Legacy P

Dr. Kevin Fermanich
and
Dr. Mathew Dornbush
University of Wisconsin-Green Bay

UNIVERSITY of WISCONSIN
GREEN BAY

19th Annual Fox-Wolf Watershed Alliance Conference

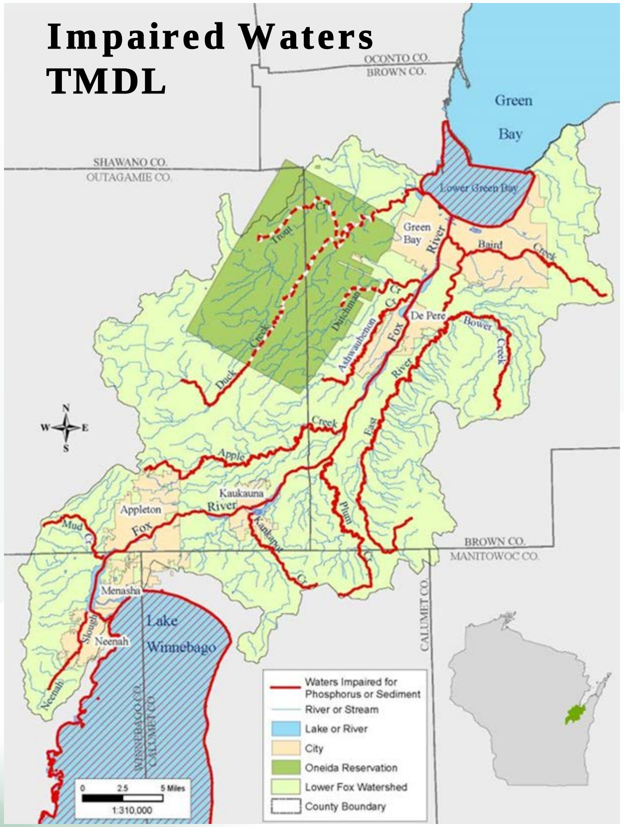
Outline

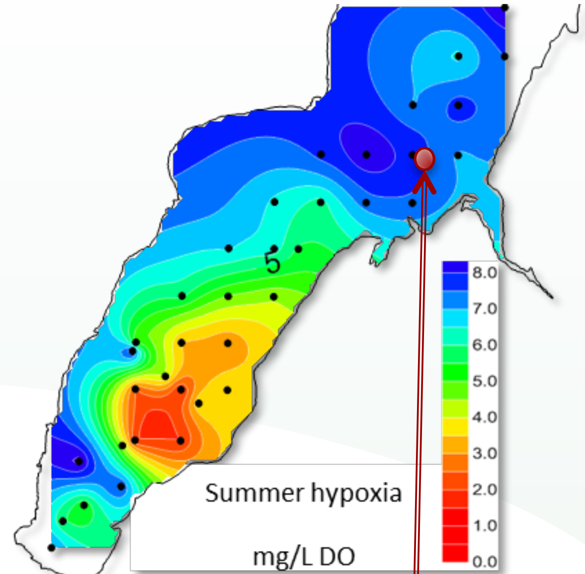
- The Challenge
- Definitions and what really matters
- Implications?
- Paths forward?
- Conclusions

UNIVERSITY of WISCONSIN
GREEN BAY

Tributaries, Fox River, Bay suffer from Eutrophication, Hypoxia, Habitat Degradation

- Phosphorus (P) key driver

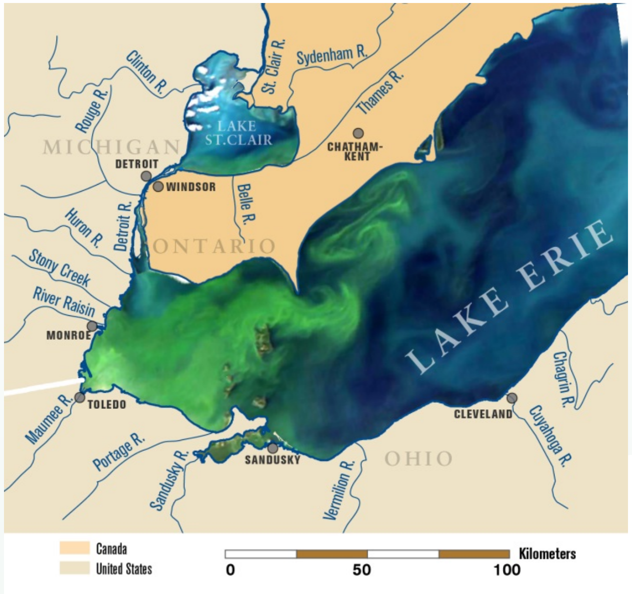




August 29, 2013

UNIVERSITY of WISCONSIN
GREEN BAY

Similar Issues throughout the Great Lakes



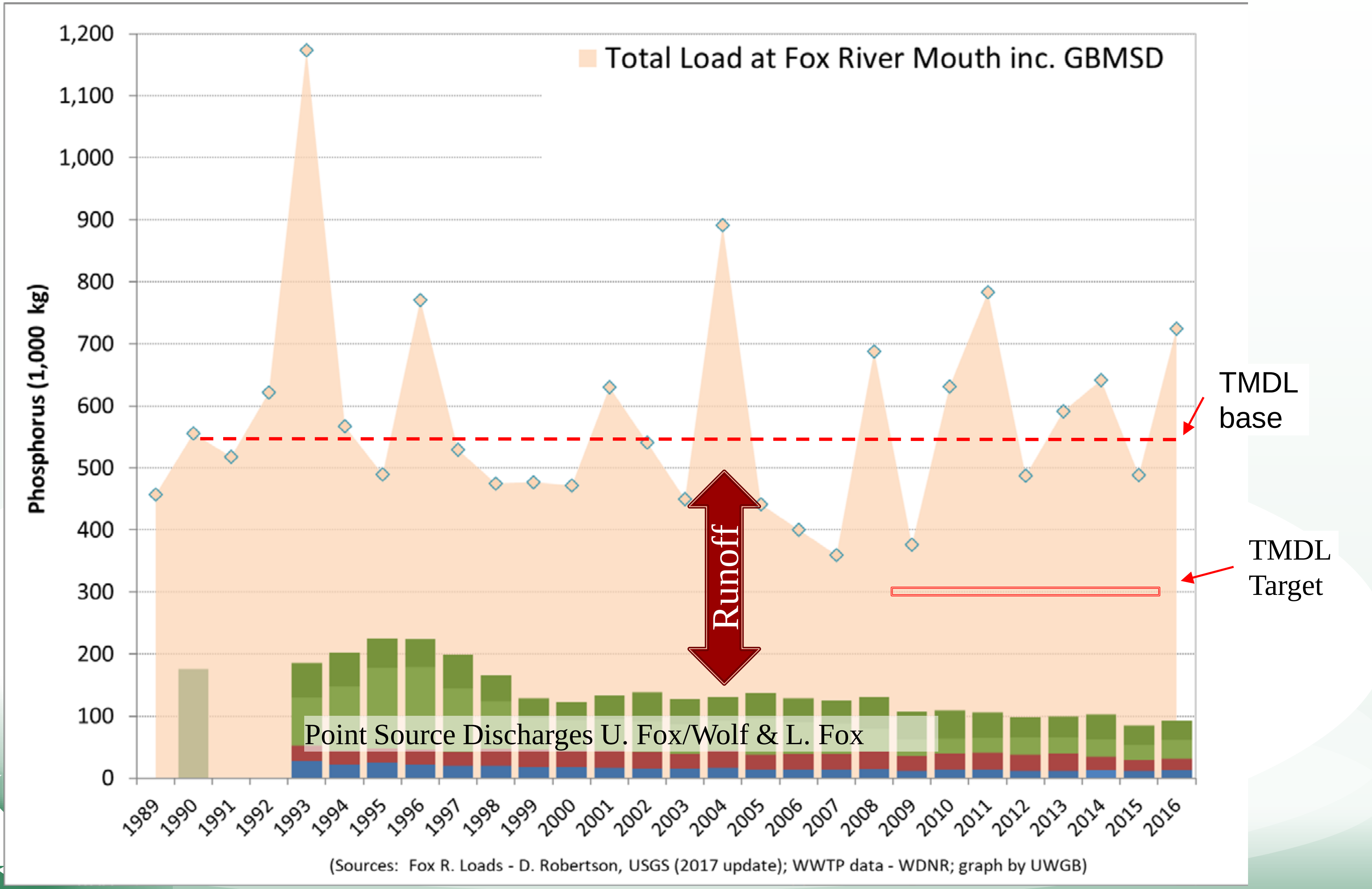
Satellite image from September 3, 2011, Map by Michigan Sea Grant.

Saginaw Bay Photo Credit: NASA EO

Photo of sediment plume at mouth of Fox River in April 2011.

University of Wisconsin
Green Bay

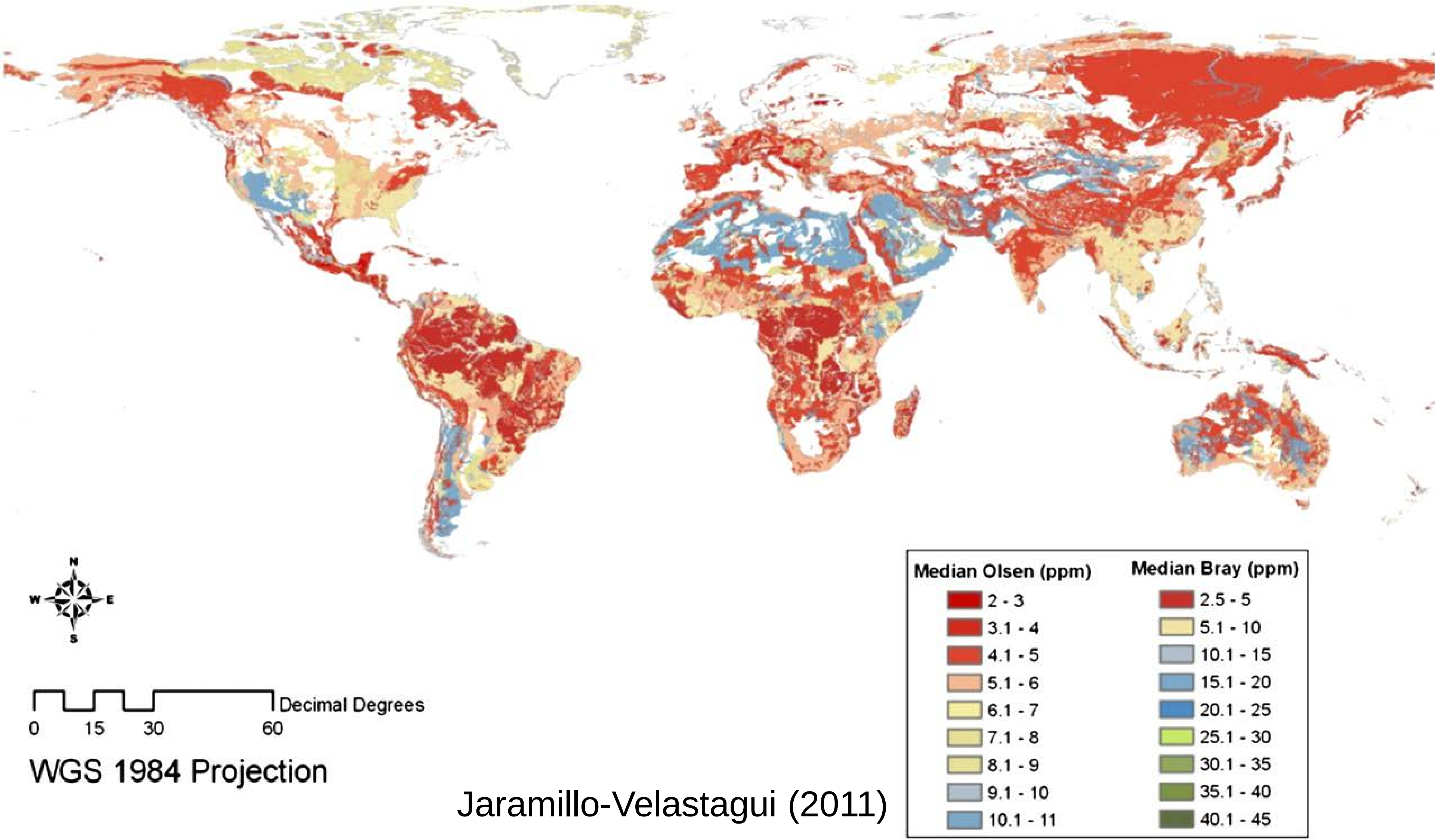
Annual Fox River Total P Export to Green Bay
>50% from Lake Winnebago (Upper Fox-Wolf Rivers)



UNIVERSITY of WISCONSIN
GREEN BAY

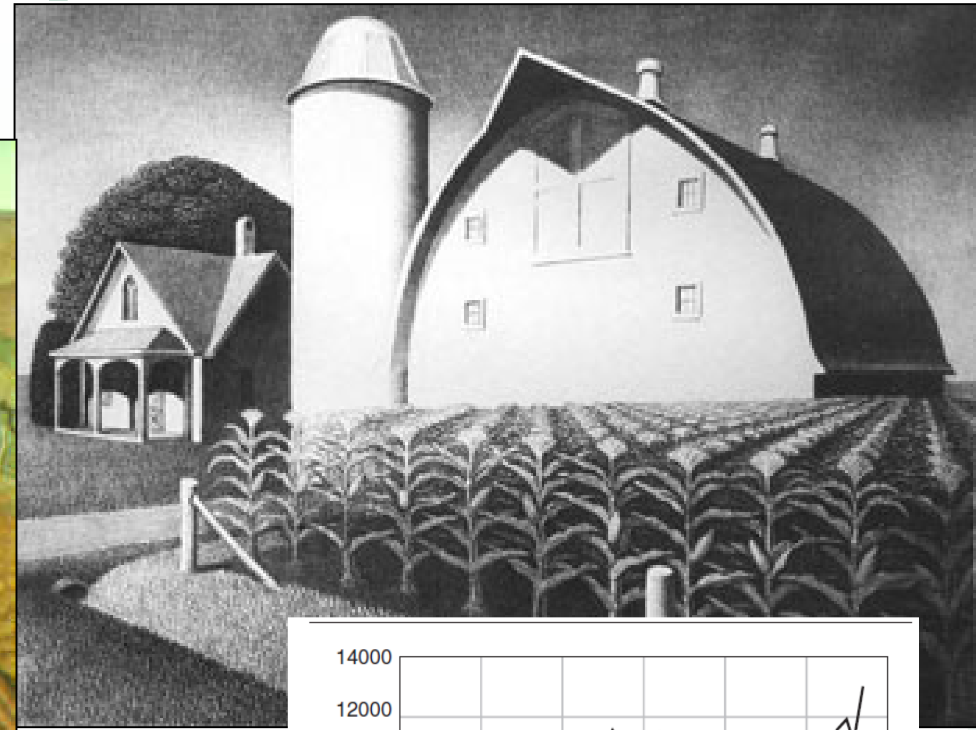
(Data Sources: Fox R. Loads: D. Robertson, USGS; WWTP Discharge data: WDNR; graph by UWGB; draft, updated 7/2017)

Global P availability does not reflect natural abundance



Jaramillo-Velastagui (2011)

Agriculture has changed since Grant Wood painted the Midwest - specialization



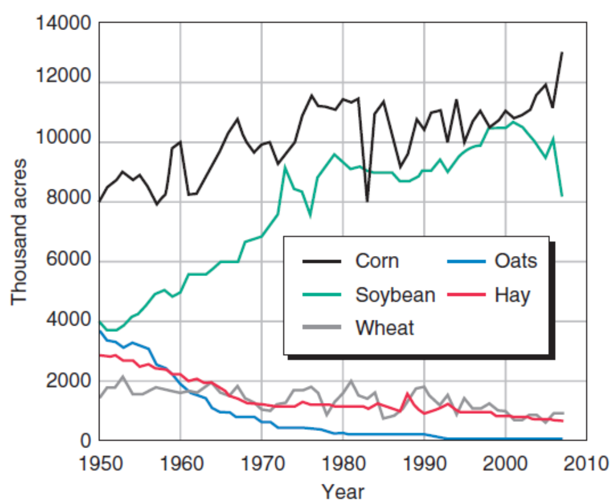
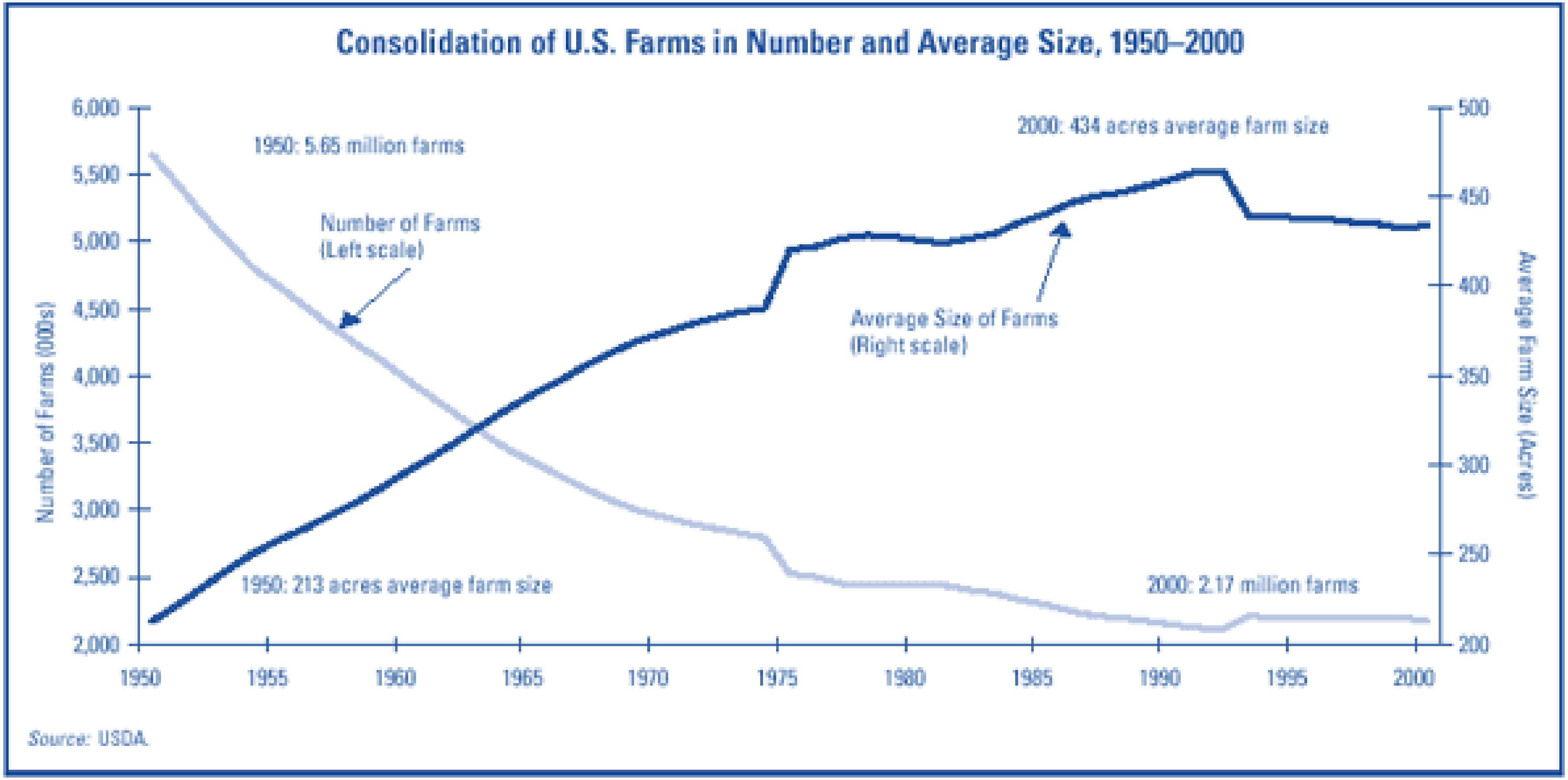


