Addressing Water Quality Concerns through Nutrient and Water Management

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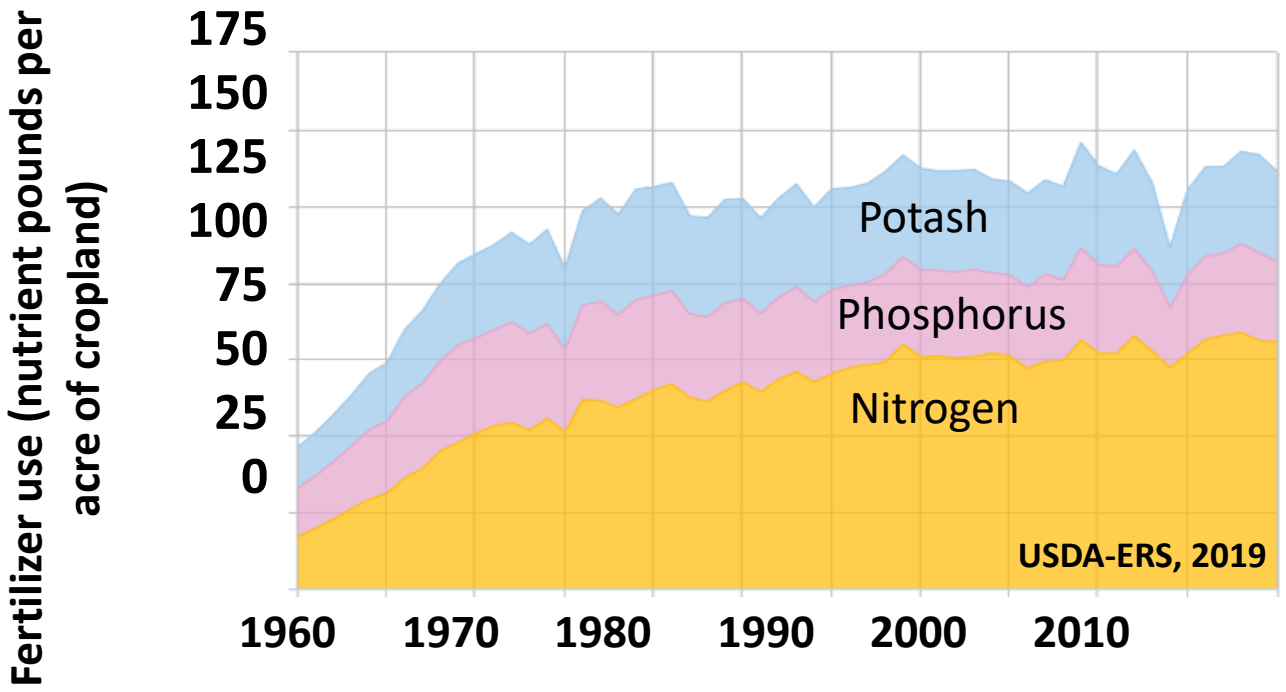
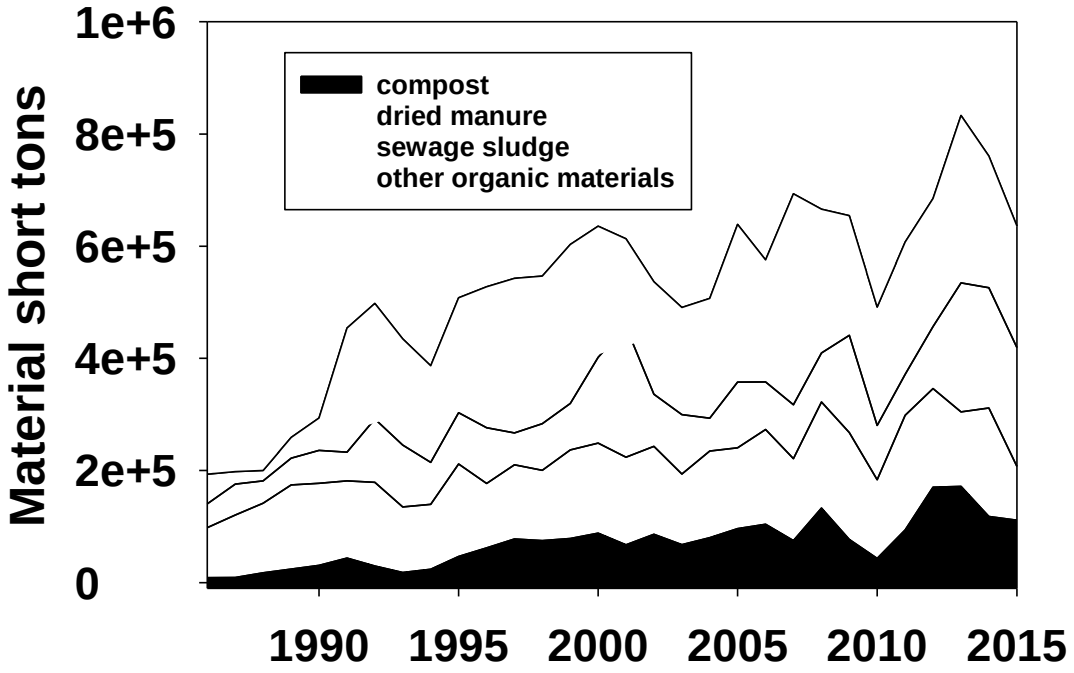
The need for nutrient and water management?

