Phosphorus Flows and Balances for the Lake Mendota and Yahara River Watersheds: 1992-2017

Eric Booth, PhD, Associate Scientist

Department of Agronomy, Department of Civil & Environmental Engineering

University of Wisconsin - Madison

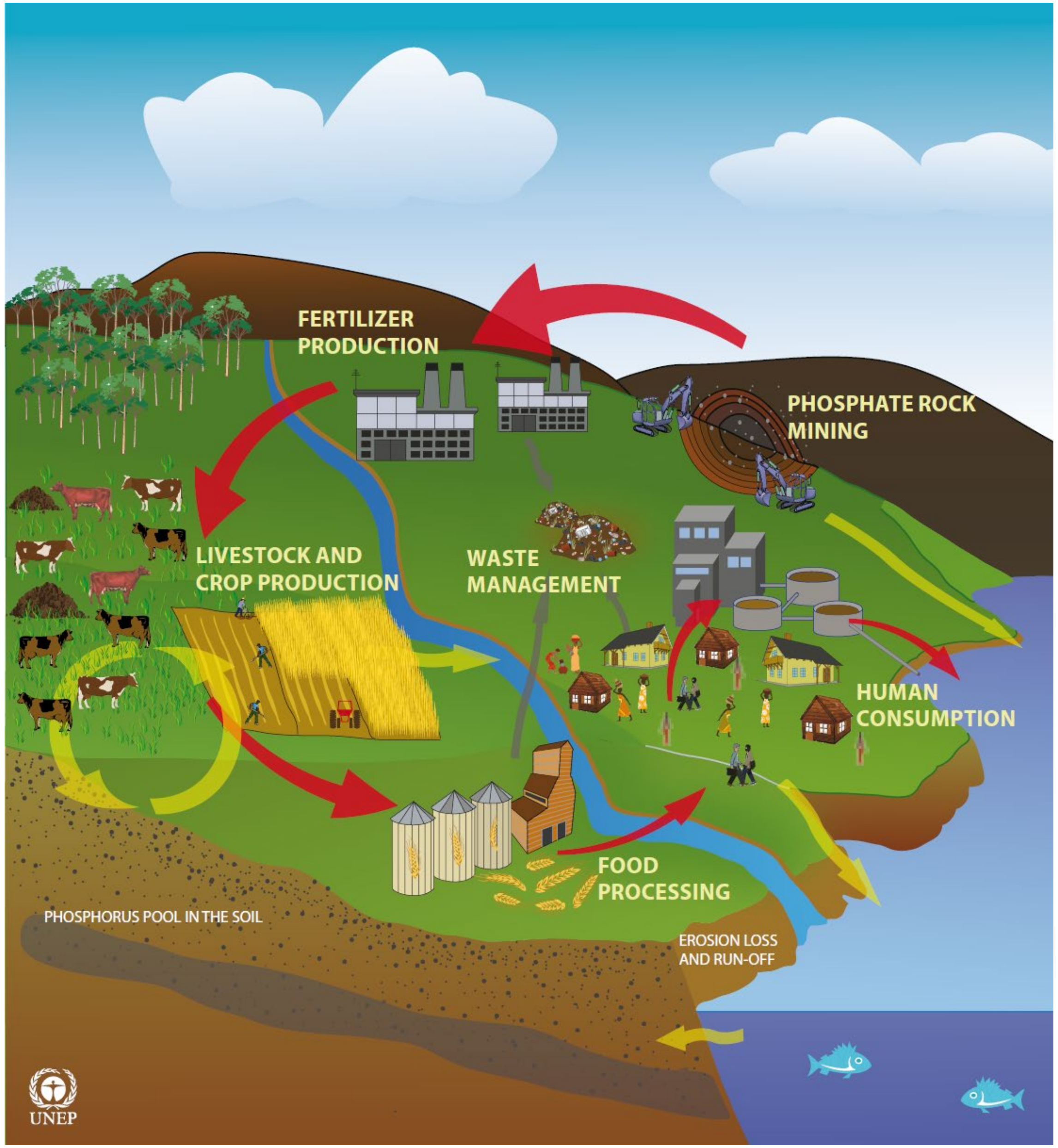
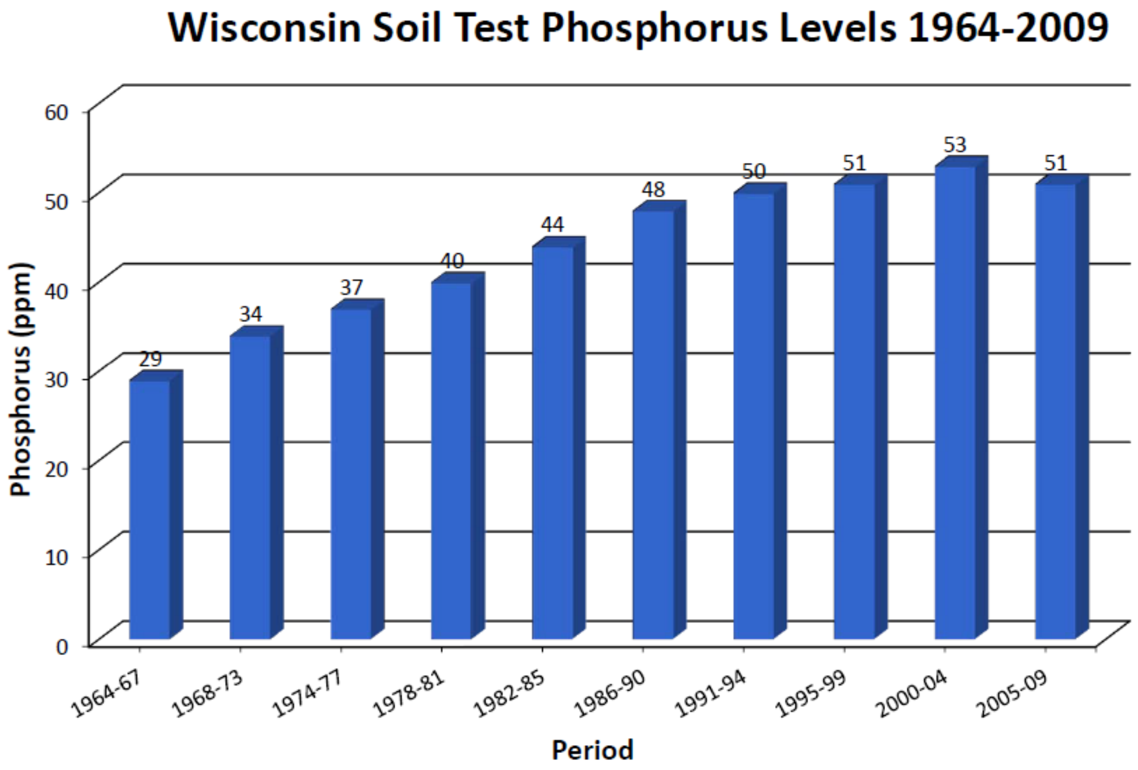


Figure 1: Phosphorus flows in the environment. To enhance food production, phosphorus is added to soil in the form of mineral fertilizer or manure. Most of the phosphorus not taken up by plants remains in the soil and can be used in the future. Phosphorus can be transferred to surface water when it is mined or processed, when excess fertilizer is applied to soil, when soil is eroded, or when effluent is discharged from sewage treatment works. Red arrows show the primary direction of the phosphorus flows; yellow arrows the recycling of phosphorus in the crop and soil system and movement towards water bodies; and grey arrows the phosphorus lost through food wastages in landfills.

Global P Cycle

- Highly modified by humans
- Before modern agriculture: Contrast between slow migration from rock to ocean and relatively rapid and efficient cycling between soil and plant

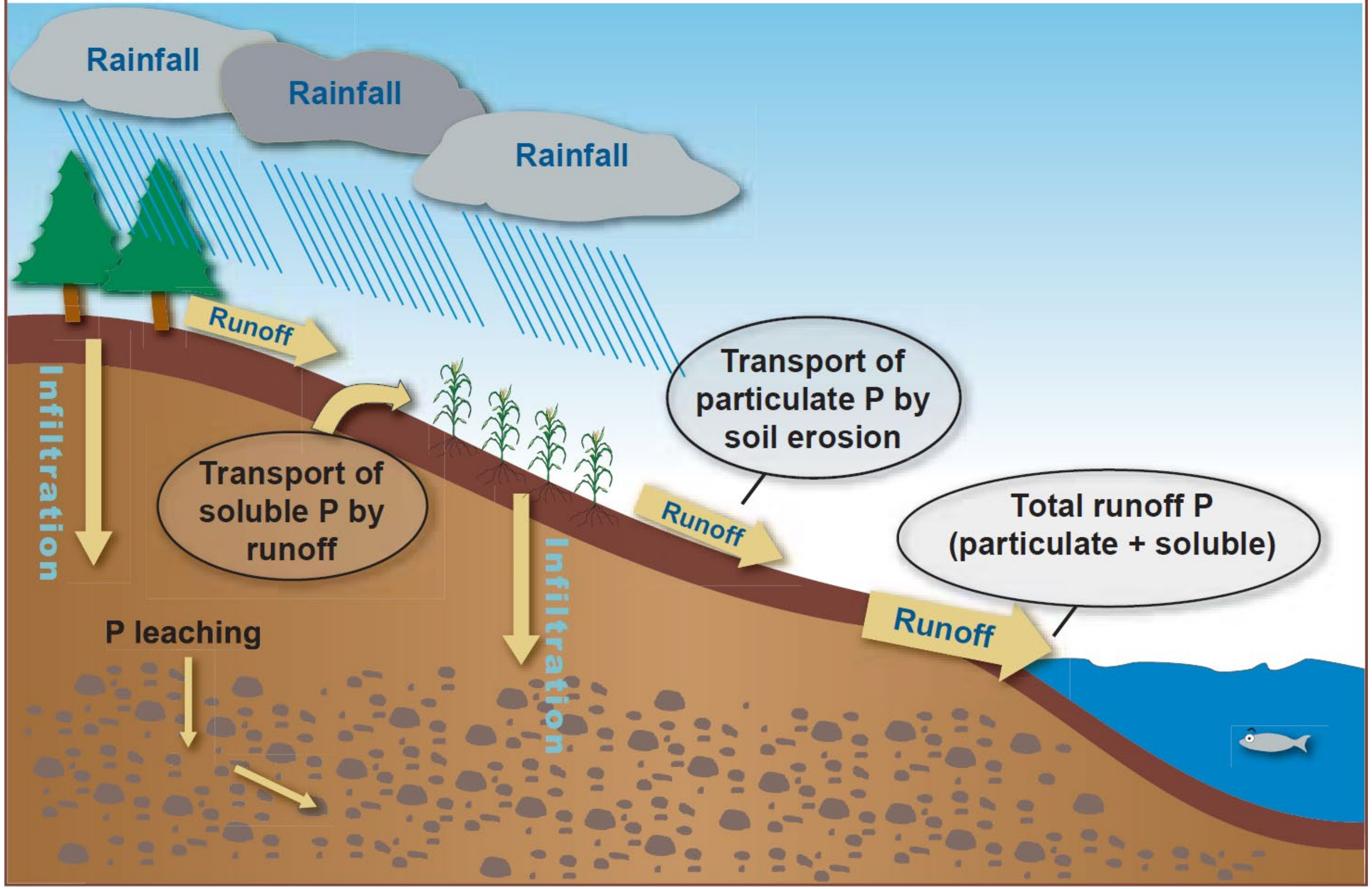
Transfer from Rock to Soil & Lake Bottoms



(Adapted from Bundy and Peters, UW-Soil Science)

P Transport

Figure 2. Phosphorus movement from landscapes.



P reduction strategies

1. **TRANSPORT**: reduce transport of existing P in soil and on surface

2. **SUPPLY**: reduce supply of existing P in watershed

Where is this supply located?

- Soils
  - Native prairie: 100-150 ppm
  - Cropland (Sixmile): 500-800 ppm

UW-Madison Soil Science

- Stream network
  - Streambed: 1000 – 2000 ppm

- Riparian wetlands

- Unincorporated fertilizer/manure

How is P supply related to P loading?

