Significance of Tile Drainage as a Conduit for Phosphorus Transport: Current Research, Literature Review, and Potential Solutions

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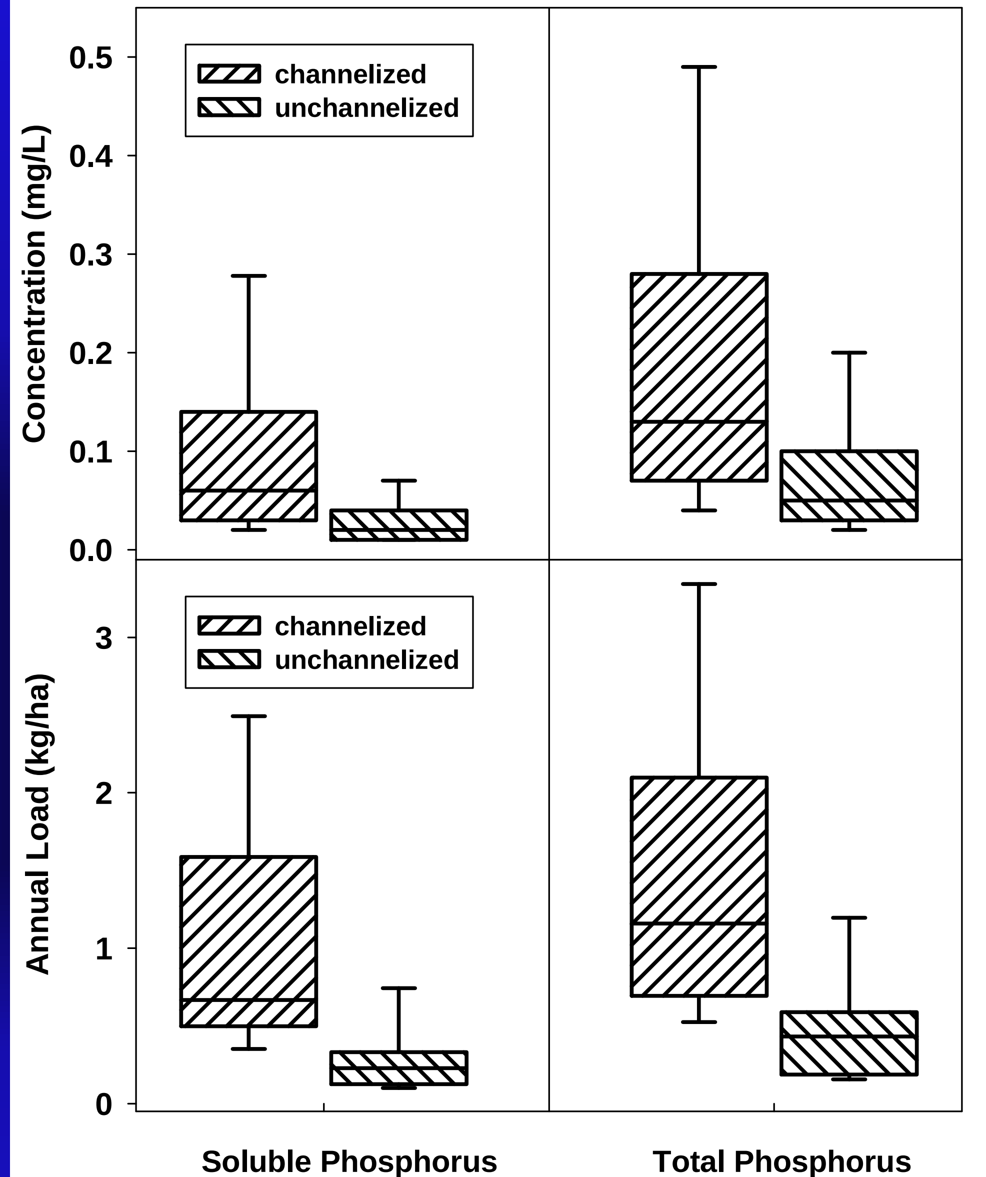
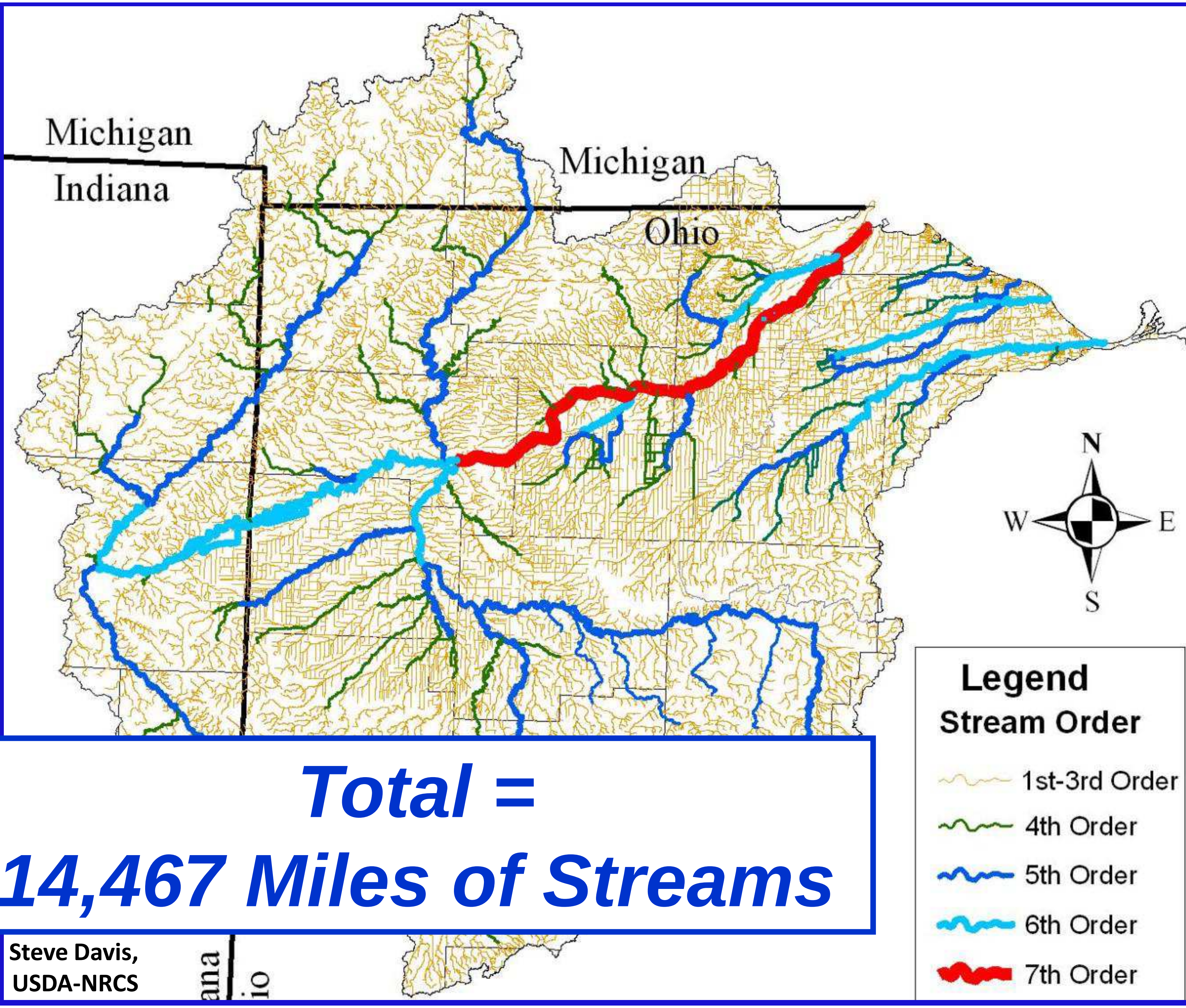
Ohio Phosphorus Task Force, September 5, 2012



2005-2010 phosphorus concentration and annual loading for channelized and unchannelized streams in UBWC watershed, Ohio.



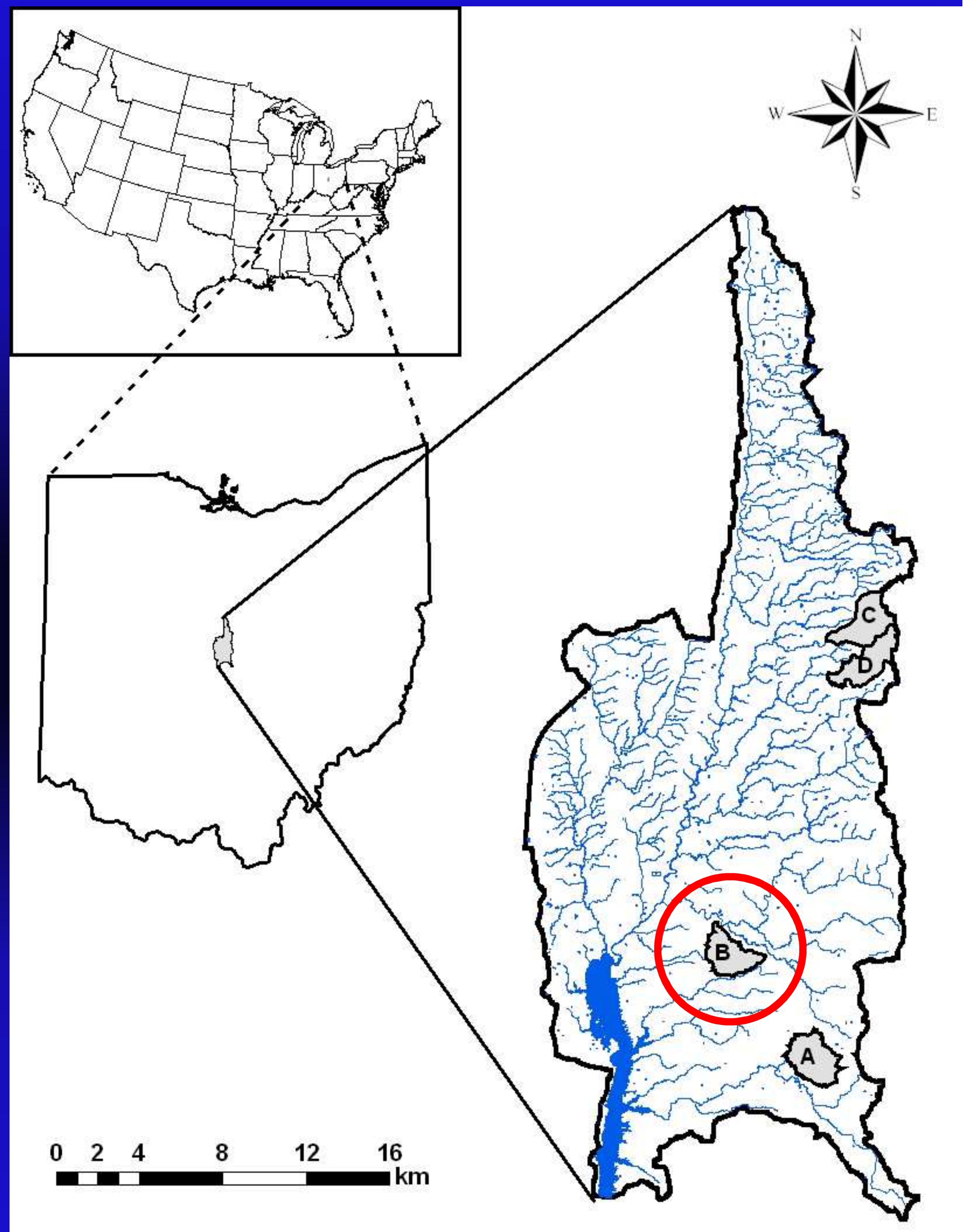
Total =

14,467 Miles of Streams

Steve Davis, USDA-NRCS

Upper Big Walnut Creek Watershed

- USGS 10-digit watershed (HUC 05060001-13)
- 492 km² drainage area
- 686 km of perennial and intermittent streams
- drinking water supply for approx. 800,000
- approx. 60% cropland
- significant portion systematically tile drained
- silt loam and clayey somewhat poorly to poorly drained soils
- normal rainfall is 985 mm



Study Watershed

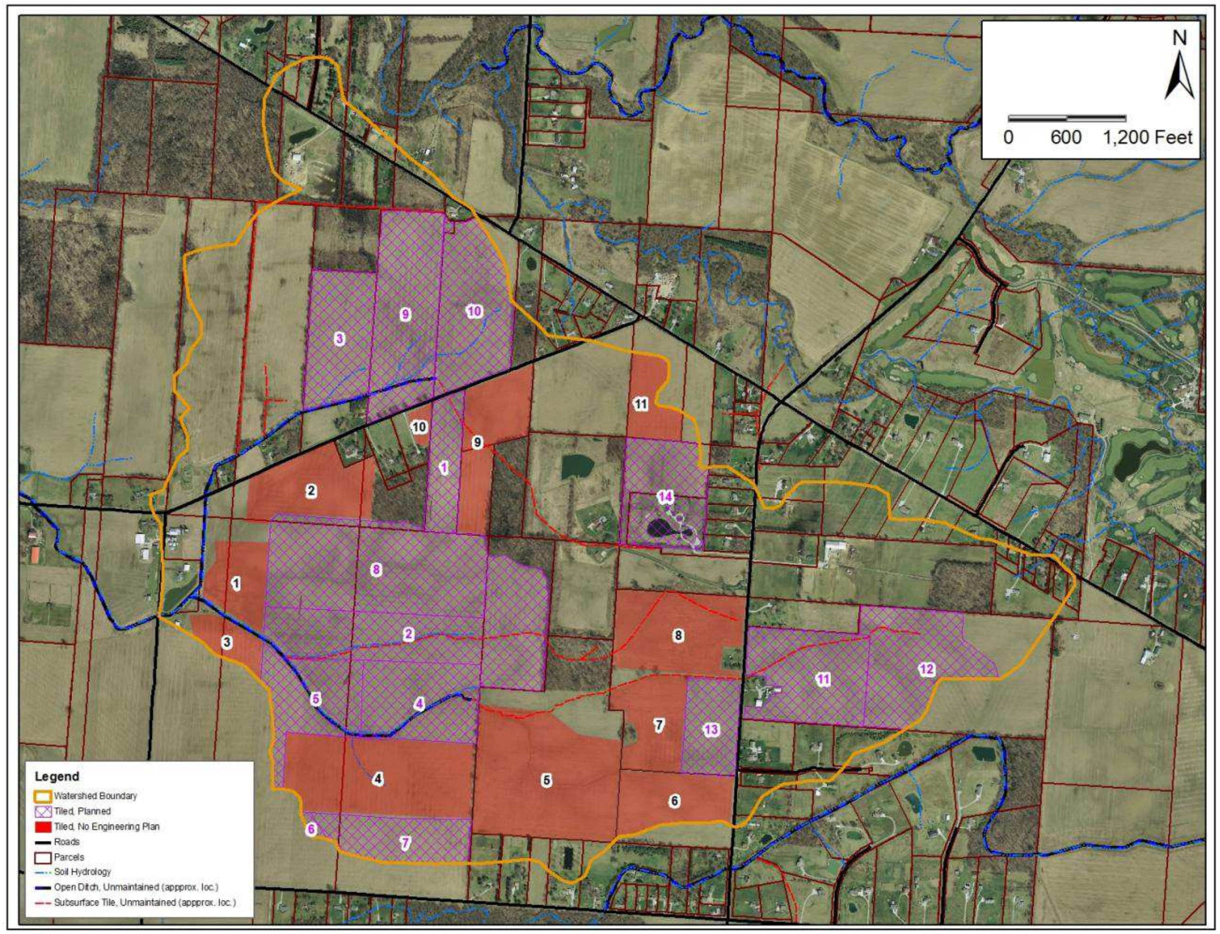
Drainage area: 389 ha

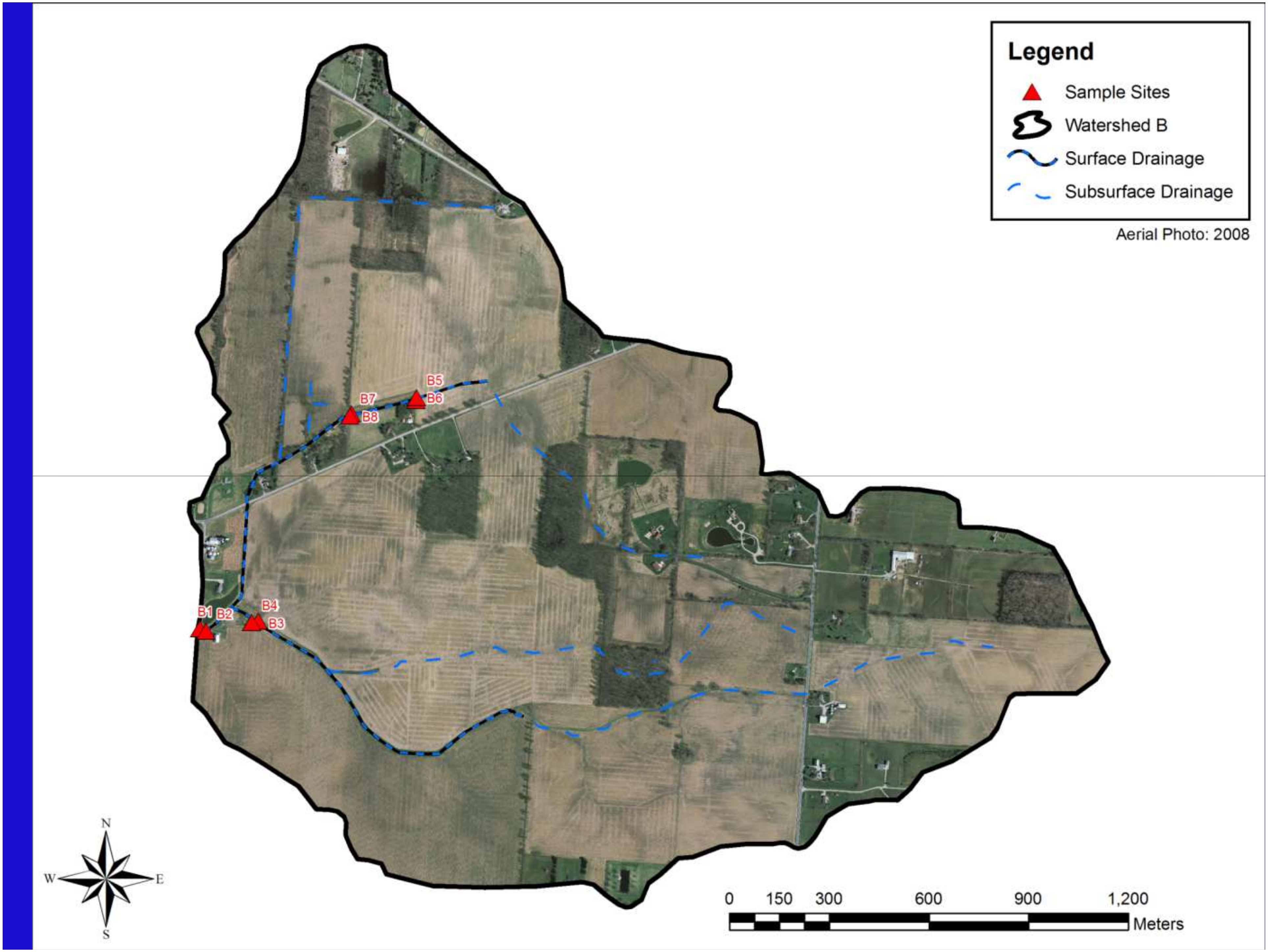
Soils: Bennington silt loam (52.9%); Pewamo clay loam (46.2%)

Land use: Agriculture (73%); Woodland (10.4%); Urban/farmstead   (21%)

Cropping: primarily corn-soybean rotation; rotational tillage

Drainage characteristics: 78% of watershed drainage area systematically tile drained





Legend
Sample Sites
Watershed B
Surface Drainage
Subsurface Drainage
Aerial Photo: 2008
B1
B2
B3
B4
B5
B6
B7
B8
N
S
E
W
0
150
300
600
900
1,200
Meters

Sampling Sites

B1 – Watershed Outlet (8' Parshall Flume)

B2 – 8" tile main

B3 – 24" county main

B4 – 8" tile main

B5 – 15" main

B6 – 15" county main

B8 – 8" tile main

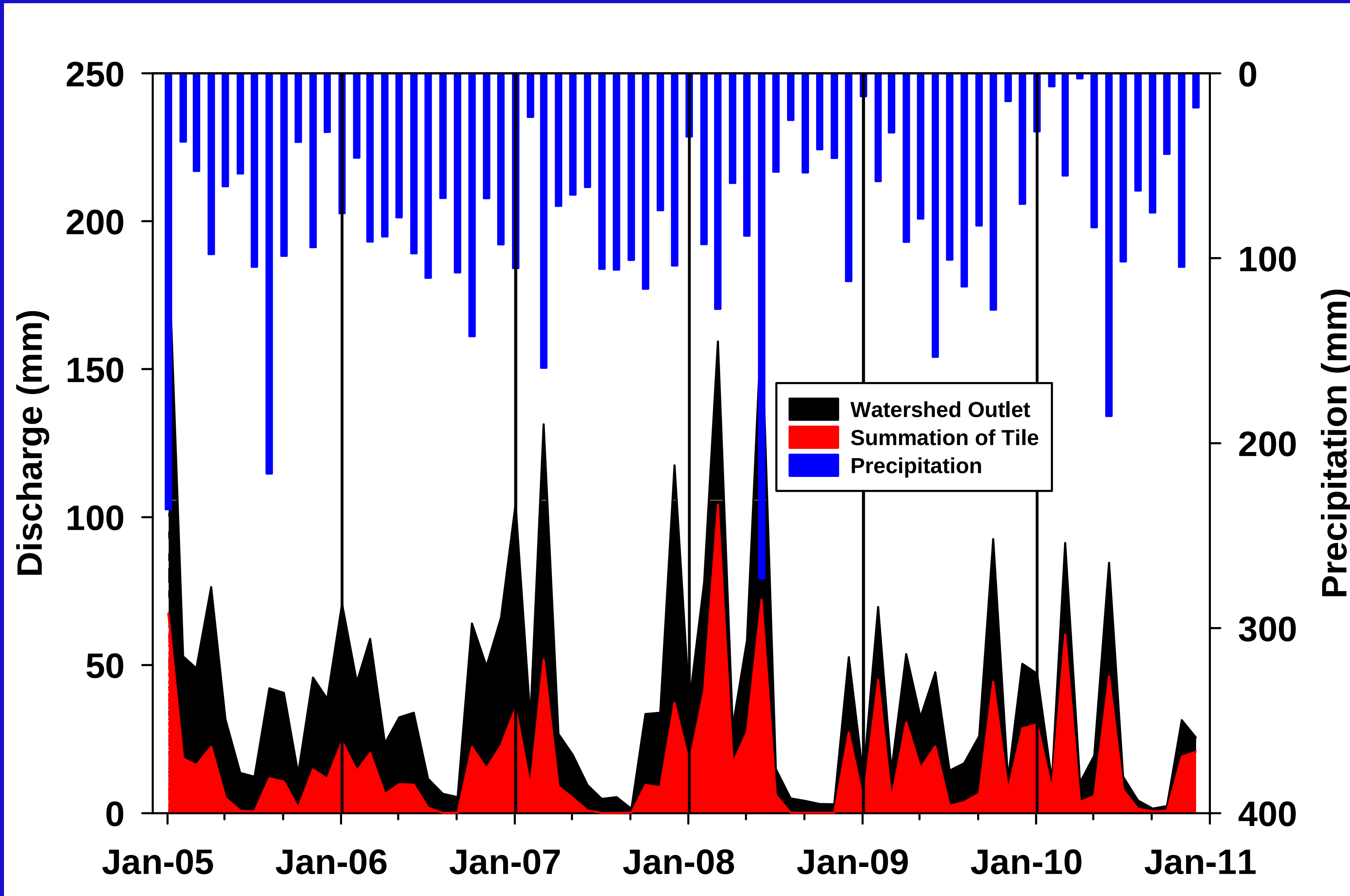
Hydrology Measurements

- **Flow and time based sampling**
- **Discrete and weekly composites**
- **Subsurface and surface discharge**
- **Precipitation and other climate variables**

Sampling Methodology

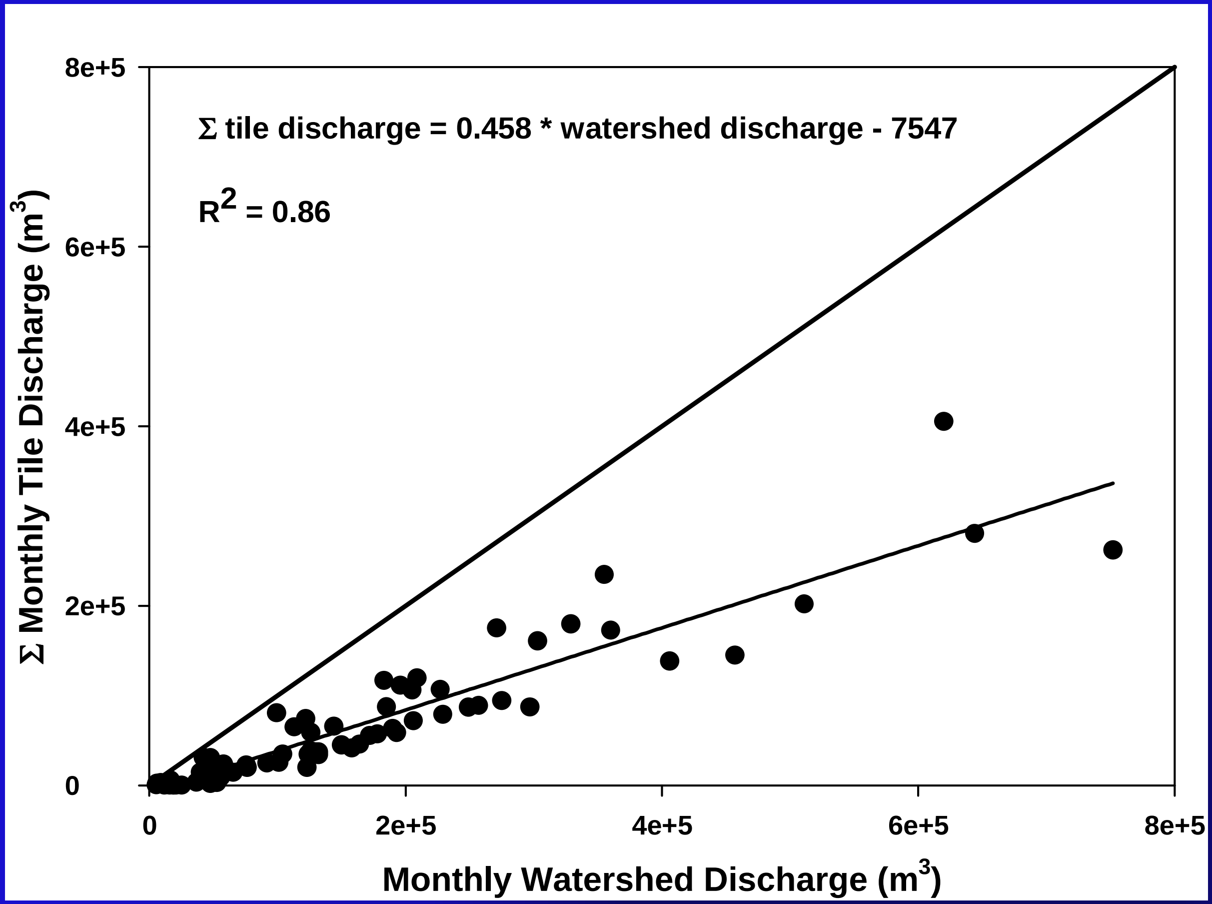
- Flumes and weirs with automated sampling equipment
- Hydrology recorded on a 10 minute interval
- Samples taken every 6 hours and composited on a weekly basis

Tile flow and hydrology



Shift in rainfall timing in 2008:

32% of annual rainfall occurred in May and Jun (2008-2010) compared to 12% in 2005-2007



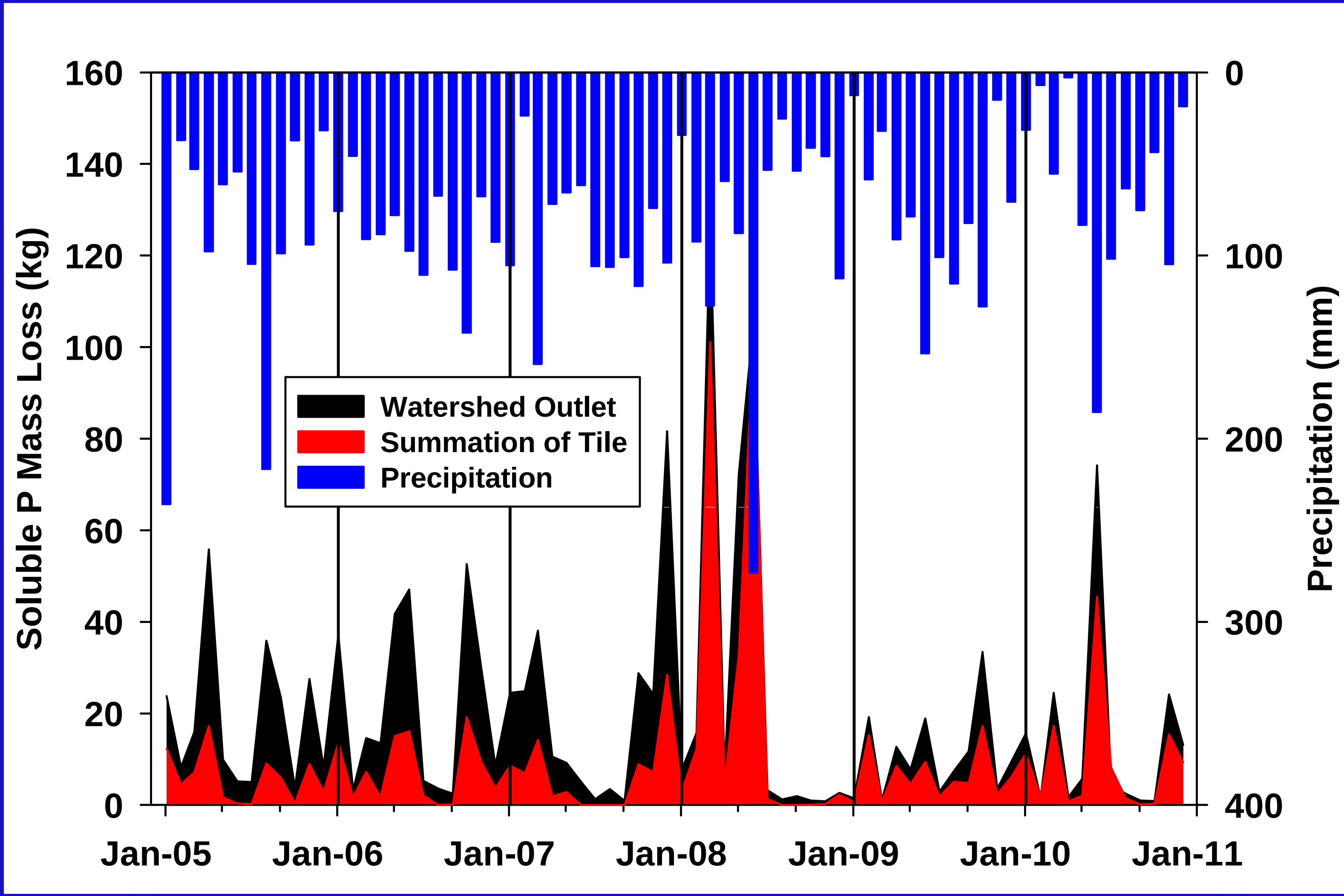
Annual Fractions

	Tile Q /Watershed Q	Tile Q /Pcp
2005	0.30	0.16
2006	0.31	0.14
2007	0.32	0.15
2008	0.51	0.31
2009	0.49	0.23
2010	0.60	0.27
AVG	0.42	0.21

42% of annual basin discharge originated from tile flow in Ontario, CA (McCrae et al., 2007)

