Agricultural Wetlandscapes

Land-Use Legacies and Water Quality Futures

Kim Van Meter

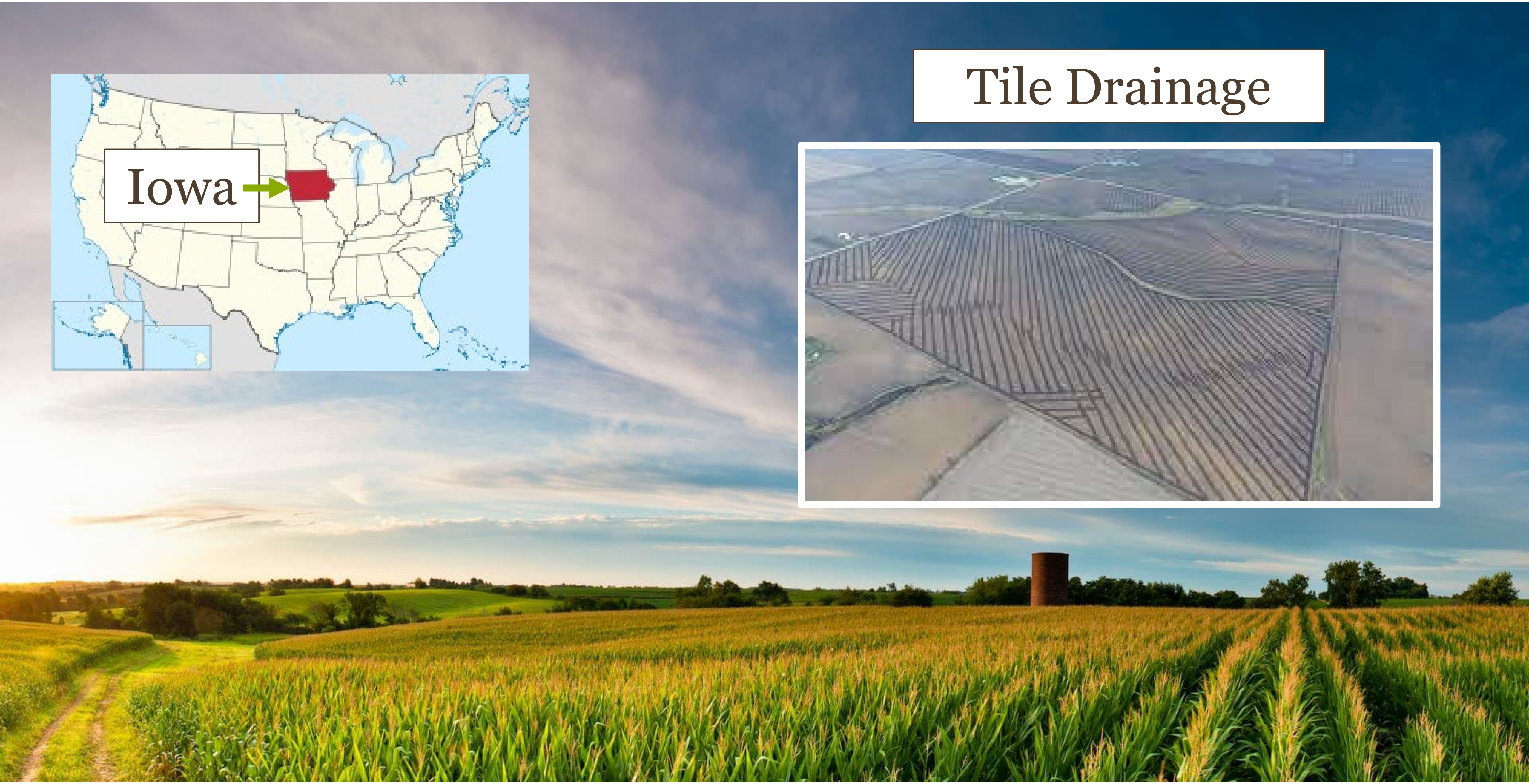
September 21st , 2022

PennState College of Earth and Mineral Sciences

Penn State University Water Insights Seminar Series

Earth and Environmental Systems Institute

Tile Drainage



POLITICOMAGAZINE

AP Photo

Clay Masters is a reporter for Iowa Public Radio.

A year ago, the Des Moines Water Works, the state of Iowa's largest water utility, filed suit against three rural counties, charging that for years they had been polluting the city's drinking water with impunity. In Iowa, where courtesy and cooperation rule, this was tantamount to a declaration of war.

Op-ed: Water Pollution in Iowa Is Environmental Injustice

White farmers in the state's corn, soy, and hog industries are turning a blind eye to the nitrate pollution impacting Black, brown, and low-income residents most.

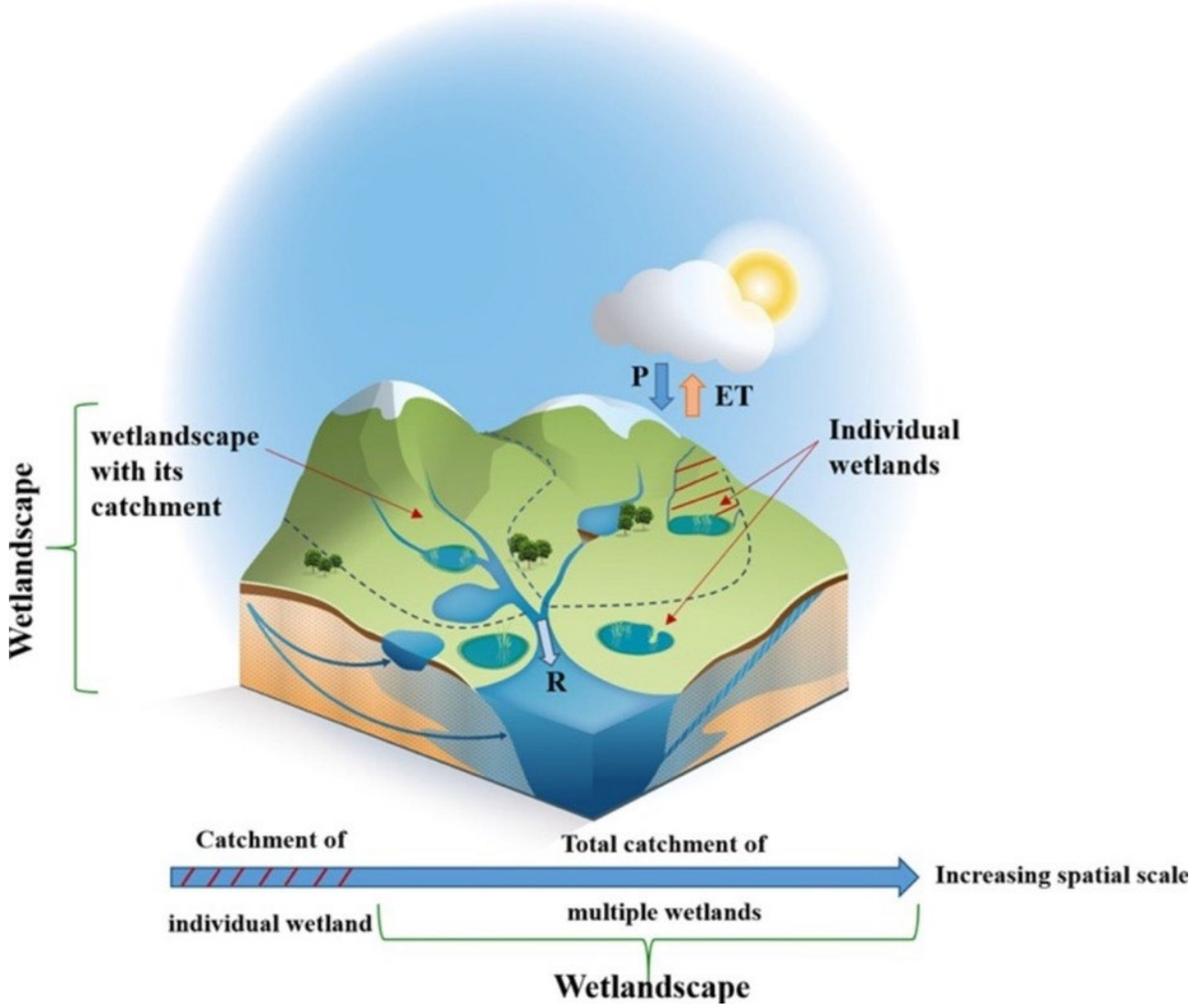
BY CHRIS JONES • MARCH 26, 2021

ELSEVIER

Ecological Engineering
Volume 108, Part B, November 2017, Pages 489-497

Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management

Josefin Thorslund [a], Jerker Jarsjo [a], Fernando Jaramillo [a, b], James W. Jawitz [c], Stefano Manzoni [a], Nandita B. Basu [d], Sergey R. Chalov [e], Matthew J. Cohen [f], Irena F. Creed [g], Romain Goldenberg [a], Anna Hylin [a], Zahra Kalantari [a], Antonis D. Koussis [h], Steve W. Lyon [a], Katerina Mazi [h], Johanna Mard [i], Klas Persson [a], Jan Pietro [a], Carmen Prieto [a], Andrew Quin [a], Kimberly Van Meter [d], Georgia Destouni [a, j]



What are Nature-Based-Solutions?

Use of **NATURE** to address a range of global environmental and social challenges

CLIMATE

WATER QUALITY

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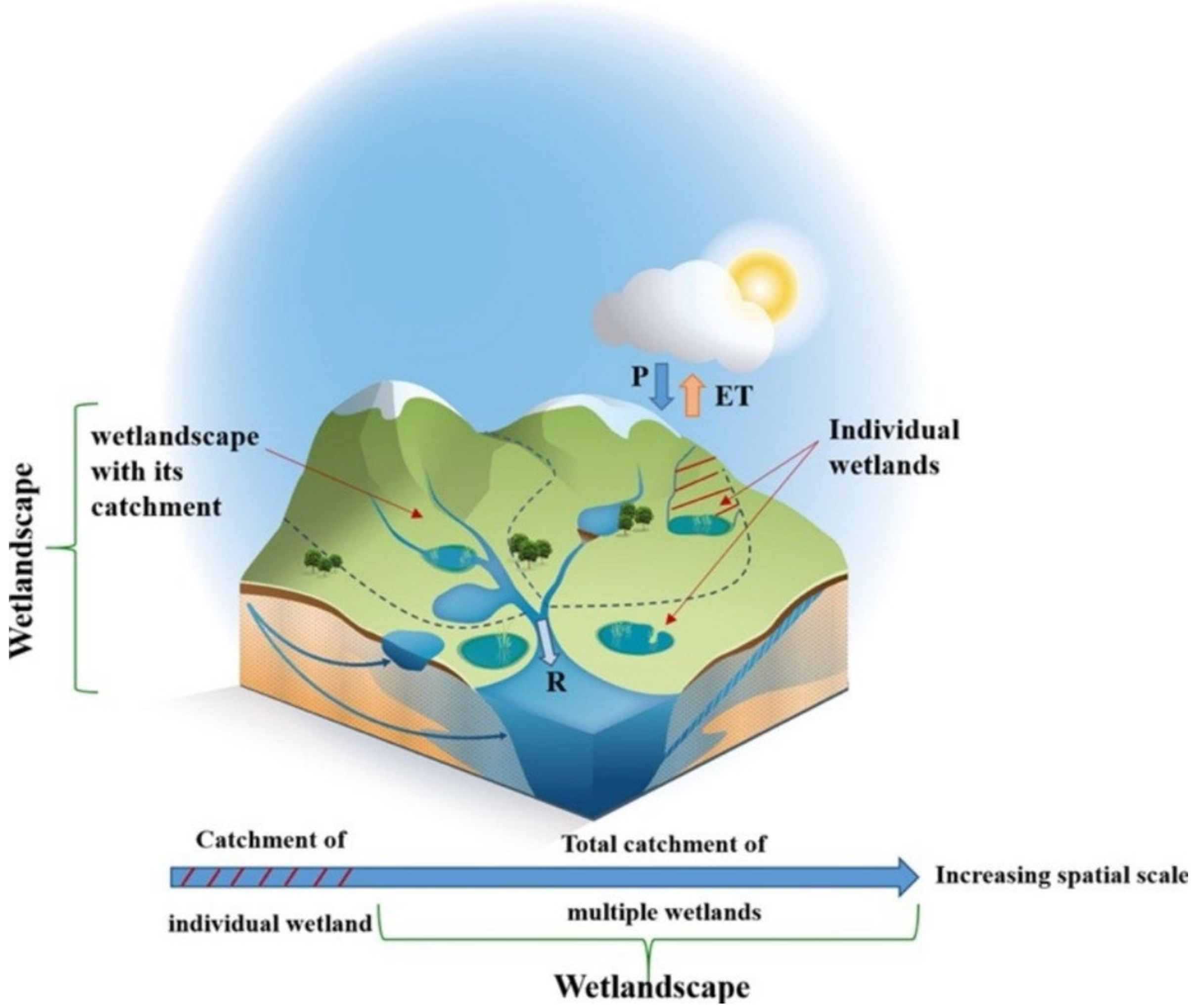


What are Nature-Based-Solutions?

Use of **NATURE** to address a range of global environmental and social challenges

Carbon Sequestration

Water Purification

Flood Control

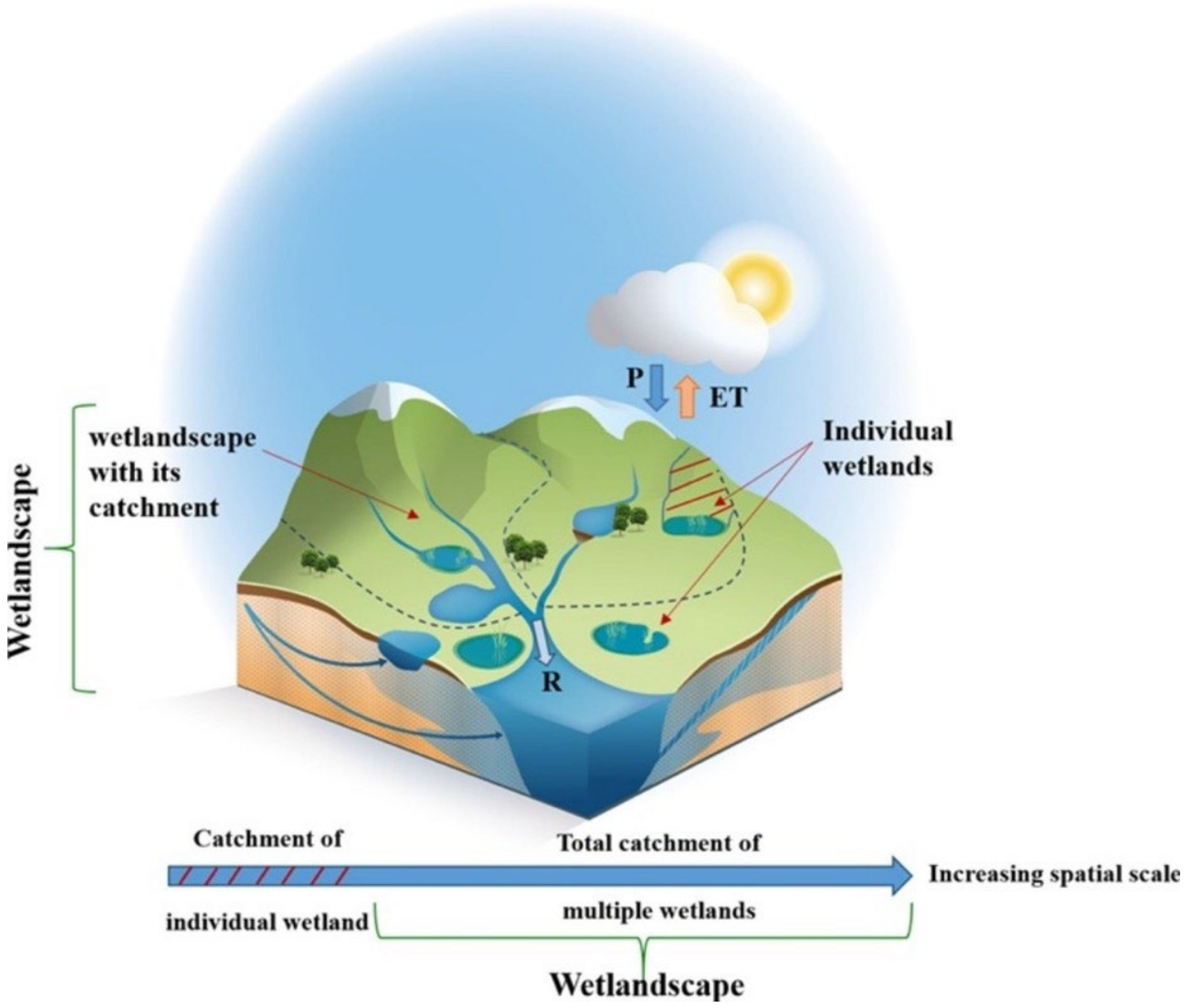
Biodiversity Support

What is the appropriate scale for studying wetland functions?

WETLANDSCAPE

…a need to consider the large-scale functioning of the hydrologically coupled SYSTEM of multiple wetlands and their total hydrological catchment

Thorslund et al. 2017



What is the appropriate scale for studying wetland functions?

WETLANDSCAPE

...a need to consider the large-scale functioning of the hydrologically coupled SYSTEM of multiple wetlands and their total hydrological catchment

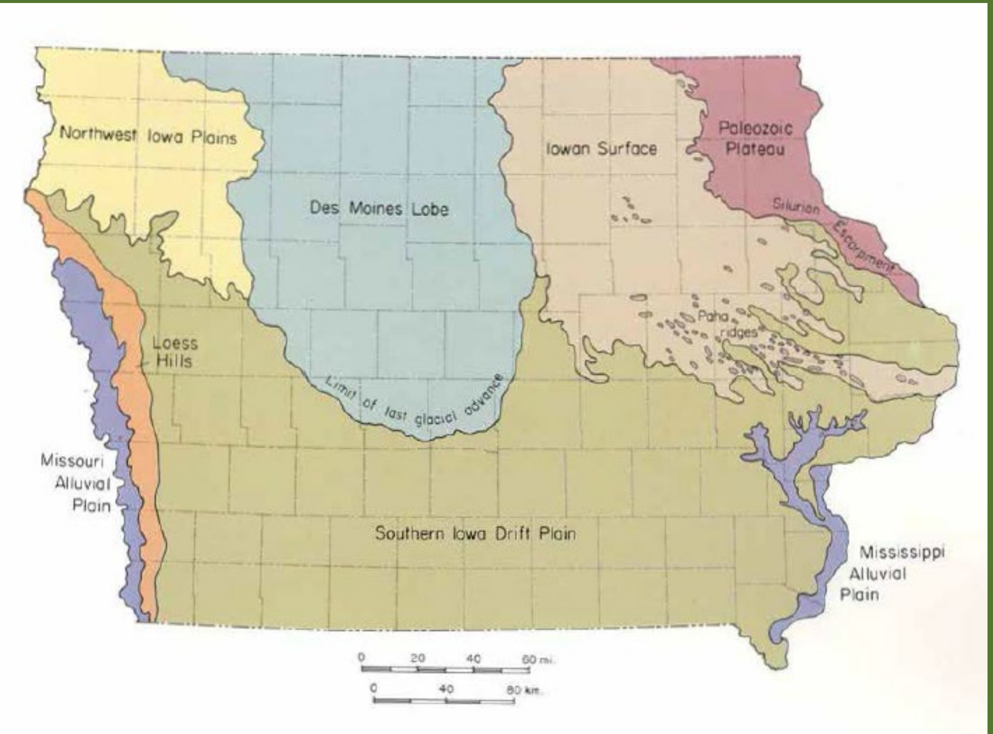
Thorslund et al. 2017

"the scale must be enlarged from the individual wetland project to include the broader landscape. Only this broader view can provide the context within which decision-makers can evaluate the potential cumulative effects of individual mitigation decisions on broad-scale patterns of wetland diversity".