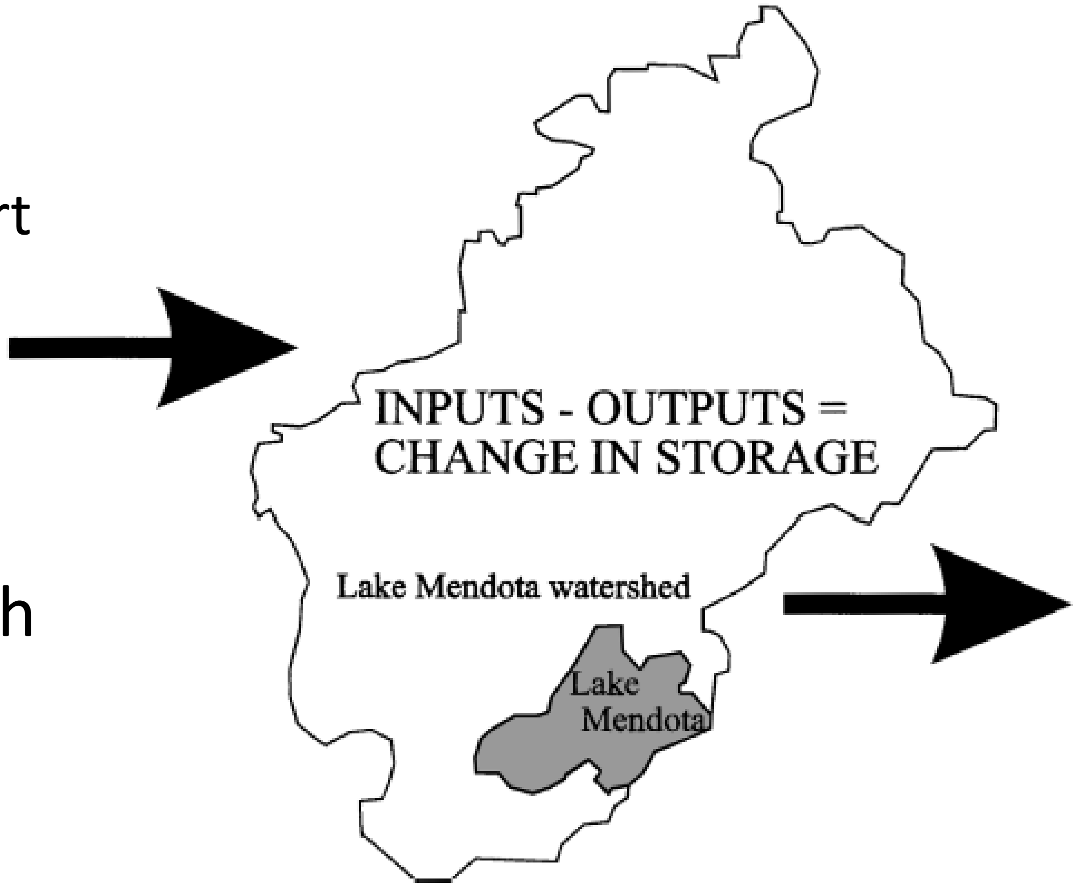
- General Rule
  - The higher the P supply…the more that is available and susceptible to transport via runoff
  - Higher soil P levels lead to higher P runoff values (all other things being equal)
- Not all of the P supply is equally susceptible to transport

Finn Ryan

What is a Phosphorus Budget?

- Conservation of Mass
  - IN: Food, feed, fertilizer
  - OUT: Crops, livestock products, stream export
  - CHANGE IN STORAGE (SUPPLY)

- Reconciling deposits and withdrawals with changes in account balance



Bennett et al. 1999

What can a P budget do for P reduction efforts?

- Provide context for chronic issue of P legacy
- Accounting tool that measures long-term changes in P runoff risk
- Identify opportunities where balance can be restored

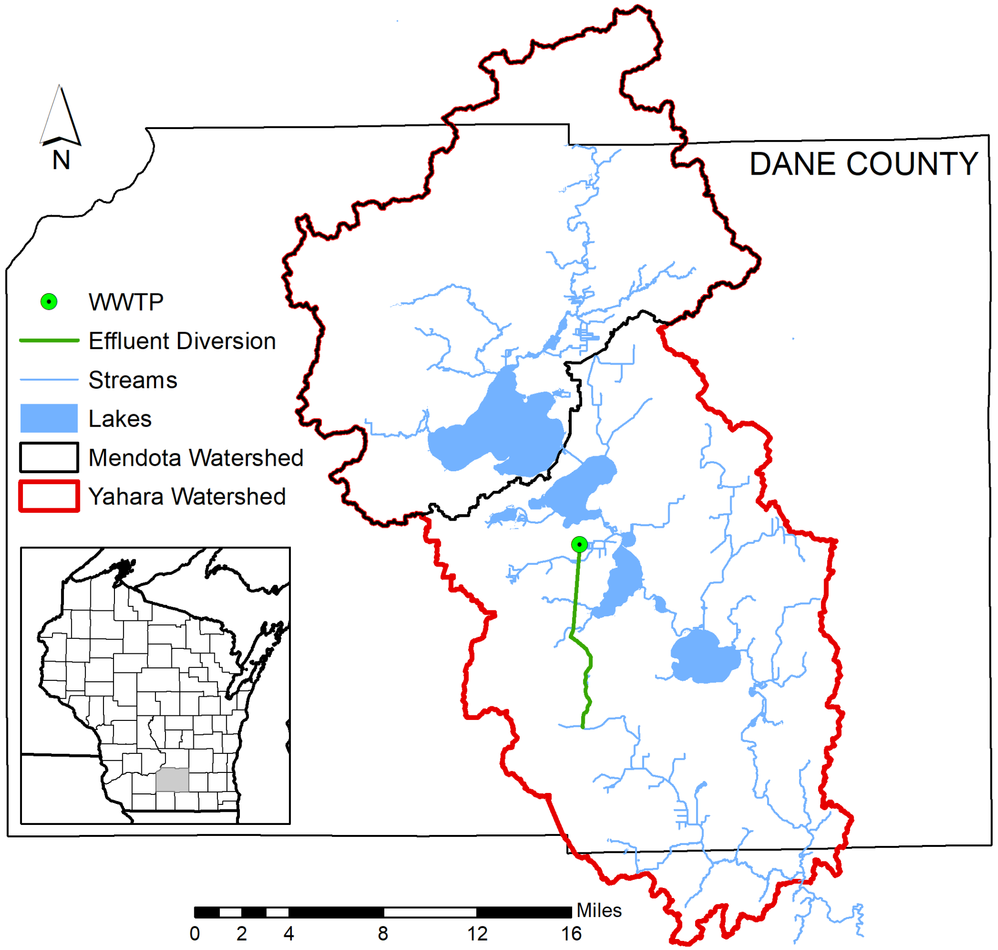
What **can't** a P budget do for P reduction efforts?

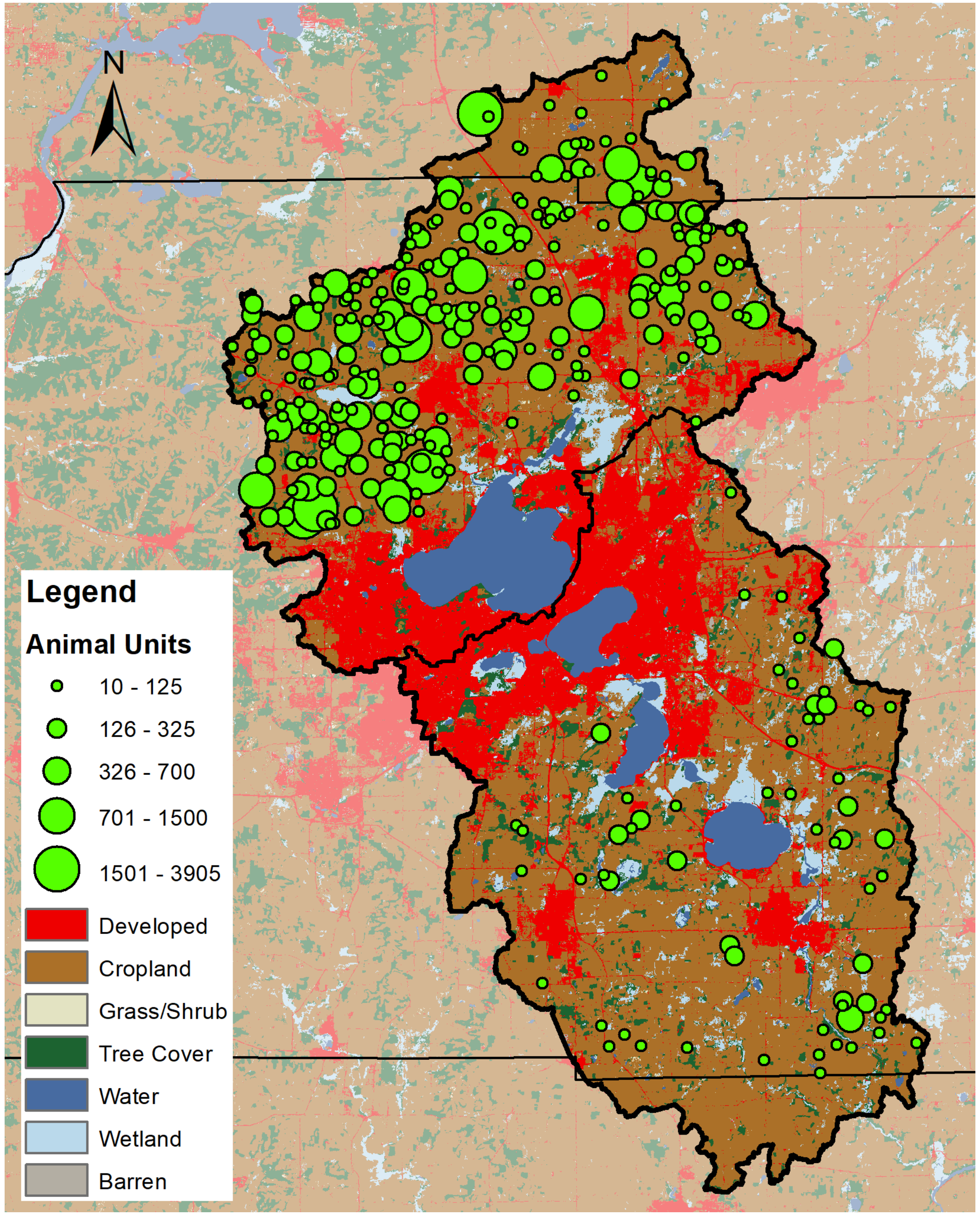
- Target specific transport “hot-spots” on the landscape
- Offer quick fixes to water quality issues

- Must be paired with tools that target transport reduction of existing P
  - SNAP+, Cover Crops, Harvestable Buffers, Suck the Muck