Source

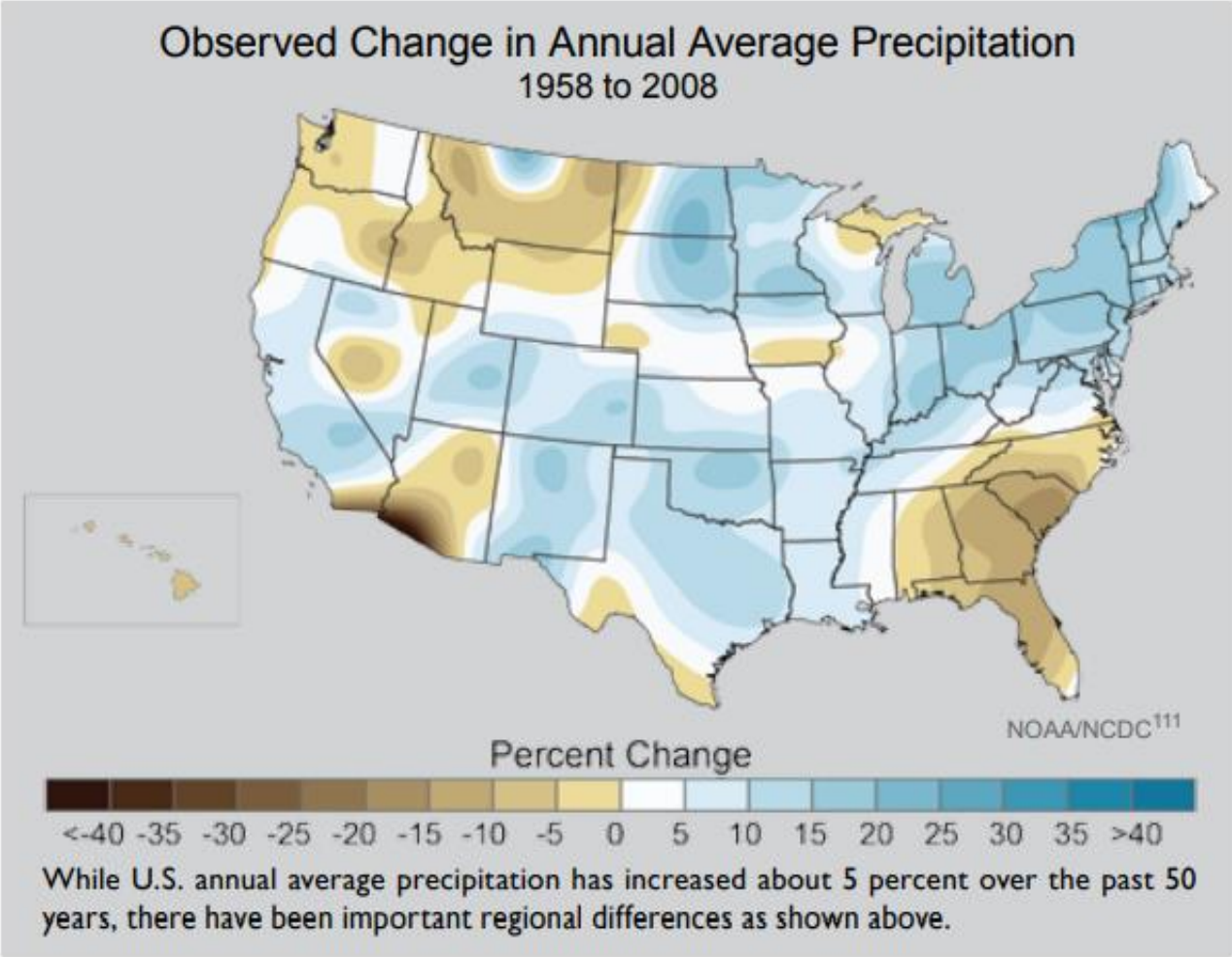
Transport

Fertilizer source/use in the US





Volumes and intensities of rainfall events are changing



Karl et al. 2009

Photo credit: Jed Stinner

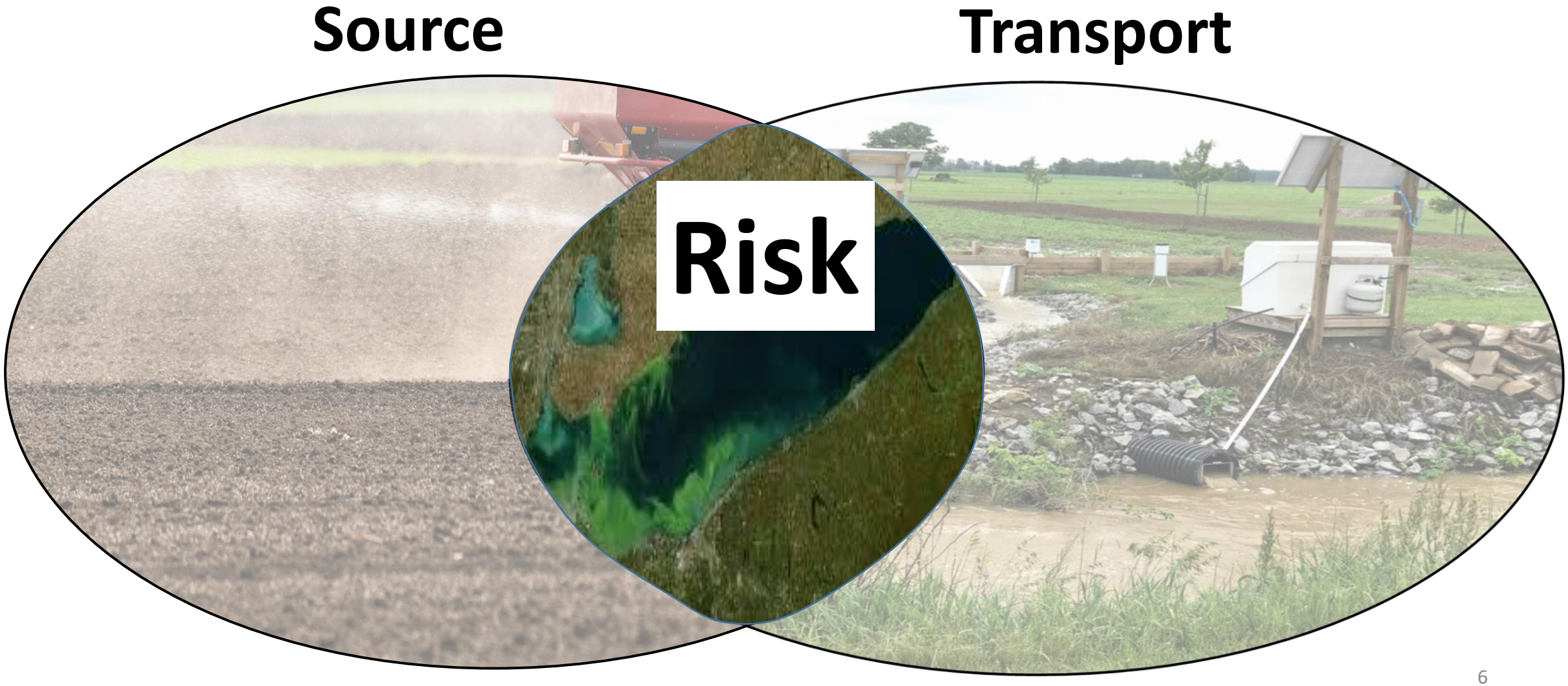
- 4% increase in national precipitation since 1958
- 5-15% in Western Lake Erie Basin region
- Since 1895, 8 of the top 10 wettest years measured since 1990
- 6 of those occurred since 2004

The need for nutrient and water management?

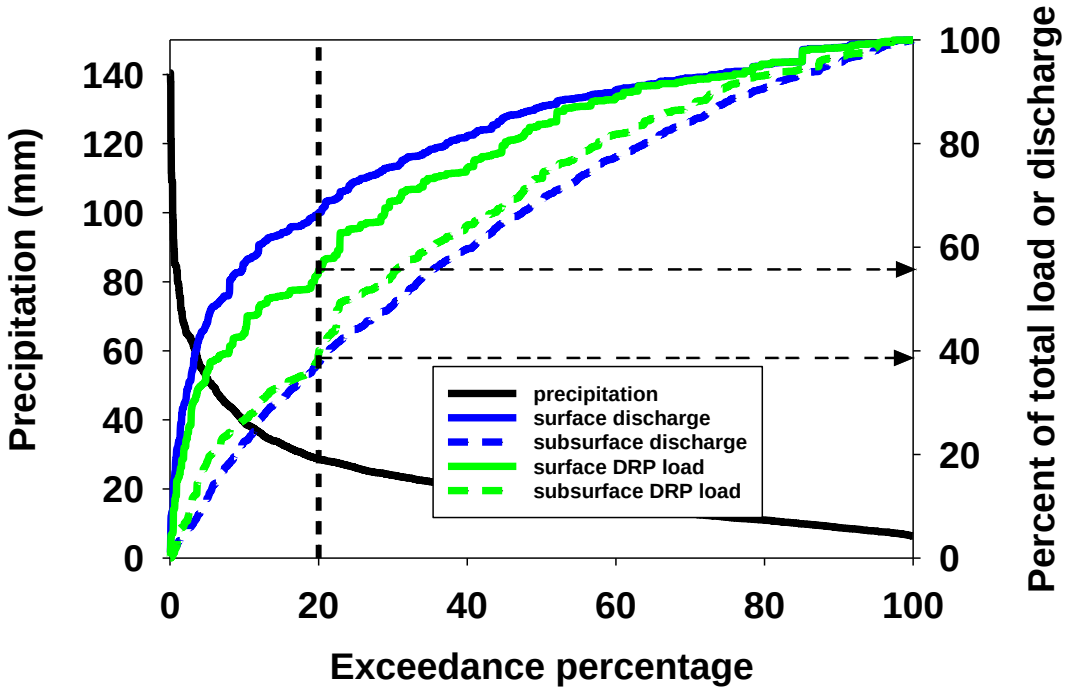
Source

Transport

Risk is a function of the magnitude of source and transport



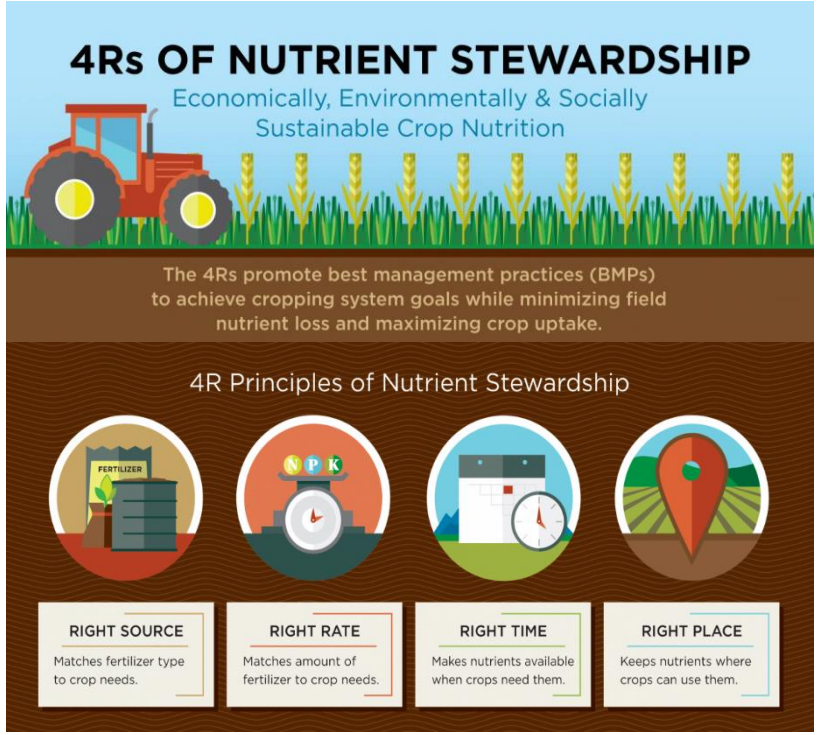
Nutrient transport is disproportionately impacted by larger precipitation events



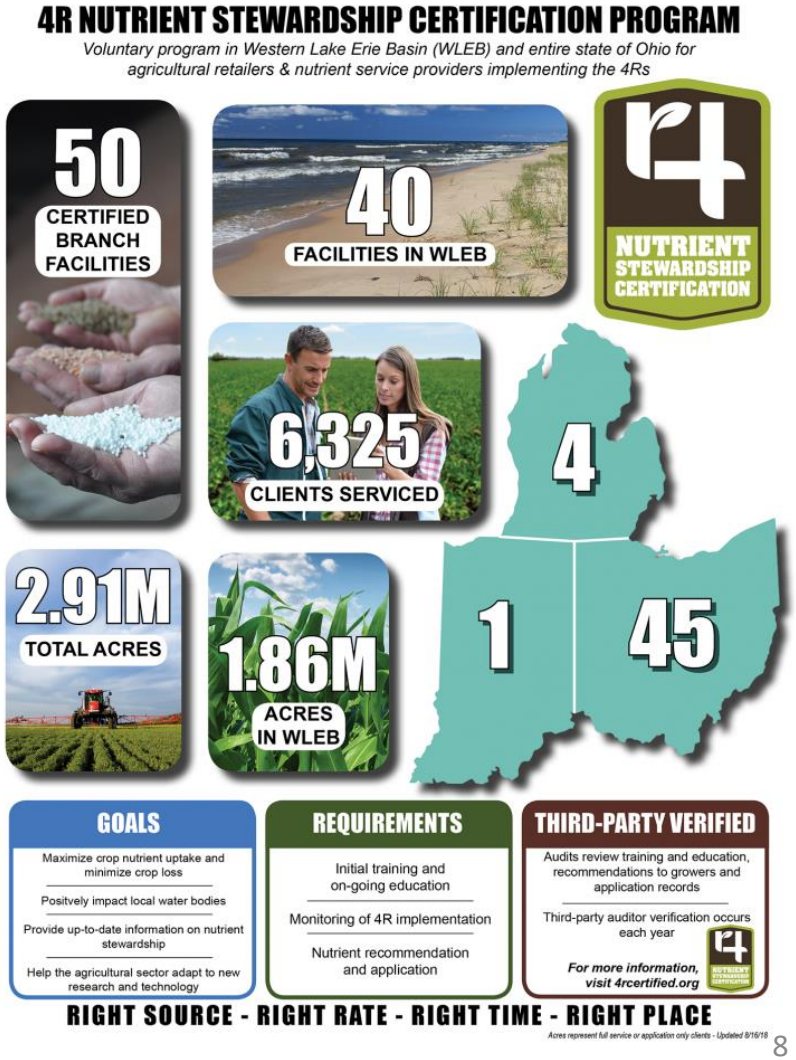
- Phosphorus loading is event driven
- 80% of phosphorus loading in surface runoff occurs during 10 days per year
- 80% of phosphorus loading in tile drainage occurs during 45 days per year
- 60% of surface and 40% of tile phosphorus load is generated from precipitation events exceeding 1.25 inches

Williams et al., 2018; AWRA 54:1039-1054
Pease et al., 2018; J. Great Lakes Res. 44:43-53.