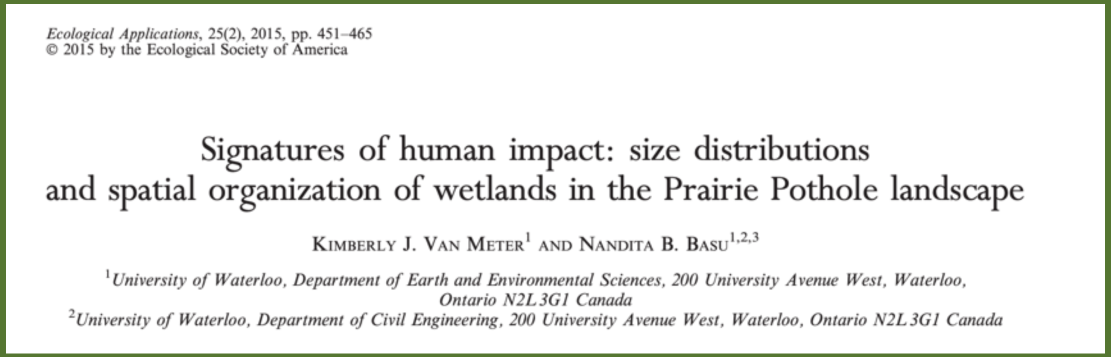
E.M. Preston & Barbara Bedford (1988)

Prairie Pothole Region

700,000 km²



Landform Regions of Iowa


Ecological Applications, 25(2), 2015, pp. 451–465

Signatures of human impact: size distributions and spatial organization of wetlands in the Prairie Pothole landscape

Kimberly J. Van Meter[1] and Nandita B. Basu[1,2,3]

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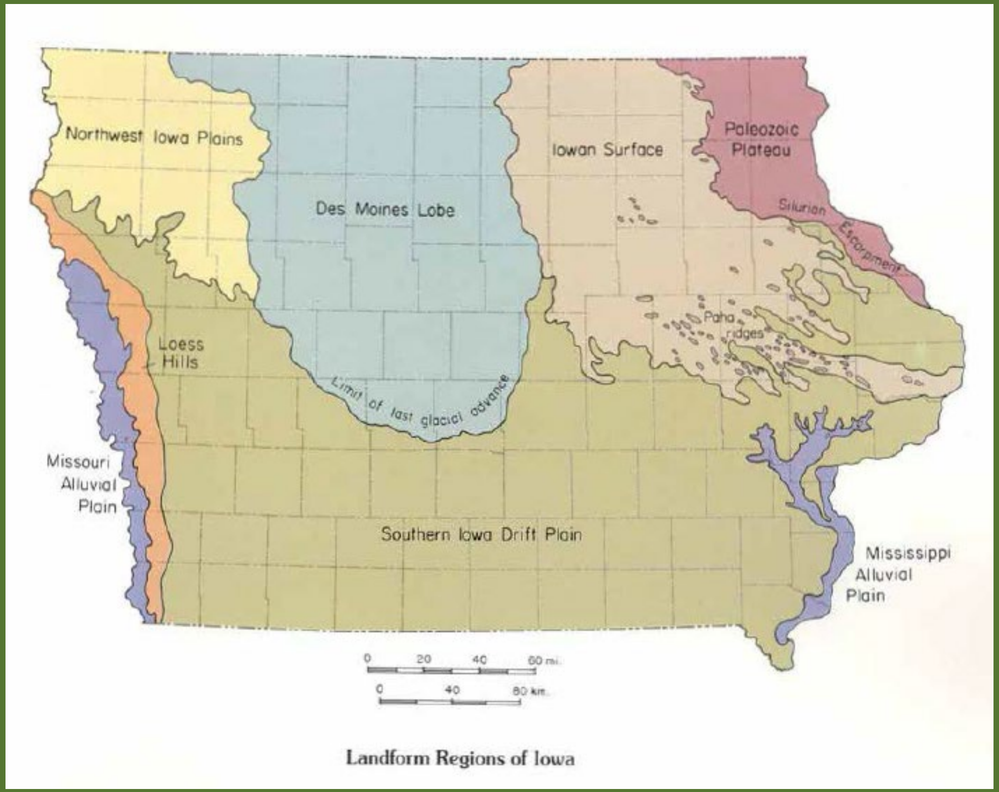
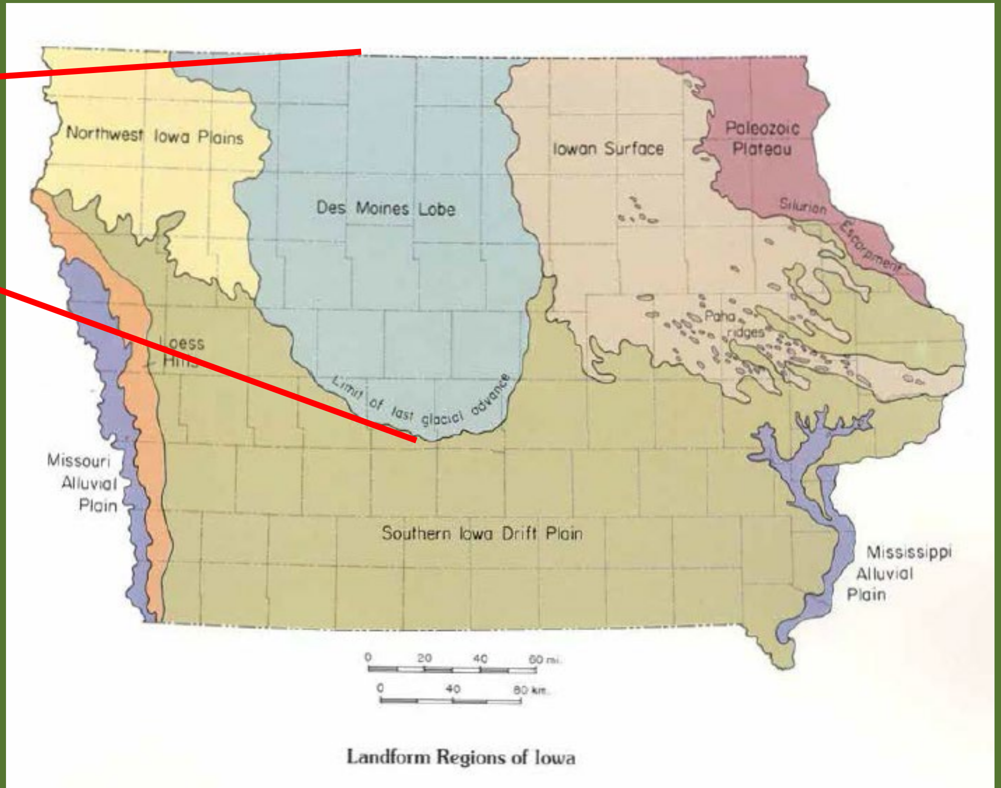
[2]*University of Waterloo, Department of Civil Engineering, 200 University Avenue West, Waterloo, Ontario N2L 3G1 Canada*

700,000 km²



Study Area

Iowa portion of the Des Moines Lobe



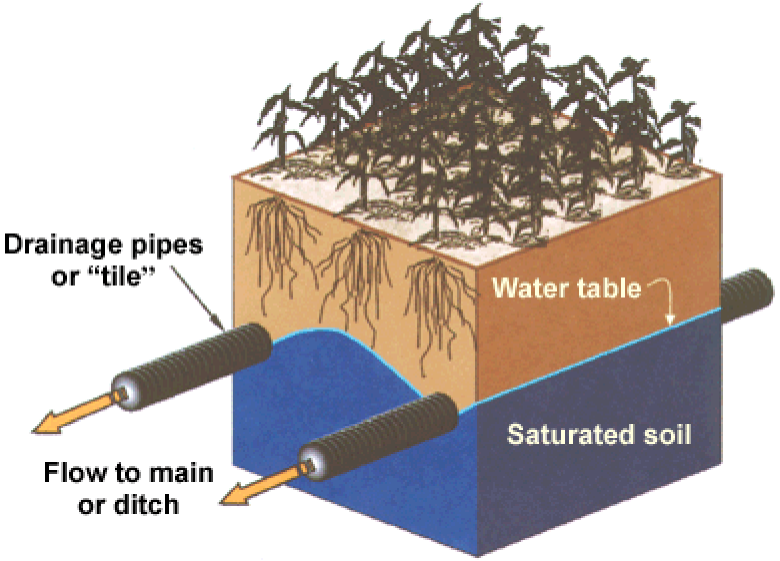
Availability of high-resolution (1-m) LiDAR data with ±18 cm vertical accuracy

Objectives

To better our understanding of the size distribution and spatial organization of historical wetlands

To explore the role of human impacts in altering historical patterns

European Settlement
Draining the Prairies



Des Moines Lobe Prairie Potholes

Farmed Wetlands

"farmed areas that in most years have standing water for at least 7 consecutive days or saturated soils for 14 consecutive days during the growing season"

Methodology

LiDAR and Soil Survey data used to identify depressional wetlands located on hydric soil

National Wetlands Inventory (NWI) data used to identify current wetlands

2008 Satellite image, Story County, Iowa

Methodology

LiDAR and Soil Survey data used to identify depressional wetlands located on hydric soil

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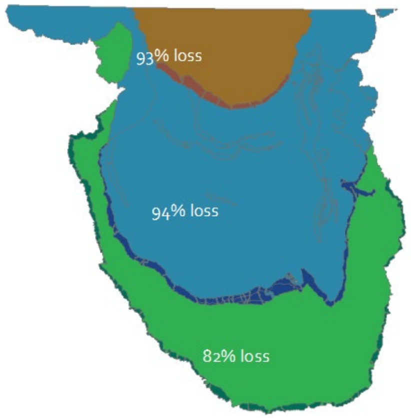
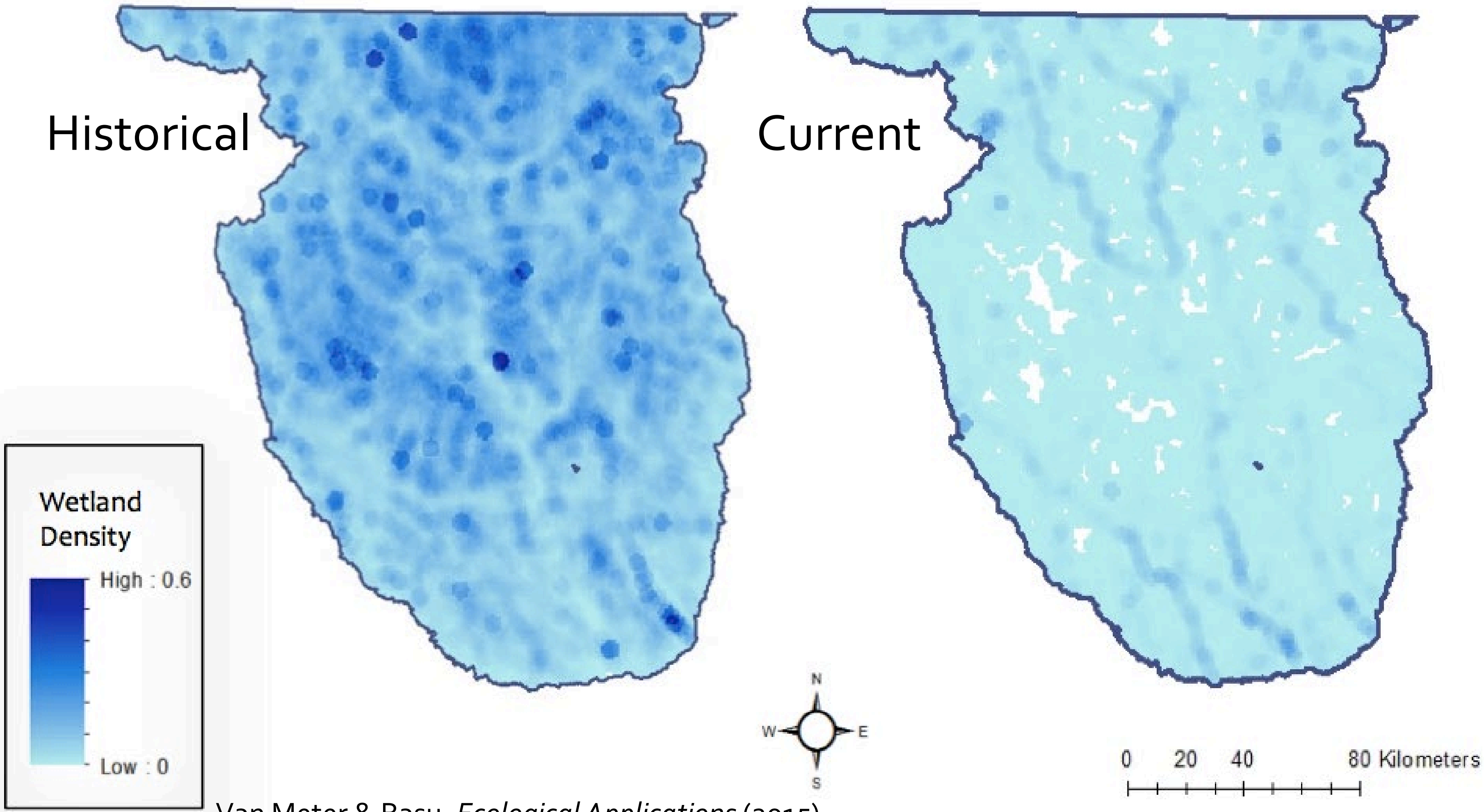
National Wetlands Inventory (NWI) data used to identify current wetlands

Reductions in Wetland Density



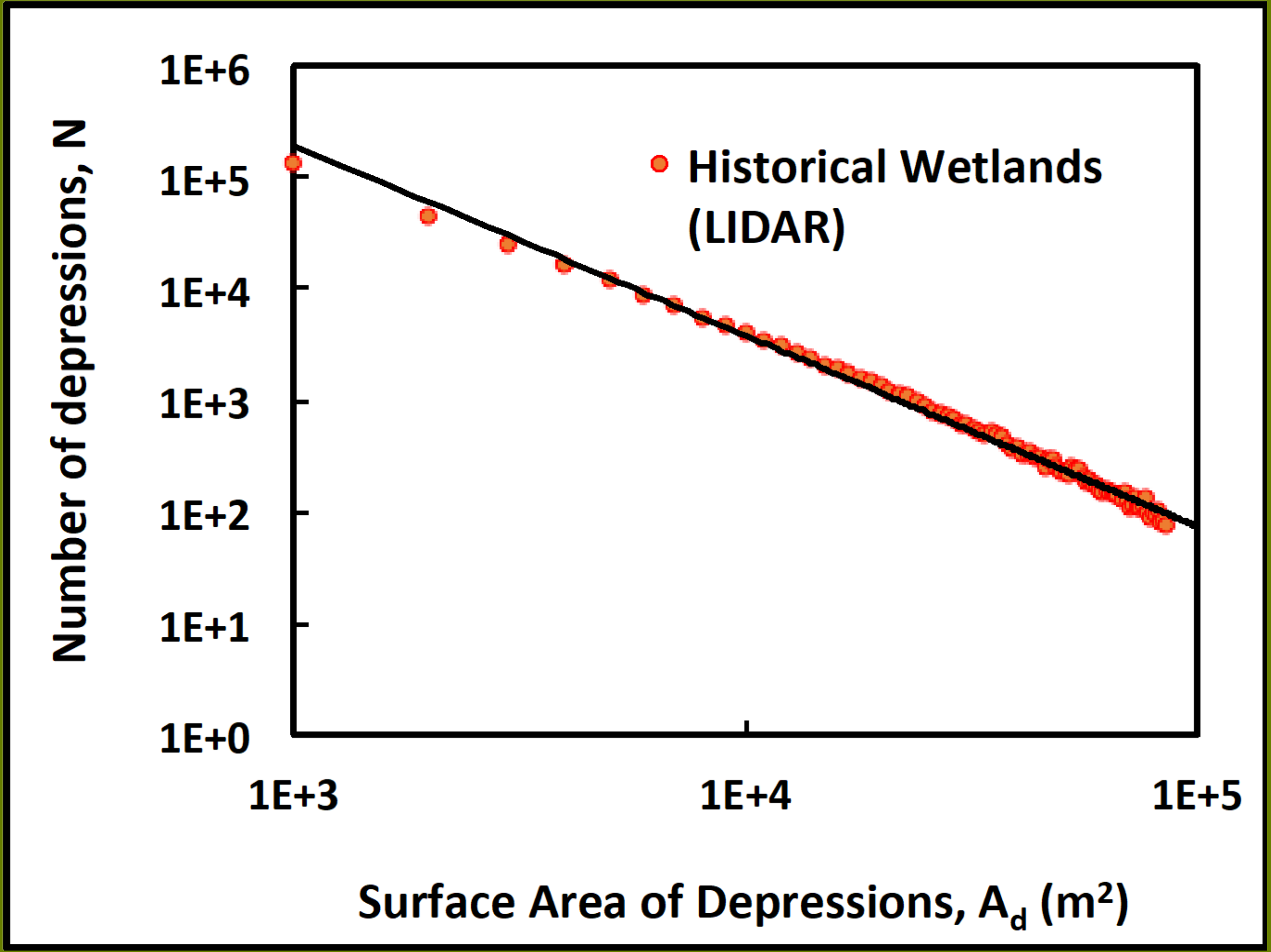
Overall
90%
Loss of
Historical
Wetland
Area



Van Meter & Basu, *Ecological Applications* (2015)

Mean Nearest Neighbor Distances: Historical 150 m, Current 197 m

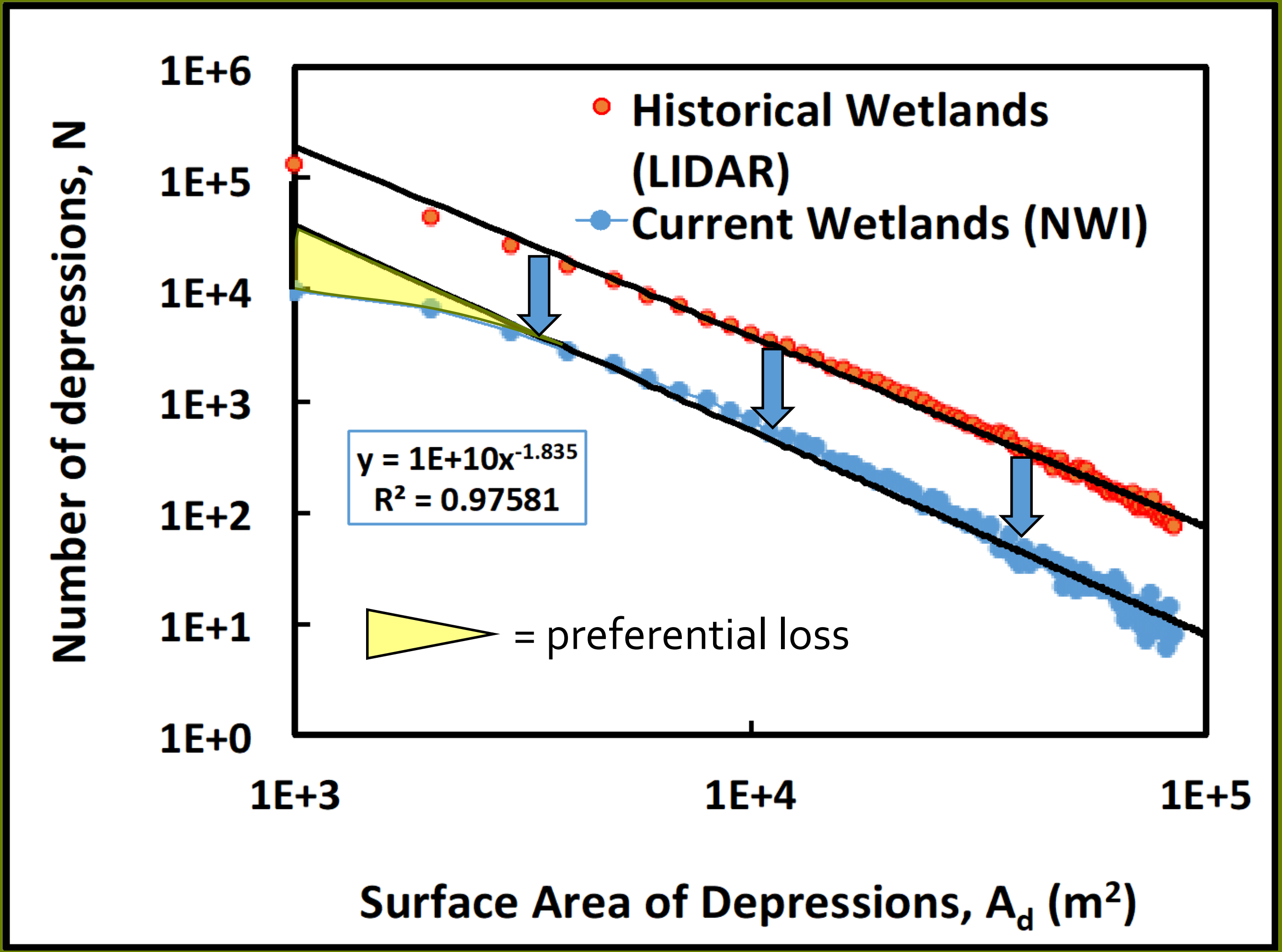
Size-Frequency Distributions of Historical Wetlands follow a Power Law Relationship



Van Meter & Basu, *Ecological Applications* (2015)

