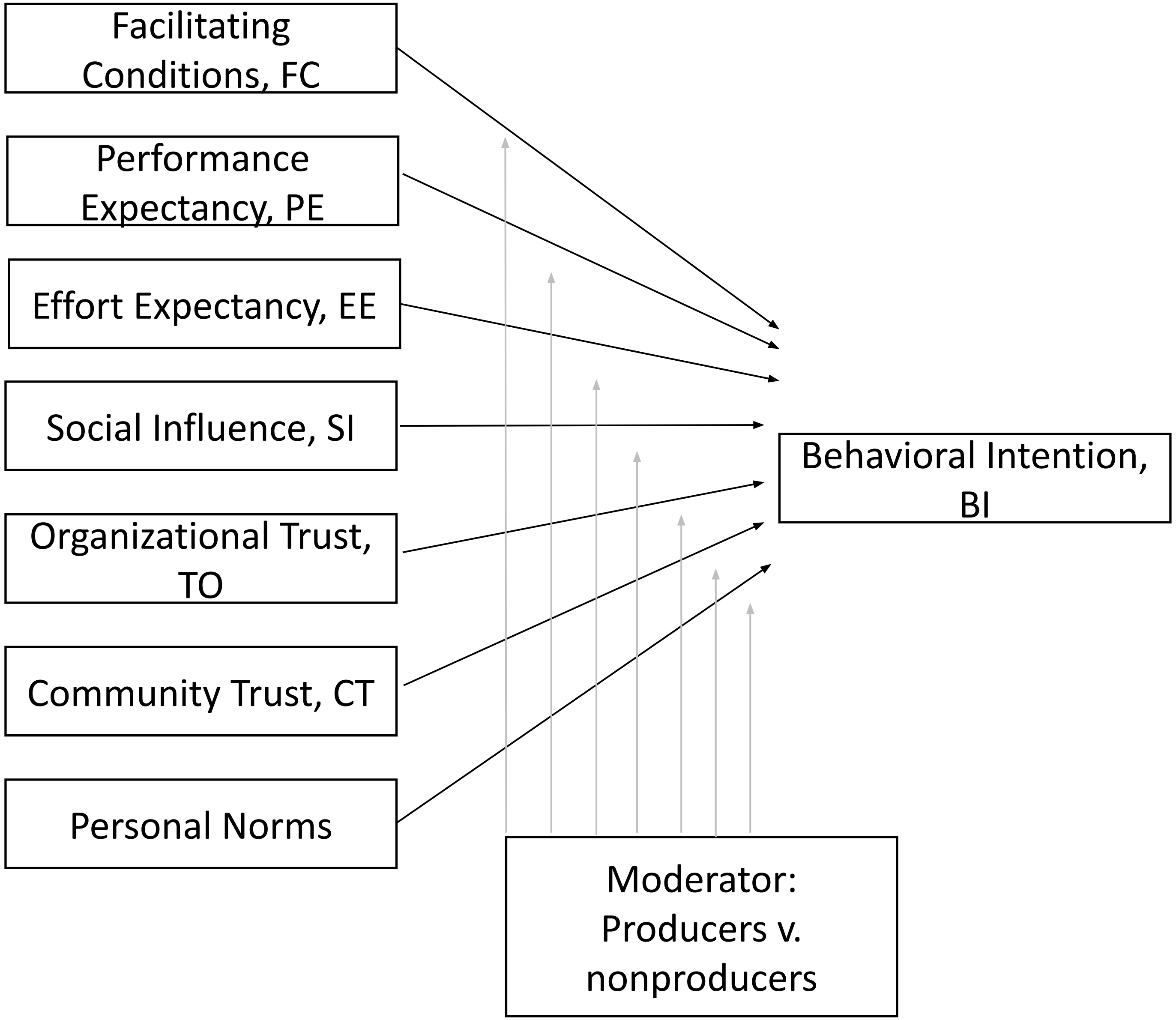
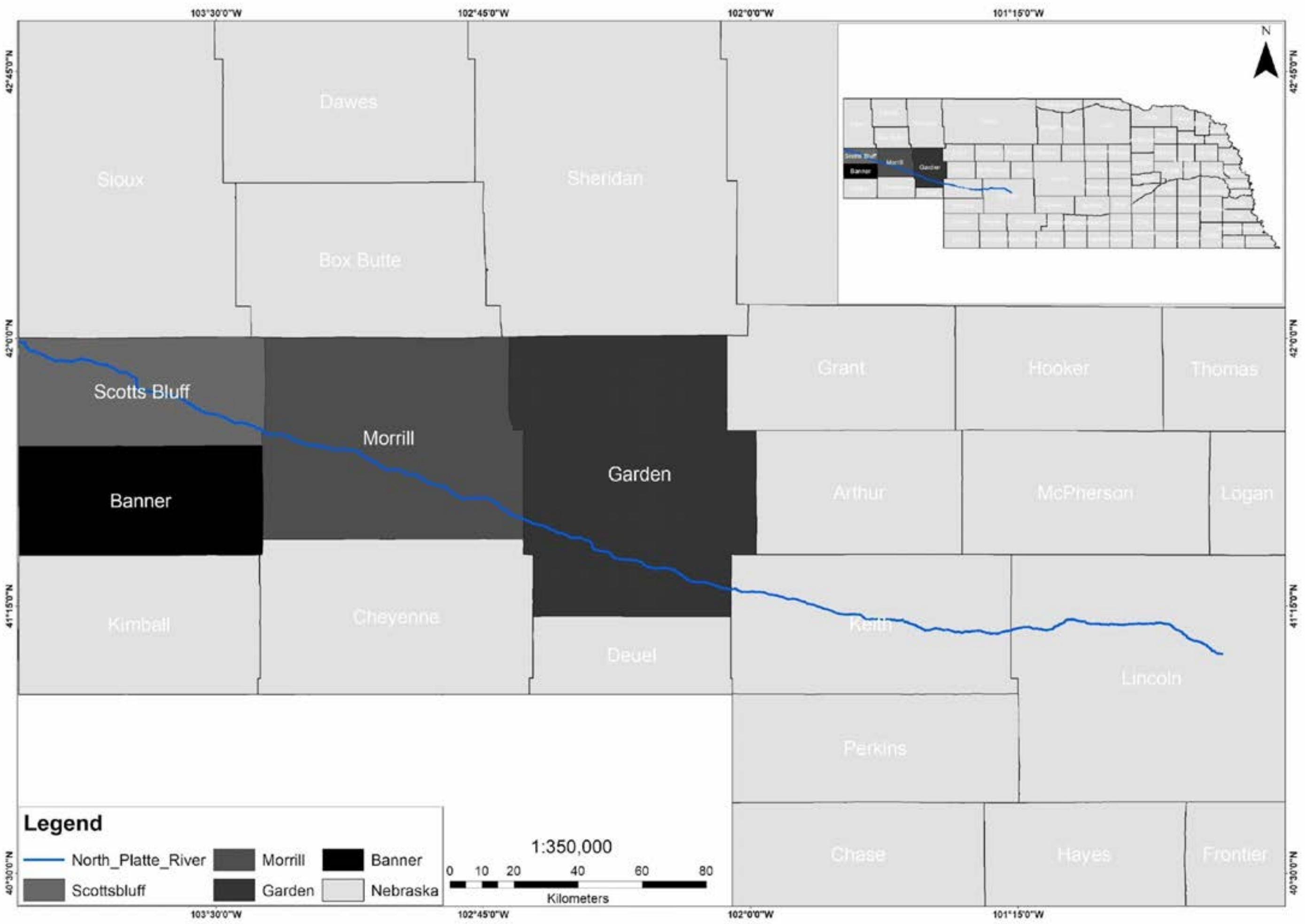
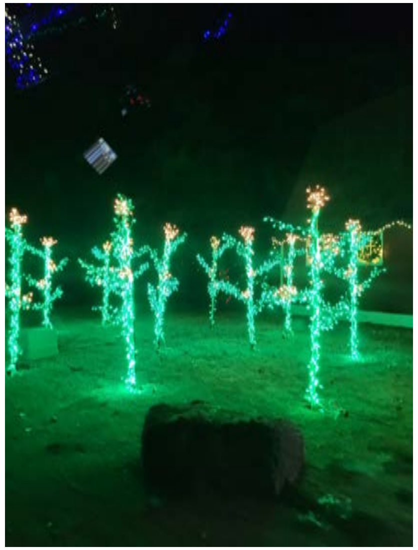
Performance Expectancy, PE
Effort Expectancy, EE
Social Influence, SI
Behavioral Intention, BI
Use of technology


Facilitating Conditions, FC
Performance Expectancy, PE
Effort Expectancy, EE
Social Influence, SI
Organizational Trust, TO
Community Trust, CT
Personal Norms
Behavioral Intention, BI
Use of technology
Moderator: Producers v. nonproducers


Facilitating Conditions, FC
Performance Expectancy, PE
Effort Expectancy, EE
Social Influence, SI
Organizational Trust, TO
Community Trust, CT
Personal Norms
Behavioral Intention, BI
Moderator: Producers v. nonproducers

Study System: North Platte River (NPR) Valley, western Nebraska

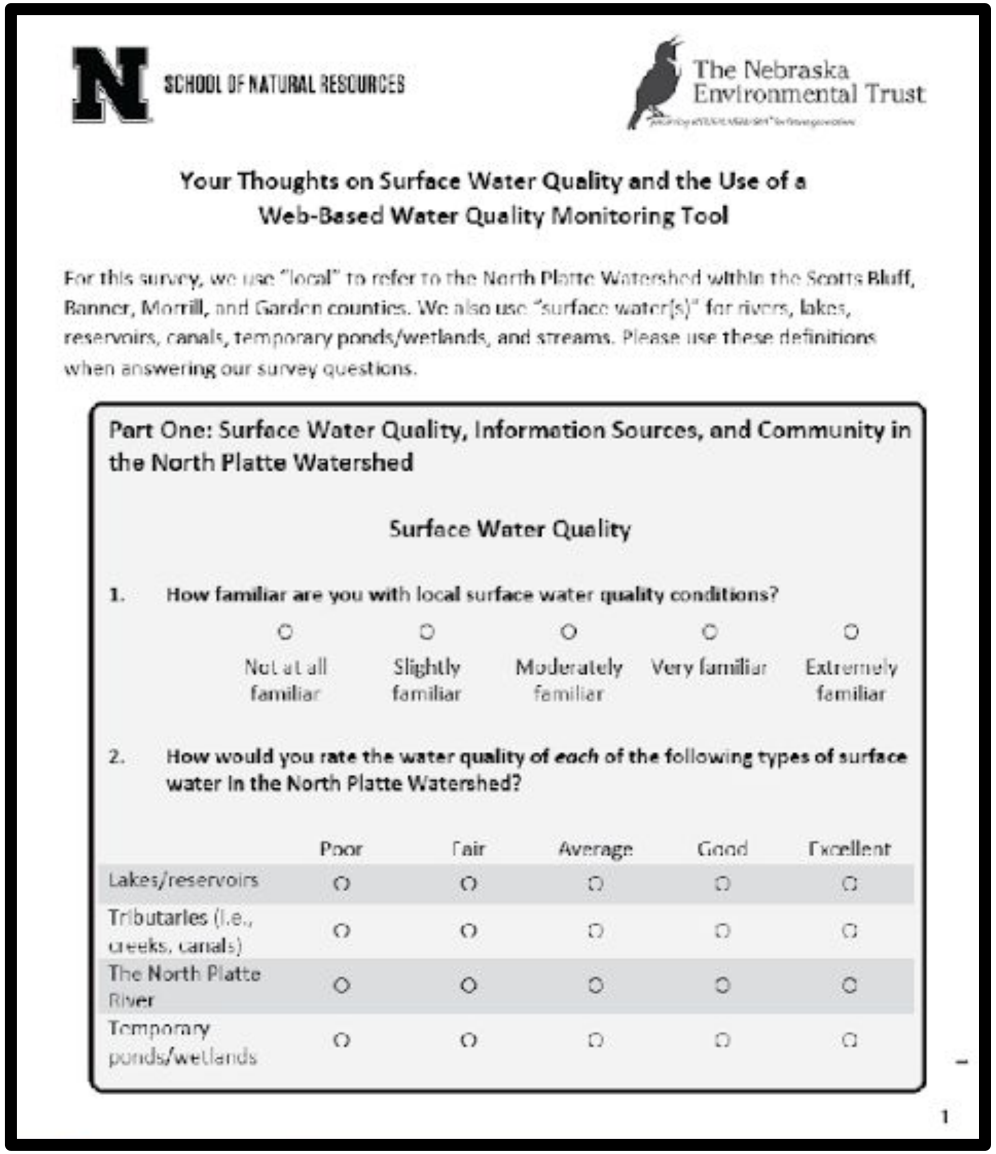




Christmas lights emphasize multi-use landscapes

Methods:

- Survey Design
  - Four sections:
    - Perceptions of local water quality
    - Drivers for a web-based WQ monitoring tool
      - Five-point Likert scale
    - Land description
    - Demographics info



N SCHOOL OF NATURAL RESOURCES

The Nebraska Environmental Trust

Your Thoughts on Surface Water Quality and the Use of a Web-Based Water Quality Monitoring Tool

For this survey, we use "local" to refer to the North Platte Watershed within the Scotts Bluff, Banner, Morrill, and Garden counties. We also use "surface water(s)" for rivers, lakes, reservoirs, canals, temporary ponds/wetlands, and streams. Please use these definitions when answering our survey questions.

Part One: Surface Water Quality, Information Sources, and Community in the North Platte Watershed

Surface Water Quality

1. How familiar are you with local surface water quality conditions?

○ Not at all familiar ○ Slightly familiar ○ Moderately familiar ○ Very familiar ○ Extremely familiar

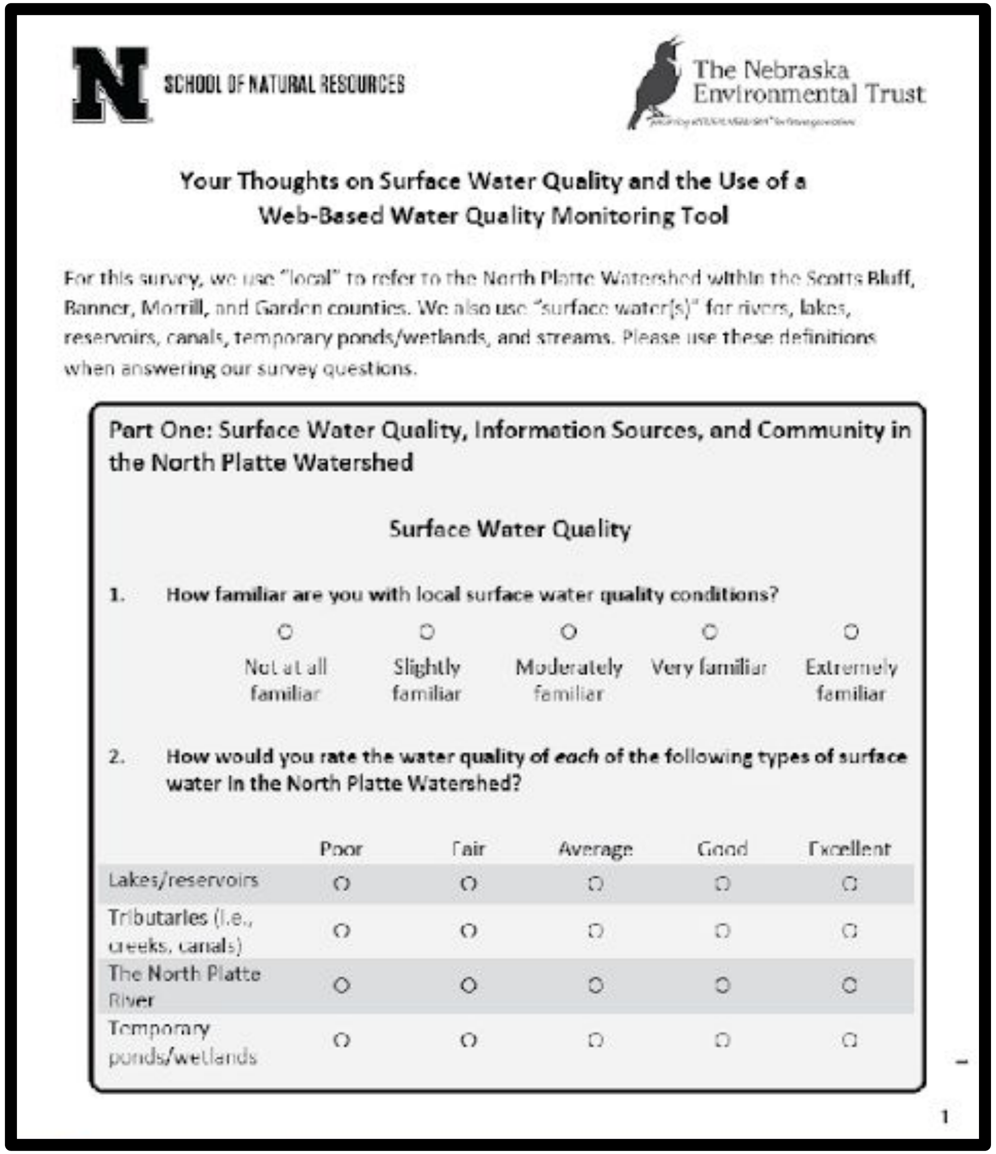
2. How would you rate the water quality of *each* of the following types of surface water in the North Platte Watershed?