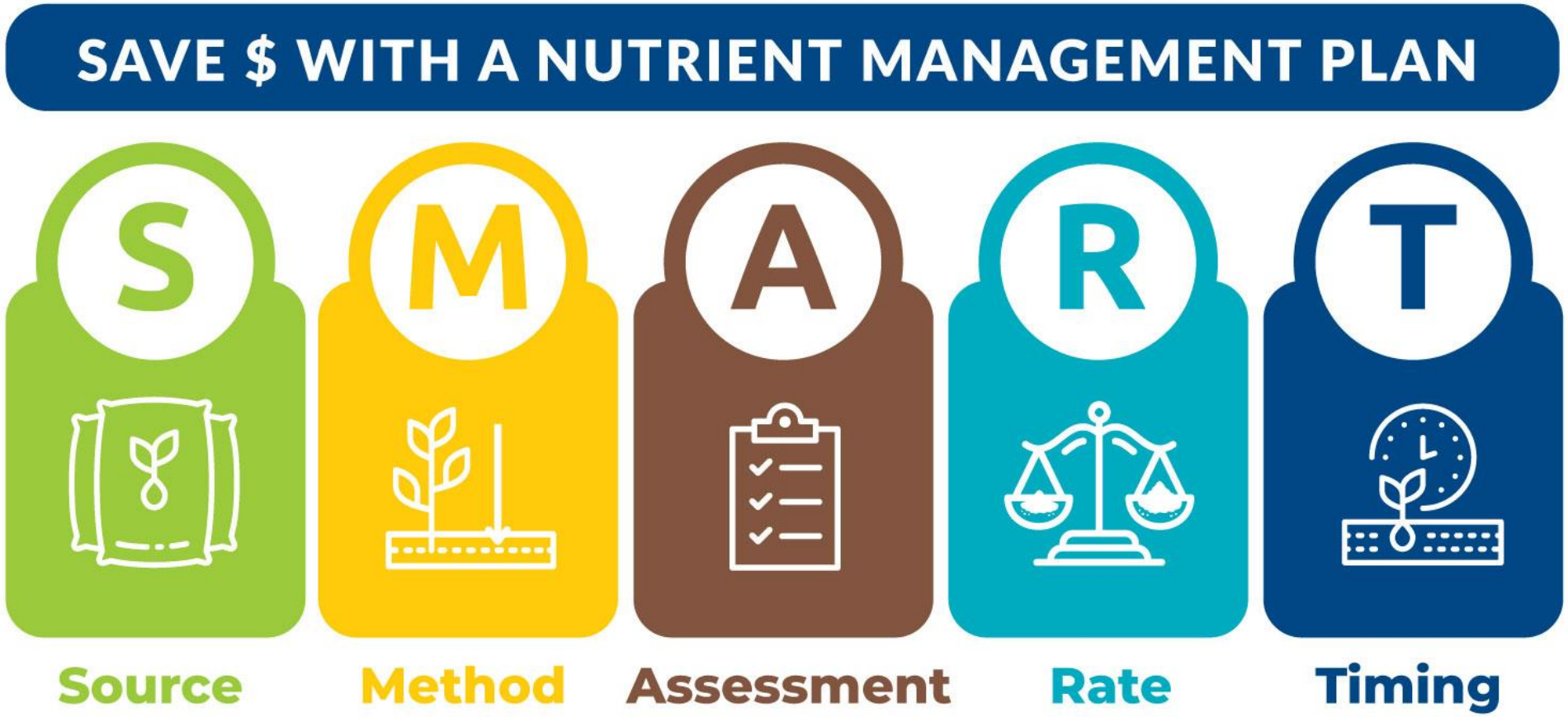
4R nutrient stewardship certification program developed to maximize crop uptake and minimize nutrient losses



Vollmer-Sanders et al., 2016:

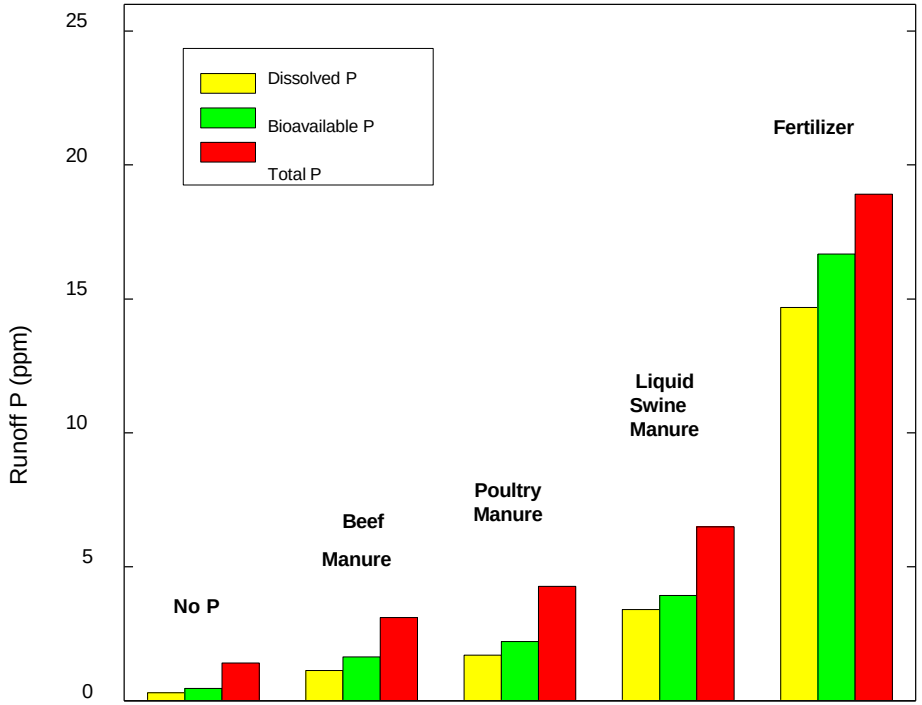


SMART nutrient management should be the minimum goal for every producer



https://www.farmers.gov/conservation/nutrient-management

Solubility of organic and inorganic sources varies



Concentration of dissolved, bioavailable, and total P in surface runoff for rainfall events occurring within 24 hours of broadcasting 100 lb P_2O_5/acre using fertilizer and manure sources to untilled soils with soybean or corn residue (**Mallarino et al., 2007)**

- **Inorganic fertilizers are generally more soluble than organic sources**
- **Continued use of organic sources increases soil test phosphorus as well as phosphorus concentrations in discharge**

Mallarino et al., 2007; Smith et al., 2016; Kinley et al 2007

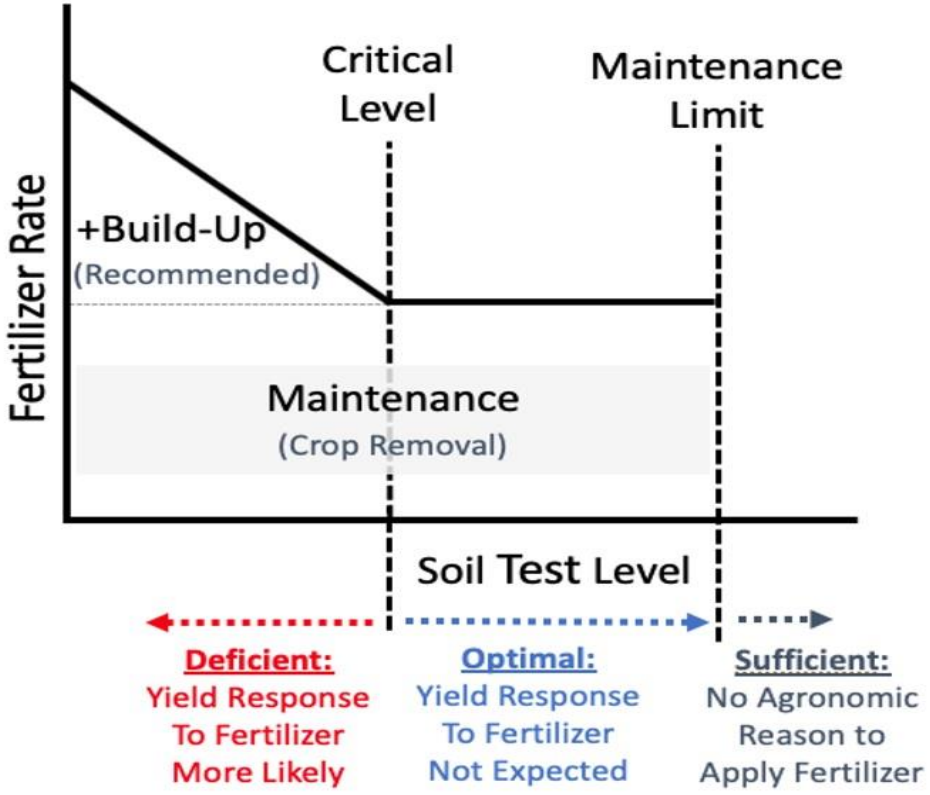
Manures applied at equal rates to inorganic sources tend to slightly increase tile DRP loads