Overall, 90% loss of historical wetland area

Preferential loss of smaller wetlands



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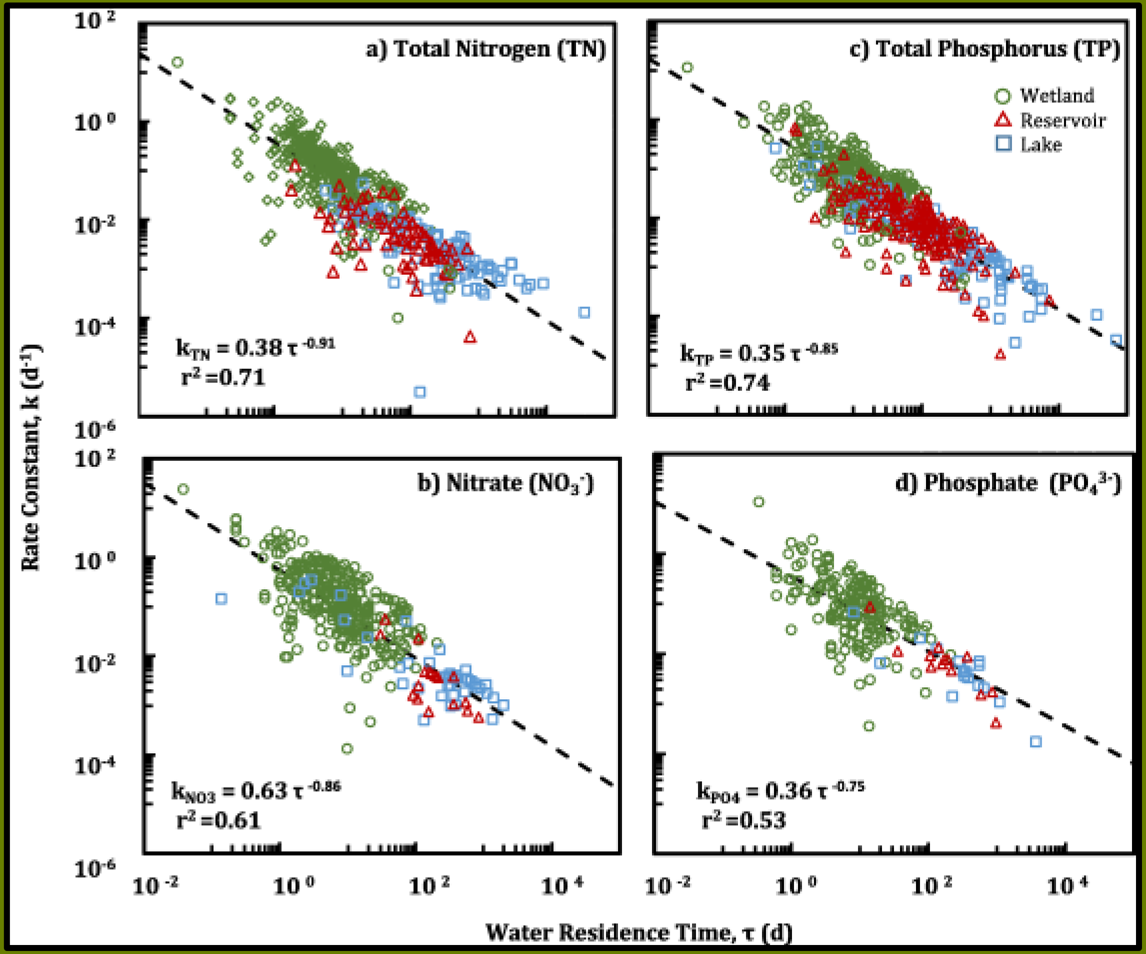
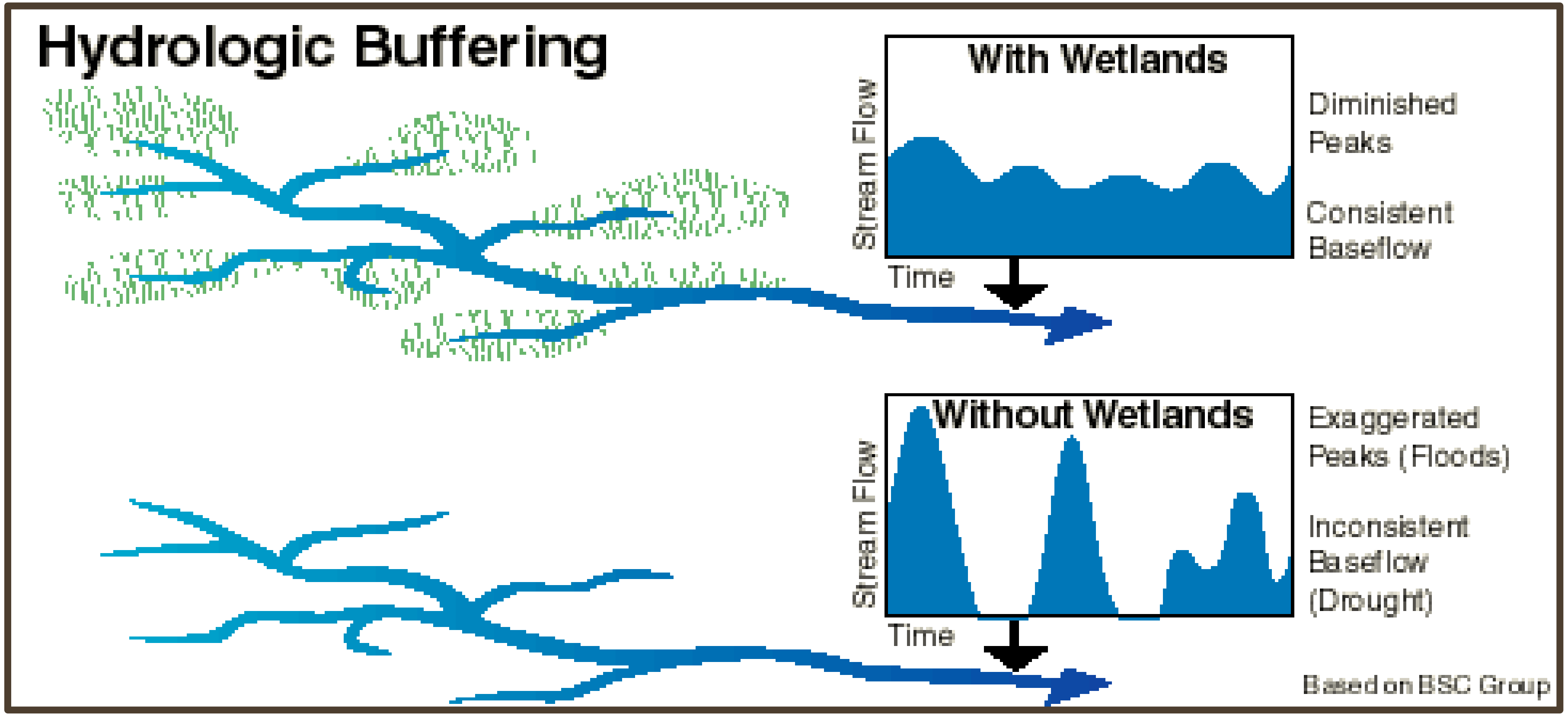
Water Quality



Cheng & Basu (2017)

Smaller wetlands have faster denitrification kinetics (similar to headwater streams)

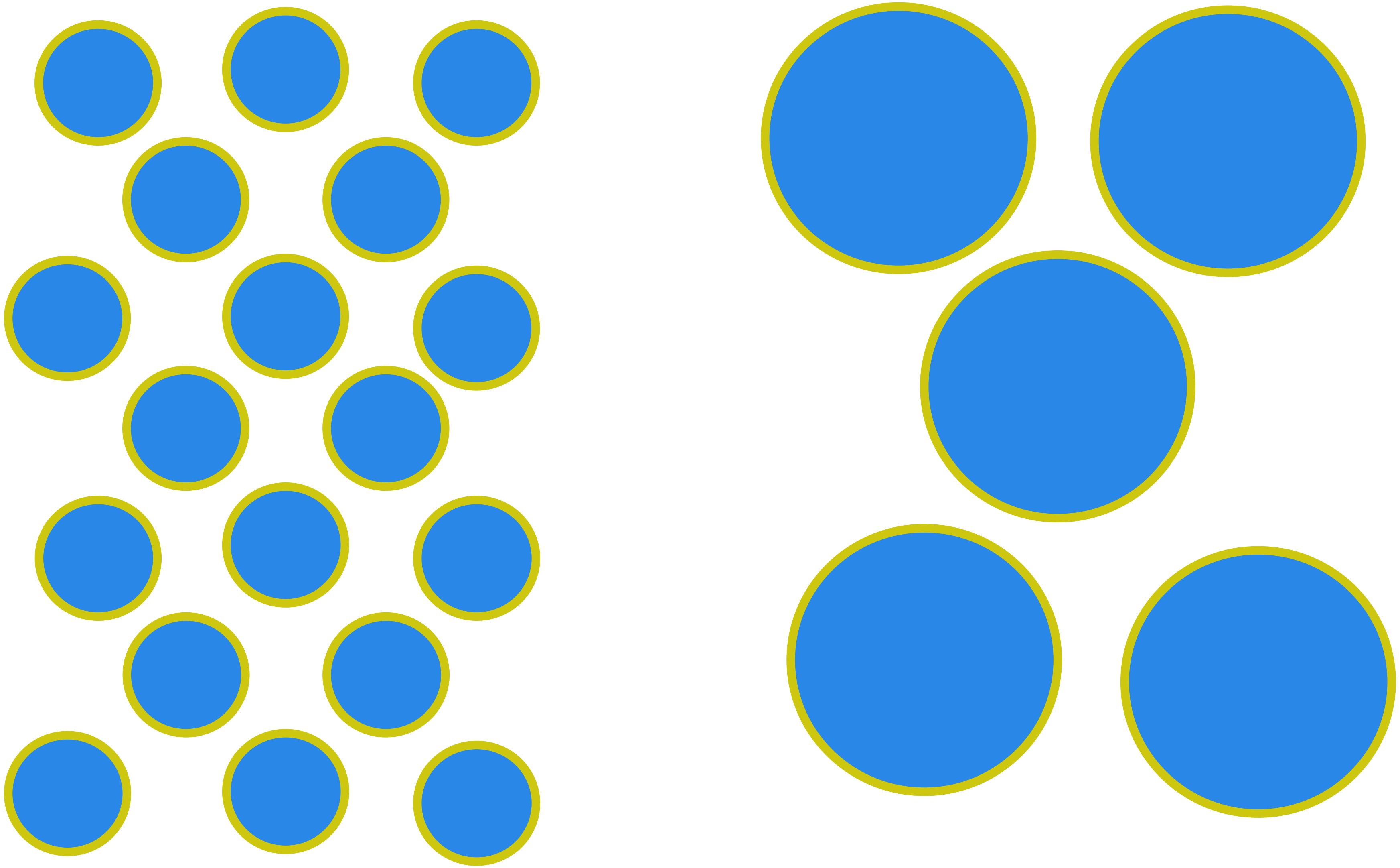
Groundwater Recharge & Flood Control



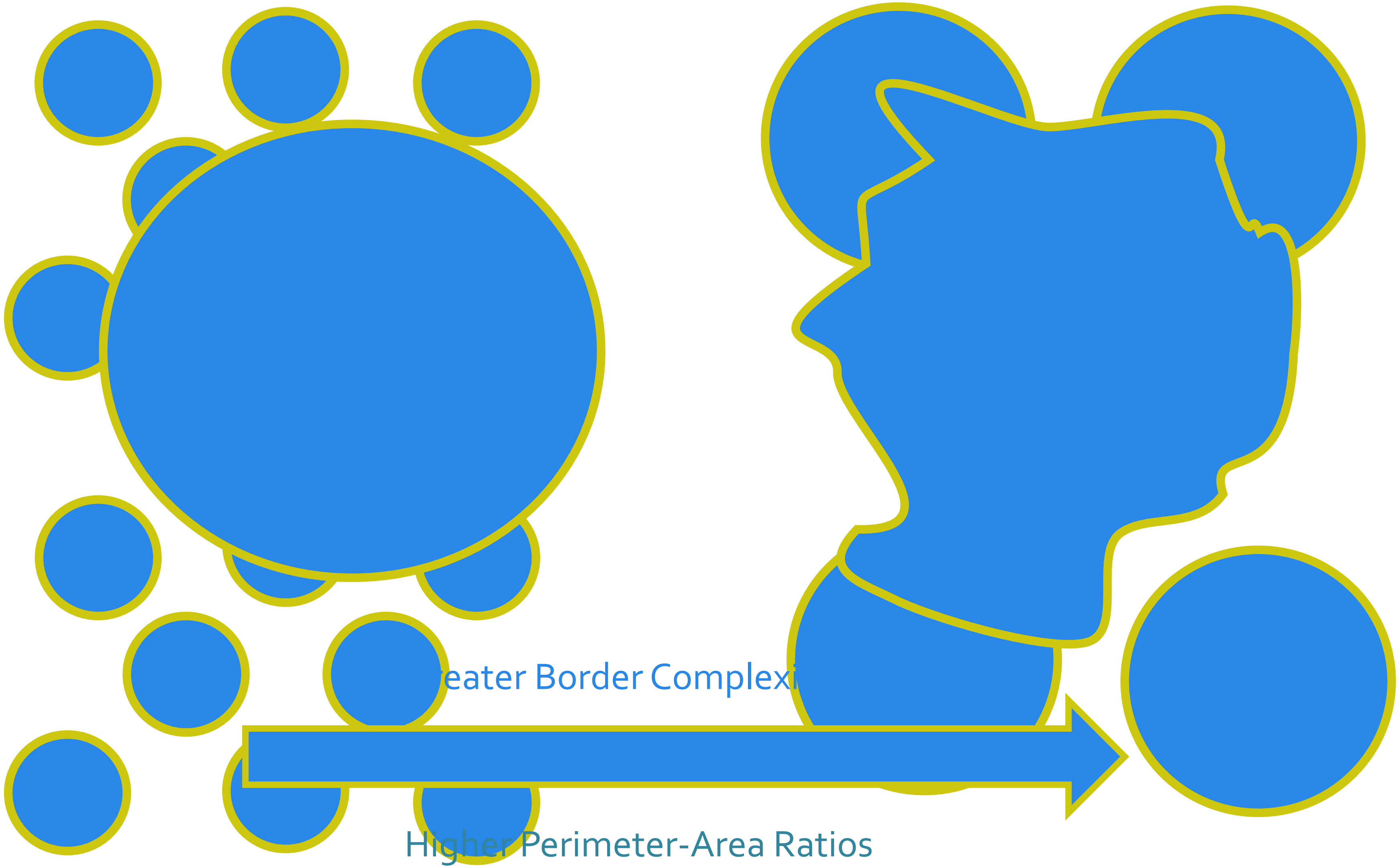
Smaller wetlands have high perimeter to volume ratios, providing more surface area through which water can infiltrate into groundwater.

Perimeter-Area Ratio

What about Wet Shape?



Perimeter-Area Ratios



Perimeter-Area Ratios

reduced species abundance

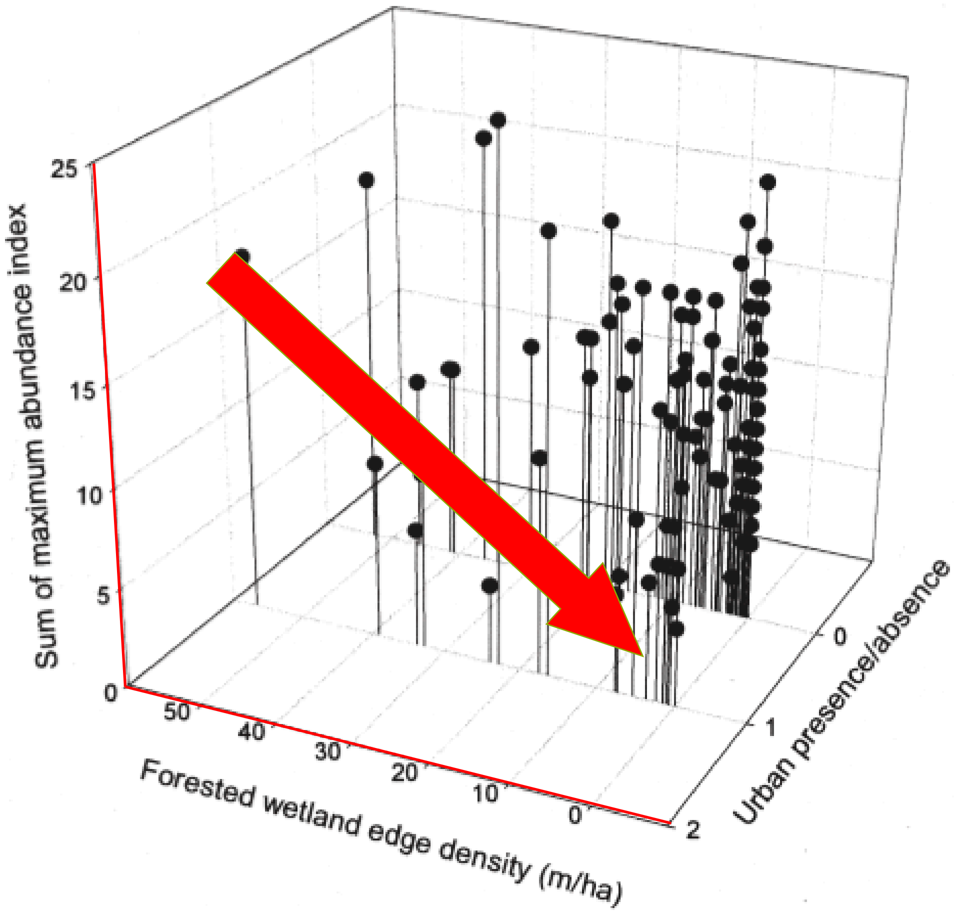


Figure 1. Iowa data for forested wetland edge density, urban presence or absence, and the sum of maximum abundance indices for all species.

Knutson et al. 1999

The size

Distribution

Matters…

Small Wetlands as Biogeochemical Hotspots

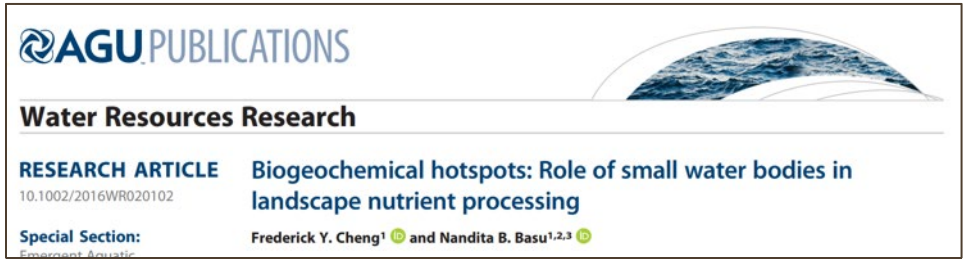
Do small wetlands matter in nutrient cycling?

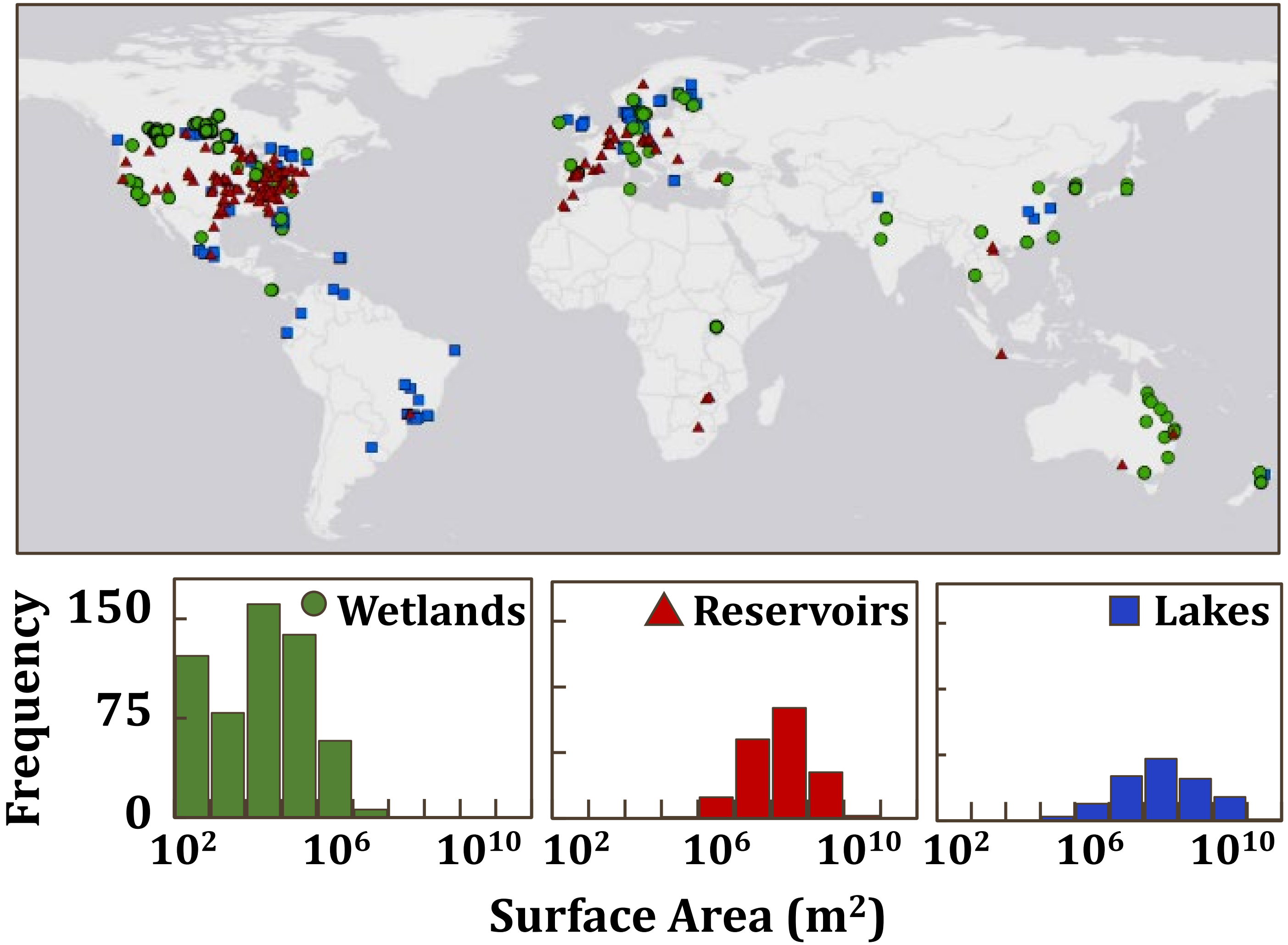
Data Synthesis

Modeling

Meta-Analysis of Nutrient Processing Rates

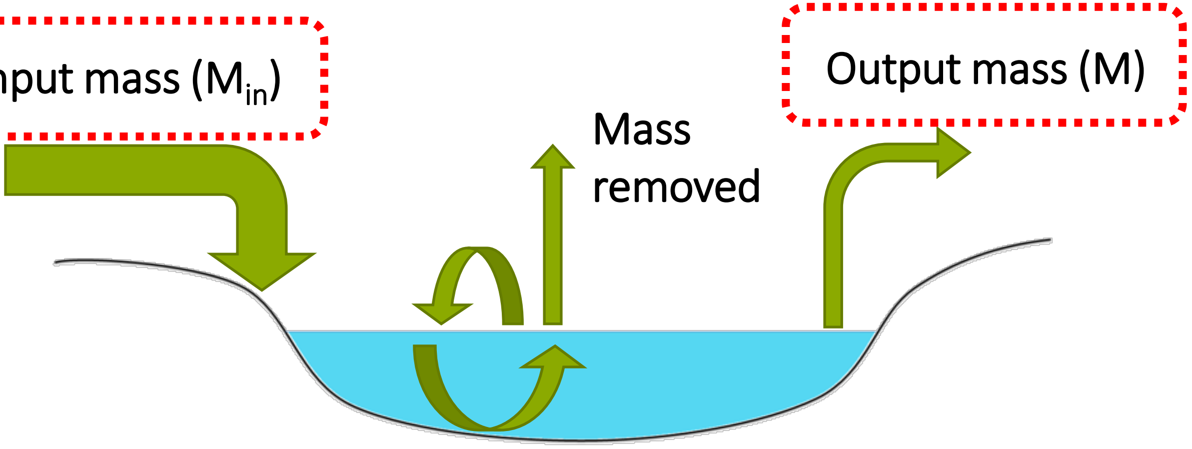
Collected data from approximately 600 water bodies relating to nitrogen and phosphorus