	Poor	Fair	Average	Good	Excellent
Lakes/reservoirs	○	○	○	○	○
Tributaries (i.e., creeks, canals)	○	○	○	○	○
The North Platte River	○	○	○	○	○
Temporary ponds/wetlands	○	○	○	○	○

1

Methods:

- Survey Design
  - Four sections:
    - Perceptions of local water quality
    - Drivers for a web-based WQ monitoring tool
      - Five-point Likert scale
    - Land description
    - Demographics info
- Tailored Dillman Design Method



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The North Platte River	○	○	○	○	○
Temporary ponds/wetlands	○	○	○	○	○

1

Results

Survey Respondent Information

62 complete survey responses
of 171 returned surveys

●

73% male
60% producer
Average age: 65

Results

Survey Respondent Information

62 complete survey responses
of 171 returned surveys

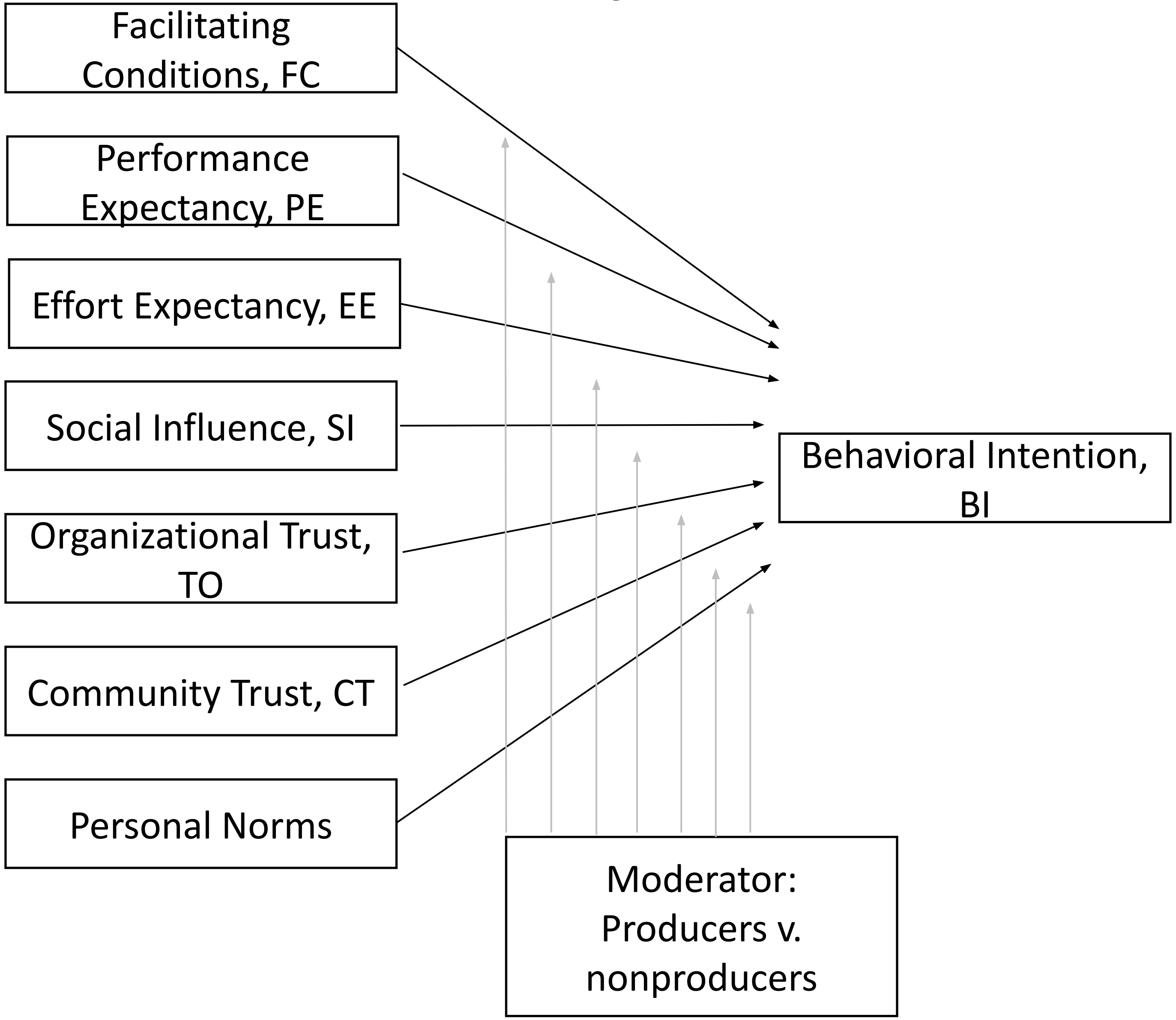
•

73% male
60% producer
Average age: 65

Local surface water quality perceptions

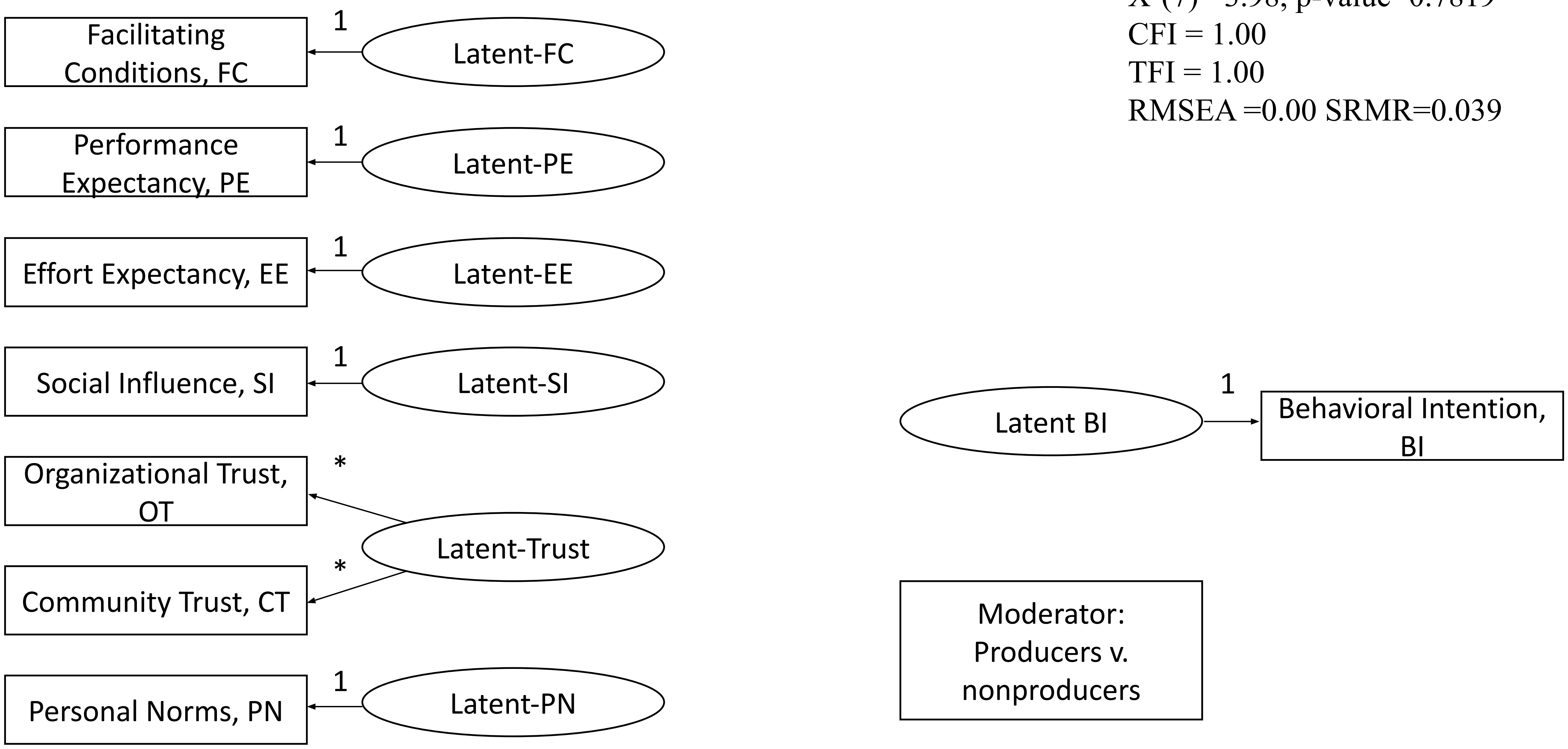
83% (river)/86% (tributaries): “average”, “good”, “excellent” water quality
44%: “never” seek out local surface water quality information

Results – Conceptual Model

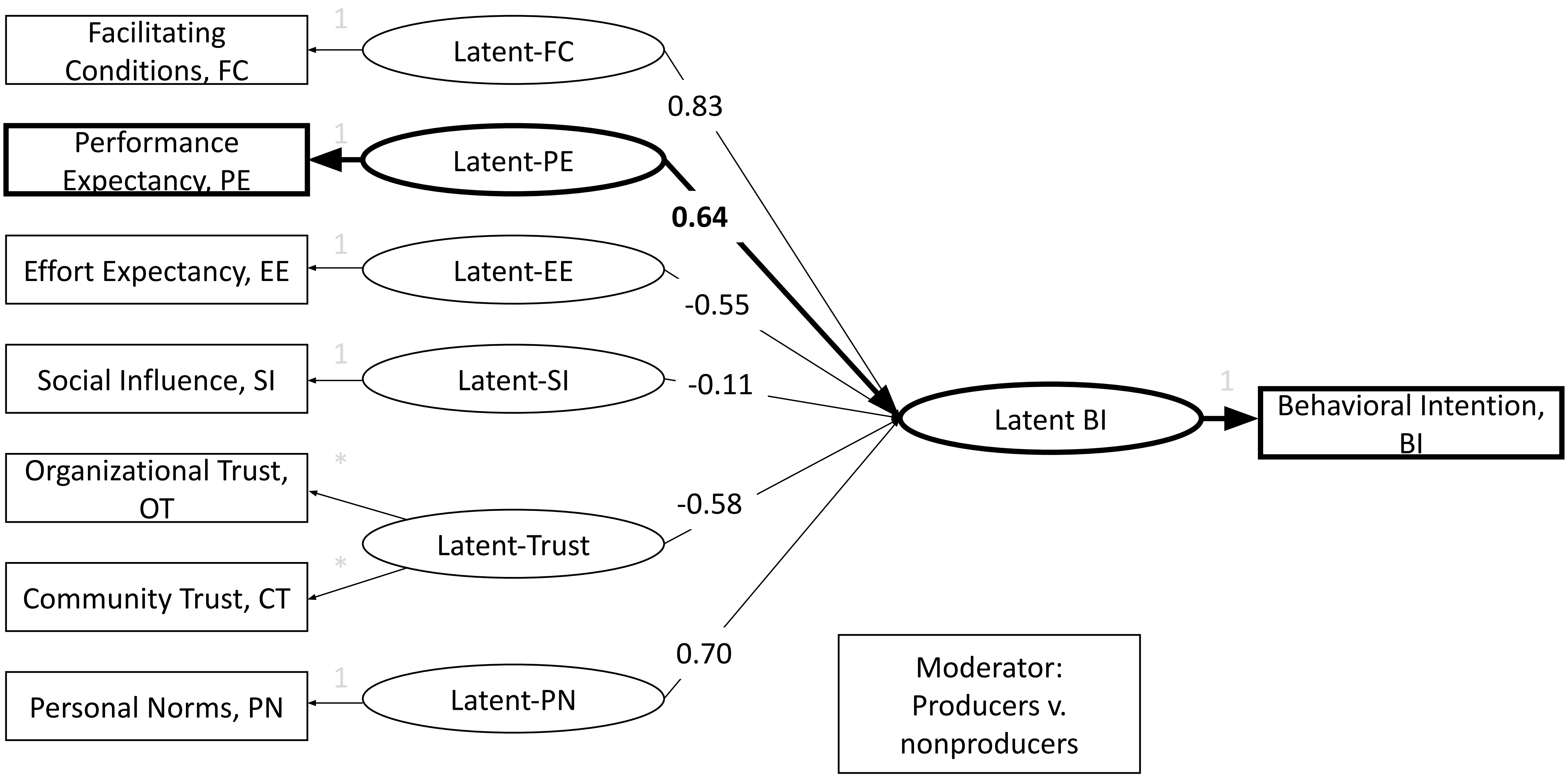


Results – Step 1. CFA

Model Fit Indices
$X^2(7)$= 3.98, p-value=0.7819
CFI = 1.00
TFI = 1.00
RMSEA =0.00 SRMR=0.039



Results – Step 2. Structural Model



Conclusion

- A majority of water users within the counties of Scotts Bluff, Banner, Garden, and Morrill perceived river and tributary water quality as average or better, while less than half did not actively seek out water quality.
- Performance expectancy had a significant, positive association with behavioral intention.