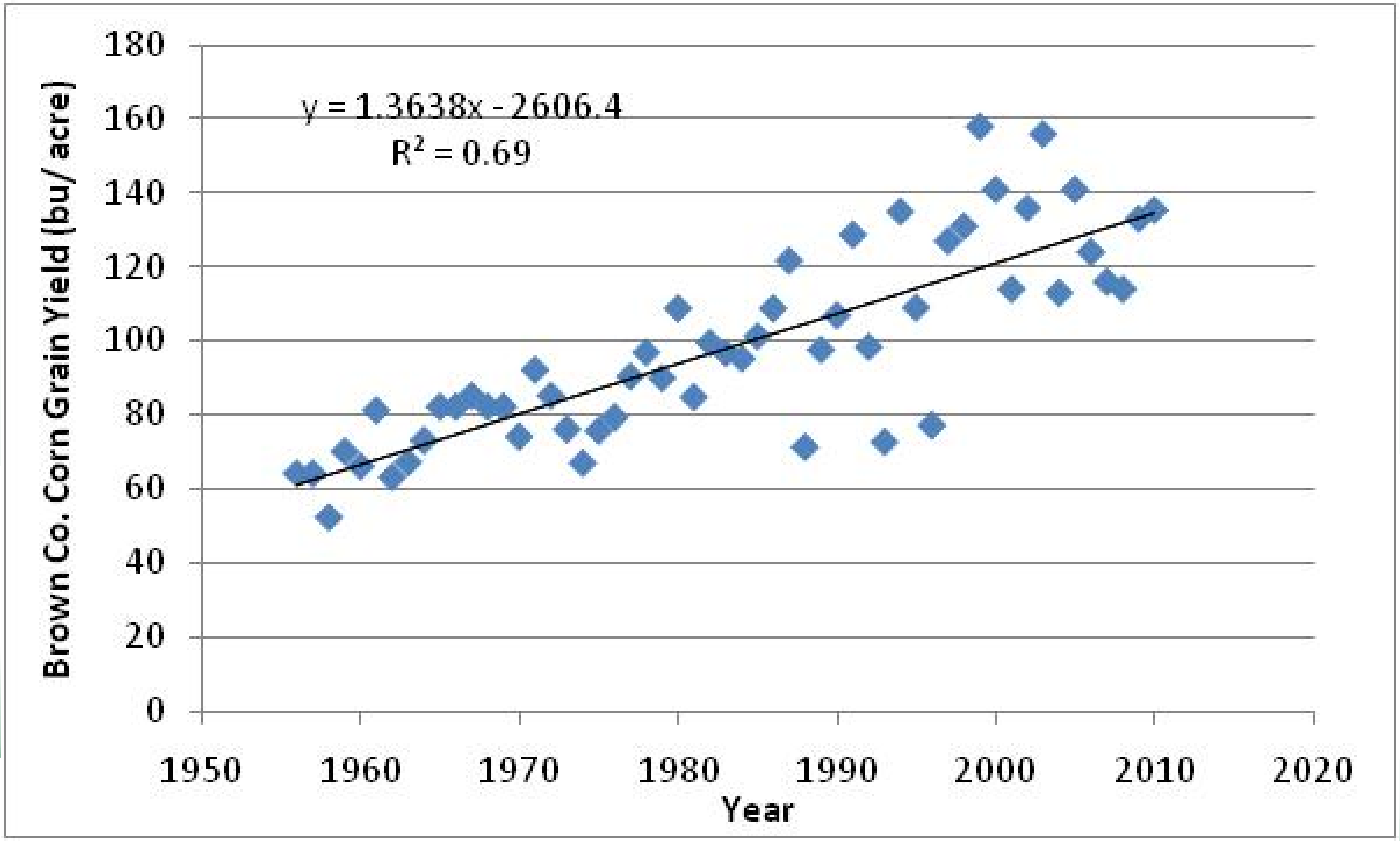
Figure 5.1. Crop acreage in Illinois, 1950 through 2007.
Source: National Agricultural Statistics Service.

Nafziger 2014

Agricultural Specialization



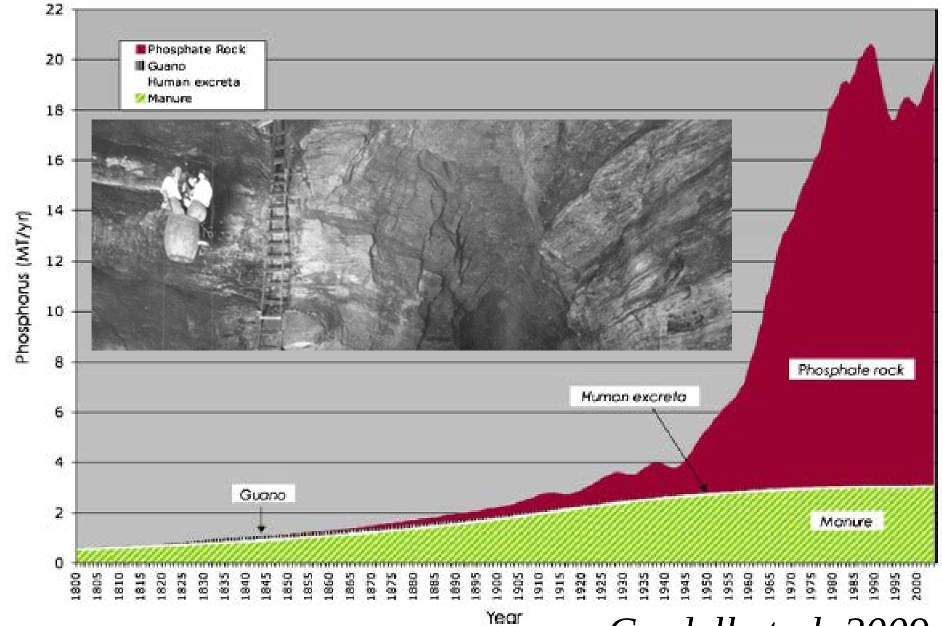
Changes in Crop Yields, Brown Co, WI



UNIVERSITY of WISCONSIN
GREEN BAY

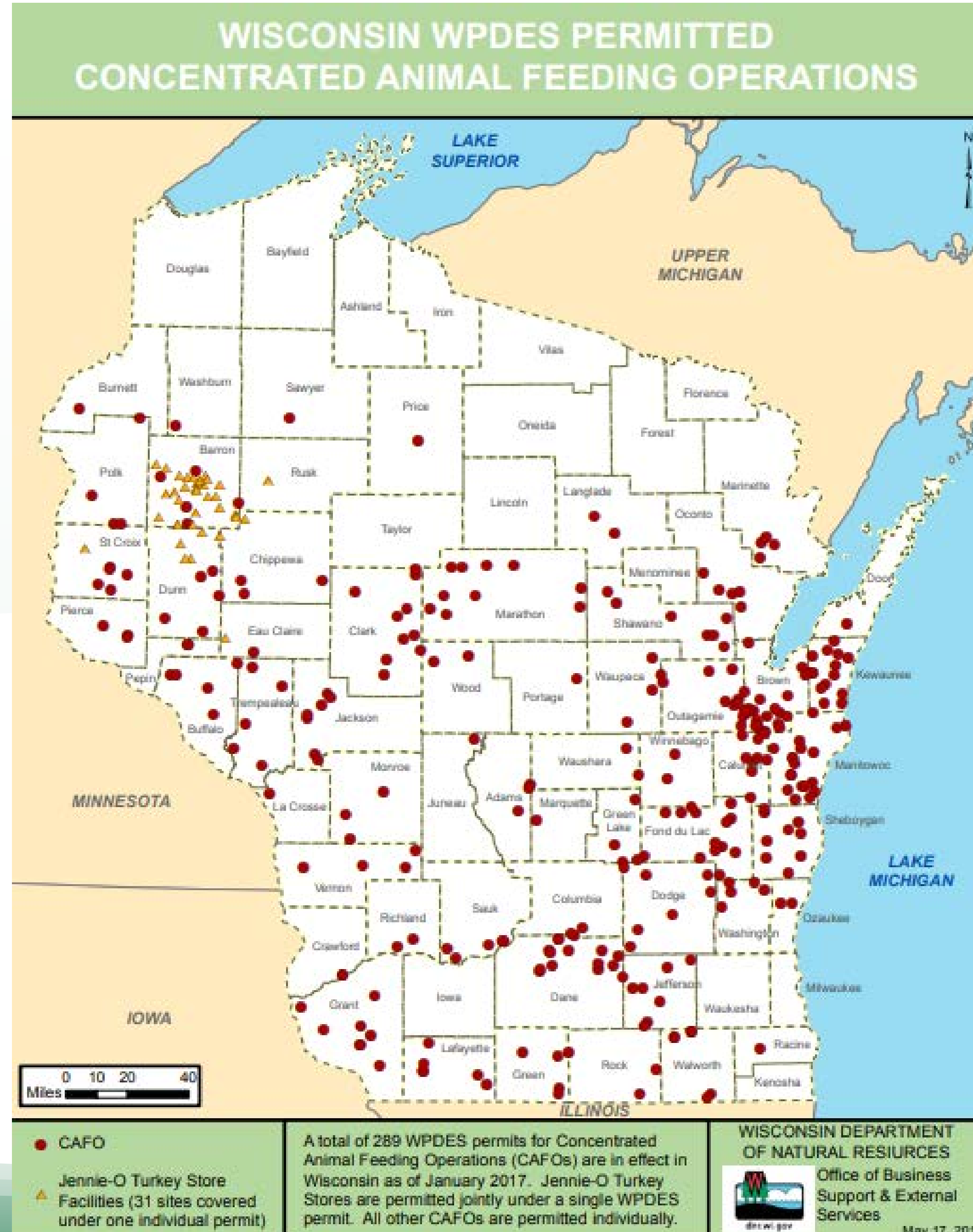
Anthropogenic P-inputs: Inorganic Fertilizers

- Increase correlates with green revolution (just like N) (Smil 2000): plants 0.2% P vs. 1.5% N
- Mined from sedimentary rocks (Florida and N. Carolina, Morocco, and W. Sahara, & China)
- Finite amount, thus may soon limit global food production (Cordell et al. 2009)
  - Globally, 50-100 years left (Cordell et al. 2009)?



Cordell et al. 2009

Dairy is a key player in the Green Bay Watershed



UNIVERSITY of WISCONSIN
GREEN BAY

Anthropogenic P-inputs: Animal Manures

Table 1. Properties of manures used in study.

Manure type	Solids	Total N	Total P	pH
	%	g kg^{-1} (dry weight basis)		
Dairy manure	16	30	6	8.0
Layer poultry manure	53	35	23	8.9
Swine Slurry	2	117	33	7.3
Broiler poultry litter, untreated	76	41	14	8.1
Broiler poultry litter, alum treated	75	44	12	7.6

Kleinman et al. 2002

- **1 hog produces manure equivalent to 3 people; 1 cow equal to 10 people**
- ***The Manure Paradox*:**
  - **Crops use N:P:K in a 3:1:2 ratio, but dairy manure is a 1:1:2 ratio (available)**
  - **Meet the crop's N need = excess P; meet the crop's P need = buy N fertilizer**

Natural P Sources

- P Inputs – all original inputs occur via weathering of rocks

  apatite = $Ca_5(PO_4)_3$
- Dust is a secondary input

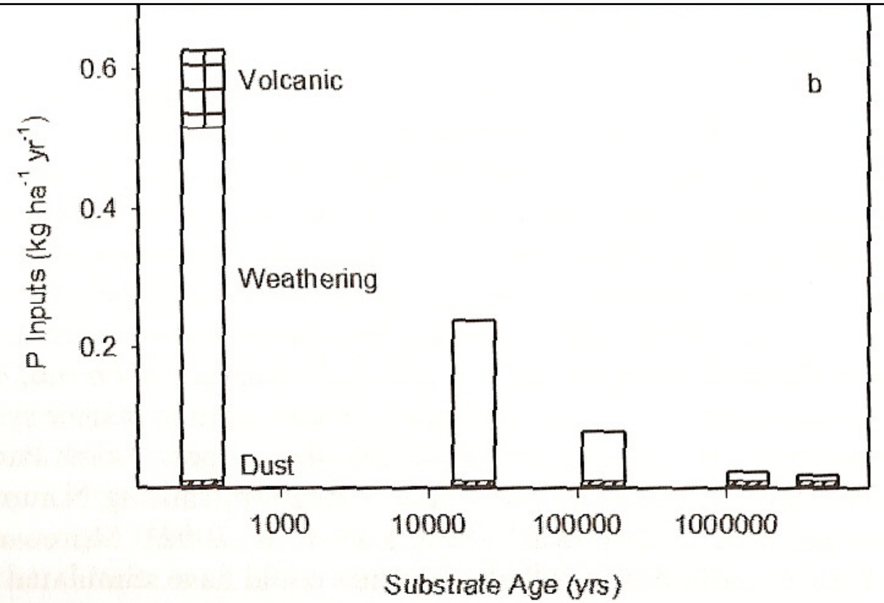


FIGURE 6.12. Inputs of N and P across the substrate age gradient, calculated as described in the text. (a) Atmospheric deposition is the dominant source of N along the gradient; biological N fixation contributes a relatively small quantity of N in all of the sites, and volcanically fixed N is a significant source in the youngest site. (b) Basalt weathering is the dominant source of P in young sites, with a small contribution from volatile volcanic sources in the youngest site, while continental dust contributes the majority of P received by the oldest site. Vitousek 2004

- **90% of P present in parent material is gone by 4.1 million years in Hawaii (Chadwick et al. 1999), most lost as DOP (Hedin et al. 2003)**

P cycling is tight, grain removal has been less than inputs, so P has accumulated in global soils

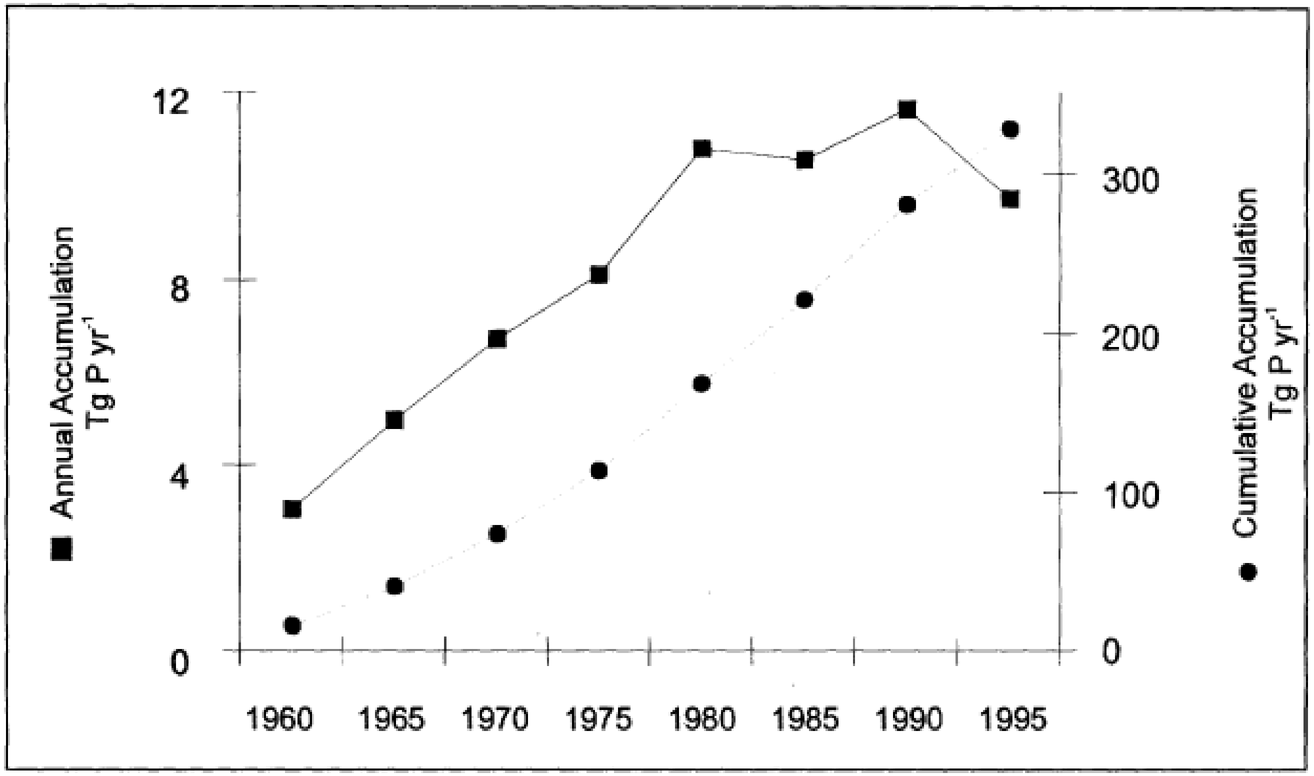
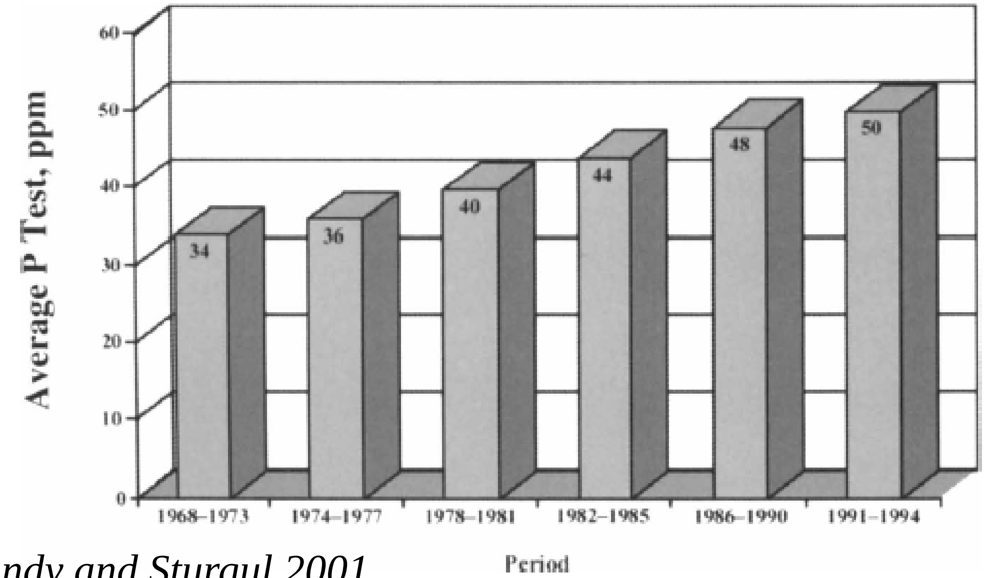


Figure 3. P accumulation in agricultural soils worldwide, 1958–1998, in Tg · yr^{-1}, as determined by global agricultural budget. Squares indicate annual P accumulation based on 5-year averages. Circles indicate cumulative P accumulation.