Modeling Nitrogen Removal in Wetlands

Assuming first-order removal kinetics



$$\boldsymbol{\rho} = \left(1 - e^{-k\tau}\right)$$

Fractional N Removal

τ is the water residence time [hydrology]

k is the first-order removal rate constant [biogeochemistry]

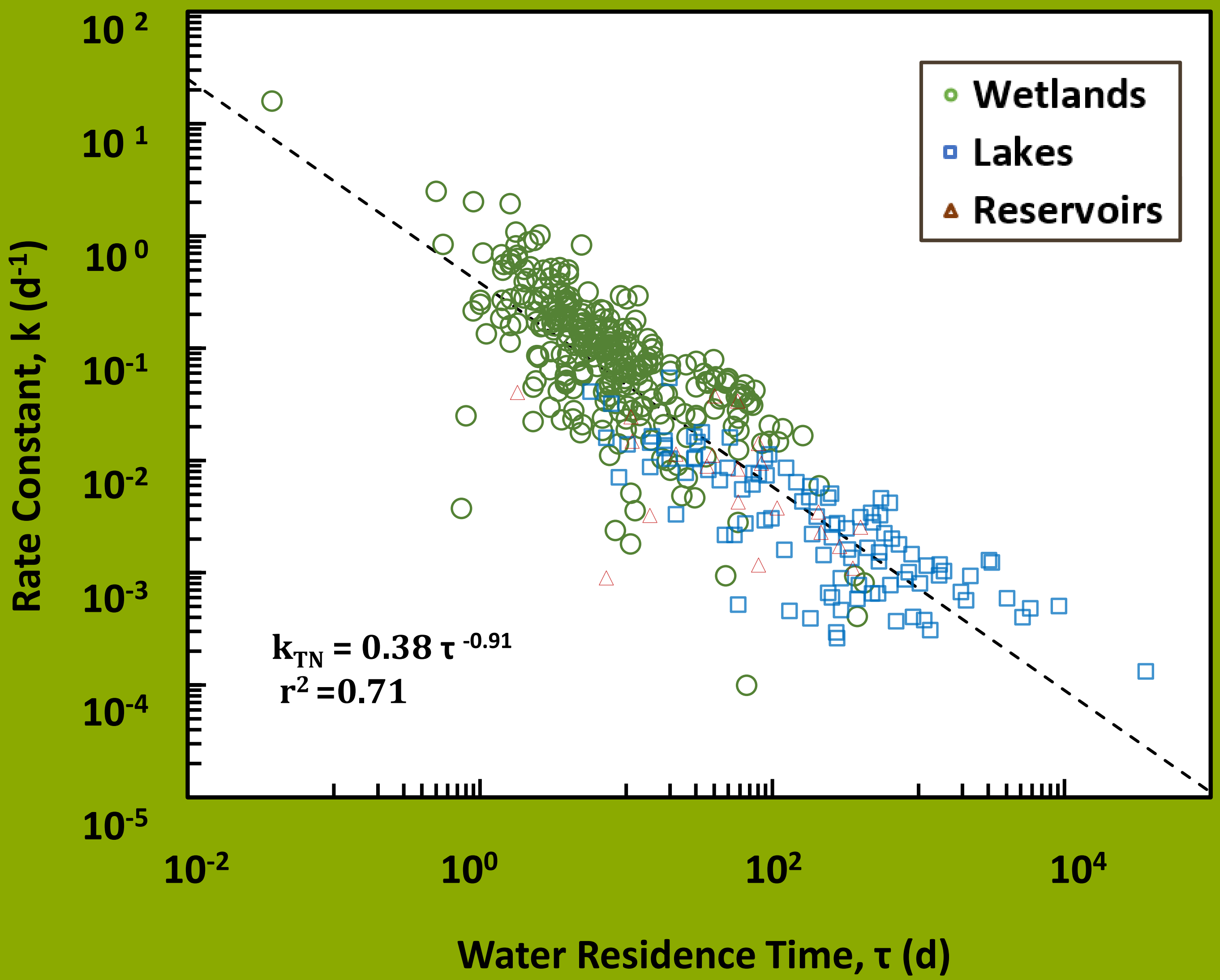
↑ k will result in higher removal

Small wetlands are more reactive

Nutrient processing rate constants scale inversely with residence times and size

Small wetlands have a higher sediment to water ratio

i.e. more contact between denitrifying bacteria and nitrogen in water in small systems



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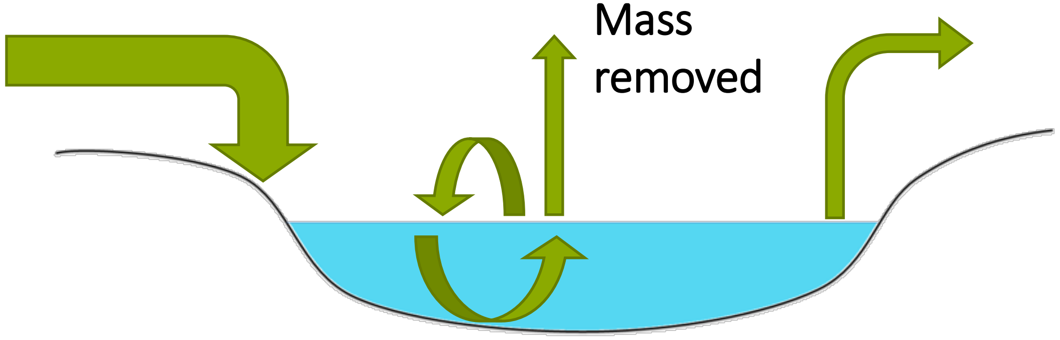


$$\boldsymbol{\rho} = \left(\mathbf{1} - \boldsymbol{e}^{-\boldsymbol{k\tau}}\right)$$

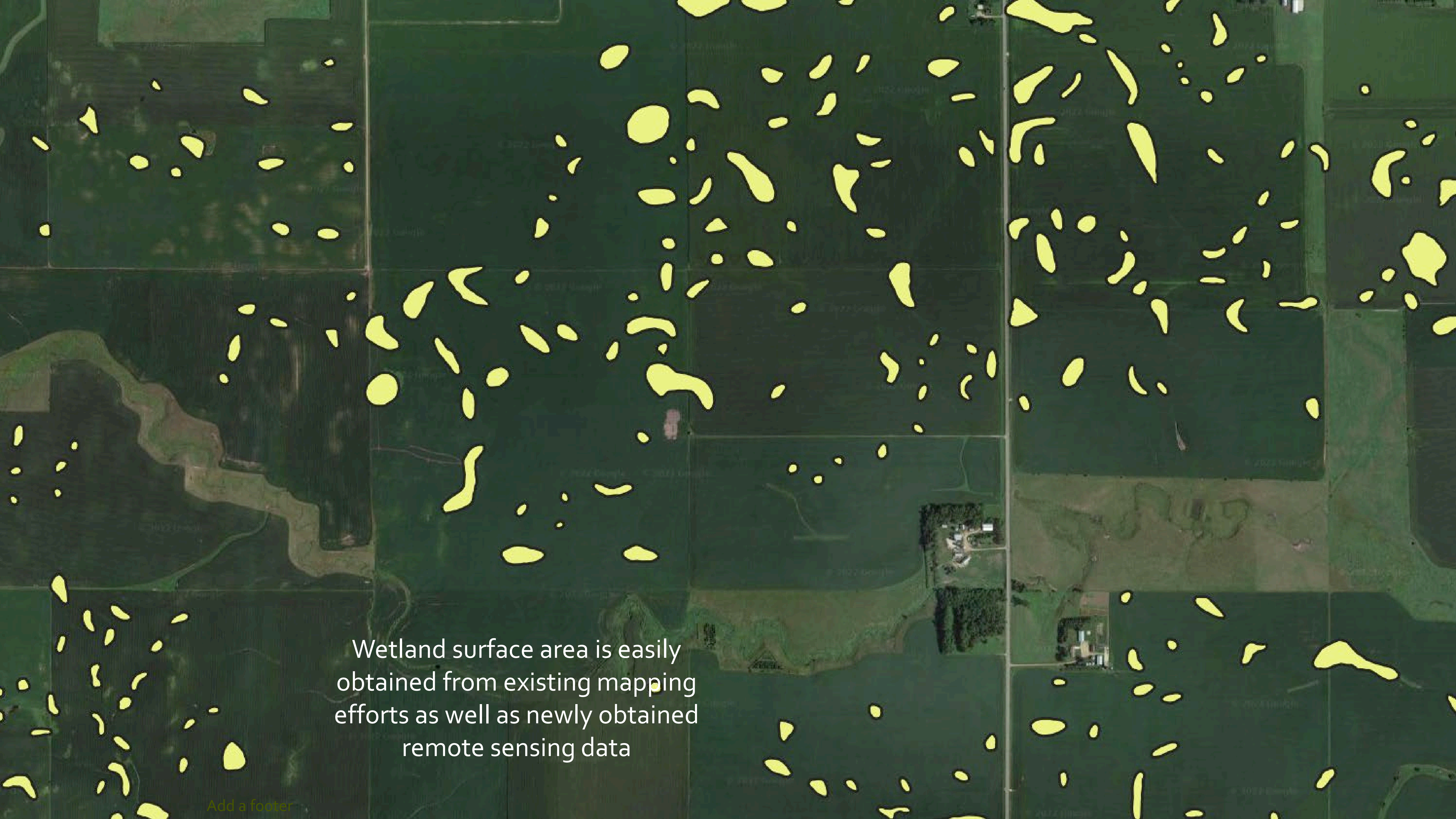
How do we get residence times for large wetlandscapes with hundreds or thousands of wetlands?

$$\tau = \frac{V}{Q}$$

Residence Time = Volume/Water Flux

$$\tau \propto SA$$

Residence Time is proportional to Surface Area


Wetland surface area is easily
obtained from existing mapping
efforts as well as newly obtained
remote sensing data
Add a footer

No net loss wetlands policy

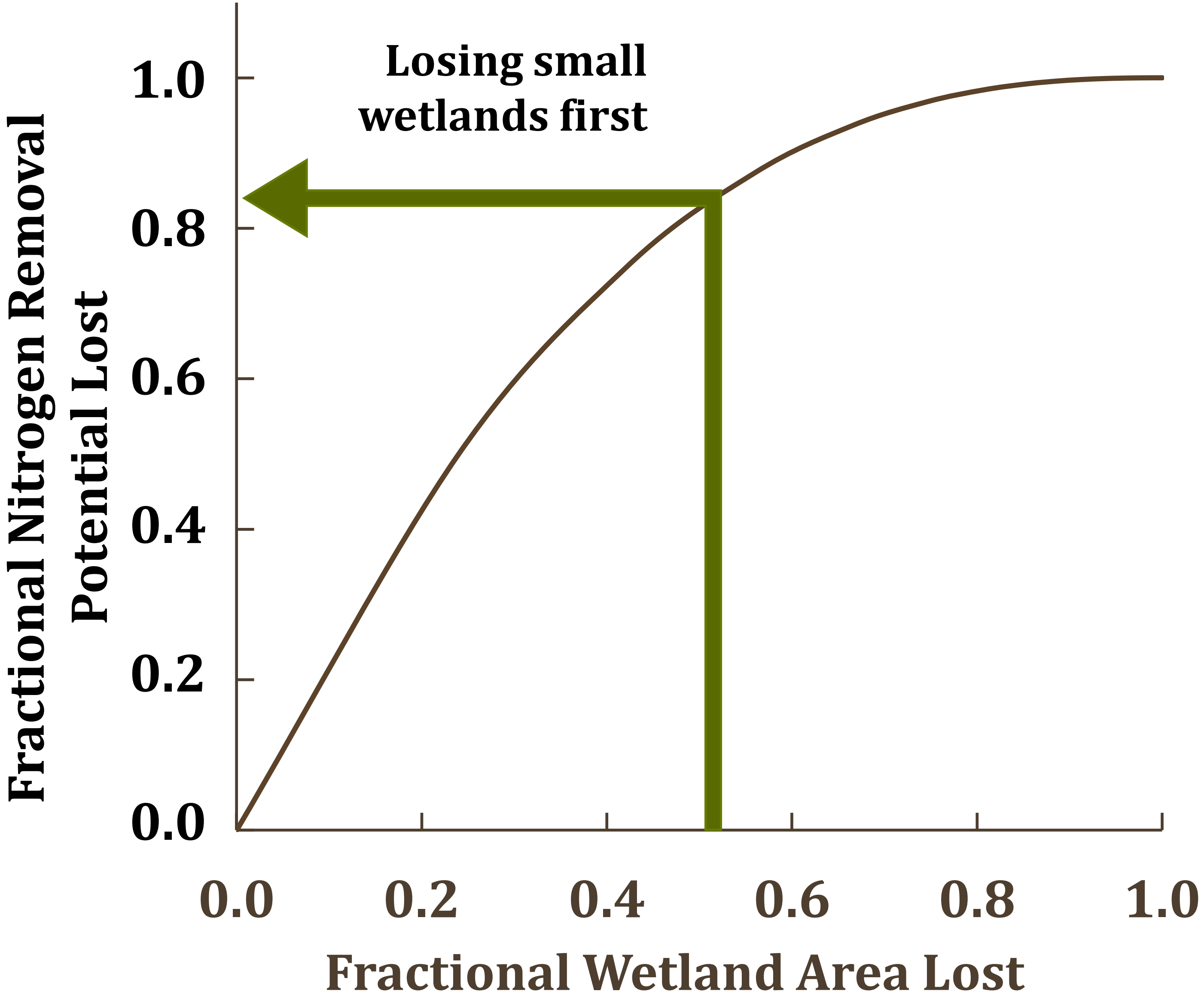
"The goal of the policy is to balance wetland loss due to economic development with wetlands reclamation, mitigation, and restorations efforts, so that the total acreage of wetlands in the country does not decrease, but remains constant or increases."

What wetlands should be protected or restored?

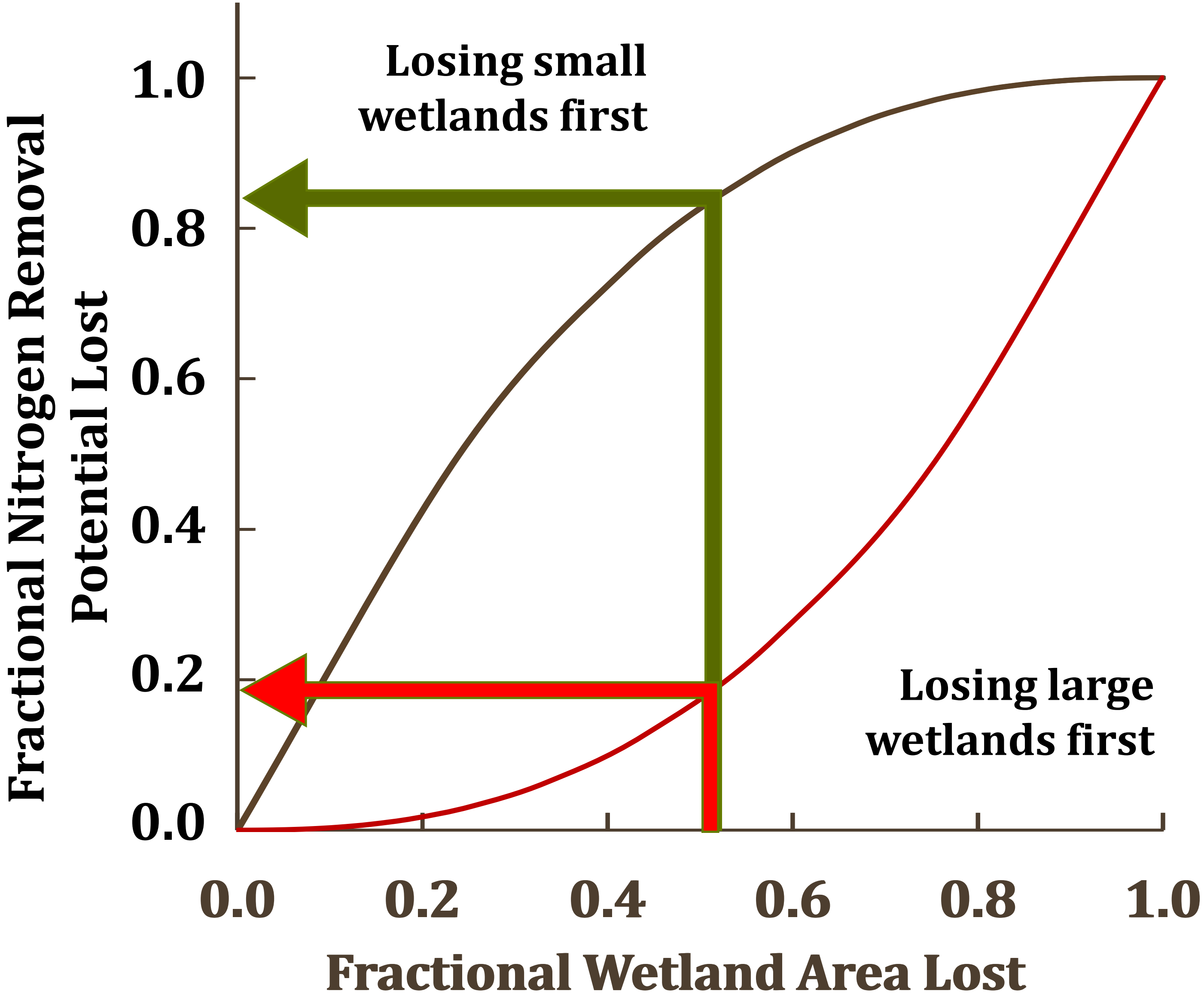
or

Small or large wetlands of the same total area?

Landscape Wetland Losses



Preferential Losses in the Landscape

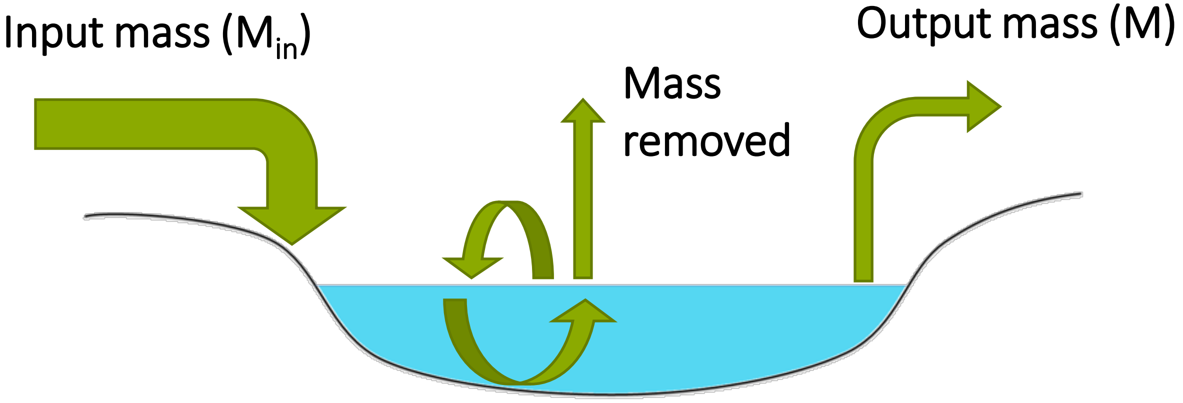


How can wetland restoration contribute to improvements in water quality?

Which wetland will remove more nitrate???