Major Drivers of Phosphorus Flows

- Livestock & Crops
- Humans
- Pets
- Climate





2017 Land Cover from USGS LCMAP

Livestock & Crops

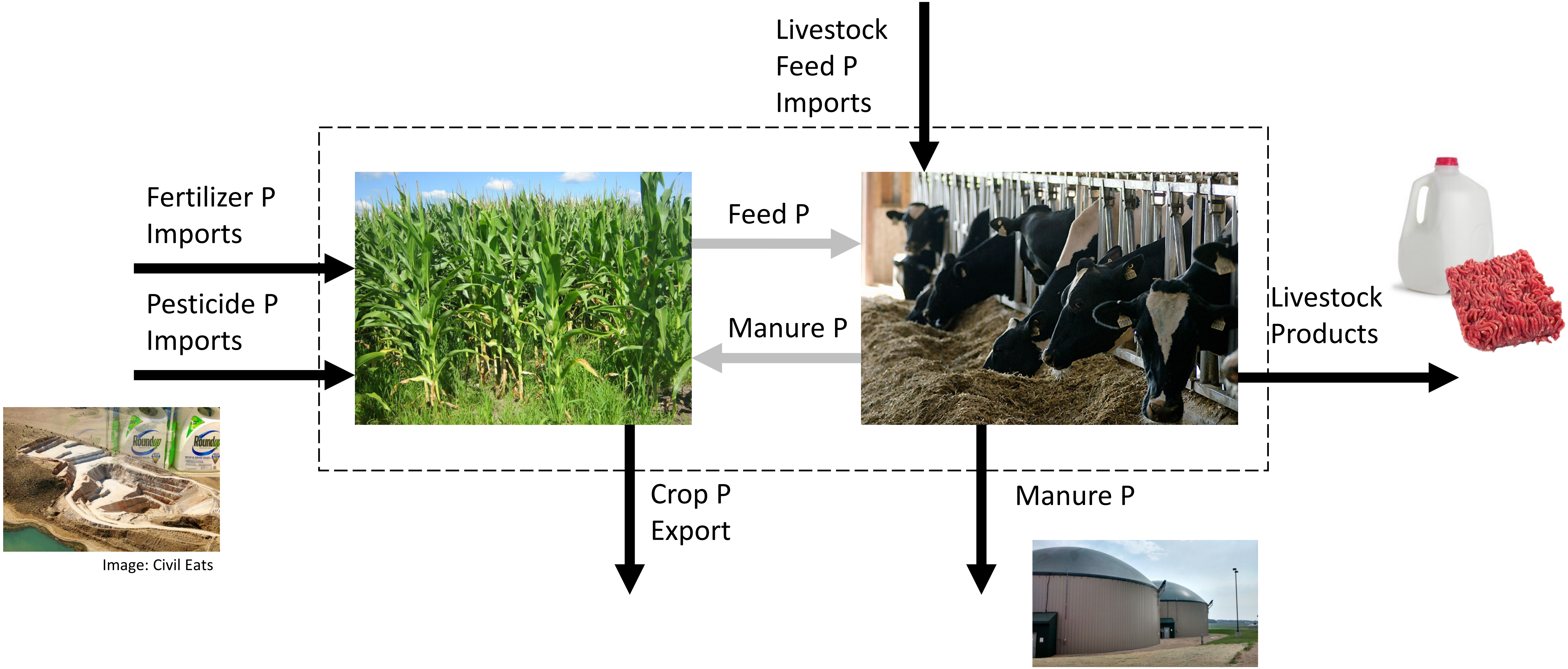


Image: Civil Eats

Humans

Household Products P Imports

Food P Imports

Image: Madison Magazine

Household Waste P to Landfill

Struvite P export

Image: Ostara

Wastewater P to Treatment Plant

Effluent P to Badfish Creek

Image: MMSD

Biosolids P to Cropland

Image: MMSD

Pets

Pet Feed
P Imports

Pet Waste P
to Landfill

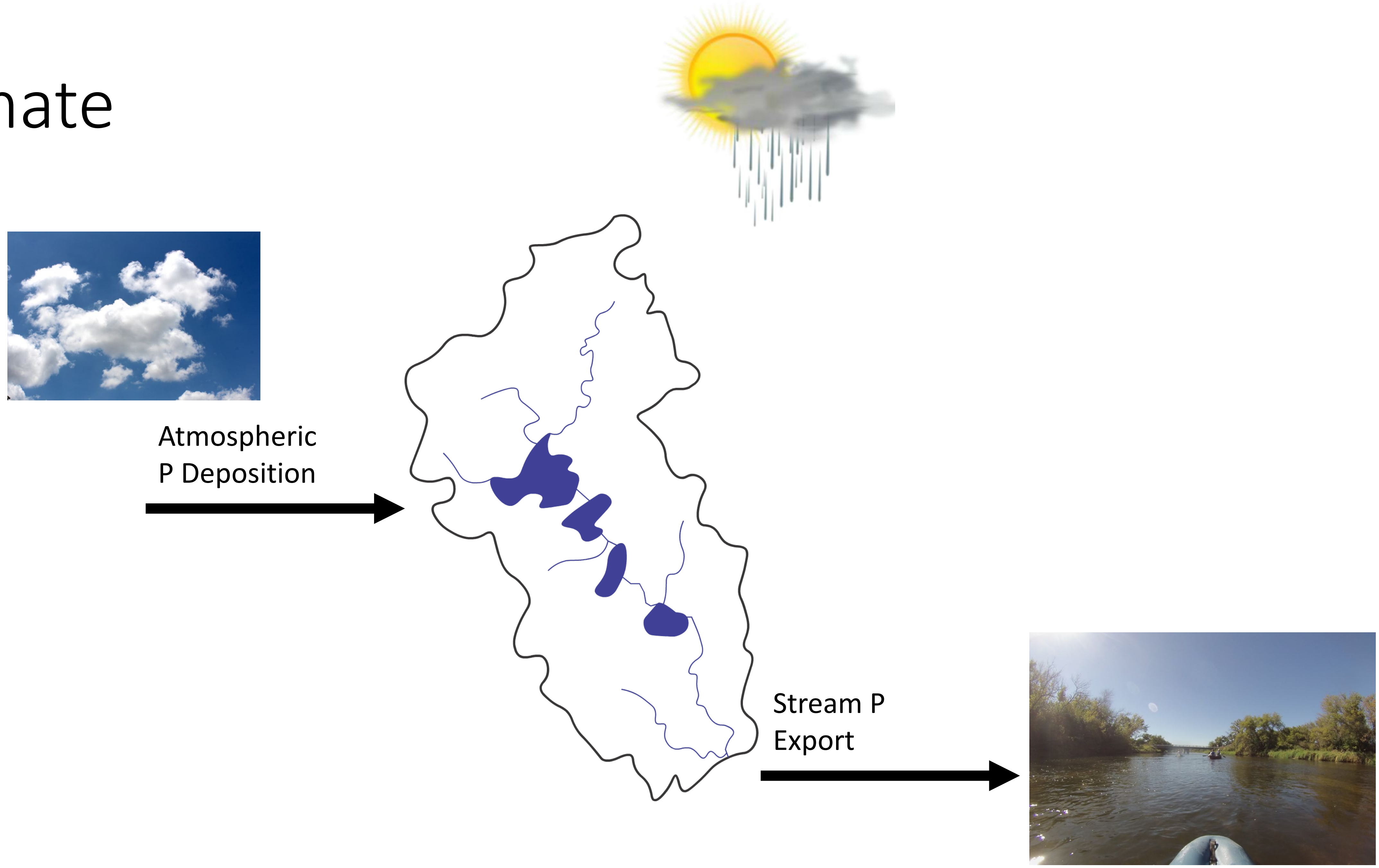
Image: Madison Magazine

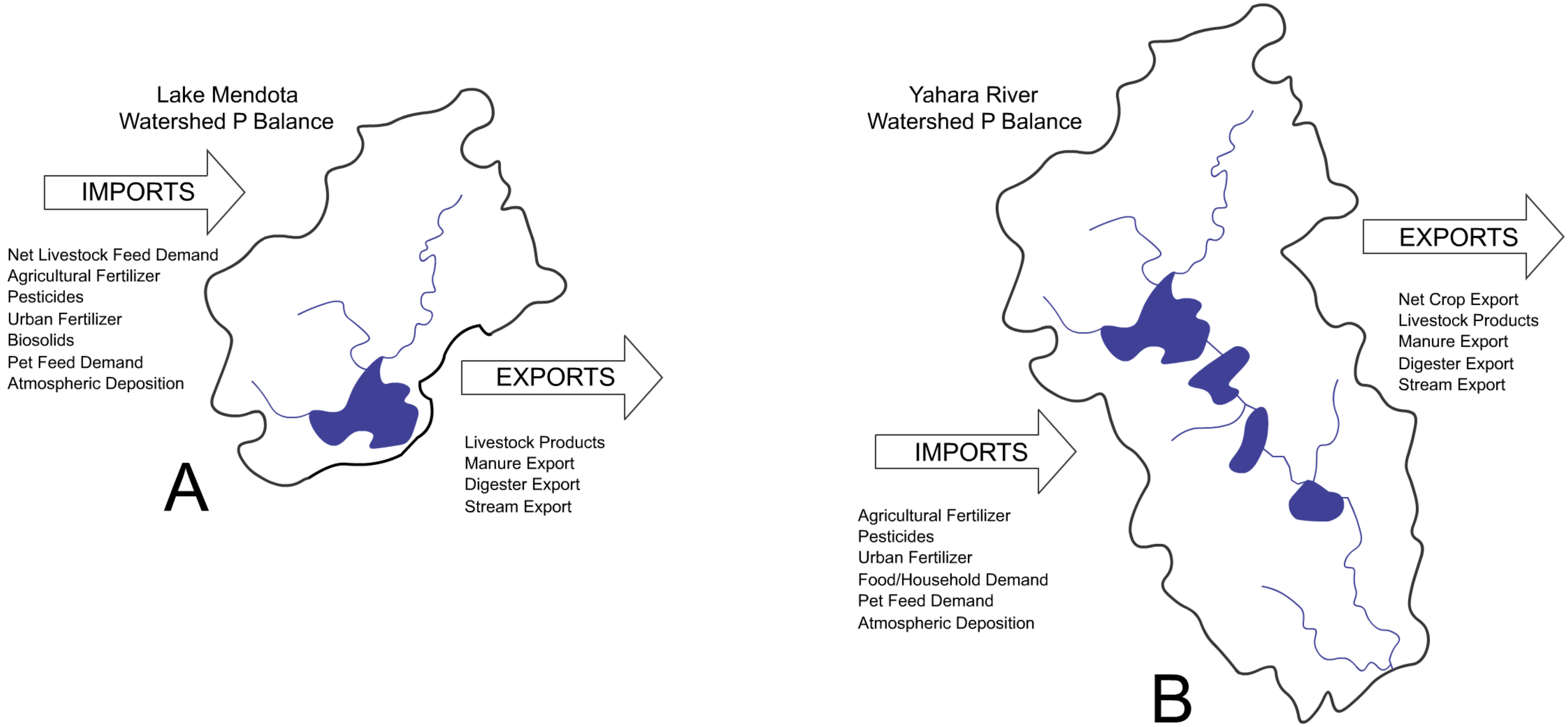
Pet Waste P
to Treatment
Plant

Image: MMSD

Pet Waste P
to Urban
Landscape

Climate





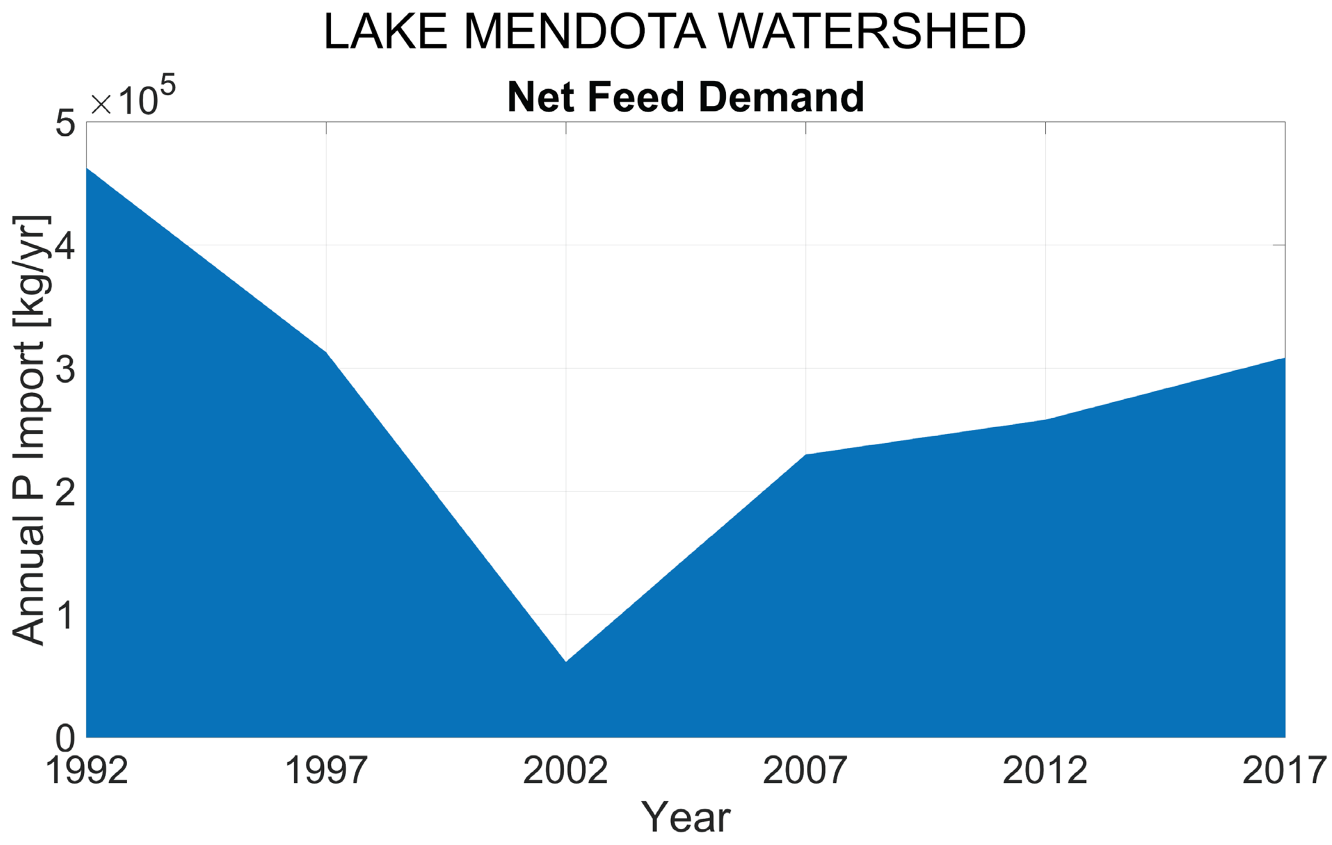
Lake Mendota
Watershed P Balance
IMPORTS
Net Livestock Feed Demand
Agricultural Fertilizer
Pesticides
Urban Fertilizer
Biosolids
Pet Feed Demand
Atmospheric Deposition
EXPORTS
Livestock Products
Manure Export
Digester Export
Stream Export
A
Yahara River
Watershed P Balance
EXPORTS
Net Crop Export
Livestock Products
Manure Export
Digester Export
Stream Export
IMPORTS
Agricultural Fertilizer
Pesticides
Urban Fertilizer
Food/Household Demand
Pet Feed Demand
Atmospheric Deposition
B