- Preliminary findings suggest statistical, but minor (grams/yr) increase in dissolved reactive phosphorus (DRP) from liquid dairy manure compared to commercial fertilizer
- Similar small increases in DRP from swine manure
- No differences in poultry litter compared to commercial fertilizer

King et al., 2022; unpublished data

Soil testing and adhering to recommended rates reduces potential for nutrient loss

- 90% of fields have crop rotation phosphorus (P) application rates at or below recommendations
- 58% of fields had zero P applied
- Soil test P (STP) above agronomic levels generally poses an environment risk, but STP above agronomic levels does NOT necessarily equal environmental risk
- As P application increases, P load increases
- Late Spring Nitrate Test (LSNT) reduced nitrogen loss by 30%



Smith et al., 2018; King et al., 2018; Duncan et al., 2017; Christianson et al., 2016

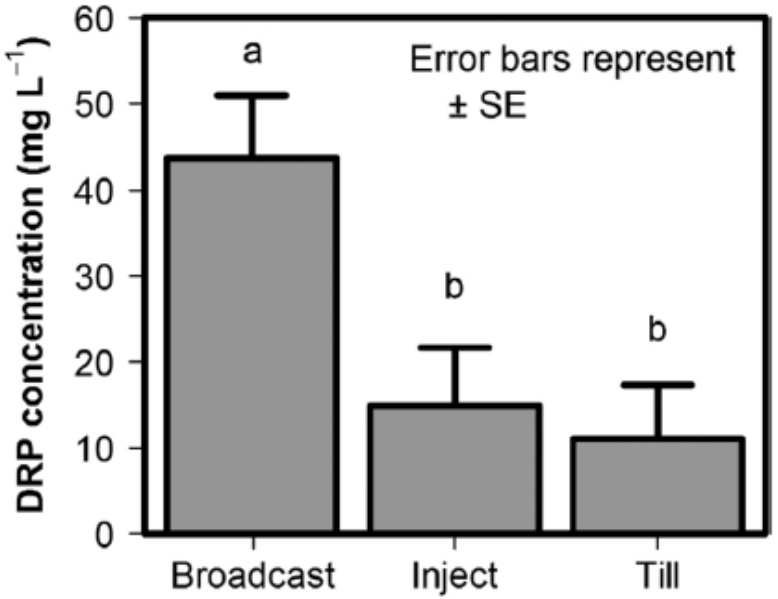
Broadcast application leads to stratification and increased losses compared to subsurface placement

Surface broadcast

Subsurface placement

- Broadcast application without incorporation leads to stratification and increased losses (Baker et al., 2017)
- Shallow (3 inches) disk tilling following broadcast application reduced tile drainage P loss by 7-fold (Williams et al., 2016)
- Broadcasting P without incorporation increased field scale dissolved P loss but reduced total P loss (King et al., unpublished data)
- With respect to manure, placement is very important as significantly less losses occur with incorporation when compared to broadcast only

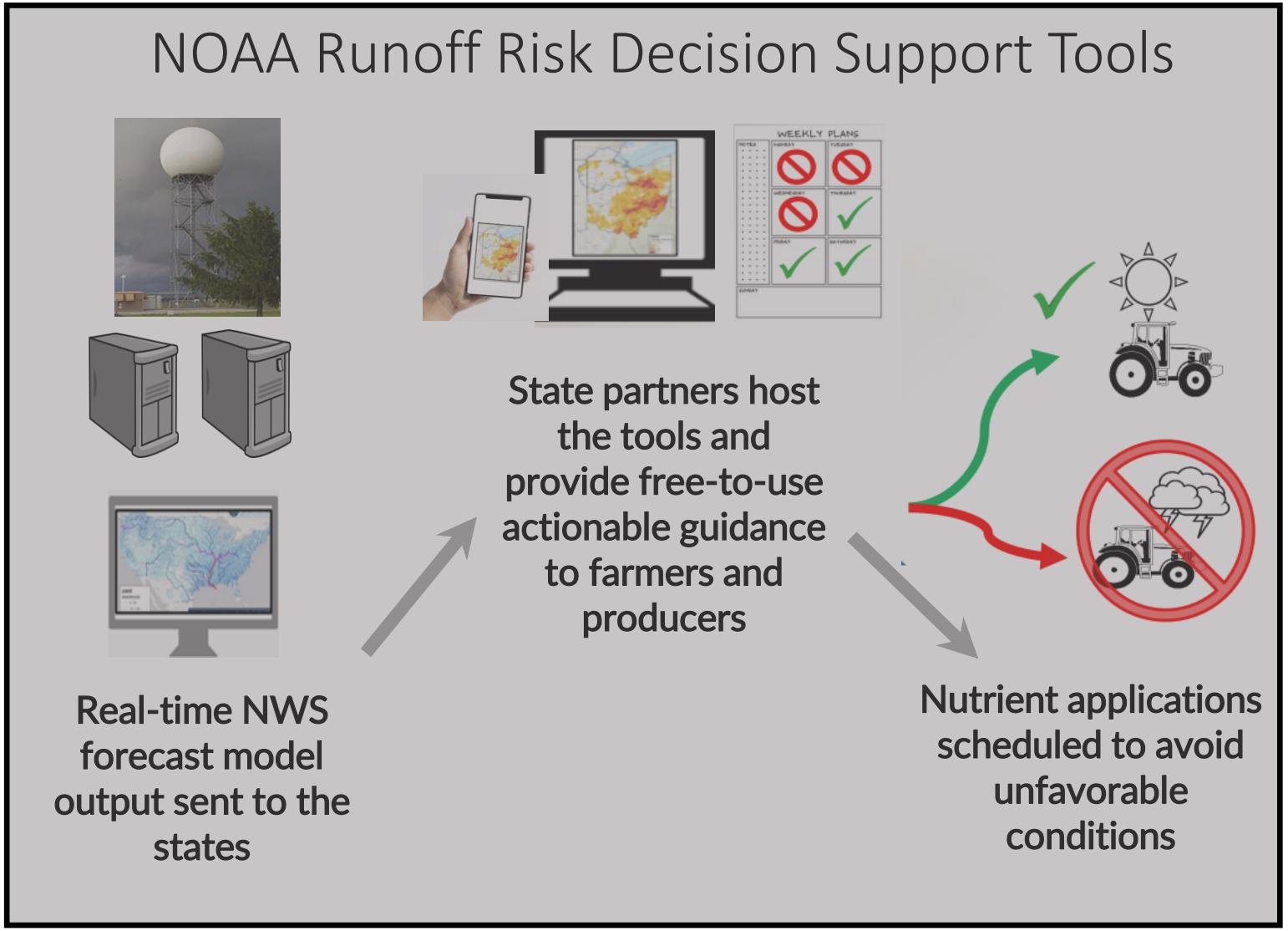
Plot scale studies reveal the importance of subsurface placement



- **Injection or tillage incorporation reduced leachate P by ~70% compared to broadcast with no incorporation** (Williams et al., 2018)

- **2x2 placement and broadcast plus disk tillage had significantly less losses compared to broadcast only application** (King et al., unpublished data)

Time since application to first rainfall decreases nutrient loss



- **Fertilizer application followed by rainfall creates potential for large incidental P losses** (Johnson et al. Unpublished data)
- **Prolonging the period between application and rainfall had a decreasing effect for both N and P** (Hanrahan et al., 2021)
- **Several rainfall simulation studies also confirm decreased nutrient loss with delayed rainfall after application** (e.g., Smith et al., 2007)

Applications closer in proximity to crop needs tend to have less loss

- **In-crop manure applications reduced nitrogen (N) loads and marginally increased P loads** (Greg LaBarge and Blanchard River Demonstration Network, unpublished data)

- **Application in winter and/or before precipitation increases loss risk** (Mallarino et al., 2015; King et al., unpublished data)

- **Spring manure applications resulted in less loss compared to fall applications** (King et al., unpublished data)