Modeling Nitrogen Removal in Wetlands

Assuming first-order removal kinetics



$$\boldsymbol{\rho} = \left(\mathbf{1} - \boldsymbol{e}^{-\boldsymbol{k\tau}}\right)$$

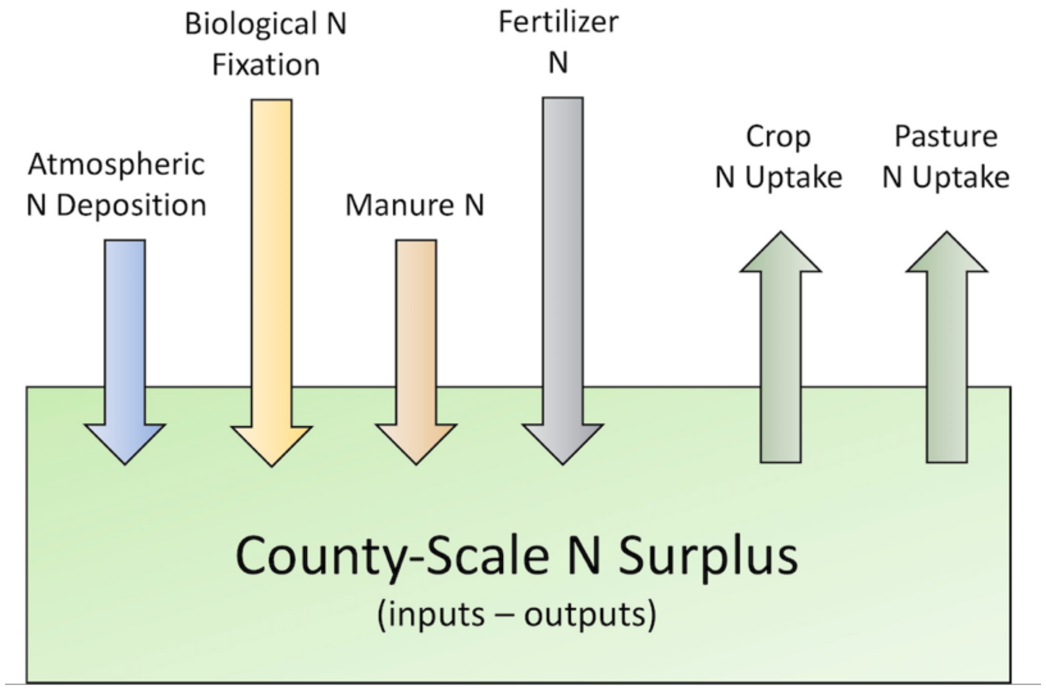
$$\boldsymbol{R} = \boldsymbol{\rho} * \boldsymbol{M_{in}}$$

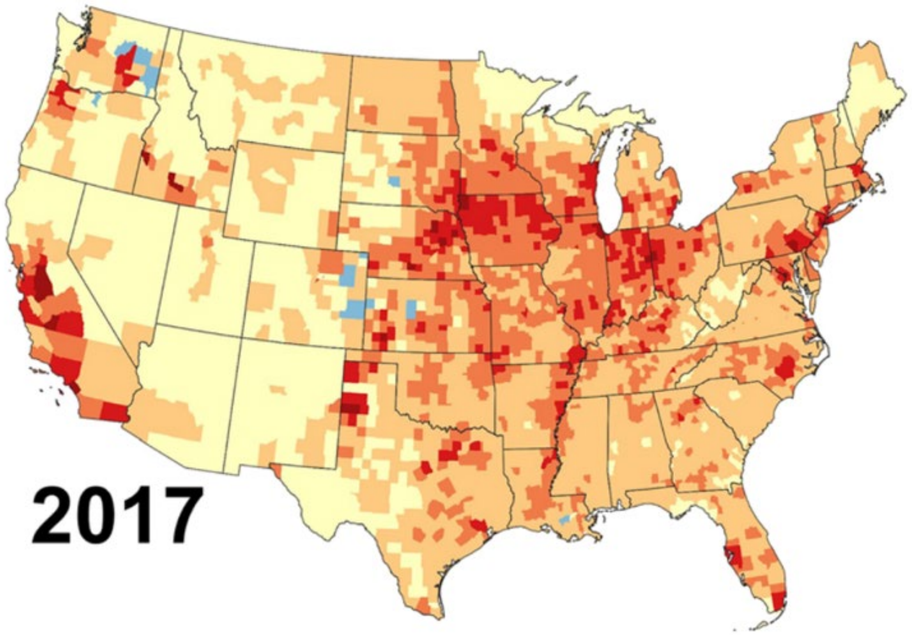
Fractional N Removal

Mass Removed

We need to know how much N mass is entering the wetland to estimate N removal!

TREND-Nitrogen County-Scale N Surplus





Byrnes, Van Meter, et al. (2020), *GBC*

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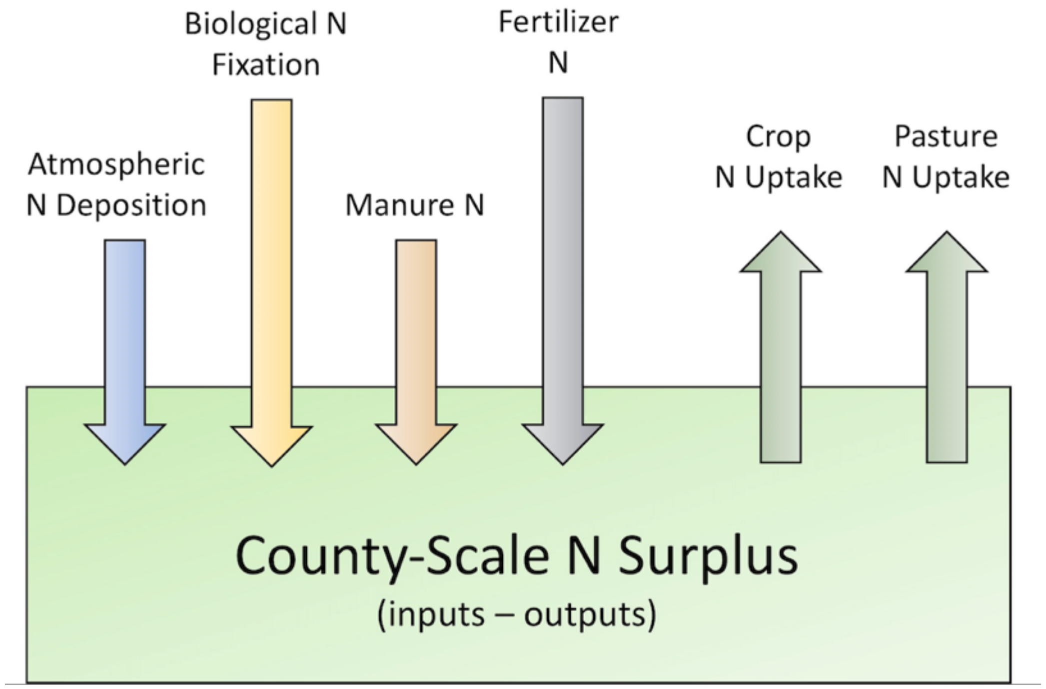

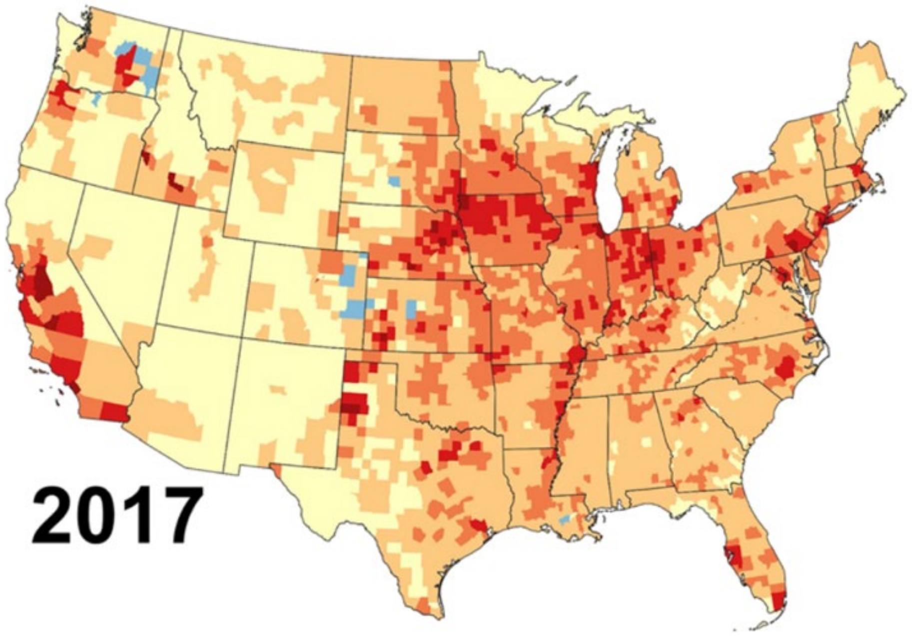

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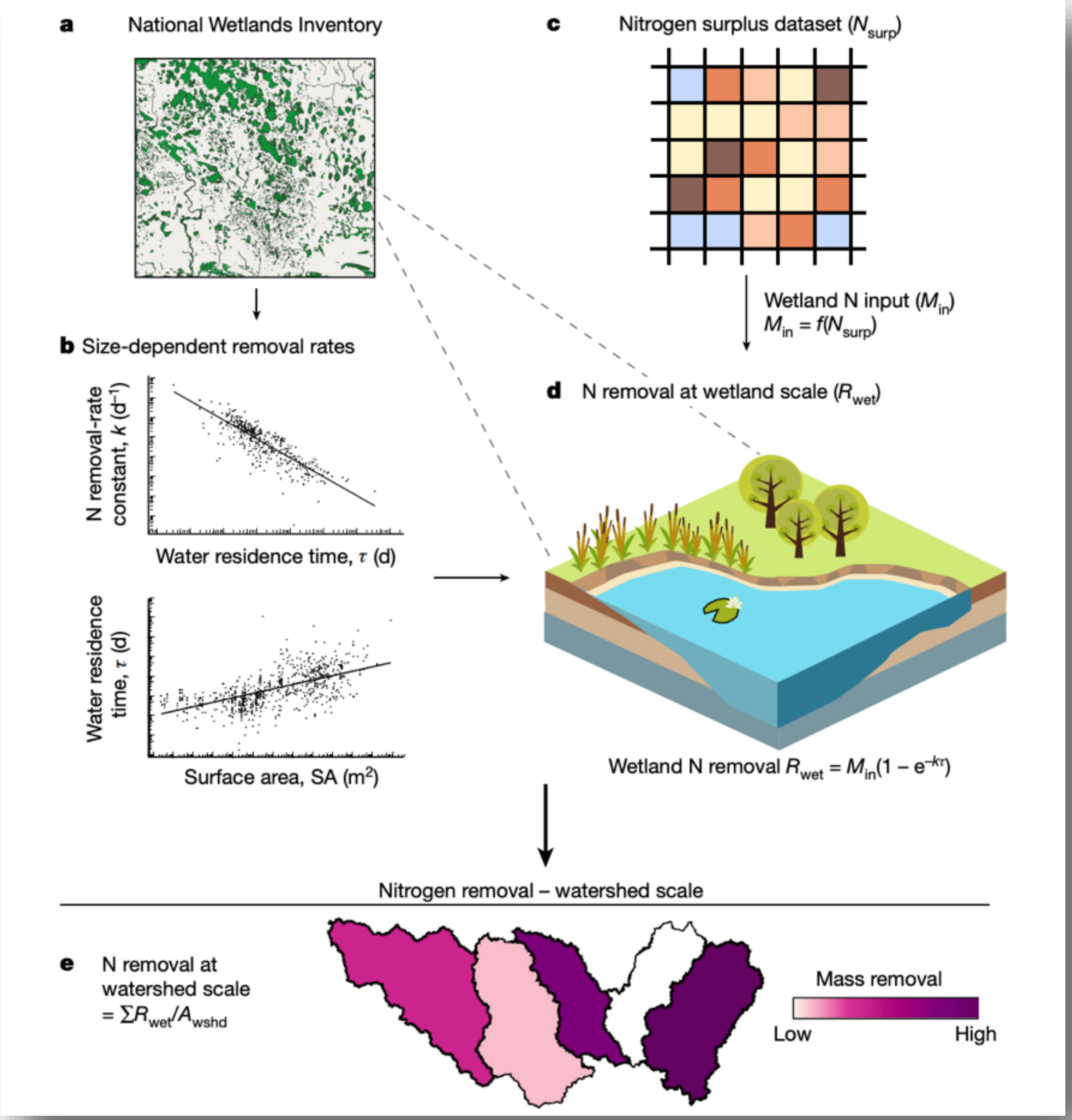
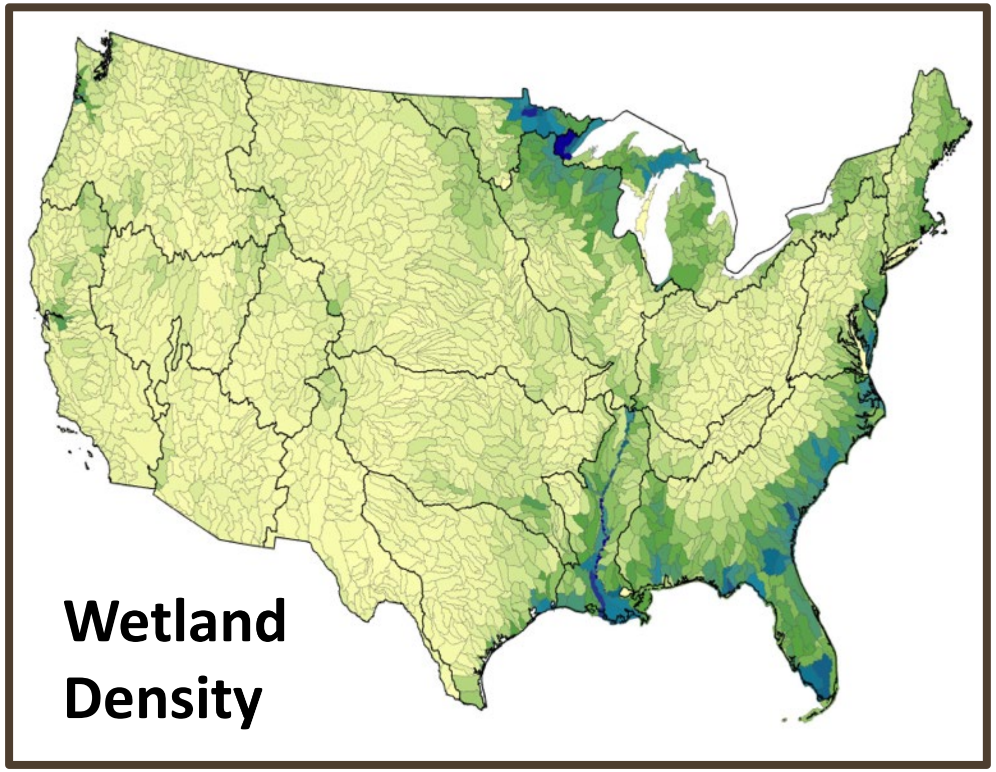
How much nitrate is being removed by current wetlands?





Cheng, Van Meter et al., *Nature* (2020)

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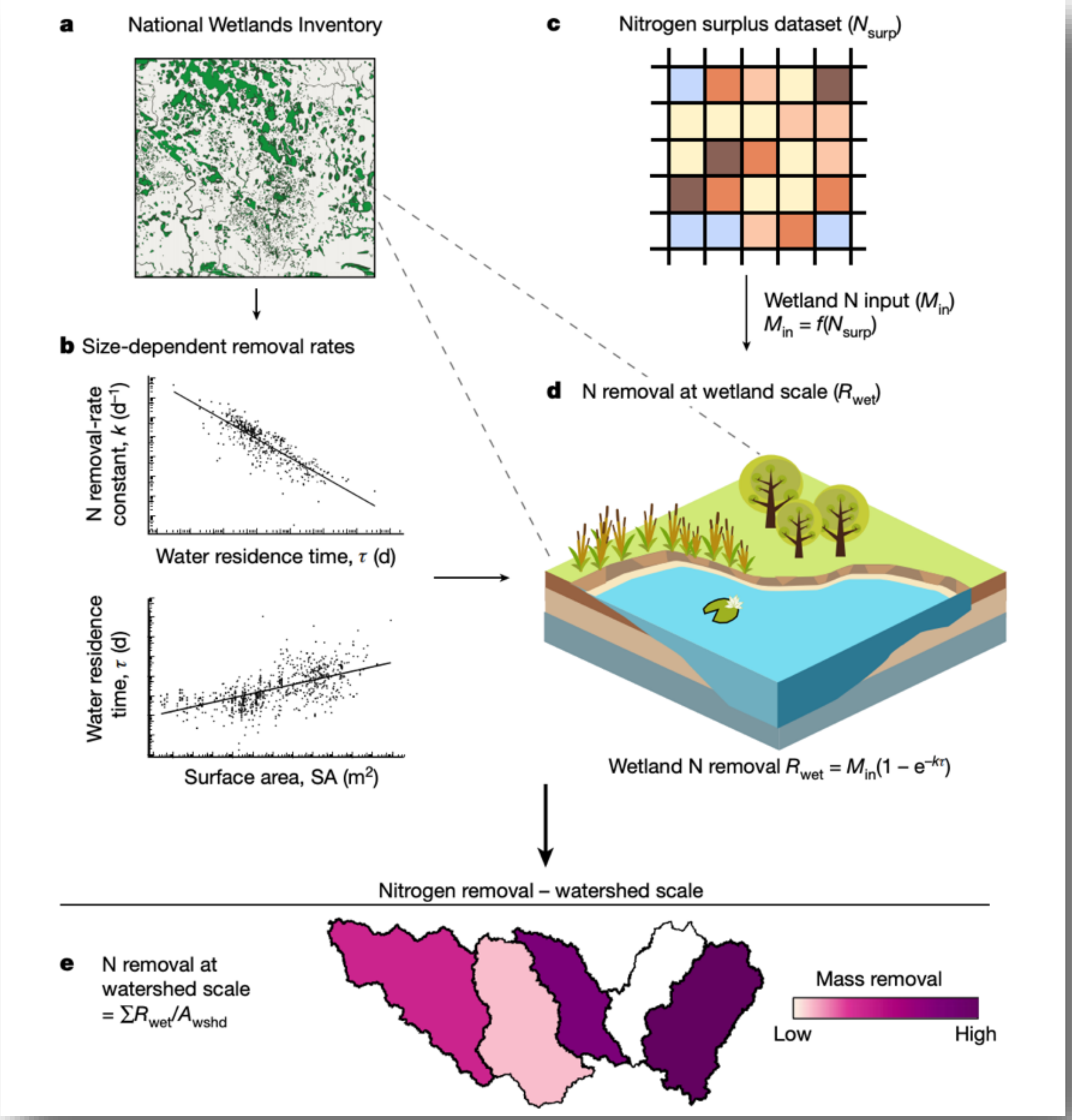
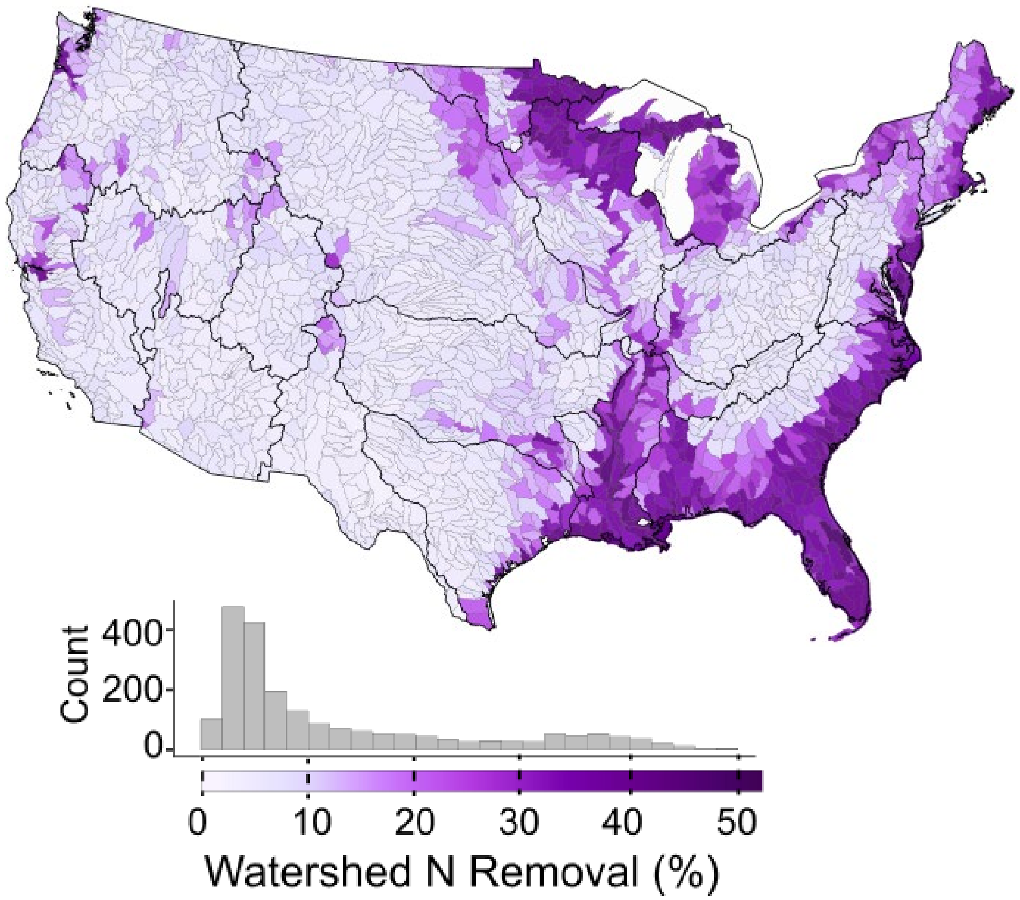