Points to consider

- Positive P accumulation rate implies the growth of legacy P
  - Long-term management challenge
- Not all P accumulation is the same
  - Where is it accumulating?
  - How “slippery” is it?
- Not all exports are good
  - Stream Export

Lake Mendota Watershed – Net Feed Demand

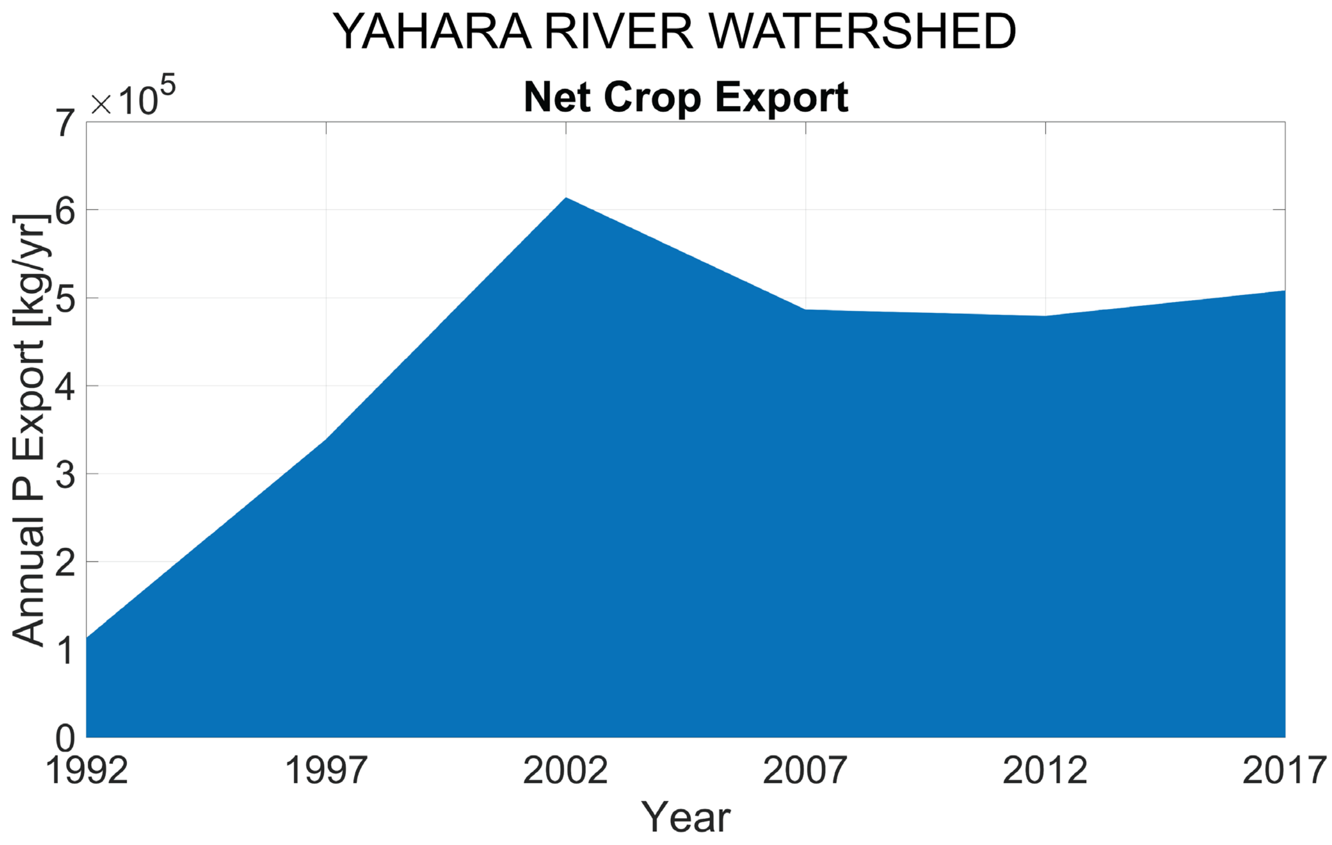
- Not enough feed is produced to meet livestock demand for all years
- Decline from 1997 to 2002 driven primarily by elimination of mineral P feed supplement
- Increase from 2002 to 2017 driven by increasing livestock population and milk production (outweighed by crop yield increases)



Net Feed Demand = Feed Demand – Crop Harvest

Yahara River Watershed – Net Crop Export

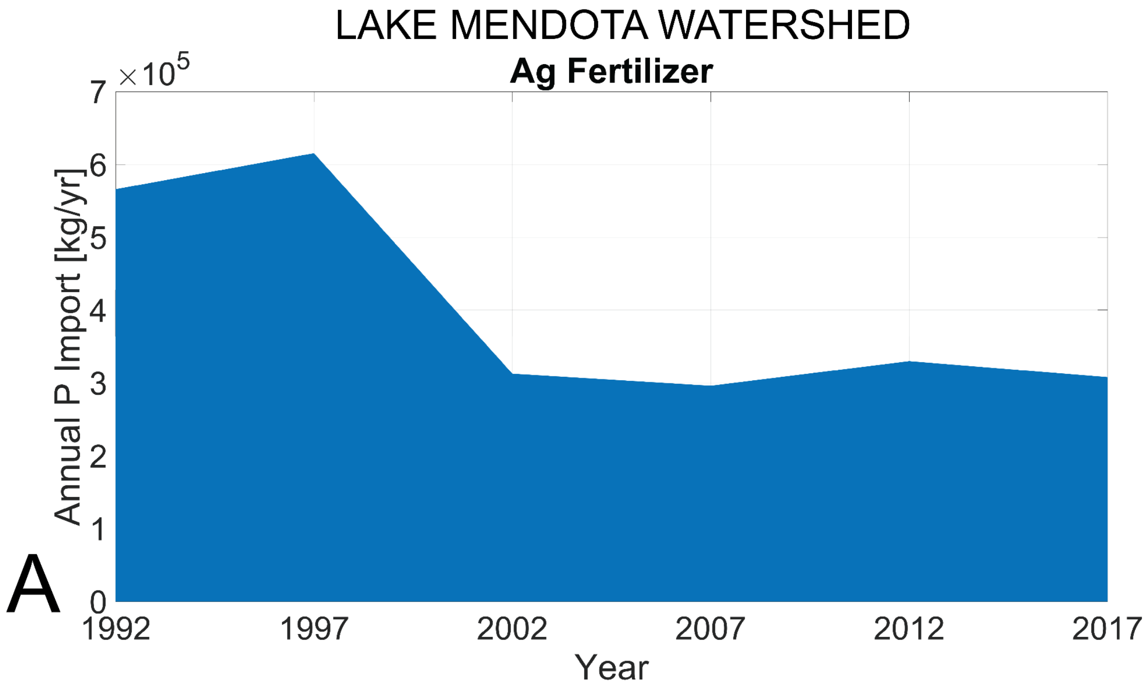
- More crop/feed is grown than what livestock demands for all years
- Increases through time as feed P declines from 1997 to 2002 and crop yields increase

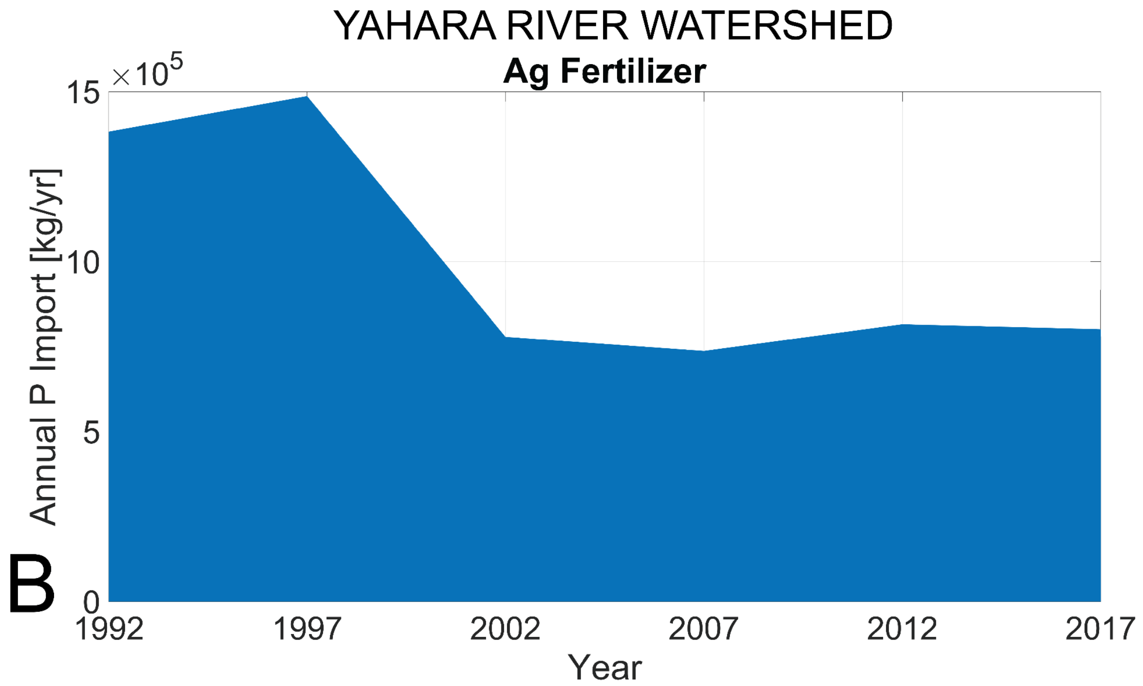


Net Crop Export = Crop Harvest – Feed Demand

Agricultural Fertilizer

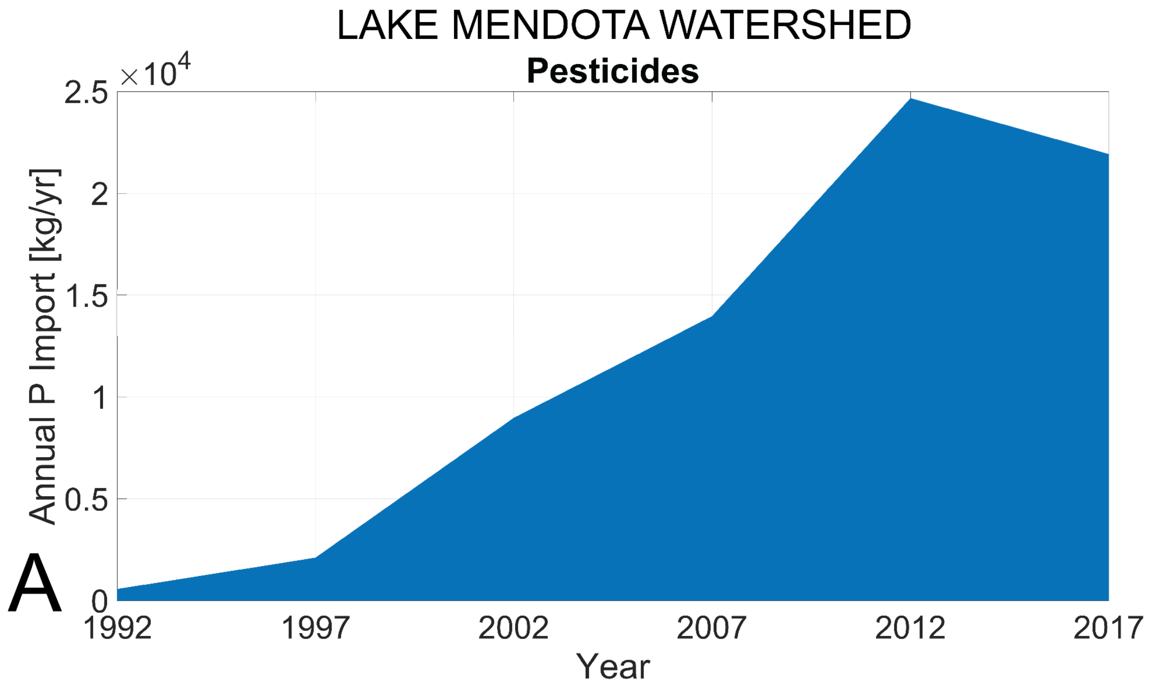
- Declines from 1992 to 2002 part of larger state- and national-level decrease in P fertilizer use
- No changes since 2002