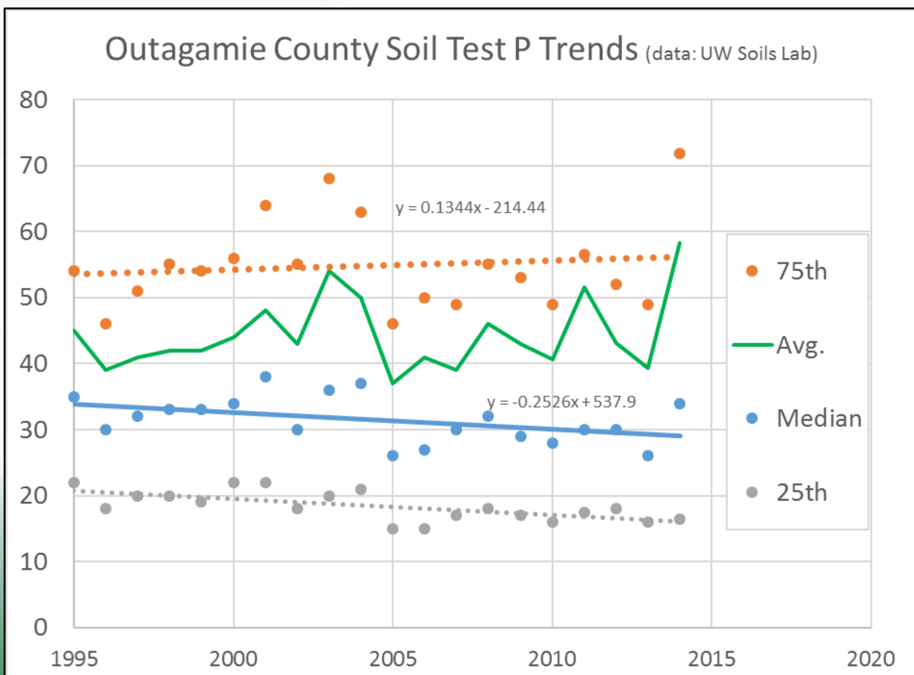
Bennett et al. 2001

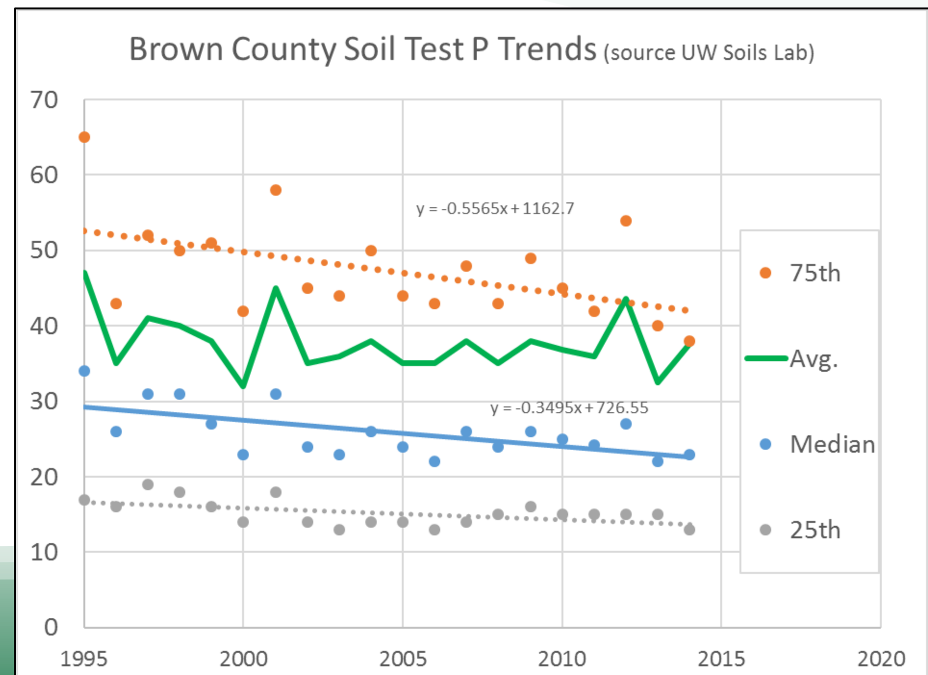
Similar Patterns in WI



Bundy and Sturgul 2001

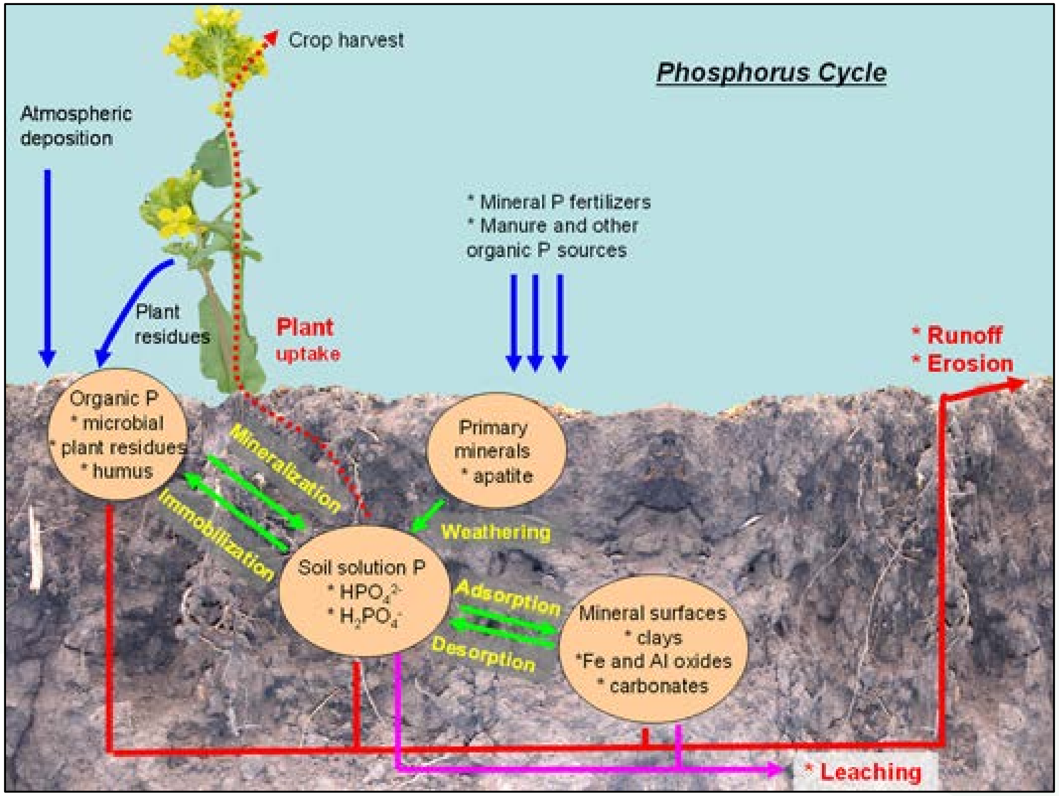
Figure 4. Average soil test phosphorus in samples analyzed by Wisconsin soil testing laboratories from 1968-1994.





Legacy P

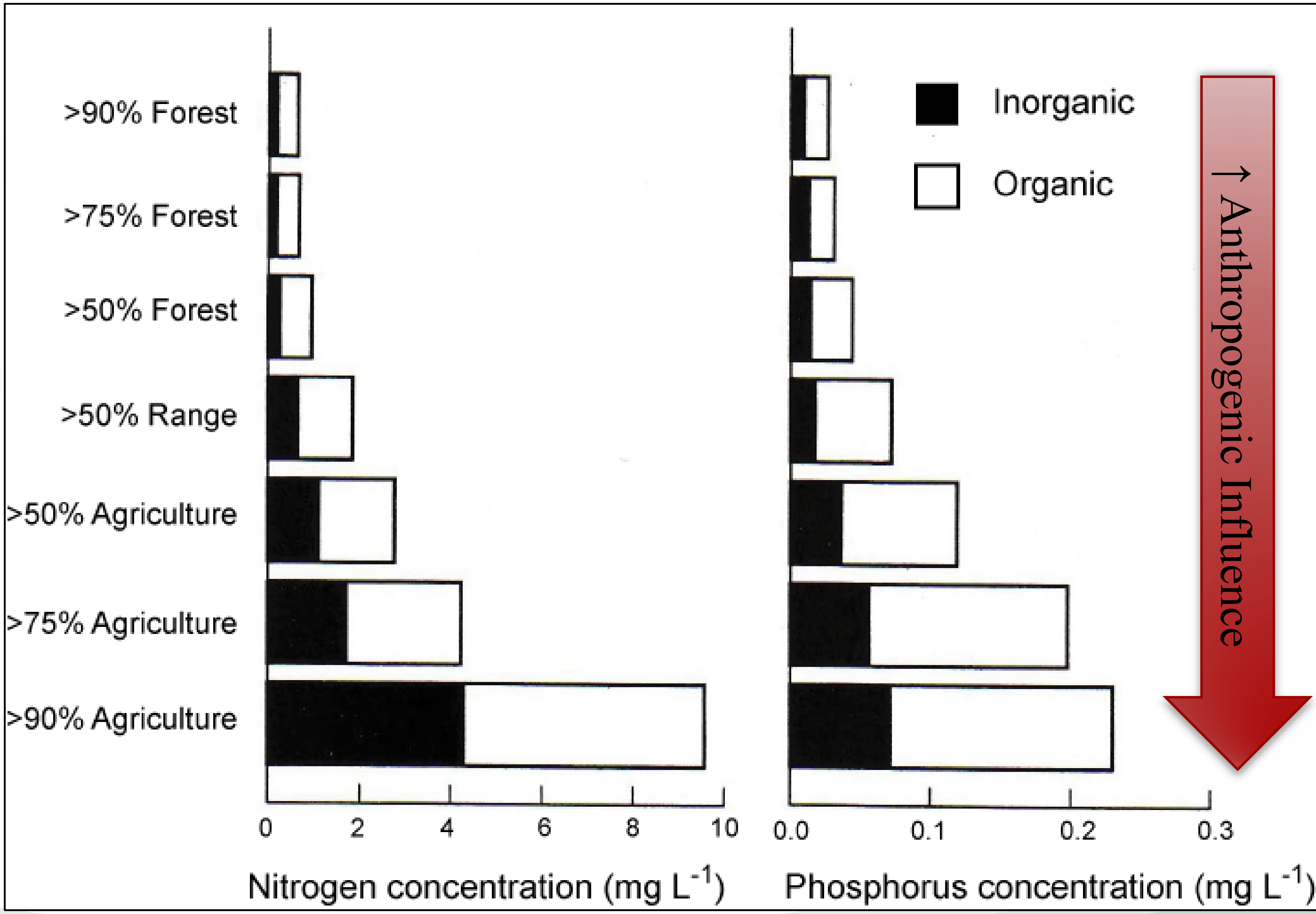
- Consider 3 factors:
  - **Pool**:
    - Soils and aquatic sediments
    - Plants and algae
  - **Form**:
    - Organic
    - Inorganic
      - Available
      - Unavailable
  - **Location**:
    - Depth
    - Landscape position



University of Wisconsin Green Bay

Only *Anthropogenic P* inputs and *Legacy P* pools are relevant for today's presentation

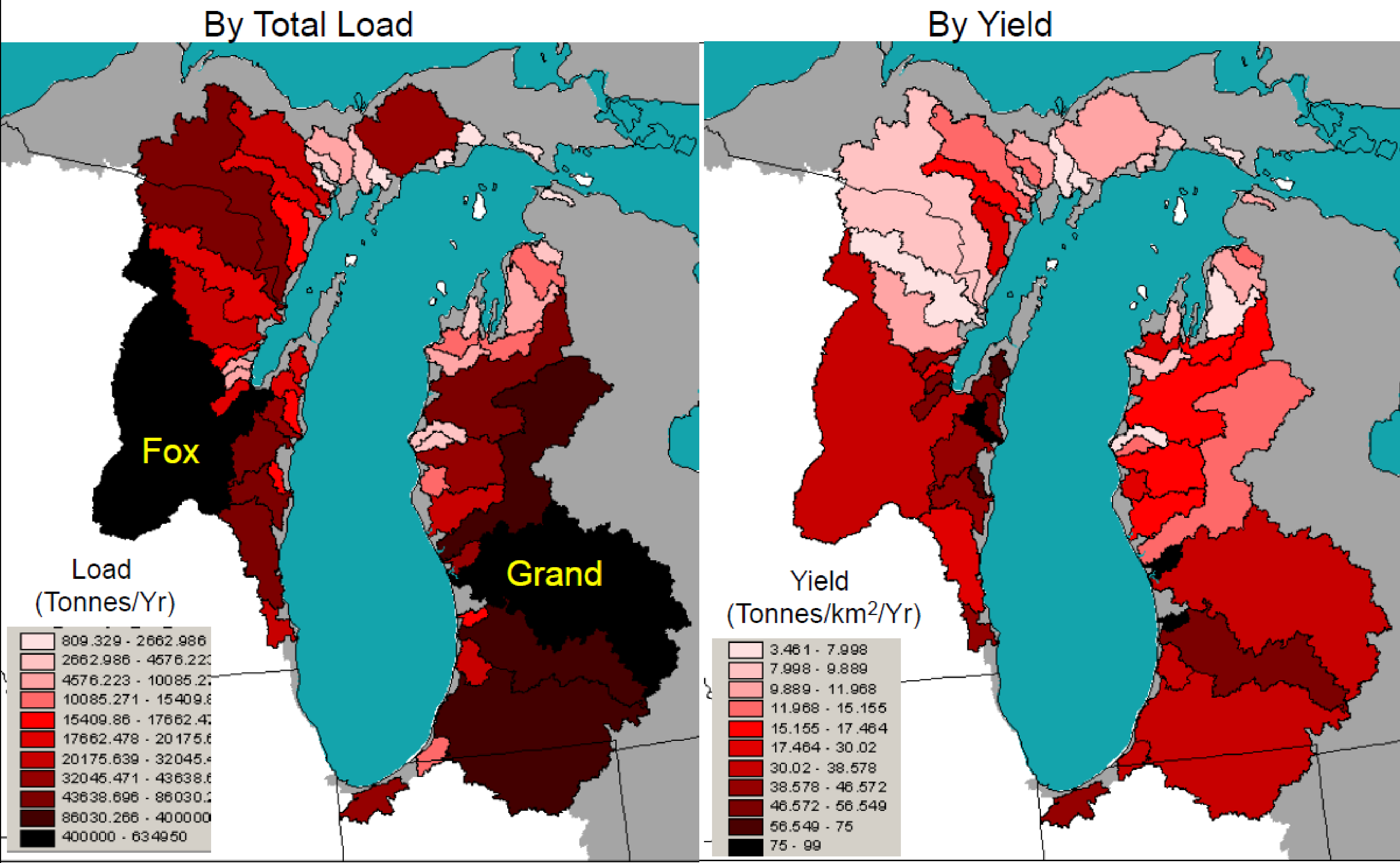
- Concentration of organic and inorganic nitrogen and phosphorus in 928 U.S. streams



Chapin et al., 2011; modified from Allan and Castillo (2007)

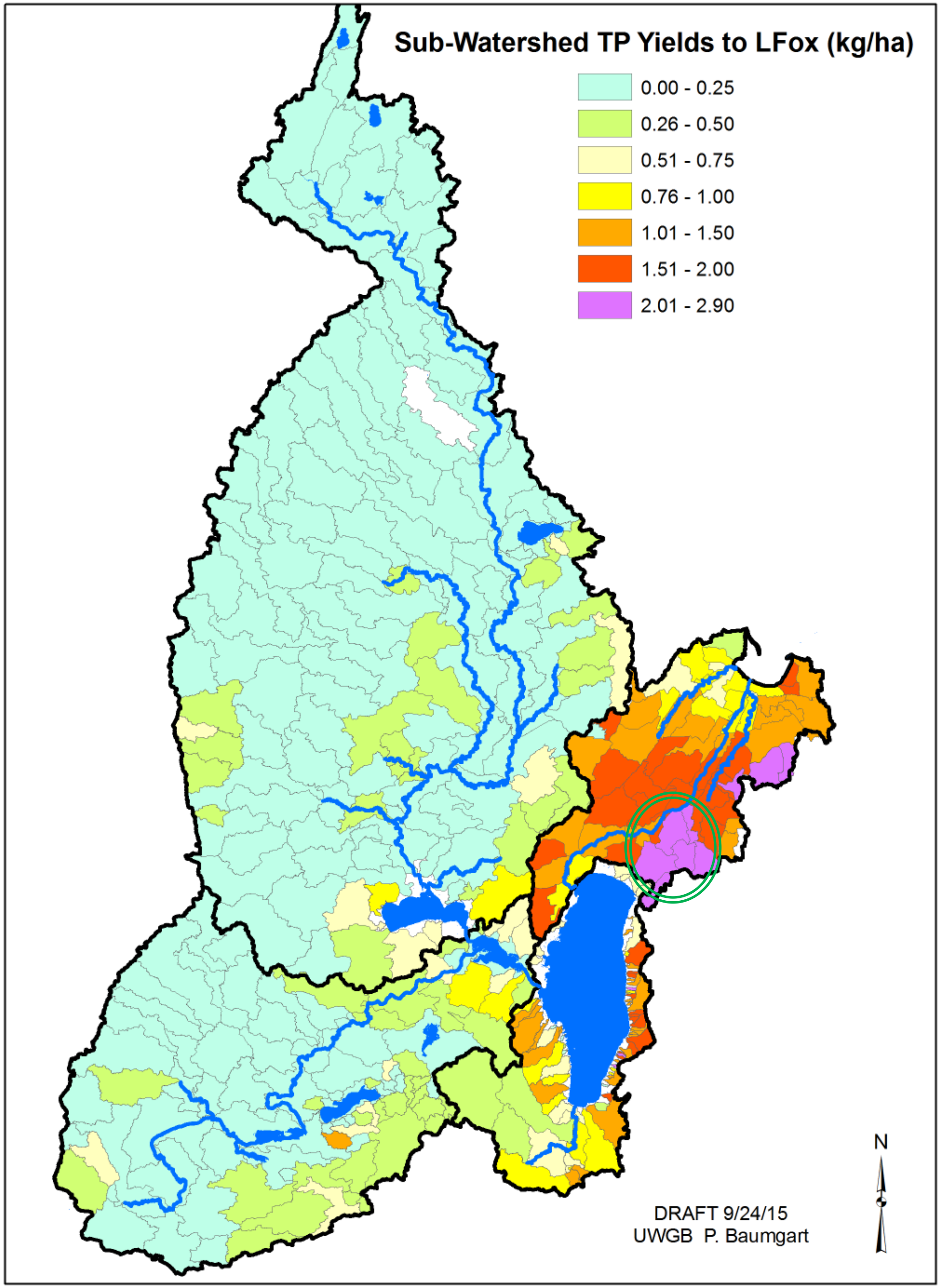
UNIVERSITY of WISCONSIN GREEN BAY

Creates variation in P outputs among **watersheds**



Robertson and Saad 2009

Ranking of Watersheds For Total Phosphorus Contributions



SWAT Simulated Total Phosphorus Yields (kg/ha) from Fox-Wolf Basin

(WY2009-13 climate,
Routed to Lower Green Bay)

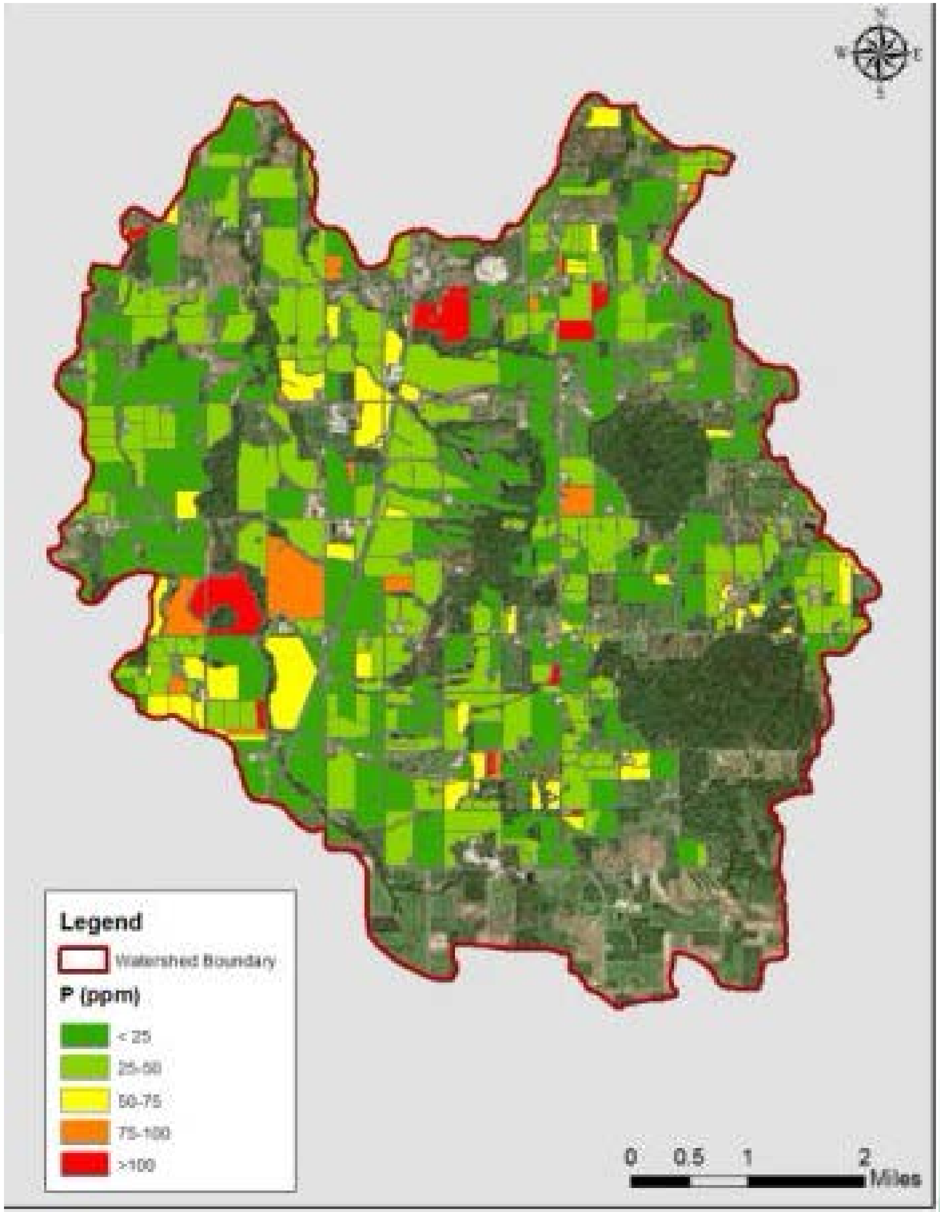
- Creates Variation: **sub-watershed scale**
- Clearly, differences in slope, land use, catchment size, etc are examples of other important contributing factors