Percent N Removal



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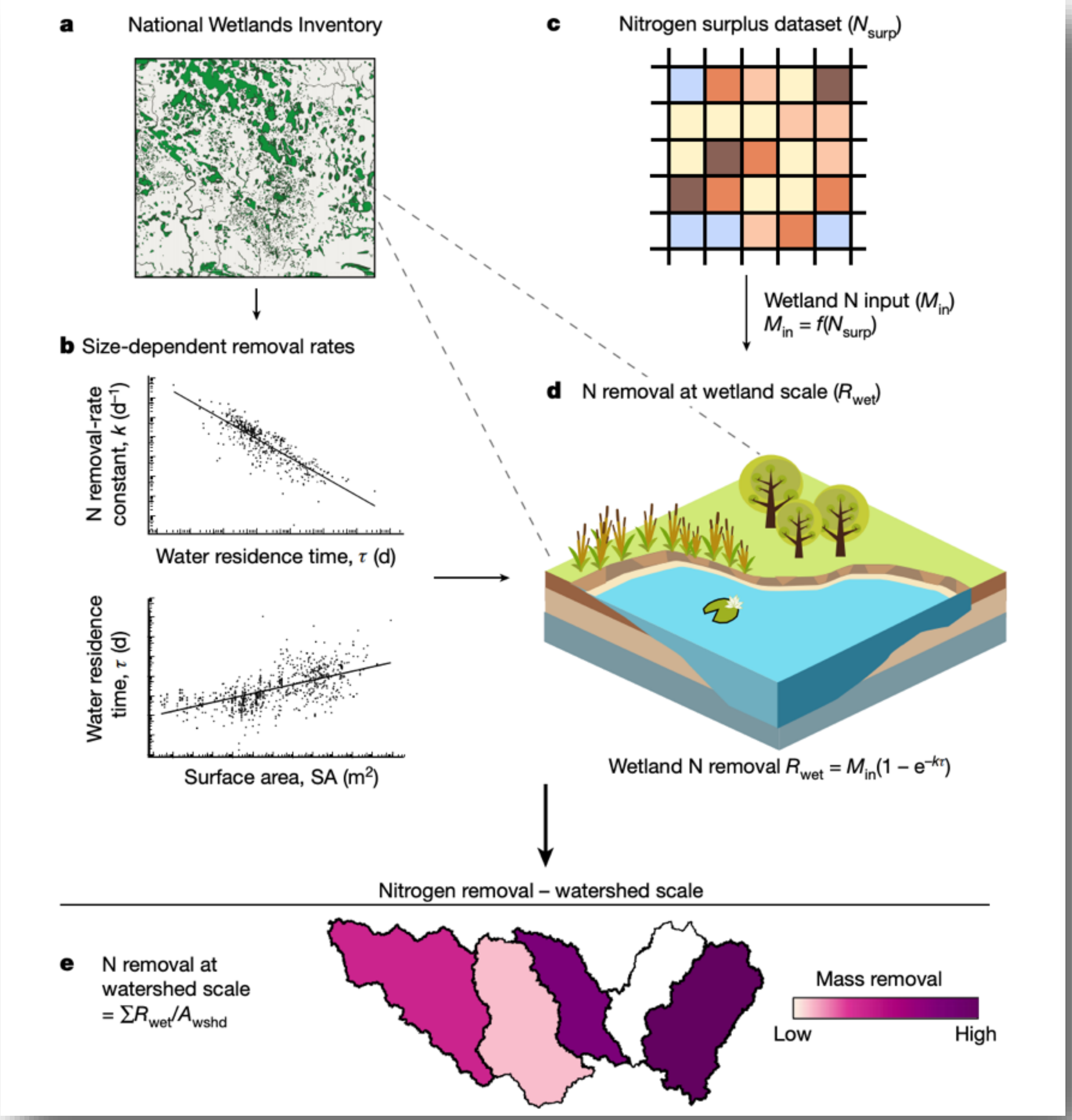
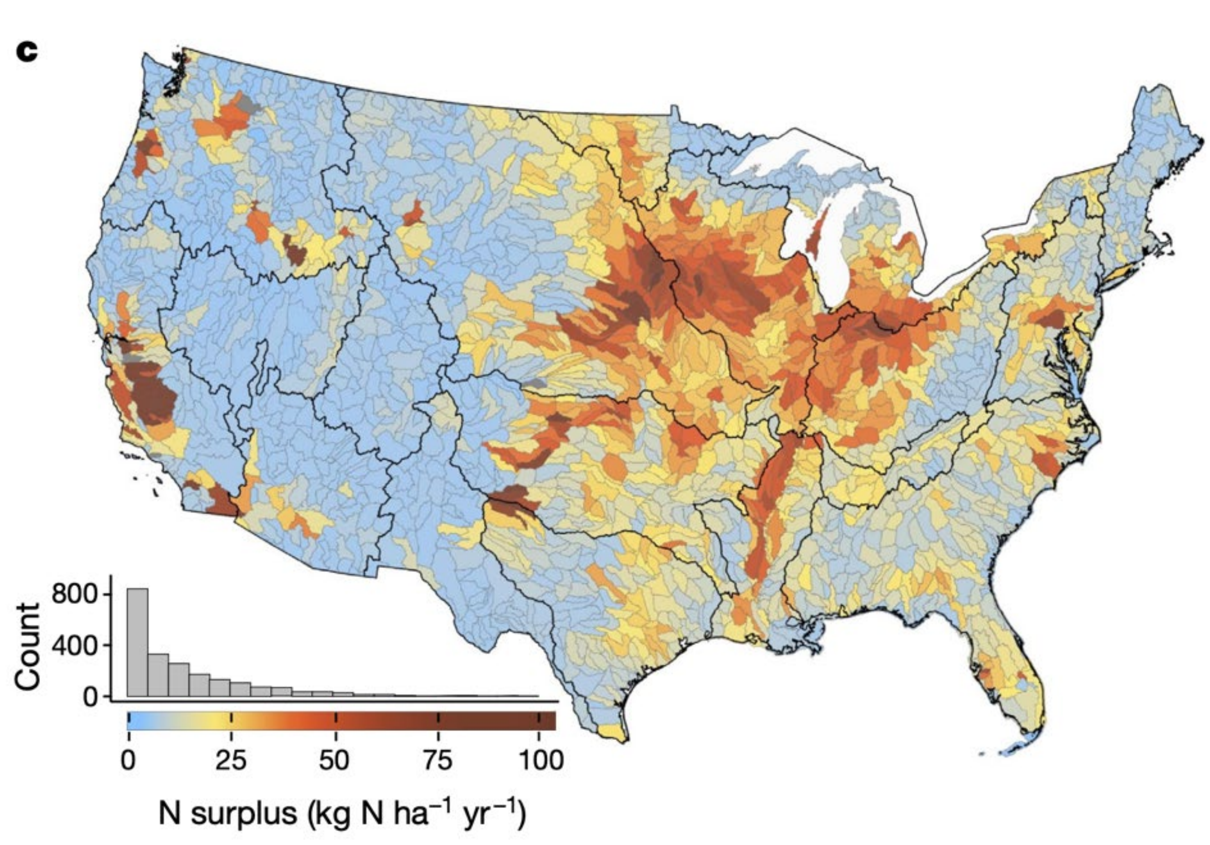


Watershed-Scale Surplus N



Cheng, Van Meter et al., *Nature* (2020)

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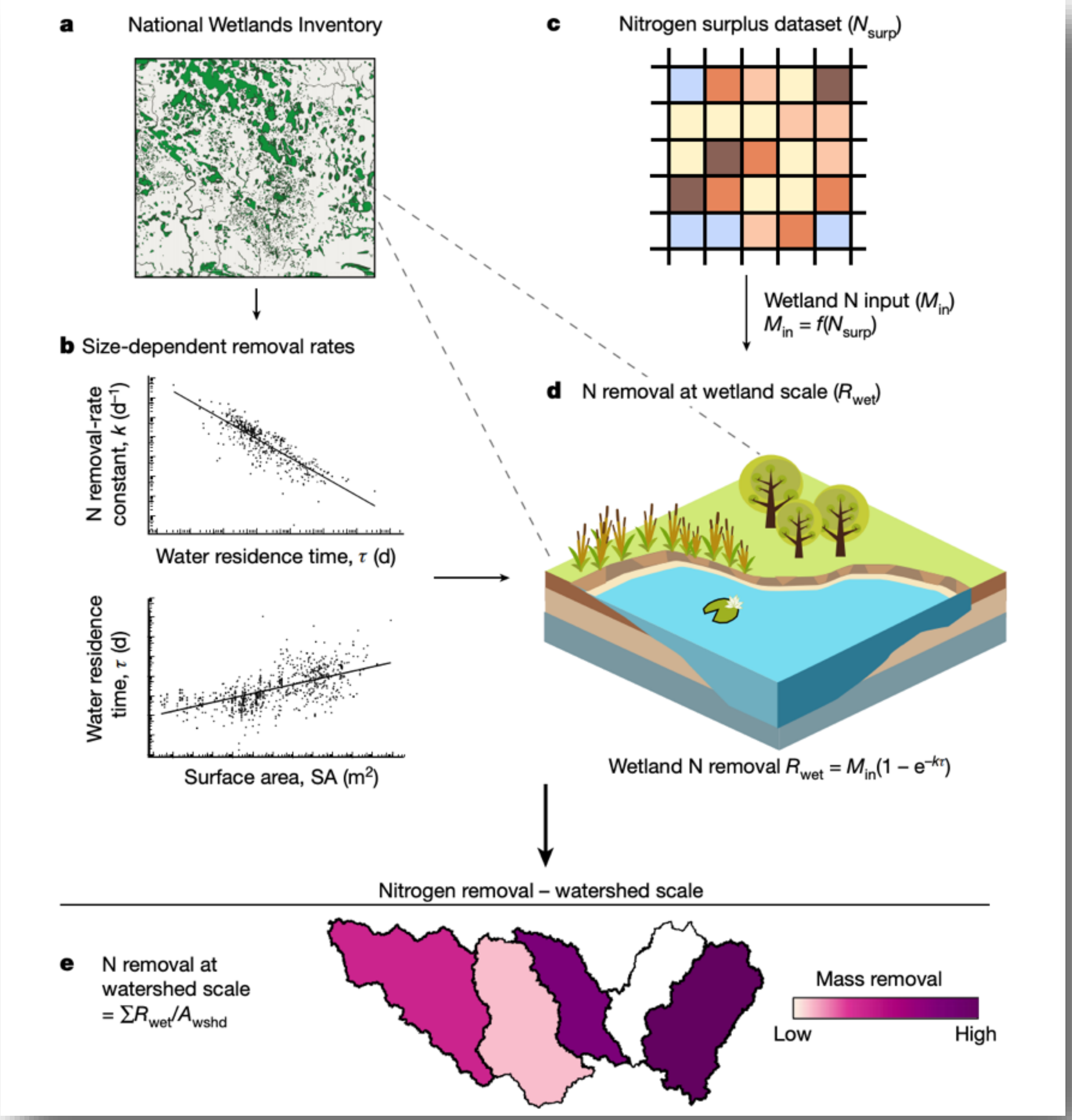
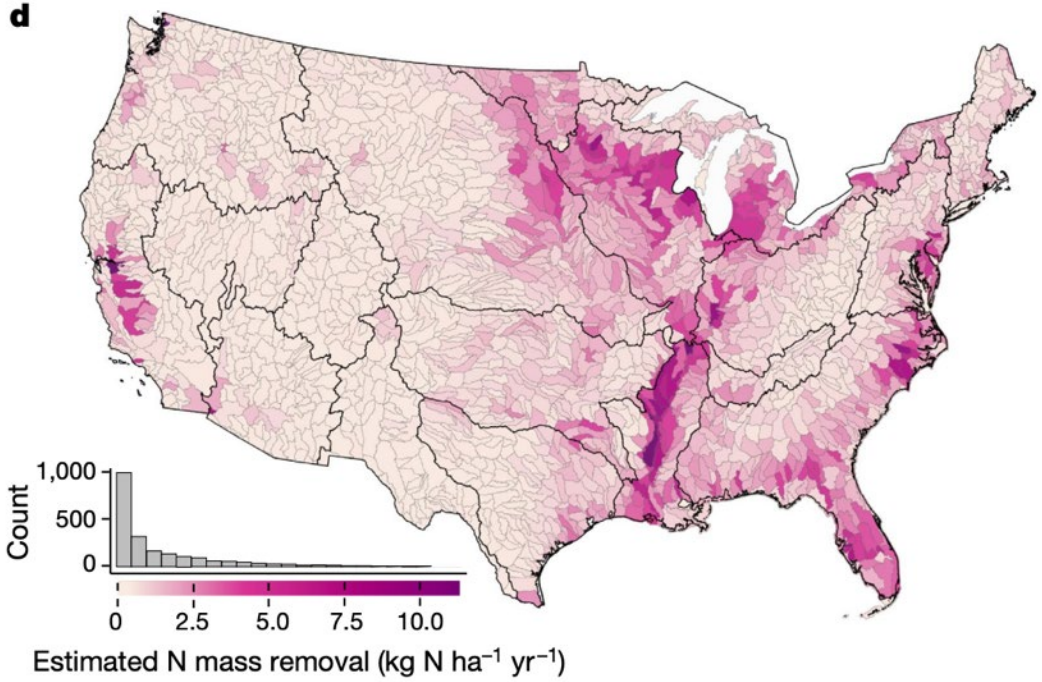


N Mass Removal

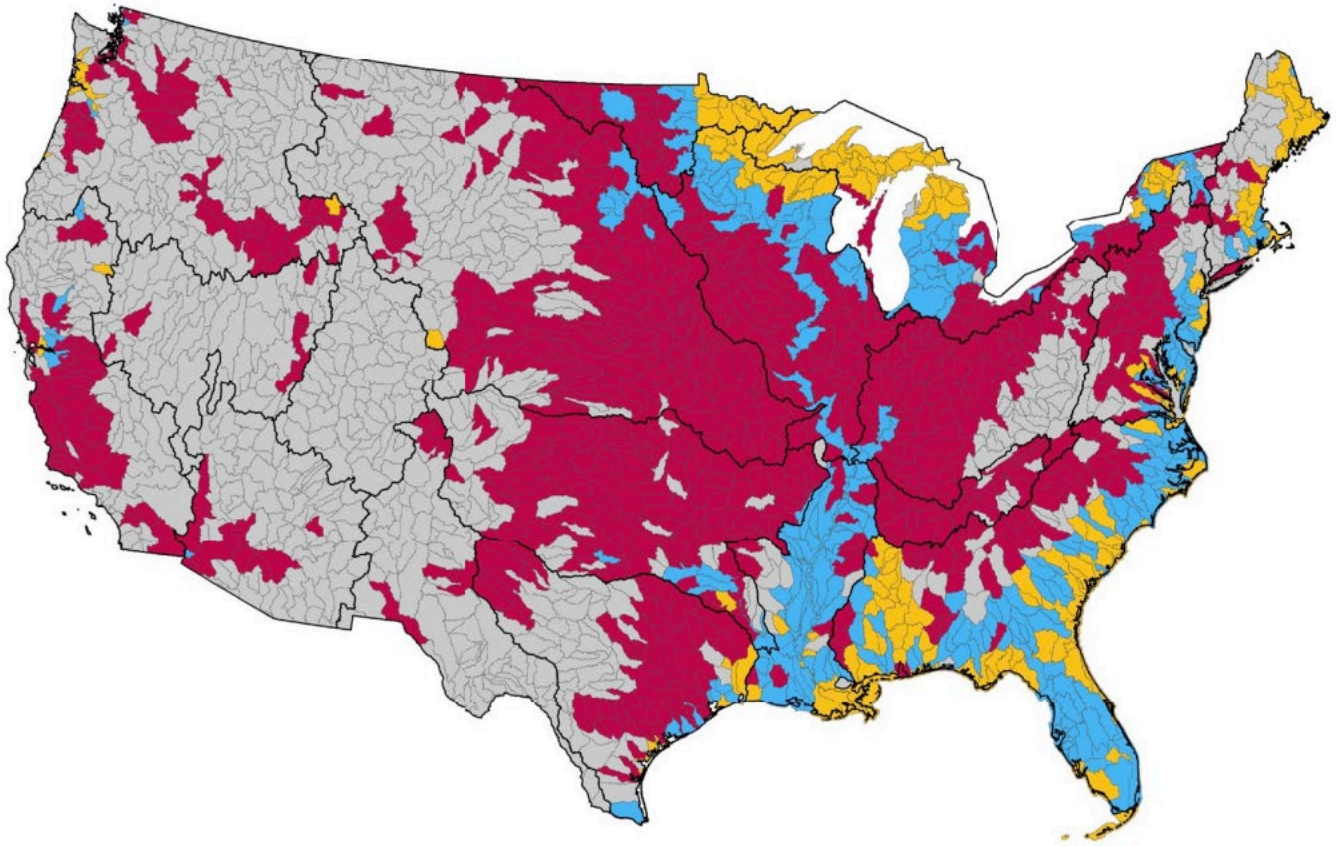


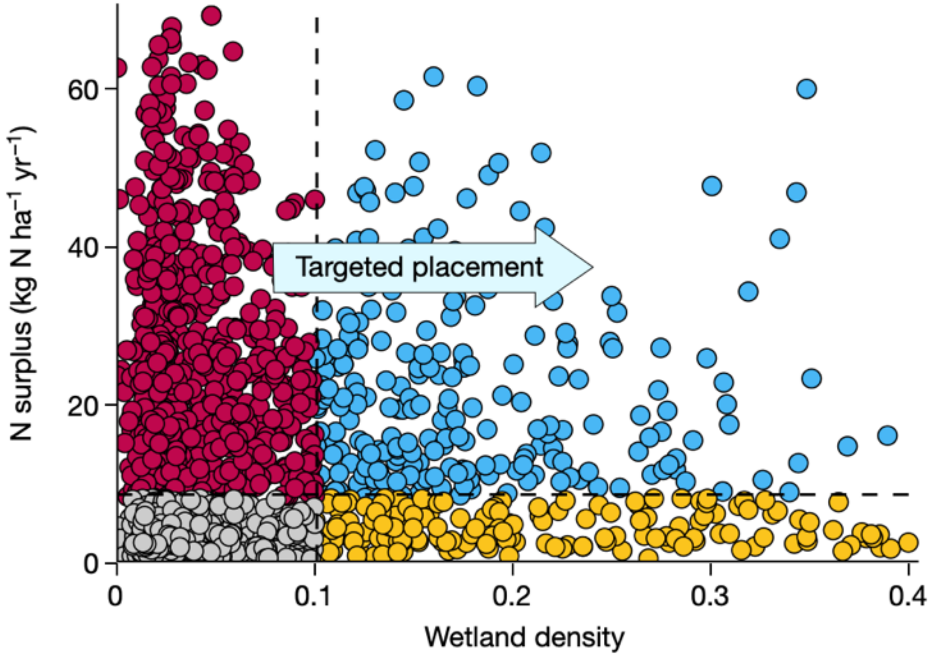
$$860 \pm 160\ ktons\ N/year$$

8% of the total N surplus

Cheng, Van Meter et al., *Nature* (2020)

Most areas with higher wetland densities have little surplus N





Cheng, Van Meter et al. 2020 (*Nature*)

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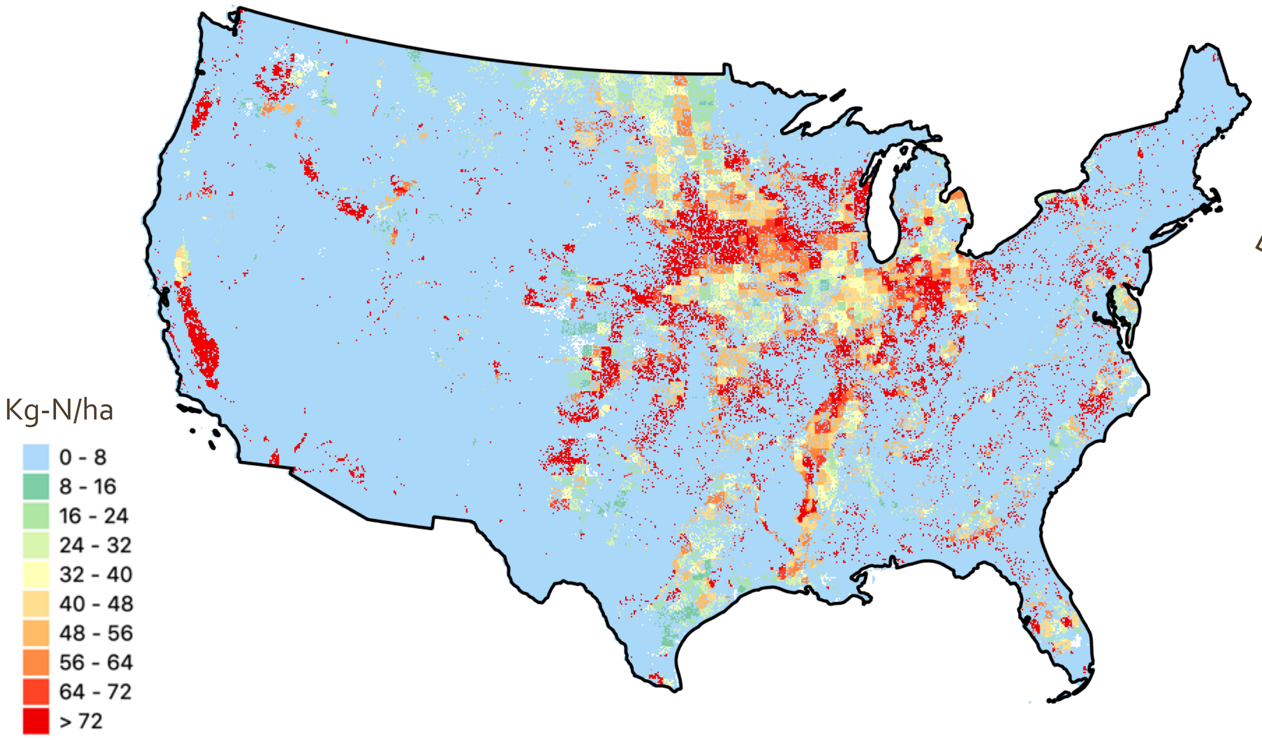
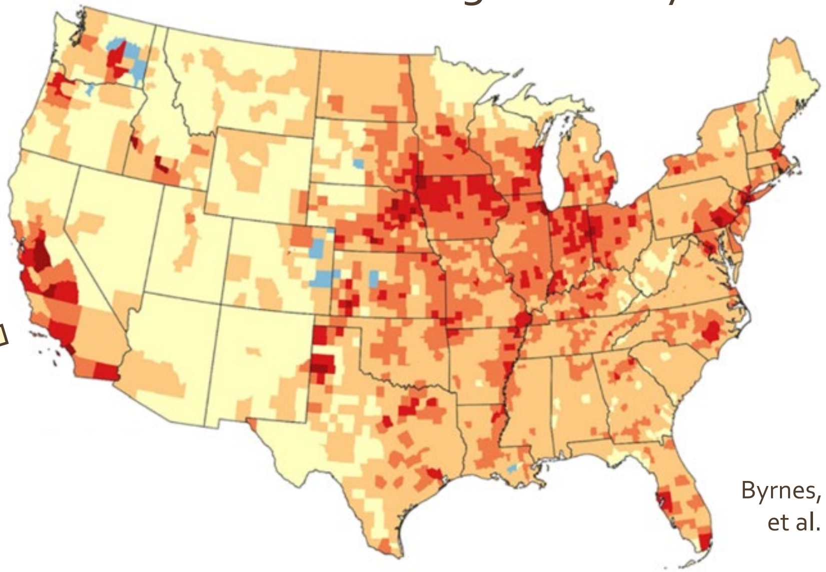