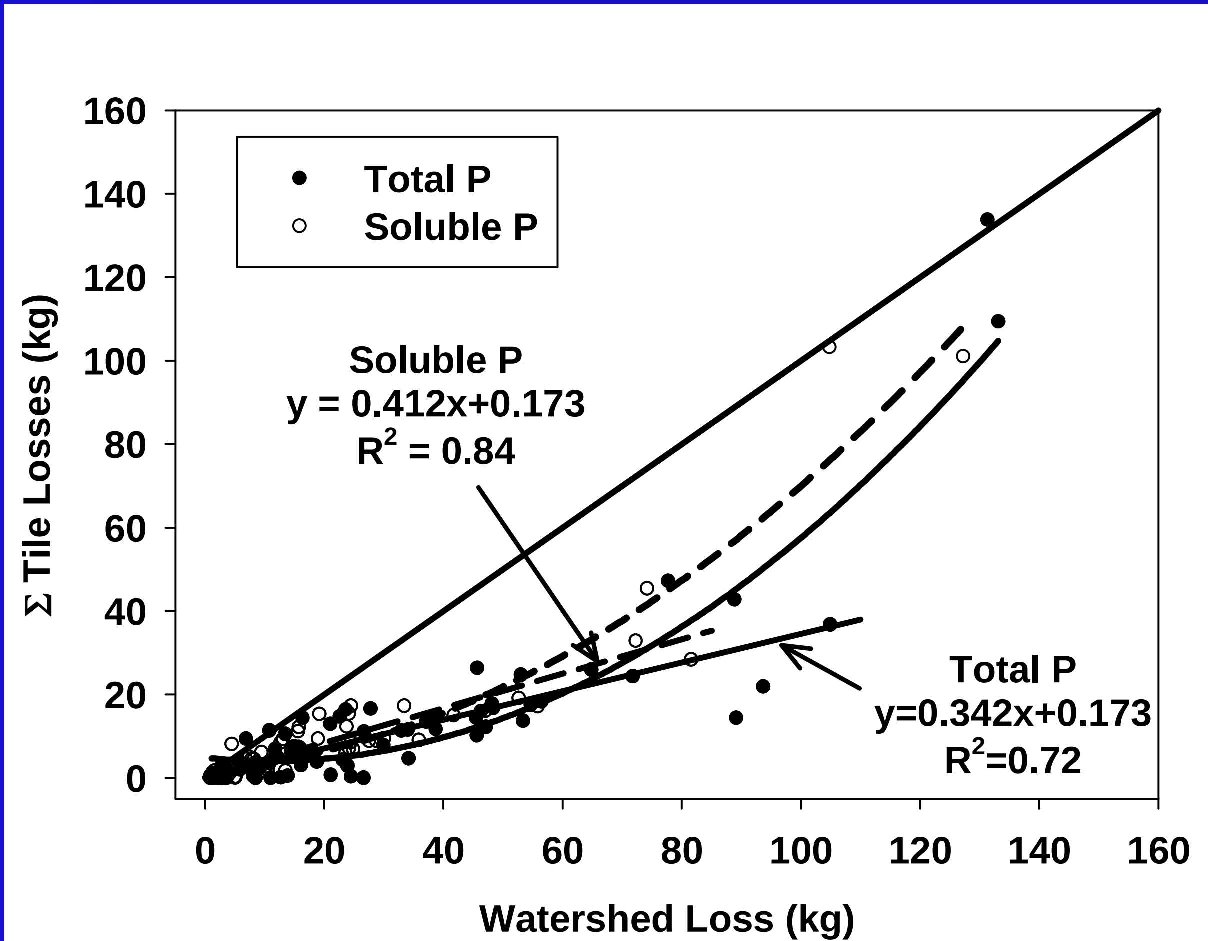
~16% of precipitation recovered in tile flow in IL (Algoazany et al., 2007)

Monthly Time Series of Soluble P loss at the watershed outlet and tile



Annual DRP Load: Watershed Outlet (0.6 kg/ha)

Summation of Tile (0.3 kg/ha)

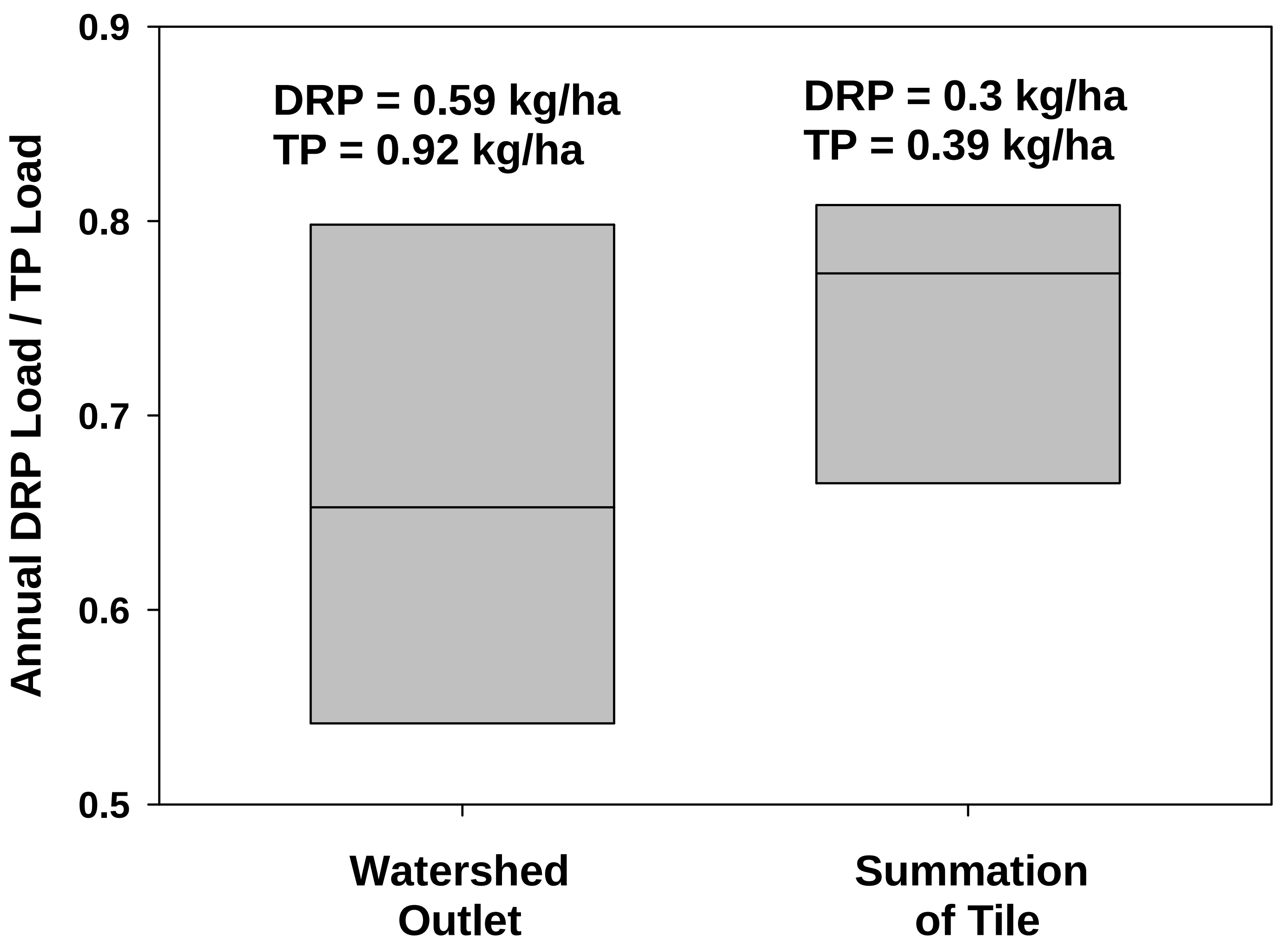


Fraction of annual watershed loading originating from tile

	Soluble P	Total P
2005	0.317	0.234
2006	0.346	0.300
2007	0.313	0.264
2008	0.756	0.759
2009	0.591	0.485
2010	0.669	0.630
	0.499	0.445
AVG	(0.447)	(0.383)

-40% of annual total phosphorus load at EOF from tile discharge (Enright and Madramootoo, 2004)

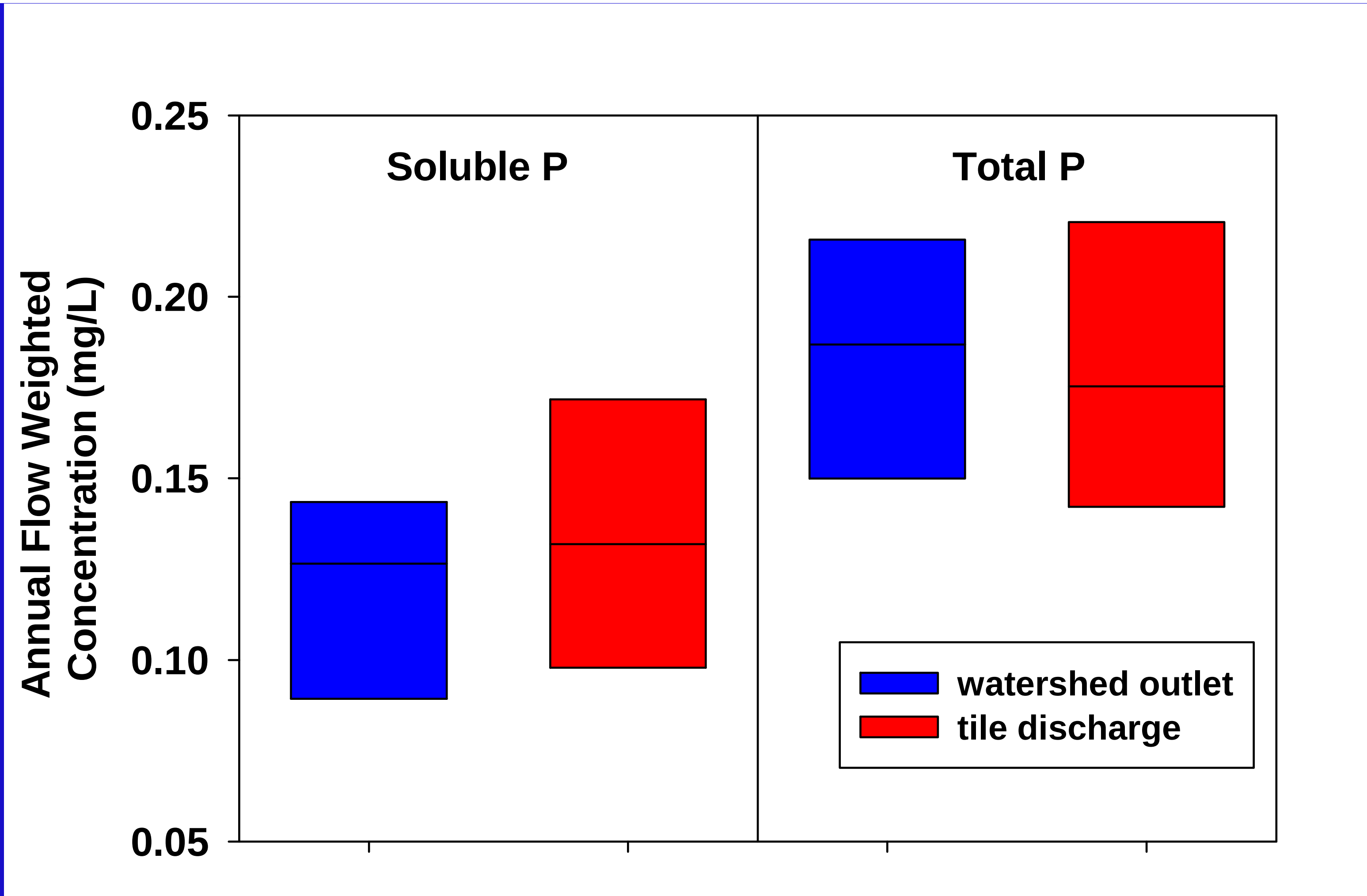
- 25% of TP and 50% of soluble P leaving watershed originated in tile drainage (Culley and Bolton, 1983)



~56% of annual tile load in MN (0.16 kg/ha) is soluble (0.09 kg/ha) (Logan et al., 1980)

~74% of annual tile load in OH (0.53 kg/ha) is soluble (0.39 kg/ha) (Logan et al., 1980)

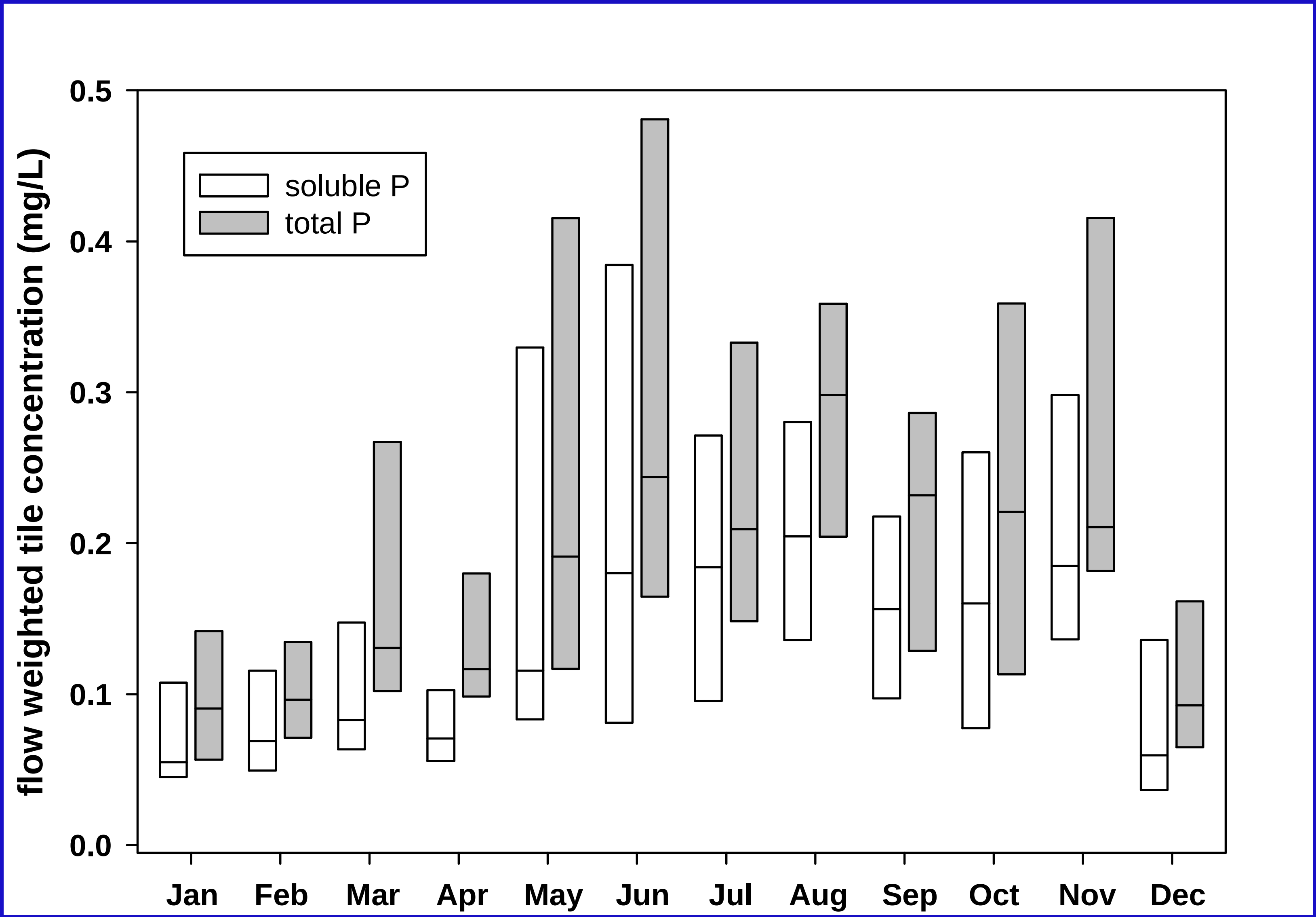
~ 77% for this study



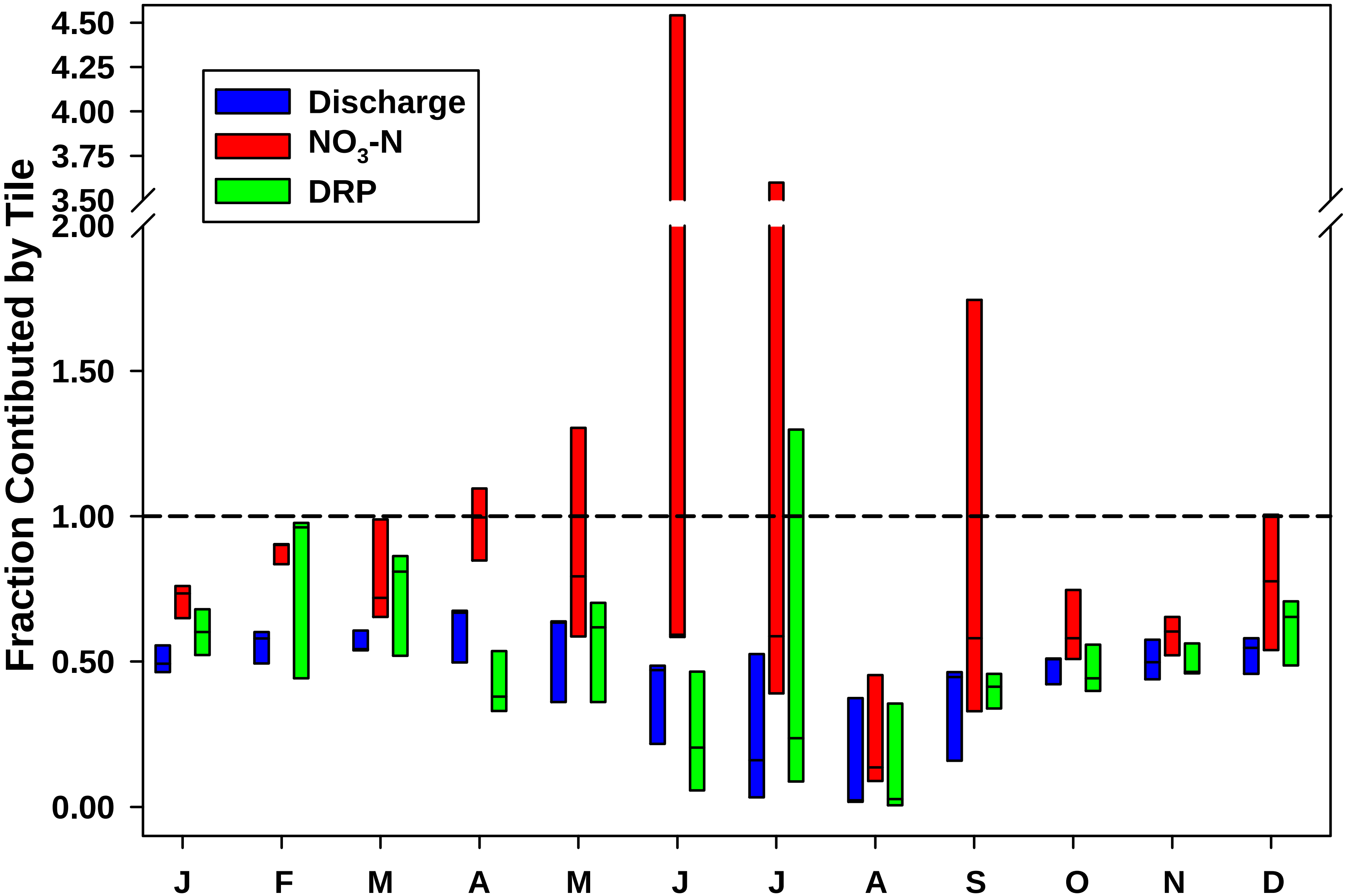
Logan et al. (1980) – 2 farm fields in OH 1972 (0.21 and 0.45 mg/L) and 1973 (0.06 and 0.14 mg/L) soluble P concentrations

Algoazany et al (2007) - soluble P in four EOF tile outlets (0.1, 0.1, 0.194, and 0.086 mg/L)

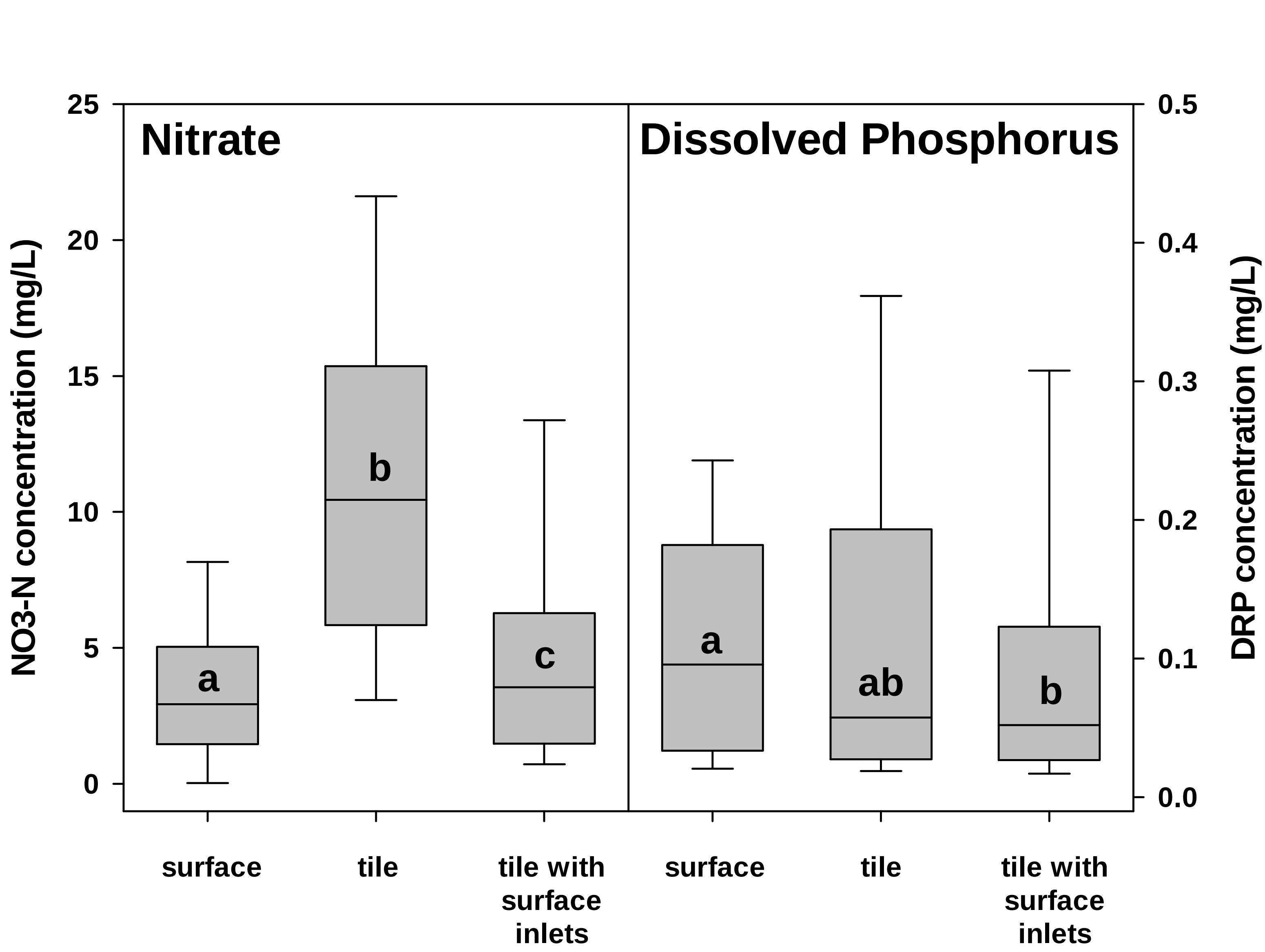
Soluble and Total P flow weighted concentrations by month over 6 year study period (2005-2010)



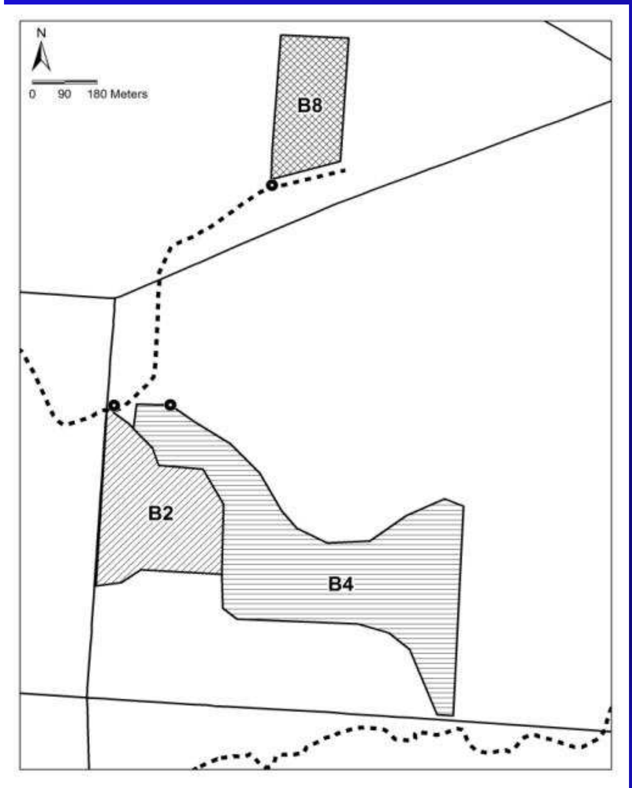
Results (tile line contributions)



Concentration considering discharge source (all data)

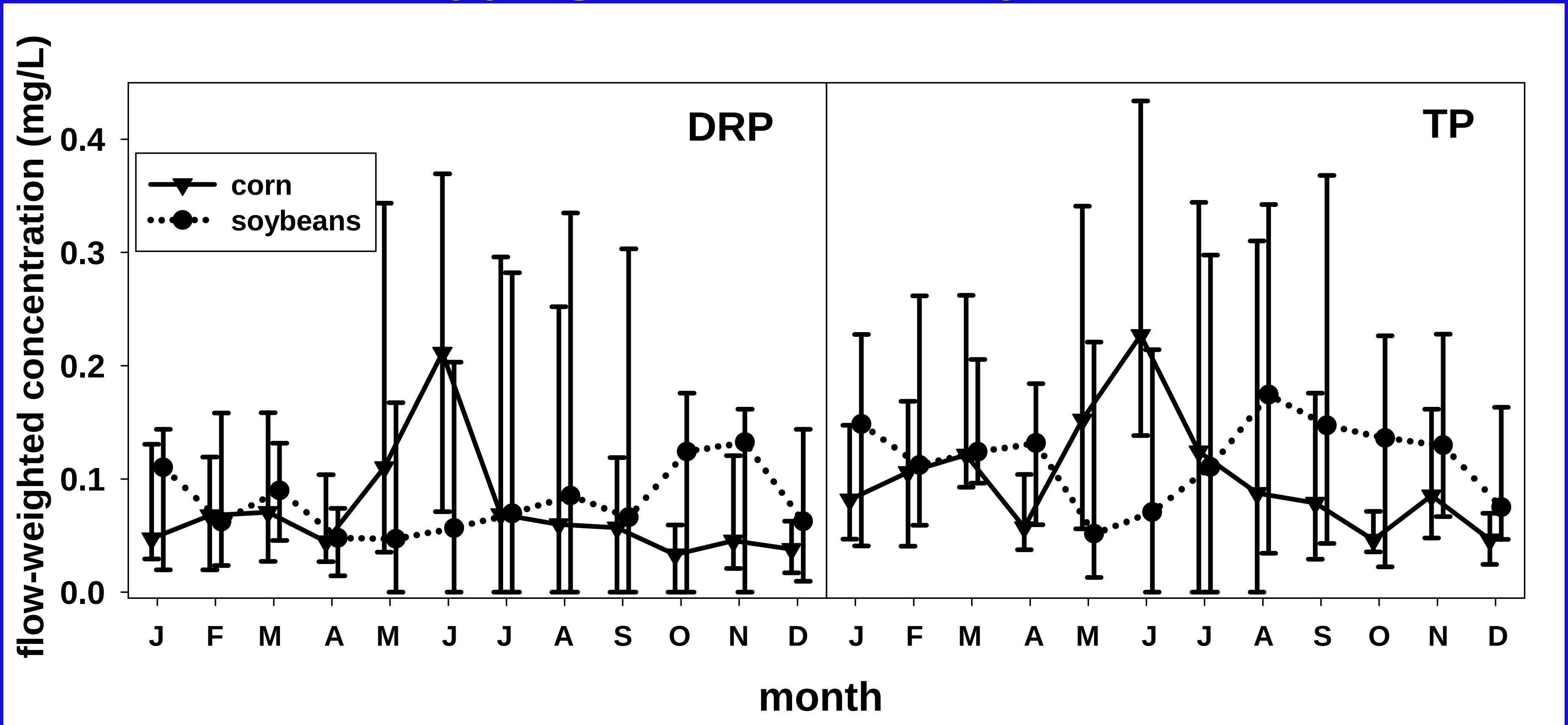


Cropping and Seasonality Effects



Year	DA (ha)	Soils (%) Bennington	Soils (%) Pewamo	tillage	crop	Elemental fertilizer applied (kg/ha) nitrogen	Elemental fertilizer applied (kg/ha) phosphorus
B2							
2004				disk-chisel	corn	194.6	14.7
2005	11.7	60	40	no-till	soybeans	0	0
2006				disk-chisel	corn	705.9	166.1
2007				no-till	soybeans	0	0
2008				no-till	soybeans	0	0
2009				disk-chisel	corn	NA	NA
2010				no-till	soybean	NA	NA
B4							
2004				disk-chisel	corn	194.6	14.7
2005	27.5	65	35	no-till	soybeans	0	0
2006				disk-chisel	corn	705.9	166.1
2007				no-till	soybeans	0	0
2008				no-till	soybeans	0	0
2009				disk-chisel	corn	NA	NA
2010				no-till	soybean	NA	NA
B8							
2004				disk-chisel	corn	194.6	14.7
2005	7.3	85	15	no-till	soybeans	0	0
2006				disk-chisel	corn	705.9	166.1
2007				no-till	soybeans	456.1	117.4
2008				disk-chisel	corn	214.3	19.5
2009				no-till	soybean	NA	NA
2010				disk-chisel	corn	NA	NA

Cropping and Seasonality Effects

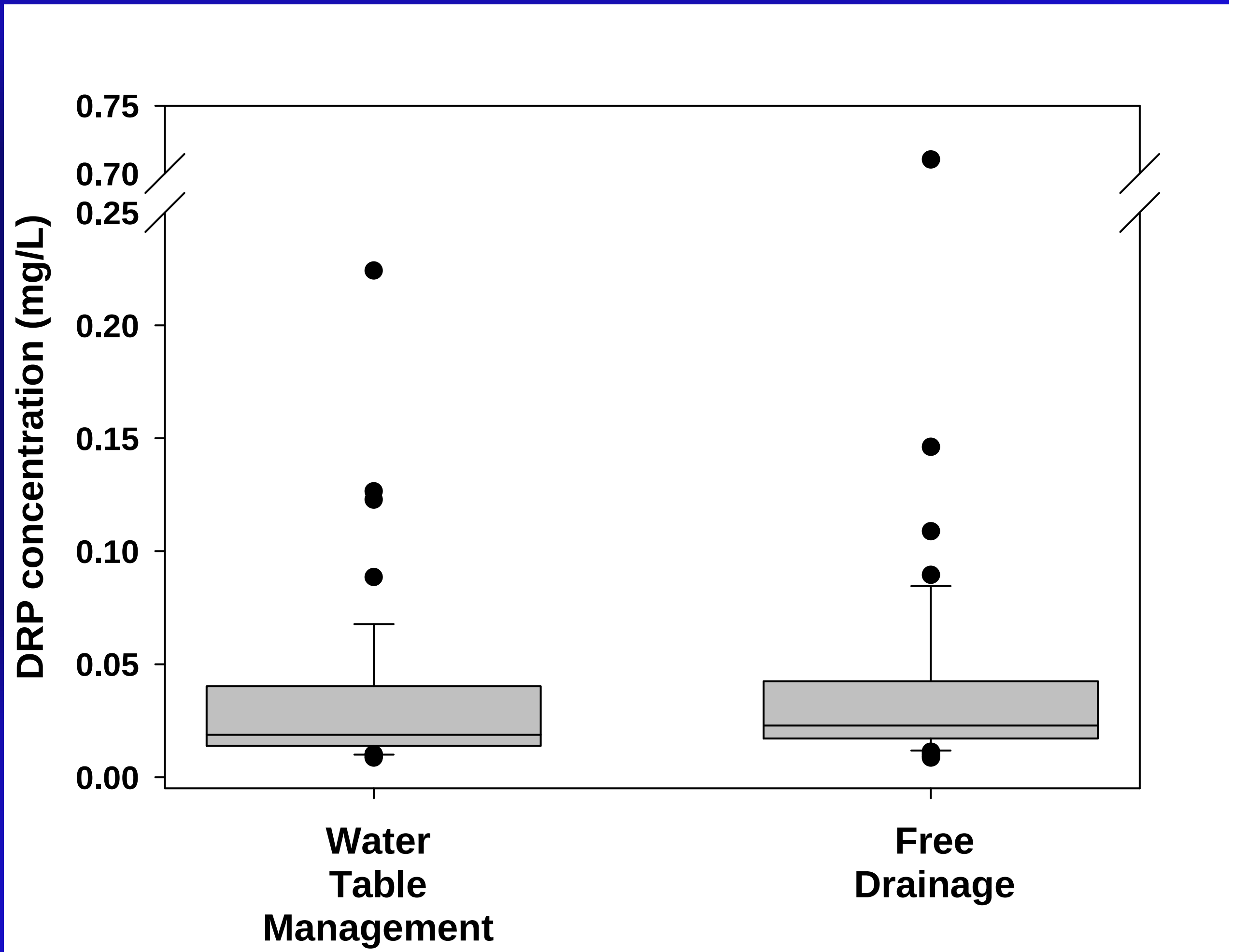


Statistical analysis for flow weighted DRP and TP concentrations using General Linear Model procedure at three edge-of-field tile sites within the Upper Big Walnut Creek watershed, Ohio.