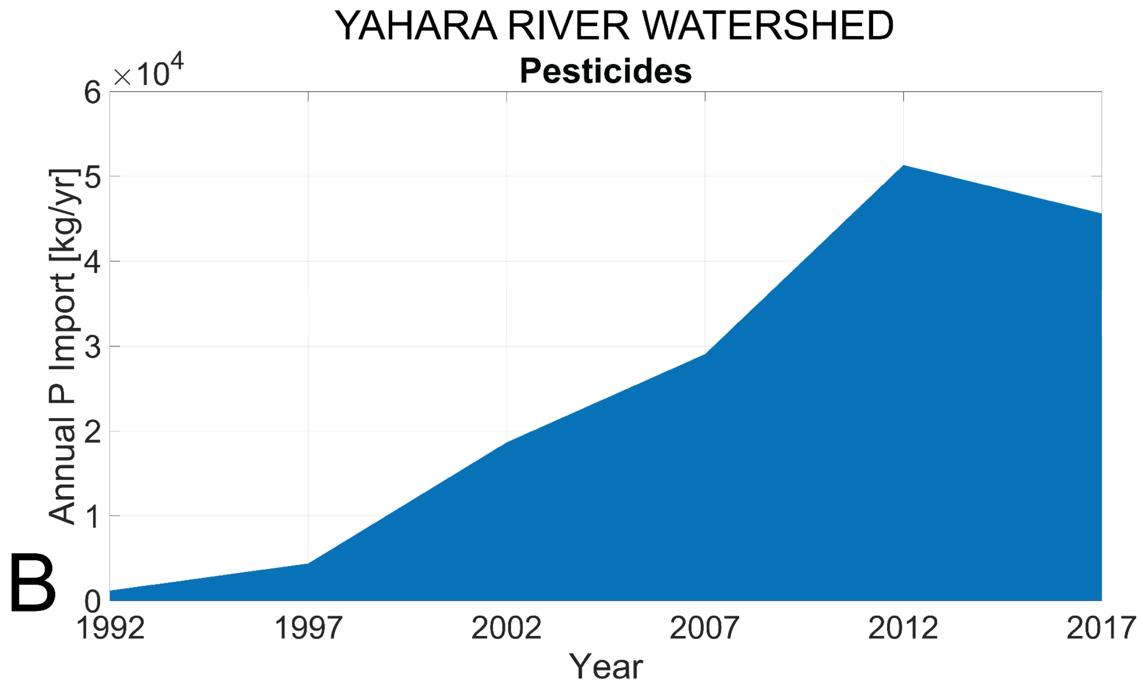




Agricultural Pesticides

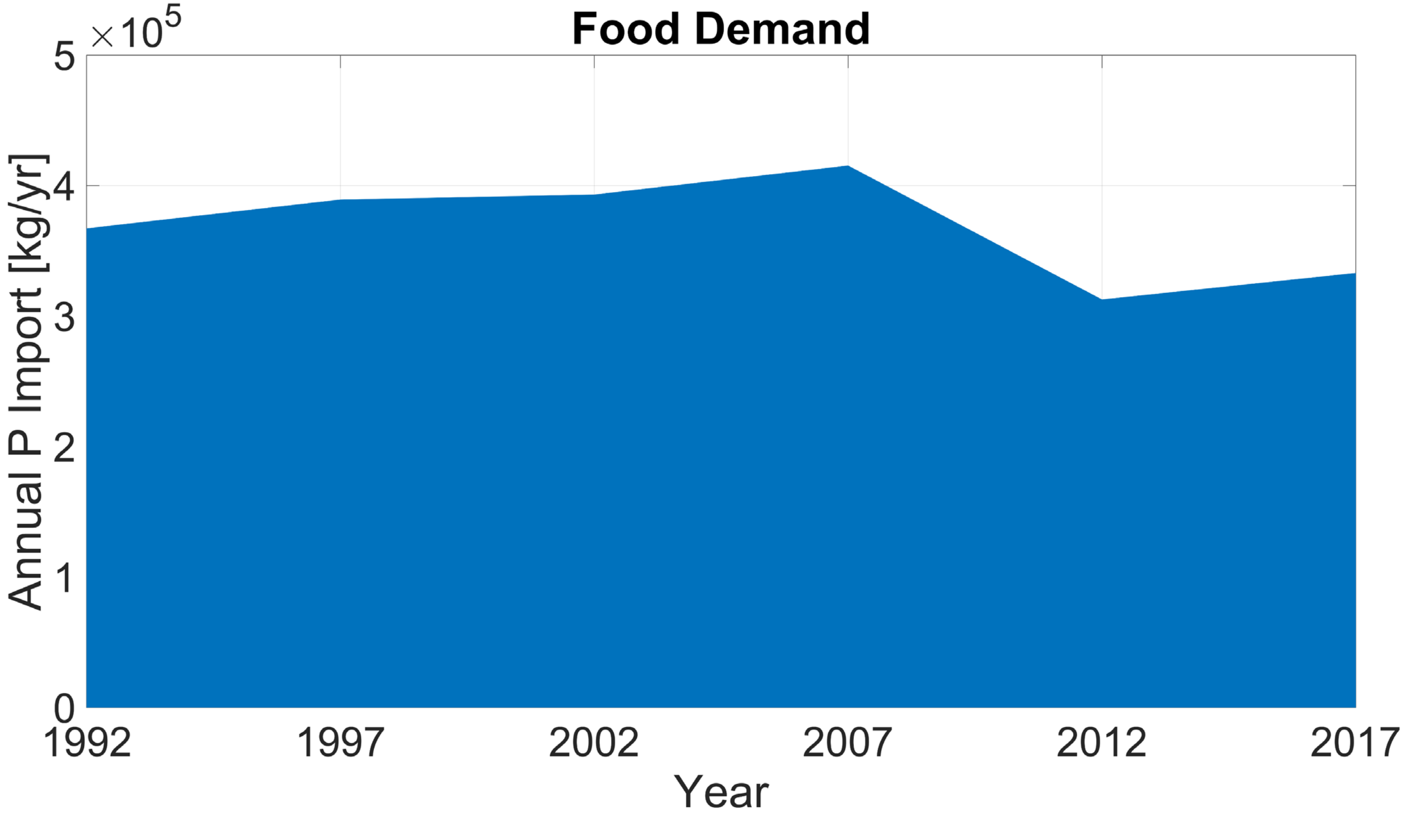
- Increasing application rate of Glyphosate with resistance genetics





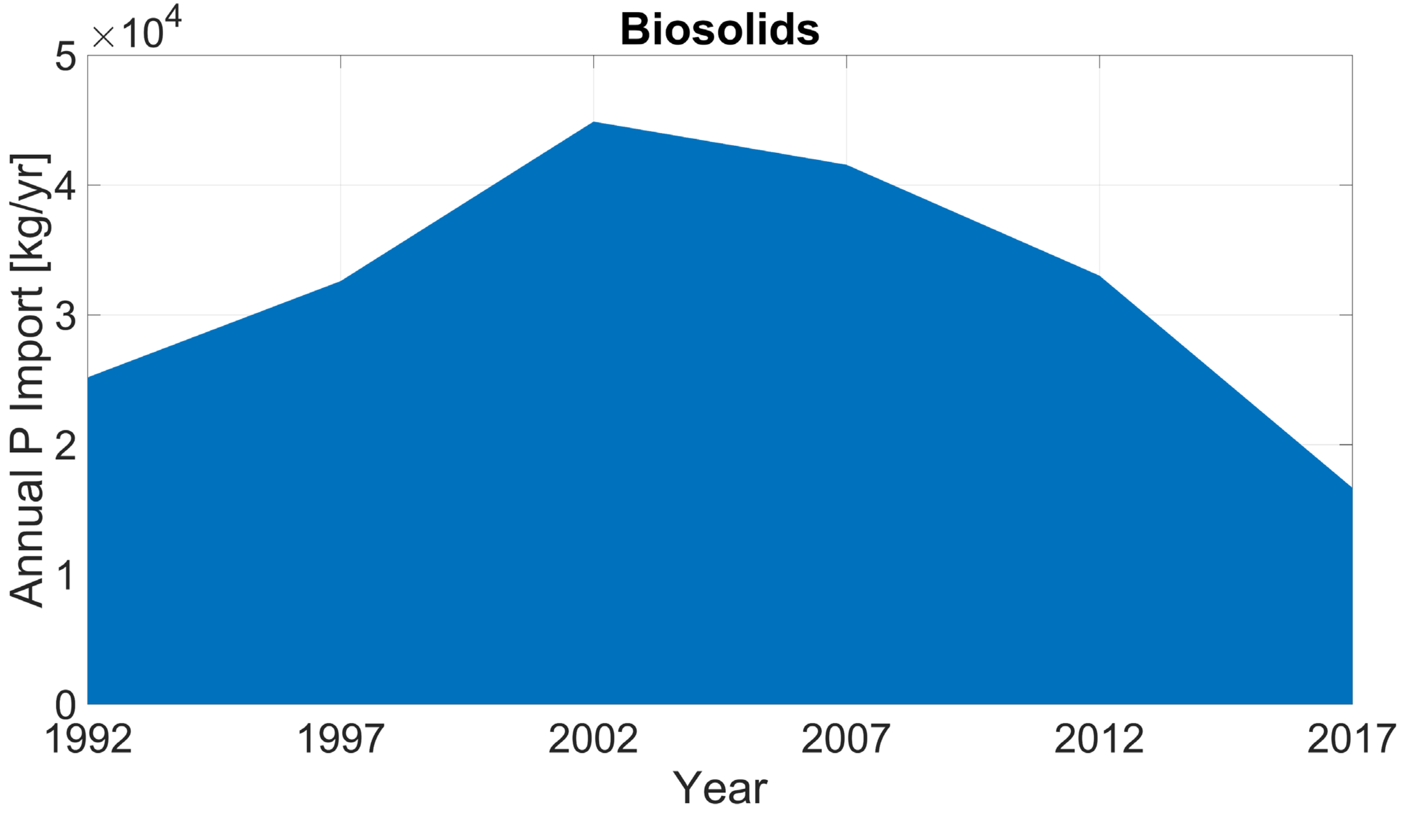
Yahara River Watershed – Food/Household Demand

- Increases with population from 1992 to 2007
- Declines from 2007 to 2012 due to reduction in household detergent P concentration