250-m Grid-Scale N Surplus

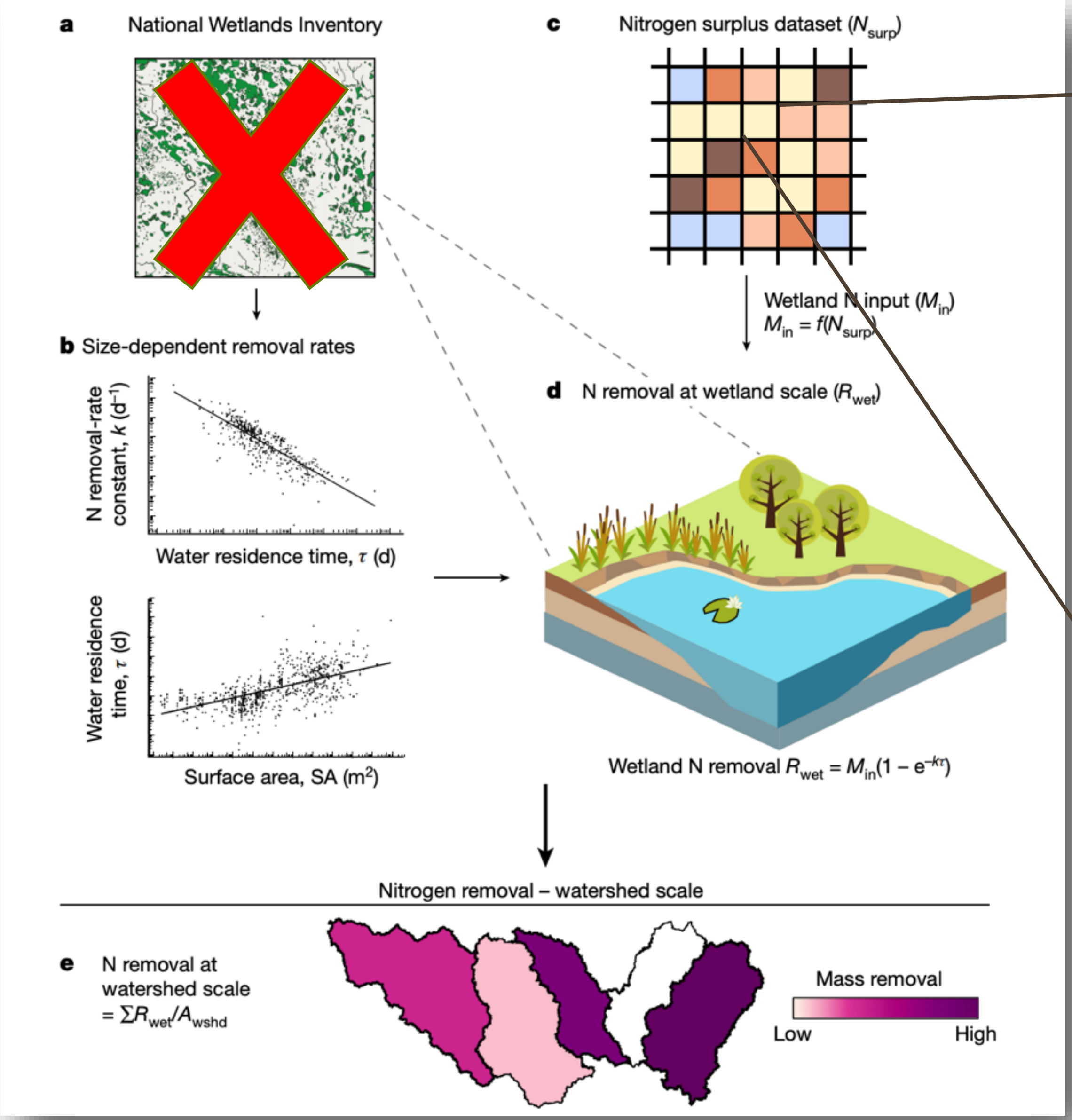
TREND-Nitrogen County-Scale N Surplus

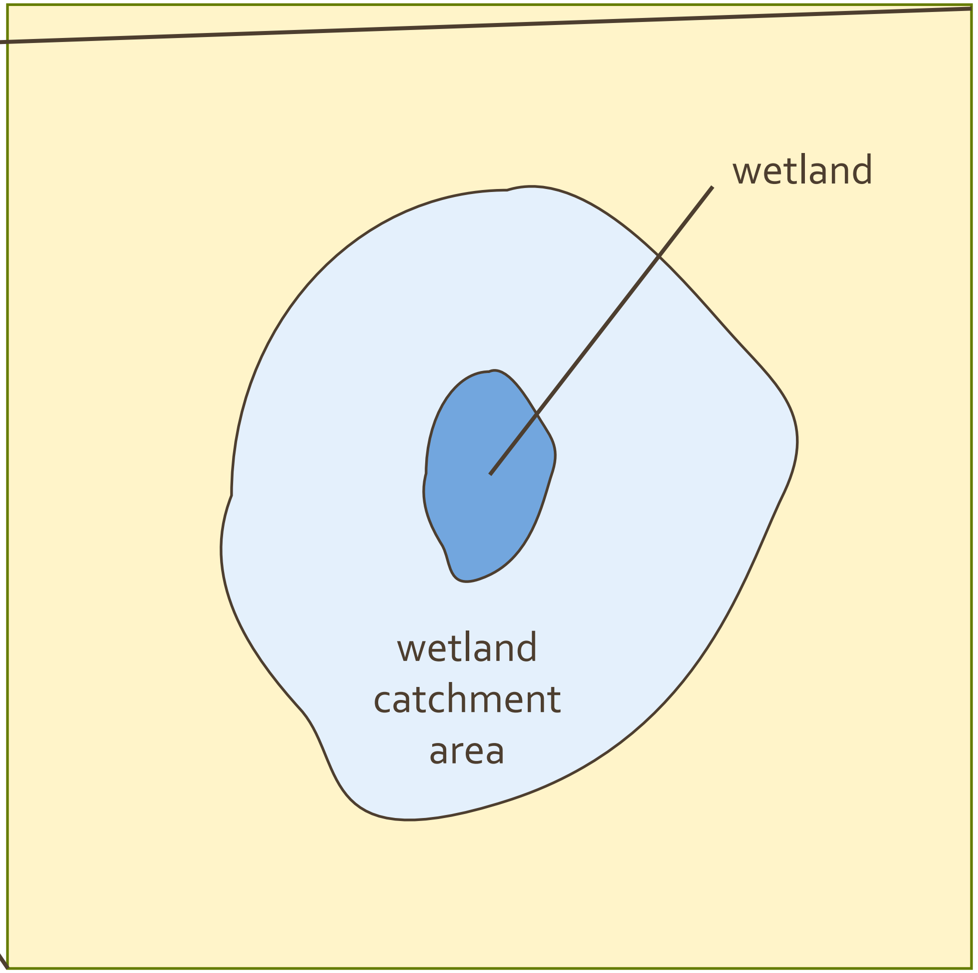


Byrnes, Van Meter, et al. 2020

National Land Cover Database

How much nitrate could be removed with wetland restoration?





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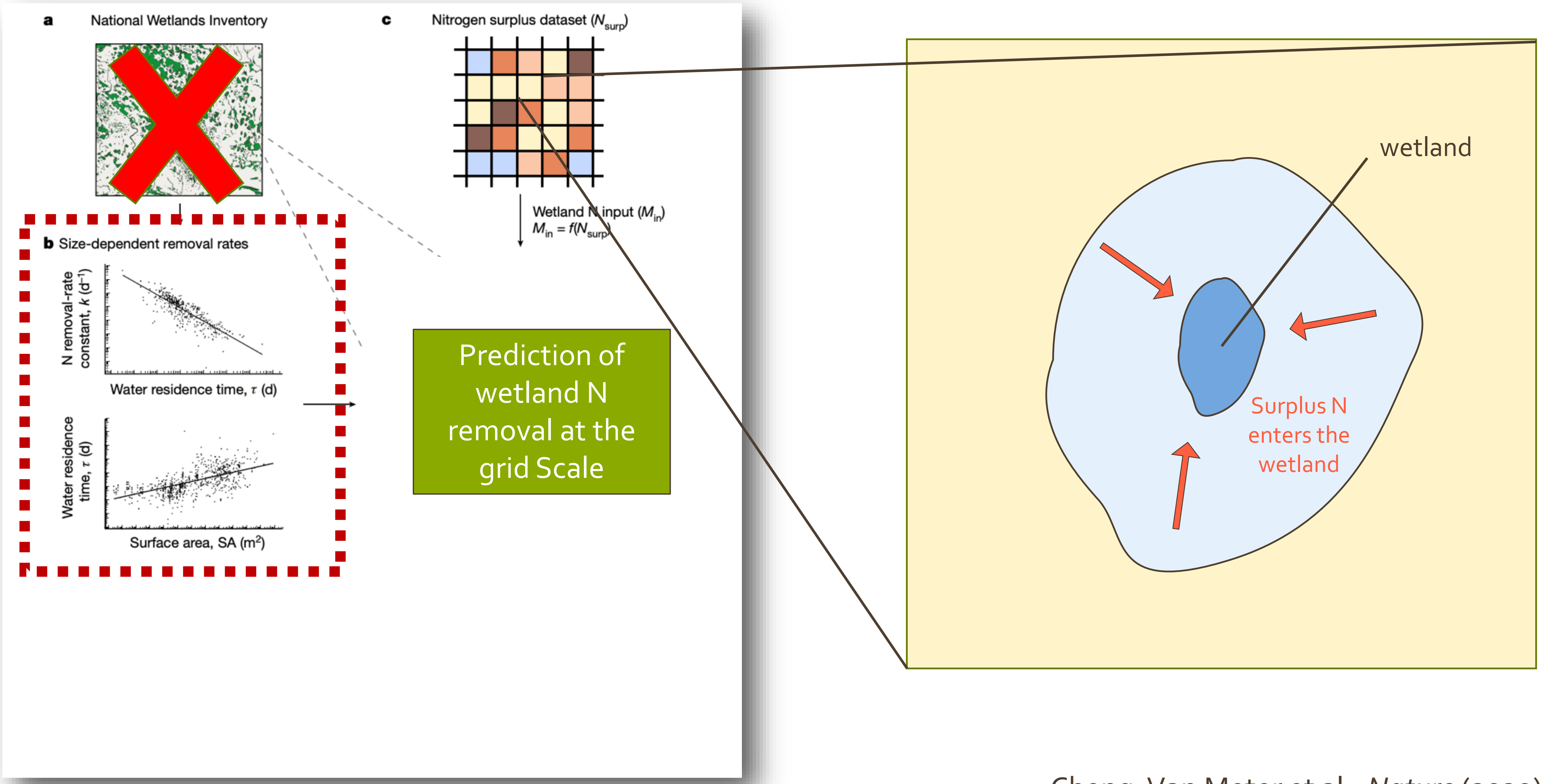
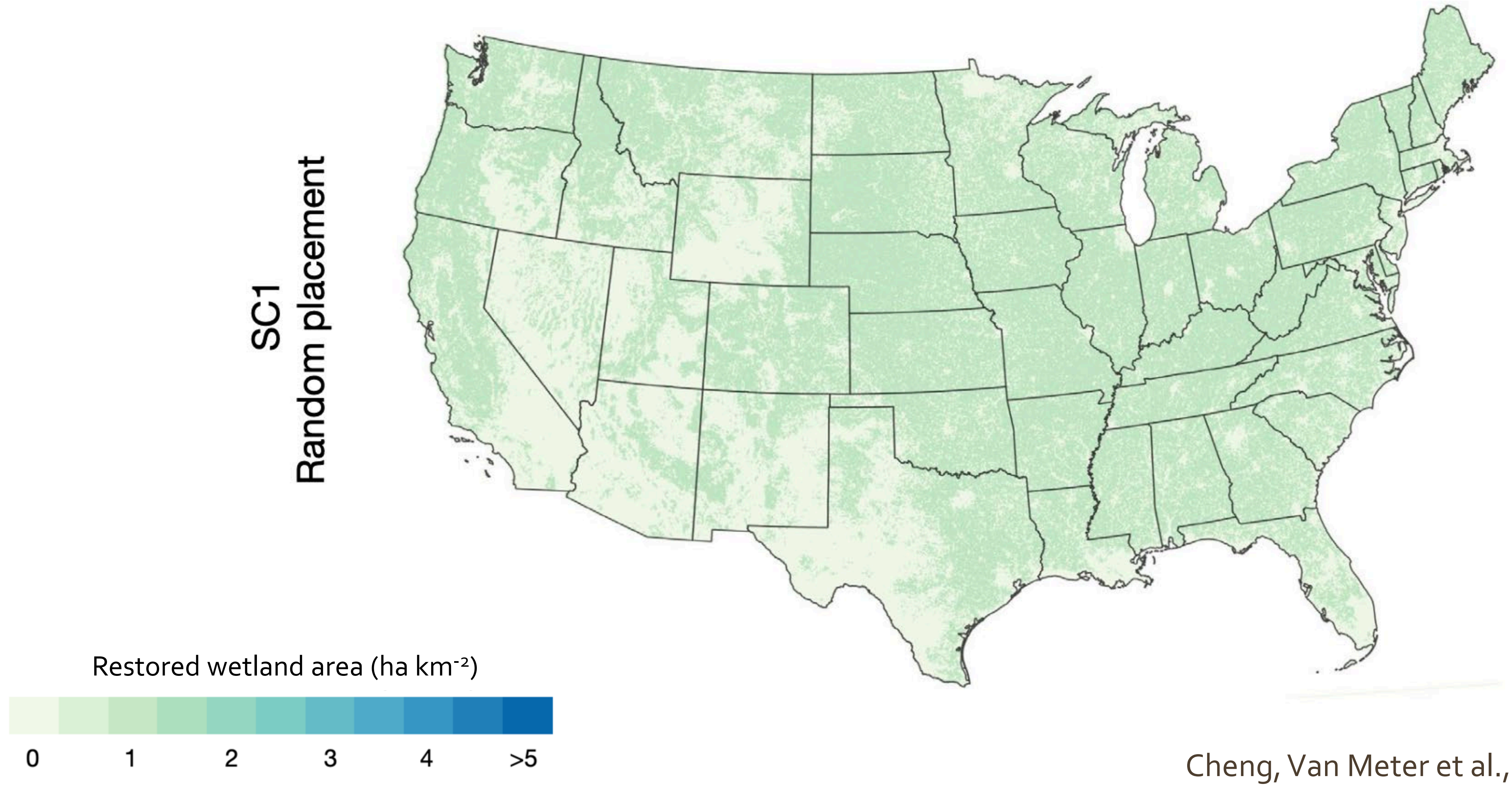


Cheng, Van Meter et al., *Nature* (2020)

Wetland Restoration Strategies

10% increase in wetland area



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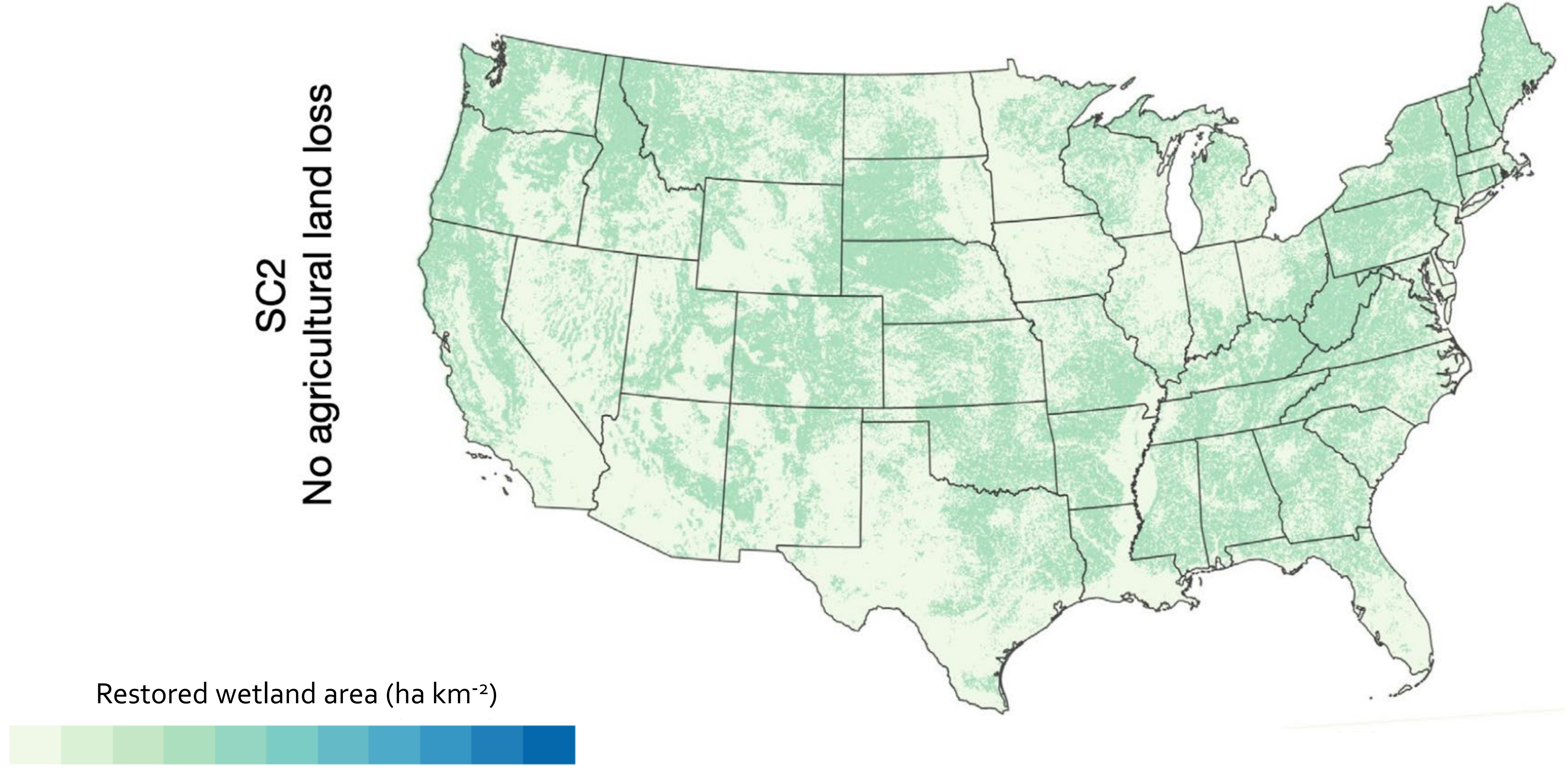
Wetland Restoration Strategies