Farmer’s Irrigation Canal diversion, NE

Rodeo

Fourth of July celebration

Concentrated animal feeding operation

Implications

- When presenting water users (or a target population) with a tool for environmental monitoring, it is important to align the WQM tool with the water users' goals and objectives.
  - *What are the water resource goals (quality/quantity) of water users?*
  - *How can resource managers make water quality more salient for local water users for the NPR Valley specifically?*

Thank you!

apoetzl2@huskers.unl.edu

Accelerating Water Quality Restoration with In-lake Management

Scott Shuler
National Manager, EutroPHIX

Sustainable Phosphorus Summit
November 4, 2022

EutroPHIX™

- Improving water quality since enacted in 1972
  - Significantly reduced point source pollution
  - Efforts are improving watersheds
  - Non-point source pollution must be addressed in new ways
- Relatively small efforts for in-lake management
- Investments needs to be more efficient
  - > $5 Trillion
  - Cost > benefits
  - Keiser and Shapiro 2019

- *Given the investment and time required to restore watersheds and realize positive water quality impacts additional <u>in-lake management</u> should be considered to accelerate water quality improvement.*

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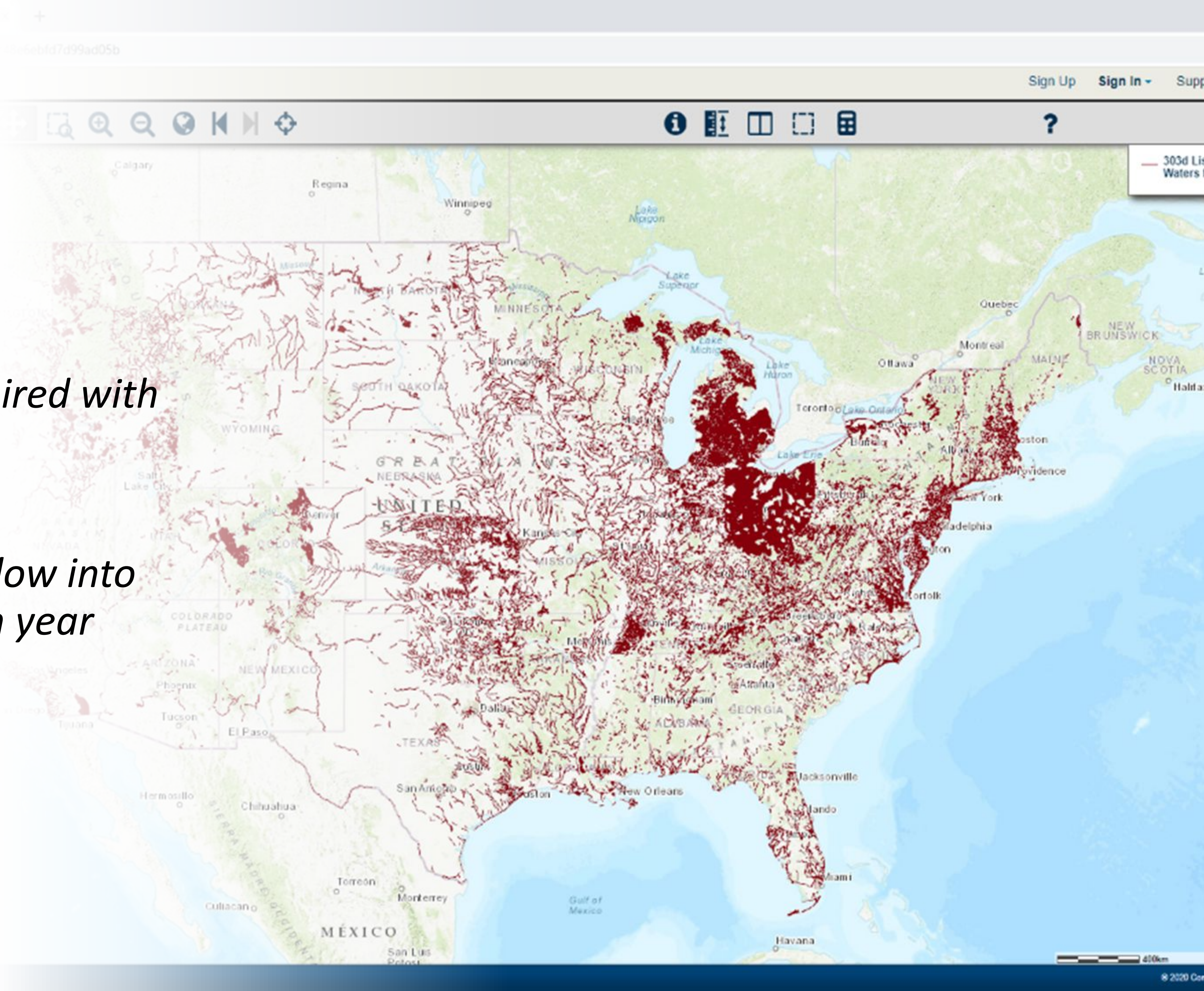
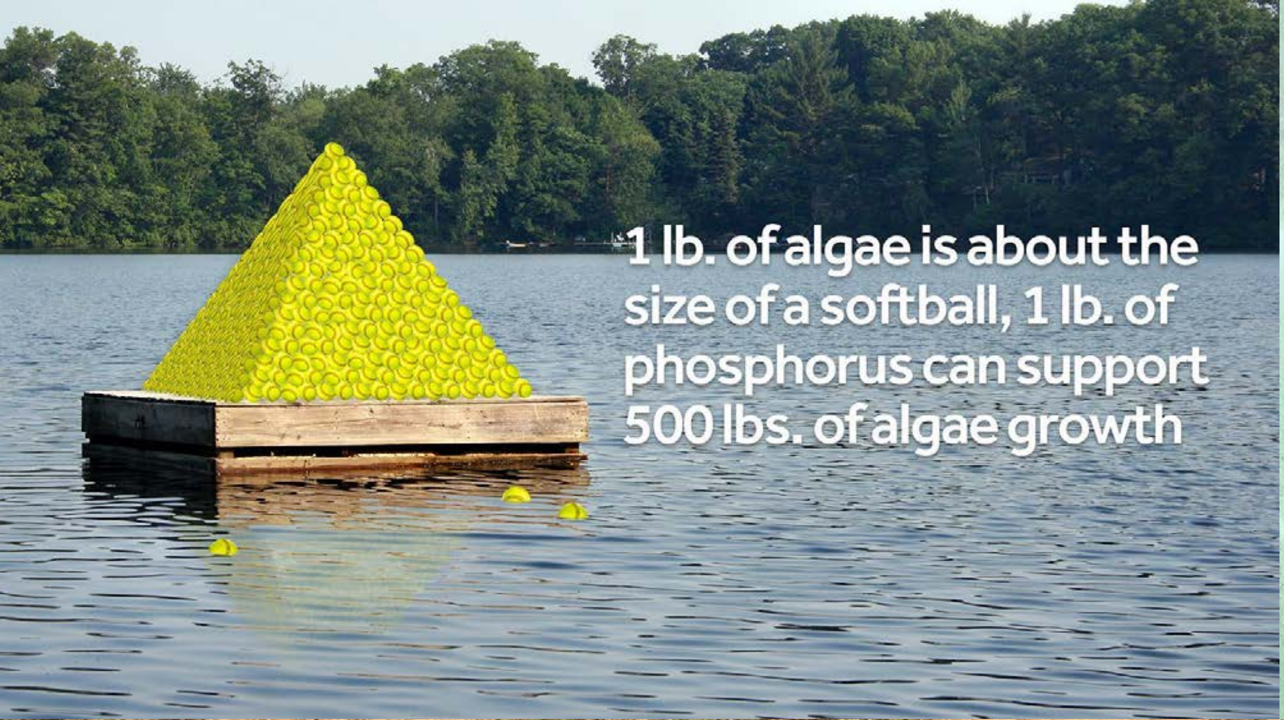
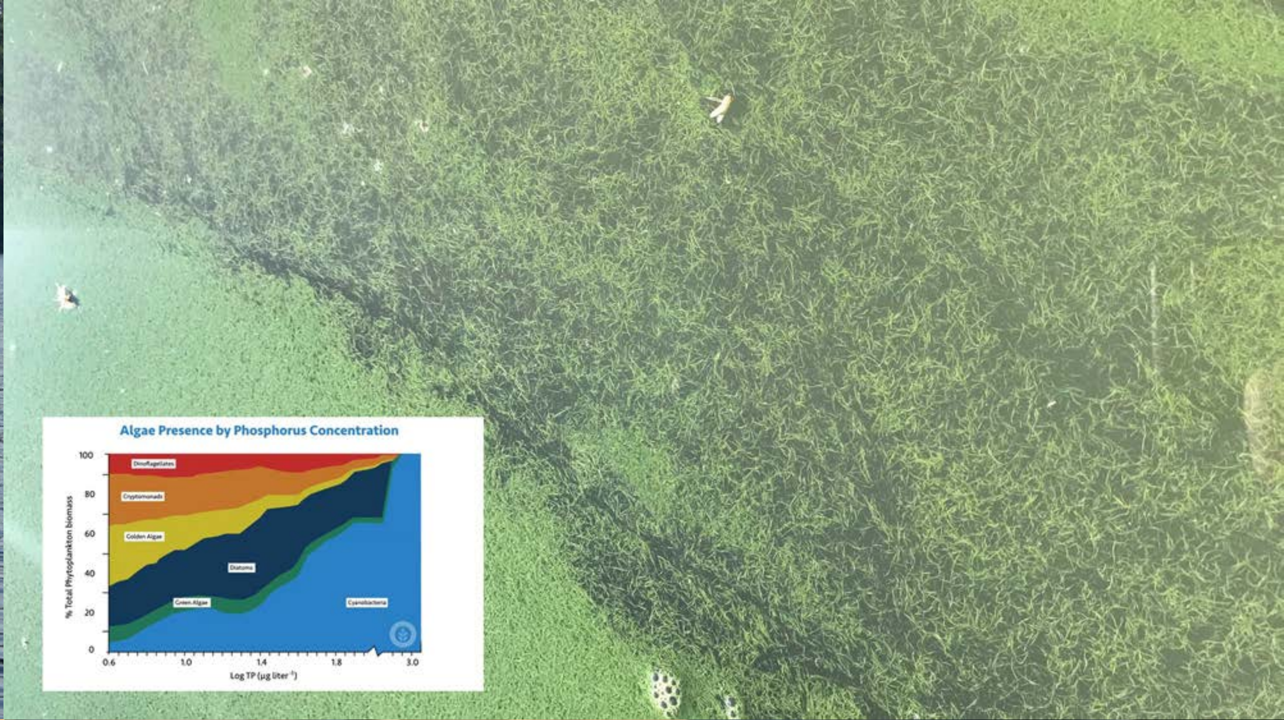
Image downloaded from https://cwa50.org/ May 17, 2022

- *Over 48,000 lakes impaired with phosphorus in the US*
- *>300,000,000 pounds flow into the Gulf of Mexico each year*




1 lb. of algae is about the size of a softball, 1 lb. of phosphorus can support 500 lbs. of algae growth

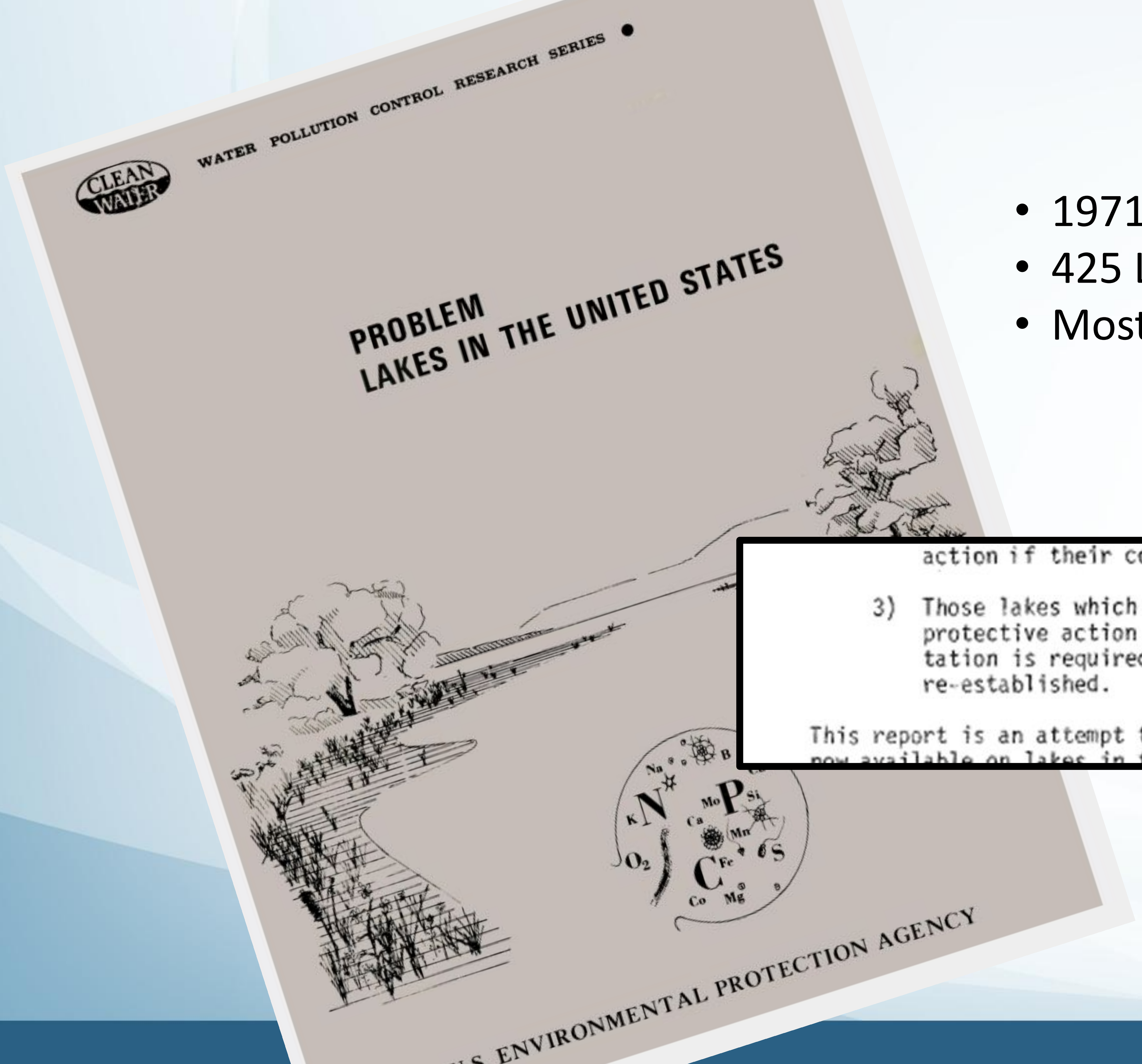

Algae Presence by Phosphorus Concentration
% Total Phytoplankton biomass
100
80
60
40
20
0
Dinoflagellates
Cryptomonads
Golden Algae
Diatoms
Green Algae
Cyanobacteria
0.6
1.0
1.4
1.8
3.0
Log TP (µg liter⁻¹)


WPTV NEWSCHANNEL 5 | AT 11PM
NEW RESEARCH ON AIRBORNE TOXINS
MARTIN COUNTY
11:07
80°
-1:15
CC

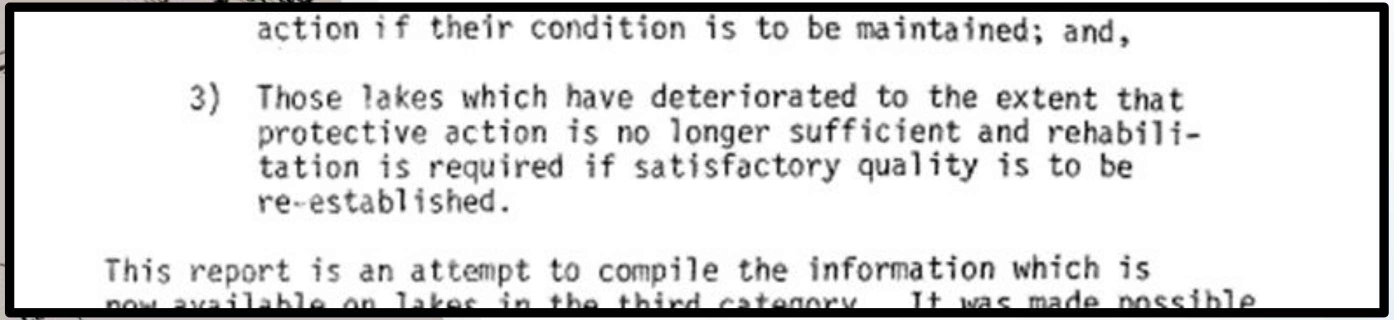





POTABLE WATER



- 1971
- 425 Lakes
- Most are still impaired


action if their condition is to be maintained; and,

3) Those lakes which have deteriorated to the extent that protective action is no longer sufficient and rehabilitation is required if satisfactory quality is to be re-established.