Source of Variation	DF	DRP F	DRP P	Total P F	Total P P
Crop	1	0.001	0.973	0.045	0.832
Season	1	3.985	**0.047**	6.238	**0.013**
Crop x Season	1	0.059	0.808	0.736	0.392

Water Table Management

- Part of a 5 state CIG
- Northwest Ohio (8 paired sites)
- 2011 data (n=48 for each drainage type)



Preliminary Findings (2005-2010)

- Tile drainage accounts for approximately 46% of the watershed discharge on monthly basis
- Tile drainage generally accounts for approximately 41% of the DRP and 34% of the TP measured at the watershed outlet
- At watershed outlet DRP (0.59 kg/ha/yr) accounts for 64% of the TP (0.92 kg/ha/yr) losses
- For summation tile outlets DRP (0.3 kg/ha/yr) accounts for 77% of the TP (0.39 kg/ha/yr) losses

Preliminary Findings (2005-2010) continued

- Median annual flow weighted DRP concentration at the watershed outlet was 0.127 mg/L compared to 0.132 mg/L for tile while median annual flow weighted TP concentration at the watershed outlet was 0.187 mg/L compared to 0.175 mg/L for the tile

- Bimodal distribution of p concentrations in tile with peaks in growing season and after harvest

- There is a seasonal (growing vs non-growing) effect on DRP and TP concentration

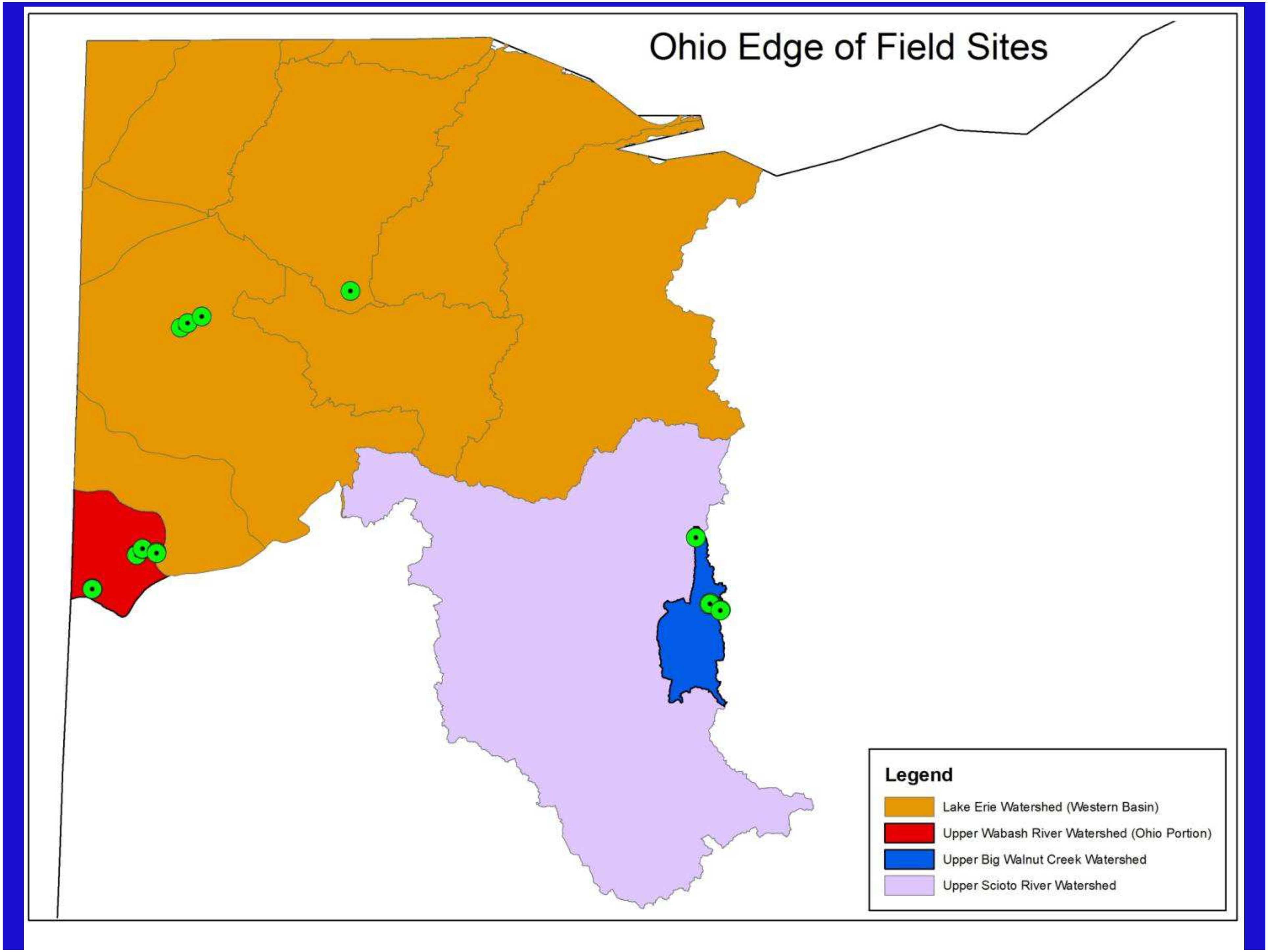
Edge-of-Field Assessments

Objective: Elucidate and quantify the surface and subsurface hydrology and water quality impacts of innovative conservation management practices and develop a suite of practices to address and mitigate offsite phosphorus delivery in support of:

Conservation Effects Assessment Project (CEAP)

Mississippi River Basin Initiative (MRBI)

Ohio Phosphorus Risk Index Initiative


Ohio Edge of Field Sites
Legend
Lake Erie Watershed (Western Basin)
Upper Wabash River Watershed (Ohio Portion)
Upper Big Walnut Creek Watershed
Upper Scioto River Watershed

Edge-of-Field Assessment Approach

Before/After Control Impact Design

- **Minimum of one crop rotation per before and after period**

Currently: 16 fields (8 pairs) and 6 tiled fields (3 pair) all instrumented

- **4 pair in UBWC watershed**
- **4 pair in Upper Wabash/Grand Lake St. Mary**
- **3 pair (6 fields) with subsurface tile drainage (1 in UBWC and 2 in Upper Wabash)**

Seeking additional 4 pair of fields in WLEB

- **2 pair identified**








Current Site Characteristics

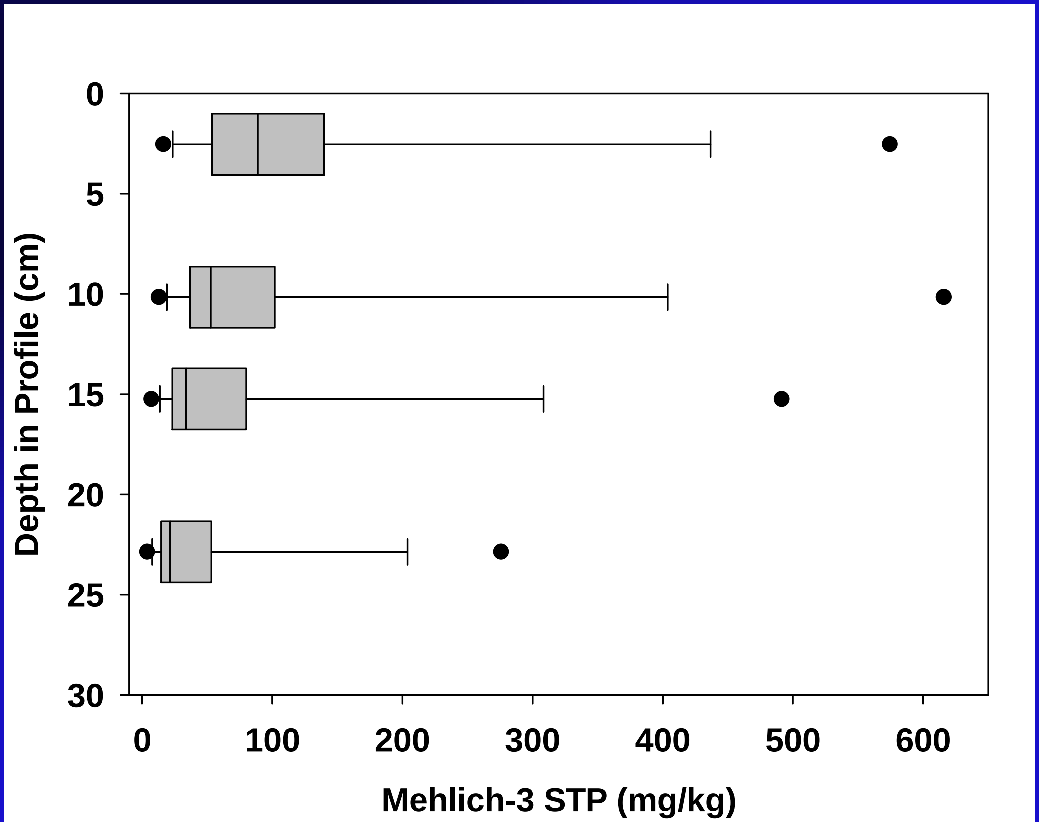
Representative of major soils in Ohio

Random and systematic tile drainage

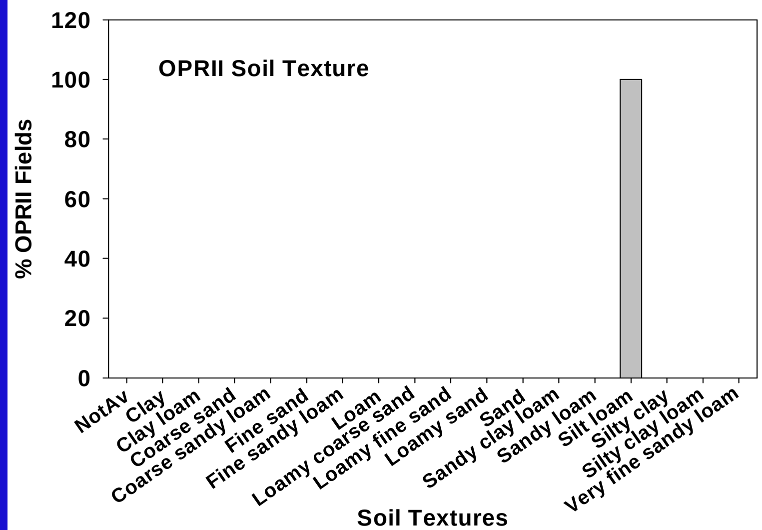
Range of tillage management (long-term no-till and rotational tillage)

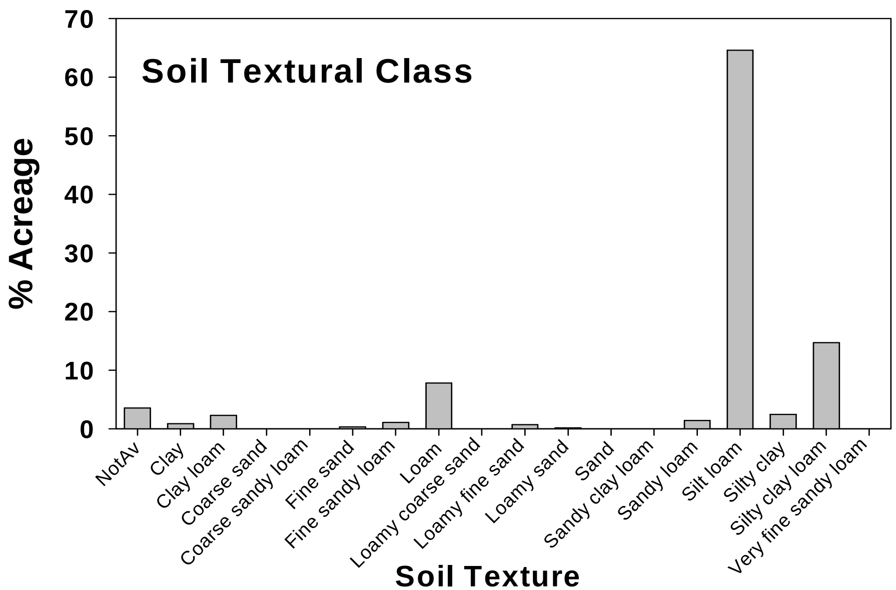
Representative of different fertility management approaches (commercial vs manure)

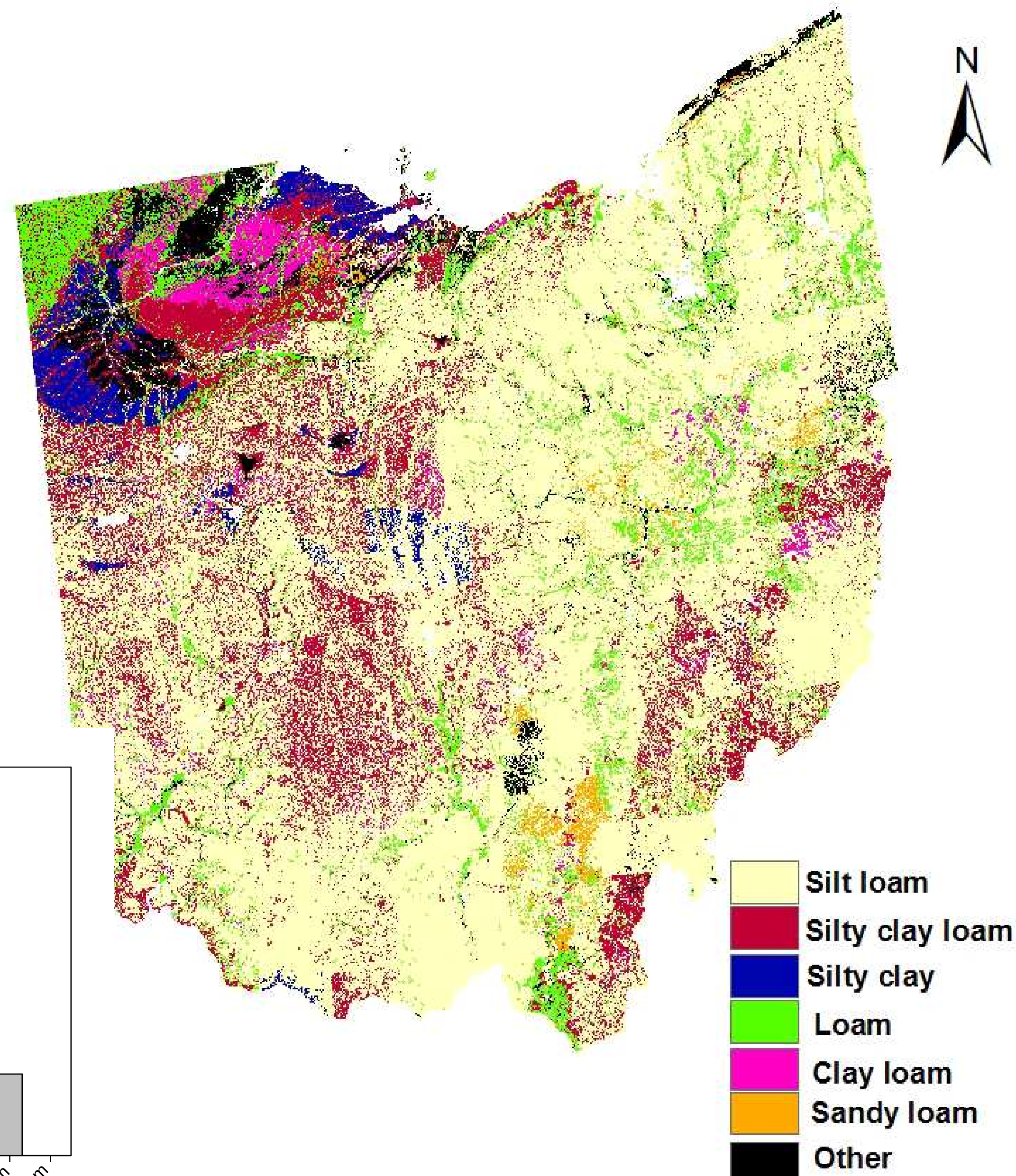
Wide range of Soil Test Phosphorus



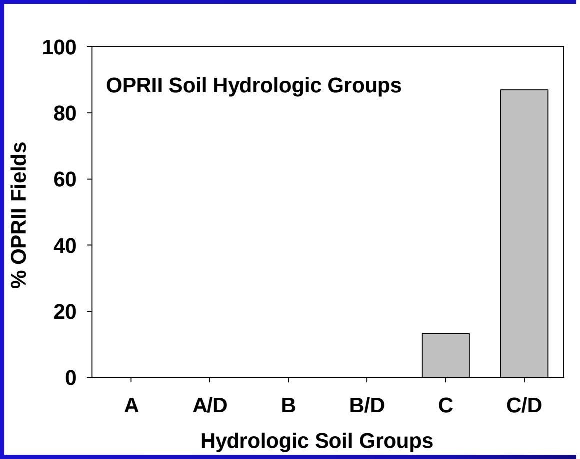
Soil Texture

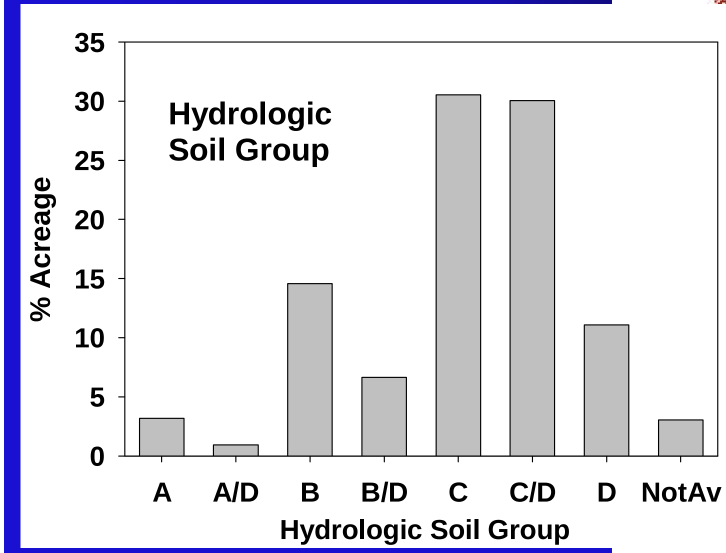


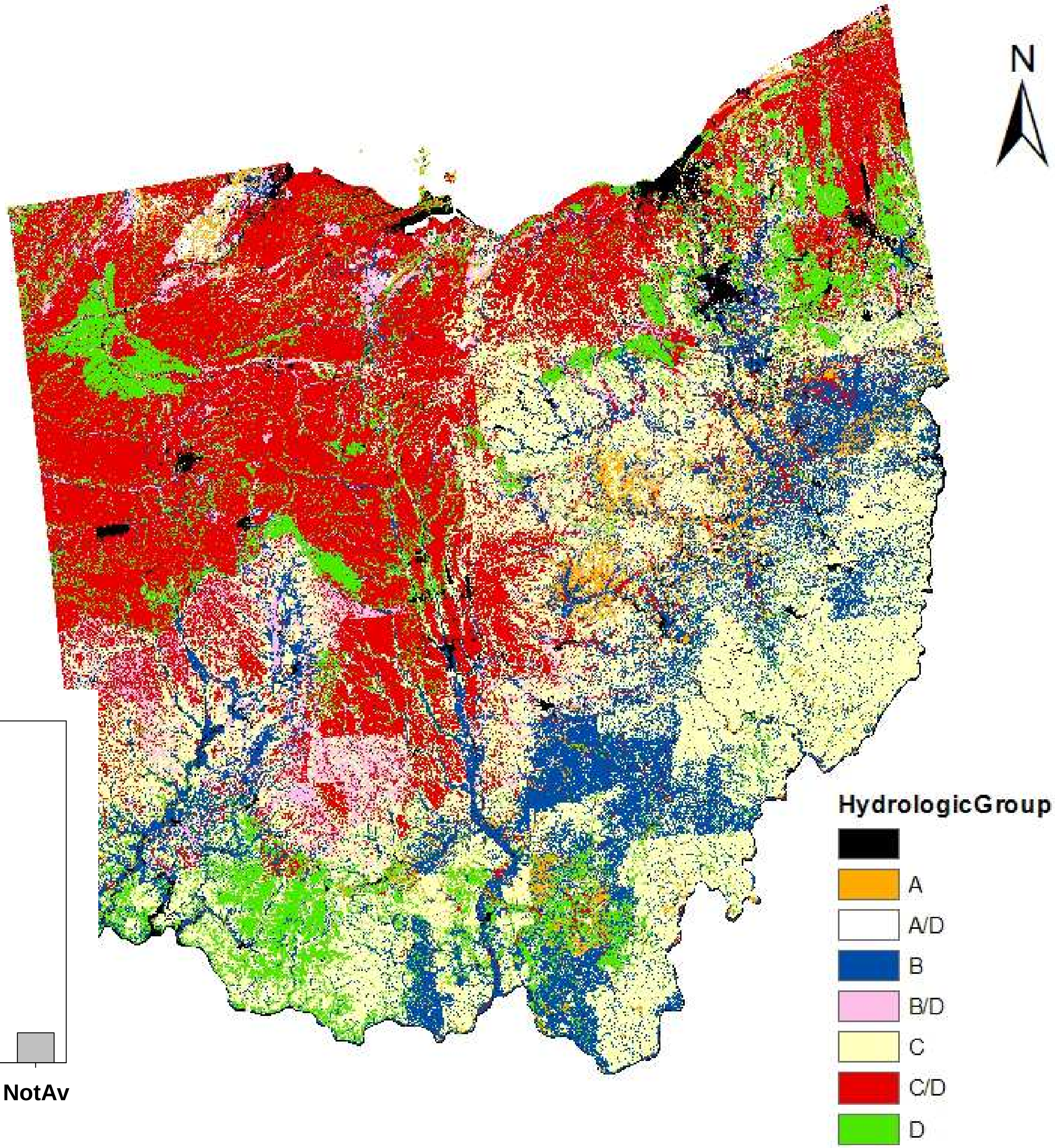




Field Runoff Class





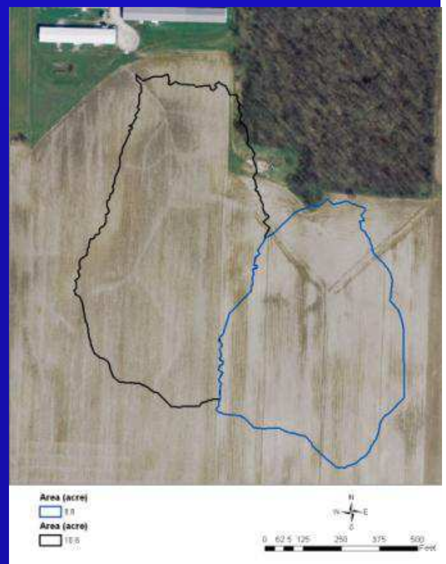


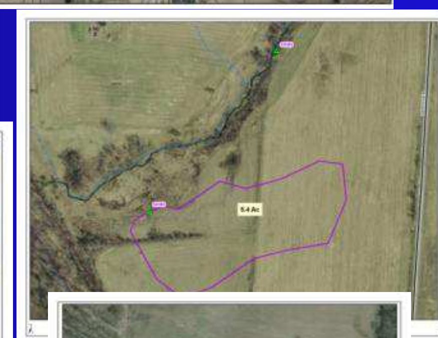
Potential Practices to Investigate

- Water table management
- Cover crops
- Banding vs broadcast
- Spring vs fall vs split application
- Incorporation
- Deep injection
- Tillage vs no-till
- Tri state recommendation vs reduced rate
- Manure vs commercial fertilizers
- End-of-tile filters and enriched bioreactors
- Land application of gypsum
- Controlled traffic and variable rate application
- Other




Approach: Paired Design with EOF Monitoring





Instrumentation

Designed for 10 year recurrence interval

H-flumes for surface runoff

Compound weirs and area velocity sensors for subsurface tile flow

Data collection

- 10 minute hydrology (discharge and rainfall)
- time interval sampling
  - every 6 hours composited daily for tile flow
  - variable for surface flow and weighted toward rising limb of hydrograph










Initial Findings

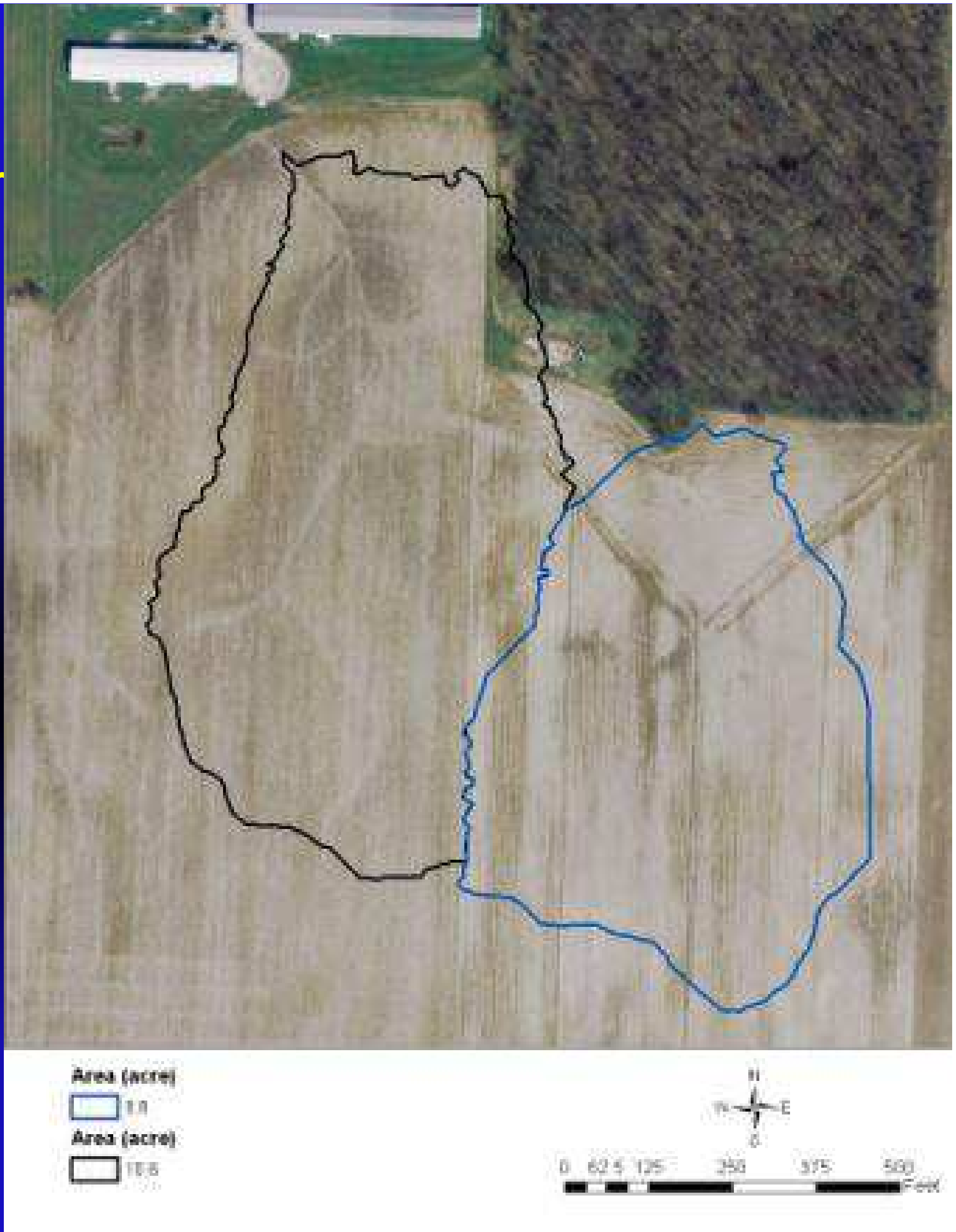
Location: Upper Wabash Watershed, Mercer County, Ohio