Field Variability

Upper East River Sub-Watershed

Soil Test P

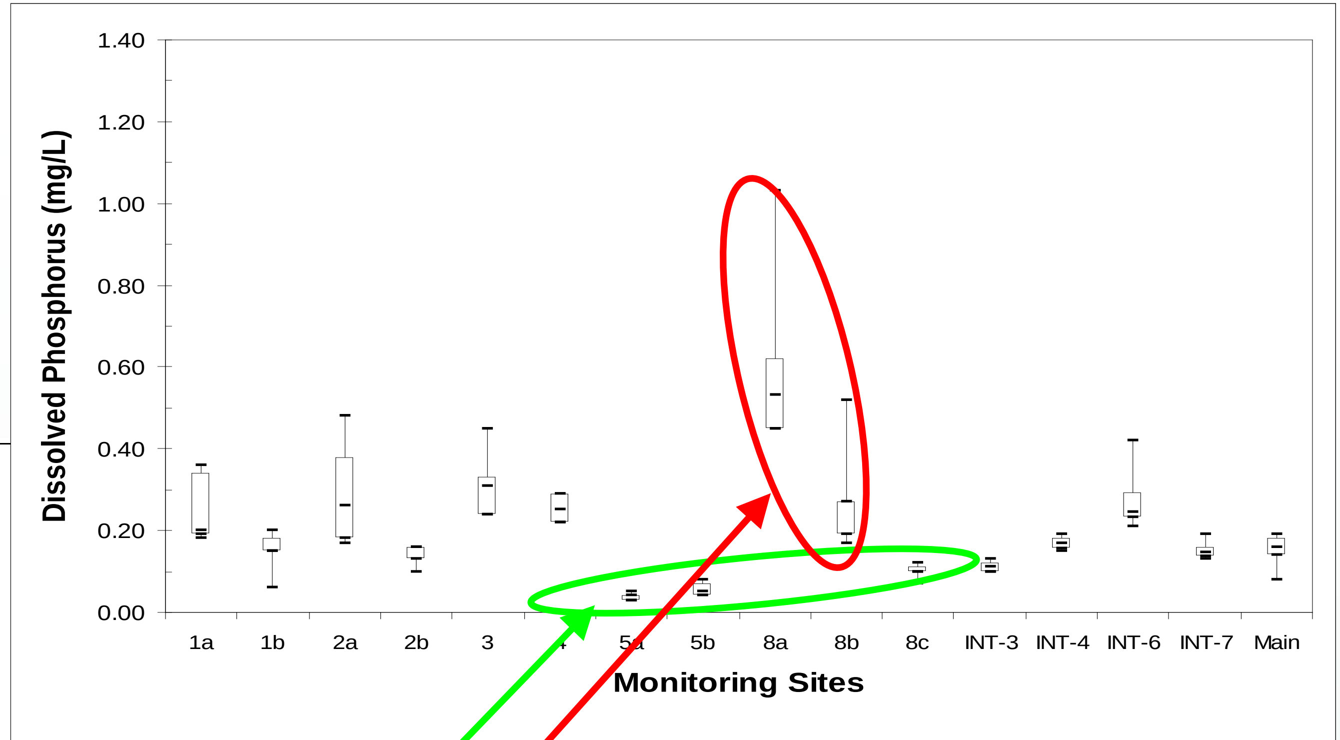
(note only the dark green fields are ≤ crop needs)

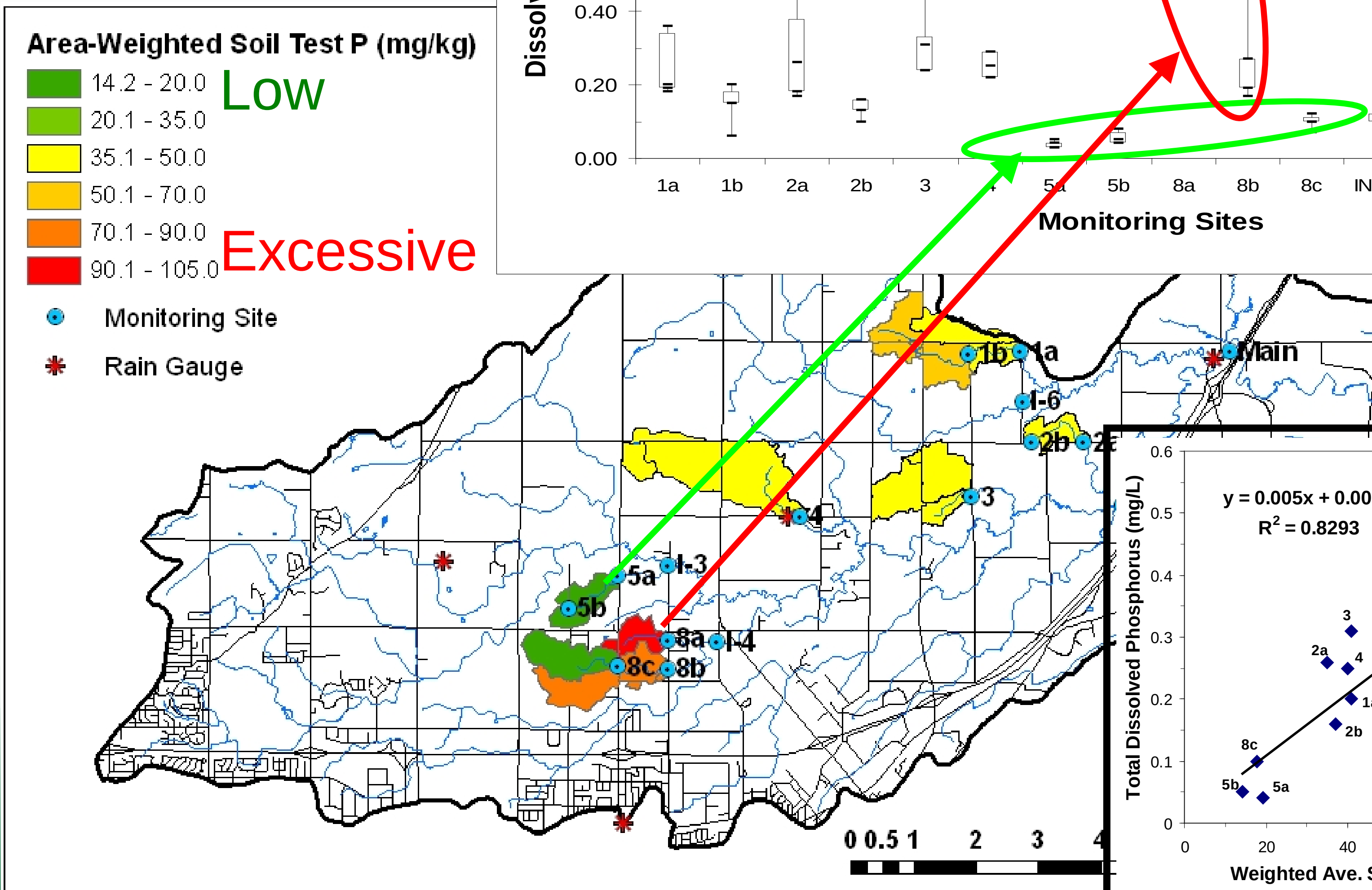


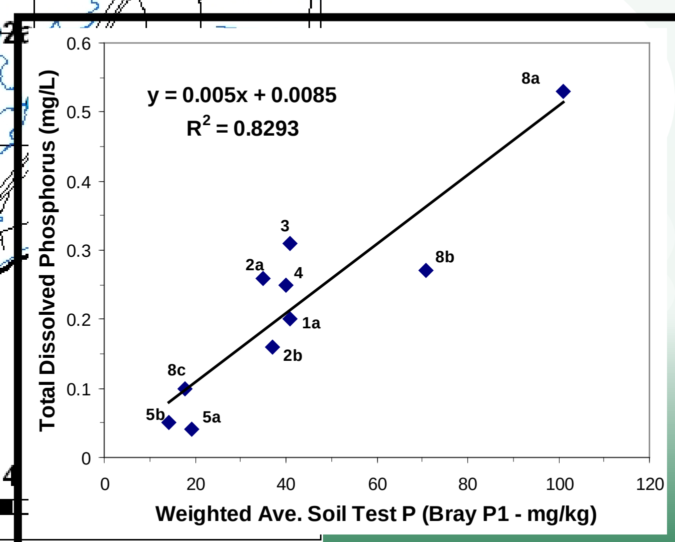
Nonpoint Source Implementation Plan for the Upper East River Watershed 2015

UNIVERSITY of WISCONSIN GREEN BAY

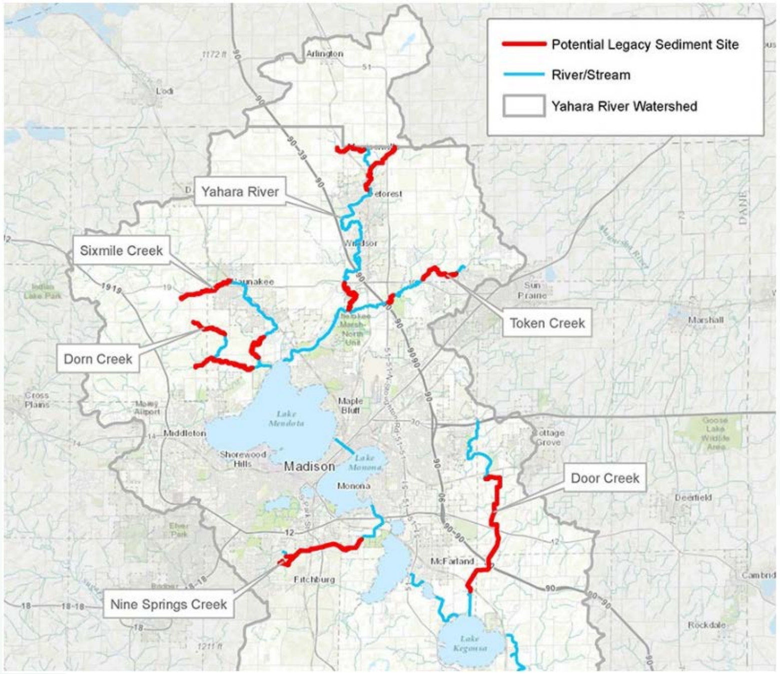
Runoff Dissolved P linked to Soil P levels

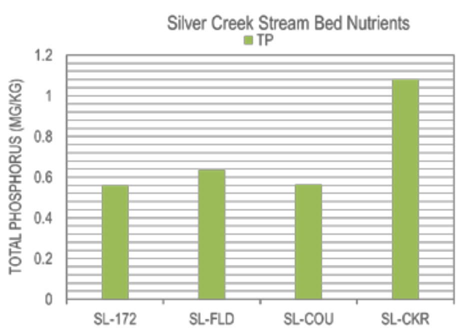






River/Stream Legacy P





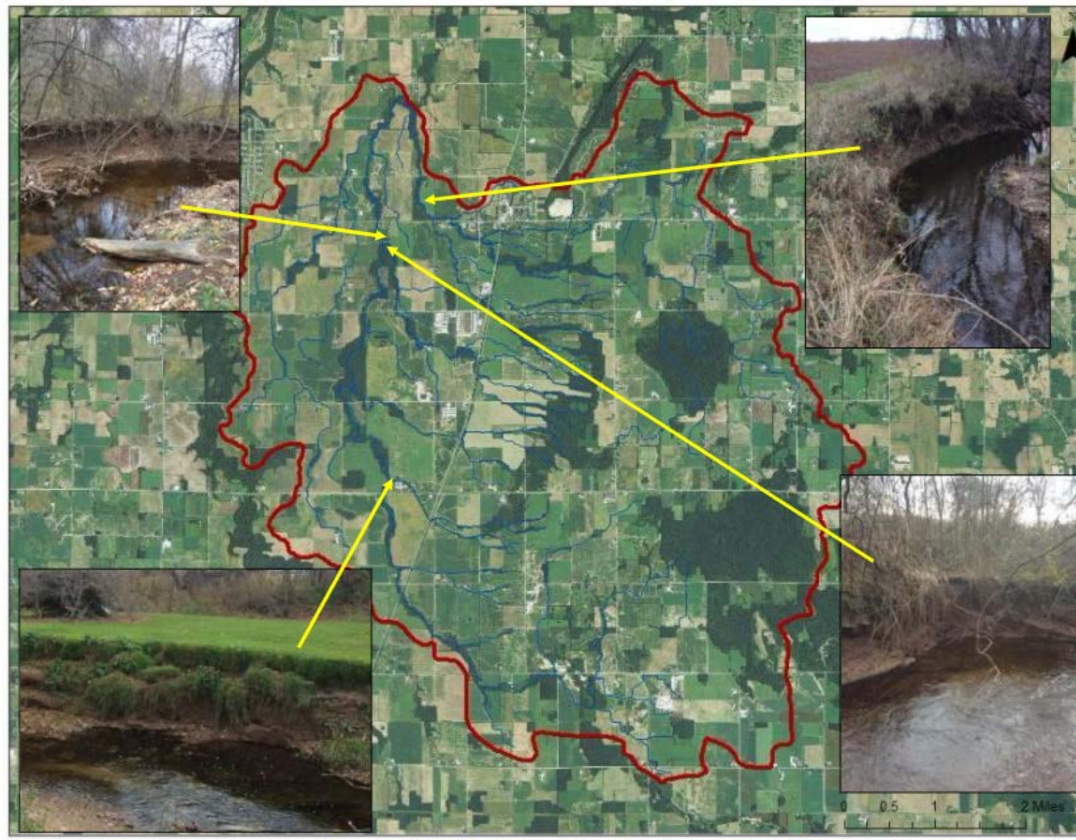


Figure 24. Streambank erosion sites on Upper East River.

UNIVERSITY of WISCONSIN
GREEN BAY

Legacy soil P within **Fields**

- Influences are long-lasting

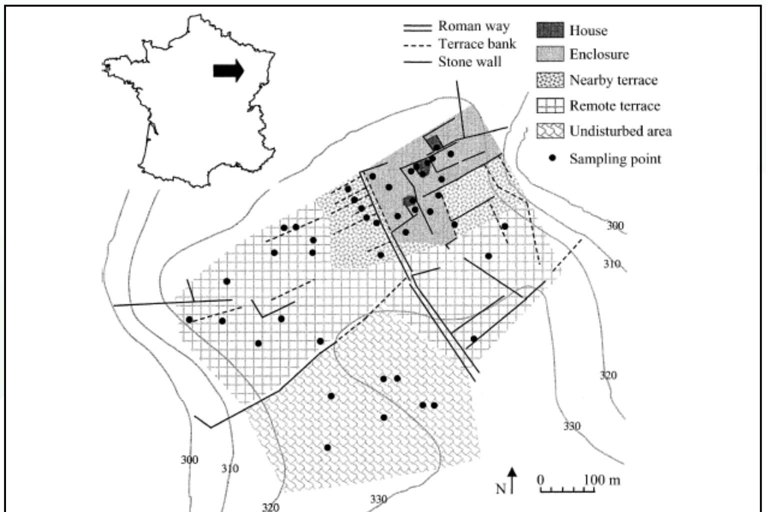
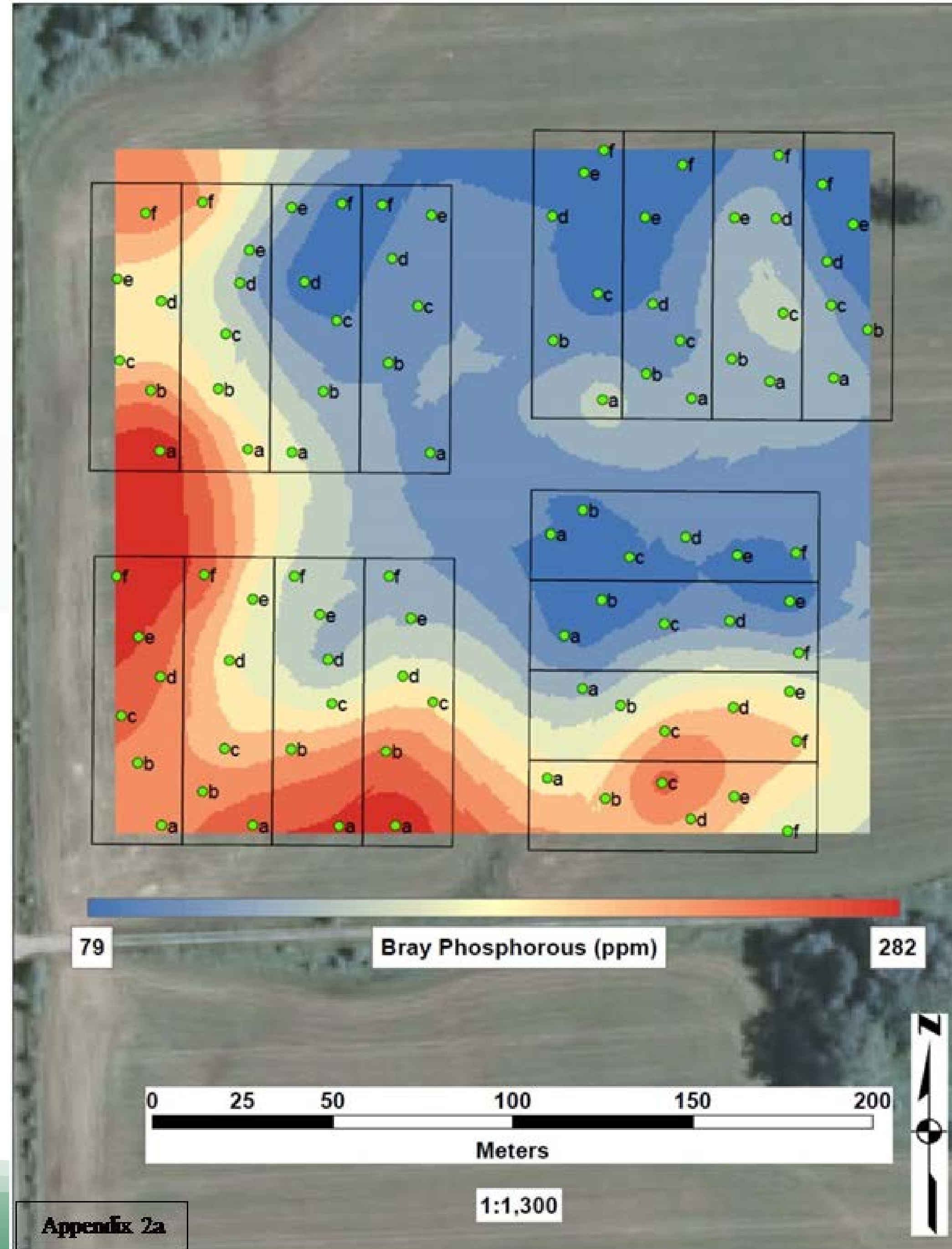


FIG. 1. Map of the site with indications of former land use intensity according to archaeological investigations.