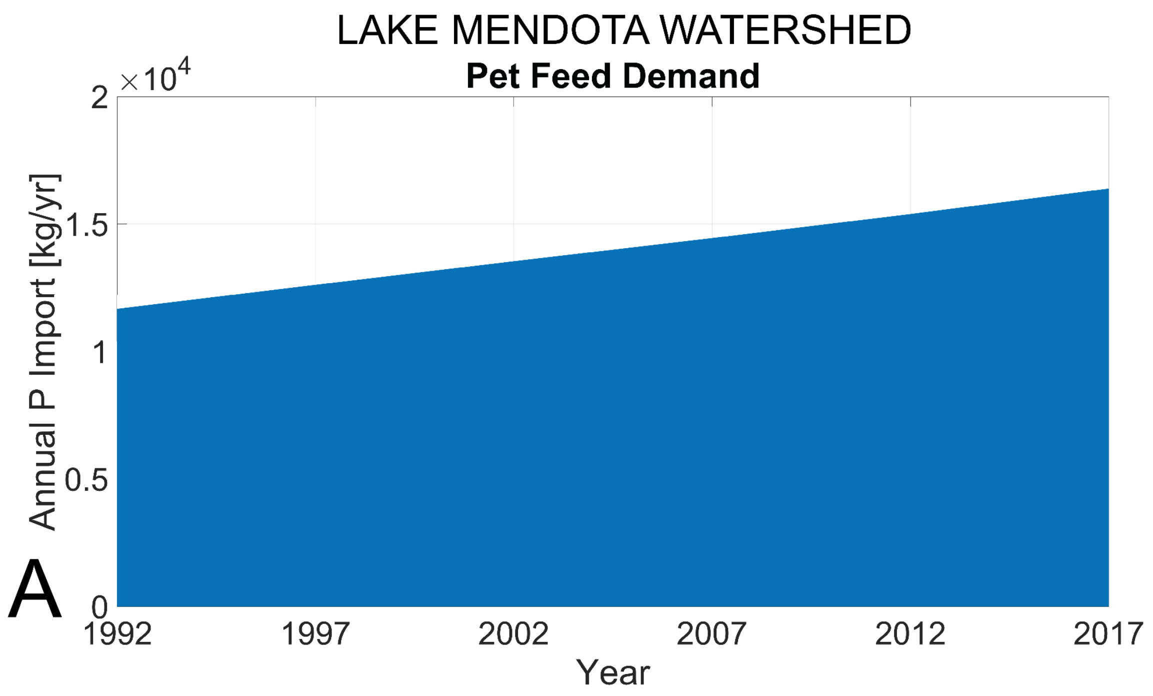
Lake Mendota Watershed – Biosolids

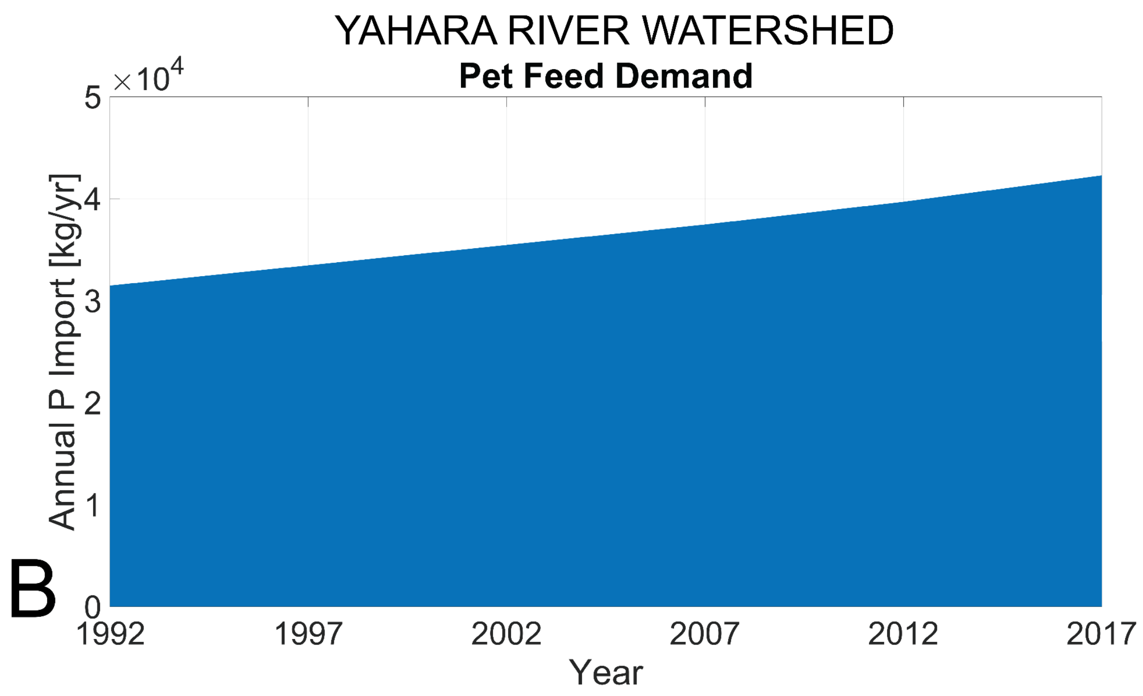
- Enhanced P treatment (biological P removal) early in period leads to more Biosolids P
- Decline after 2002 from reduction in influent P, addition of struvite harvesting, and reduction of spreading in Mendota watershed



Pet Feed Demand

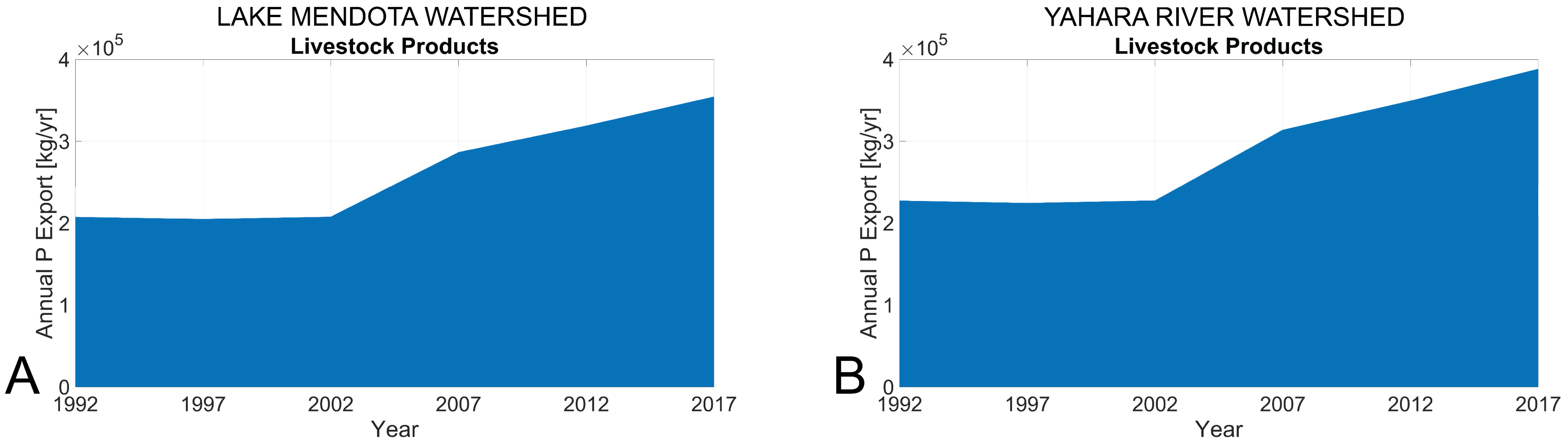
- Similar in magnitude to biosolids P and atmospheric P deposition
- Increases with human population





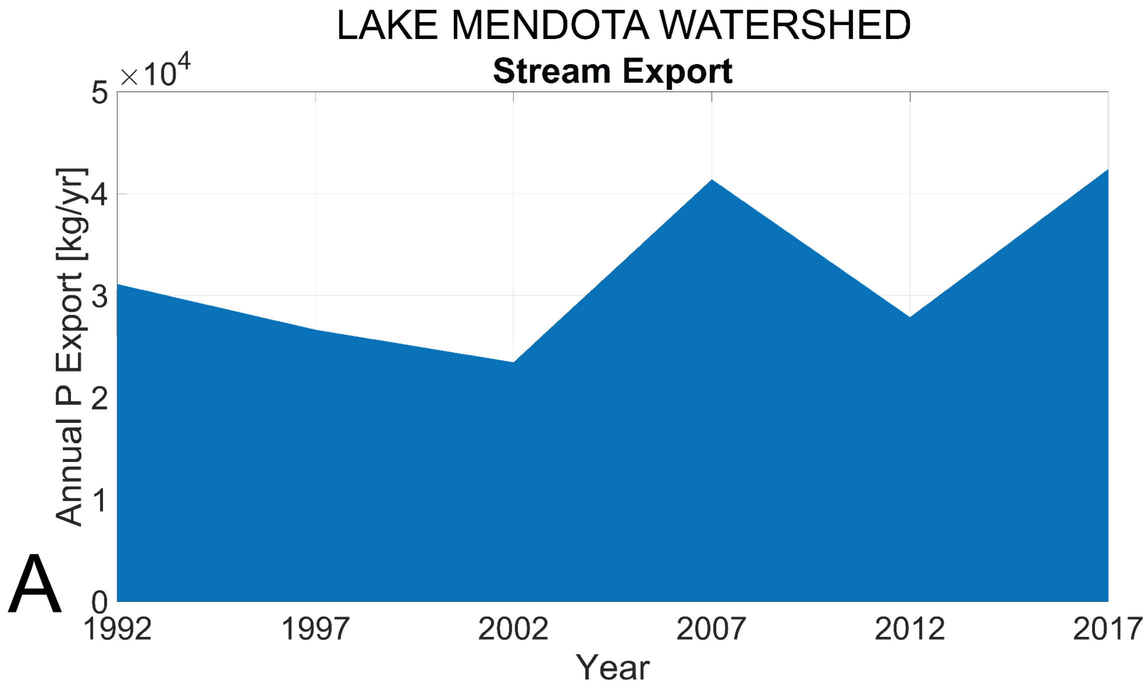
Livestock Products

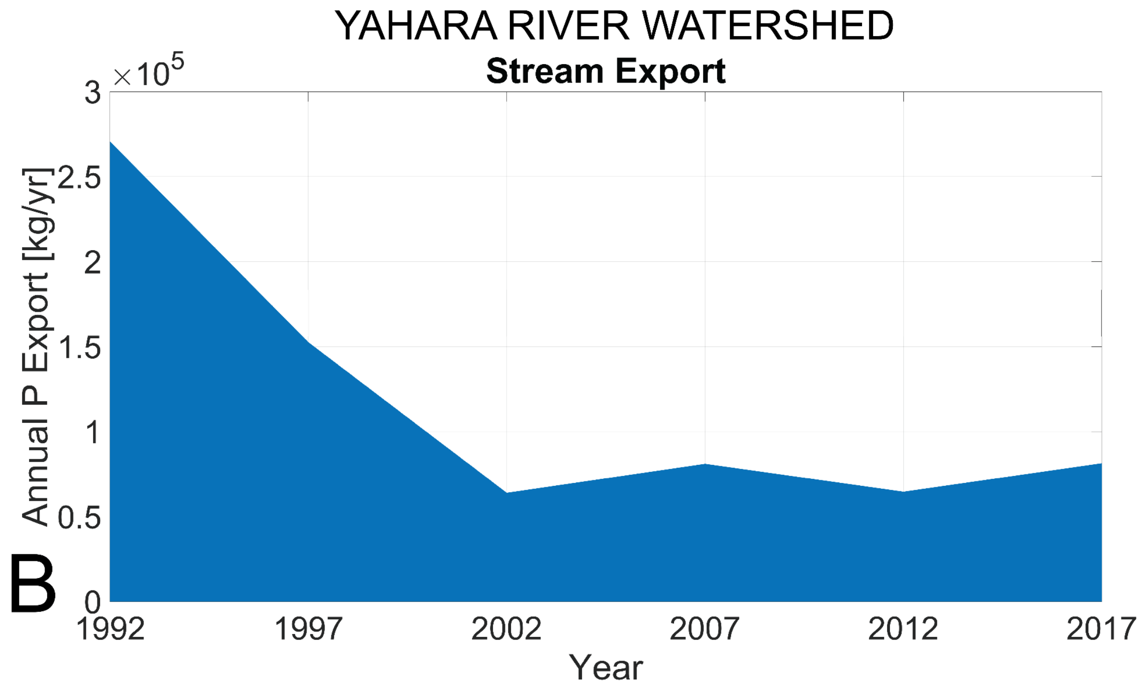
- Increase after 2002 driven primarily by increases in milk production