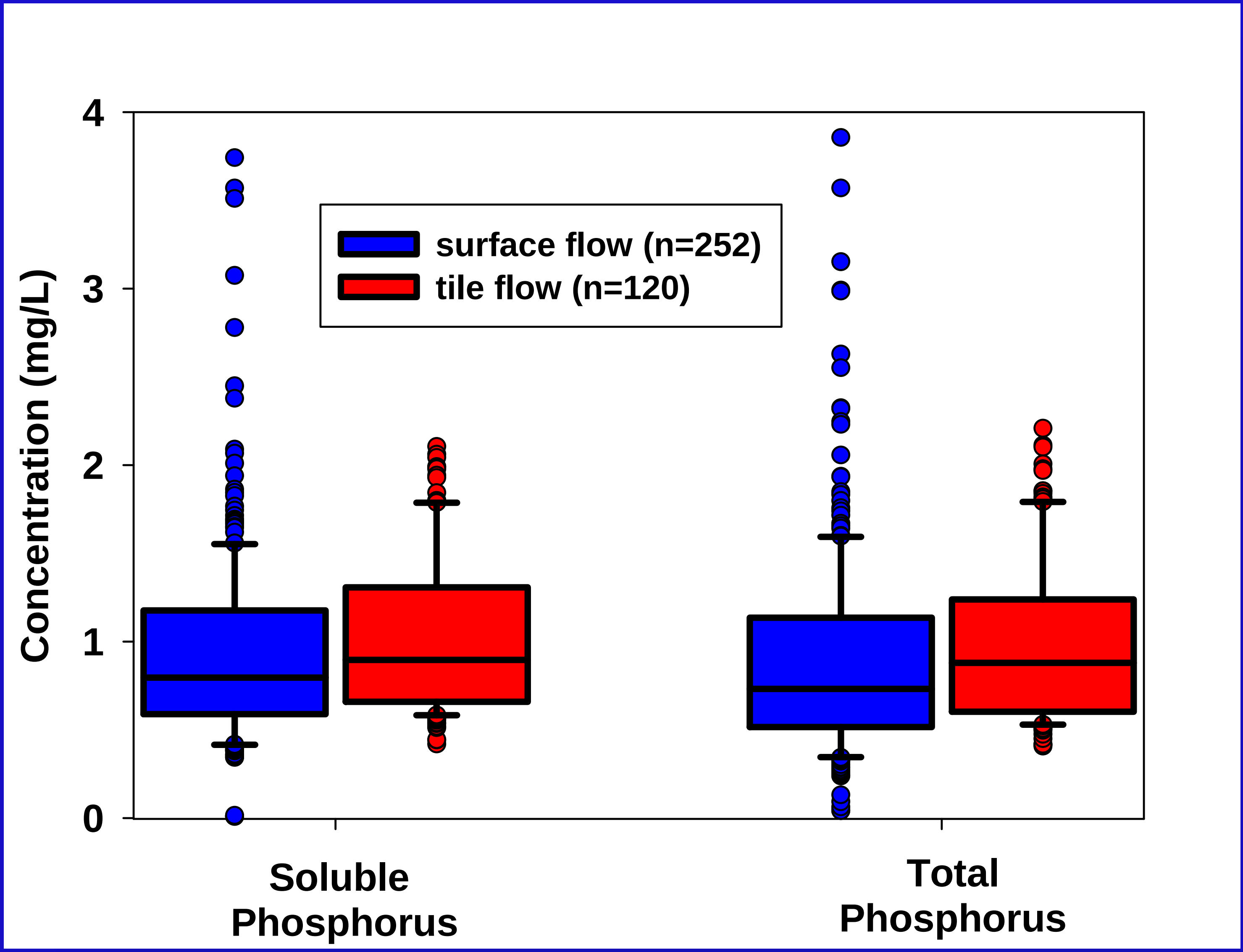
Drainage Area: 5 & 7 ha

Soil: Blount silt loam

Land-use: Agriculture – corn-soybean rotation; no-till

Subsurface drainage: random; ~1 m depth

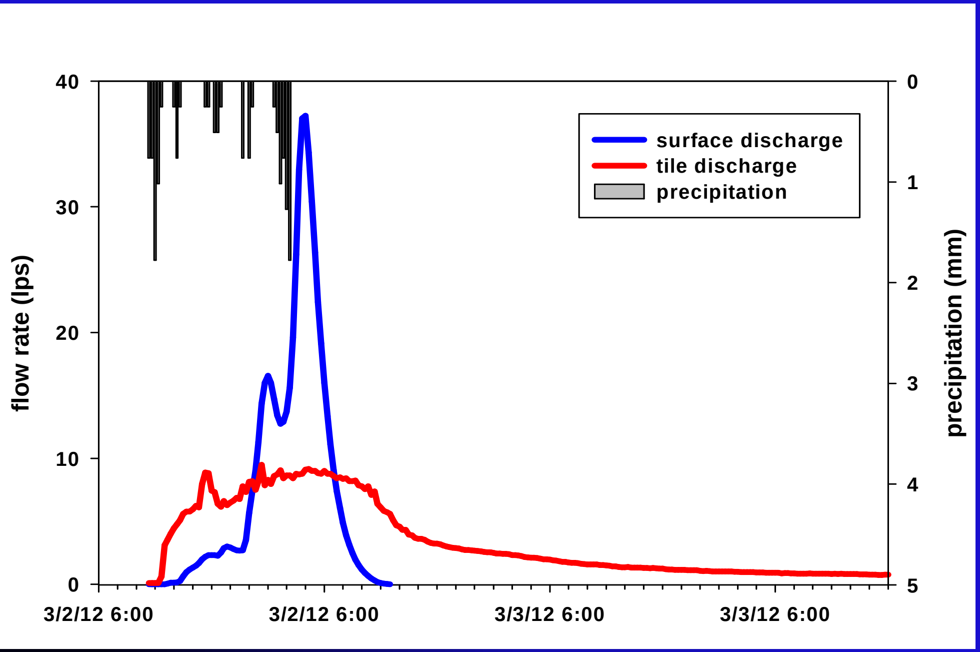


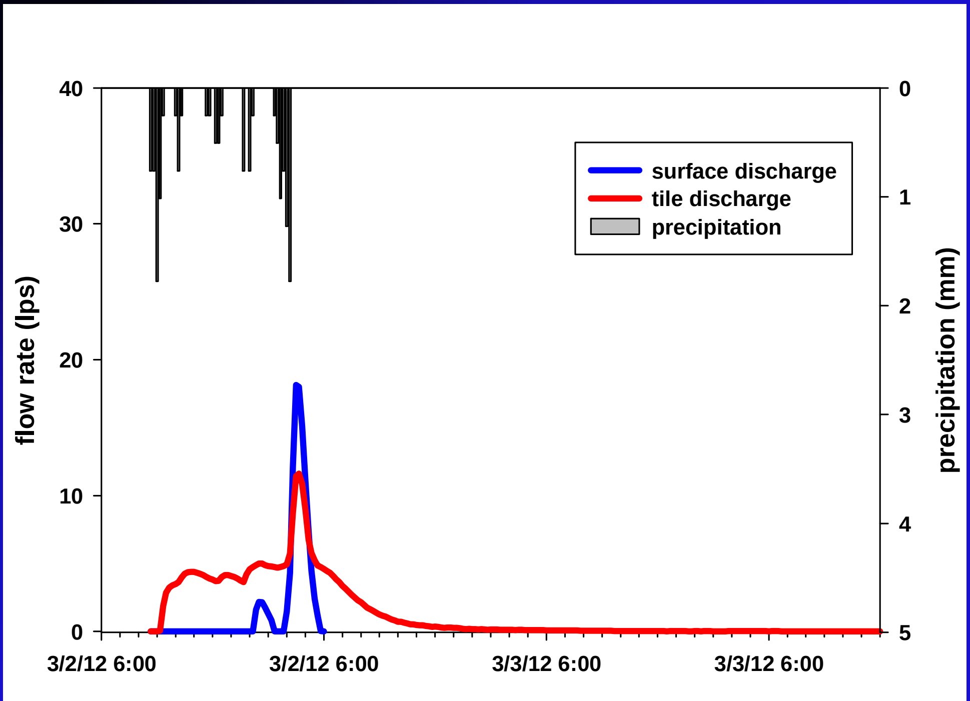


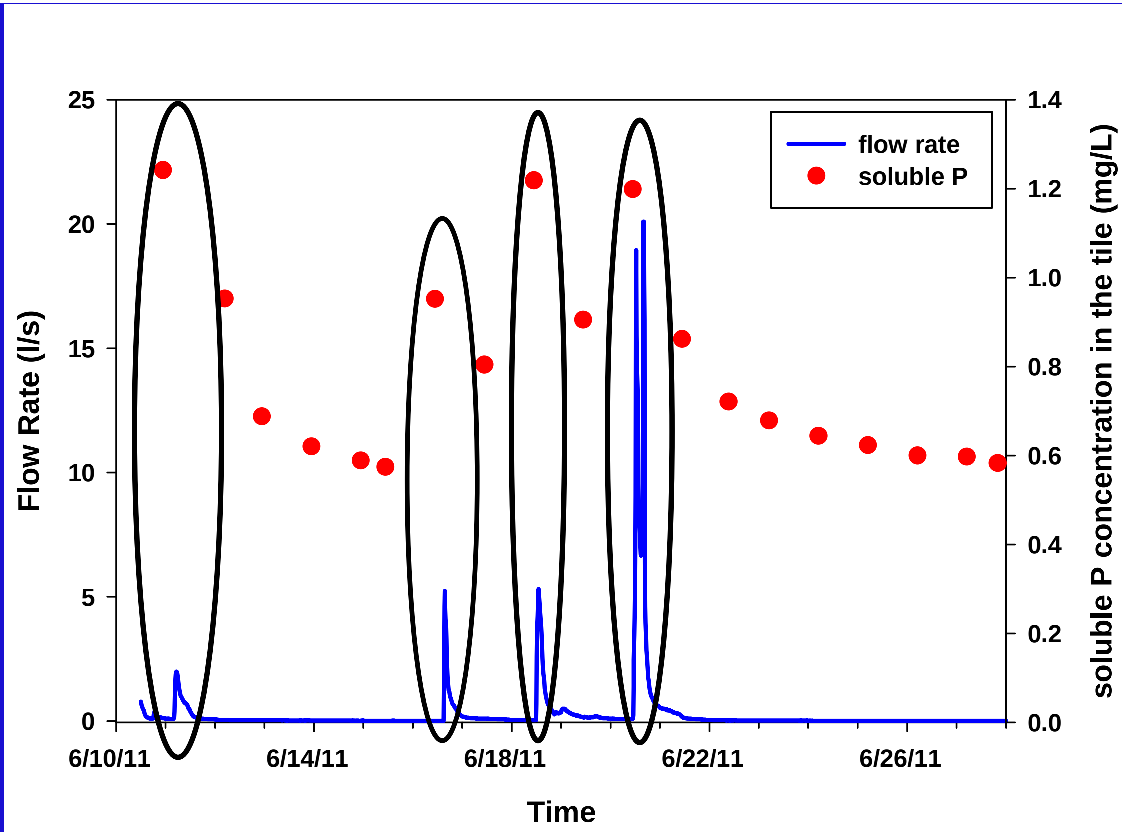
Range of concentrations collected for Mercer County EOF site from 6/1/2011 to 12/31/2011

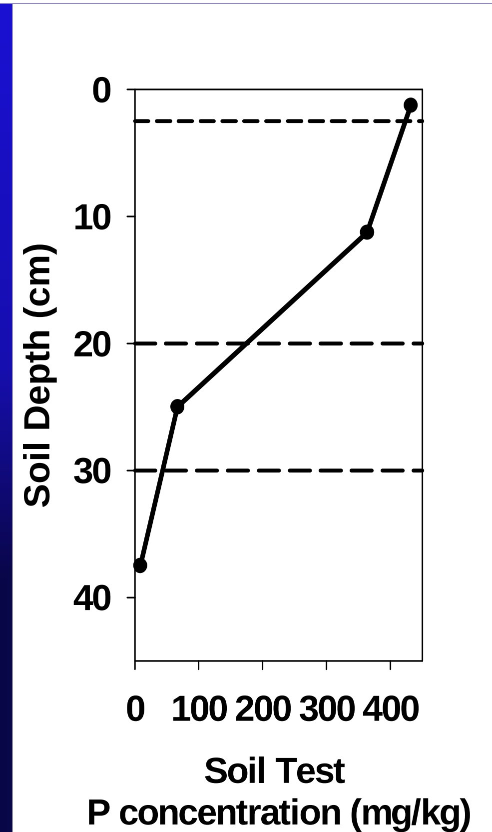
Event date and DRP load (kg)

	Rainfall	Surface Site		Tile Site	
	(mm)	1	2	1	2
1/17/2012 3:10	15.0	0.449	0.181	0.879	0.283
3/2/2012 8:40	15.0	0.329	0.035	0.886	0.127
3/8/2012 7:50	7.4	0	0	0.241	0.022
3/23/2012 9:40	16.3	0.001	0.014	2.184	0.05
4/26/2012 1:50	8.1	0	0	0	0
4/30/2012 17:40	11.9	0.001	0	0	0
5/1/2012 13:20	16.0	0.098	0.046	0.303	0.095
5/7/2012 9:30	18.3	0.021	0.01	0	0.042
5/29/2012 4:10	21.3	0.002	0	0.002	0









Chemograph of soluble P concentration in tile flow and graph of Mehlich 3 STP from the same field (Mercer County, OH)

Positive correlation between peaks in concentrations and tile discharge indicate fast flow processes (preferential flow) and connection to surface sources

Location: Beaver Creek Subwatershed of the Grand Lake St. Mary watershed, Mercer County, Ohio

Drainage Areas: 3.2 and 2.3 ha

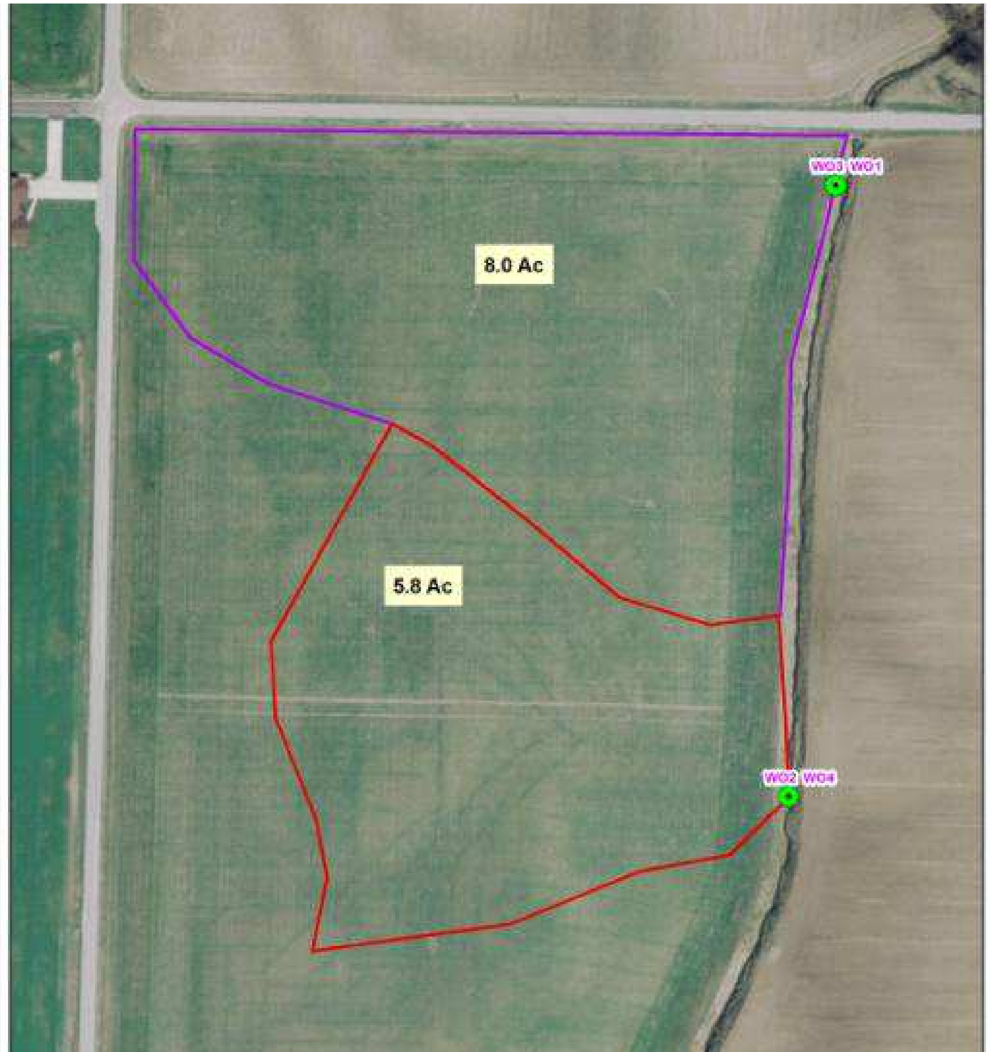
Soils: Blount silt loam (Fine, illitic, mesic Aeric Epiaqualfs) somewhat poorly drained soils

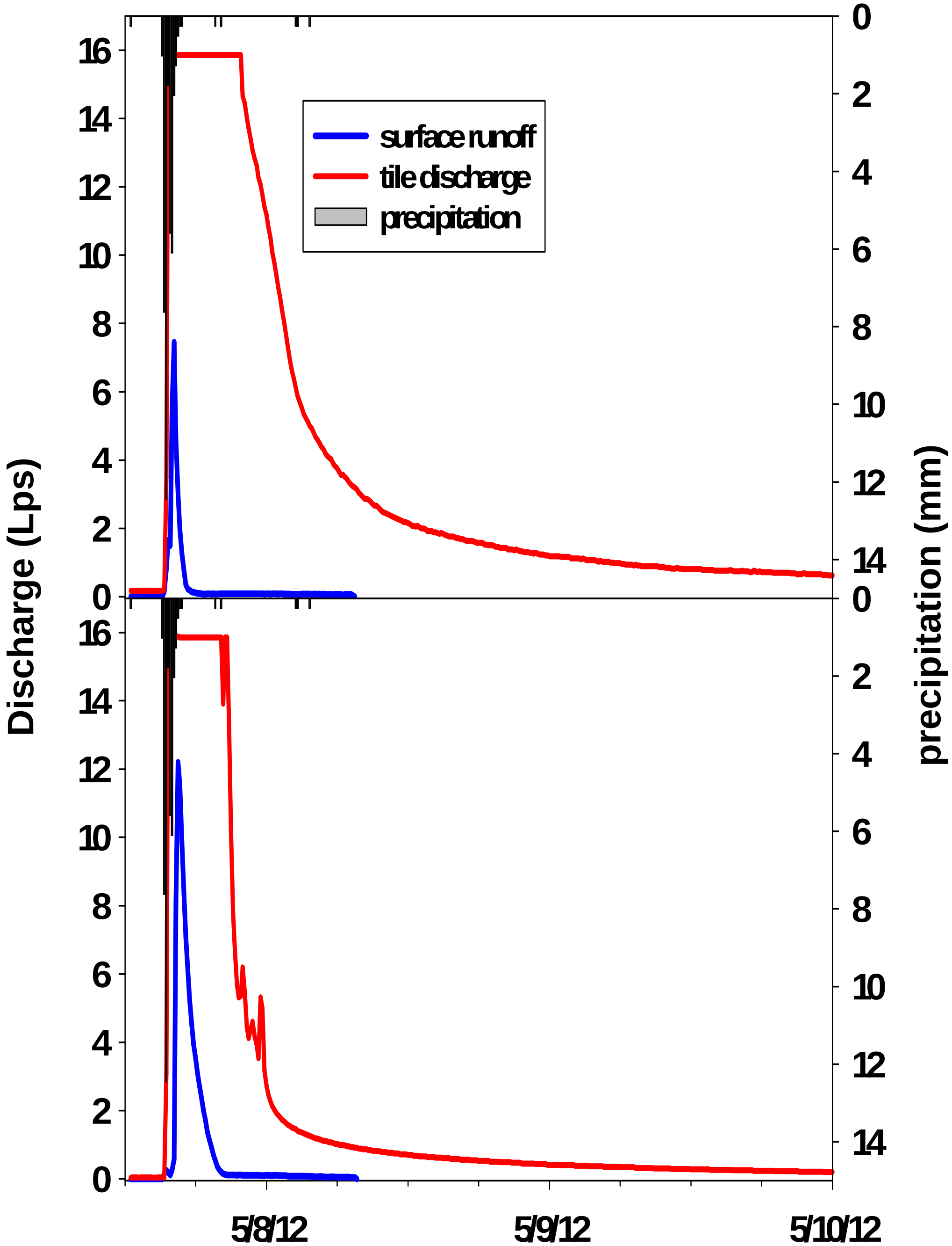
Pewamo silty clay loam (Fine, mixed, active, mesic Typic Argiaquolls) very poorly drained

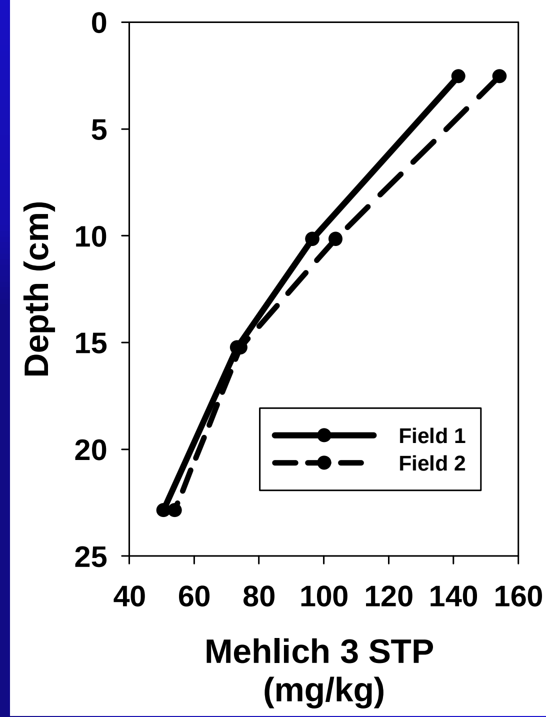
Glynwood silt loam (Fine, illitic, mesic Aquic Hapludalfs) moderately well drained

Land use: crop production agriculture (C-S-W rotation)

Subsurface drainage: systematic tile 1 m depth on 60 ft spacing







EMC for NO3-N and DRP from 36.8mm rainfall event on 5/7/12

	Surface Sites			Tile Sites	
NO_3-N	21.2	46.5		26.8	30.8
DRP	1.0	1.6		0.6	0.3

EOF Summary

- 16 fields (8 pair) currently instrumented
  - 8 fields in Upper Big Walnut Creek watershed
  - 8 fields in Upper Wabash watershed
- 7 end-of-tile pipes instrumented (3 pair +1)
- 10 fields (5 EOF pair) in WLEB (2 pair already identified) with discrete subsurface drainage
- gradient of soil test phosphorus levels ranging from agronomic levels of 20ppm to greater than 400ppm in surface layer
- Investigating the impact of multiple single and combined conservation practices

Data Interpretation

"No one trusts the model except the model developer yet everyone trusts the field data except the person who collected it." (anonymous)

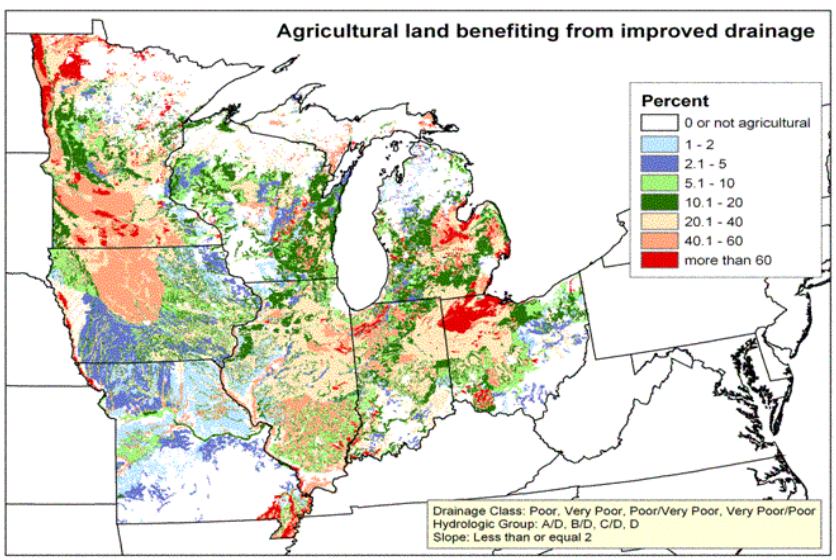
Literature Review

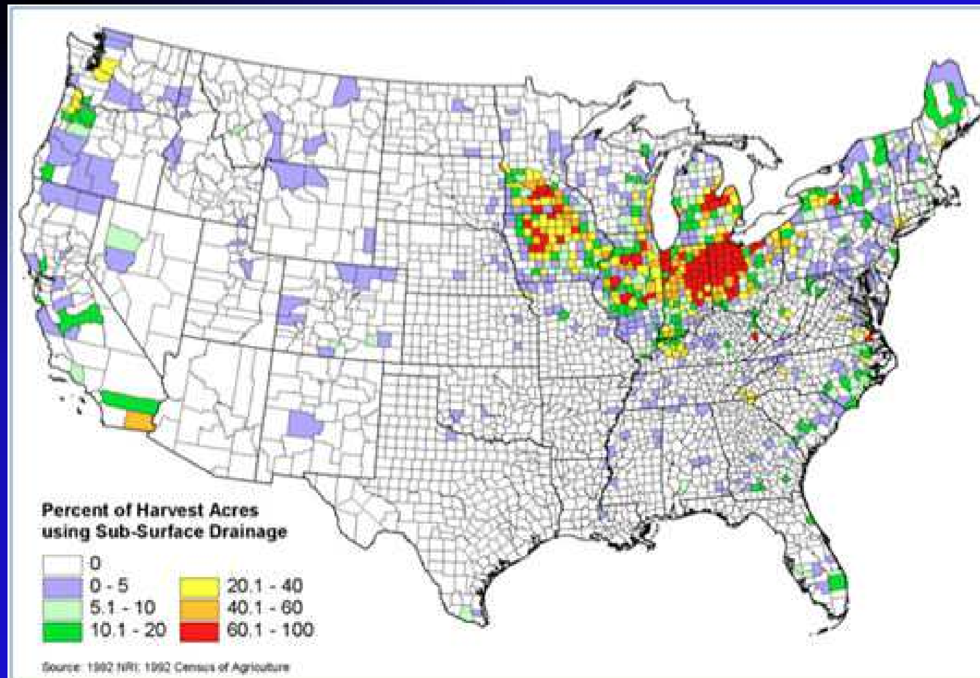
Extent of Tile Drainage

43 million ha of soil in US classified as wet; 31 million drained (Pavlis, 1987)

37% of cropland acres in the Midwest (Zucker and Brown, 1998)

- number of acres drained essentially remaining constant
- random drains converted to systematic drains and aging drainage infrastructures are being updated
- intensity (split spacing) increasing to accommodate larger farming enterprises and shorter windows for agricultural practices





Necessity of Tile Drainage

25% of cropland in US and Canada could not be farmed without tile drainage (Skaggs et al., 1994)

Tile Drainage (Fausey et al., 1987):

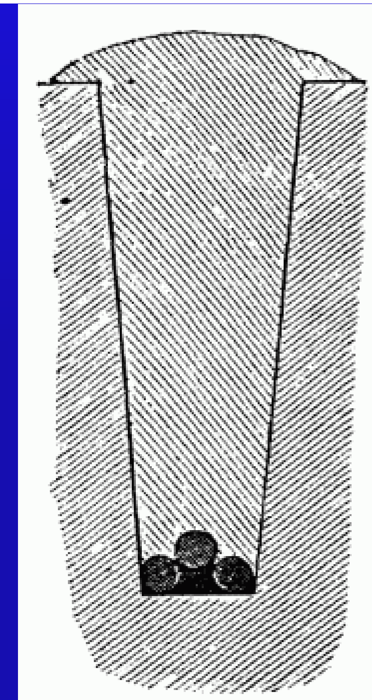
- provides trafficable conditions for field operations
- promotes root development by preventing exposure of plants to excess water

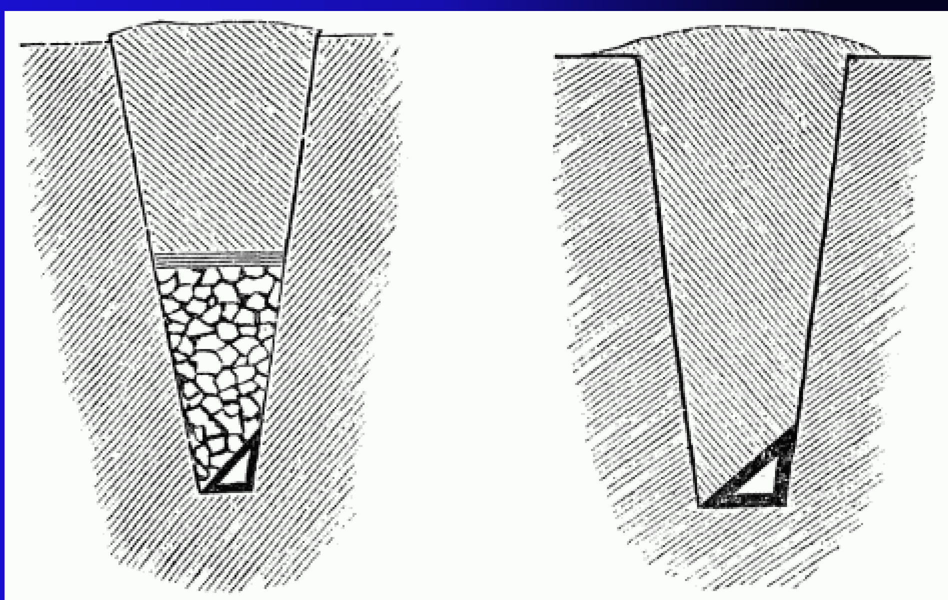
Laying subsurface drain tile with a machine. Shallow tiles and ditches were generally dug by hand. About four miles west of Dawson, Lac qui Parle County, circa 1906. (MHS photo)

Excerpts from *Farm Drainage*, by Henry French published in 1860.

- "The agriculture of Ohio can make no farther marked progress until a good system of under-drainage has been adopted." - John H. Klippart, Esq., the learned Secretary of the Ohio Board of Agriculture,

- "One of two things must be done by us here. Clay predominates in our soil, and we must under-drain our land, or sell and move west." - A writer in the *Country Gentleman*, from Ashtabula County, Ohio



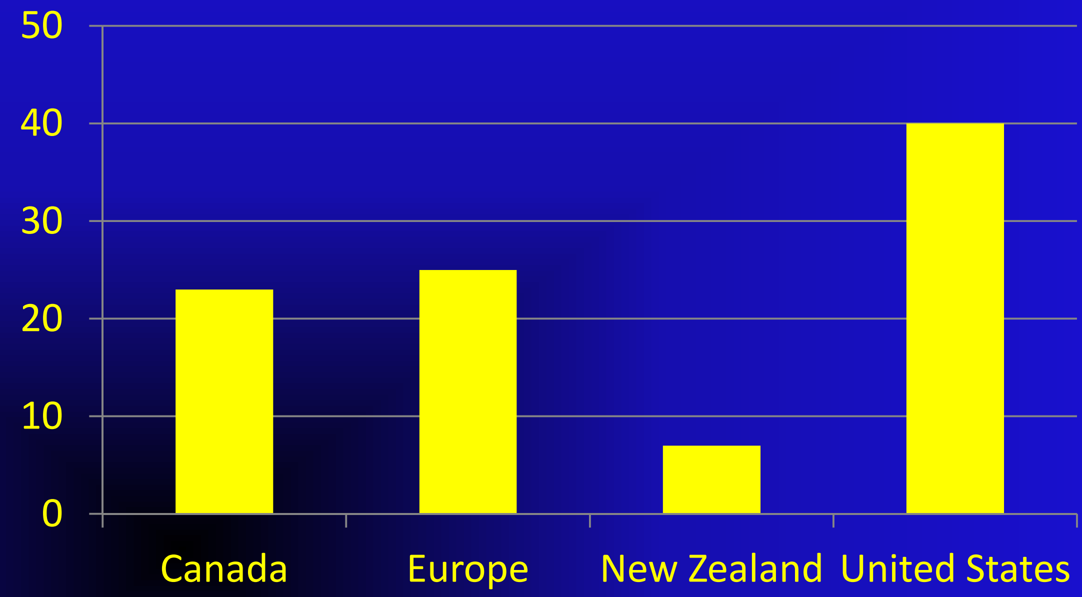


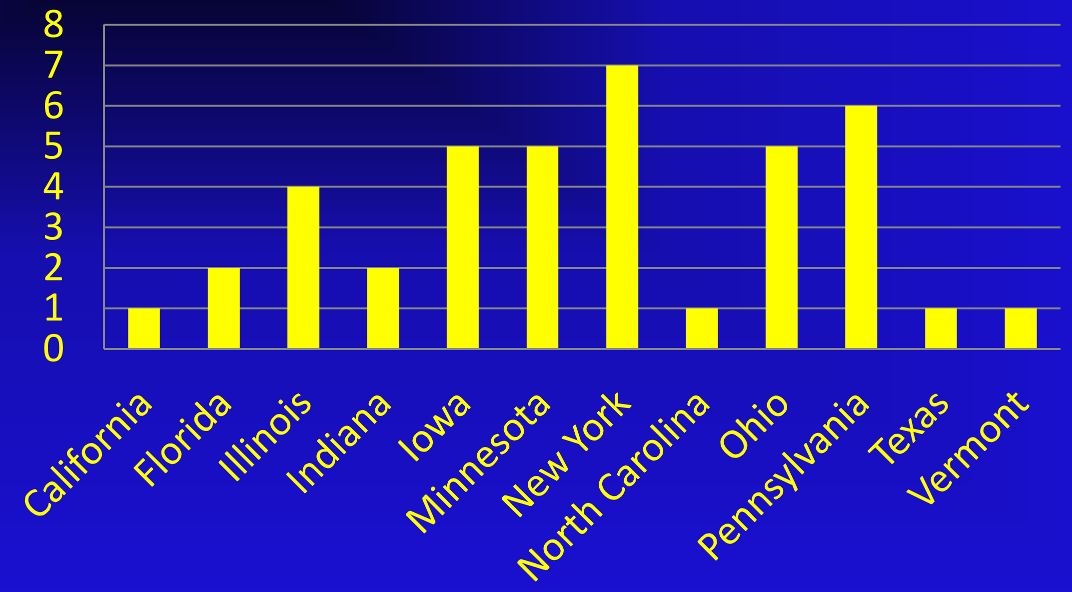
Factors Affecting Phosphorus Transport to Tile Drainage

Physical/Drainage Design Factors
- soils (12)
- depth (4)
- spacing (2)
- surface inlets (2)

Management Impacts
- tillage (12)
- cropping (23)
- fertilizer source (24)
- STP and application rates (17)
- placement (5)

Hydrologic and Climatic Effects
- baseflow vs. event flow) (7)
- seasonality (8)





Soils - Lysimeter Studies

Djodjic et al. (1999): Sweden

- 1.2 m long column lysimeters
- ***Melby sand and Lanna clay***
- 100kgP/ha applied
- Five 100 mm water events on 7 day interval
- Avg P leaching on clay (4 kg/ha) and sand (0.056 kg/ha)
- ***Rapid transport through macropores on the clay soils***
- 80% of total p in leachate was in soluble form

Heathwaite and Dils (2000): Pistern Hill catchment, Leicestershire, UK.