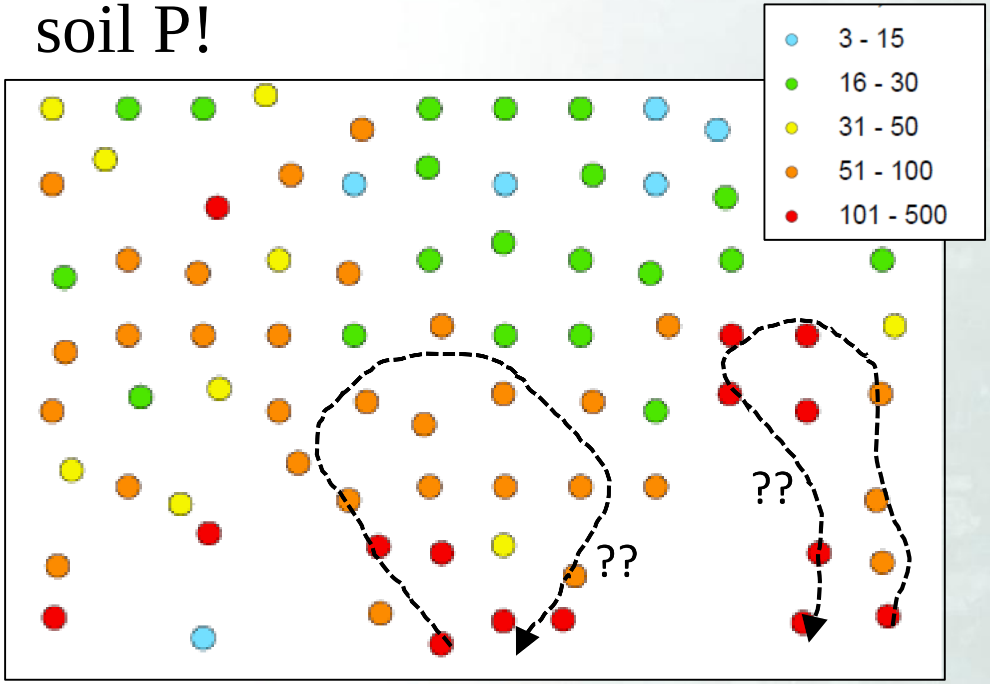
Dupouey et al. 2002

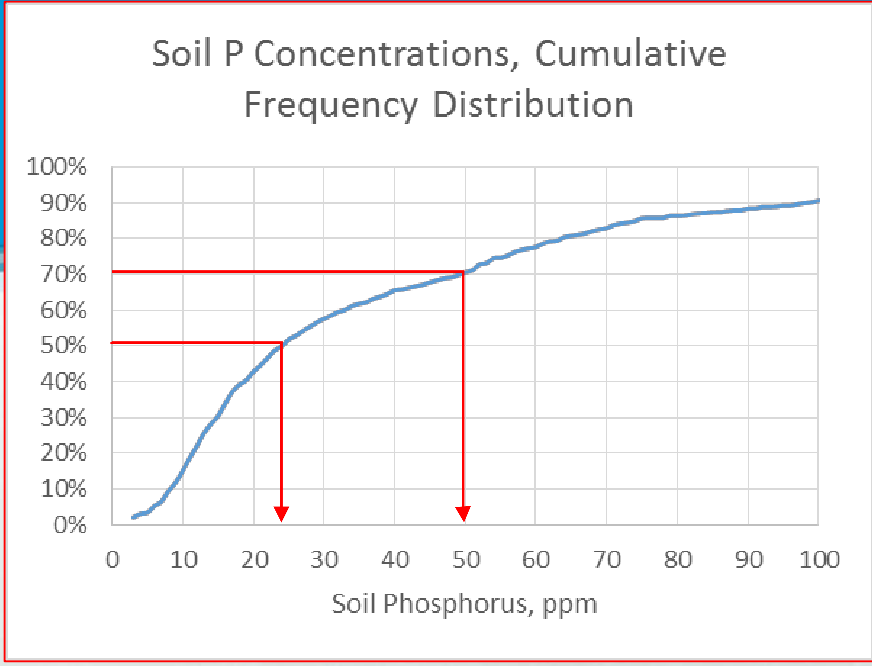


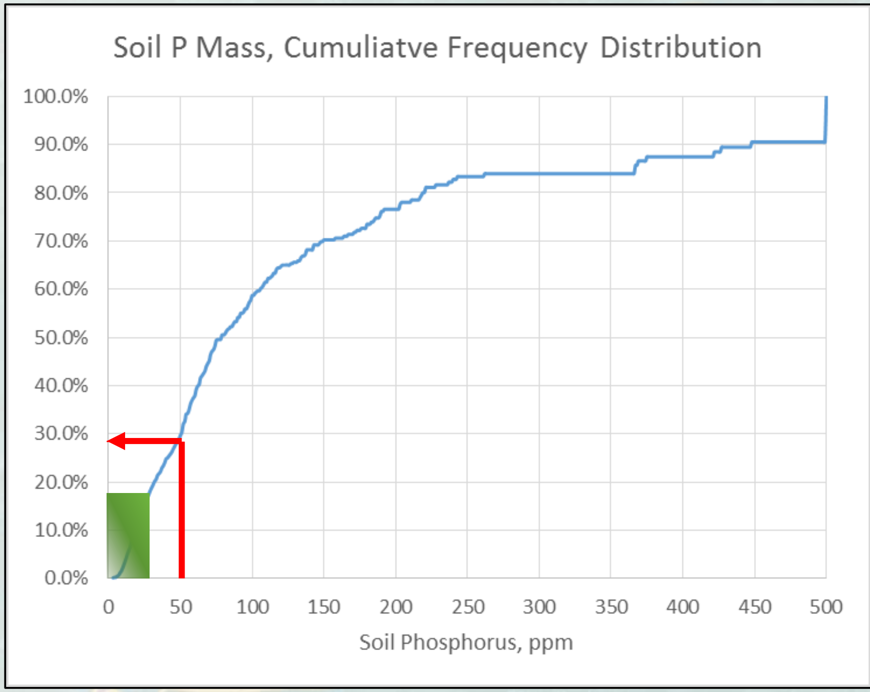
University *of* Wisconsin
Green Bay

Initial Results

- Variability (surprise!)
  - Soil P: 3 to 553ppm
- A disproportionately small portion of the landscape holds a disproportionately large portion of soil P!

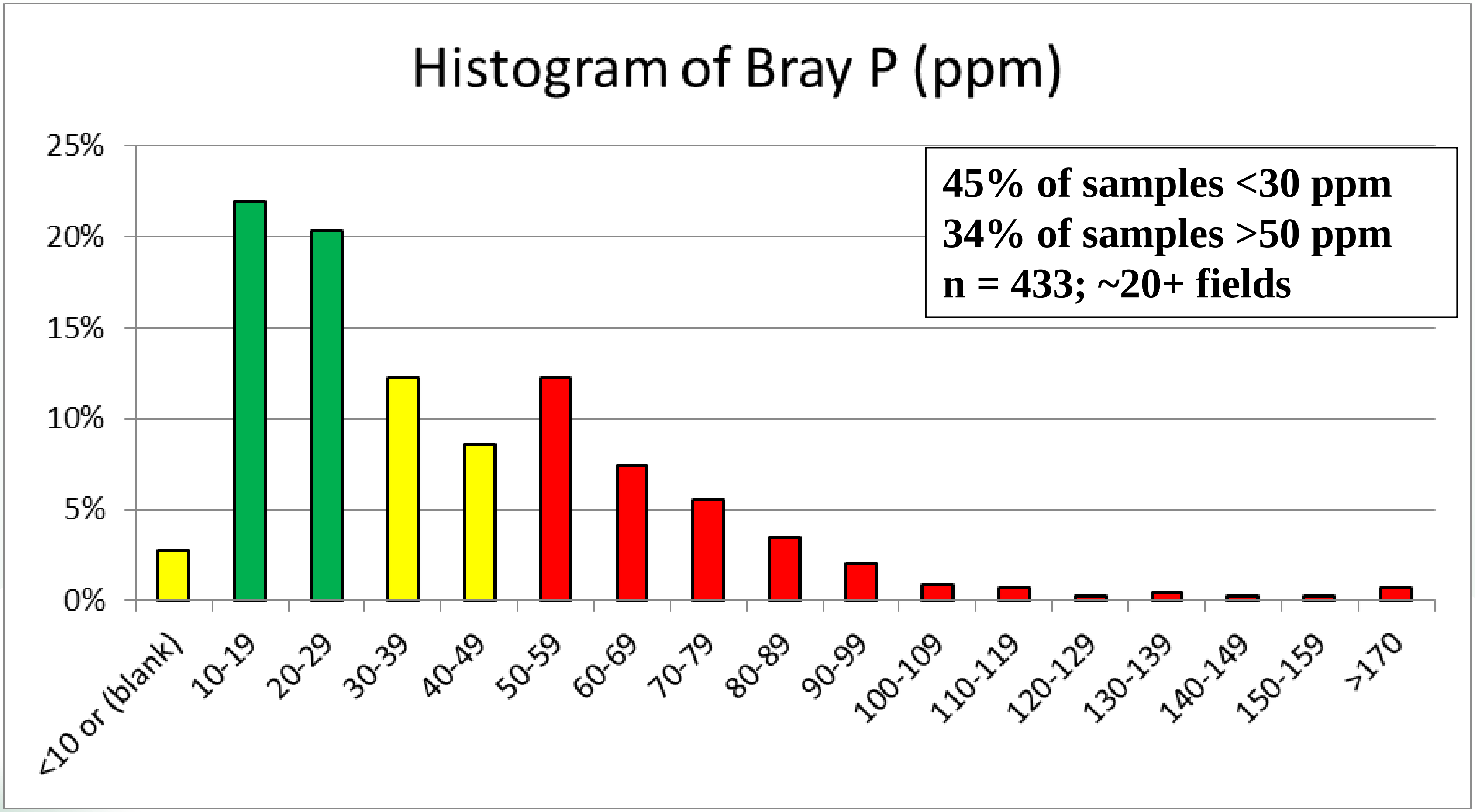






CH2MHILL. AgVentures ENVIRO-PROS McMAHON ENGINEERS ARCHITECTS TILTH AGRONOMY

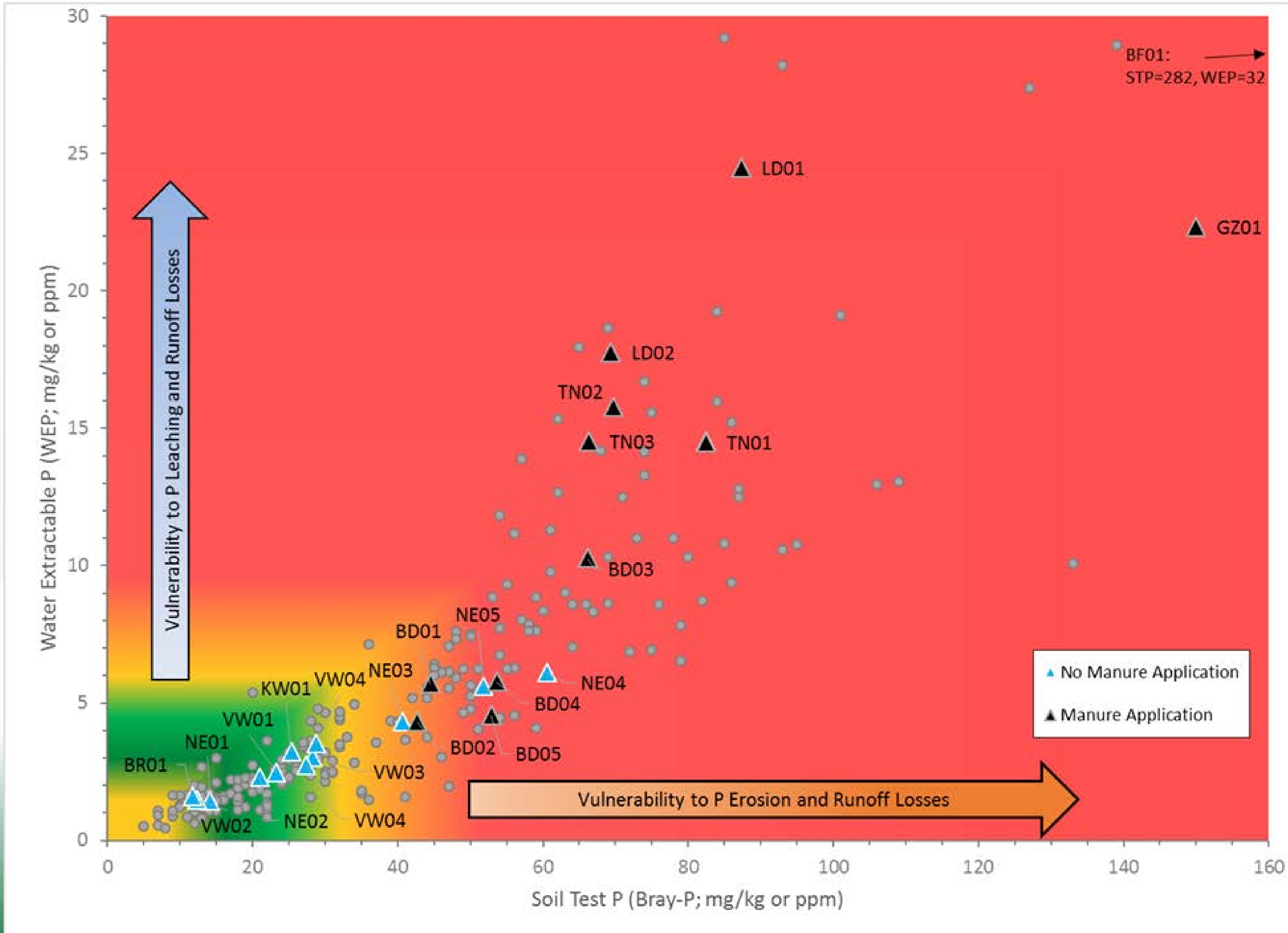
We derived a similar pattern independently



Soil Test Phosphorous (Bray P, ppm) composite, agronomic point samples collected from LFDFN fields and comparison sites in fall 2014 or spring 2015.

UNIVERSITY of WISCONSIN GREEN BAY

Vulnerability of Fields to Phosphorous Losses



University of Wisconsin Green Bay

Docter, Dornbush and Fermanich, 2016

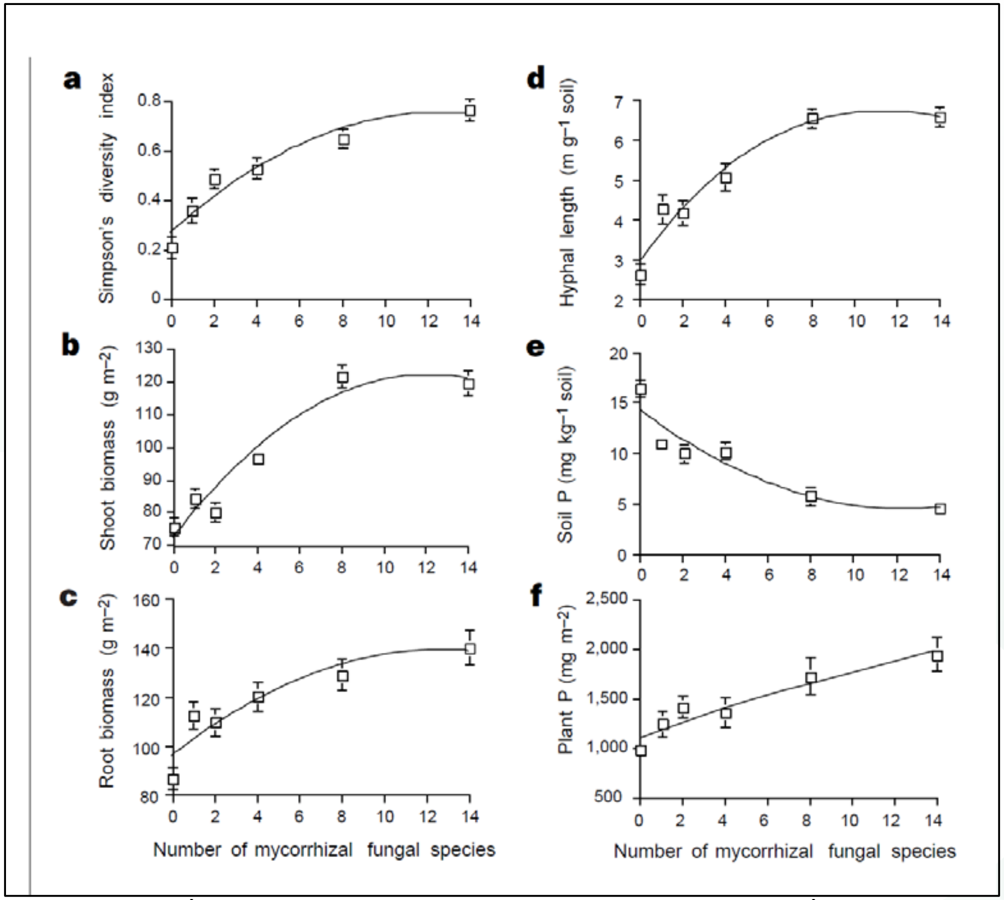
Cultural Challenge

- Blue water = good; green water = bad
- Low to moderate nutrient waters = good; high nutrient waters = bad.
- What about for soils?
- Low to moderate nutrient soils = ~~good~~ bad; high nutrient soils = ~~bad~~ good.
  - Cultural legacy of cheap nutrients, single service focus, and rational thoughts of contingency planning