This report is an attempt to compile the information which is

In-lake Management

- Complement to watershed management
- Water-column stripping
  - EutroSORB® WC
  - Alum
- Sediment inactivation
  - EutroSORB G
  - Alum
  - Phoslock®
- Inlet filtration / nutrient inactivation
- Aeration

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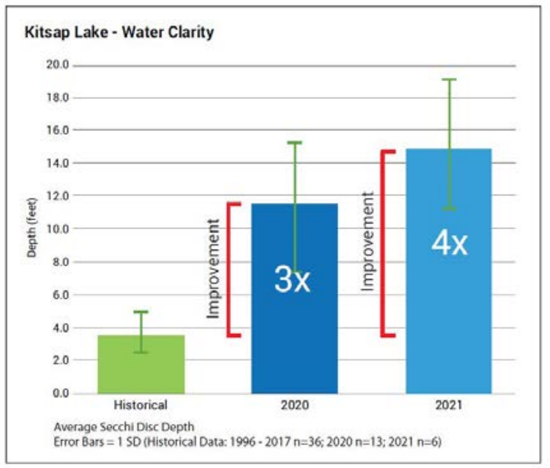
EutroSORB® G
Phosphorus Locking Technology

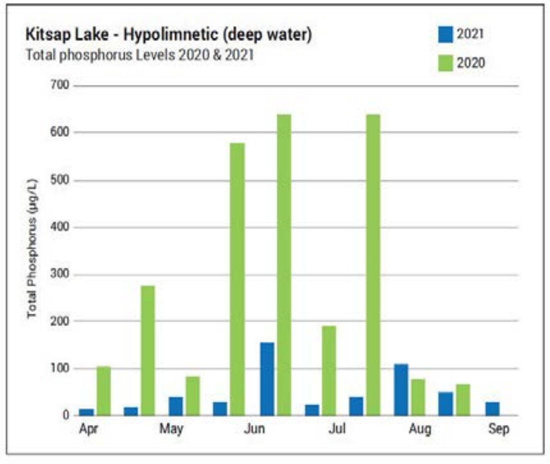
Kitsap Lake, WA

- 99.5-ha lake, 5.5m av. depth
- Mix of forested and developed watershed (~7.2km^2)
- Anoxic bottom water in summer, cyanobacteria blooms summer/fall
- **Internal loading of P source of problems**
- Storm drains also needed upgrading
- Phosphorus Management Plan developed utilizing adaptive management strategies

Kitsap Lake, Bremerton, WA

- No HABs or associated toxins
- 4X increase in Secchi disk readings
- Improved water quality
- Nutrient goals met
- Decreased hypolimnetic phosphorus release





Benefits of In-lake Management

- Rapid water quality improvement
  - *Or preservation of current trophic state*
- Often needed to realize improvement within a generation(s)
- Less favorable environments for HABs
- Improved oxygen levels
- Improved breakdown of organic matter
- <u>Less down-stream phosphorus loading</u>

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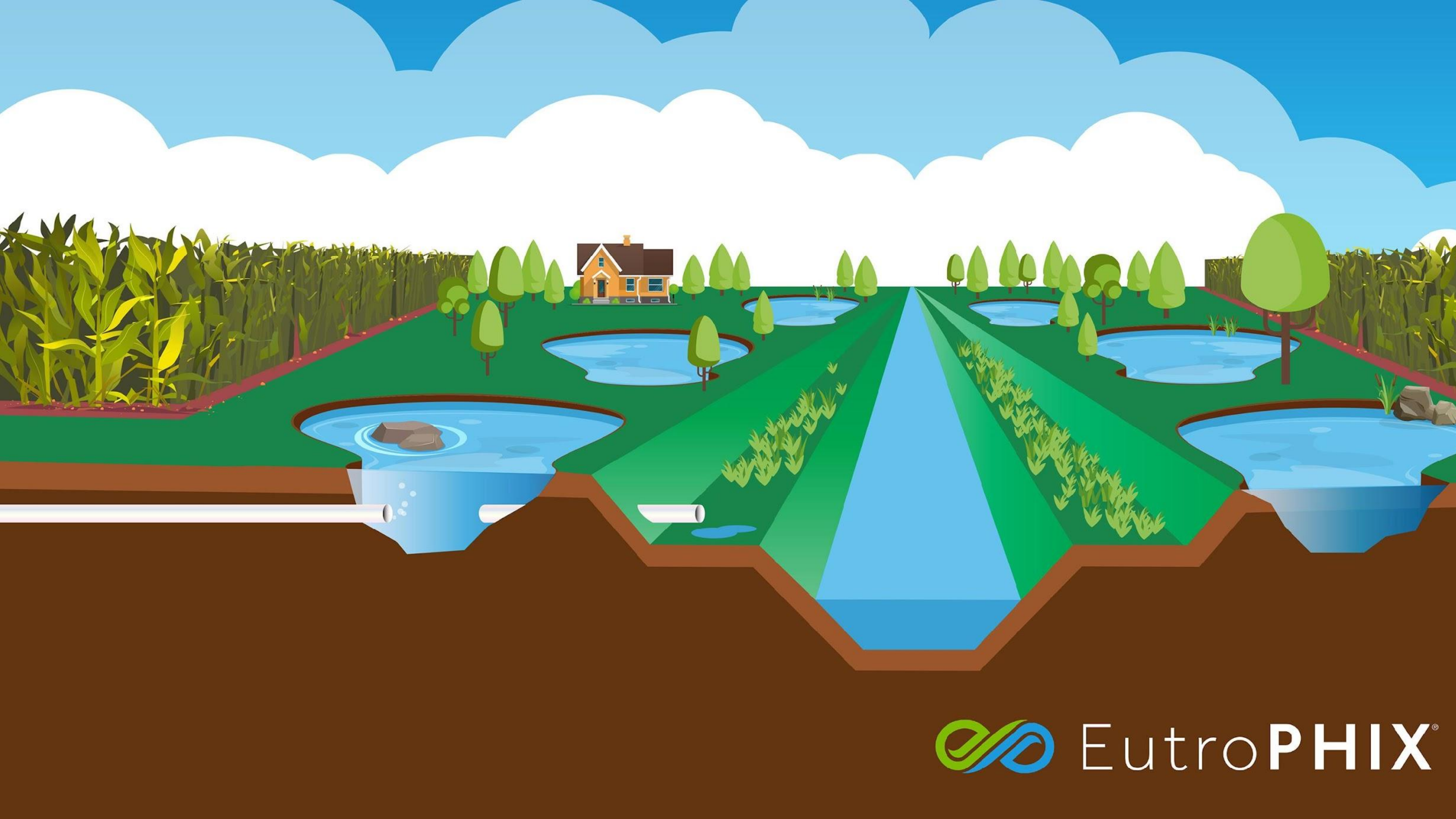
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Summary

- *The Clean Water Act - improving water quality since enacted in 1972*
  - Much success has occurred
  - We have a long way to go
- *Given the investment and time required to restore watersheds and realize positive water quality impacts additional <u>in-lake management</u> should be considered to accelerate water quality improvement*
- Phosphorus mitigation at the lake level is a viable management strategy to restore waterbodies and improve designated uses
- Adaptable to a wide range of lake and stream conditions

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Questions & Discussion

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National Manager

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Electrochemical Urine Stabilization with Concomitant Phosphorus Recovery using Magnesium Anodes and Peroxide-producing Cathodes

Philip Arve
Prithvi Simha
Dyllon Randall
Sudeep Popat

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Acknowledgments

Sudeep Popat
Clemson

Lab Group, December 2021

Prithvi Simha
SLU

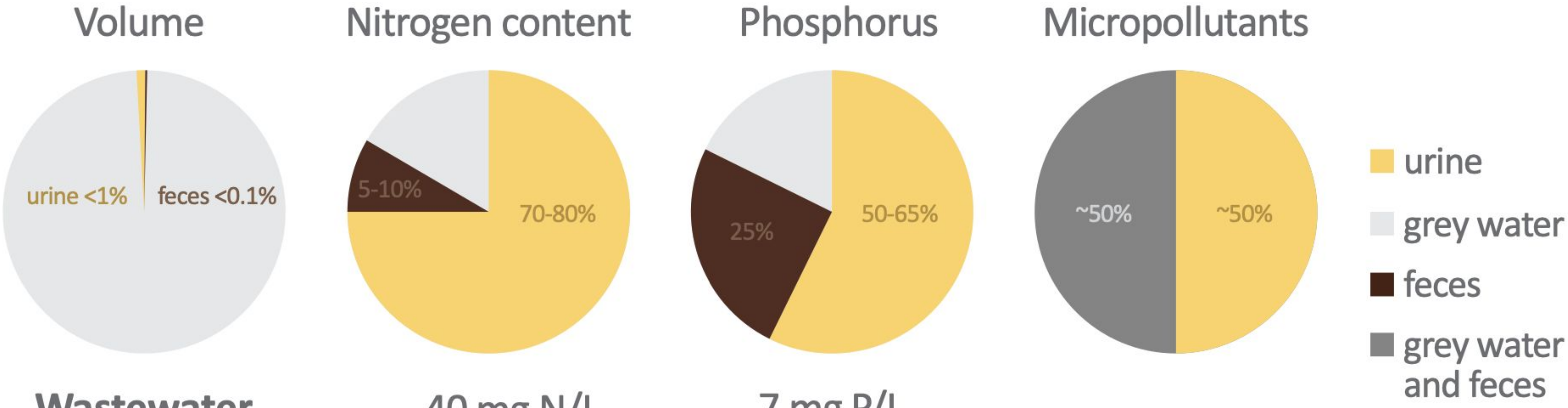
Dyllon Randall
UCT

Funding:

NASA EPSCoR

NASA SC Space Grant Consortium

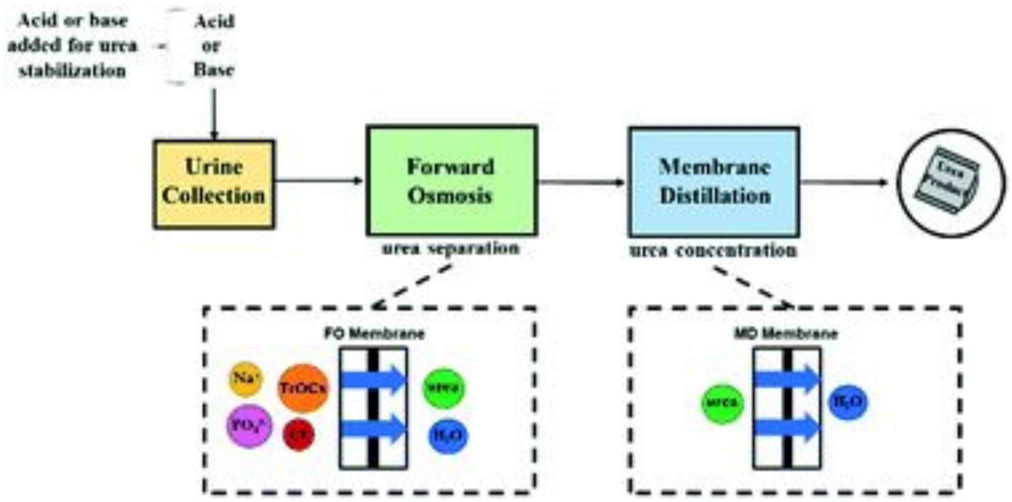
Recovering N and P from Urine



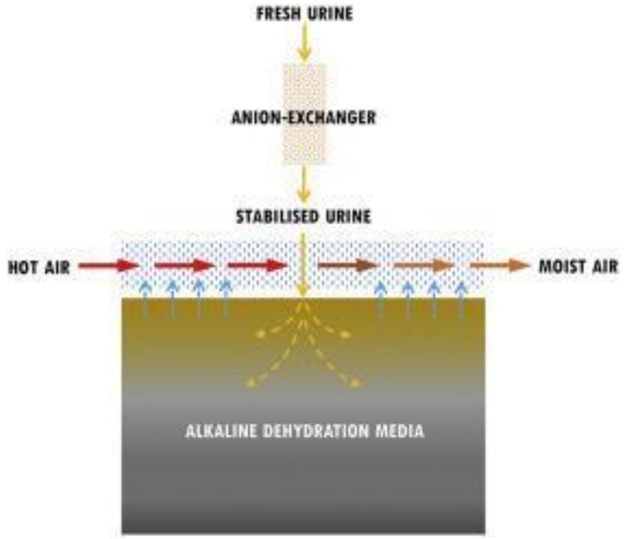
Wastewater	40 mg N/L	7 mg P/L
Urine	6000 mg N/L	300 mg P/L
	As urea	*As phosphate*

Source: The Rich Earth Institute

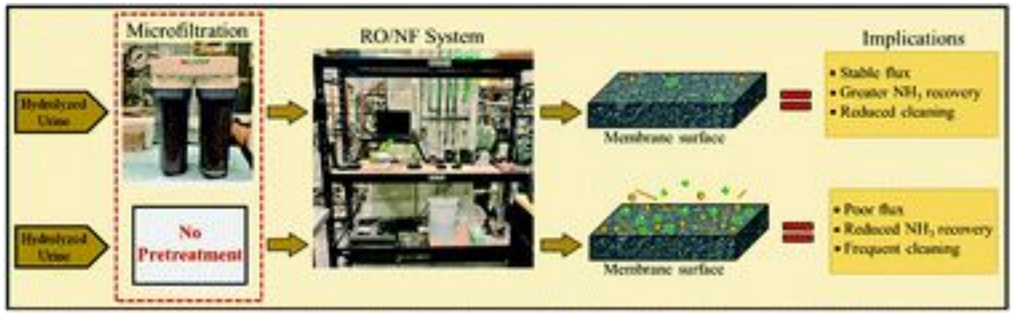
Technologies for Recovering N and P



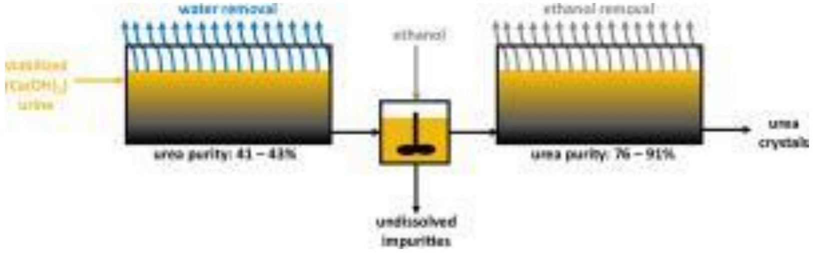
Urea recovery by FO-MD (Ray et al., 2019)



Urea recovery by alkaline dehydration (Simha et al., 2018)