- macropore (0-45 cm) vs matrix flow (0-20 cm)
- suction lysimeters and piezometers
- ***matrix flow (0.385 mg TP/L***, 0.076 mg PP/L, and 0.259 mg DRP/L)
- ***macropore flow (0.842 mg TP/L***; 0.576 mg PP/L, and 0.195 mg DRP/L)
- 68% of TP load was particulate

Soils - Plot Studies

van Es et al. (2004):

- Cornell research farm, Willsboro, NY
- 3 year study (1997-1999)
- 16 plots (18x18m) on a clay loam
- 16 plots (14mx14m) on a loamy sand
- drain lines at 0.9m depth
- Liquid dairy manure applied at annual rate of 93800L in early fall, late fall early spring and split application
- ***Flow weighted TP concentrations were 0.013 mg TP/L on loamy sand and 0.504 mg TP/L on clay loam.***

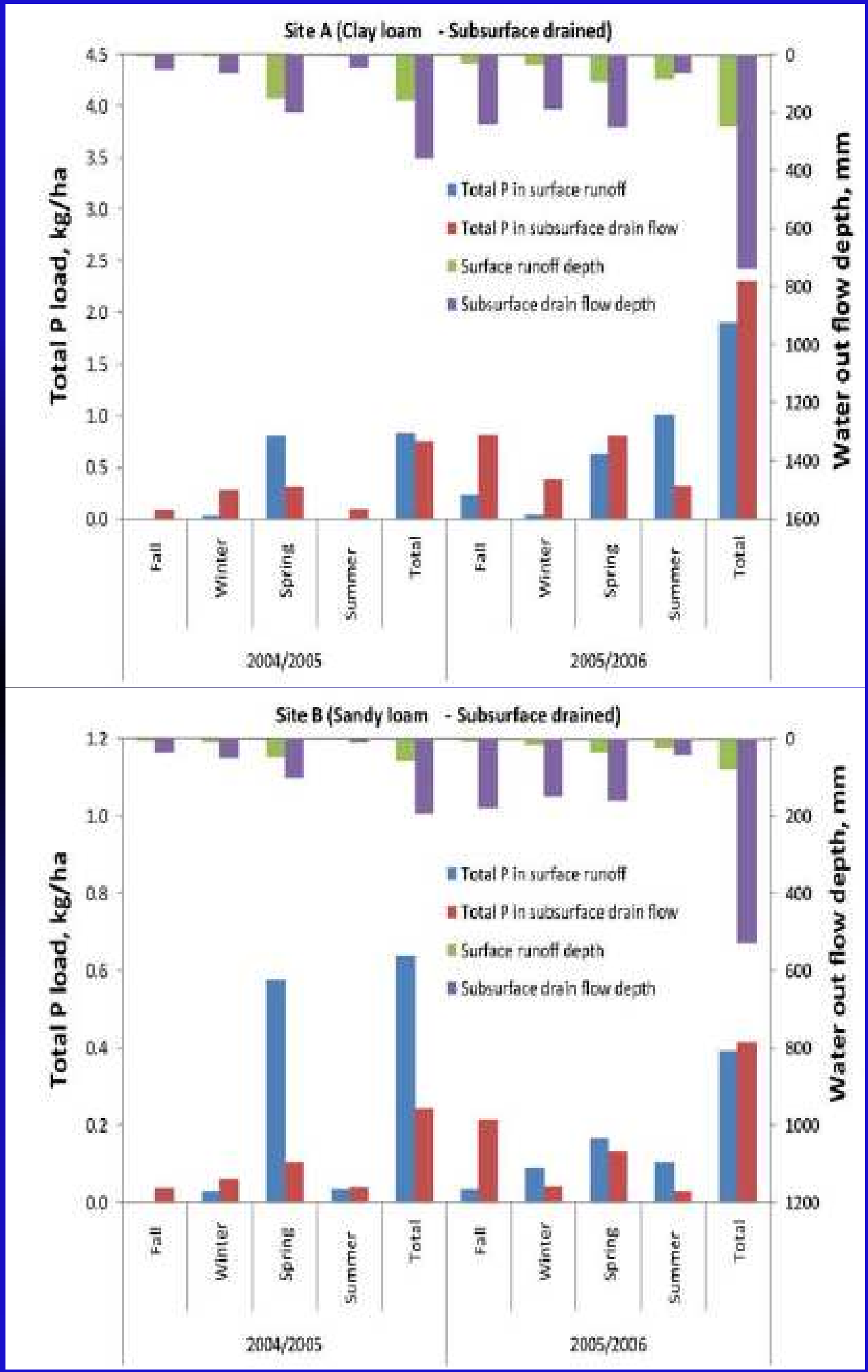
Soils – Field Scale Studies

Eastman et al. (2010):

- Pike River watershed southern Quebec,
- 2 hydrologic year study (2005-2006)–
- sandy loam and clay loam soils.
- Tile drainage in sandy loam soil reduced surface runoff and total p losses whereas in clay loam soils the opposite was true.
- 80% of TP was PP at clay loam sites but only 20% on sandy loam sites

Bottcher et al. (1981):

- 17 ha subsurface drainage system, 1976-1978
- Hoytville silty clay soil
- DRP conc. (0.04 mg/L) DRP load (0.035 kg/ha)
- drain flow accounted for 10% of rainfall.
- First rainfall in late April following application moved large amount of P to tile



Tile Spacing

Kladivko et al. (1991):

- Clermont silt loam near Butlerville, IN
- Continuous corn with one pass of a chisel plow and two passes with a disc
- drain spacing of 5, 10, and 20 m
- 75cm depth
- Three year study 1985-1987.
- DRP concentration range: 0.005 to 0.1 mg DRP/L
- Avg. DRP loading across plots 0.04 kg/ha/yr
- ***Greater losses with 5m compared to 20m spacing***

Addiscott et al. (2000):

- Brimstone Farm, Oxfordshire, UK
- Soil: Denchworth series (55-60% clay)
- 0.24 ha plots
- Combination of mole (0.55 m deep) and pipe drains (0.9 m deep)
- ***Increasing the spacing between moles from 2 to 4 m did not change DRP losses***

Tile Depth

Culley et al. (1983):

- Woodslee, Ontario, Canada – Brookston soil series
- 2 year study (1980-1981)
- Plots (approx. 12 x 80 m)
- Lateral spacing same
- Drainage depth - 0.6 m and 1.0 m
- Two P application rates (30 and 60 kg/ha/yr)
- ***DRP and TP concentrations decreased with depth***

drainage depth (m)	DRP (mg/L)		TP (mg/L)	
	application rate (kg/ha/yr)			
	30	60	30	60
0.6	0.1	0.2	0.33	0.44
1	0.05	0.09	0.16	0.21

Schwab et al (1980):

- 10 year study in northwest, Ohio on
- Toledo silty clay, 0.22 ha plots
- Drainage depth (1m deep and 12 m spacing) or (0.5m deep and 6 m spacing).
- ***Avg. annual loss - 1.2 kg TP/ha deep drains compared to 0.8 kg TP/ha for shallow drains***
- Concentrations for deep drains ranged from 0.5 to 1 mg TP/L with average annual concentration of 0.7 mg TP/L.
- No concentration data presented for shallow drains.

Stamm et al. (1998):

- Switzerland
- grassland fields
- Two drainage depths (0.5 and 1.0 m)
- Event analysis
- DRP was the largest fraction of TP (50% at site 1 and 70% at site 2)
- P transport through preferential flow paths was significant
- ***Shallow drain site had greater DRP concentrations than did deeper drain site.***

Surface Inlets

Ginting et al. (2000):

- two depressions/surface inlets (44.3 and 41.5 ha) in southcentral MN.
- 3 years (1996-1998)
- Madelia and Spicer silty clay loam
- In snowmelt 52 to 83% of TP was DRP compared to 18% to 33% in rainfall runoff.

	Rainfall Runoff	Snowmelt
TP loss (g/ha)	41.2	57.3
DRP loss (g/ha)	13.0	41.1
TP (mg/L)	0.7-6.5	0.2-2.9
DRP (mg/L)	0.1-0.5	0.2-0.9

Management (Tillage)

Gaynor and Findlay (1995):

- Ontario, Canada; 12.2 by 82.5 m plots
- Brookston clay loam
- continuous corn, 1988 to 1990
- Subsurface drainage accounted for 55 to 68% of DRP
- Zero, ridge, and conventional tillage
- DRP concentrations (0.54, 0.34, 0.24 mg/L)
- TP concentrations (1.07, 1.07, and 0.8 mg/L)
- DRP mass loss (0.865, 0.526, and 0.382 kg/ha)
- ***Conservation tillage reduced erosion but increased p loss.***

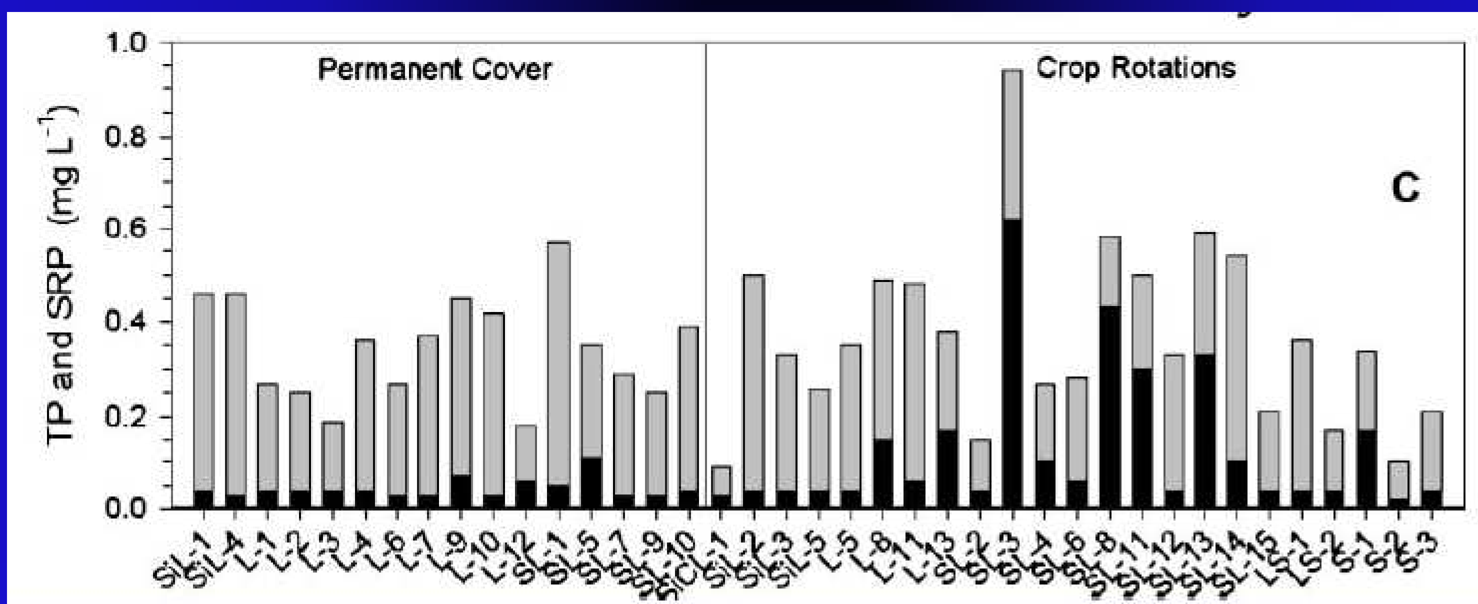
Schwab et al. (1973):

- Toledo silty clay soil near Sandusky, Ohio
- 0.55 acre plots, continuous corn 1969-1971
- No-tillage vs conventional tillage
- Concentrations: conventional tillage (0.6 mg TP/L) and for no-tillage (0.5mgTP/L).
- Losses: conventional tillage (0.5lbsTP/acre) and for no-tillage (0.6lbsTP/acre).
- ***Essentially no differences in TP with respect to tillage***

Management (Cropping)

Kinley et al. (2007):

- 39 agricultural fields in Nova Scotia, CA, 2002 - 2003
- ***DRP generally greater and more variable with crop rotation compared to permanent cover***
- attributed to use of swine and poultry manure on crops in rotation compared to dairy manure on permanent cover



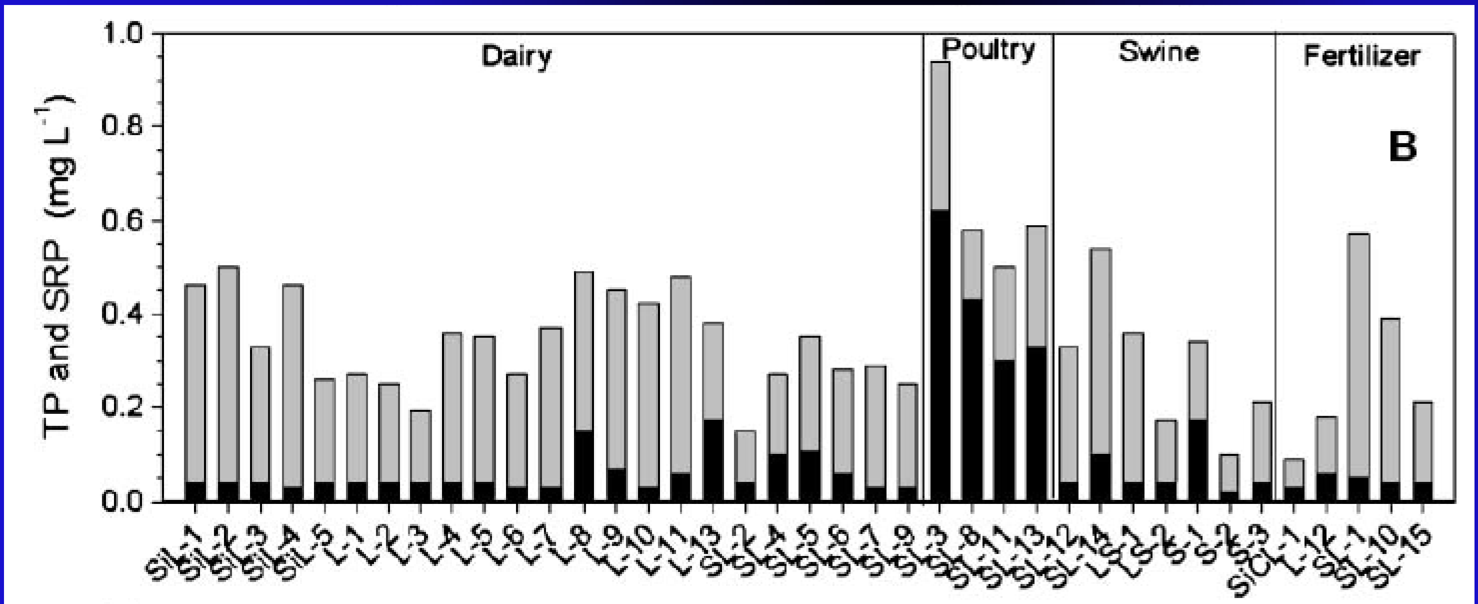
Management (Fertilizer Source)

Kinley et al. (2007):

- 39 agricultural fields in Nova Scotia, CA, 2002 - 2003
- ***Use of poultry and swine manure generally had greater proportions of DRP when compared with dairy manure and commercial fertilizers.***

Randall et al. (2000):

- 4 year plot study, 1993-1997, Waseca,
- Webster clay loam soil, with continuous corn
- Dairy manure and urea at two N rates in fall
- ***TP and DRP in tile drainage were not different between treatments***
- Max DRP conc.: urea 0.02 mg/L; manure 0.06 mg/L
- Max TP conc.: urea 0.08 mg/L; manure 0.12 mg/L



Kinley et al. (2007)

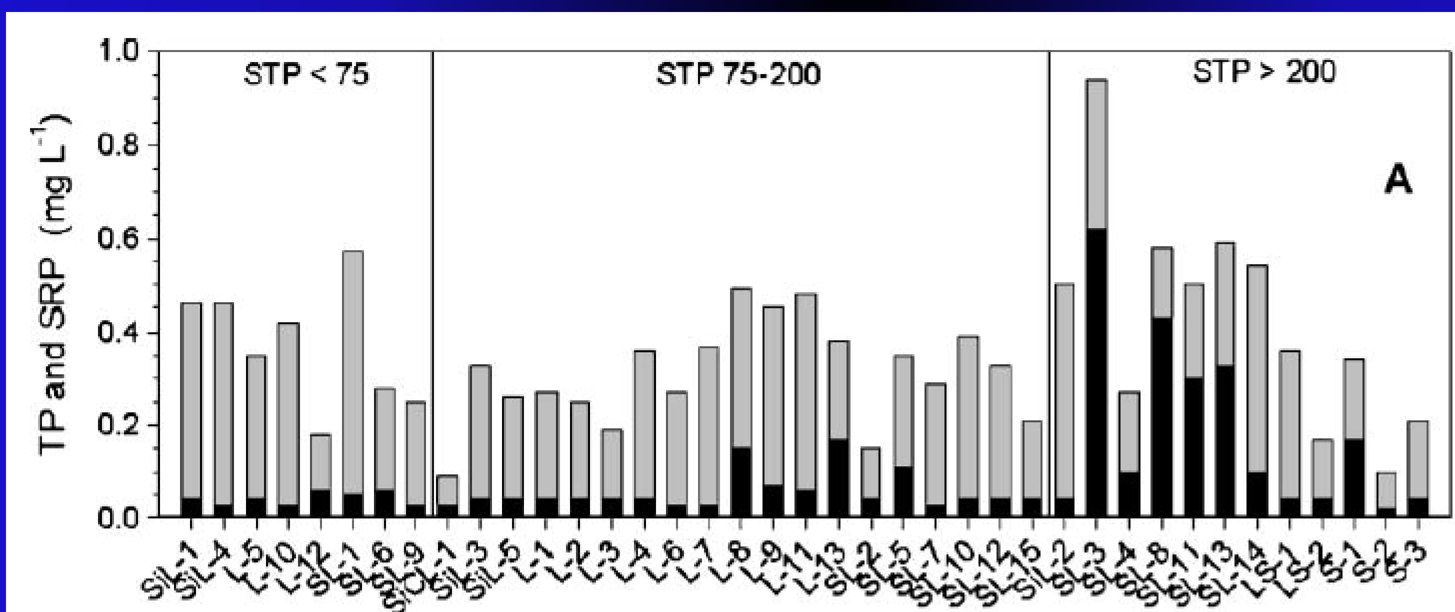
Management (Fertilizer Rates)

Algoazany et al (2007):

- LVW in Illinois – 4 subsurface sites, 1994-2000
- average annual DRP conc. 0.102, 0.099, 0.194, and 0.086 mg/L
- ***greater application rate and applying p after crop harvest had greater soluble p transport in tile***
- ***Site where P was applied every 2 years had greater P concentration in tile drainage***

Ball-Coelho et al., 2007:

- Huron silt loam soil Ontario, Canada.
- Liquid swine manure injected and topdressed
- high injection application rates (>56 m3/ha) contaminant transport to tiles was immediate with 3 year DRP concentrations 2.5 mg DRP/L



Kinley et al. (2007)

Management (Fertilizer Placement)

Turtola and Jaakkola (1995):

- southwest Finland
- 16 plots (33m x 33m), 3 years (1980-1982)
- Broadcast vs. banding
- Conc. range 0.01 mg DRP/L to 1.45 mg DRP/L
- ***DRP conc. peaks occurred after broadcast appl.***

Ball-Coelho et al., 2007:

- Huron silt loam soil Ontario, Canada.
- Liquid swine manure injected and topdressed
- ***Surface banding apps did not reach tile immediately*** but were transported in rains that fell 3d after application (0.1 mg DRP/L)
- Greater concentrations during and following sidedressing injection

Hydrology (Base flow vs. Event flow)

Kleinman et al. (2003):

- Susquehanna River Basin, PA
- Conventionally tilled corn-soybean-wheat field,
- poultry manure annually at rate of 85 kg P/ha/yr.
- Baseflow and stormflow samples in tile flow
- ***Loads from storm flow surpassed those of baseflow despite approximately 10 time more discharge volume in baseflow.***

	DRP (mg/L)	TP (mg/L)
Base flow	**0.009-0.012 (0.01)**	**0.014-0.023 (0.019)**
Storm flow	**0.056 - 0.146 (0.102)**	**0.099-0.498 (0.283)**

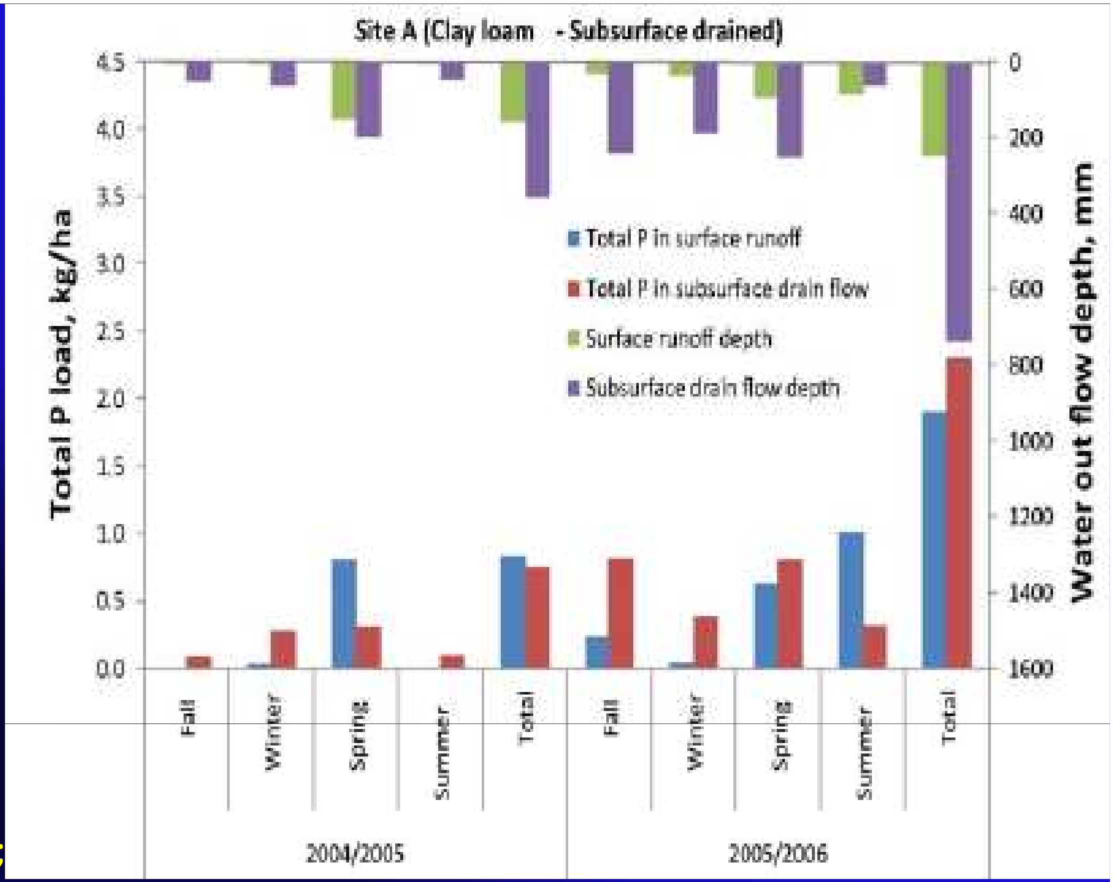
Seasonality

Eastman et al. (2010):

- Pike River watershed, Quebec, CA

Bolton et al. (1970):

- Woodslee, Ontario Canada
- Brookston clay soil, 1961-1967
- 12.2 m x 76.2 m plots
- TP concentrations were seasonal
- lower in the spring than fall and winter (Jan-Mar 0.17; Apr-Jun 0.15; Jul-Sep 0.27; Oct-Dec 0.21).



Macrae et al. (2007):

- Strawberry Creek Watershed, Ontario, CA
- Median DRP concentration greatest with snow melt followed by winter and then summer periods
- median TP concentration greatest in summer followed by snow melt and then winter.

Review Summary

Approximately 90 manuscripts to date with data collected worldwide (50% of papers are from US.

Physical/Drainage Design Factors

soils – more potential for preferential flow (i.e. higher clay content) greater losses
depth - inconclusive
spacing - closer the drains greater the losses
surface inlets – representative of surface runoff, not tile flow

Management Impacts

tillage – inconclusive: no-till reduces erosion but in some cases increases subsurface losses
cropping – more cover is better
fertilizer source – swine manure more of a problem than other sources
STP and application rates – apply only what crop requires and during that crop year
placement - incorporation or contact with soil reduces losses

Hydrologic and Climatic Effects

baseflow vs. event flow – losses greater with storm flow compared to baseflow
seasonality –icnonclusive: seasonal variations different with respect to DRP and TP

Strategies for Addressing Agricultural Induced Phosphorus Transport

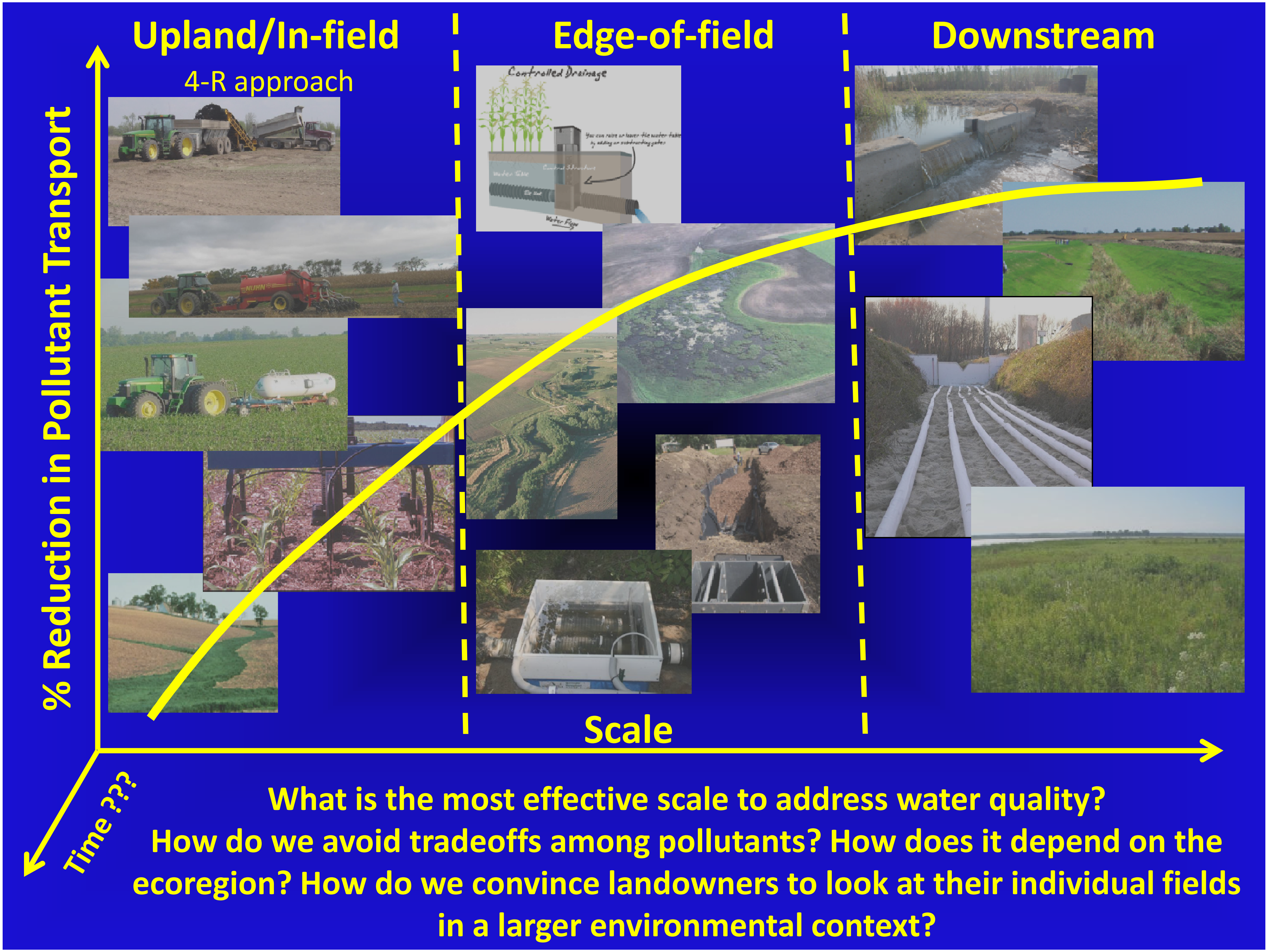
Upland Management
- 4Rs
- Interruption of connection to surface

Structural Hydrologic Control
- Water table management
- blind inlets

Filtration
- End-of-tile and in-stream
- Enhanced bioreactors

Edge-of-field
- Buffers (vegetated and saturated)
- wetlands

Ditch Design and Management
- Two stage, natural, and over-wide ditches
- Dredging
- Vegetated channels


Upland/In-field
4-R approach
Edge-of-field
Controlled Drainage
Downstream
% Reduction in Pollutant Transport
Scale
Time ???
What is the most effective scale to address water quality?
How do we avoid tradeoffs among pollutants? How does it depend on the ecoregion? How do we convince landowners to look at their individual fields in a larger environmental context?