Site specific aspects and regional trends should be considered

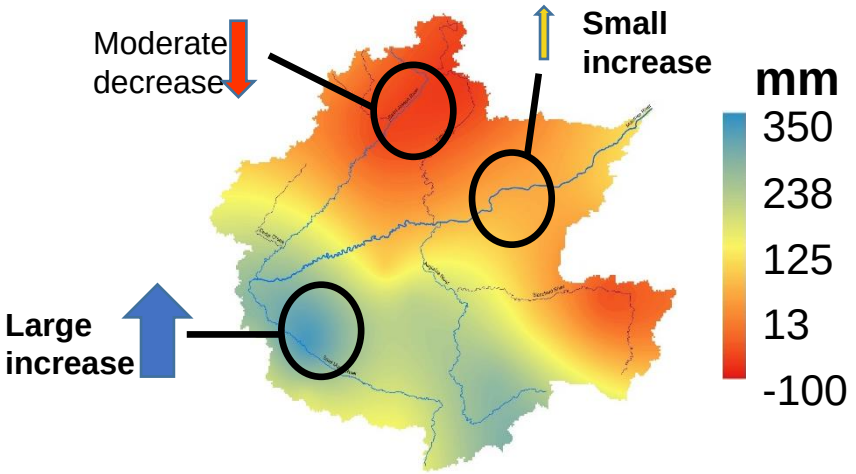
Assessment

Soil quality

Producer capability/resources

Legacy/Variable source area

Local/regional climate change

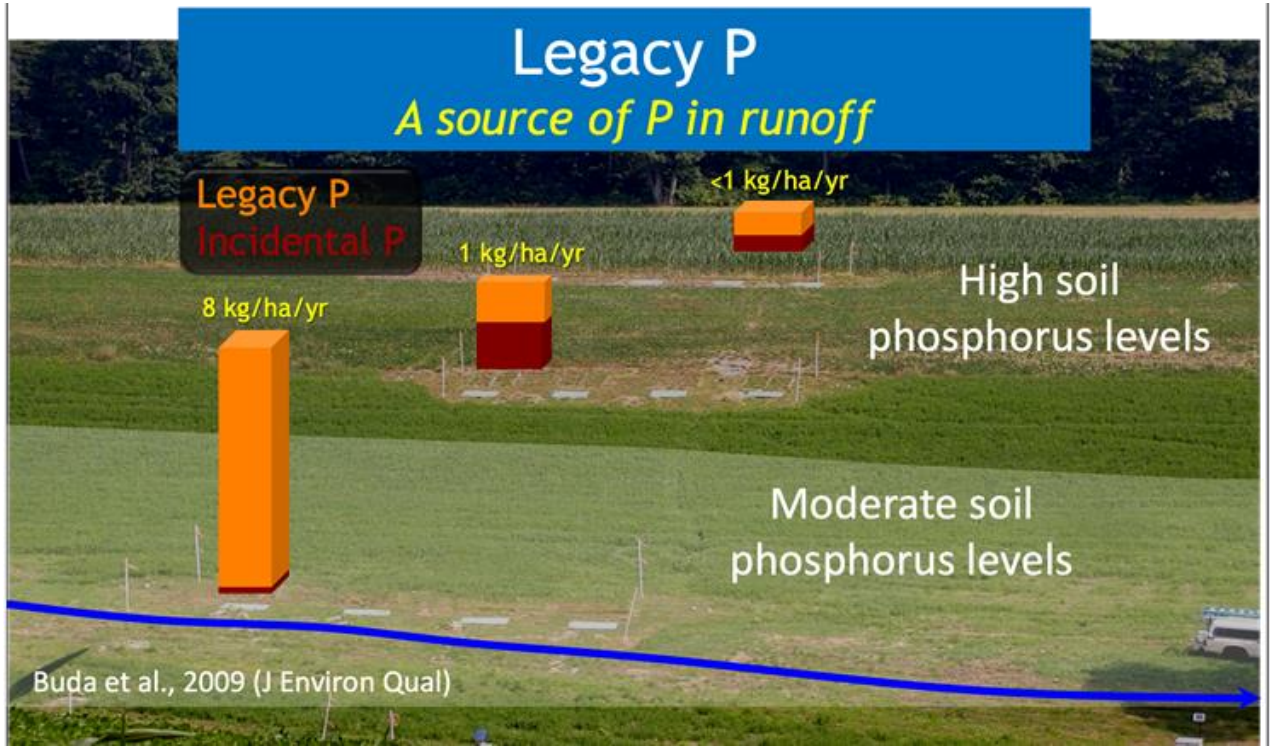


Change since mid 1970s

Poor soil quality alters natural flow paths that short circuits matrix and natural soil ‘filtering’

- Poor soil quality can reduce infiltration leading to increased surface runoff
- Poor soil quality, related to soil structure can enhance desiccation cracking and preferential flow
- Preferential flow is a direct flow pathway to tile drainage
- Has implications for fertilizer source, placement, and timing

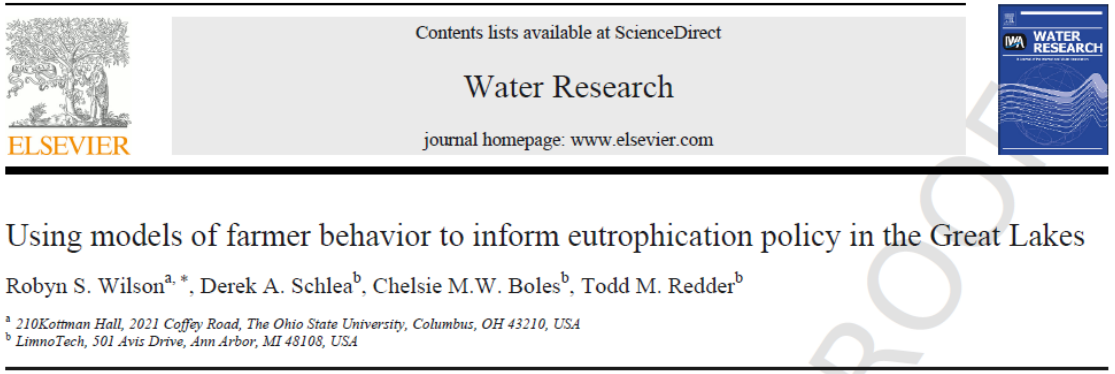
Variable source areas or 'hot spots' can disproportionately contribute to field loss



- Variable source areas can vary based on hydrologic connectivity, soil texture, and slope differences and significantly increase field losses
- Legacy P can serve as a chronic source of nutrients for years/decades and mask effects of current conservation efforts
- Management strategies will vary depending on the primary source of P

Producer perception and resources are often cited as reasons for not adopting conservation practices

Assessment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Using models of farmer behavior to inform eutrophication policy in the Great Lakes

Robyn S. Wilson[a, *], Derek A. Schlea[b], Chelsie M.W. Boles[b], Todd M. Redder[b]

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Wilson et al., 2019: 45:4-11.

- Barriers to practice adoption
  - Perceived practice efficacy
  - Financial and time burden
- Need:
  - Better cost-benefit information
  - Site-specific decision support tools
  - Technical assistance

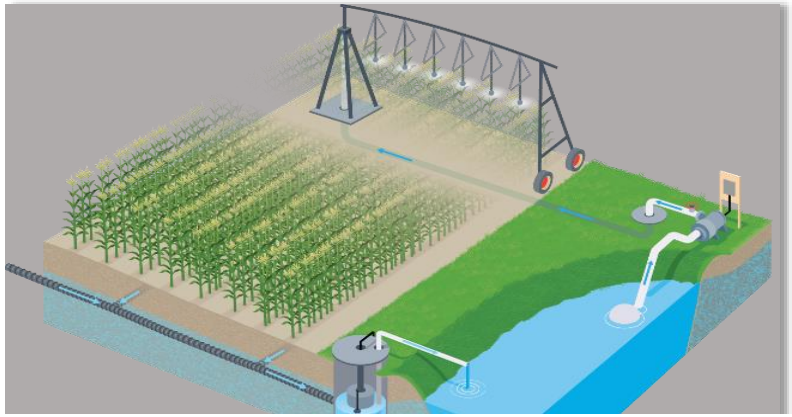
Changes in precipitation amounts, intensities and timing may make parts of SMART implementation a challenge

Photos by: Jed Stinner & anonymous

Water management can reduce hydrologic connectivity and improve water quality

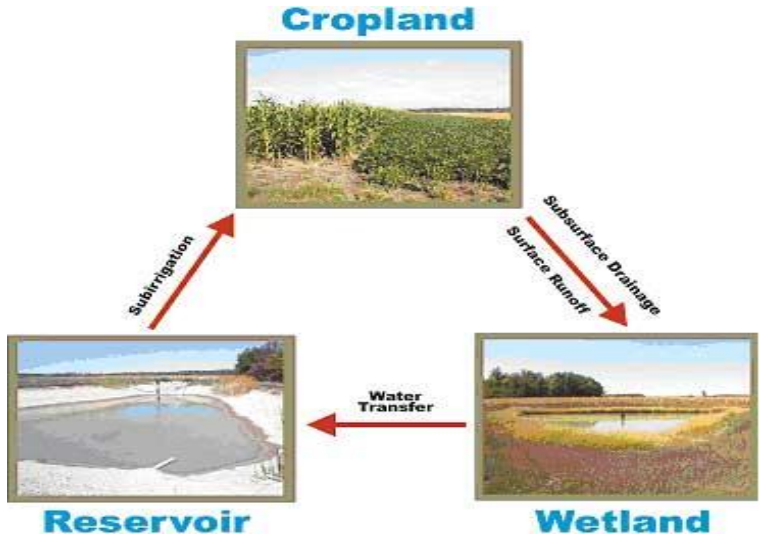
Controlled drainage

Blind inlets



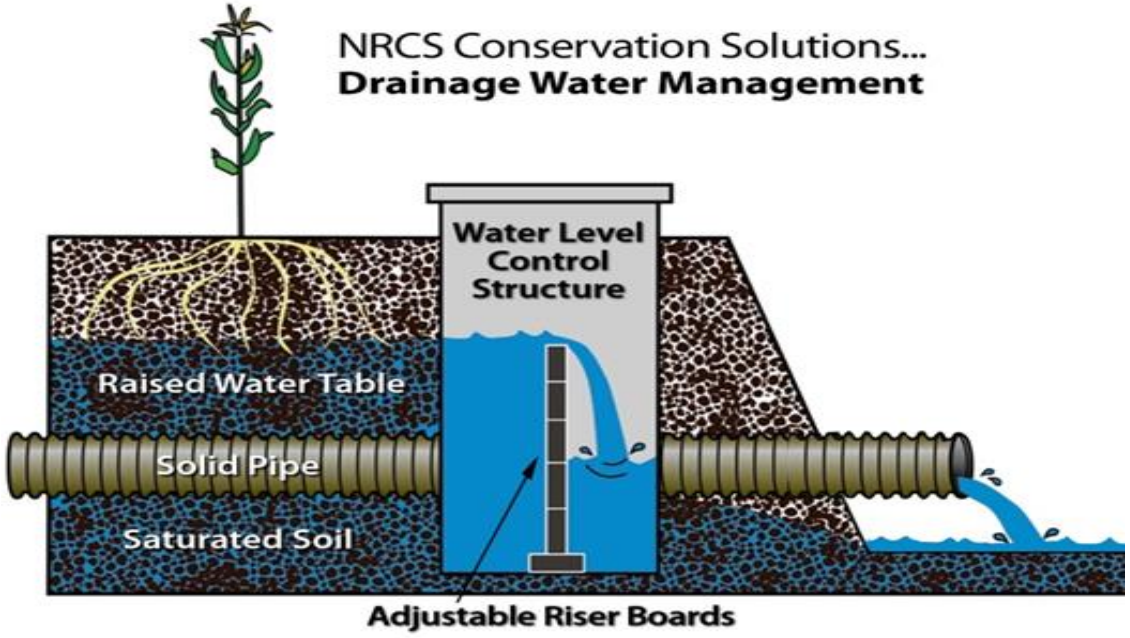
Drainage water recycling

Wetlands



Cover crops

Drainage water management (controlled drainage) promotes in-field water storage



- Significantly reduced drainage volume
- Significantly decreased nitrate (NO_3)
- Mixed results for DRP and TP
- May increase surface discharge as well as nutrient losses but should not negate overall benefits
- Potential increase in crop yield in effective area