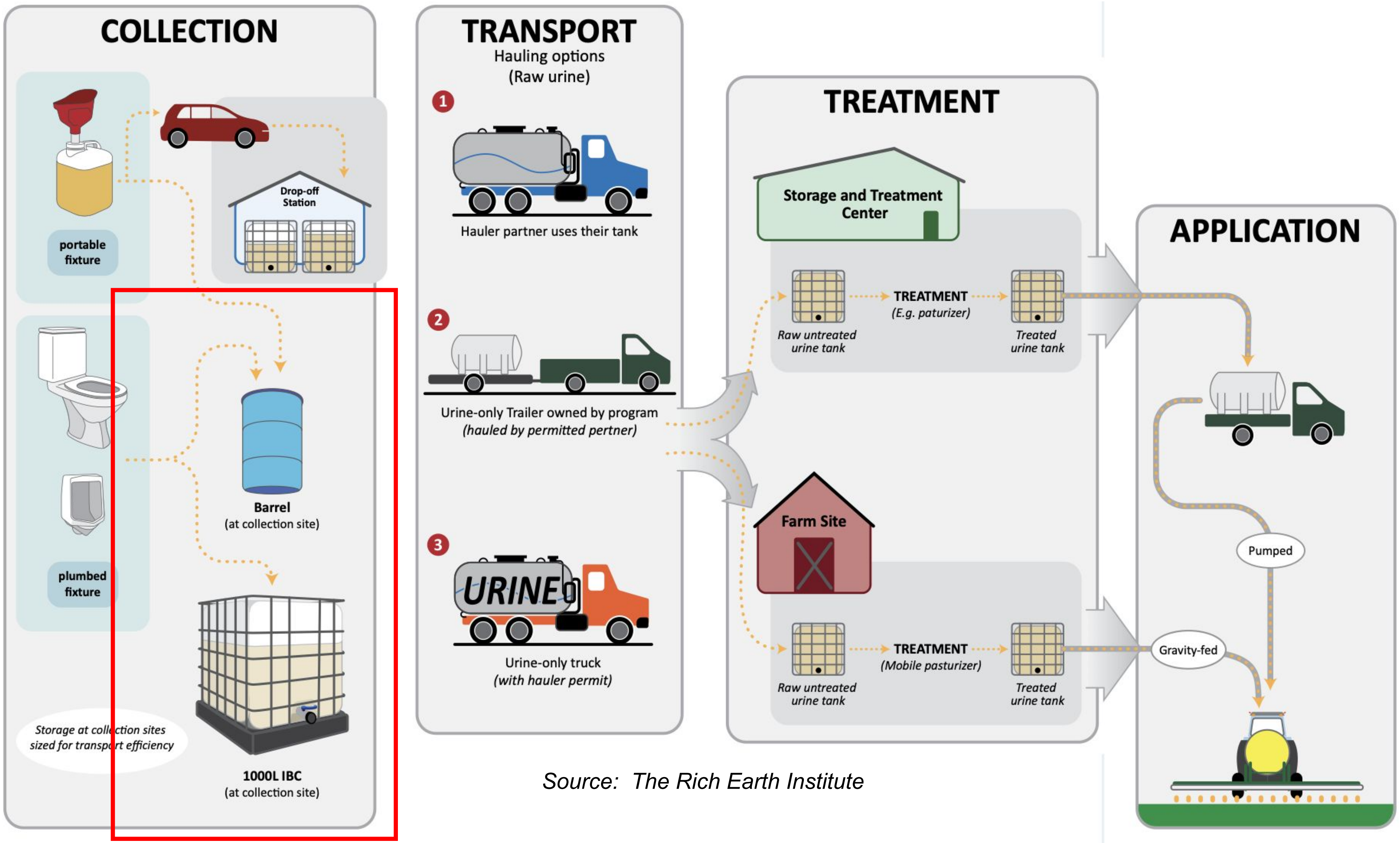


Ammonia recovery by nanofiltration (Ray et al., 2022)



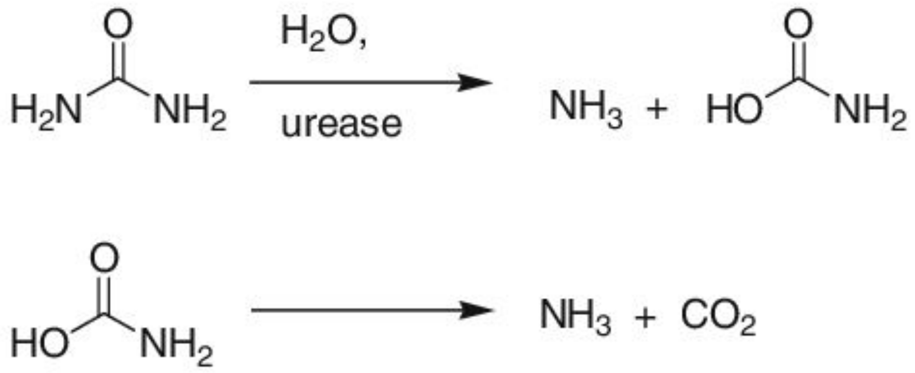
Urea recovery by ethanol evaporation (Marepula et al., 2021)

Urine Diversion and Nutrient Recycling

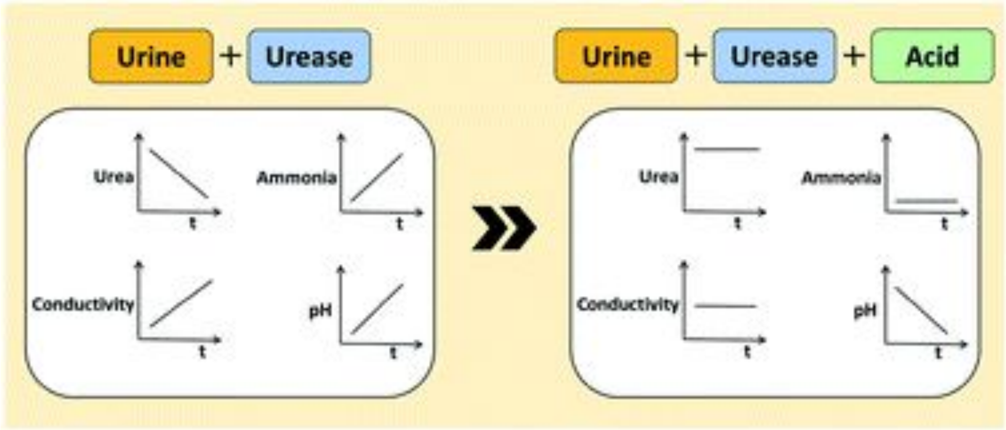


Source: The Rich Earth Institute

Urea Hydrolysis as a Problem and Its Prevention



Ray et al., ES:WRT, 2018

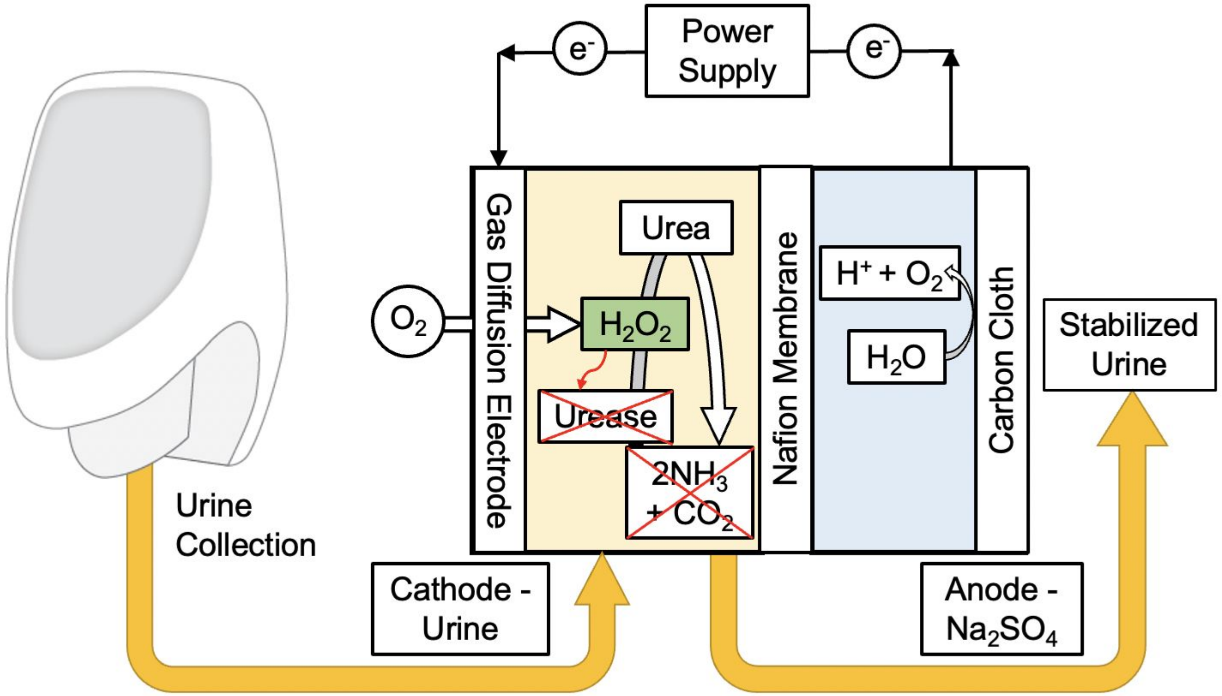


The ubiquitous urease enzyme catalyzes the hydrolysis of urea in urine to ammonia and carbon dioxide, making storage and transport difficult

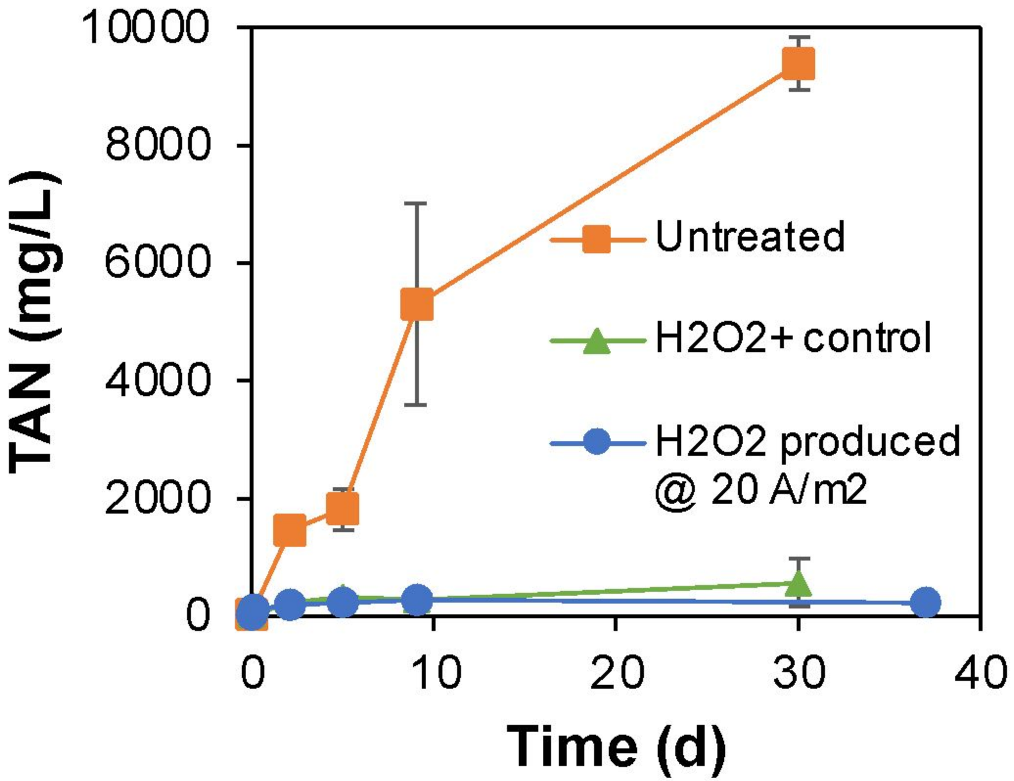
Increasing ammonia concentration, conductivity and pH are hallmarks of urea hydrolysis

Urea hydrolysis can be inhibited by adding acid (vinegar) or base (caustic)

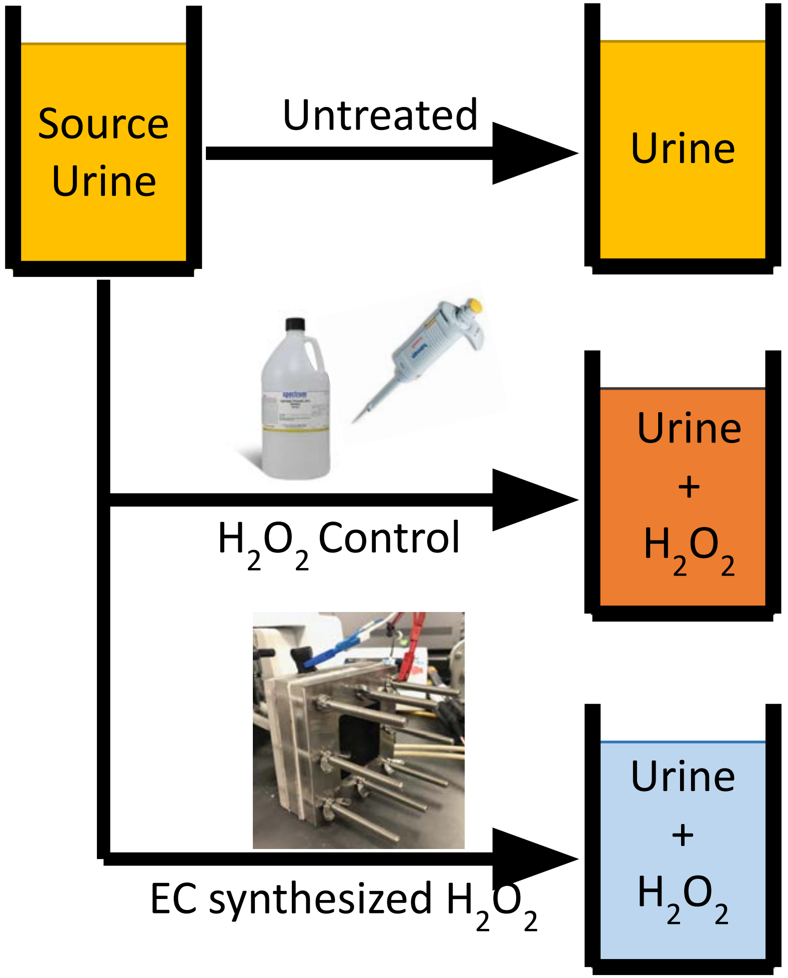
Using Electro-synthesized H_2O_2 for Urea Stabilization