Upland Management (4 Rs)

- Rate
  - adhere to soil test recommendations
  - apply only what is needed in crop year; avoid multi-year applications (Algoazany et al., 2007)

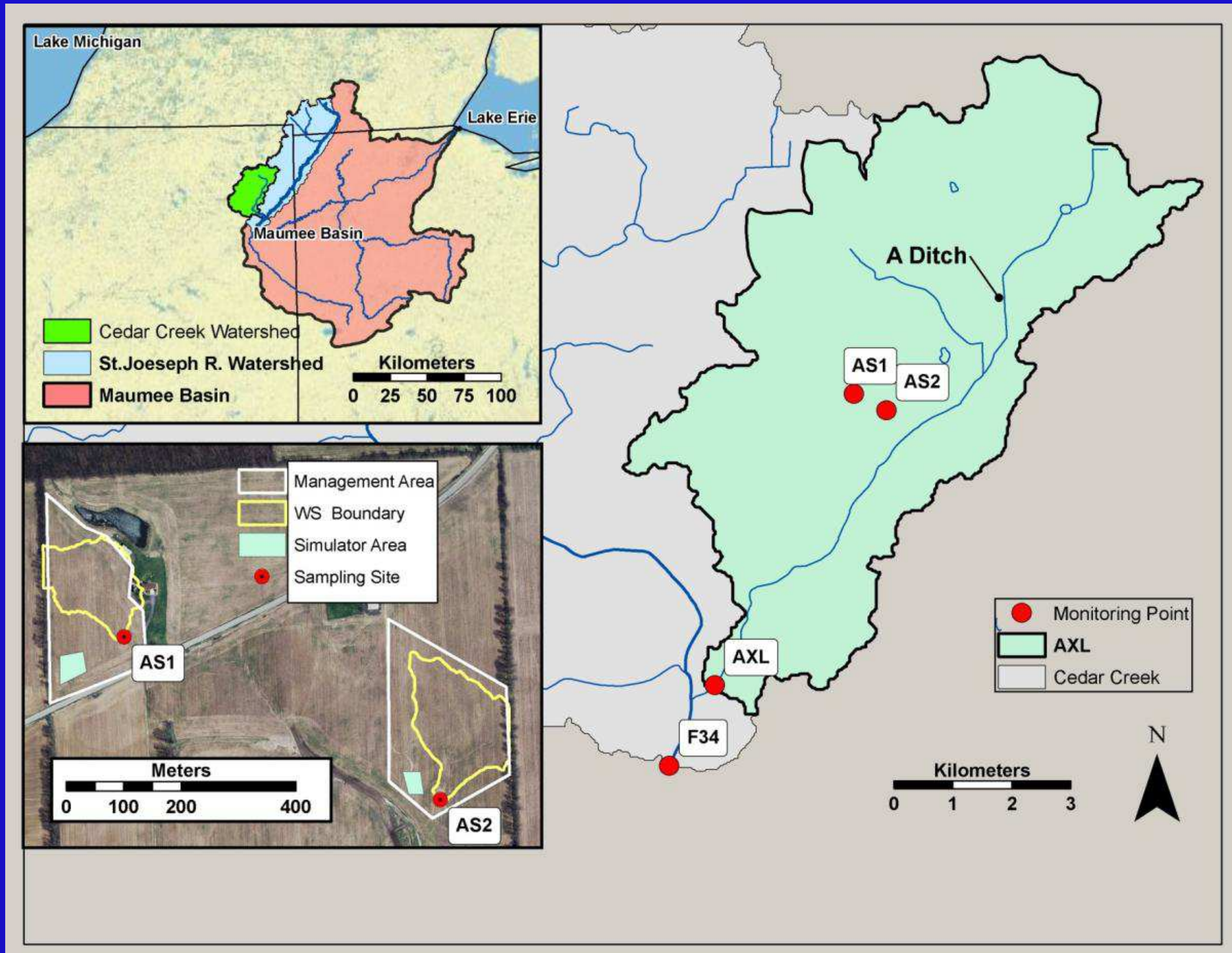
- Source
  - manure vs. commercial (Phillips et al., 1981)

- Placement
  - incorporation
  - precision application
  - banding vs. broadcast

- Timing
  - be cognizant of weather predictions and avoid application prior to rainfall
  - avoid winter time manure applications – winter applied manure had greatest concentrations of dissolved P in tile effluent (Phillips et al., 1981)

Promote soil biological diversity

- Soil organisms control transformation between inorganic and organic P forms (Frossard et al., 2000; Illmer et al., 1995)
- Addition of microbial energy sources increased mobility of P by 38 times (Hannapel et al., 1963a)
- Mobilization of P by microbial population was most important factor in P transport (Hannapel et al., 1963b)
- Microbiocidal activity following glyphosate application was altered (Zobiole et al., 2010)



Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Field Level BMP/CP Comparisons

- No-Till, Corn/Bean Rotation (AS1)
- Rotational Till, Corn/Bean Rotation (AS2)
- Conventional Tillage (Chisel/Disk), Alfalfa/Wheat/Corn/Bean/Oats (ADE & ADW)

- Comparisons:
  – management
  – crops
  – surface v. tile flow

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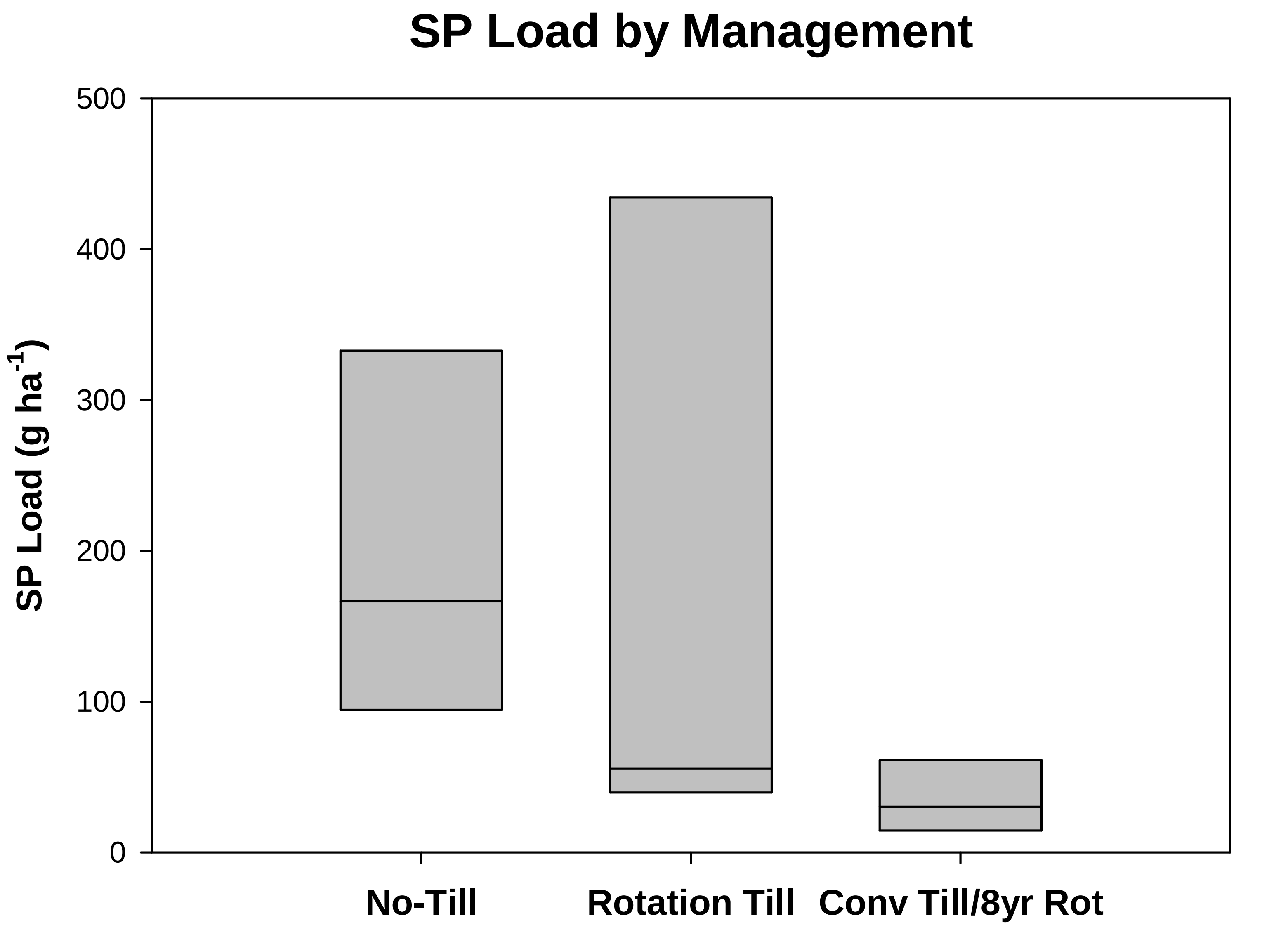

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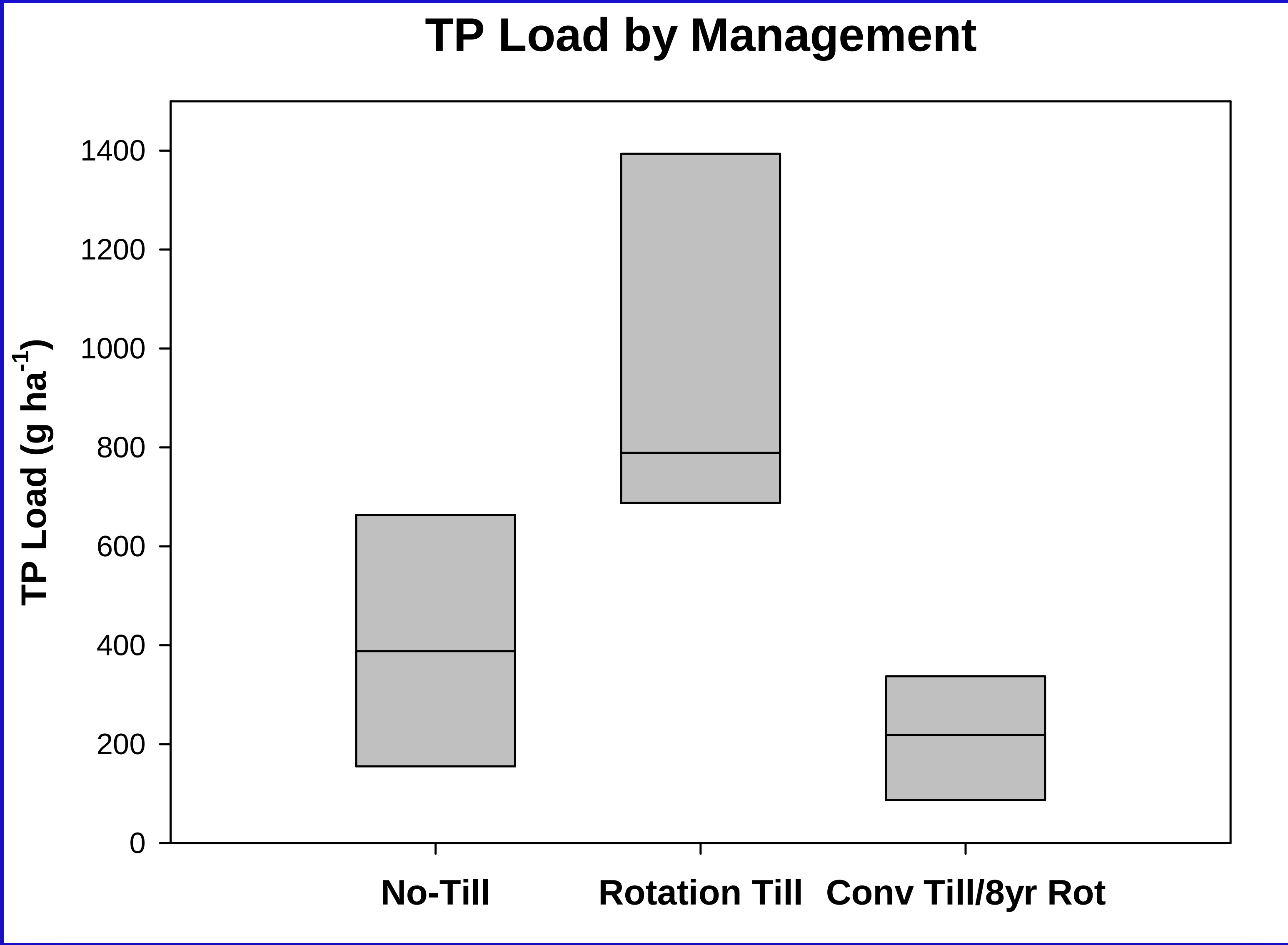

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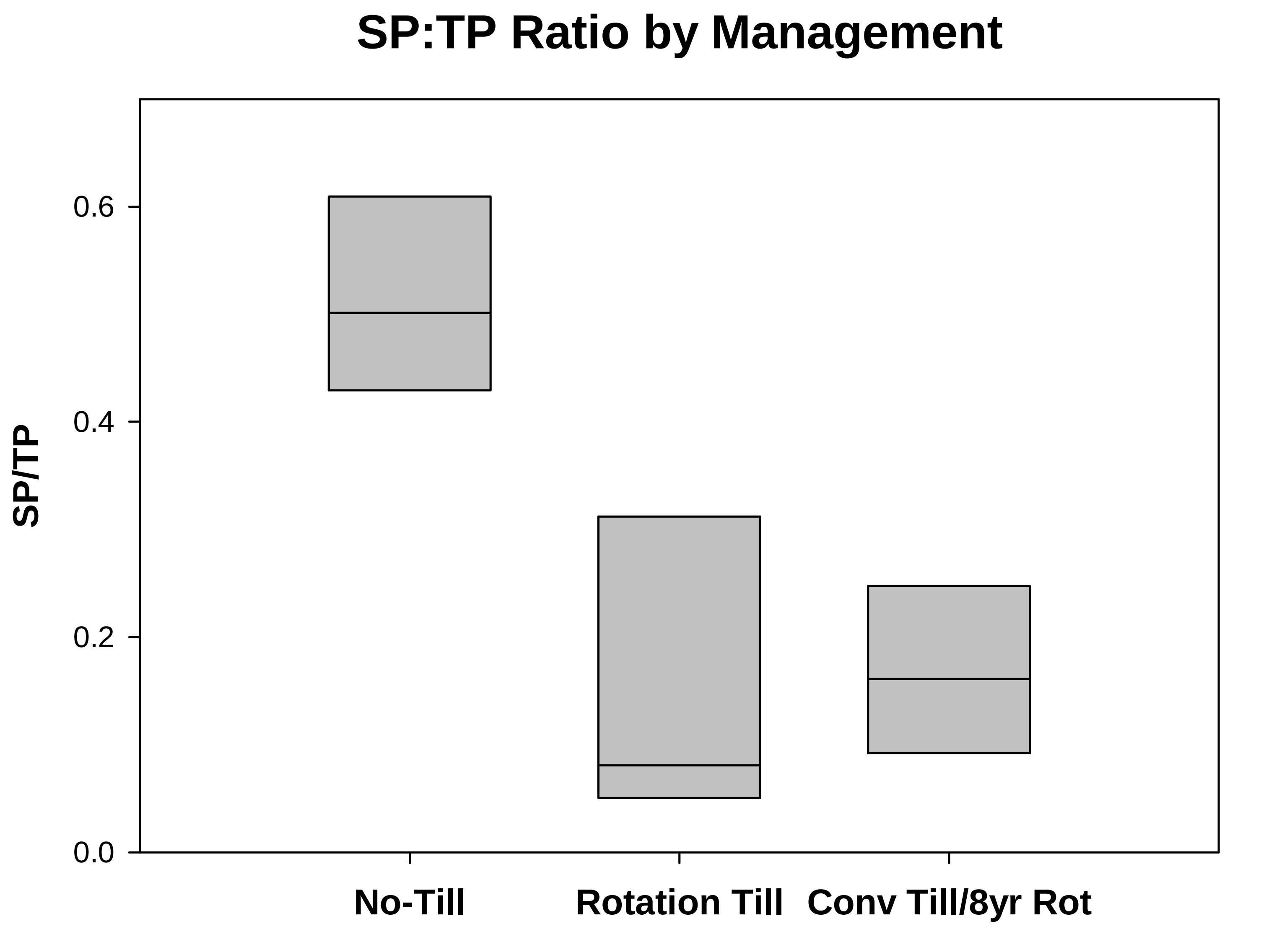

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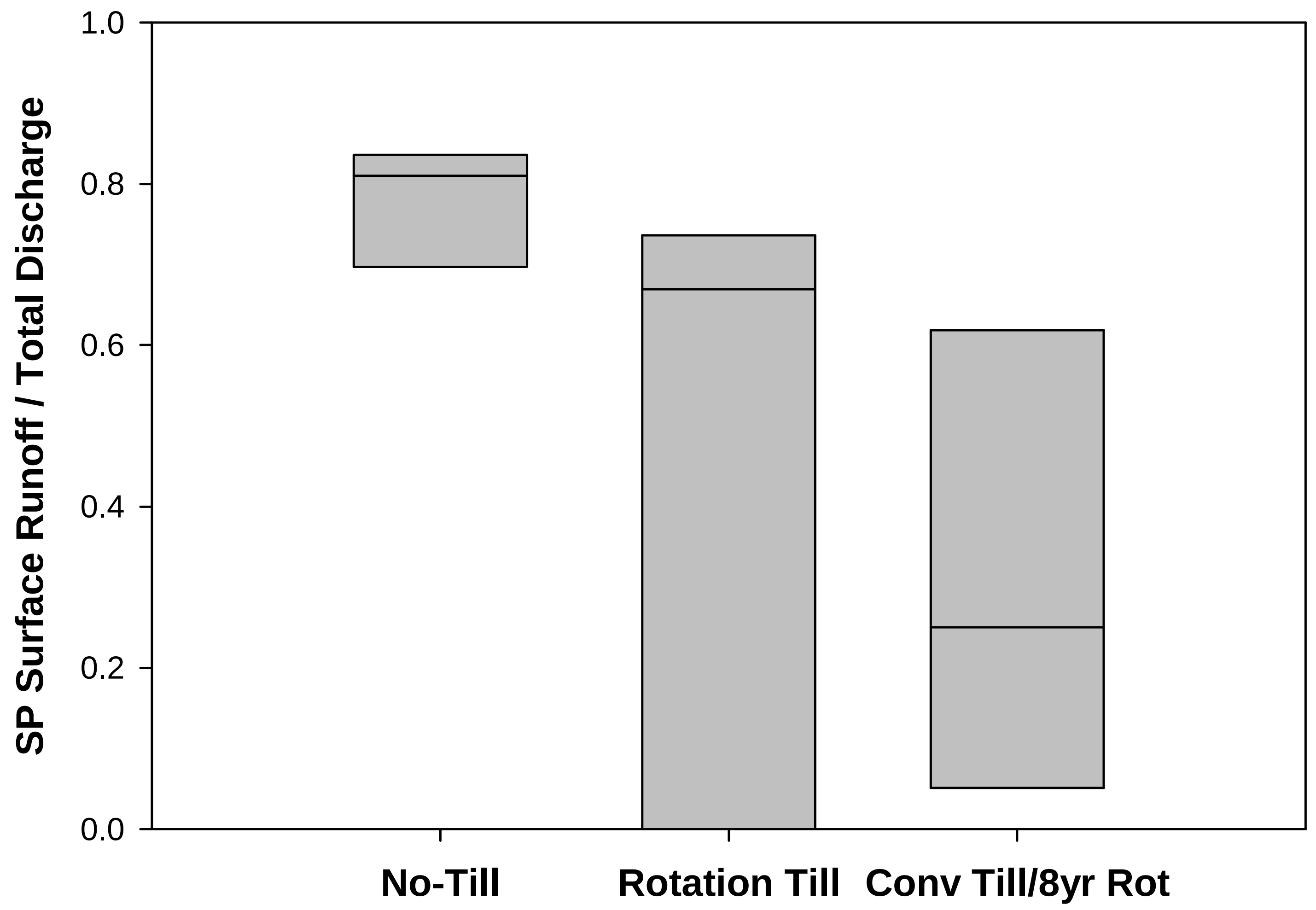
SP in Surface Runoff:Total Discharge Ratio by Management



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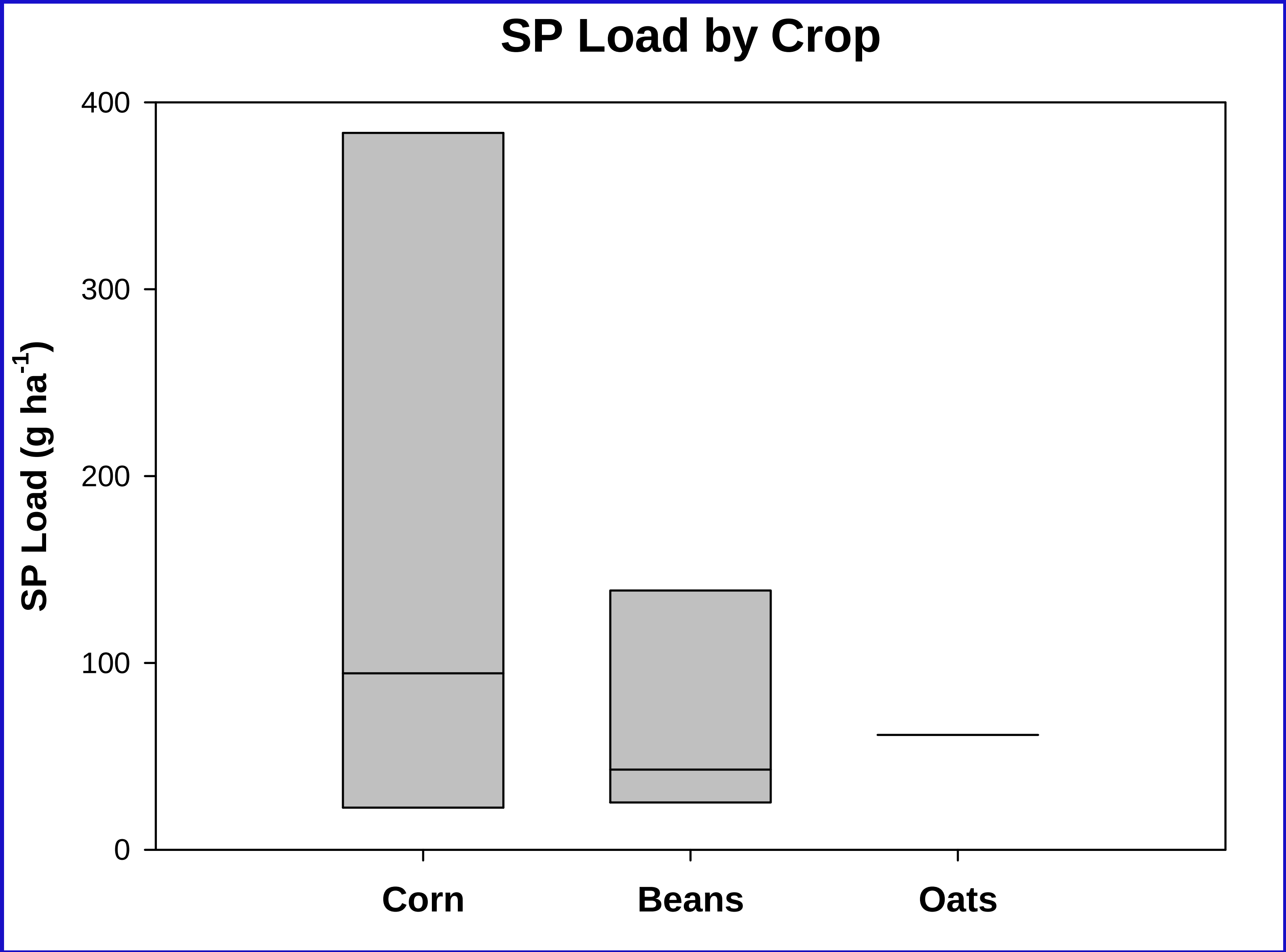

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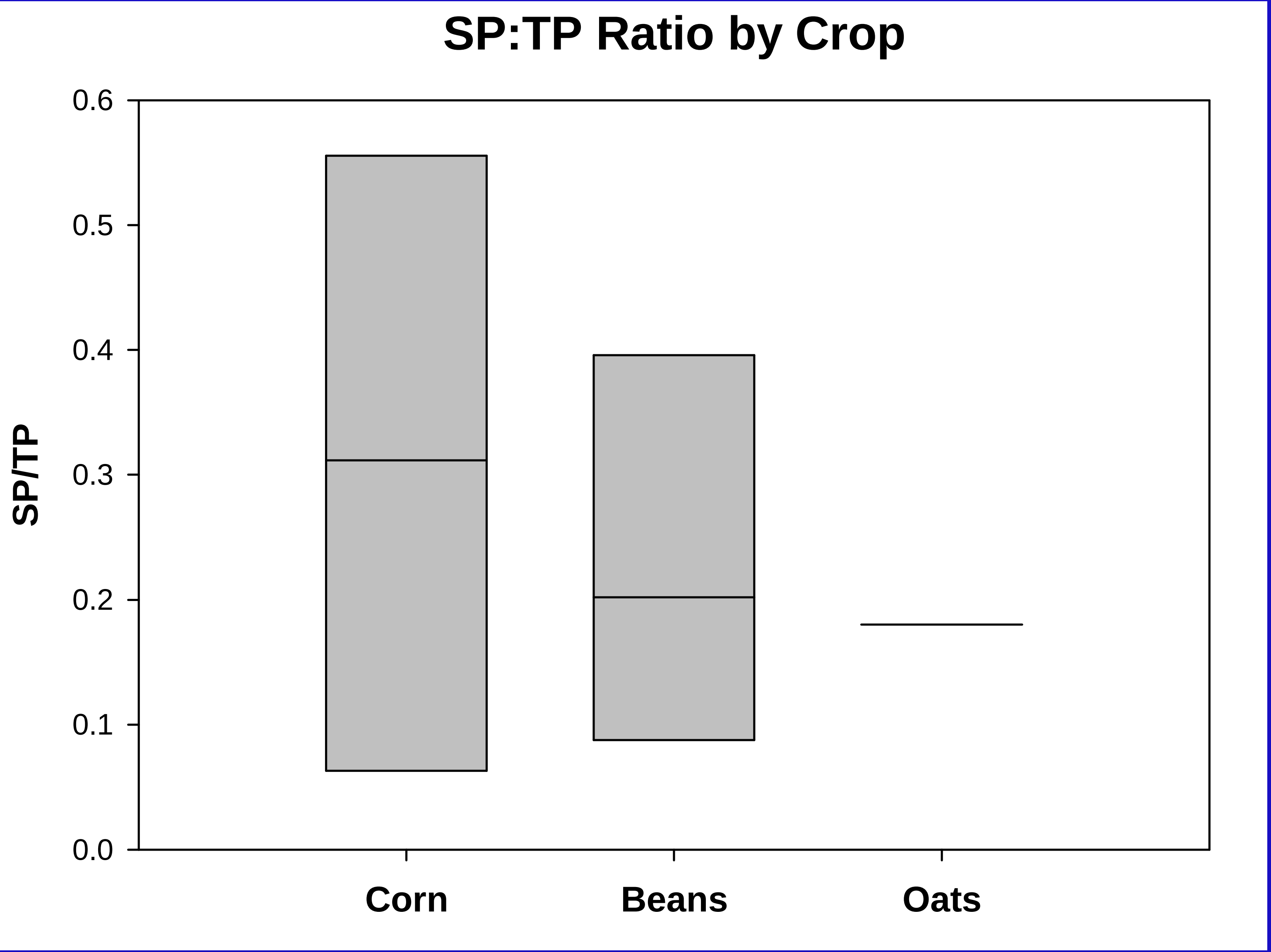

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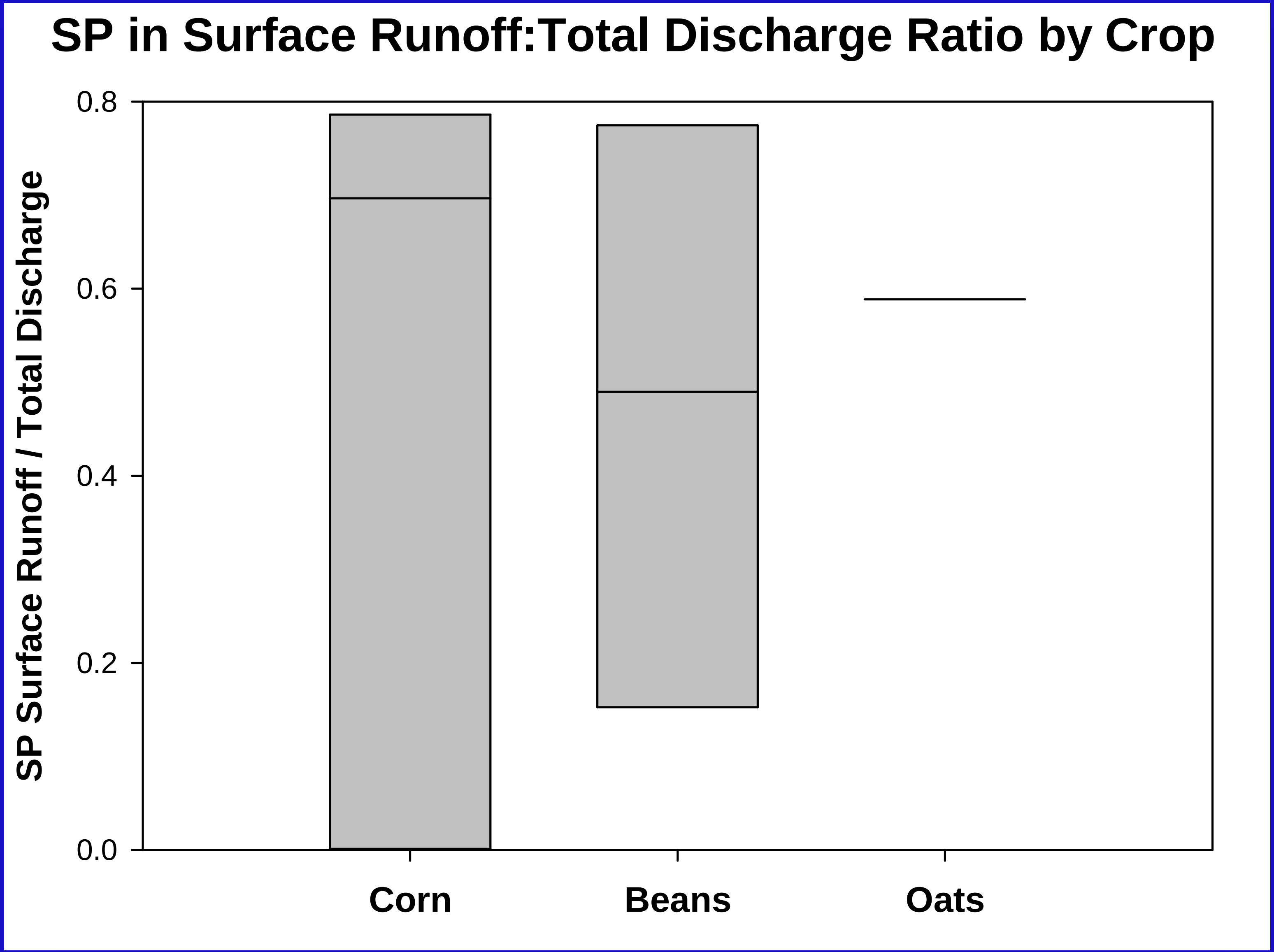

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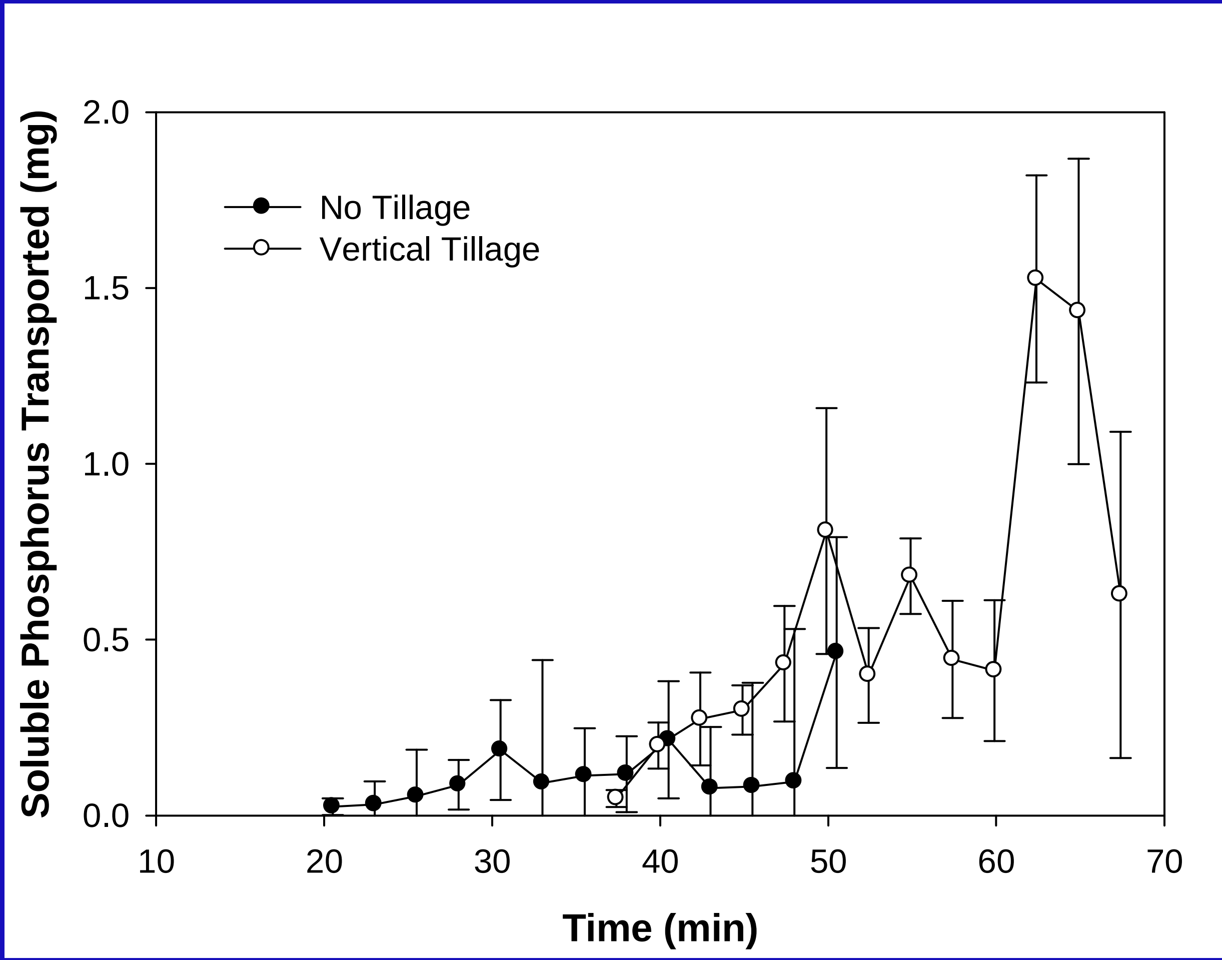
Vertical Tillage