King et al., 2022; Ghane et al., 2012; Wang et al., 2020

Blind inlets disrupt surface flow to tile drainage and filter surface runoff

- Slow down movement of water and promote sedimentation
- Variable results for NO3-N
- Phosphorus reduction approximately 50%
- Sediment reduction up to 70%

Smith et al., 2013; Williams et al., 2020

Wetlands have potential to reduce moderate discharge rates and become nutrient sinks

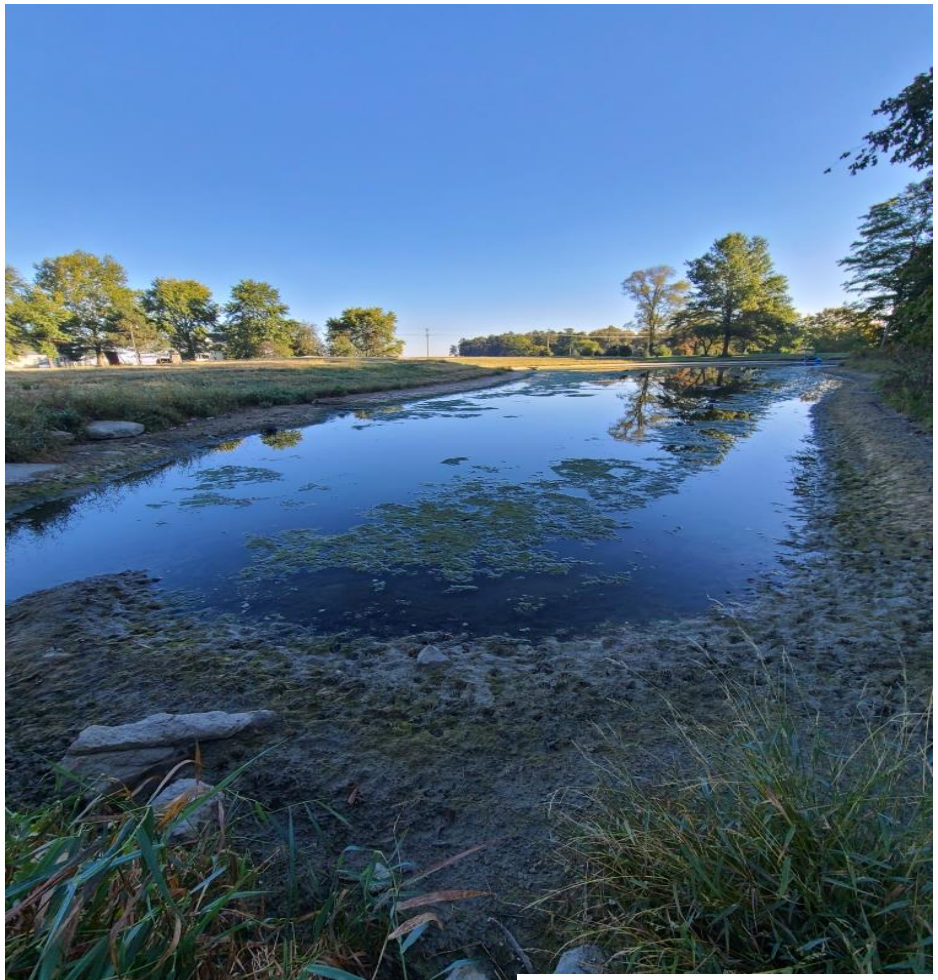
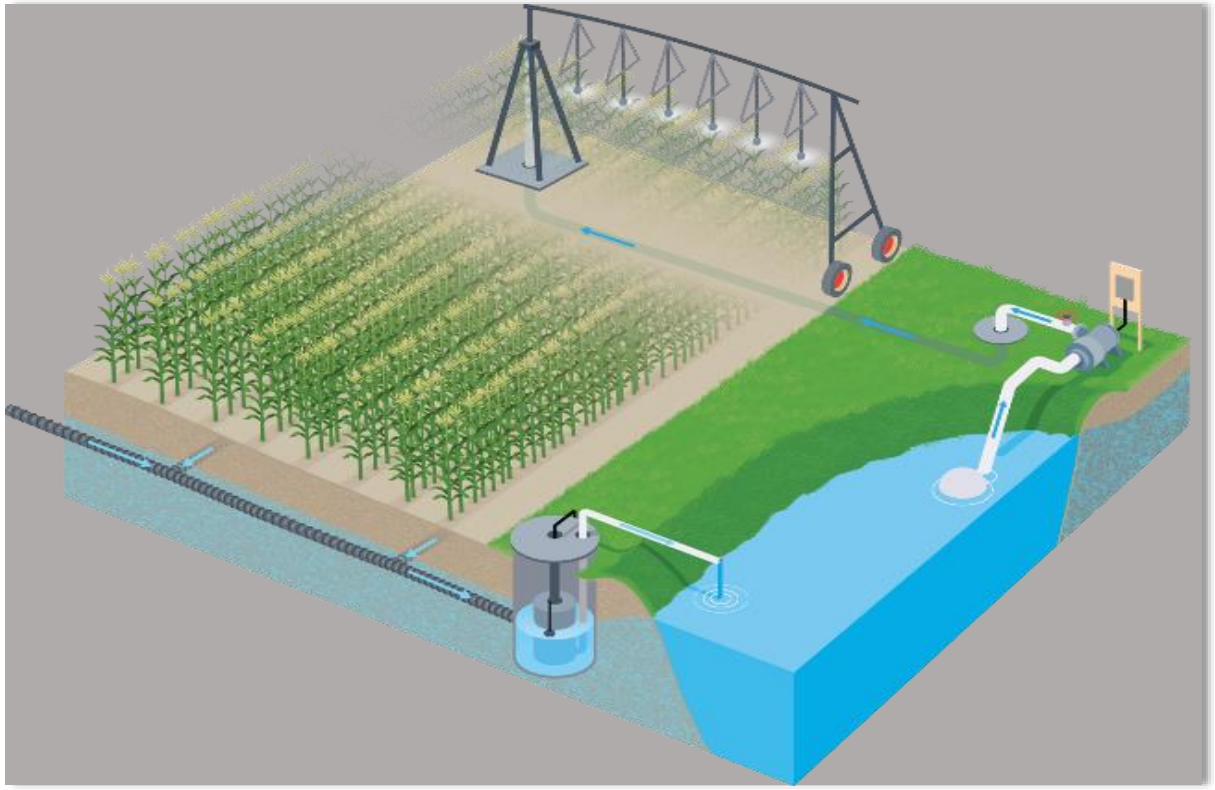


Photo credit: Jed Stinner

- **Reduce both N and P**
- **Limited in addressing larger discharge rates**
- **Limited lifetime before transitioning from a sink to a source**

Braskerud et al. (2005)

Drainage water recycling is an approach to move toward a zero discharge system



Hay et al., 2021

- Captures and stores drainage water for later irrigation
- Increases crop production
- Significant N and P reductions to downstream waters
- Other potential benefits include flood control and wildlife habitat

Cover crops alter field scale hydrology and nutrient delivery

- **Field scale hydrology**
  - **Increased Evapotranspiration (ET)**
  - **0.5 to 2.0 inches less surface runoff**
  - **0.5 to 3.0 inches greater tile discharge**

- **Tile drainage nutrients**
  - **Significant tile NO_3-N reductions**
  - **Mixed results on tile drainage phosphorus**

Shedekar et al.: unpublished data; Zhang et al., 2017; Hanrahan et al., 2018; 2021; Christianson et al., 2021

When nutrient and water management are not enough

Phosphorus removal structures

Photo credit: Chad Penn

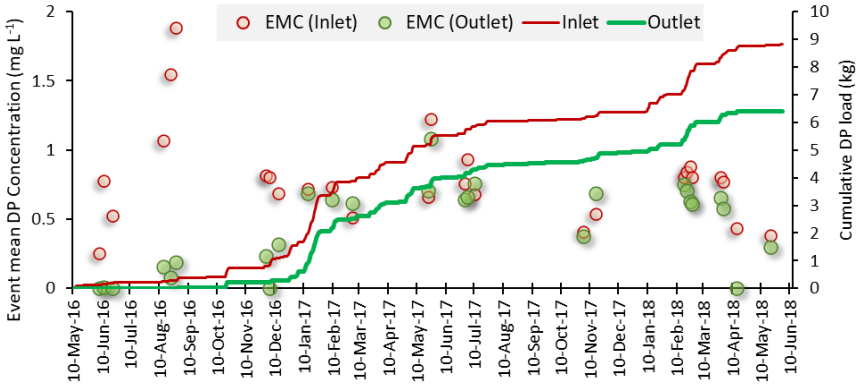
Denitrifying bioreactors

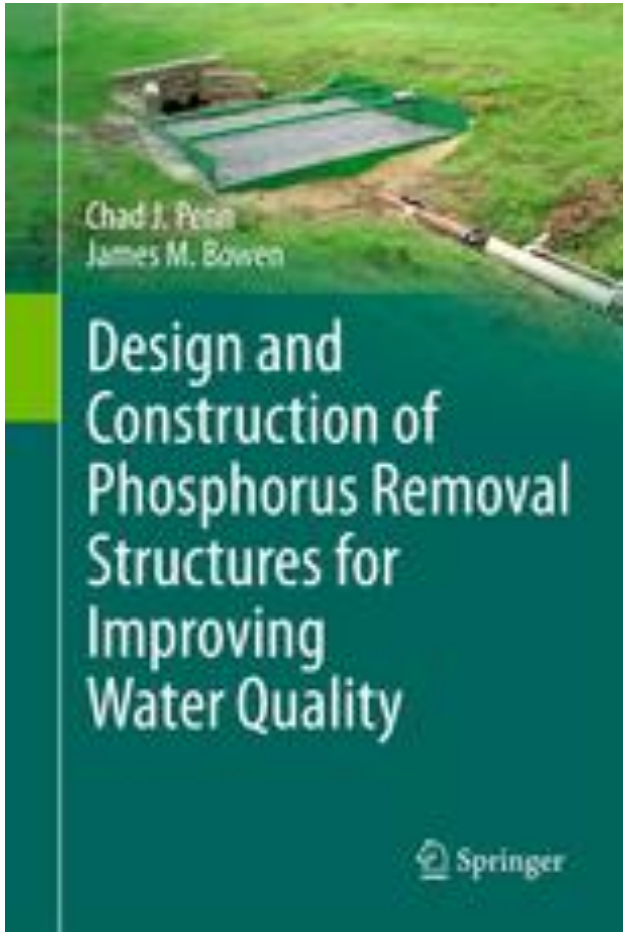
Photo courtesy of Iowa Soybean Association