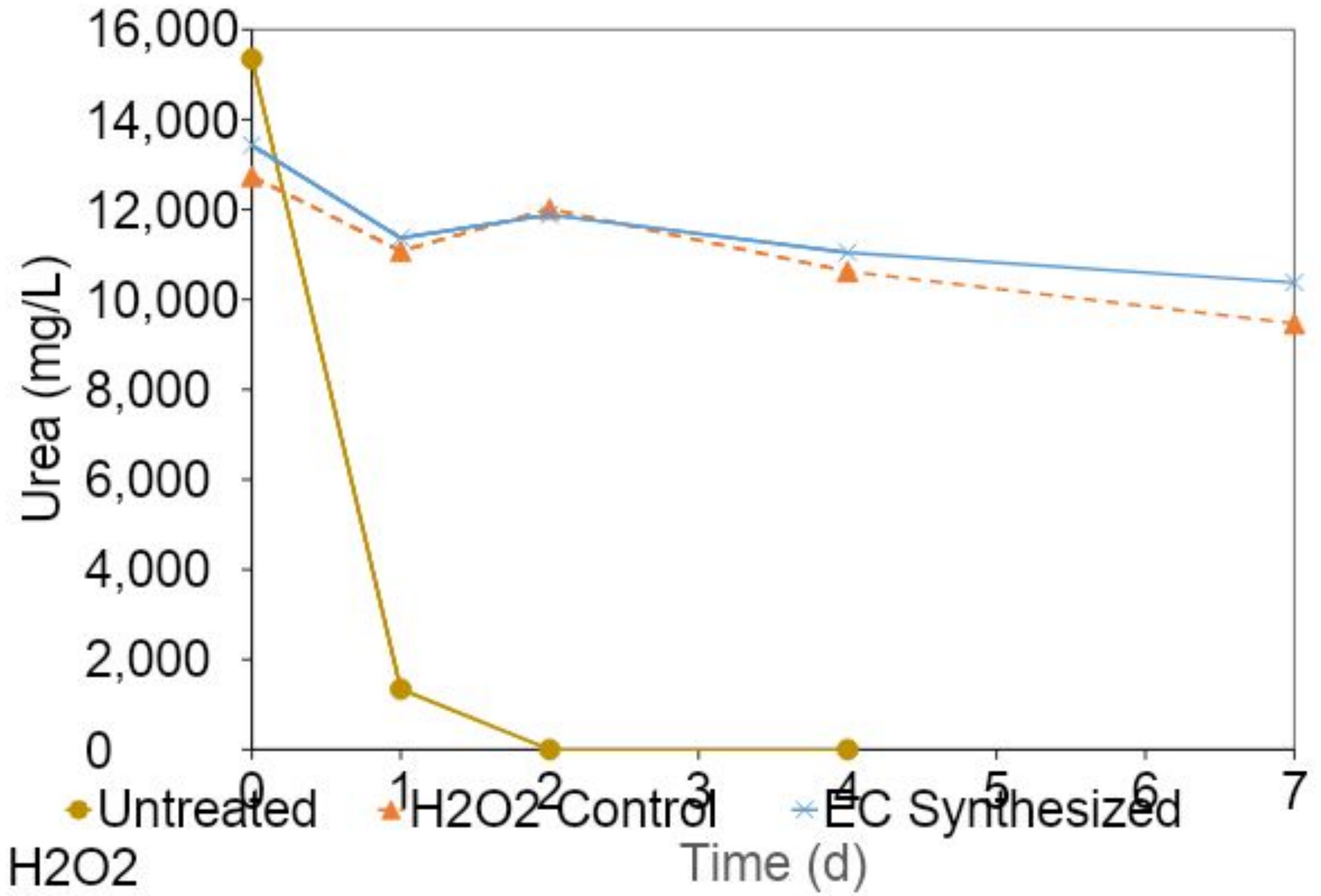


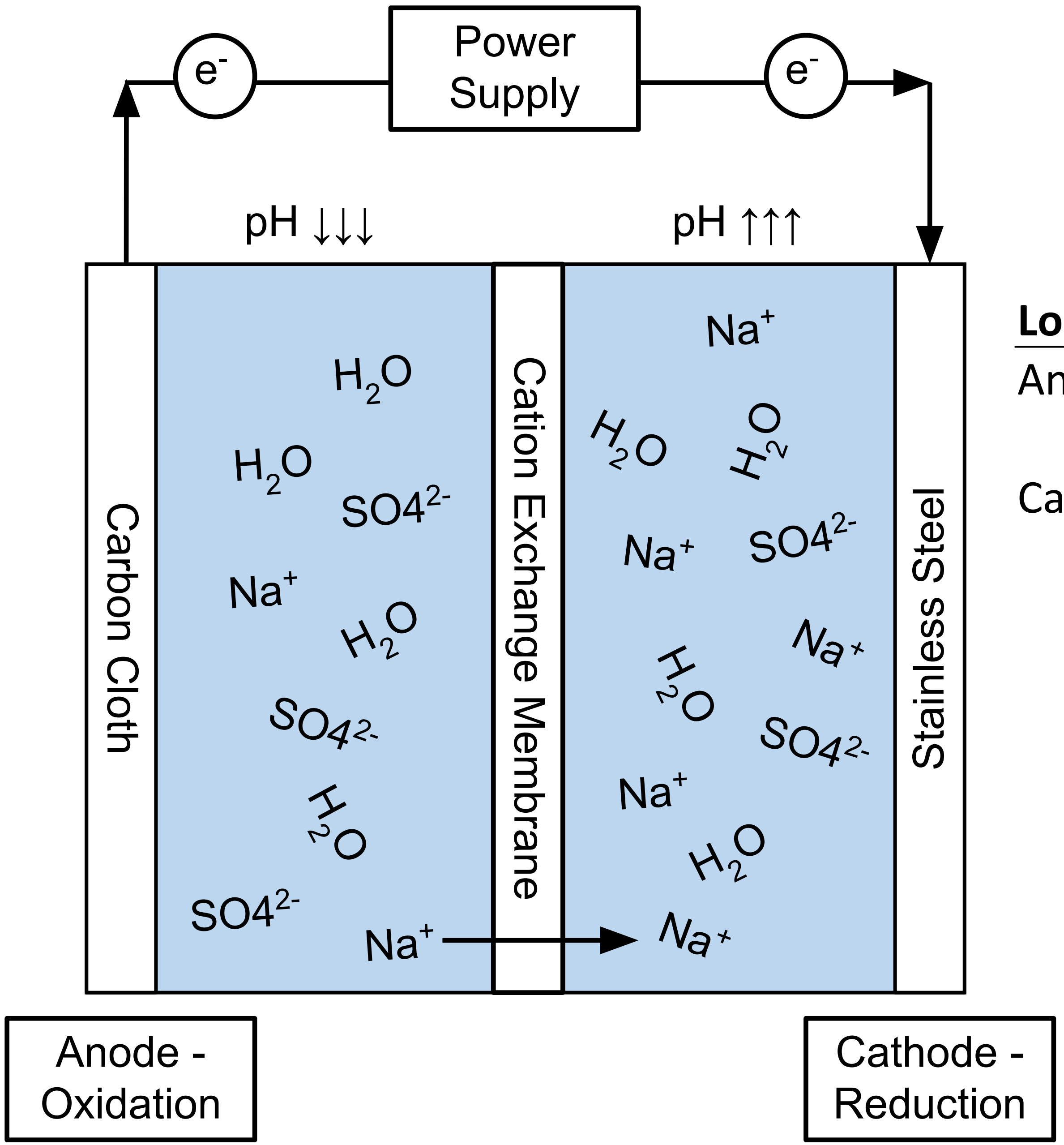
Arve and Popat, ACS ES&T Engineering, 2021



Proof-of-concept with Real Urine





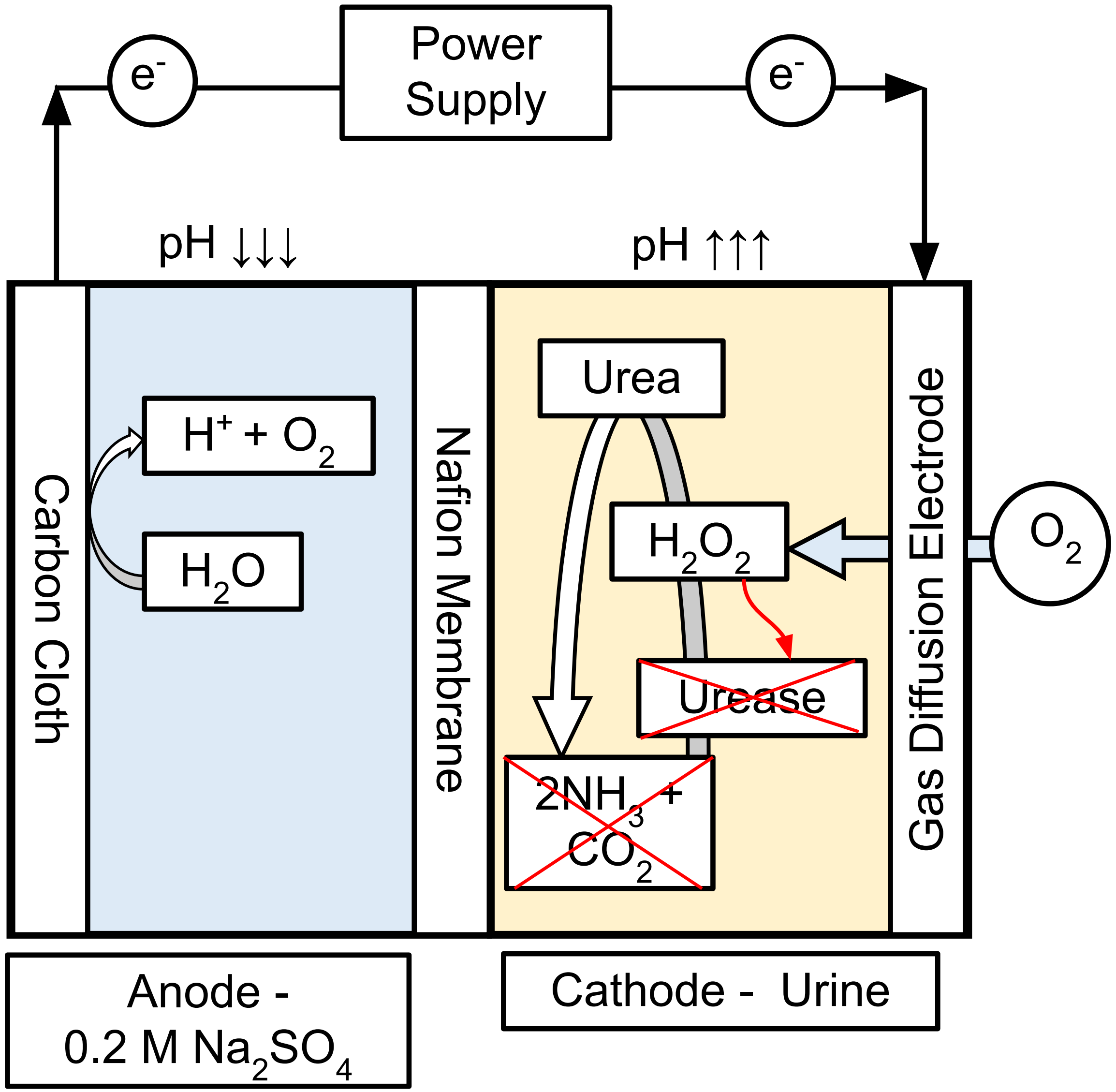


Location	Half-Reaction	E^0 (V)
Anode	$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$	+1.23
Cathode	$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$	-0.83

Whole cell potential:

$$E^0_{red} - E^0_{ox} = E^0_{cell}$$

$$(-0.83\ V) - (1.23\ V) = -2.06\ V$$



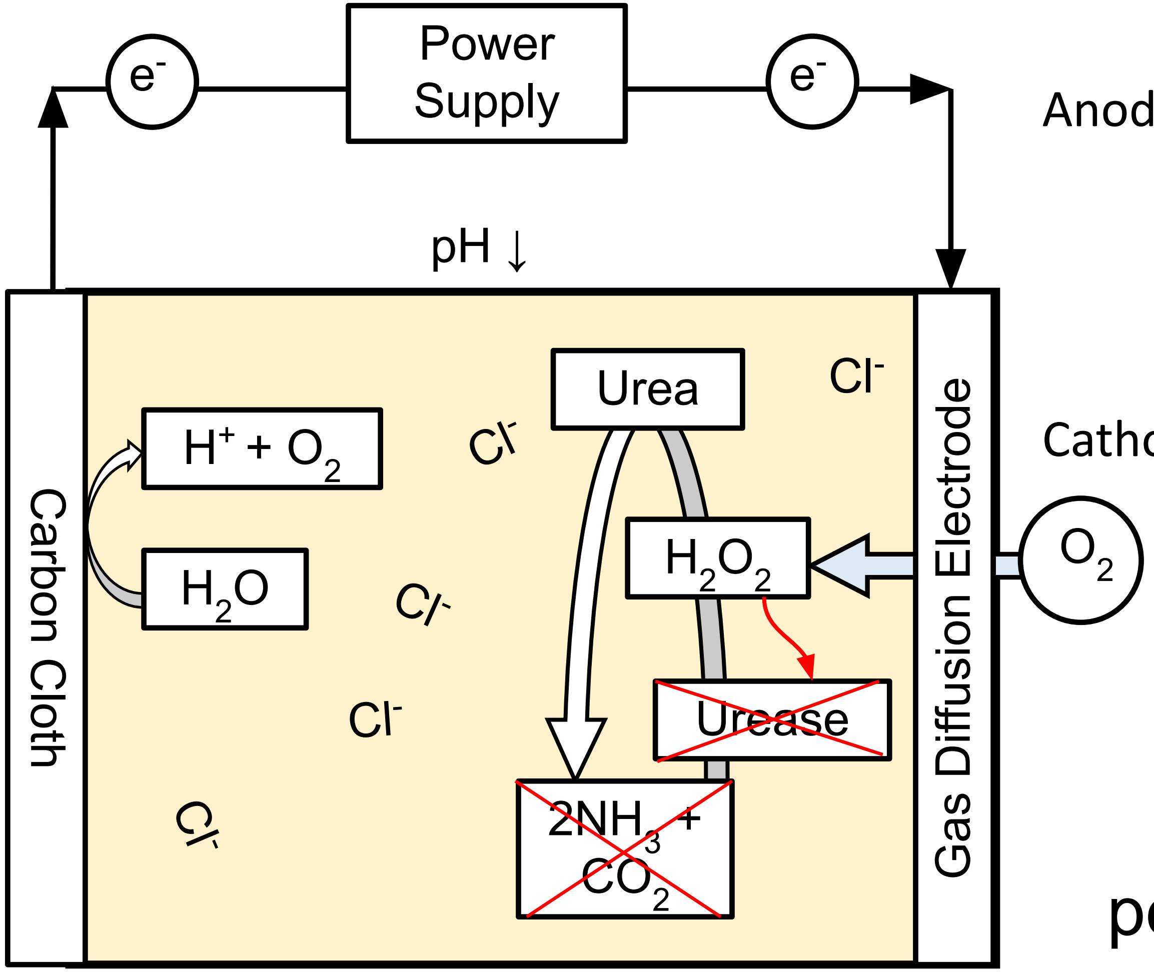
Location	**Half-Reaction**	**E^0 (V)**
Anode	$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$	+1.23
Cathode	$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2$	+0.695

Whole cell potential:

$$E^0_{red} - E^0_{ox} = E^0_{cell}$$

$$(0.695\ V) - (1.23\ V) = -0.535\ V$$

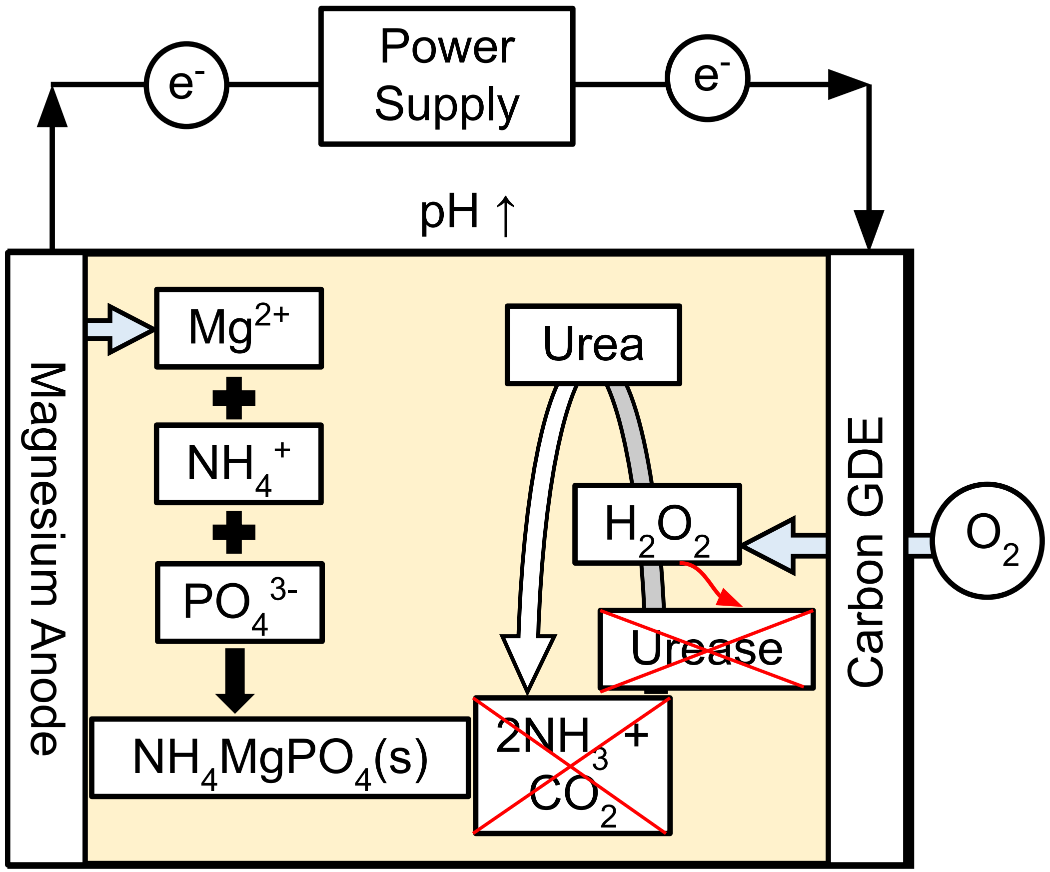
Elevated pH in cathode chamber induces calcium phosphate precipitation