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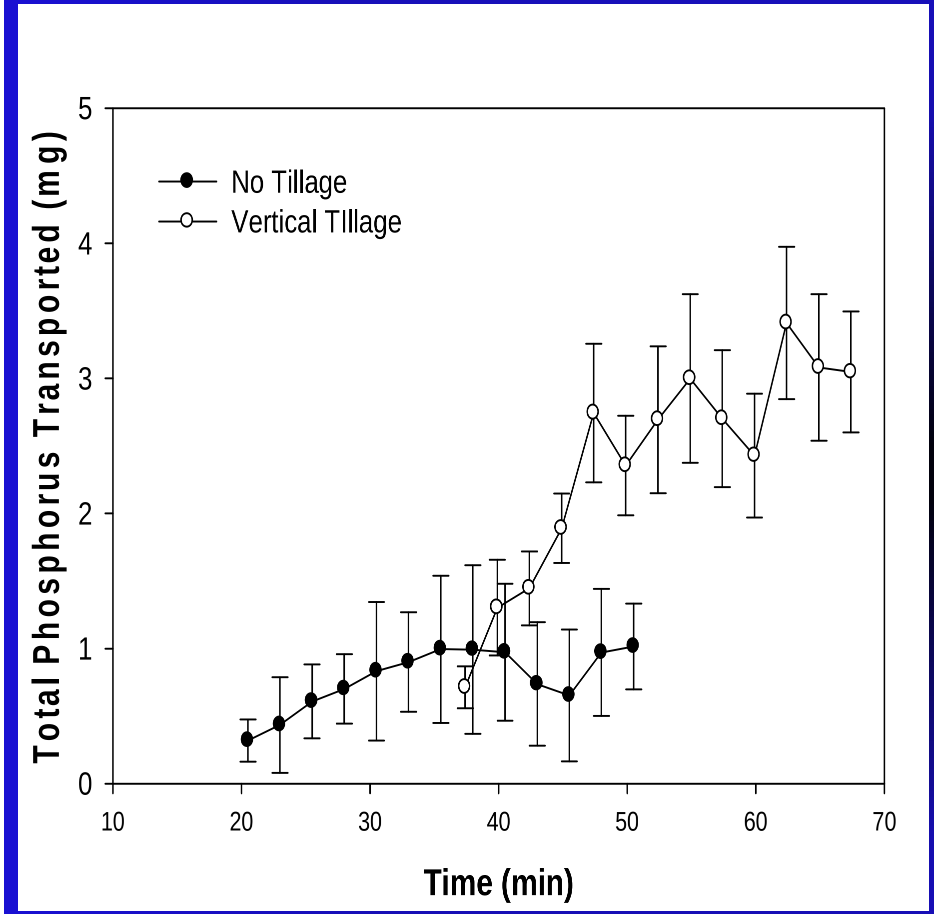
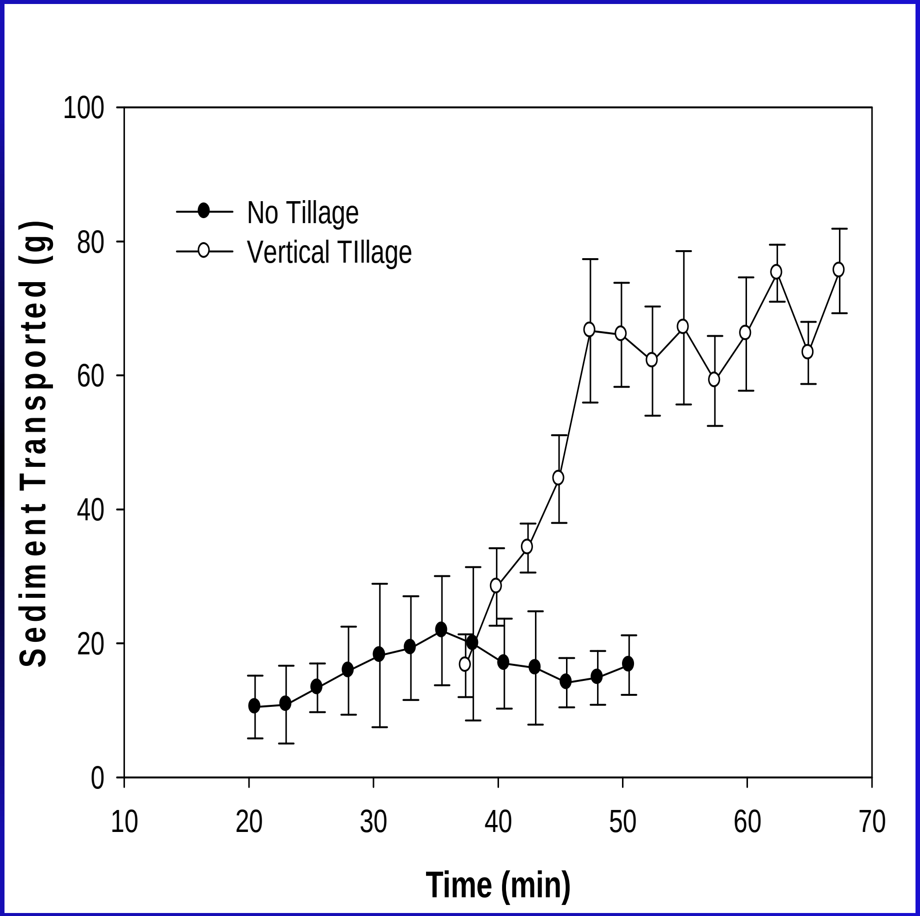
Vertical Tillage





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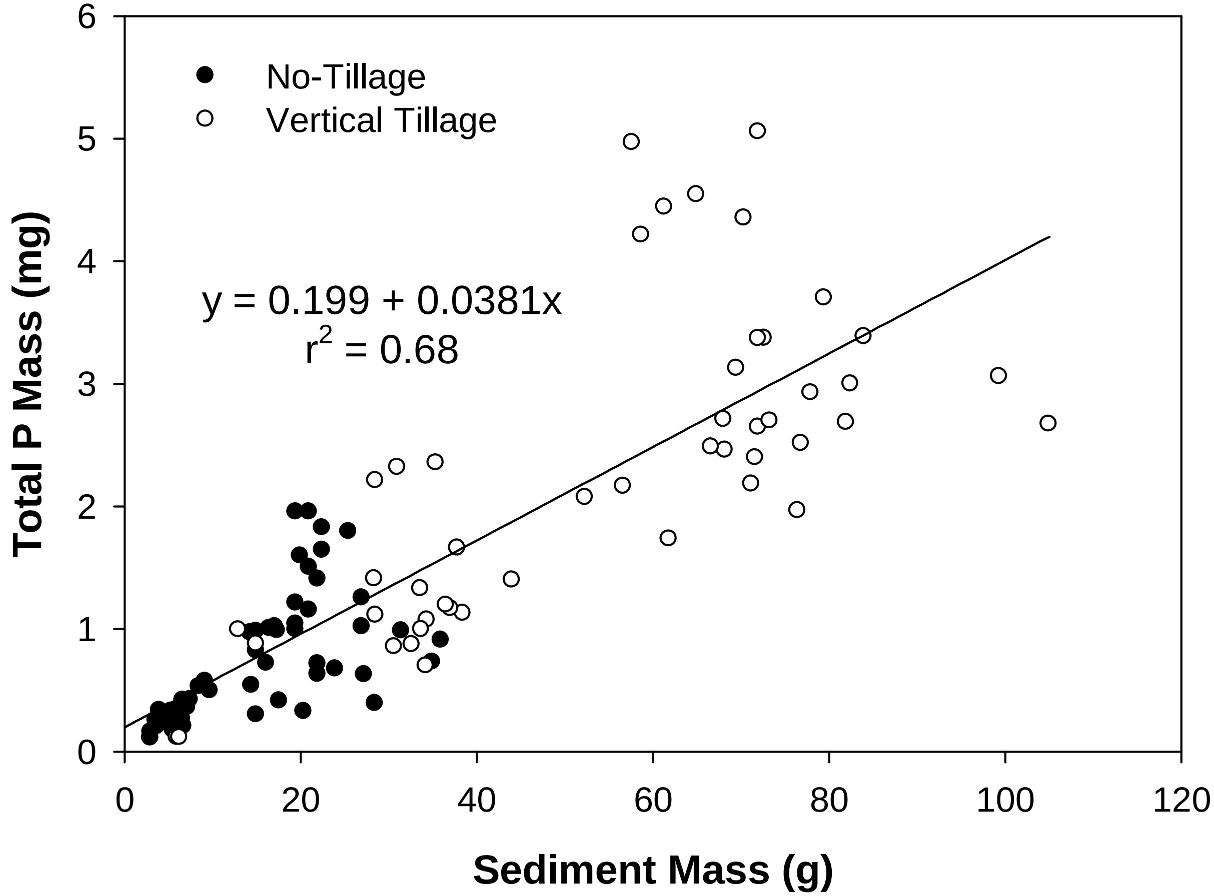
Vertical Tillage



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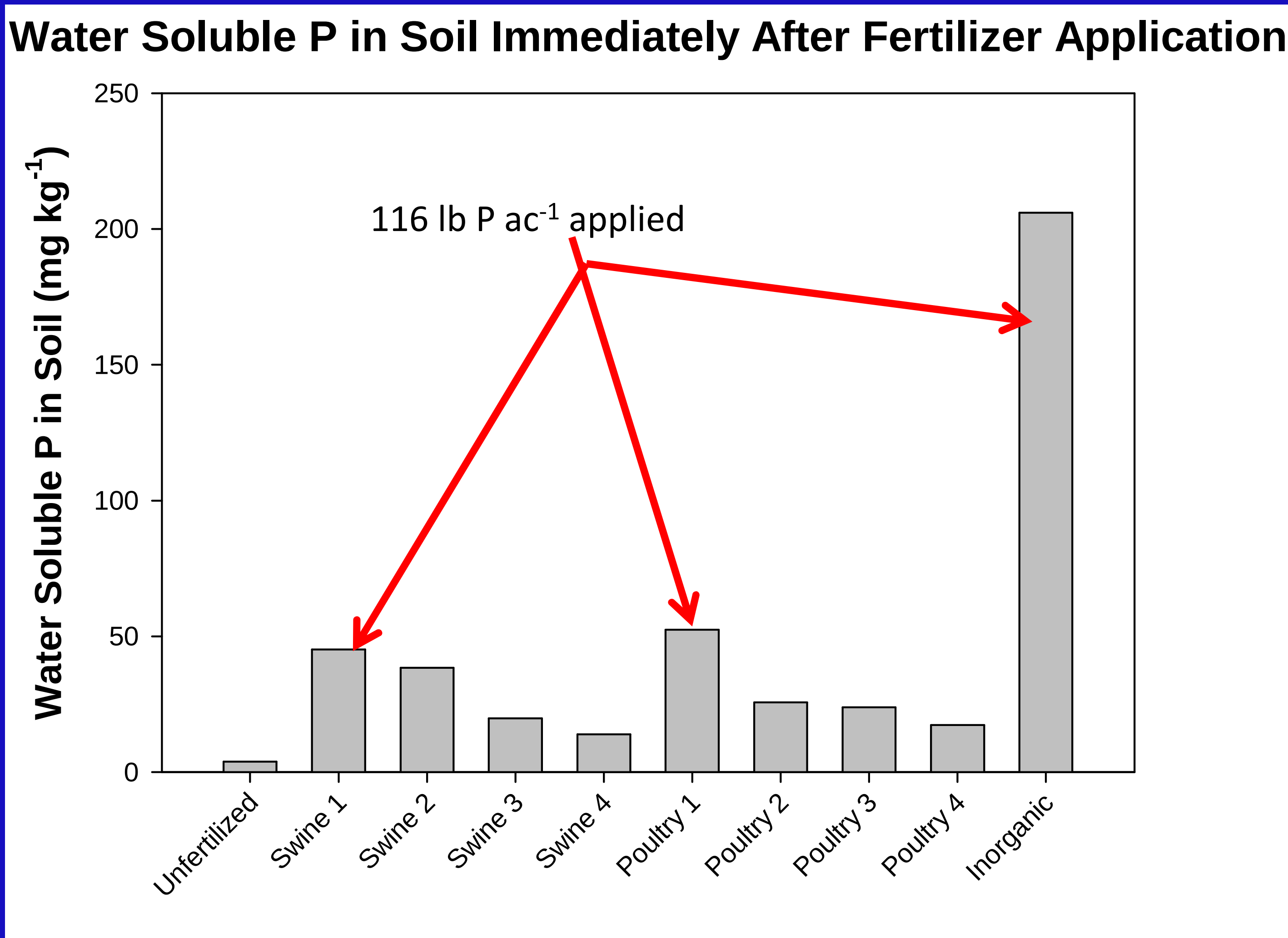
Fertilizer Source



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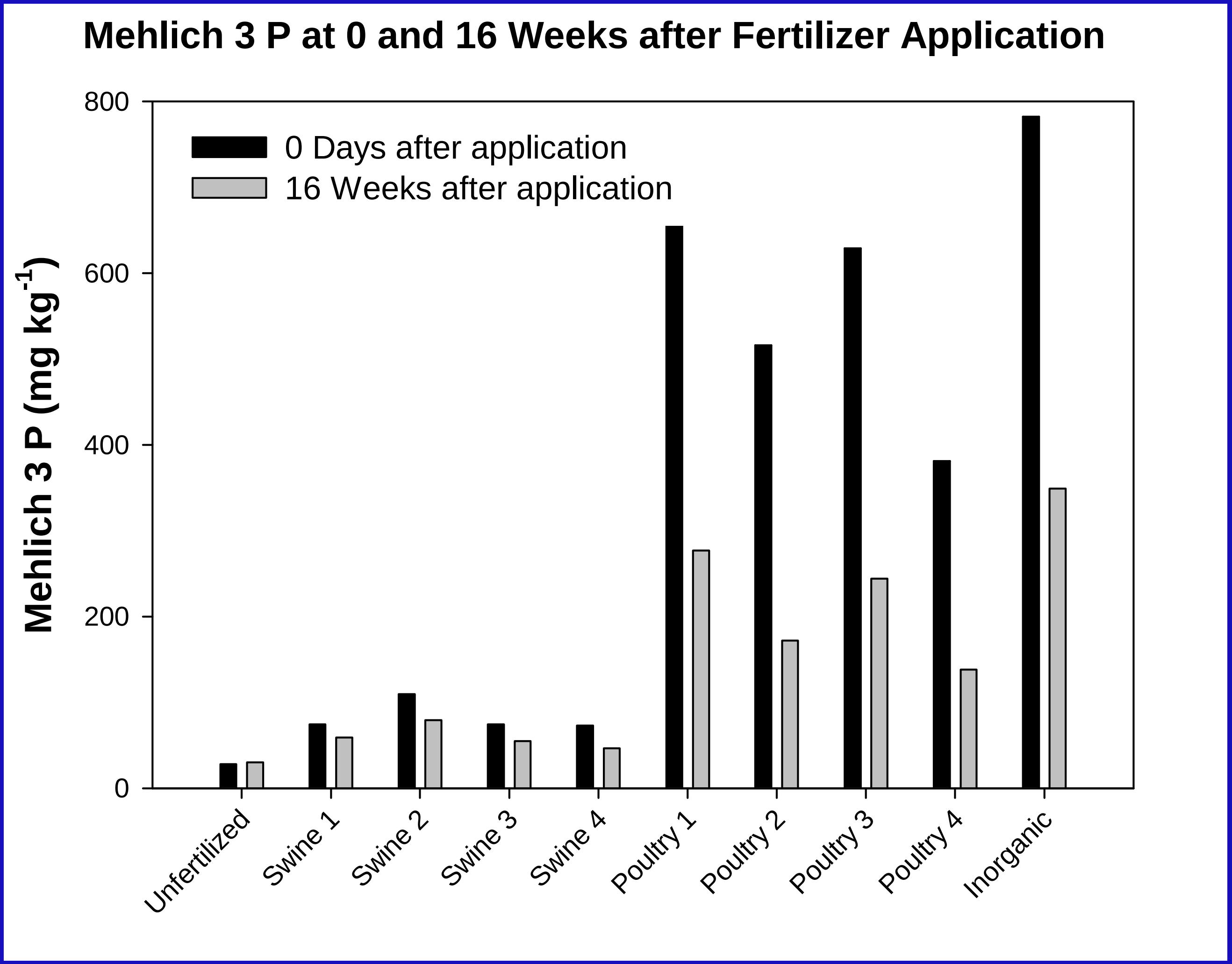

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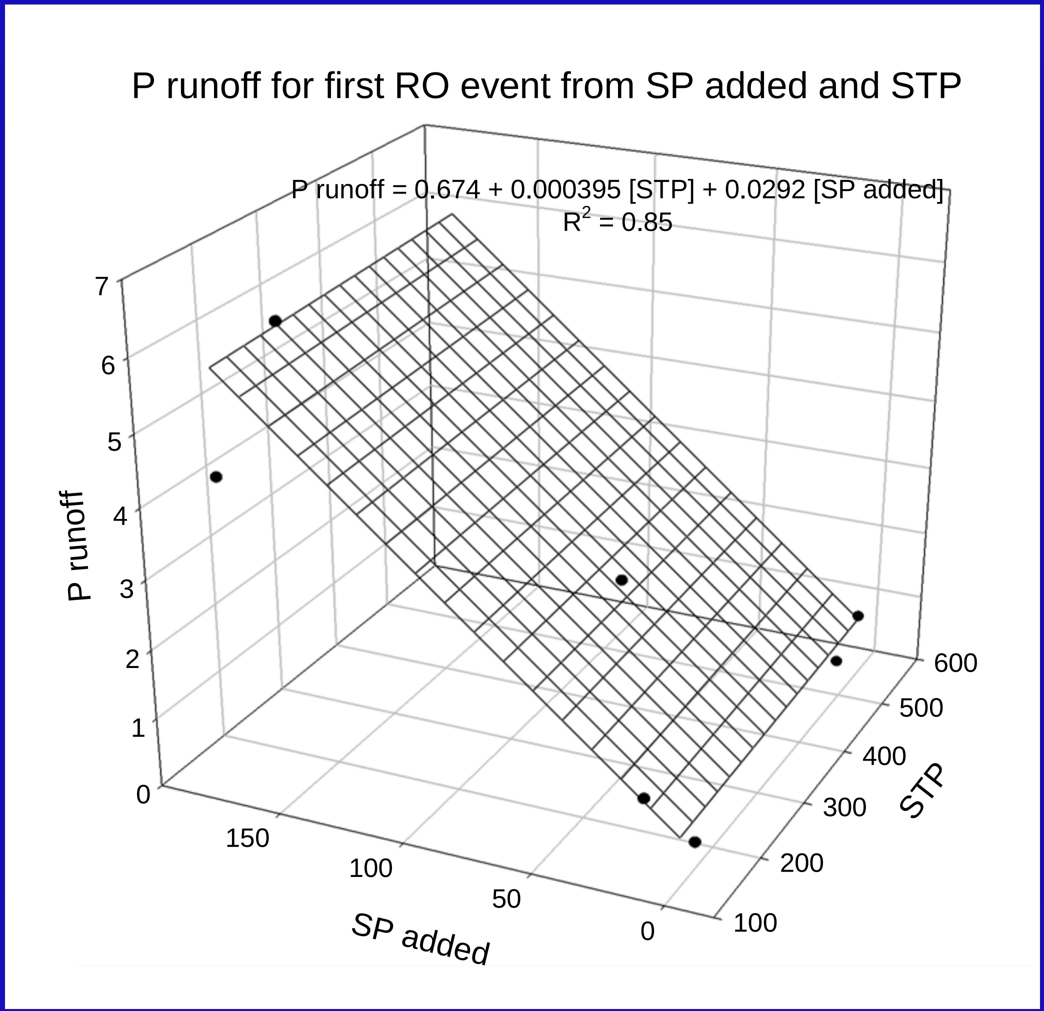

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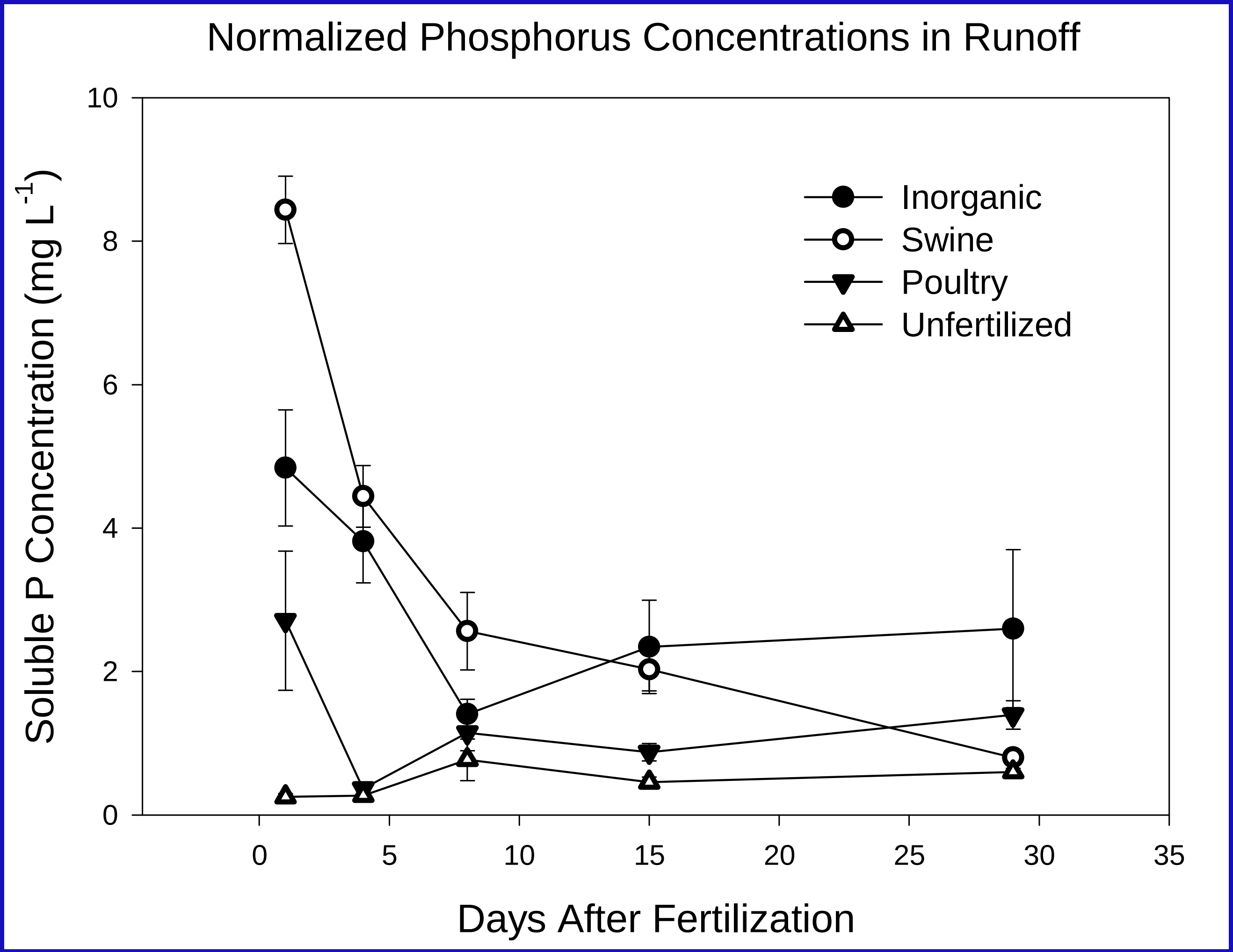
Fertilizer Source



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Conclusions – Cropping & Management

- More frequent, lower rates of fertilizer result in less loss
- Longer rotations lose less P
- No-till may result in > SP loss, but must balance that with < TP loss
- More P lost with corn (due to P applications???)

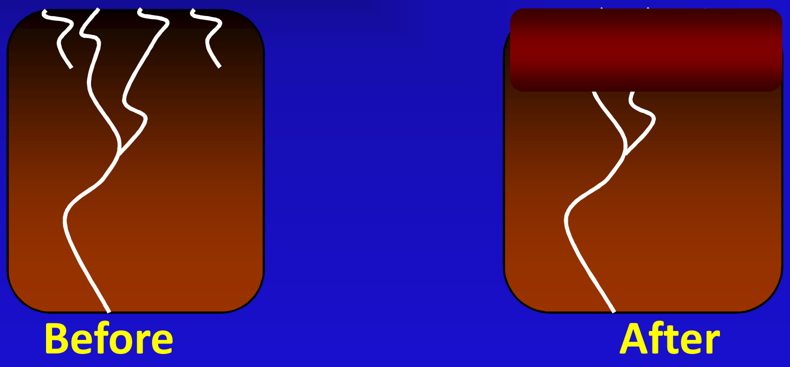
Conclusions – Fertilizer Source

- Manures < P loss & soil P increase than inorganic fertilizers
- Fertilizer applications overwhelm soil available P
- Surface applications have greater potential for loss
- Time between application and 1st Runoff Event decrease P Loading

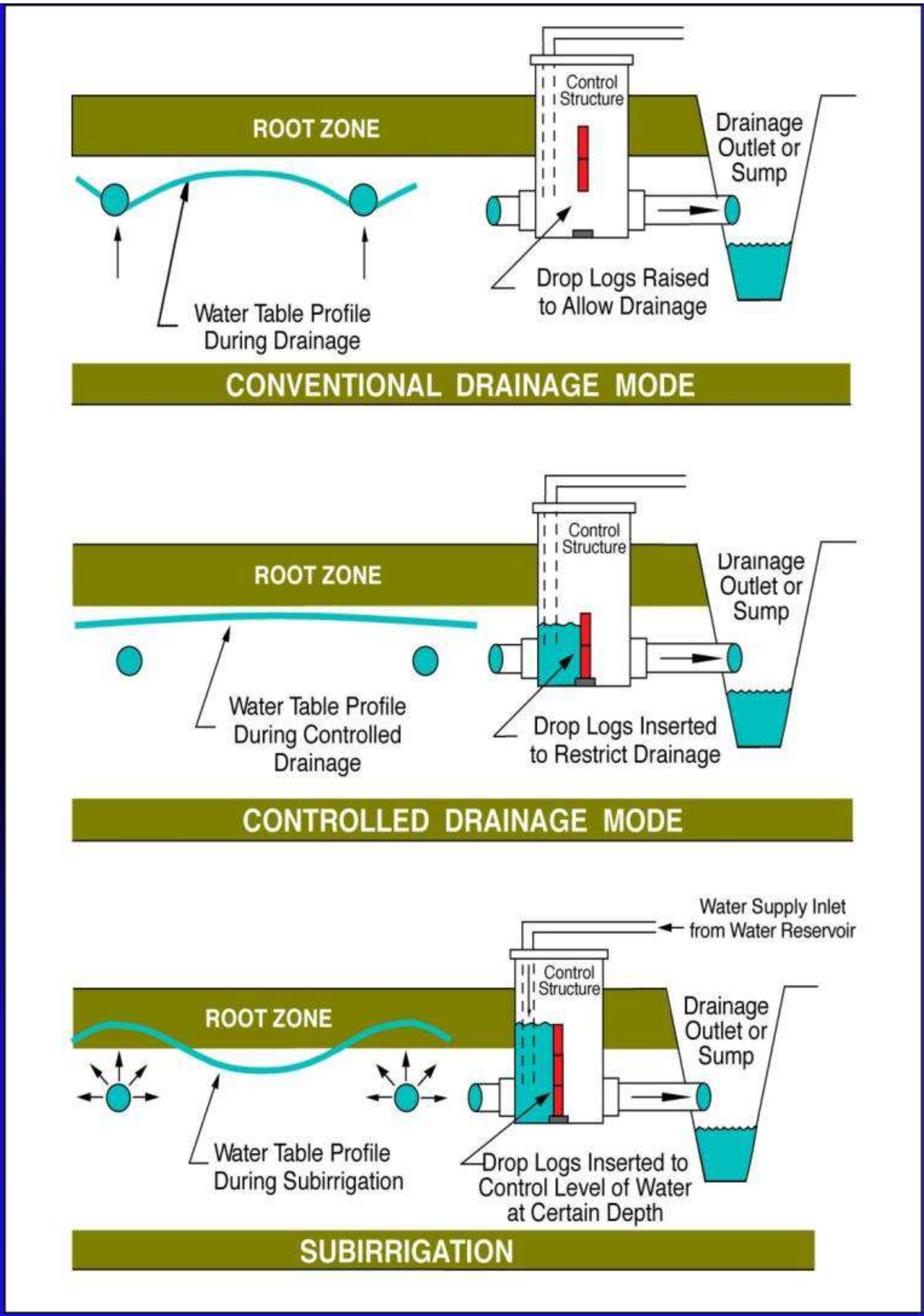
Interrupt Connection to Surface Sources

-Disrupt macropore and preferential flow paths through tillage

- Increase buffering capacity

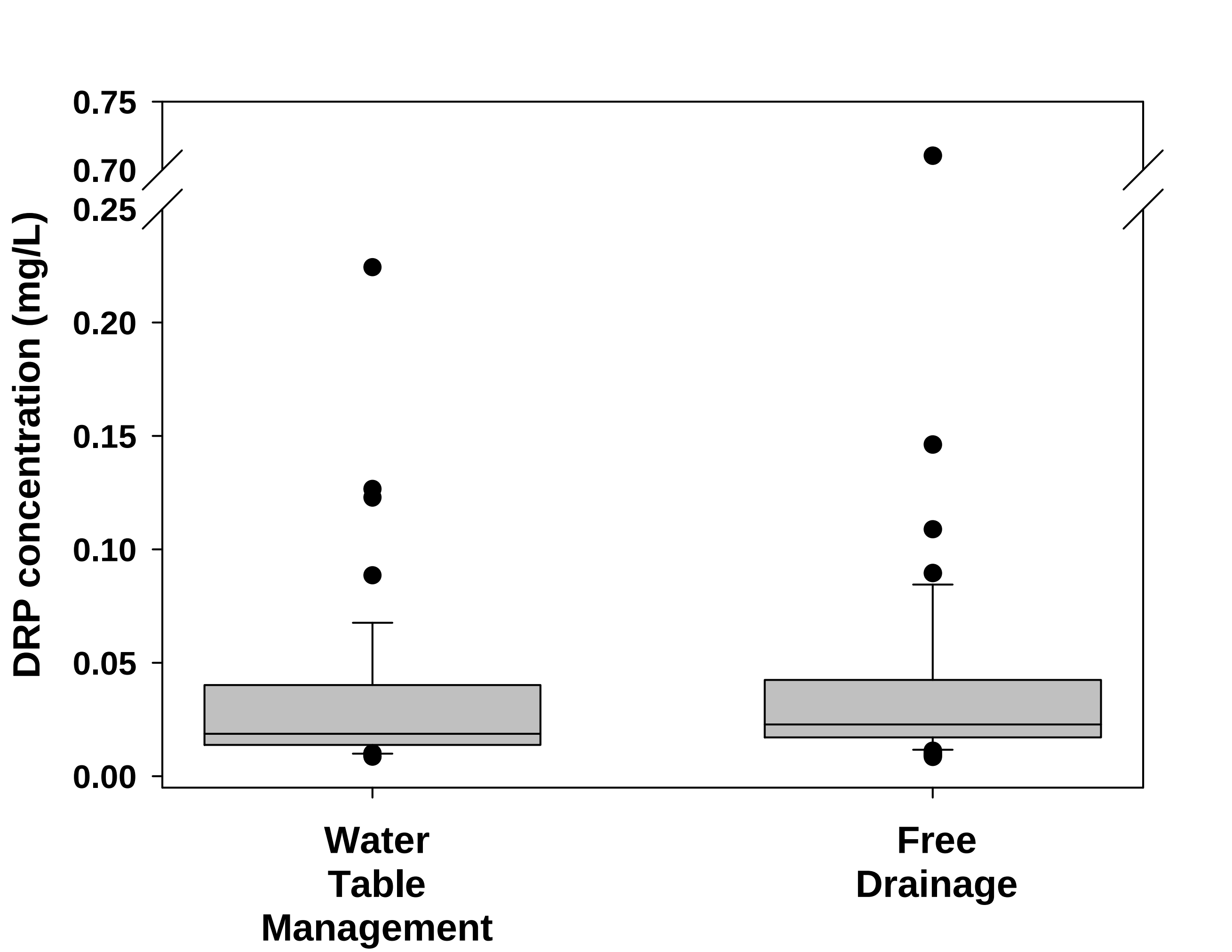


Water Table Management

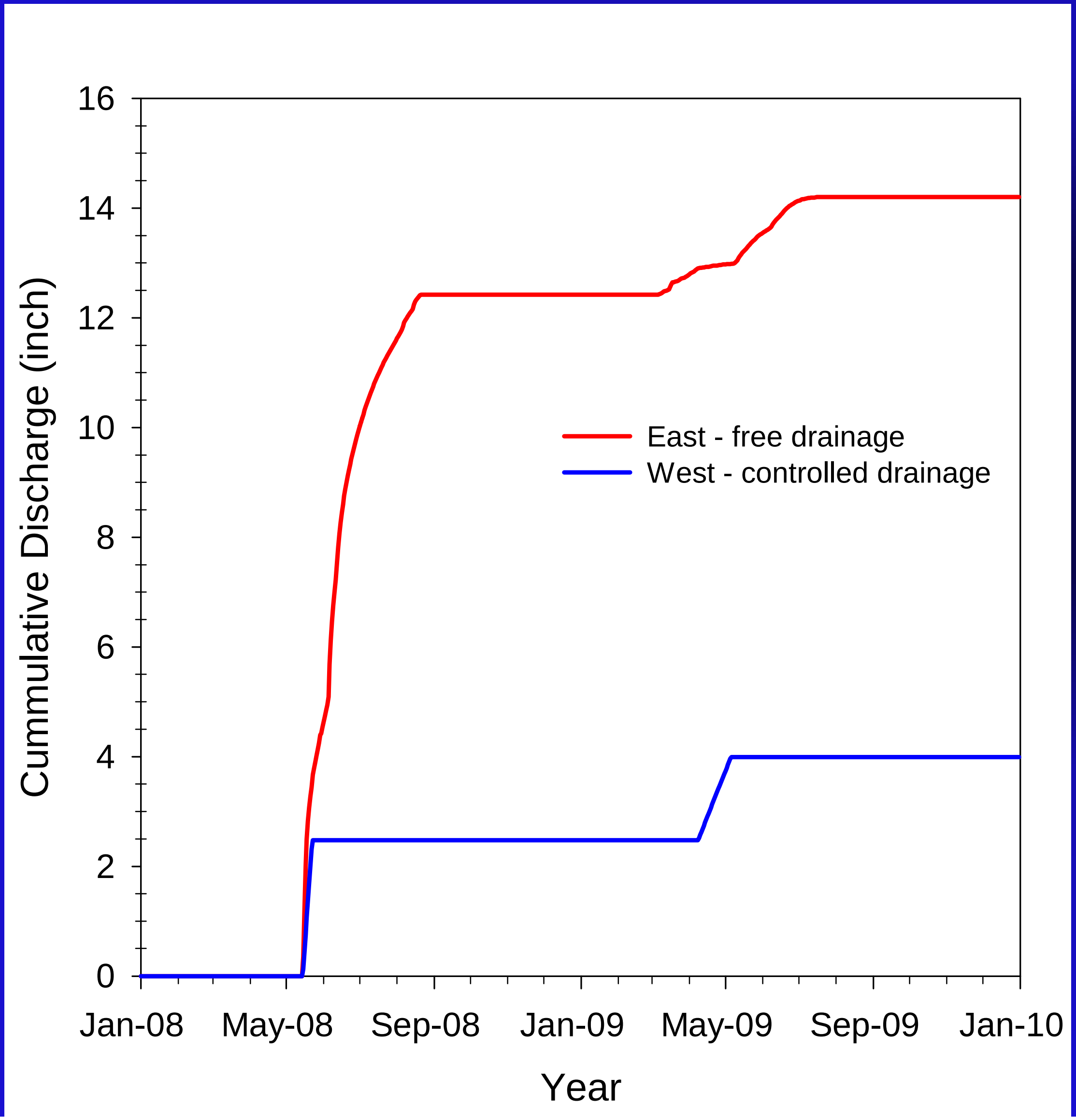


Water Table Management

- Part of a 5 state CIG
- Northwest Ohio (8 paired sites)
- 2011 data (n=48 for each drainage type)