UNIVERSITY *of* WISCONSIN
GREEN BAY

Implications of high soil P – diversity, mycorrhizae, etc

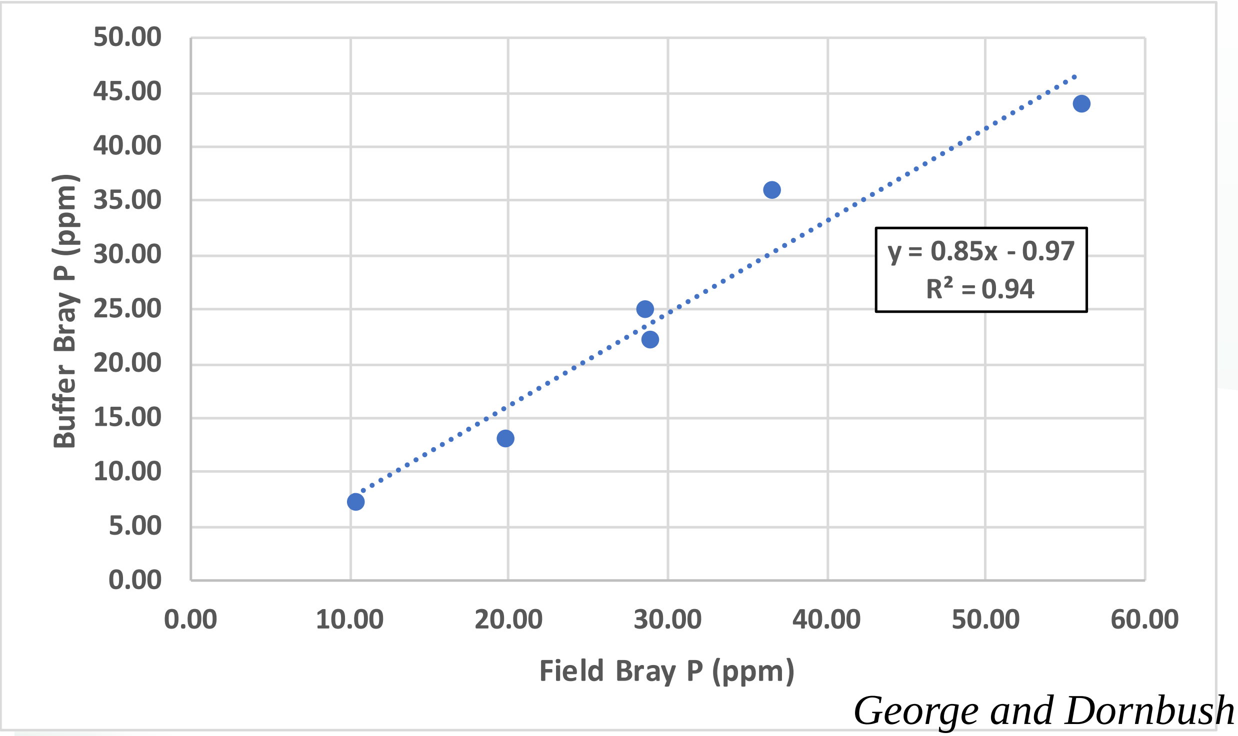
G. Fewless



Van der Heijden et al. 1998

University of Wisconsin
Green Bay

Implications for other BMPs



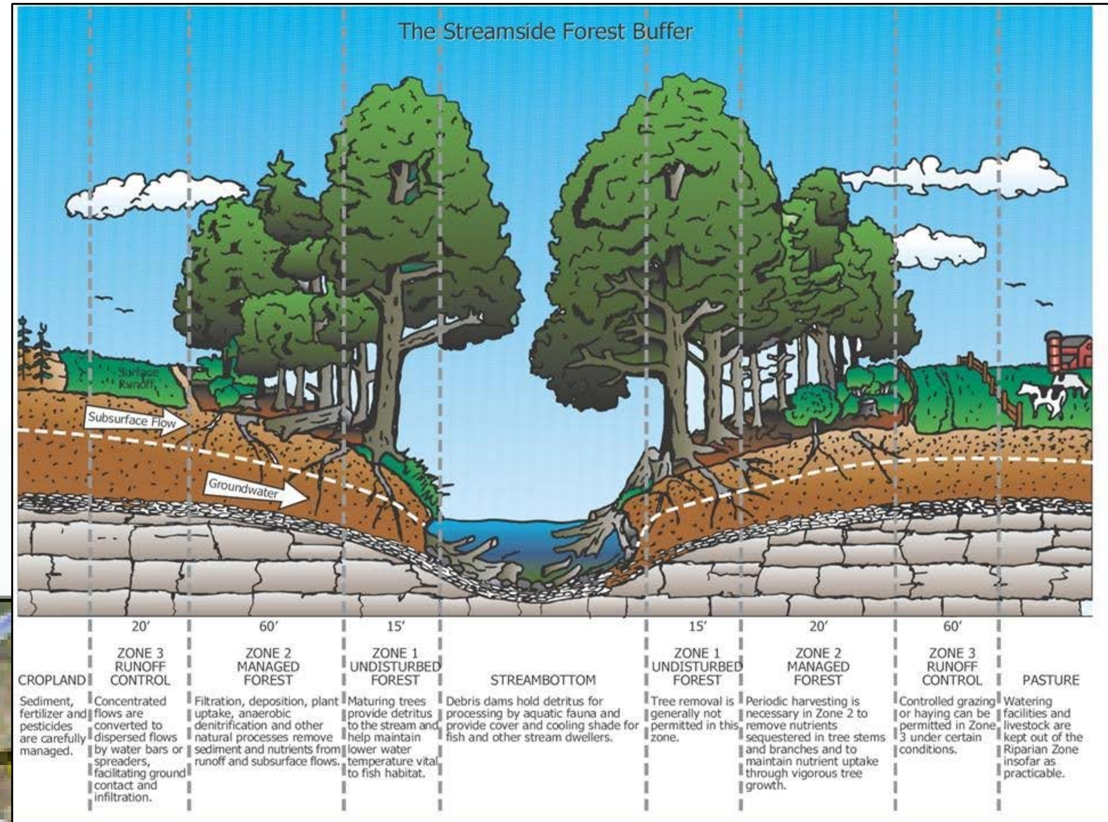
Ex. riparian buffer on Bear Creek in Story County, Iowa

George and Dornbush (unpublished)

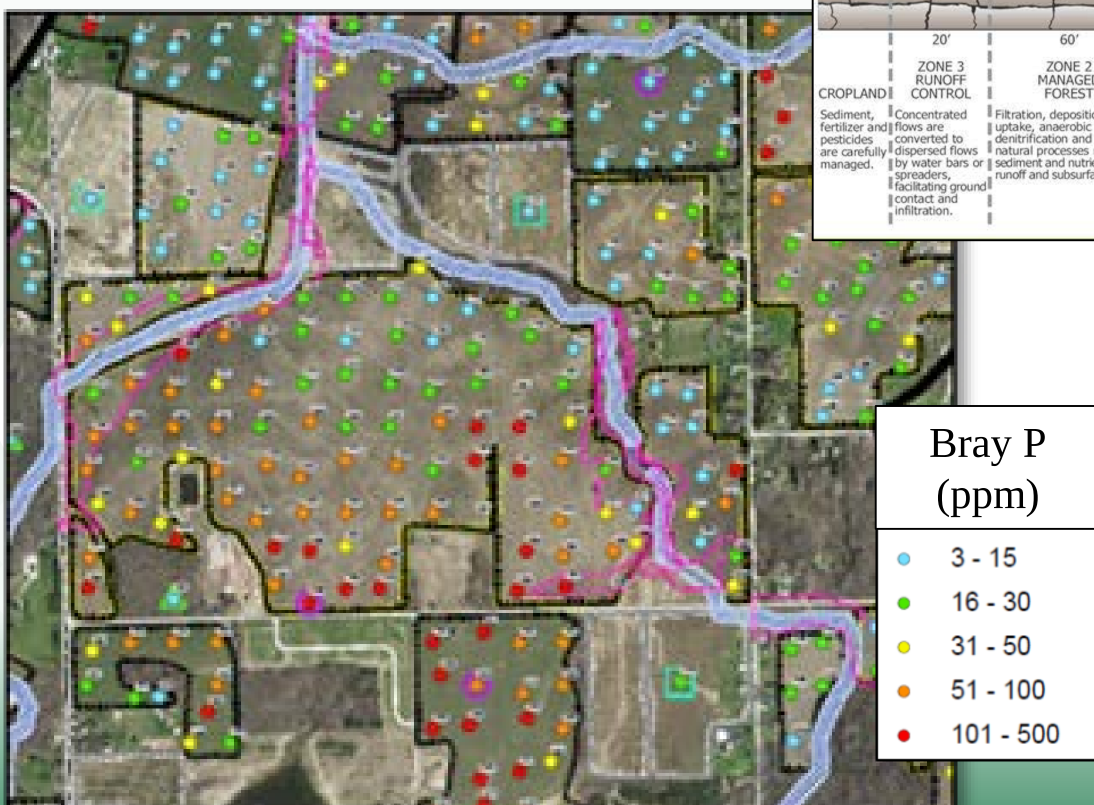
- Mean values taken for six independent buffers in the Silver Creek Watershed, WI

University of Wisconsin
GREEN BAY

Nutrient Management Plans for our BMPs?



https://agbmps.osu.edu/

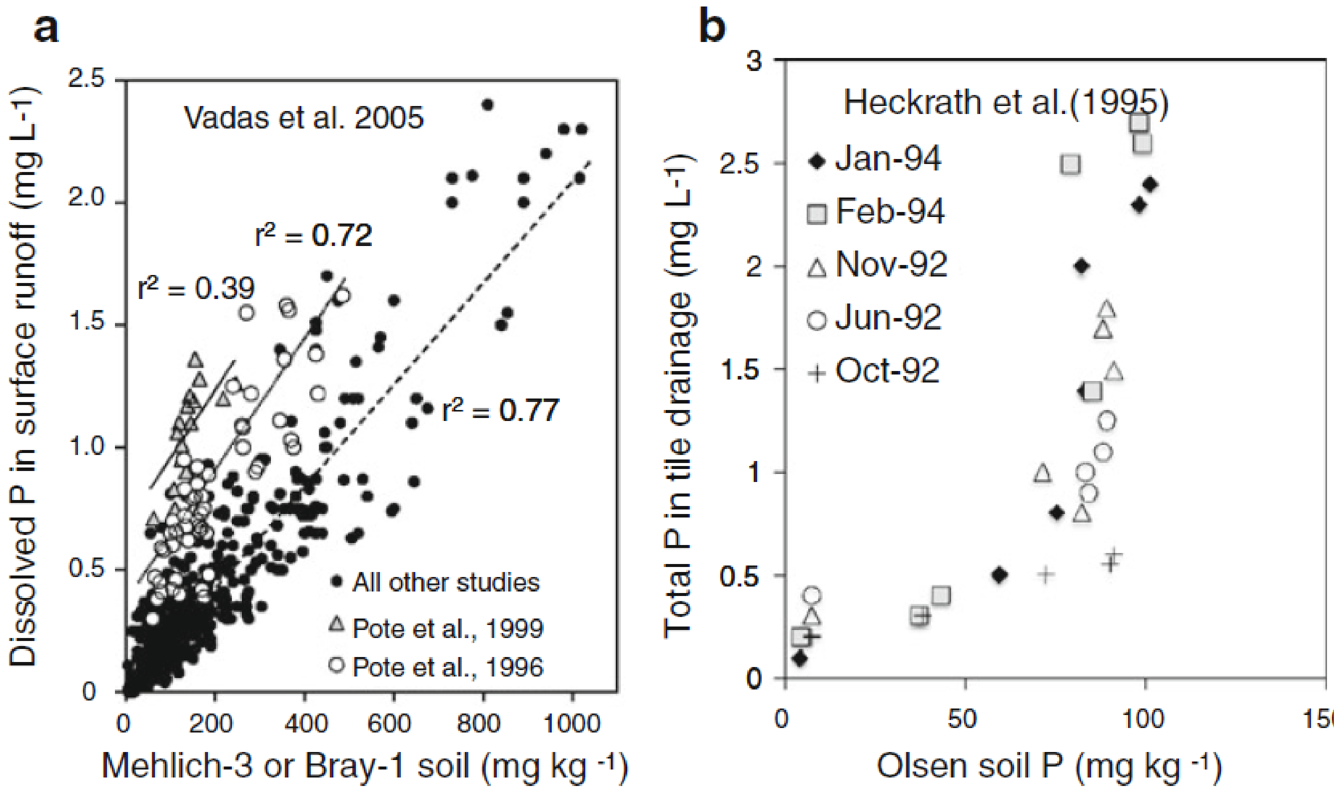


- True if established with high Bray soils.
- True at some point in time – accumulation?

Leaching losses are generally small in natural systems

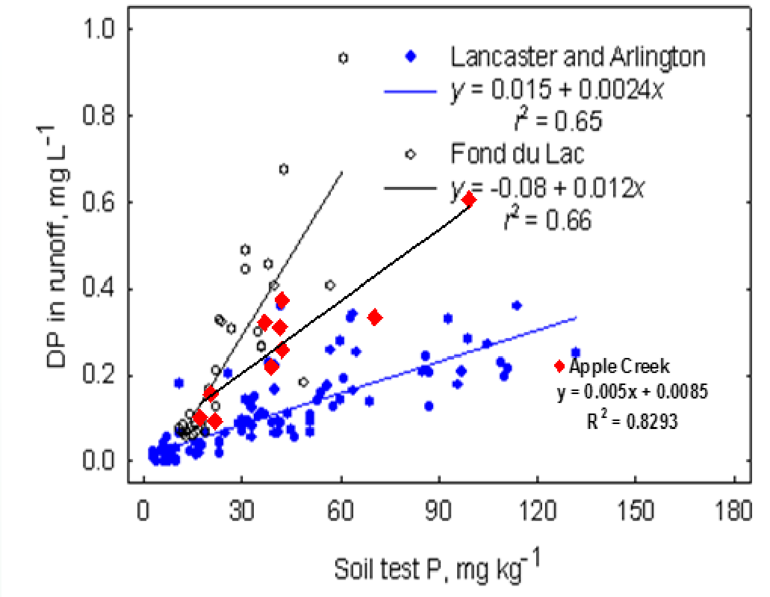
Fig. 2 Concentrations of P in surface runoff and tile drainage waters as a function of soil test P concentration. Surface runoff data (**a**) are adapted from a summary of studies in the U.S. A. by Vadas et al. (2005). Drainage data (**b**) are adapted from long-term experiments on the Broadbalk plots in the U.K. described by Heckrath et al. (1995)

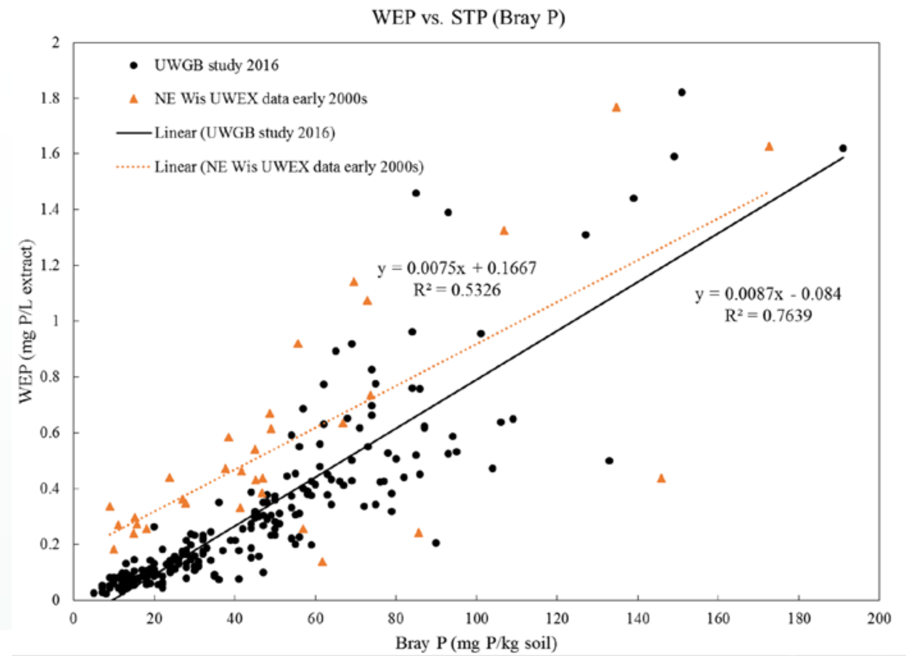
Kleinman et al. 2011



- Agricultural soils follow a different rule – soil P threshold levels

UNIVERSITY of WISCONSIN
GREEN BAY





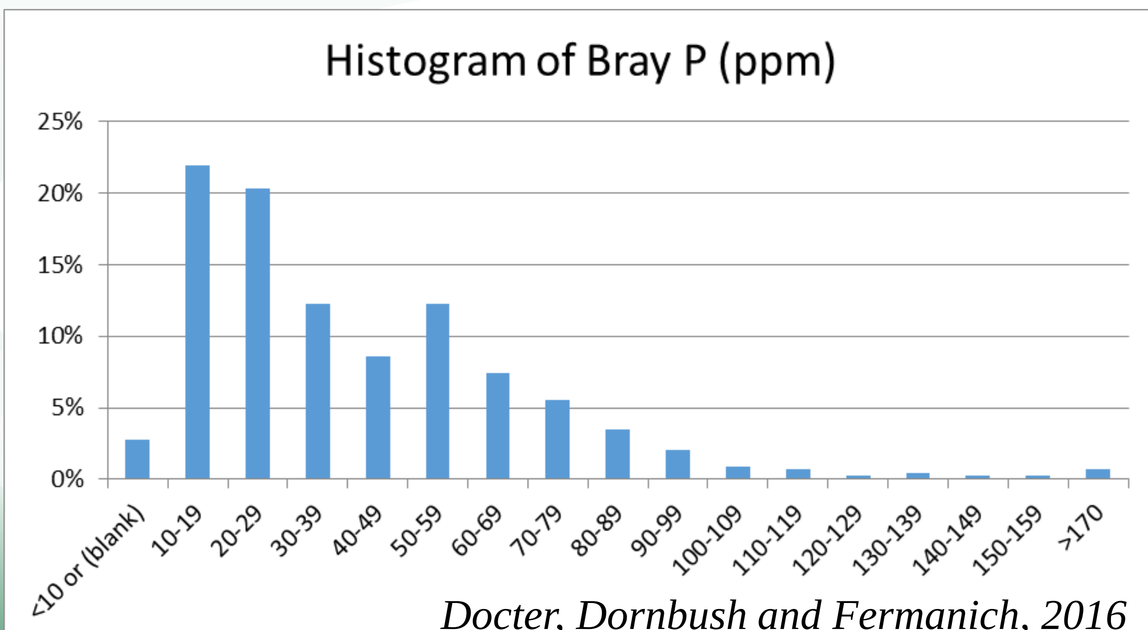
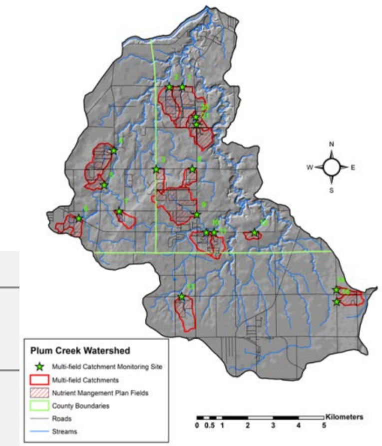
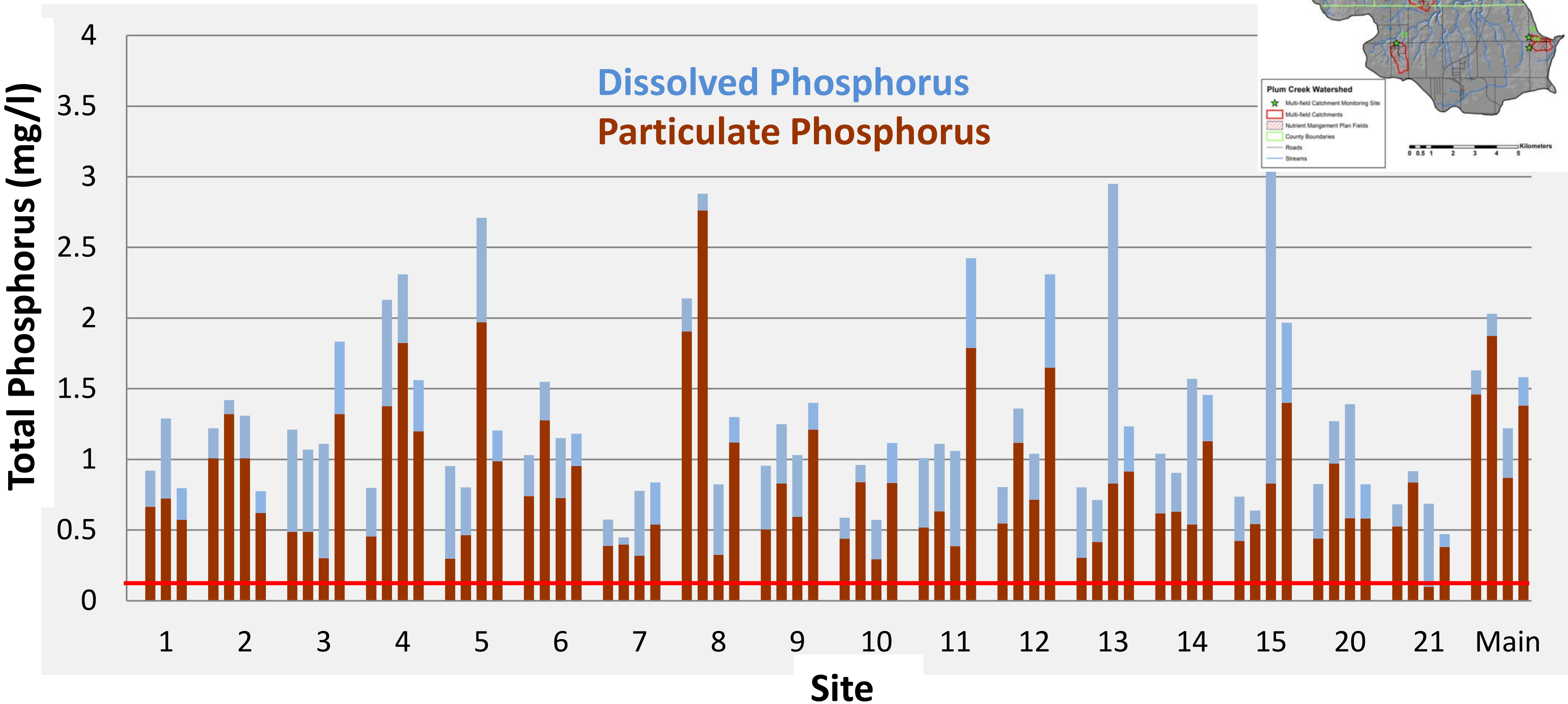


Figure 6 Soil Test Phosphorous Levels - Soil Test Phosphorus (Bray P, ppm) distribution for 433 composite, agronomic point samples collected from LFDFN fields and comparison sites in fall 2014 or spring 2015. 45% of the samples had STP values < 30 ppm, while 34% of the samples were >50 ppm.