Location	Half-Reaction	E^0 (V)
	$CO(NH_2)_2 + 6OH^- \rightarrow N_2 + 5H_2O + CO_2 + 6e^-$	-0.746
	$H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$	+0.695
Anode		
	$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$	+1.23
	$2Cl^- \rightarrow Cl_2 + 2e^-$	+1.36
Cathode	$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2$	+0.695

Chlorine oxidizes urea and hydrogen peroxide and reacts with organics in urine to produce disinfection by-products

Adding Phosphorus Recovery as Struvite



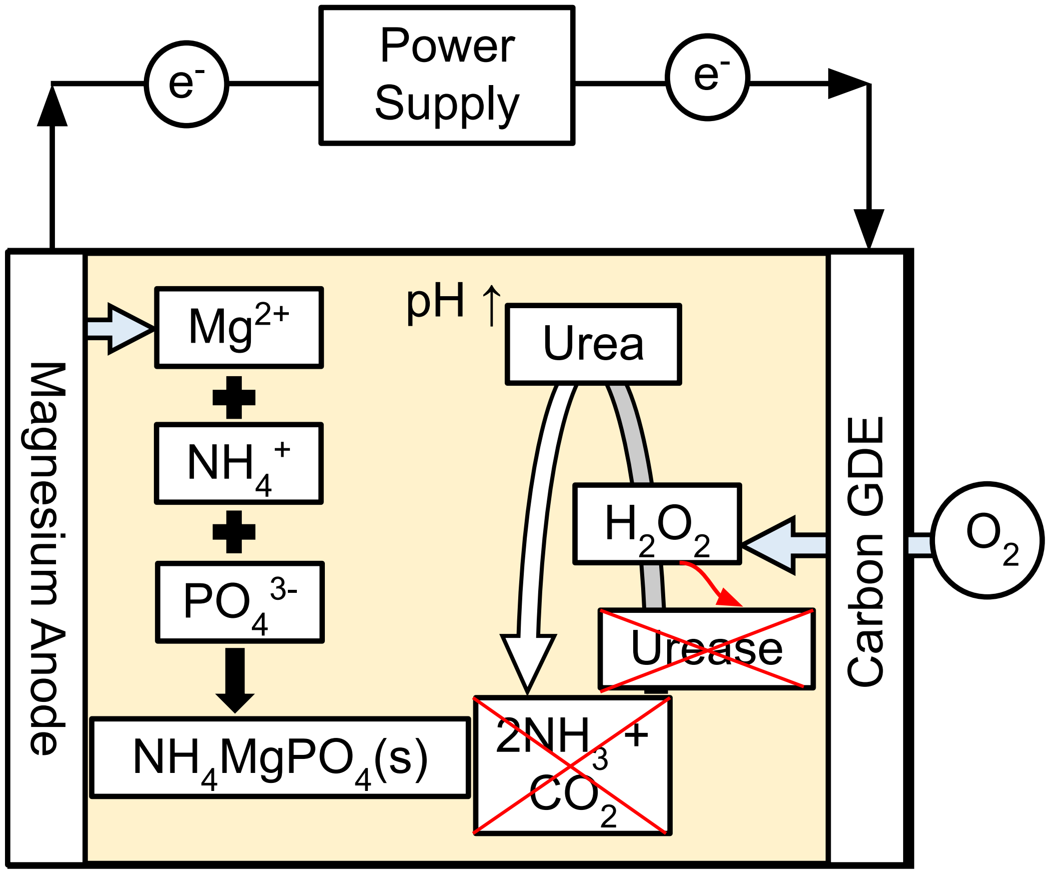
Location	Half-Reaction	E^0 (V)
Anode	$Mg \rightarrow Mg^{2+} + 2e^-$	-2.37
Cathode	$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2$	+0.695

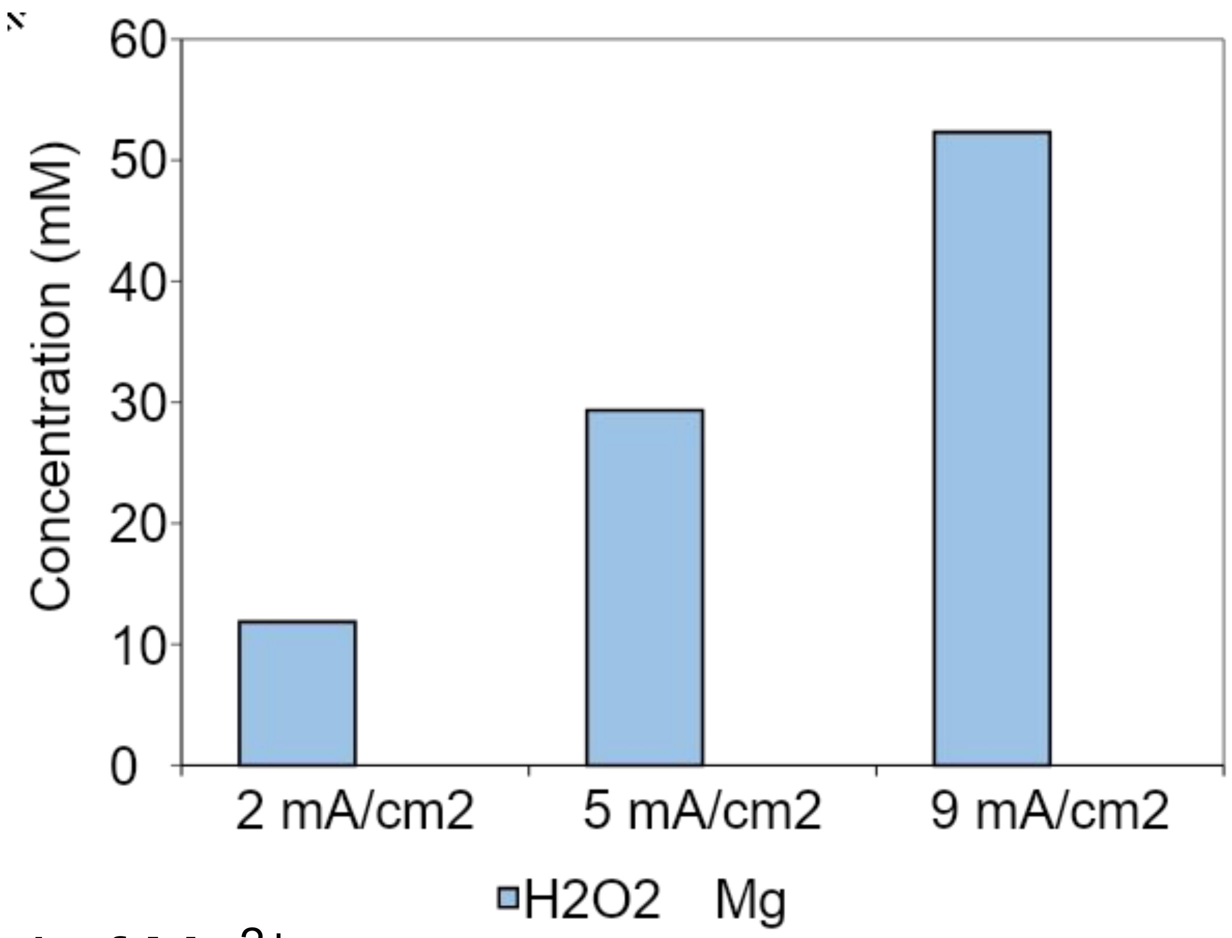
Whole cell potential:

$$E^0_{red} - E^0_{ox} = E^0_{cell}$$

$$(0.695\ V) - (-2.36\ V) = 3.07\ V$$

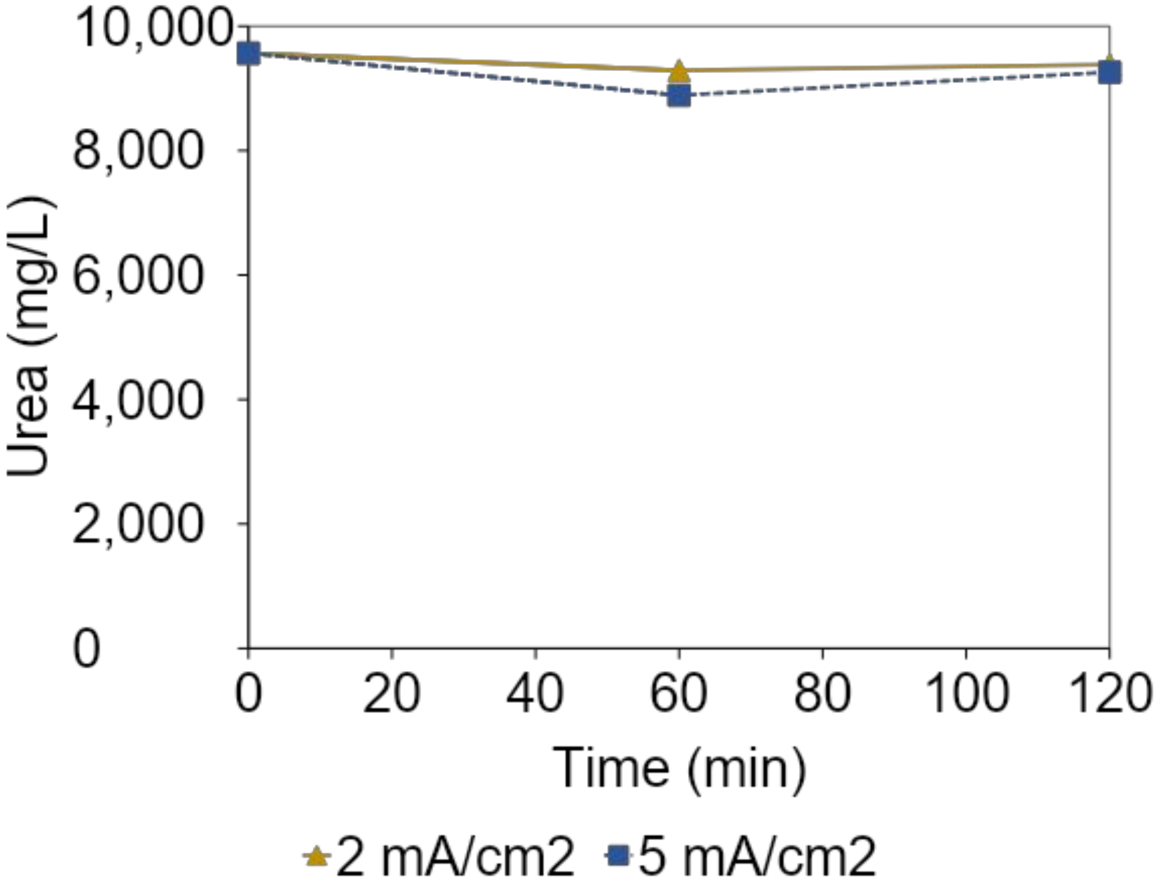
Proof-of-concept – Magnesium Dissolution