Drainage ditch design

Photo credit: Brittany Hanrahan

Phosphorus removal structures are designed and implemented to target high P loss sites

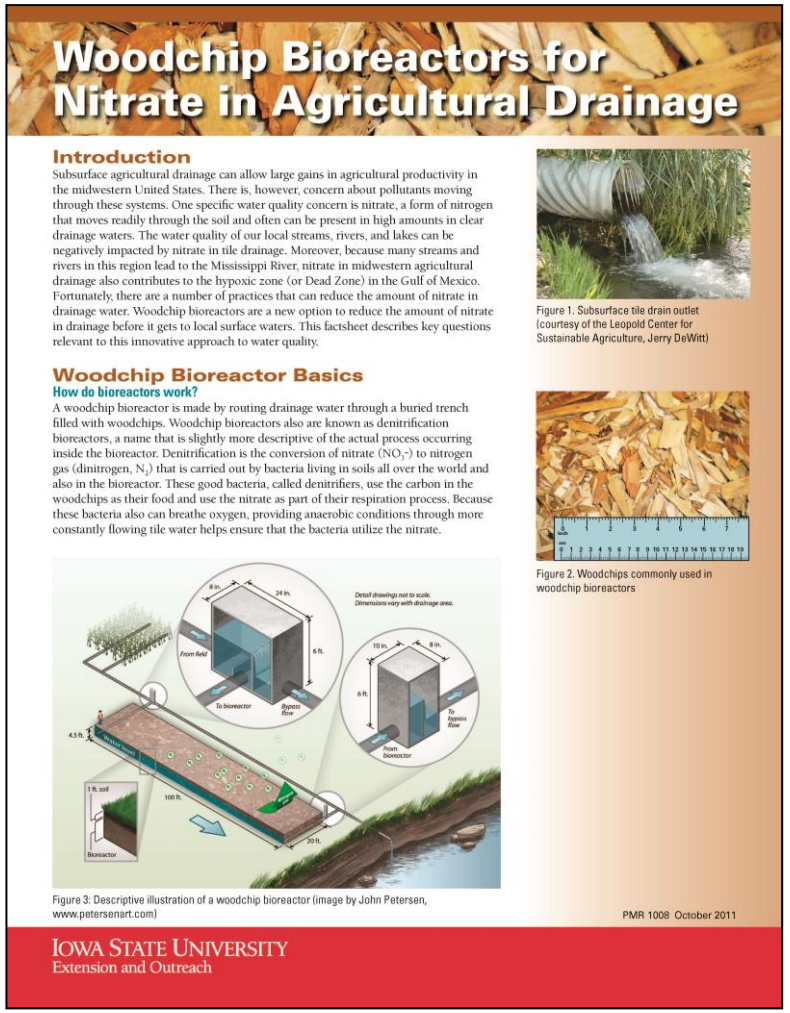




- Surface runoff or subsurface drainage
- Work better with greater P concentrations
- Generally designed to remove 40% over 3-5 yrs
- Design software is available (P-TRAP)

Denitrification bioreactors are an effective means to reduce tile drainage nitrogen

Photos courtesy of Iowa Soybean Association



Woodchip Bioreactors for Nitrate in Agricultural Drainage

Introduction

Subsurface agricultural drainage can allow large gains in agricultural productivity in the midwestern United States. There is, however, concern about pollutants moving through these systems. One specific water quality concern is nitrate, a form of nitrogen that moves readily through the soil and often can be present in high amounts in clear drainage waters. The water quality of our local streams, rivers, and lakes can be negatively impacted by nitrate in tile drainage. Moreover, because many streams and rivers in this region lead to the Mississippi River, nitrate in midwestern agricultural drainage also contributes to the hypoxic zone (or Dead Zone) in the Gulf of Mexico. Fortunately, there are a number of practices that can reduce the amount of nitrate in drainage water. Woodchip bioreactors are a new option to reduce the amount of nitrate in drainage before it gets to local surface waters. This factsheet describes key questions relevant to this innovative approach to water quality.

Woodchip Bioreactor Basics

How do bioreactors work?

A woodchip bioreactor is made by routing drainage water through a buried trench filled with woodchips. Woodchip bioreactors also are known as denitrification bioreactors, a name that is slightly more descriptive of the actual process occurring inside the bioreactor. Denitrification is the conversion of nitrate (NO_3^-) to nitrogen gas (dinitrogen, N_2) that is carried out by bacteria living in soils all over the world and also in the bioreactor. These good bacteria, called denitrifiers, use the carbon in the woodchips as their food and use the nitrate as part of their respiration process. Because these bacteria also can breathe oxygen, providing anaerobic conditions through more constantly flowing tile water helps ensure that the bacteria utilize the nitrate.

Figure 1. Subsurface tile drain outlet (courtesy of the Leopold Center for Sustainable Agriculture, Jerry DeWitt)

Figure 2. Woodchips commonly used in woodchip bioreactors

Figure 3: Descriptive illustration of a woodchip bioreactor (image by John Petersen, www.petersenart.com)

PMR 1008 October 2011

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- Generally located at the edge-of-field and seek to target 50 to 80 acres
- Typical footprint: 25’x75’x4’
- Typical carbon source is woodchips
- Nitrogen removal generally in 20-30% range
- Research continues to enhance the efficiency of the bioreactors, especially during cold climates

Gary Feyereisen; Laura Christianson

Drainage ditch design and management has the potential to create nutrient sinks

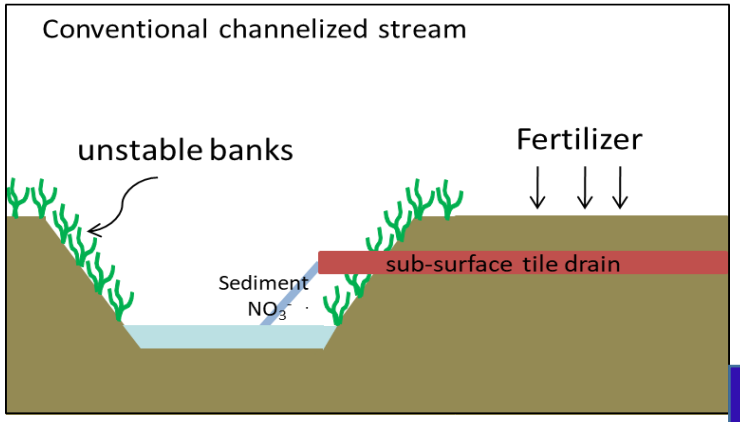


Photo by Jon Witter

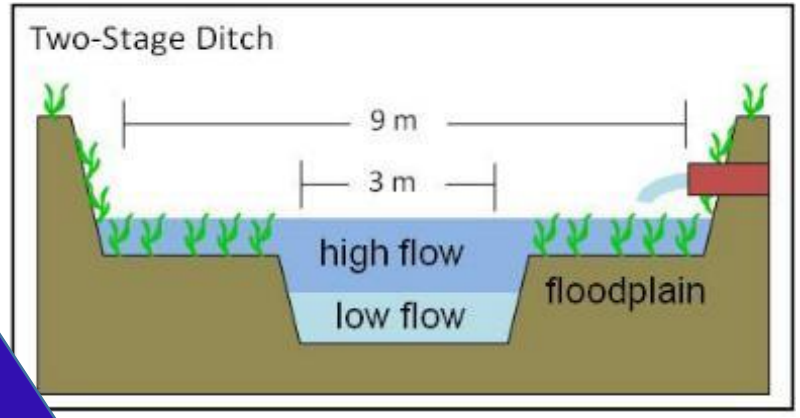
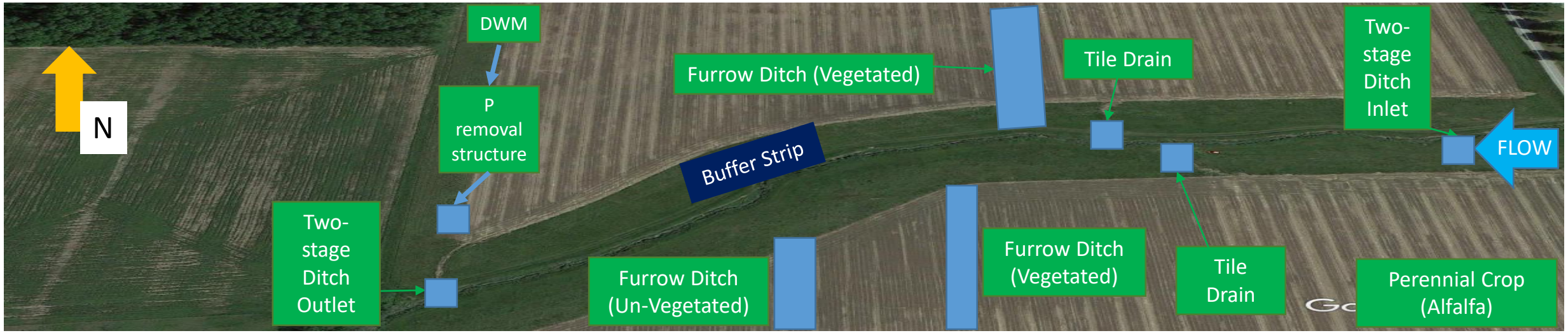