Stream Exports

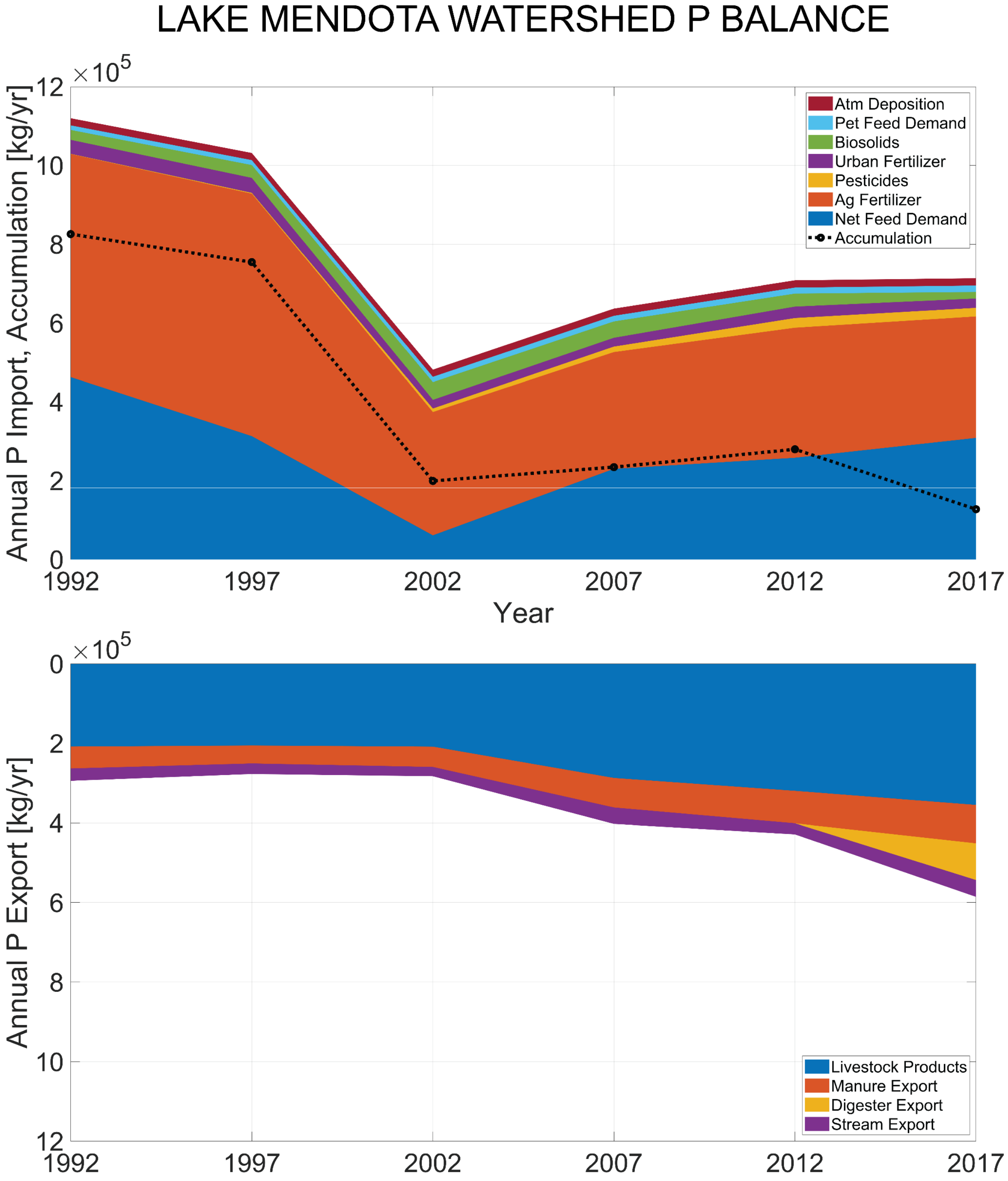
- No substantial trend in Lake Mendota tributaries
- Large decline in Yahara River from 1992 to 2002 due to treatment improvements (biological P removal)





Lake Mendota Watershed

- Agricultural fertilizer, net feed demand, and livestock products are dominant
- Accumulation rate always positive
- Accumulation rate declines sharply from 1992 to 2002 due to drops in fertilizer and mineral P feed supplements
- No major change from 2002 to 2012
- Digester export makes noticeable impact in 2017



Yahara River Watershed

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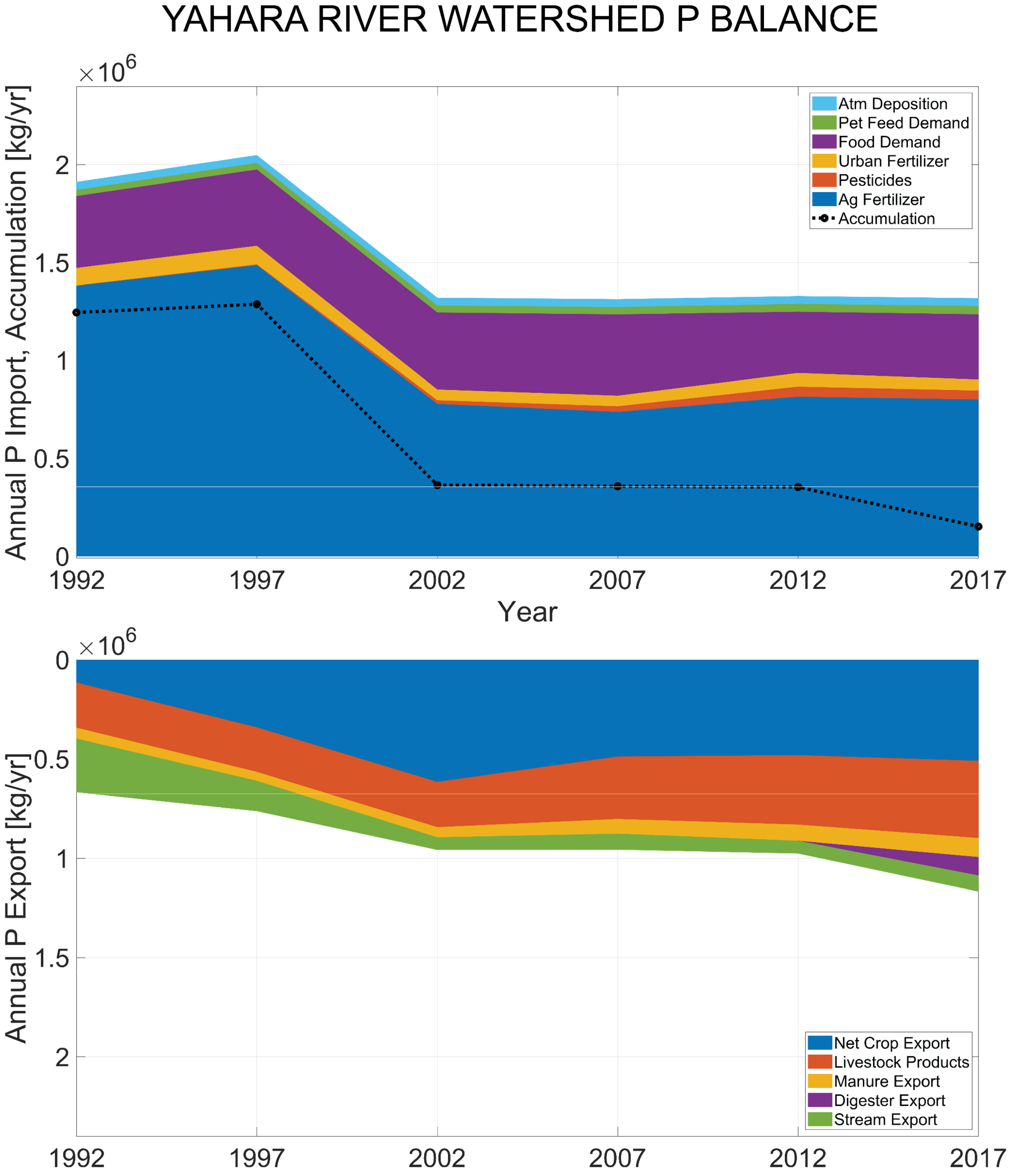
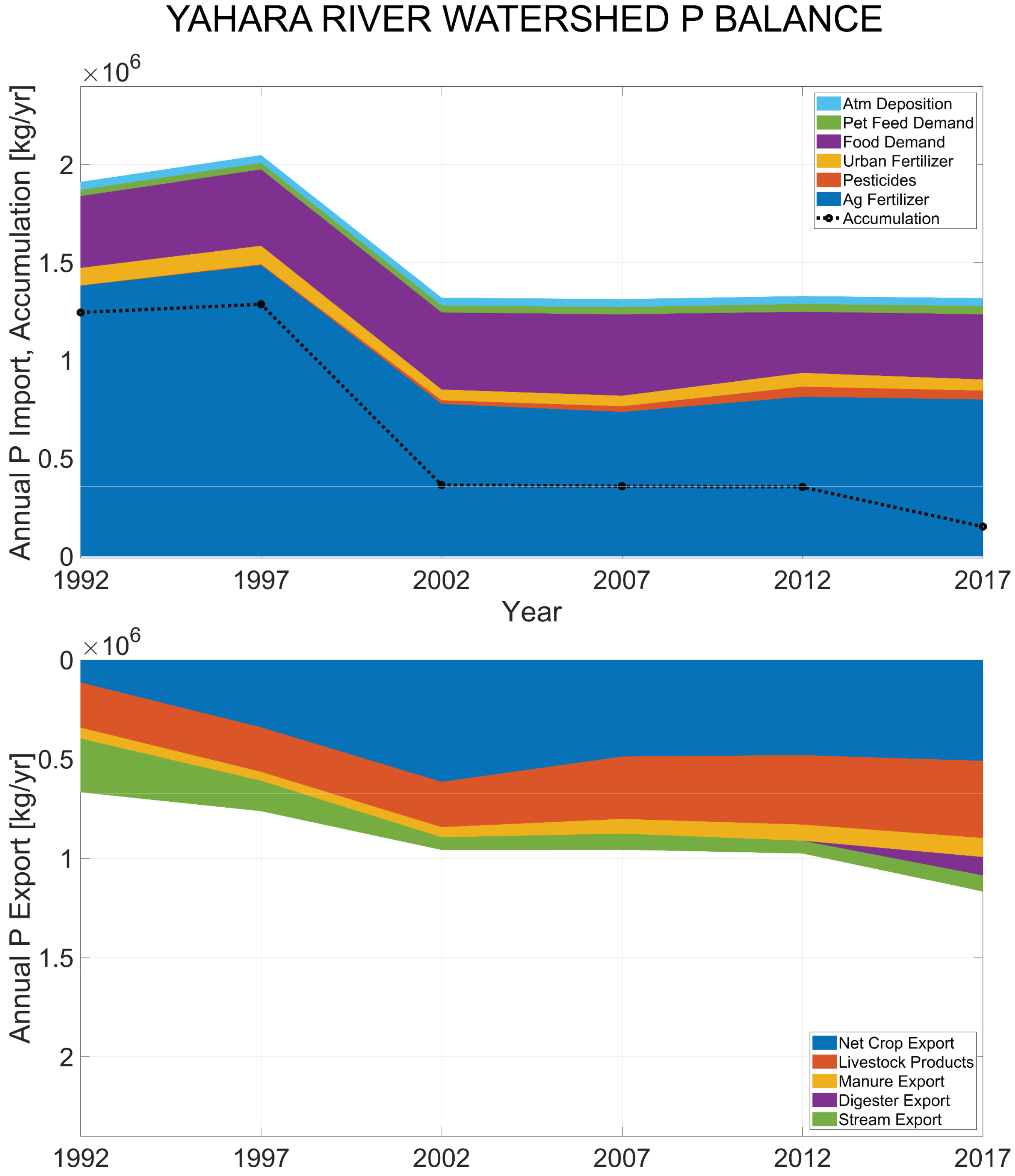


Yahara River Watershed

- Comparison
  - <u>Human waste P</u> = 320 Mg/year
    - 19 Mg/year to streams as effluent
  - <u>Dog waste P</u> = 80 Mg/year
    - 42 Mg/year uncollected
  - <u>Livestock manure P</u> = 1000 Mg/year
    - 91% in Mendota watershed
    - 19% exported
  - <u>Ag fertilizer P</u> = 800 Mg/year
    - 38% in Mendota watershed