Source area P Concentrations

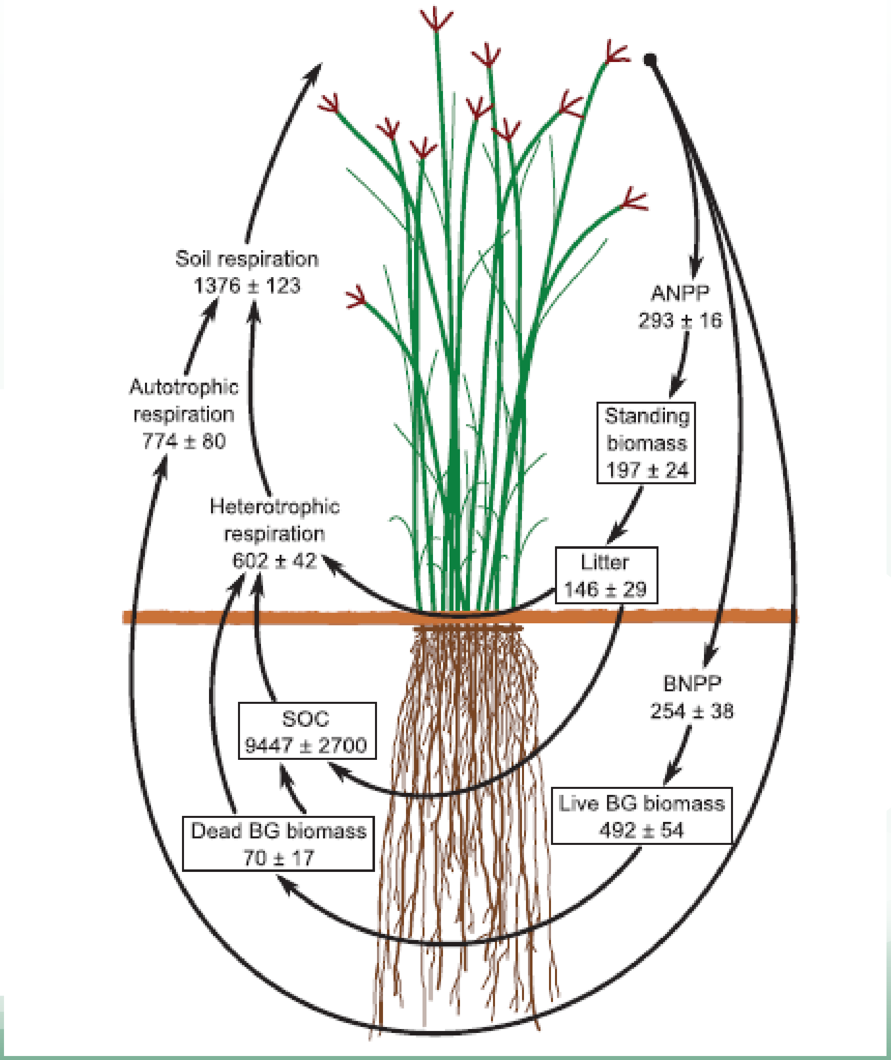




- Variation among sites and events (n= 67)
- TP Median = 1.03 mg/L
- Only 2 samples < 0.5 mg/L TP

As we saw with the *Dupouey et al. (2002) example*, Soil P unlikely to change without intentional effort

- **Options**:
  1. Reduce inputs
  2. Reduce probability of undesired exports
     a) Secure existing soil P
     b) Reduce soil P
  3. Increase desirable exports



Von Haden and Dornbush 2017

UNIVERSITY *of* WISCONSIN
GREEN BAY

Reduce Inputs

2010 State Law on Turf Grass:

94.643 Restrictions on the use and sale of fertilizer containing phosphorus.

(2) RESTRICTIONS ON USE.

(a) Except as provided in par. (b), no person may intentionally apply to turf fertilizer that is labeled as containing phosphorus or available phosphate….

UNIVERSITY of WISCONSIN
GREEN BAY

Reduce Inputs

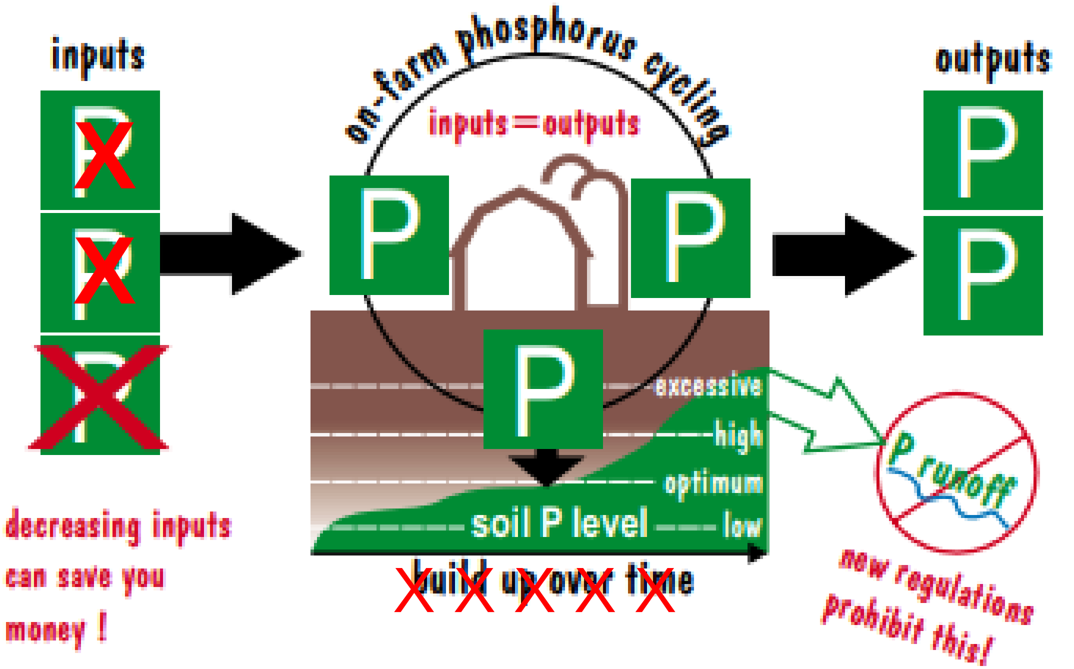


Figure 1. Loss of P from manured fields.

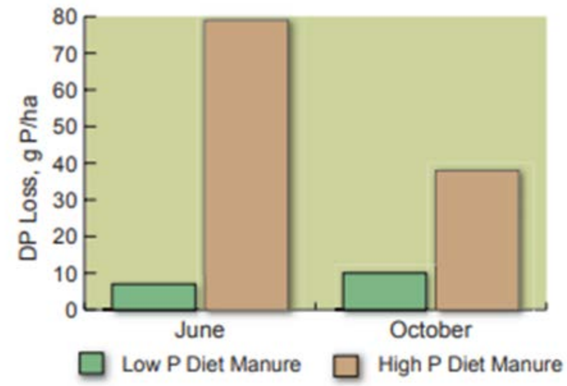
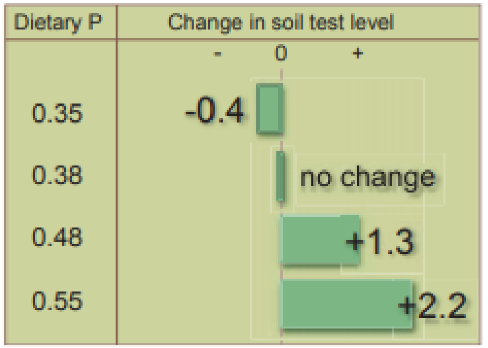


Figure 3. Potential changes in soil test P due to manure applied from dairy cattle fed various dietary P levels.

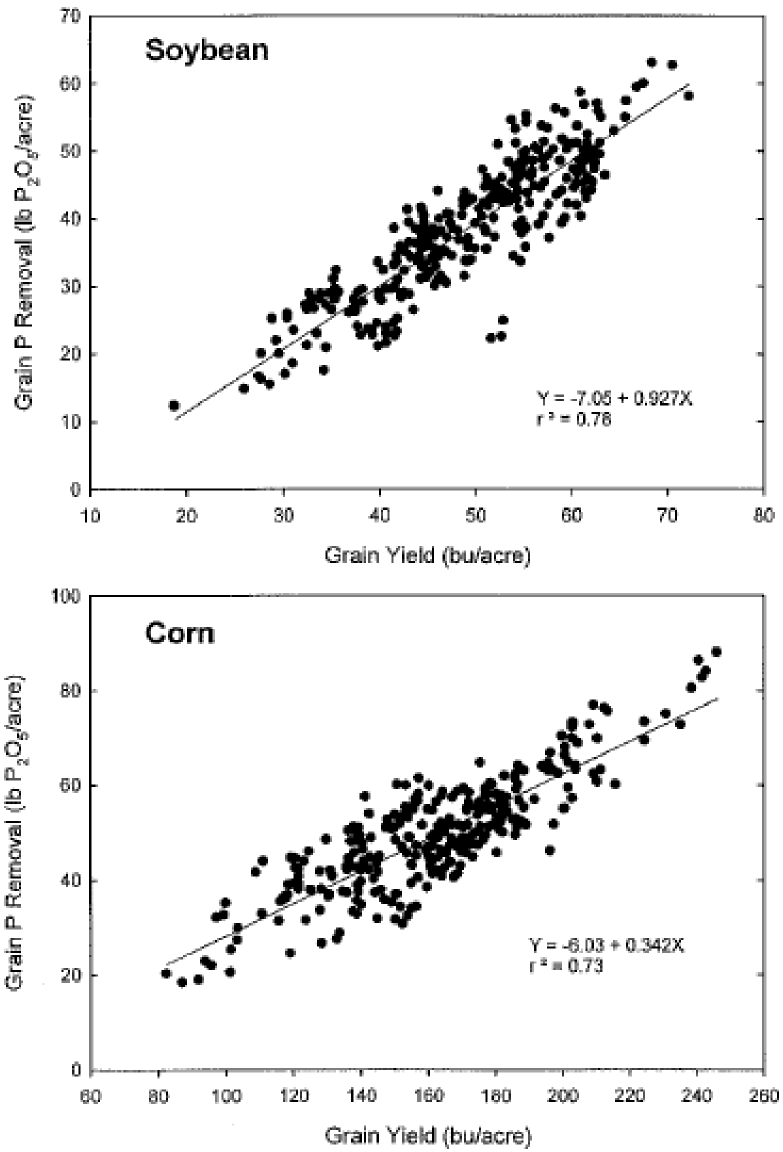


Cover Crops

- Secure existing soil P
- Infiltration, cover, etc

University *of* Wisconsin
Green Bay

Desired P exports

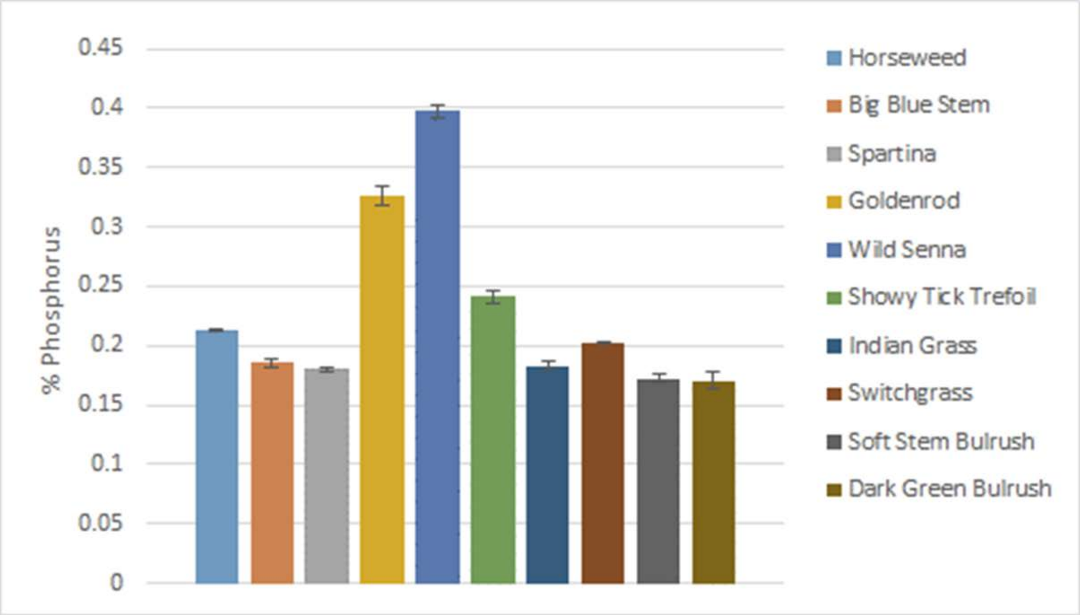


Mallerino and Prater 2007

Figure 2. Relationship between grain P removal and grain yield for corn and soybean across five sites and 12 years.

- *Removal is a function of:*
  - Biomass removed
  - P concentration:
    - species
    - green vs. senesced

Some inter-specific variation in P concentrations



George and Dornbush (unpublished)

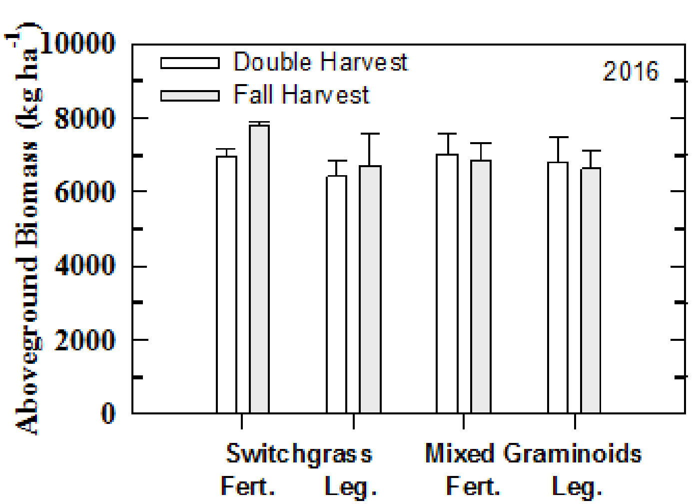
- Generally, most species, when green, are about 0.2% P dry mass (65^{o}C)

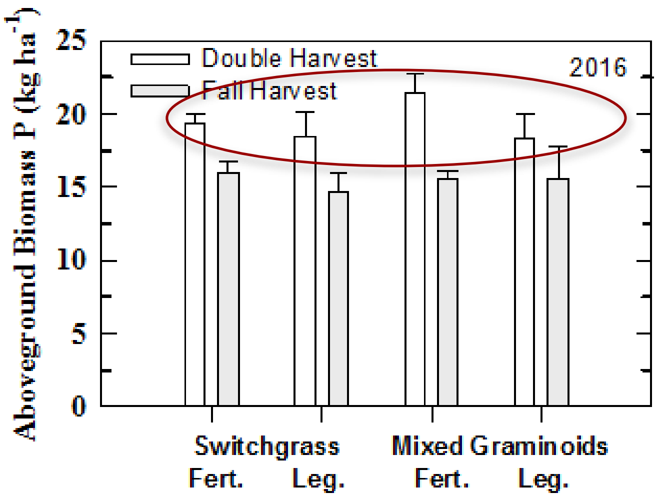
UNIVERSITY of WISCONSIN
GREEN BAY

Harvesting Perennial Grasses

George and Dornbush (In Prep)

- Switchgrass vs. mixed graminoids
- Nitrogen fertilizer vs. legume plantings
- Single late summer vs mid- & late-summer double harvest

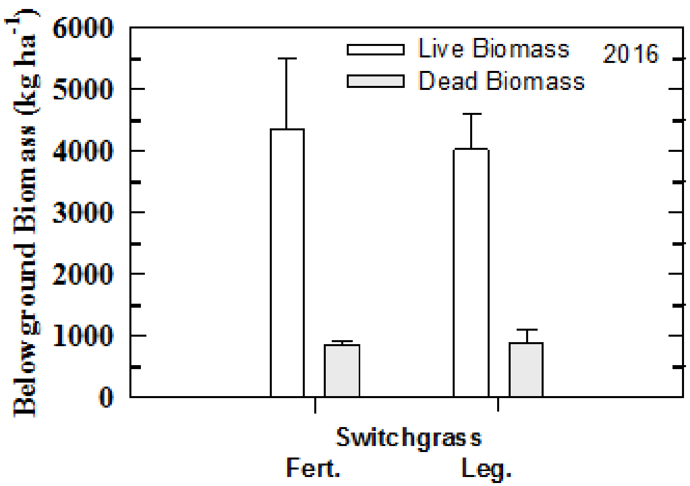


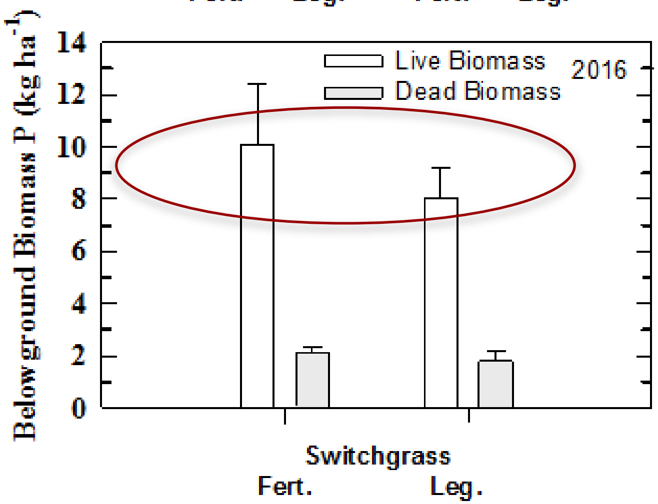


P (%):

DH: 0.29

FH: 0.22





P (%):

Fert: 0.23

Leg: 0.20

What can be harvested?

Species	DH (kg P ha^{-1})	SH (kg P ha^{-1})	Perennial Roots (kg P ha^{-1})	Source
Switchgrass	16.9	15.5	9.1	George and Dornbush (unpublished)
Corn Silage	--	8.3 to 29.7	0.0	Von Haden and Dornbush (2017)
Wheat grain & straw	--	21.7 (included wet areas)	0.0	Von Haden and Dornbush (2017)
Various buffers		8.8 (5.1 to 16.5)	?	George and Dornbush (unpublished)

UNIVERSITY of WISCONSIN GREEN BAY

An ag example: soil test P changes slowly

- An Example:
  - Soil test P = 75 ppm (EH)
  - Track drawdown of P over a CCOHHH rotation.
  - Removal of P_2O_5 over rotation = 340 lbs P_2O_5
  - Change in soil test P = 340 lb P_2O_5/18 = 19 ppm P

Still excessively high !

Soil test P = 56 ppm (EH) after the 6-year rotation.