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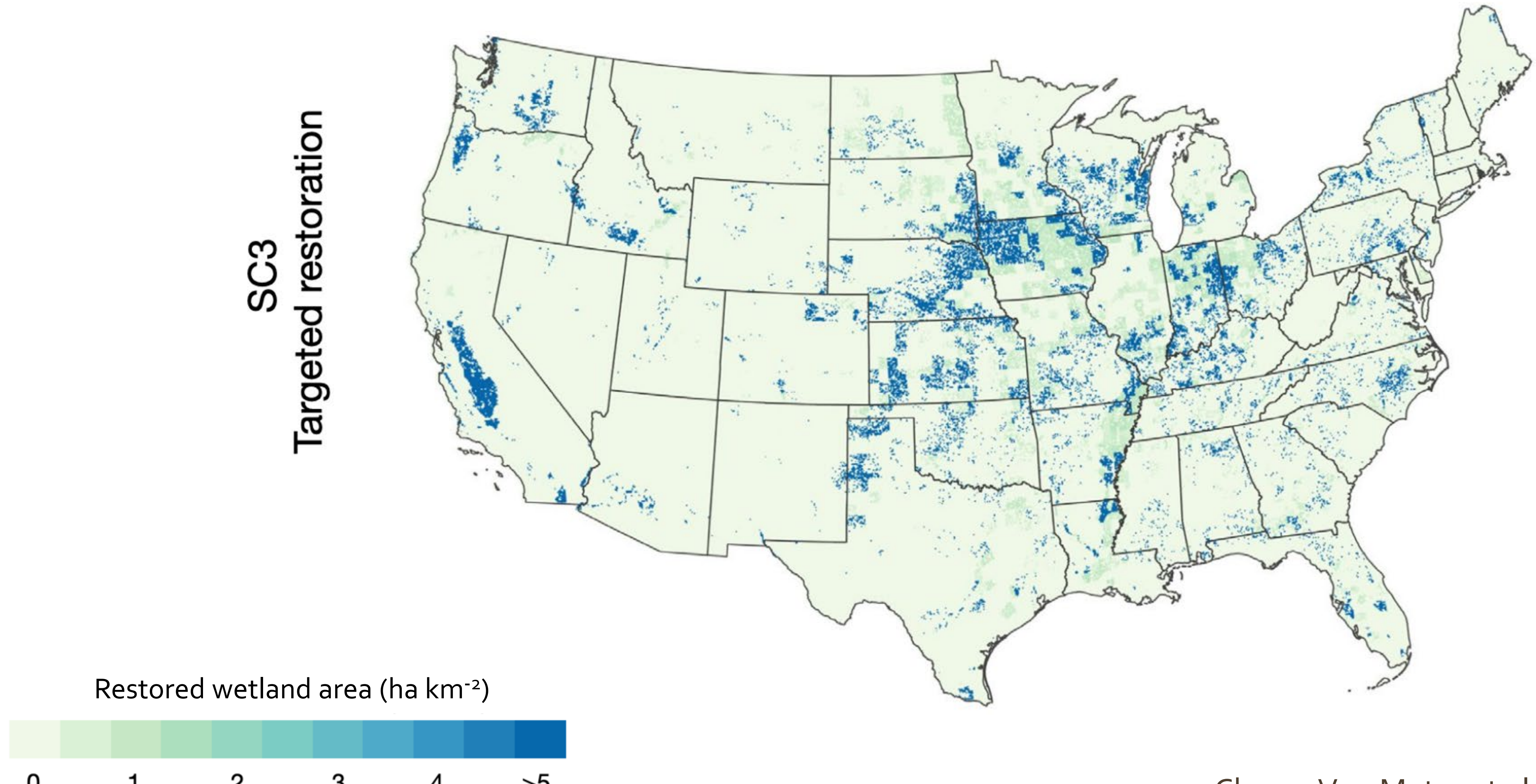
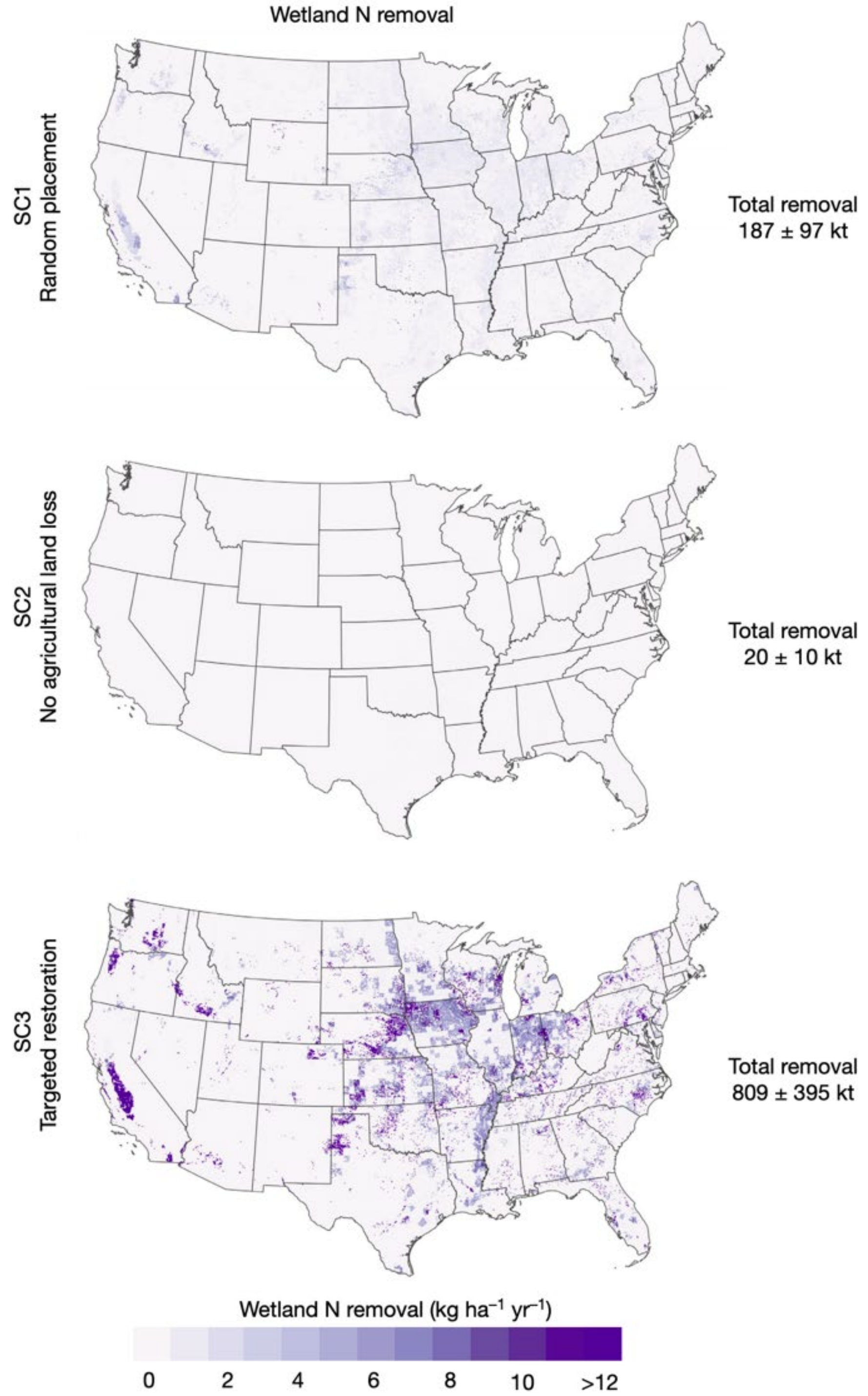
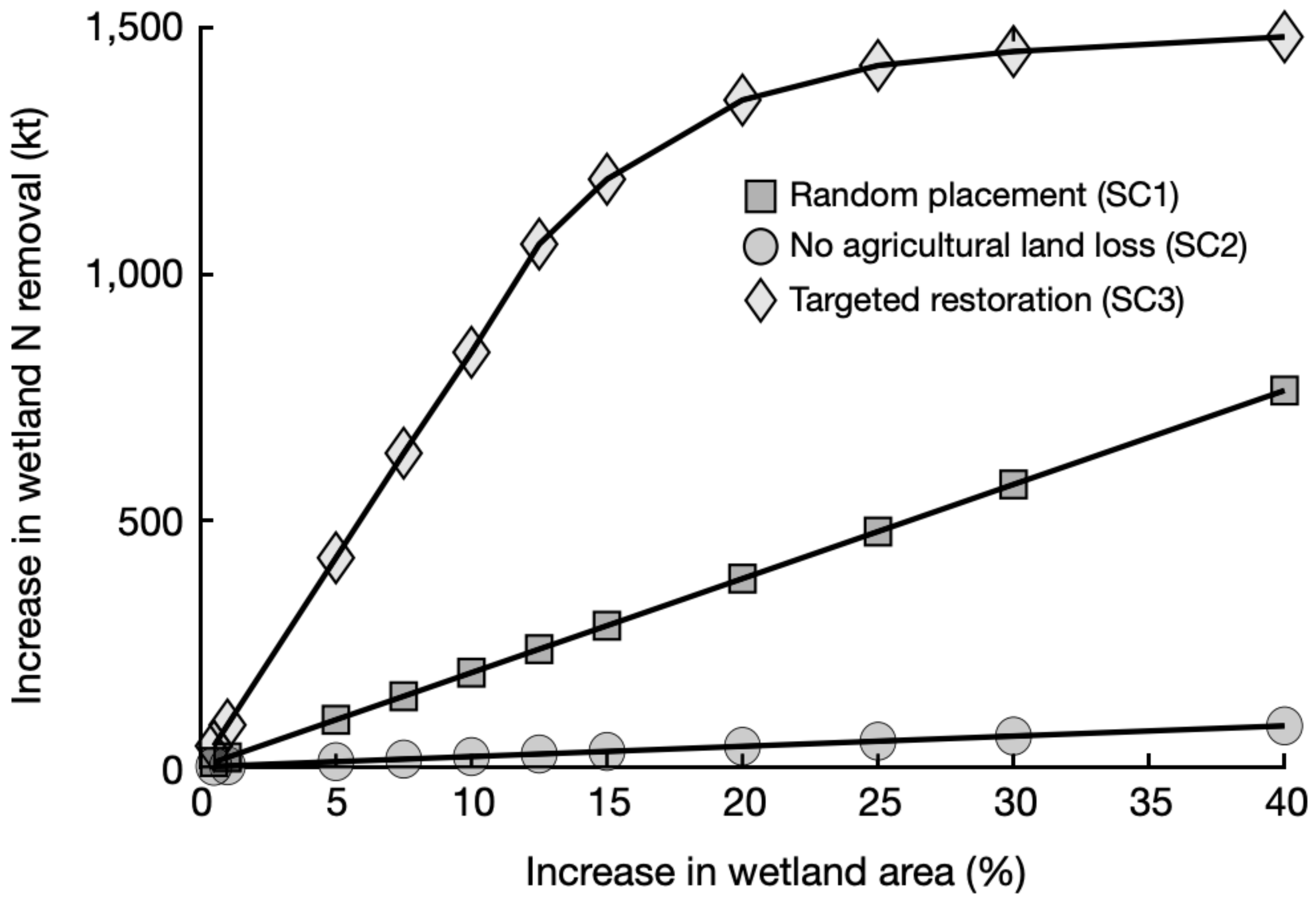


Cheng, Van Meter et al., *Nature* (2020)

Targeted wetland restoration efforts can optimize water quality benefits





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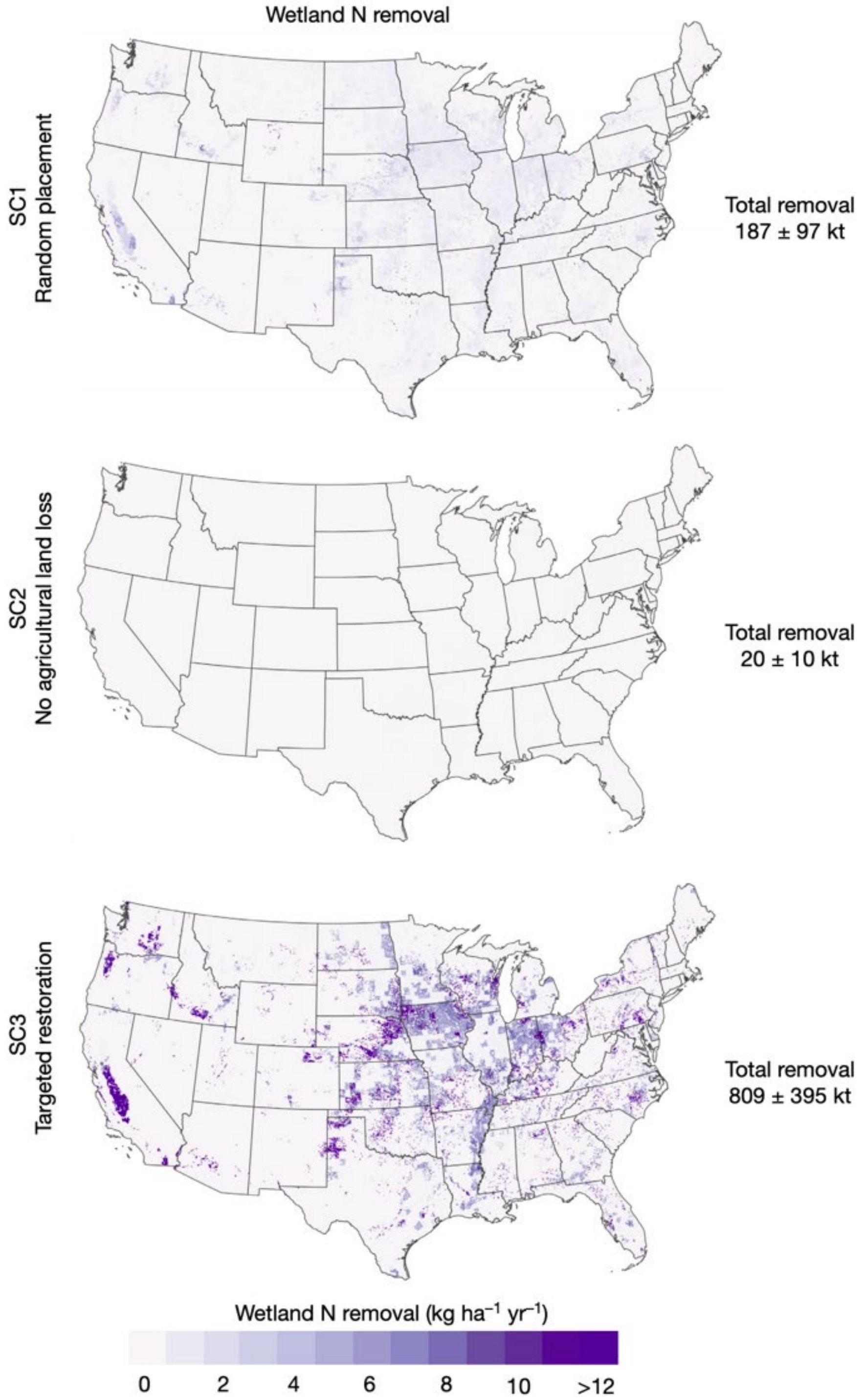
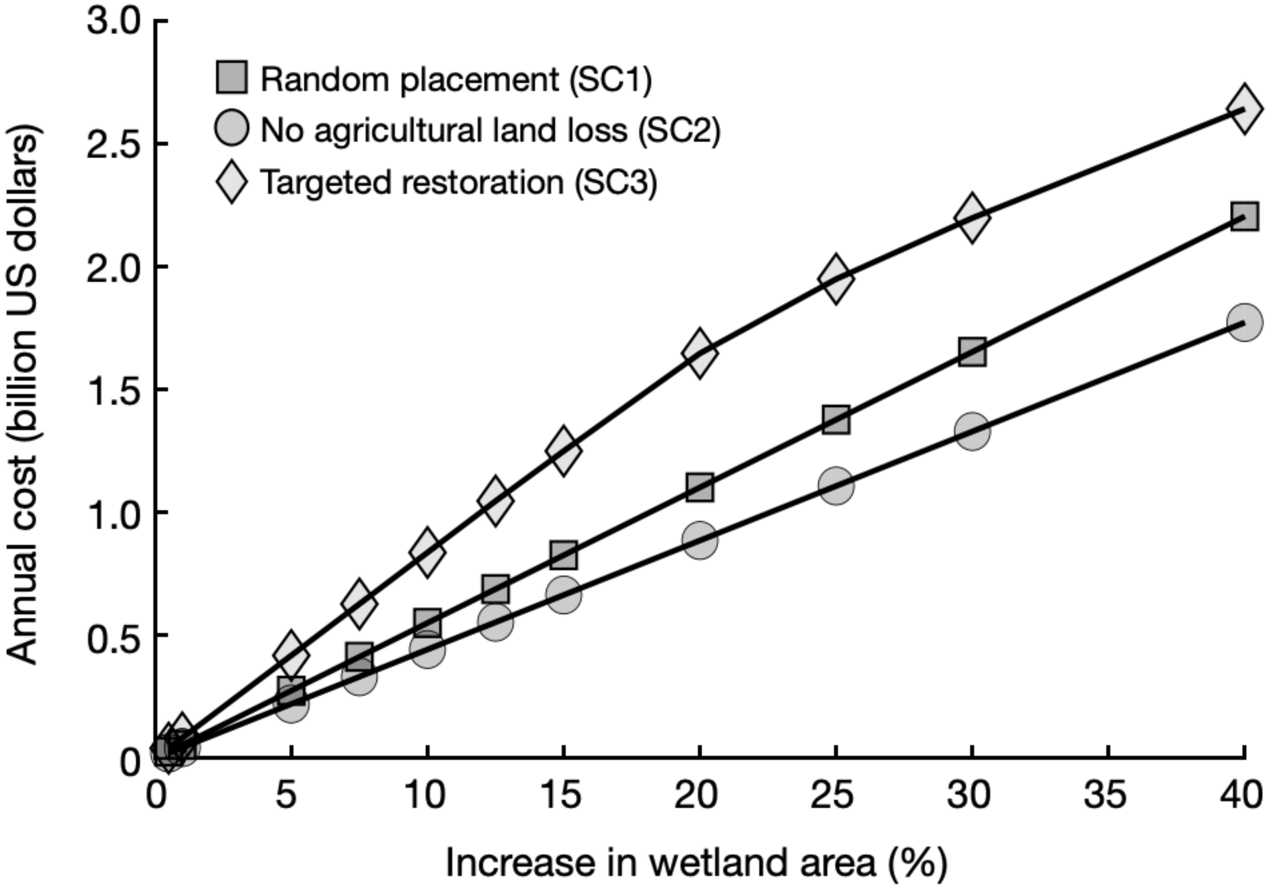
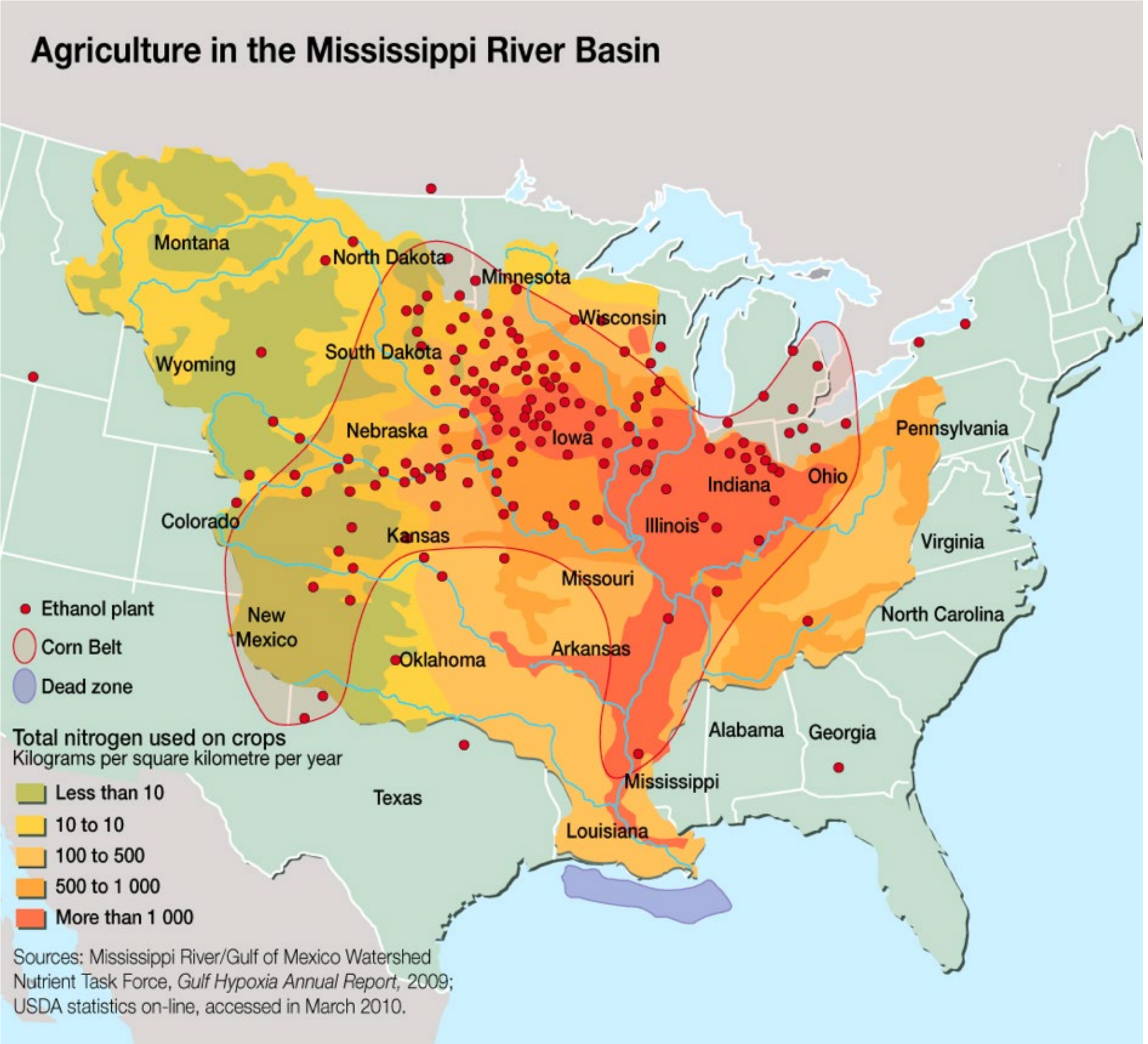
Targeted wetland restoration efforts can optimize water quality benefits





Cheng, Van Meter et al., *Nature* (2020)

How can wetland restoration contribute to improvements in water quality?



Wetlands in the Mississippi River Basin currently remove approximately 440 ktons N per year

Without existing wetlands, N loads in the MRB would be ~50% higher than they are now.

A ***targeted*** 22% increase in wetland area in the Mississippi River Basin could result in an approximately 40% decrease in N loads—bringing us closer to policy goals for improving water quality in the Gulf of Mexico.

Cheng, Van Meter et al., *Nature* (2020)

Questions?

Belby et al. 2015