Photo by Jon Witter

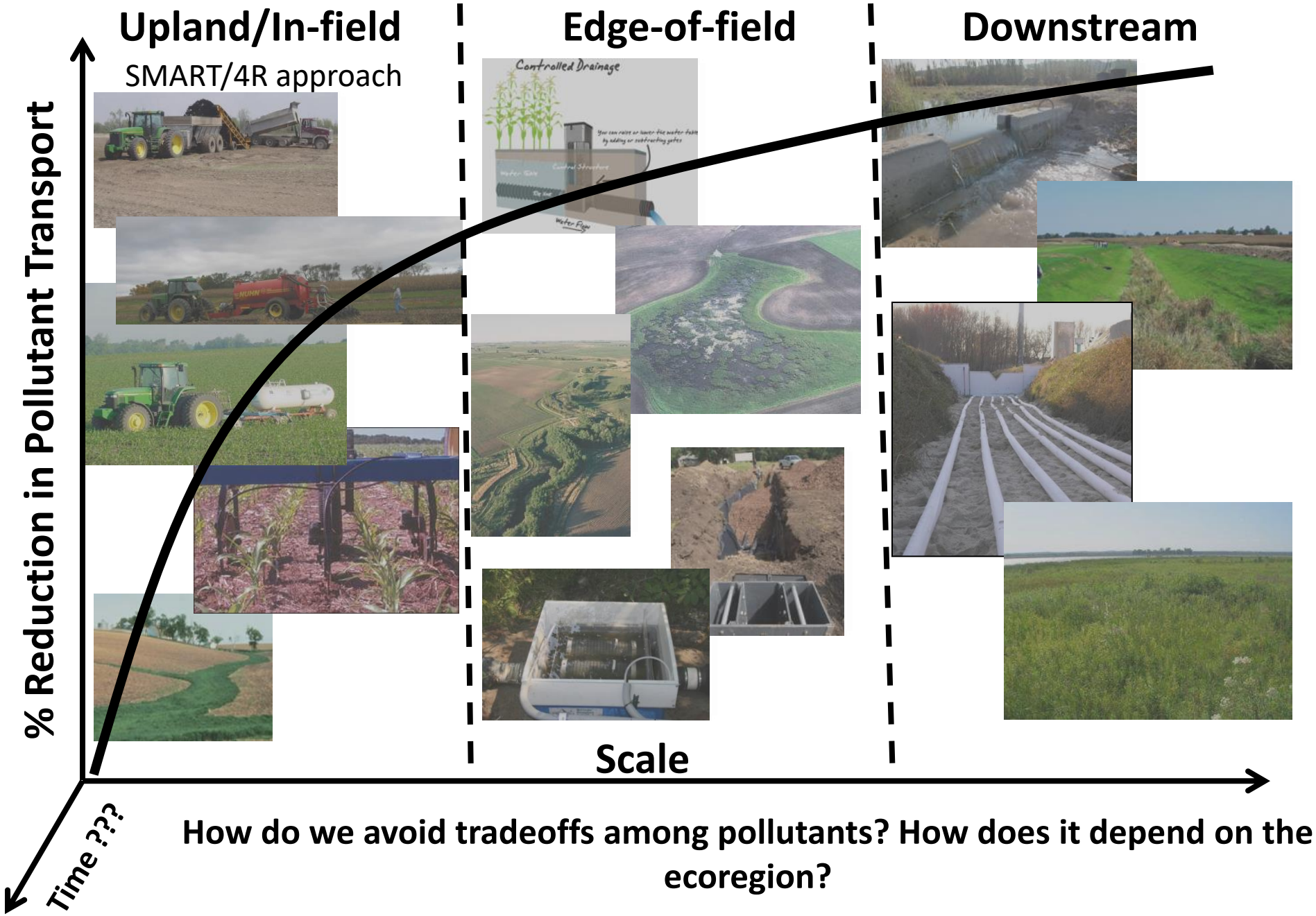
- **Engineered for channel stability**
- **Promotes sediment deposition on benches**
- **Increased nutrient retention**

Davis et al. (2015); Mahl et al. (2015); Hanrahan et al. (2018)

Stacking practices has the potential to further reduce nutrient loss



- **Include two or more in-field practices, edge-of-field, or in-stream practices**
- **Benefits may not be 100% additive but should provide additional reductions**



How do we avoid tradeoffs among pollutants? How does it depend on the ecoregion?

Summary

Solubility varies between organic and inorganic sources; when applied at equal rates, potential for slight increase in P loads

Subsurface placement significantly reduces loss potential

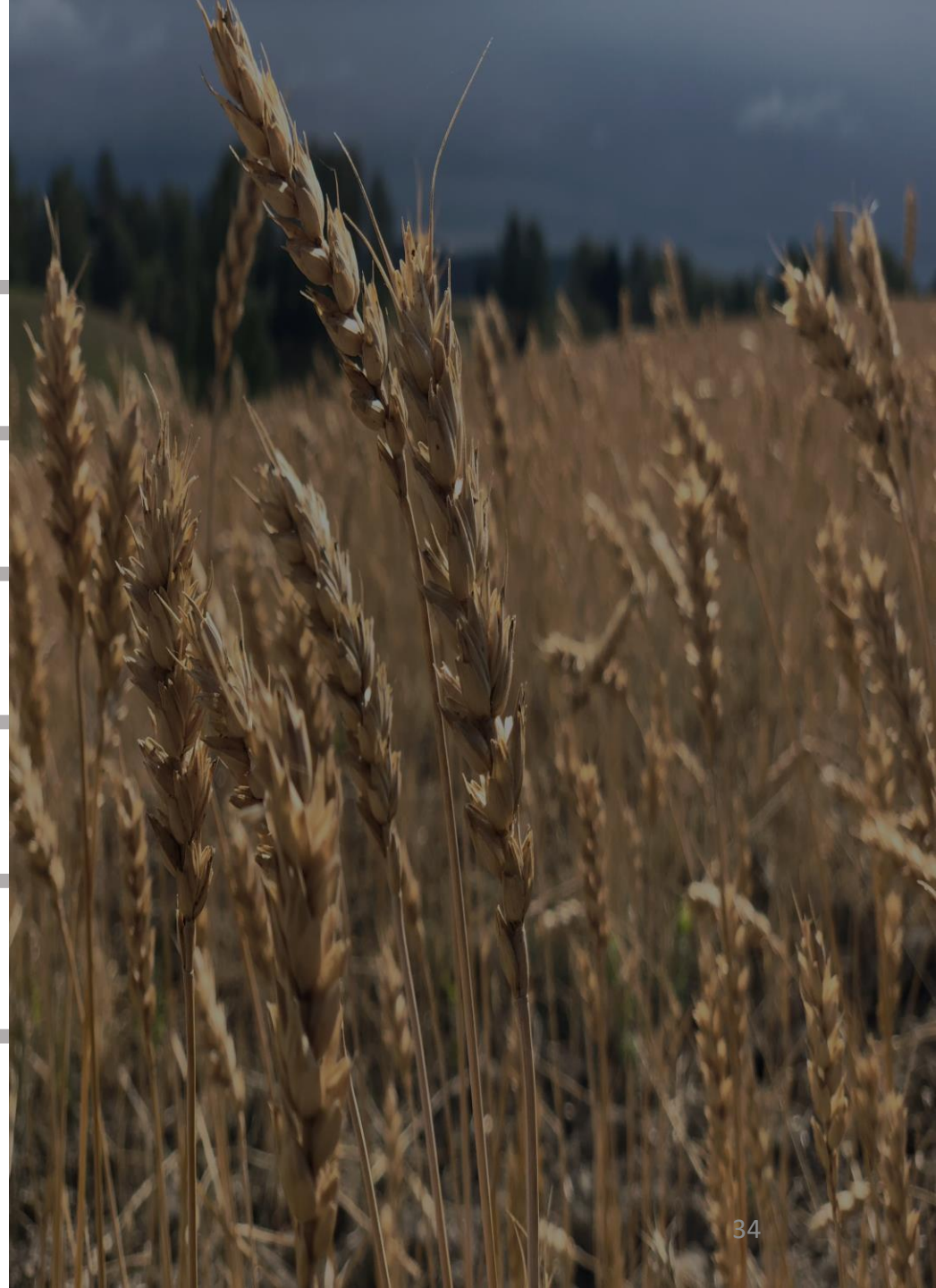
Site specific field characteristics and socioeconomic conditions need to be considered

Soil testing and adherence to land grant university guidelines reduces potential for loss

Awareness of local weather forecasts and application closer to crop utilization generally reduced loss potential

Water management is just as important as nutrient management

Stacking practices and implementing other EOF and in-stream practices may be necessary to meet nutrient reduction goals



For more information on this presentation, or more information on nutrient and water management in drained landscapes

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Citations and Additional Resources for "Achieving Water Quality Outcomes Through Nutrient and Water Management" Conservation Outcomes Webinar, f*eaturing* Dr. Kevin King, USDA Agricultural Research Service

Slide 3:
USDA-ERS: https://www.ers.usda.gov/data-products/fertilizer-use-and-price/

Slide 4:
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