(75 ppm P - 19 ppm P = 56 ppm P)

UNIVERSITY of WISCONSIN
GREEN BAY

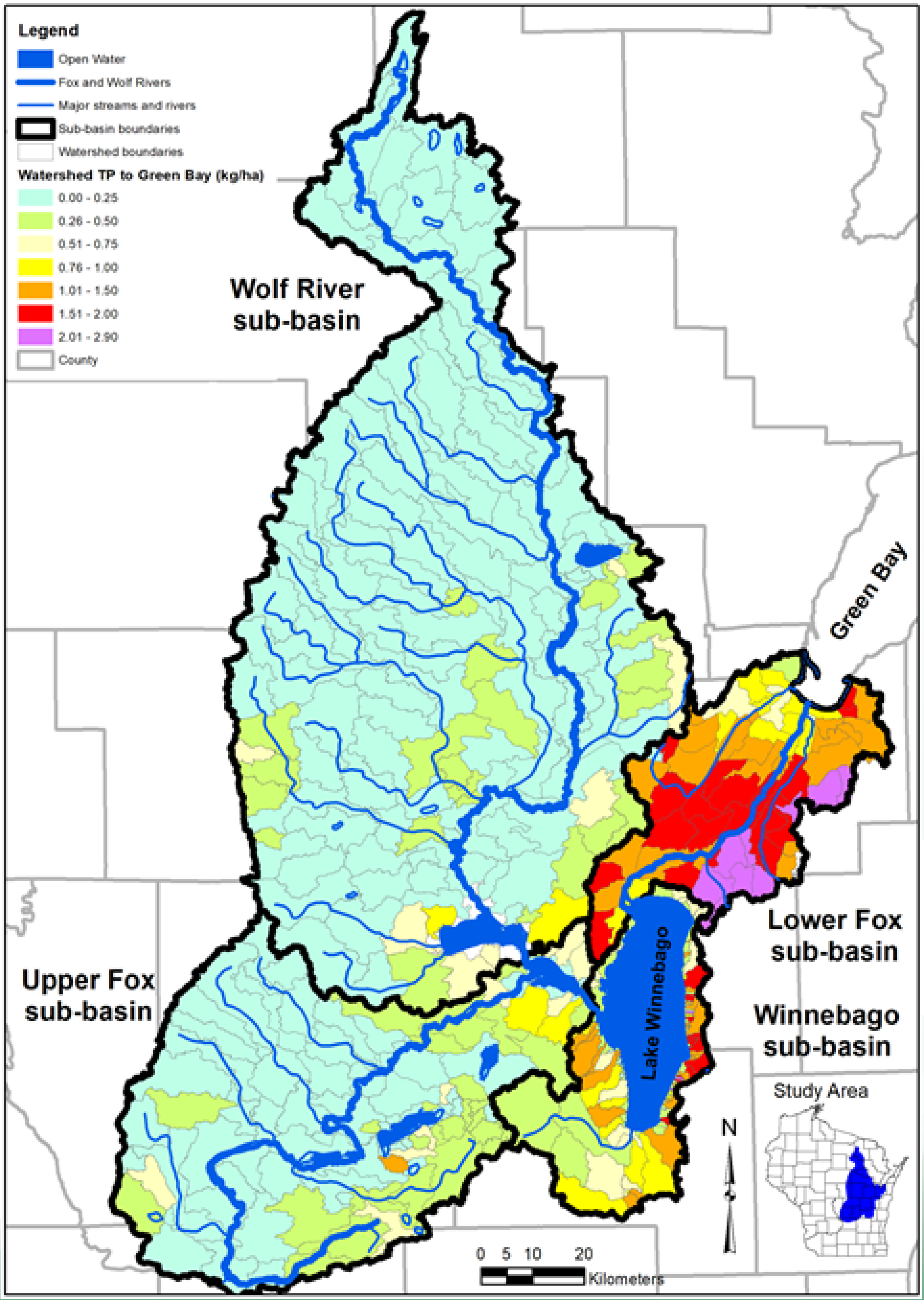
Example from Wis P-Index

- How quickly eliminating or reducing P will reduce STP and PI values will depend on the particular field and cropping system.
- a **high yielding field** in a corn silage-alfalfa rotation could be expected to remove enough phosphorus to reduce soil test P (Bray P1) by 3-5 ppm per year if **no additions** are made.
  - So if STP = 80 ppm (25% of acres) it will take 15 yrs to reduce excess P (60 ppm ÷ 4 ppm/yr)

University *of* Wisconsin
Green Bay

Reducing Soil Test P to the values in the 1970s (~15-30 ppm) across the Fox-Wolf Basin would **reduce non-point P load by 40% and total load by 34%**

(Baumgart, Fermanich, Robertson, under review JGLR)

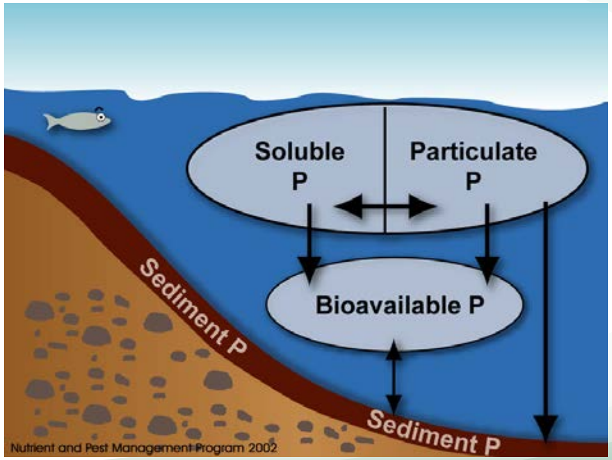


UNIVERSITY of WISCONSIN
GREEN BAY

Capturing P (and recycling?)

Wetlands can serve as both sinks and sources of P.

- Dissolved, bioavailable P

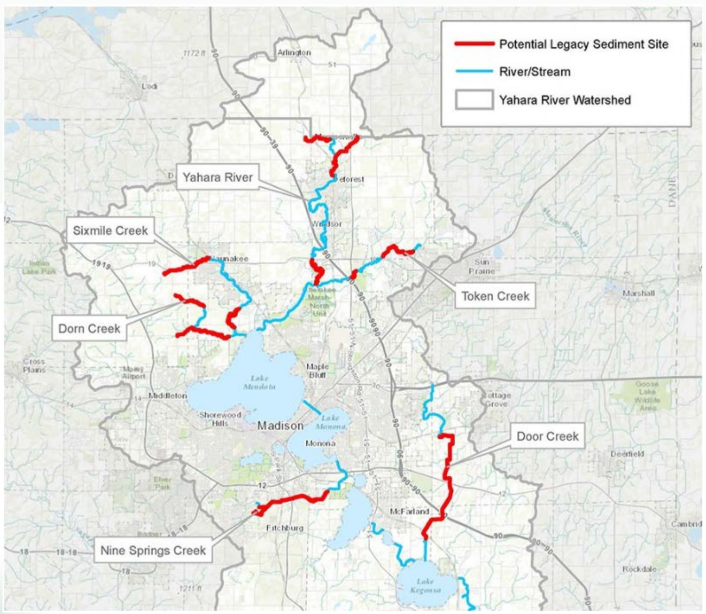


UNIVERSITY of WISCONSIN
GREEN BAY

River/Stream Legacy P Removal, Yahara Watershed (2017-2021)

$12 million over 4 years to clean 33 miles of streams which will remove 870,000 pounds of phosphorus

(source: exec.countyofdane.com//cleanlakes)



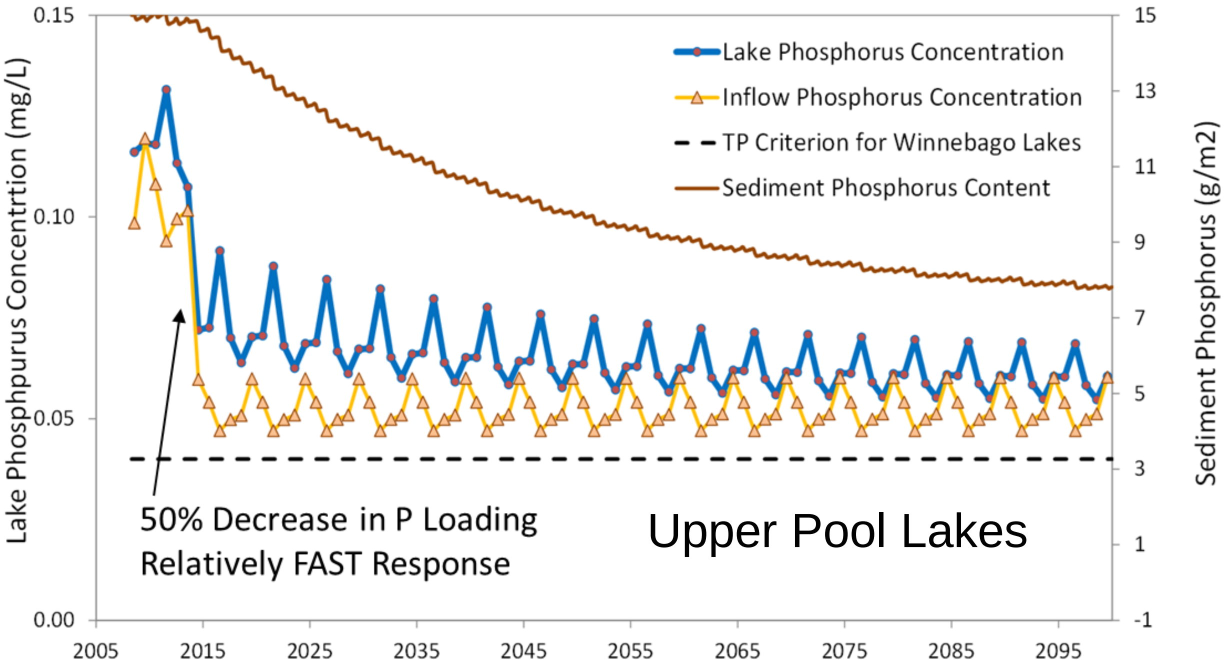
Suck the muck to protect Madison lakes

Wisconsin State Journal editorial Oct 5, 2016

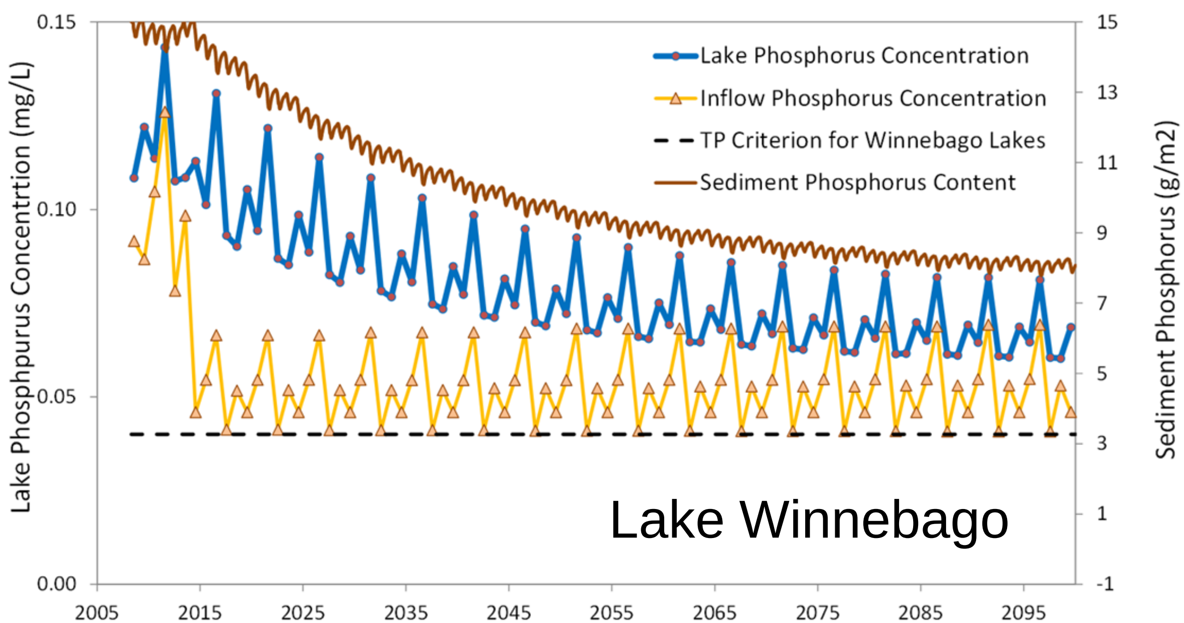
Workers vacuum phosphorus-laden muck from the bottom of Dorn Creek this week.

Dane County

Simulating the Effects of P Load Reductions in the Winnebago Pool Lakes *Source: Dale Robertson USGS*



Response in receiving waters will be slow because of Legacy P in sediment.



UNIVERSITY of WISCONSIN
GREEN BAY

P soil and Sediment Mass Balance

- Croplands: 12-15 MILLION lbs of Excess plant available P in the Lower Fox River watershed (top 6 in).
- Non-production lands: ?
- Urban and suburban soils: ?
- Rivers: ?
- Wetlands/retention ponds: ?
- Lakes: ?

UNIVERSITY of WISCONSIN
GREEN BAY

Journal of Environmental Quality ENVIRONMENTAL ISSUES

Phosphorus Legacy: Overcoming the Effects of Past Management Practices to Mitigate Future Water Quality Impairment

Andrew Sharpley,* Helen P. Jarvie, Anthony Buda, Linda May, Bryan Spears, and Peter Kleinman

vation
than
easures
ies. In
of past

DURING THE LAST DECADE, it has become apparent that many watershed-based conservation programs have failed to deliver improvements in water quality within timescales predicted by watershed managers and scientists (Jarvie et al., 2013; Meals et al., 2010; Mulla et al., 2008).

Ecosystems (2017) 20: 1468–1482
DOI: 10.1007/s10021-017-0125-0

ECOSYSTEMS CrossMark

The Influence of Legacy P on Lake Water Quality in a Midwestern Agricultural Watershed

Melissa Motew,[1]* Xi Chen,[1,2] Eric G. Booth,[3,4] Stephen R. Carpenter,[5] Pavel Pinkas,[1] Samuel C. Zipper,[4] Steven P. Loheide II,[4] Simon D. Donner,[6] Kai Tsuruta,[7] Peter A. Vadas,[8] and Christopher J. Kucharik[1,3]

[1]Nelson Institute Center for Sustainability and the Global Environment, University of Wisconsin-Madison, 1710 University Ave, Madison, Wisconsin 53706, USA; [2]Department of Geography, University of Cincinnati, Cincinnati, Ohio 45221, USA; [3]Department of

Environmental Science & Technology

Water Quality Remediation Faces Unprecedented Challenges from "Legacy Phosphorus"

Helen P. Jarvie,[†,]* Andrew N. Sharpley,[‡] Bryan Spears,[§] Anthony R. Buda,[∥] Linda May,[§] and Peter J. A. Kleinman[∥]

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[#]

2013

University of Wisconsin
GREEN BAY

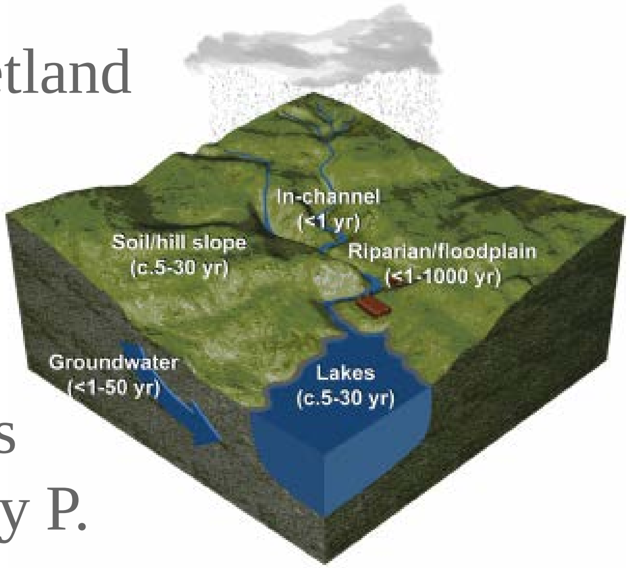
Conclusions

- Legacy P exists in current and historic cropland soils and in waterways
- Excess P is vulnerable to loss (often bio available) and suppresses beneficial soil biological processes
- Reducing P inputs is critical to legacy P reductions
- P “mining” from soil depends on cropping system and will take nearly a decade for about half our soils and many decades for the highest 20%
    - Protect and secure Legacy P from loss through perennial grasses and cover crops

UNIVERSITY of WISCONSIN
GREEN BAY

Conclusions

- Reductions in Legacy leads to reduce P inputs to waterways.
- In some systems, removal of river/stream/wetland sediments high in P is economically feasible and protects downstream lakes.



- There will be a lag in lake and bay response to reduced cropland P inputs because of areas within the watersheds with significant Legacy P.
  - Reduced Legacy P makes our watersheds and connected lakes less vulnerable to current and future large rain events.

UNIVERSITY of WISCONSIN
GREEN BAY

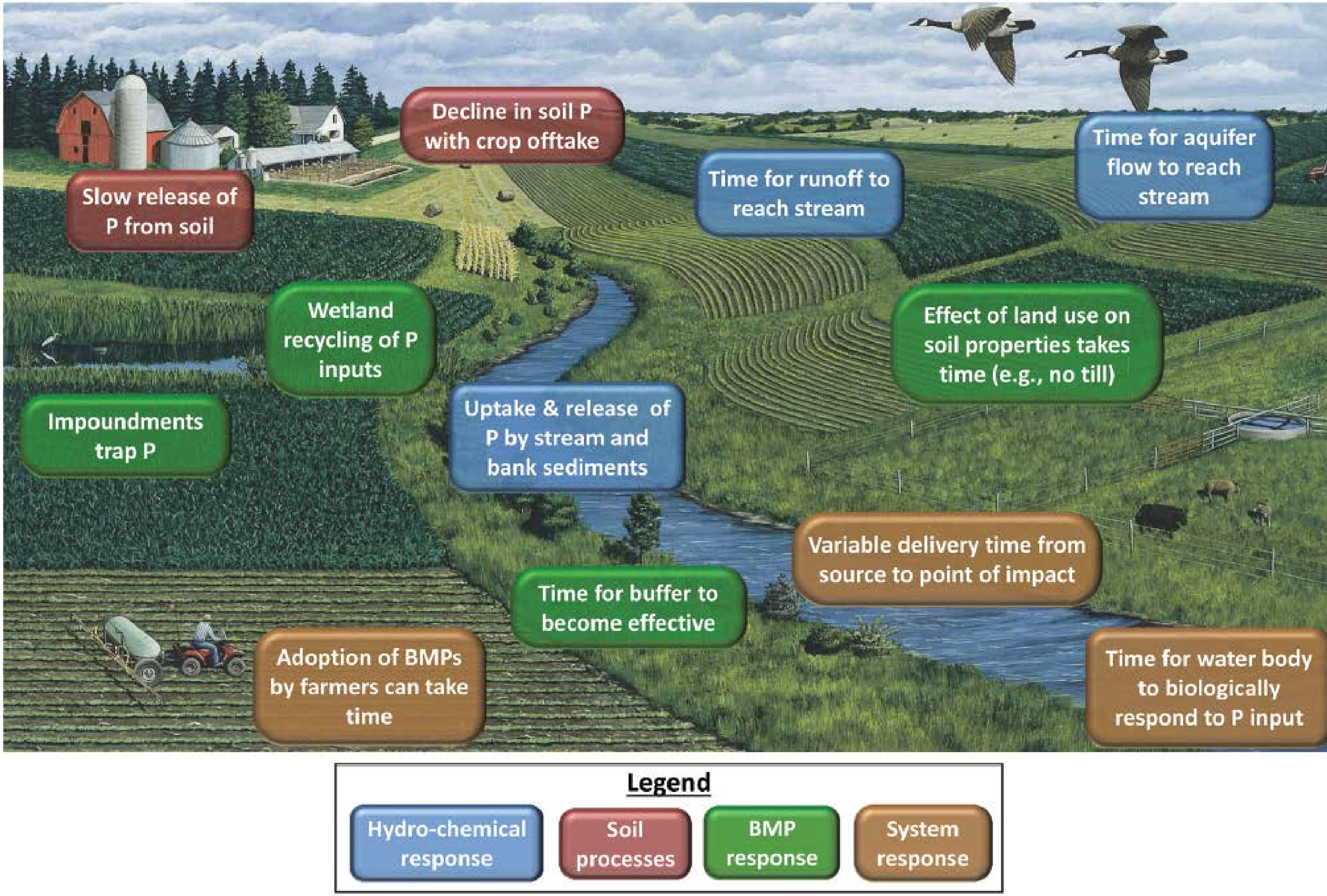


Fig. 1. Conceptual representation of natural, managed, soil, and best management practice (BMP) processes influencing the lag time for system response.

Source: Sharpley et al., 2013. Phosphorus Legacy: Overcoming the Effects of Past Management Practices to Mitigate Future Water Quality Impairment. J. Environ. Qual. 42:1308–1326

Acknowledgements

- We would like to acknowledge numerous students and other collaborators.
- Various funding sources have supported this work.

Brown County Established 1818

Outagamie County Est. 1851

USDA Natural Resources Conservation Service Wisconsin
United States Department of Agriculture

University of Wisconsin Green Bay

Oneida Nation

NEW Water

Great Lakes Restoration

- A est P