Conclusions

- Both watershed P mass balances show substantial improvement in reducing accumulation rate from 1992 to 2017
- Room for improvement
- Managing accumulated P from earlier in the record is ongoing
- New livestock inventory highlights manure management challenge
  - While soil P accumulation is declining, we still have a lot of manure applied and at-risk of transport in the same season

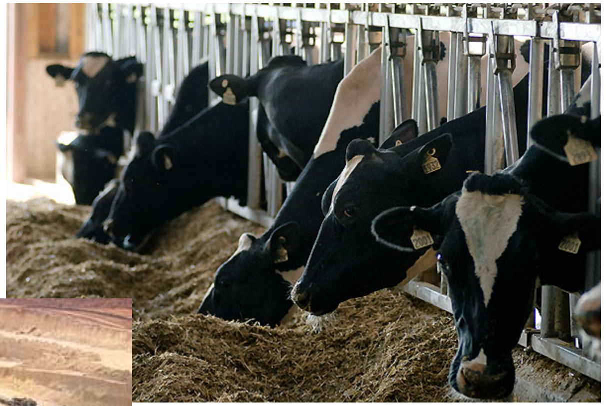
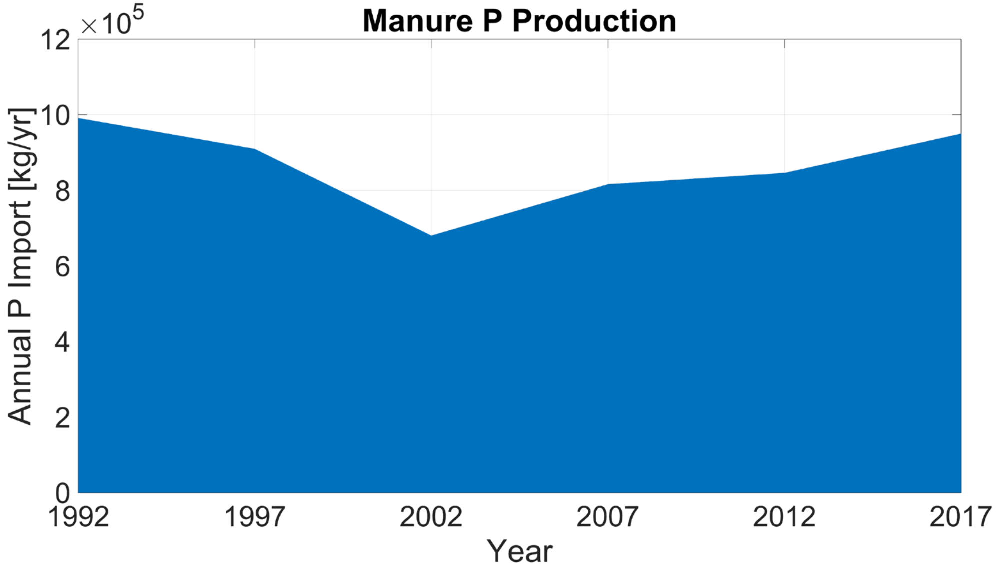


Image: IGBP



Working towards more perennial cover

- Transport and supply-based strategy

grassLAND 2.0

grasslandag.org

Take Home Points

- Watershed P Mass Balance valuable as another assessment tool in toolbox tracking changes in long-term P runoff risk
- Progress has been made in bringing down P accumulation…but P transport risk (legacy P and manure P) is still relatively high
- Urban and rural are connected through P flows…and need to be more connected through P recycling

Acknowledgements

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Report available here:
https://lwrd.countyofdane.com/plans-studies-reports

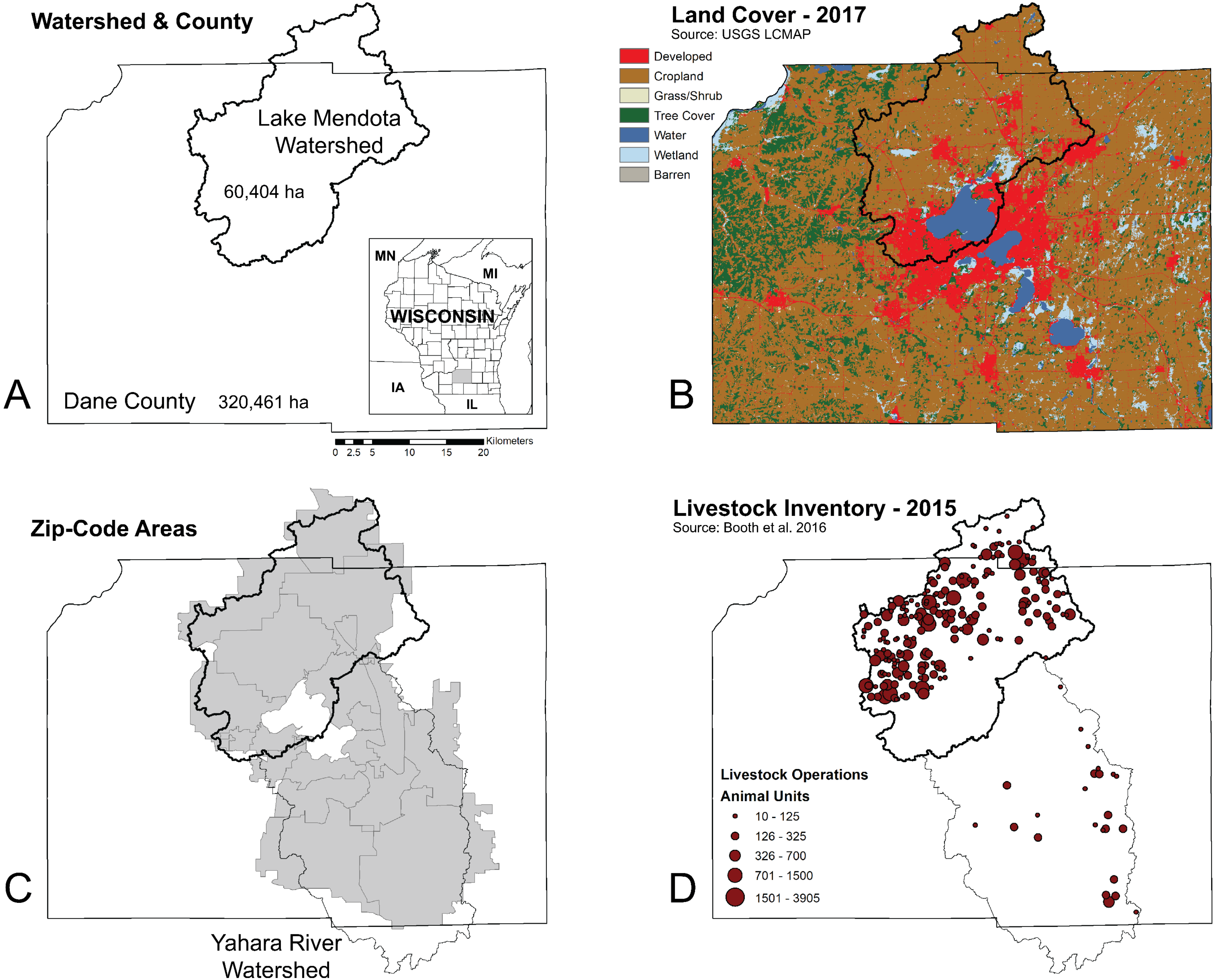
Contact:

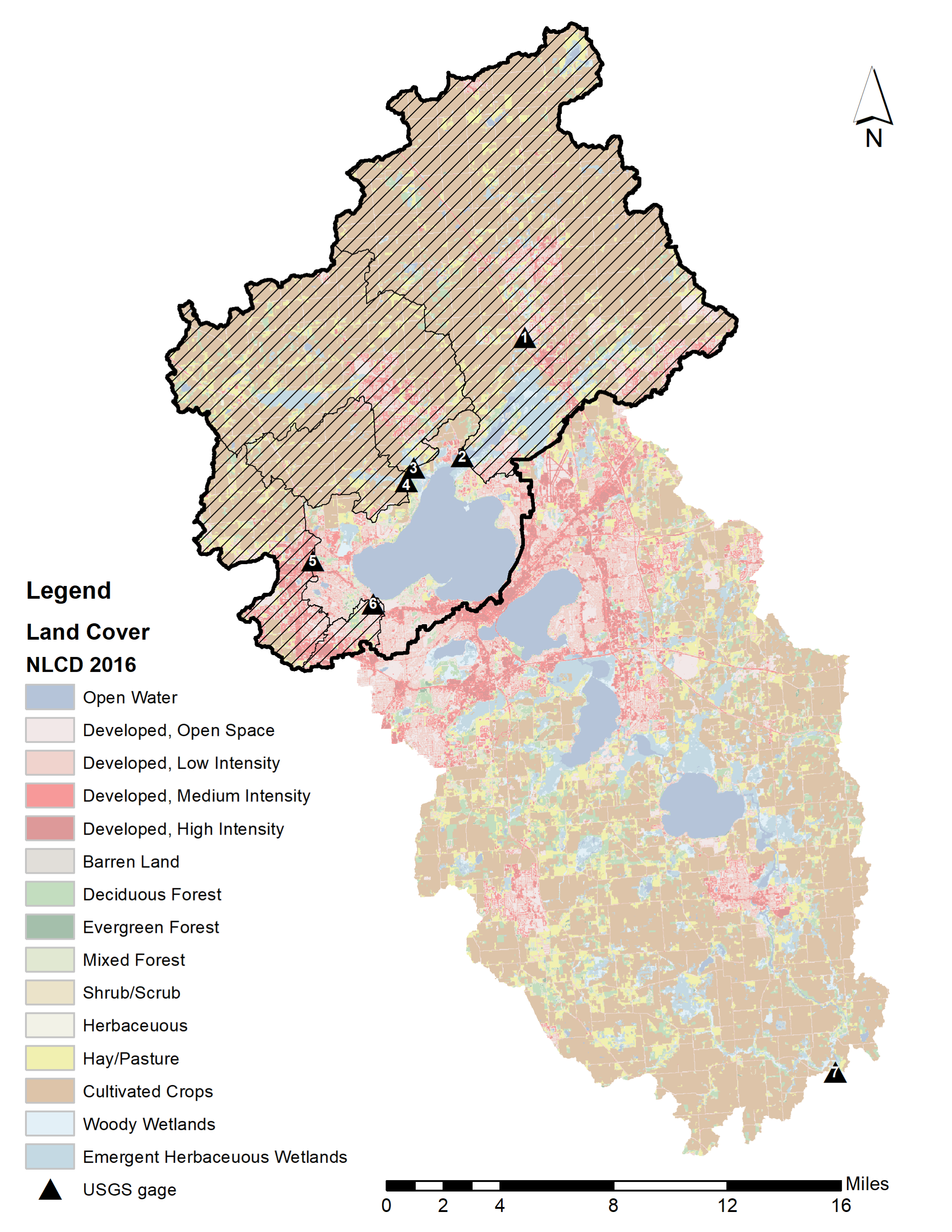
Eric Booth

egbooth@wisc.edu

GHG emissions analogy

- We are *almost* at the "net-zero" point BUT…
- We will be dealing with the legacy of P that has been building up in our "atmosphere" for decades to come
- Also this analogy breaks down when looking at annual risk…
  - It's not just the legacy P that is driving water quality outcomes in a given year
  - Acute losses of manure can play a strong role


Watershed & County
Lake Mendota Watershed
60,404 ha
MN
MI
WISCONSIN
IA
IL
A
Dane County
320,461 ha
Kilometers
0 2.5 5 10 15 20
Land Cover - 2017
Source: USGS LCMAP
Developed
Cropland
Grass/Shrub
Tree Cover
Water
Wetland
Barren
B
Zip-Code Areas
C
Yahara River Watershed
Livestock Inventory - 2015
Source: Booth et al. 2016
Livestock Operations
Animal Units
10 - 125
126 - 325
326 - 700
701 - 1500
1501 - 3905
D


N
Legend
Land Cover
NLCD 2016
Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Herbaceuous
Hay/Pasture
Cultivated Crops
Woody Wetlands
Emergent Herbaceuous Wetlands
USGS gage
Miles
0 2 4 8 12 16
1
2
3
4
5
6
7

Global P Cycle

D. Cordell et al. / Global Environmental Change 19 (2009) 292–305