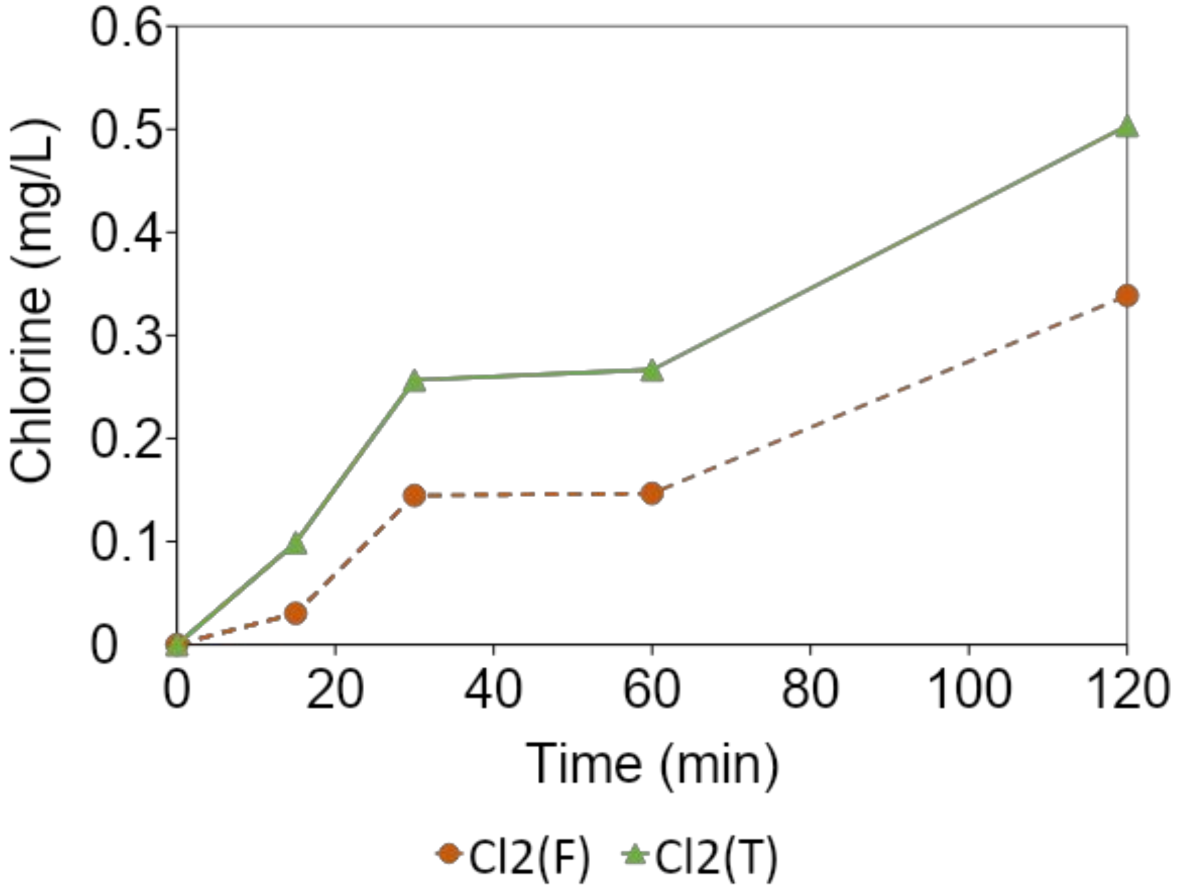


Theoretical 1 mol of Mg^{2+}
per mol of H_2O_2 produced

Proof-of-concept – Avoiding Chlorine Production and Urea Oxidation

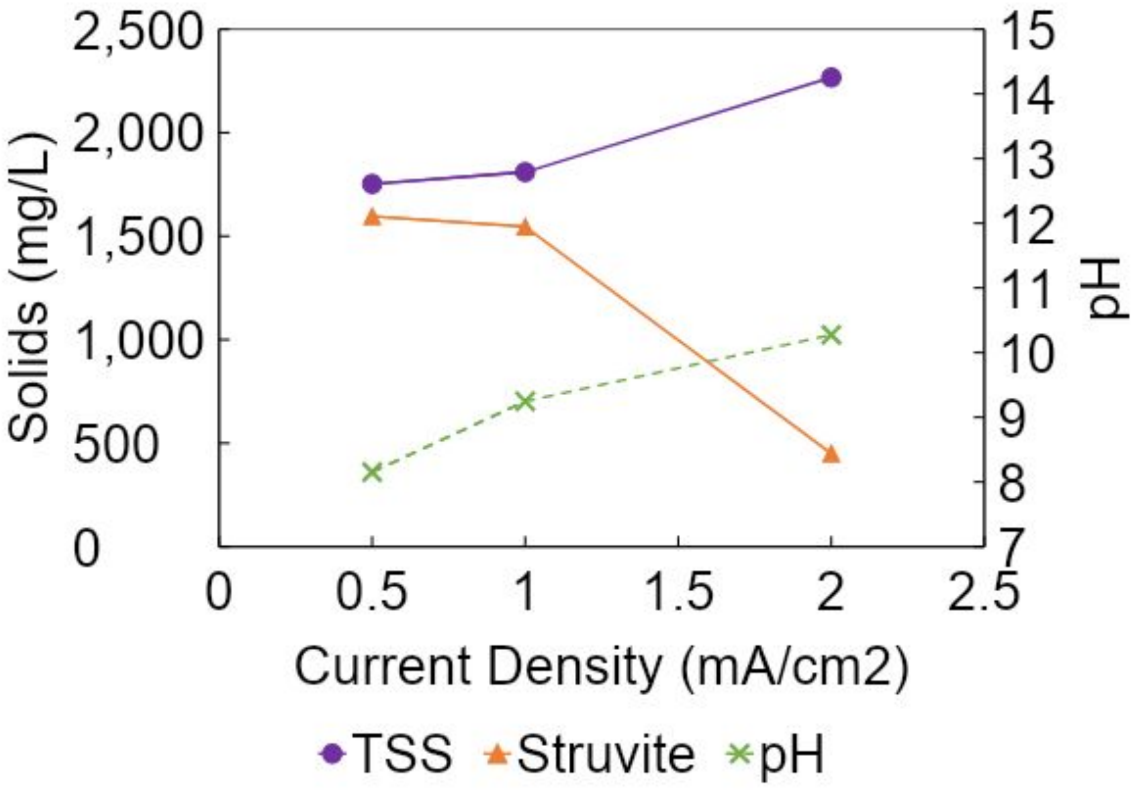


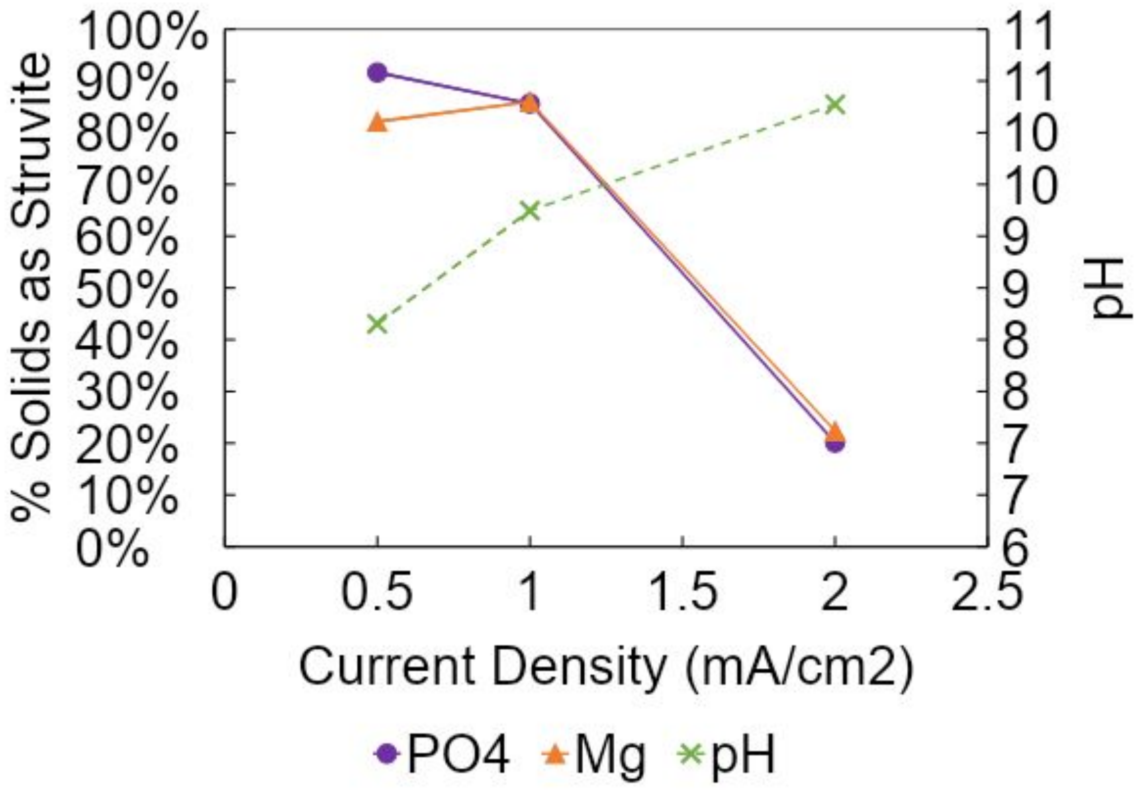
Unchanged urea concentrations



Low levels of free and total Cl_2

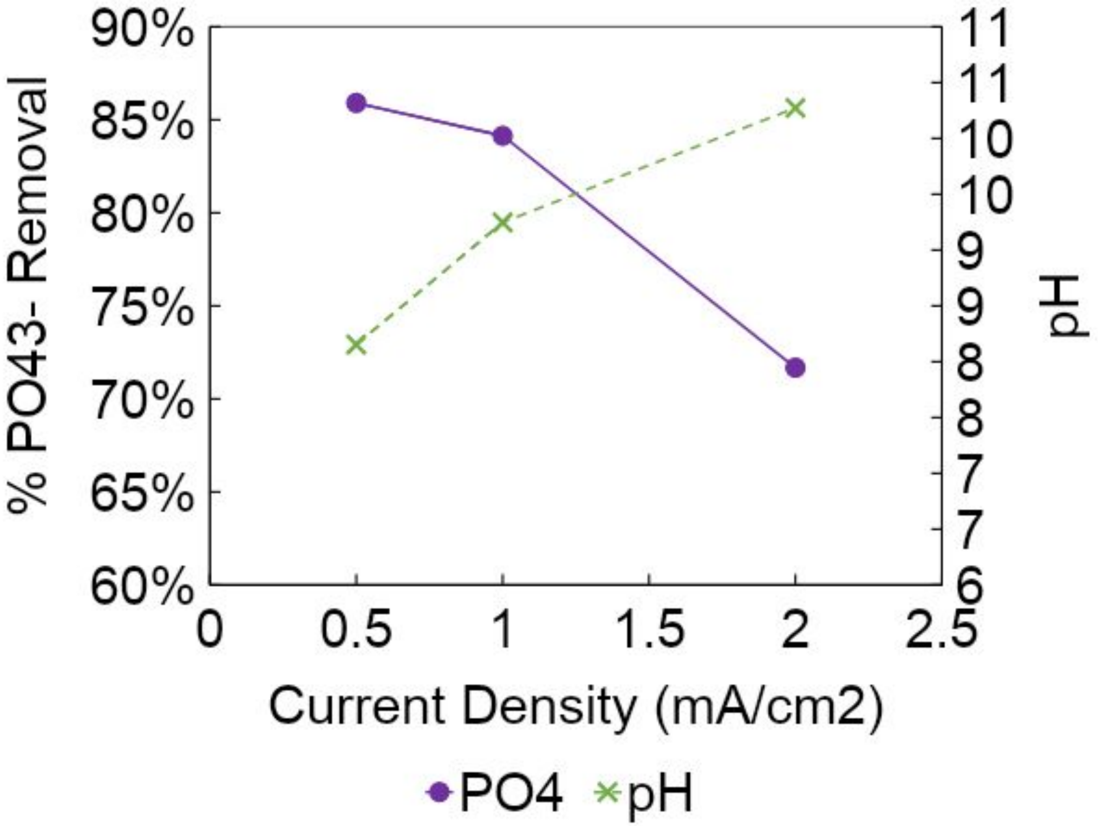
Proof-of-concept – Struvite Precipitation

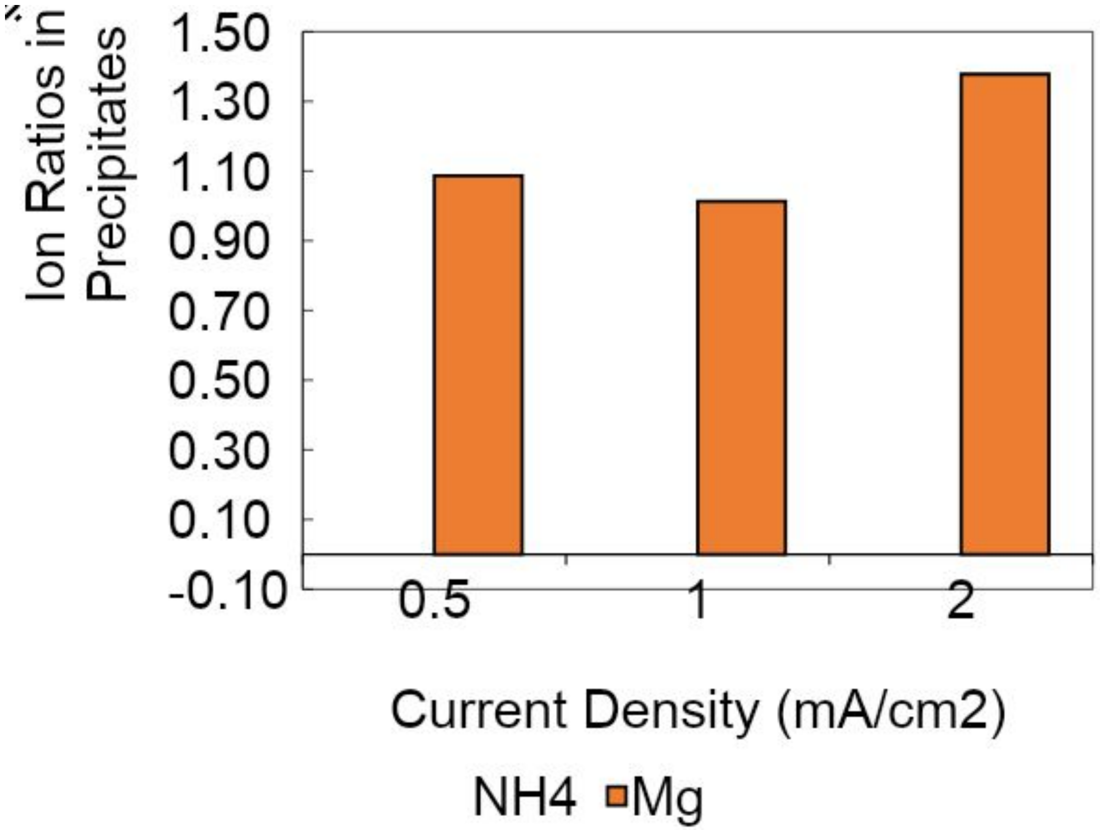




Lower struvite recovery at higher current densities, linked to a high pH achieved at higher current densities

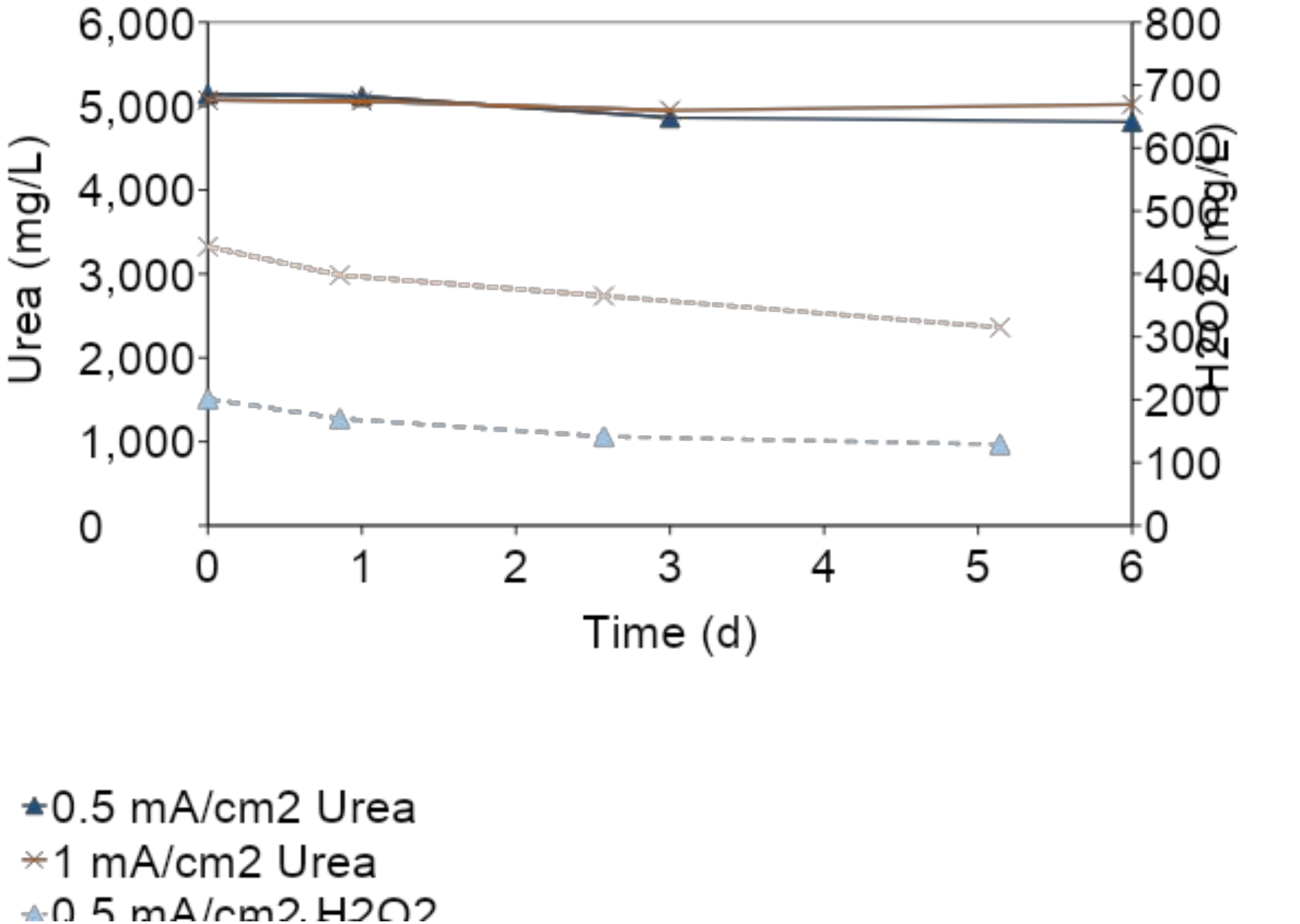
Proof-of-concept – Phosphate Removal





Phosphate removal not affected by current density, suggesting precipitation at calcium and magnesium phosphates at higher pHs

Proof-of-concept – Urea Stabilization



Take-home Messages

1. Electrochemical stabilization of real urine can be achieved with in situ electrochemical peroxide production

2. Using magnesium anodes in electrochemical urine stabilization leads to the dissolution of Mg for struvite precipitation and avoidance of Cl_2 production

3. Struvite precipitation is affected by current density, which affects the urine pH in the electrochemical cell – pHs >10 leads to phosphate recovery as calcium and/or magnesium phosphates

Electrochemical Urine Stabilization with Concomitant Phosphorus Recovery using Magnesium Anodes and Peroxide-producing Cathodes

Philip Arve
Prithvi Simha
Dyllon Randall
Sudeep Popat

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