Controlled Drainage Effectiveness (MN)



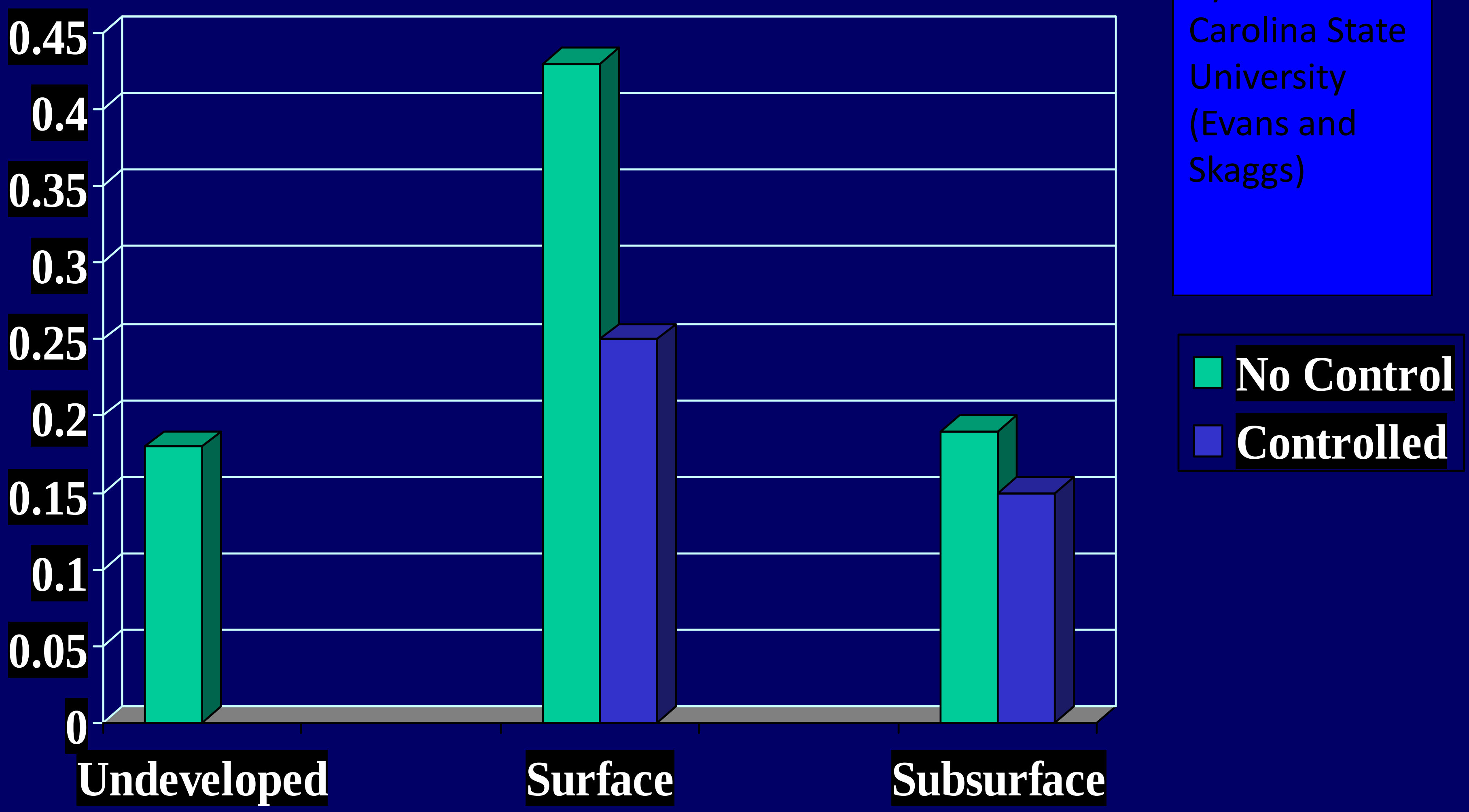
~30-60% reduction in annual drain flow

~30-50% reduction in annual nitrate load

~30-40% reduction in annual TP and DRP load

Provided by Jeff Strock

Average Annual TP Transport (#/ac)
12 Eastern NC Soils and Sites



Data provided by North Carolina State University (Evans and Skaggs)

Water Table Management

- reduced total phosphorus losses in NC by 35% (Evans et al., 1990)
- DRP losses reduced by 63% and TP losses by 50% in MN (Feser et al., 2010)
- 85% reduction in TP losses from small plots in Sweden (Wesstrom et al., 2001)

Surface Inlets

Traditional
Tile Risers

Rock Inlets

Rock inlets have been tested in other locales as an alternative to tile risers:

- Not very effective at decreasing contaminant loads
- Silt in with time
- Farm over them???

Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Alternatives to Tile Risers

- **Protect Lake Erie's water quality**
  - **Reduce <u>Sediment</u> & <u>Phosphorus</u> loads**
- **Must be a practice farmers will implement**
  - **Minimize loss of productive land**
  - **Allow farm traffic (don't like risers)**
  - **Minimal/easy maintenance**
  - **Approved for cost share**
  - **Effectively drain landscape**

Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Provided by Doug Smith
USDA-ARS, West Lafayette, IN

10’ x10’ Blind Inlet

Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Blind Inlet with riser alternate

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Blind Inlet with pit-run cover (coarse sand and gravel)

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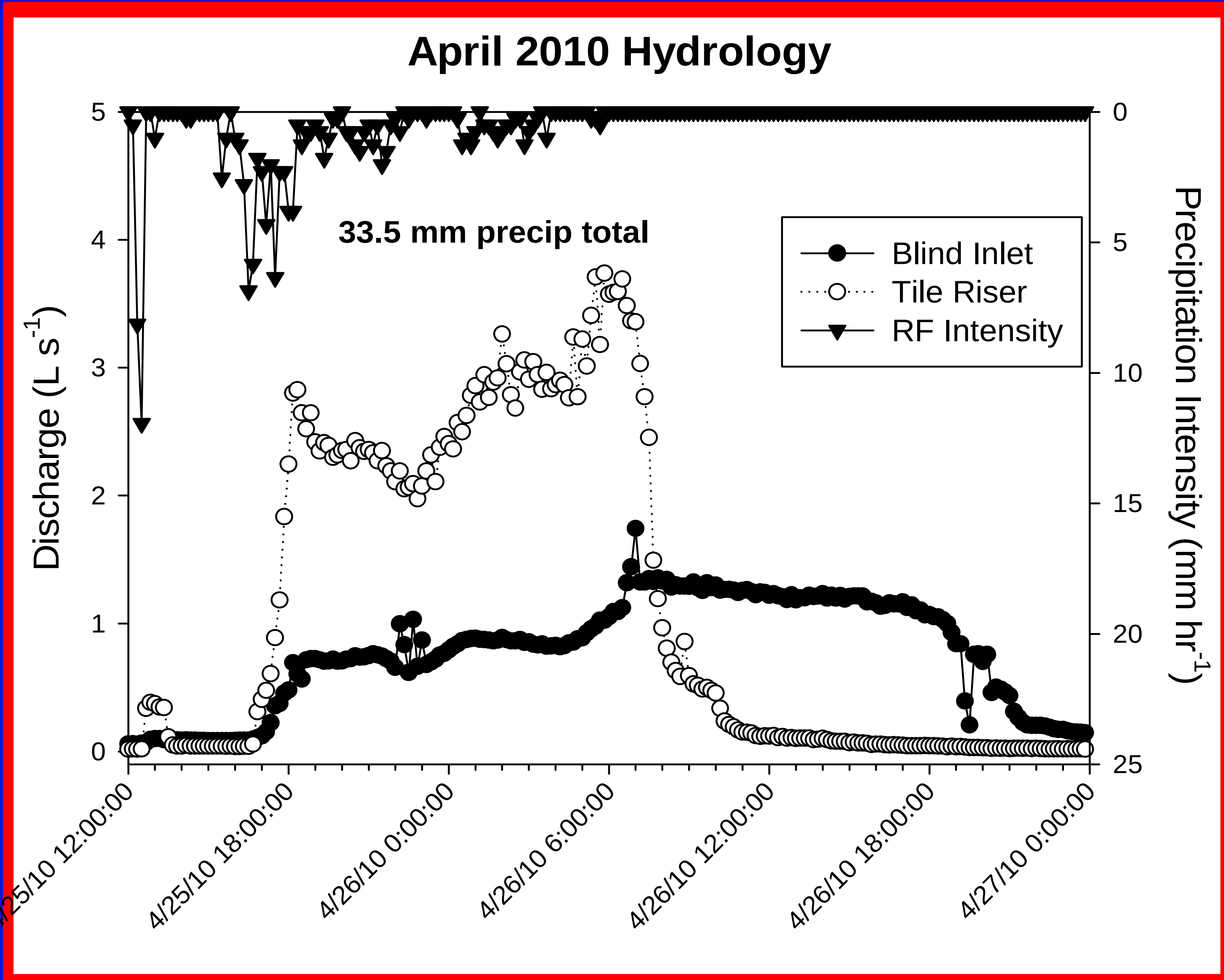

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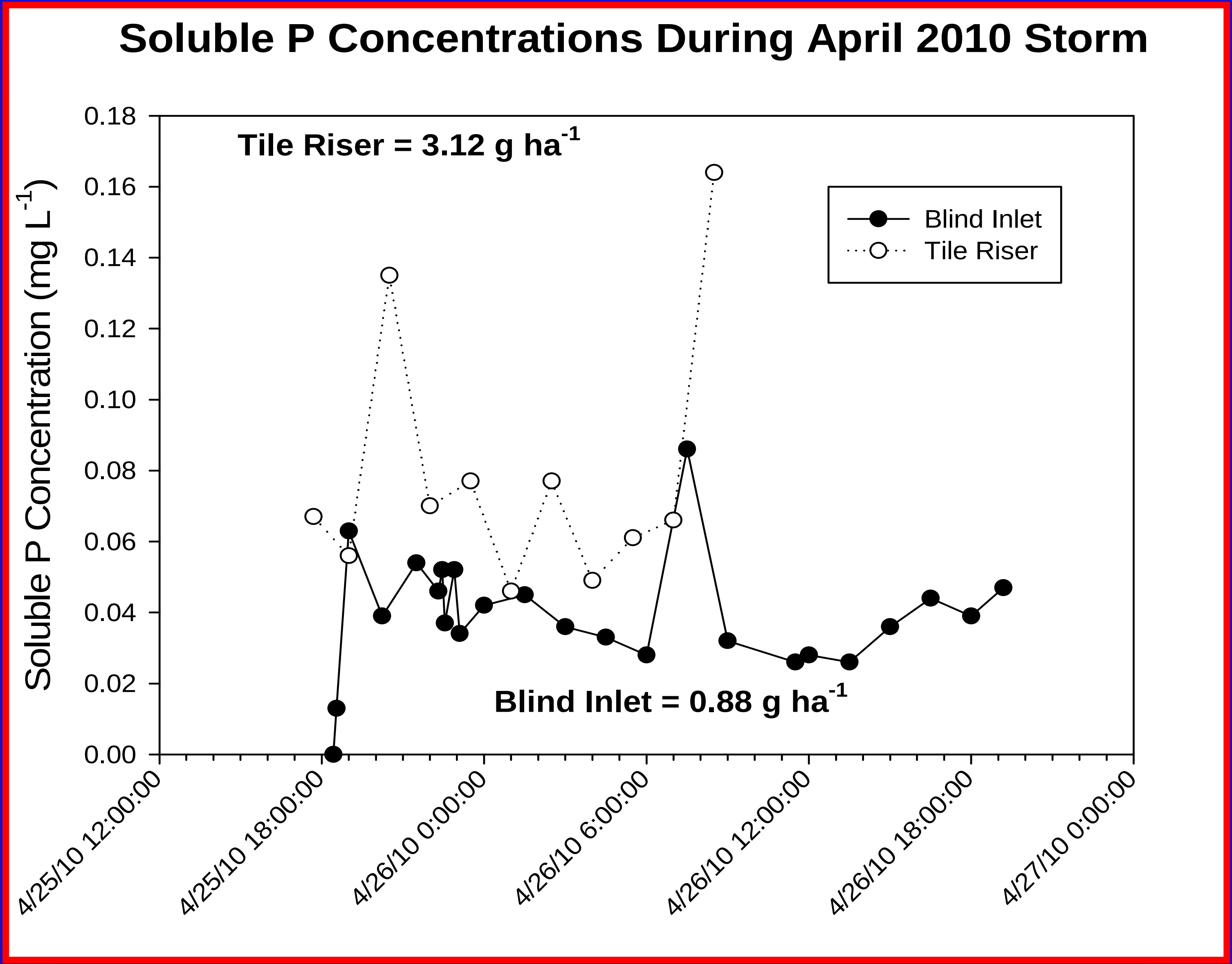

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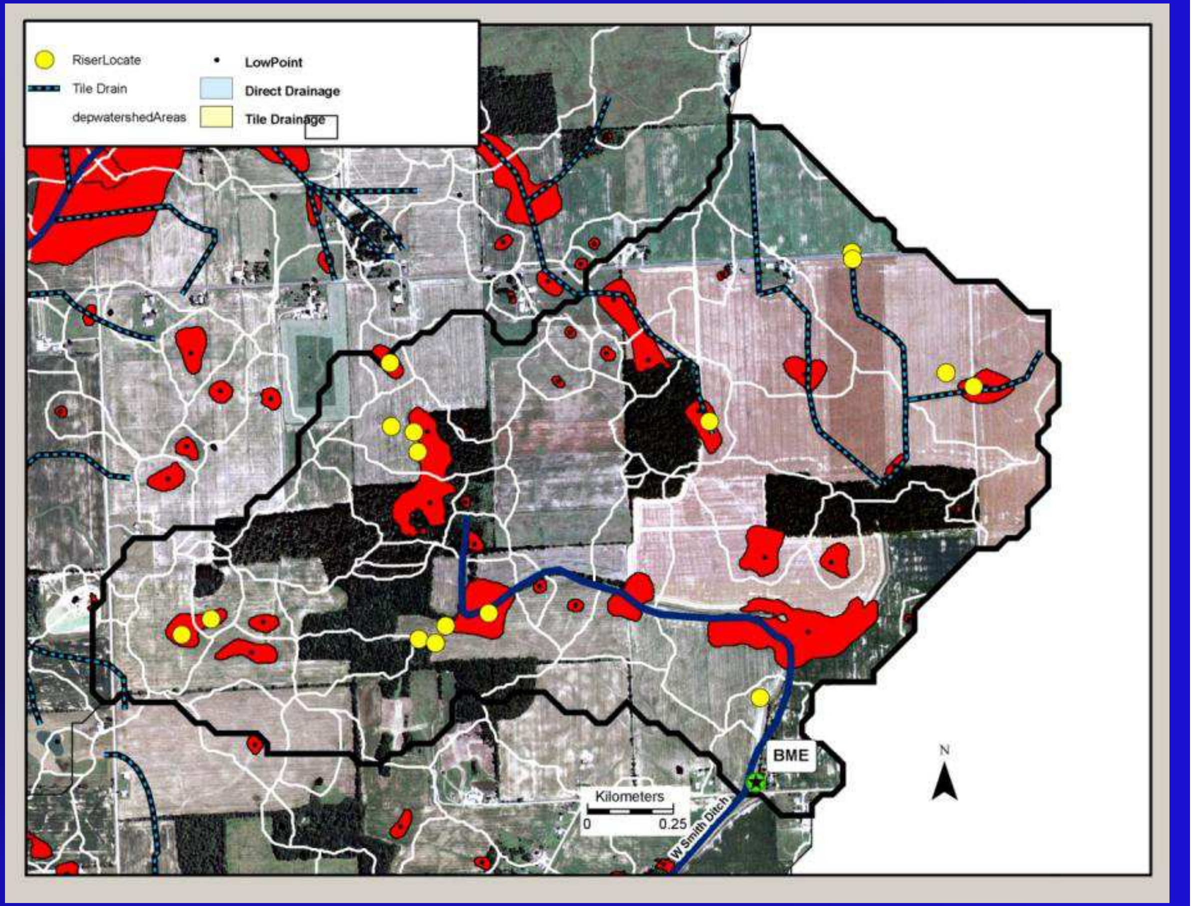
Percent Reductions in Sediment and Nutrient Loads: blind inlet vs tile risers

Nutrient	2009 % Reduction	2010 % Reduction
Sediment	11*	79
Ammonium-N	30	59
Nitrate-N	34% increase	24
Total Kjehldahl N	66	48
Soluble P	64	72
Total P	52	78

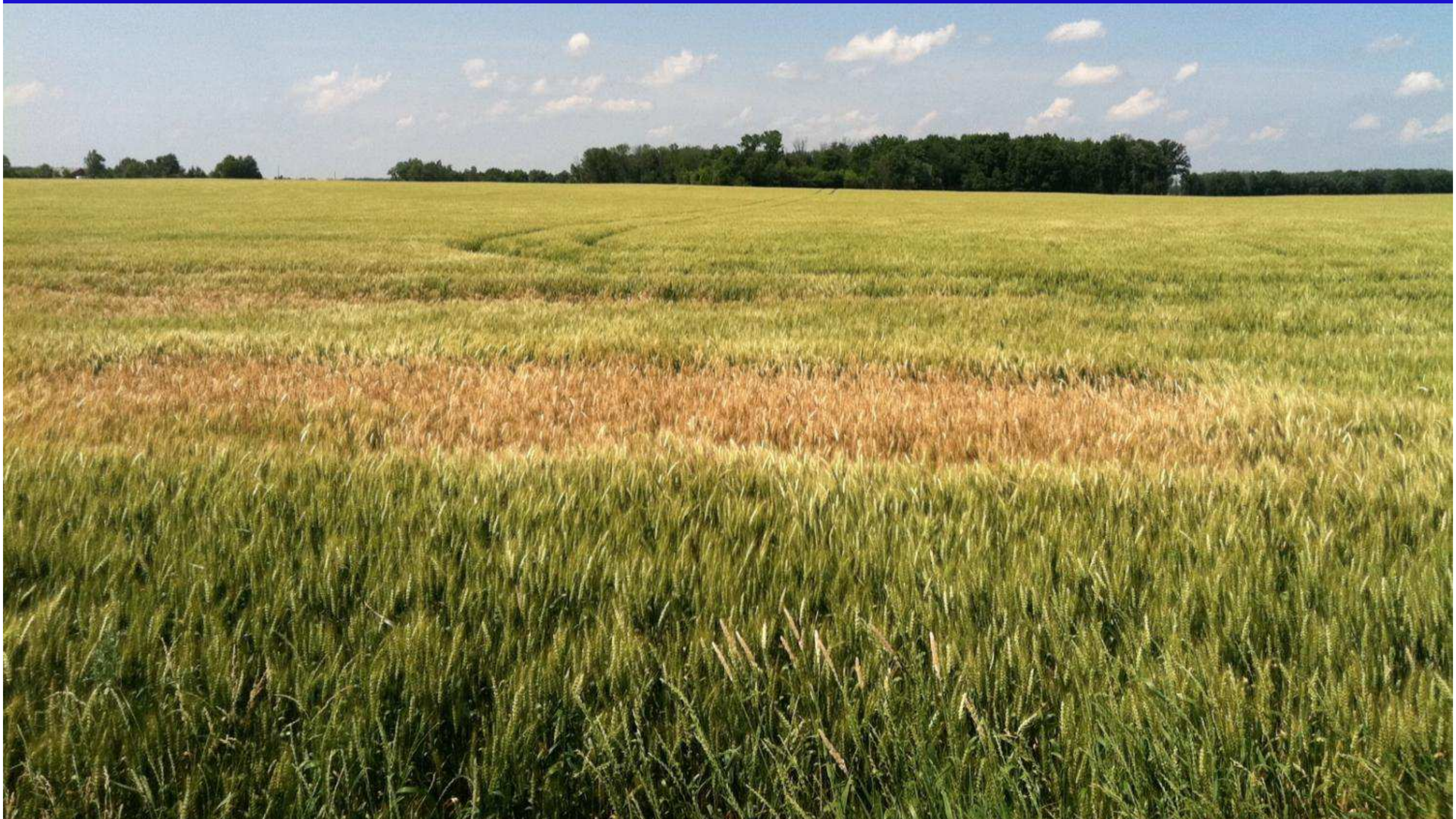
Watershed Scale Assessment

- Blanketed a 300 ha monitored watershed with blind inlets
- Work with Indiana NRCS for consideration as an approved conservation practice



Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Provided by Doug Smith
USDA-ARS, West Lafayette, IN



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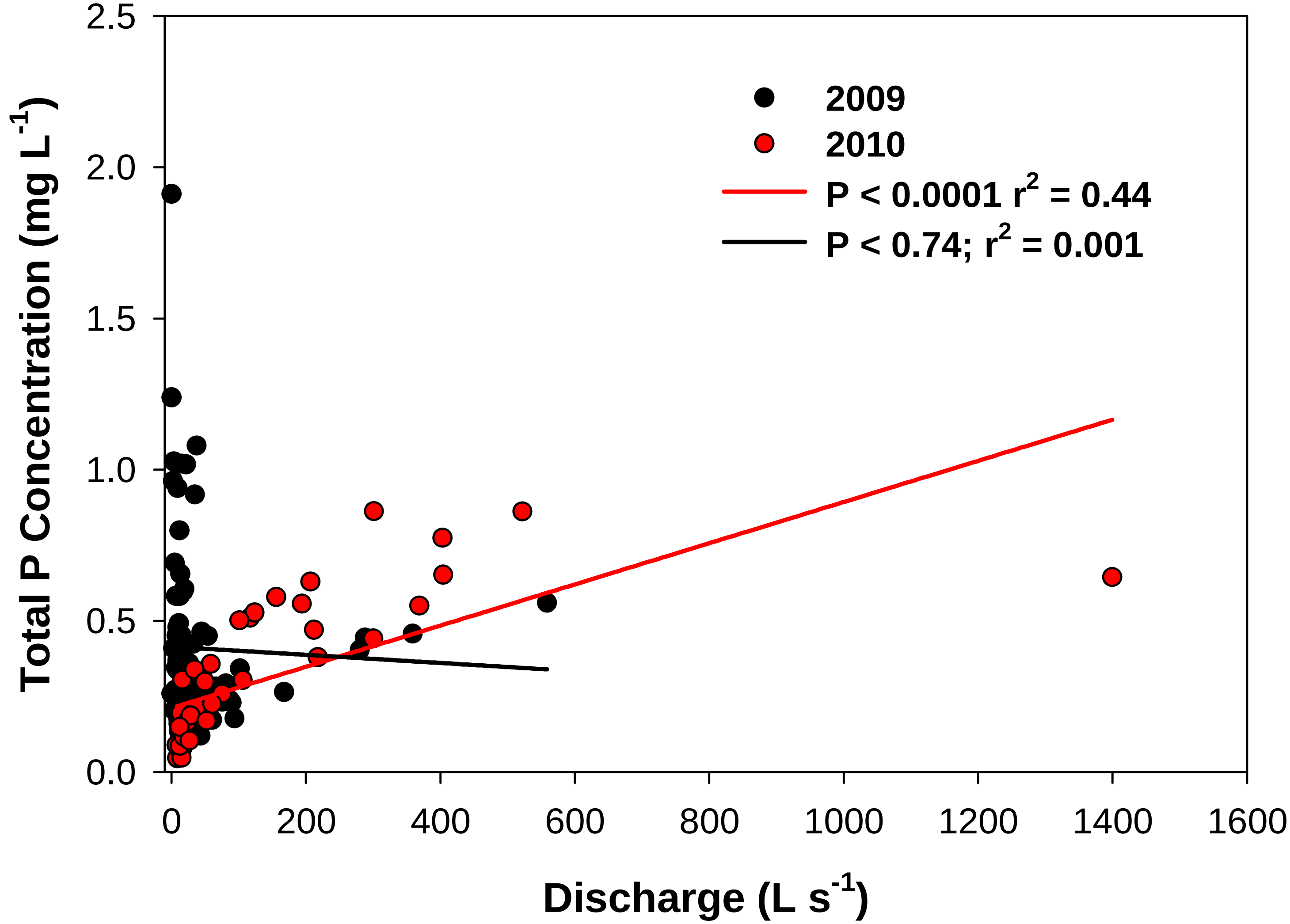
Total Phosphorus as a Function of Discharge Before (2009) and After (2010) Watershed Installation of Blind Inlets



Provided by Doug Smith
USDA-ARS, West Lafayette, IN

Conclusions – Blind Inlets

- Distant fields with risers are directly connected to streams.
- Blind inlets reduce connectivity of contaminants
- Breaking connectivity appears to decrease TP loading to streams during runoff events

Provided by Doug Smith
USDA-ARS, West Lafayette, IN

In-Stream and End-of-Tile Treatments

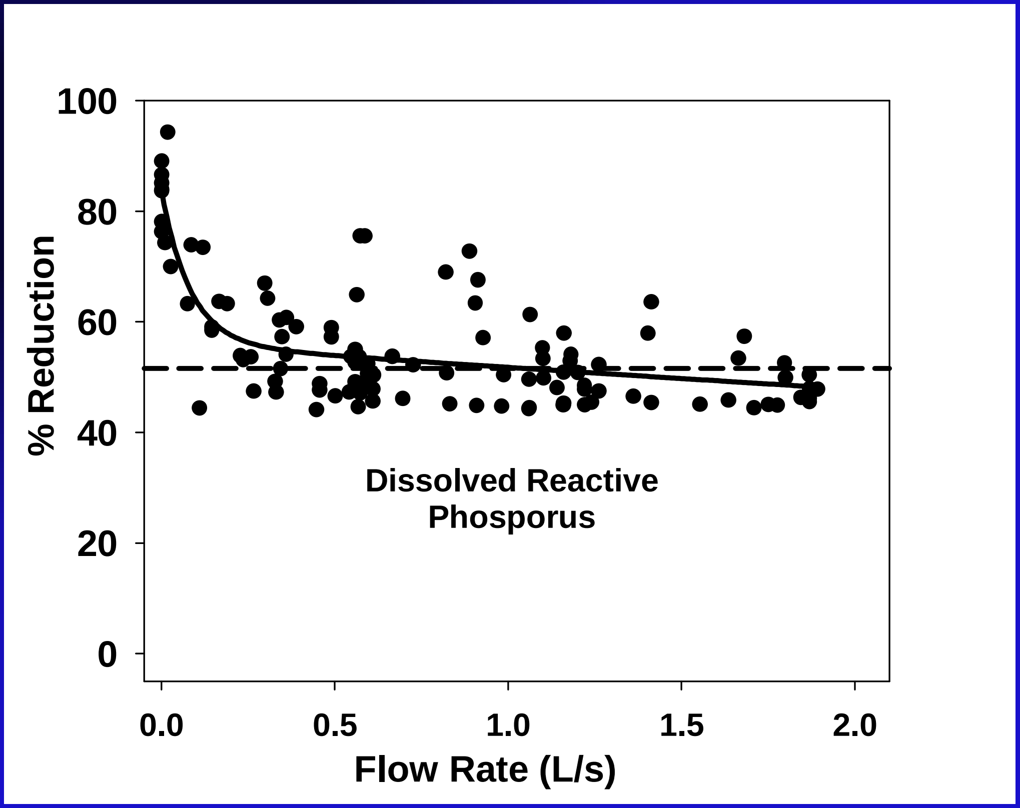
End-of-Tile Filtration

Laboratory and Field Results

- 50% reduction in DRP concentrations and loads across 3 flow rates

Constraint(s)

- Flow Rates



Ditch filter # 1

Provided by Peter Kleinman
USDA-ARS, State College, PA

Ditch Filter #2 (Gypsum filter)

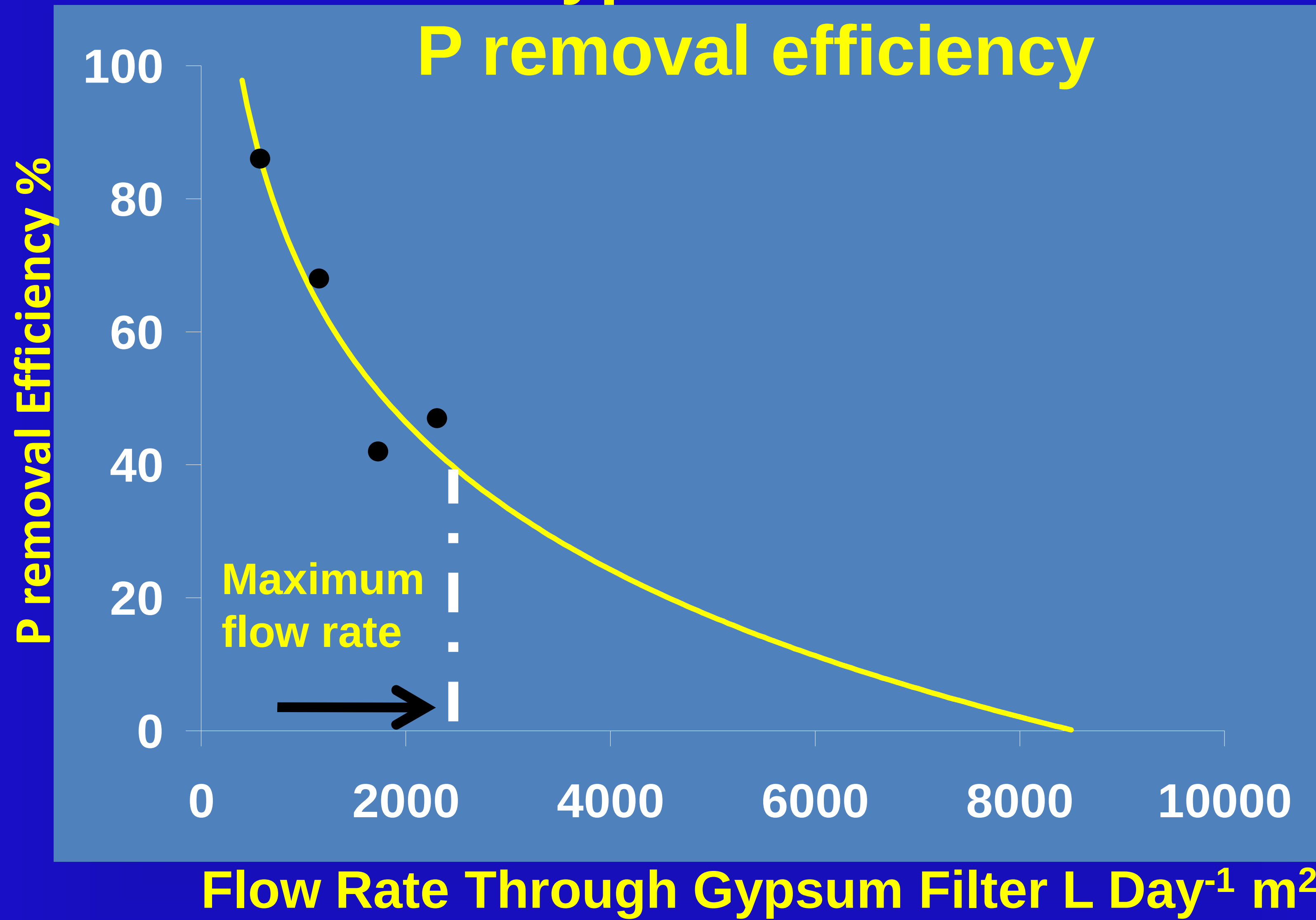
Provided by Peter Kleinman
USDA-ARS, State College, PA

In-Ditch Filtration

- Can use industrial waste materials to help remove contaminants
- Treating ditches may have benefits to fields, since multiple fields drain into ditches
- Works best during small storms (bypass flow during big storms)

FGD Gypsum Ditch Filter

P removal efficiency



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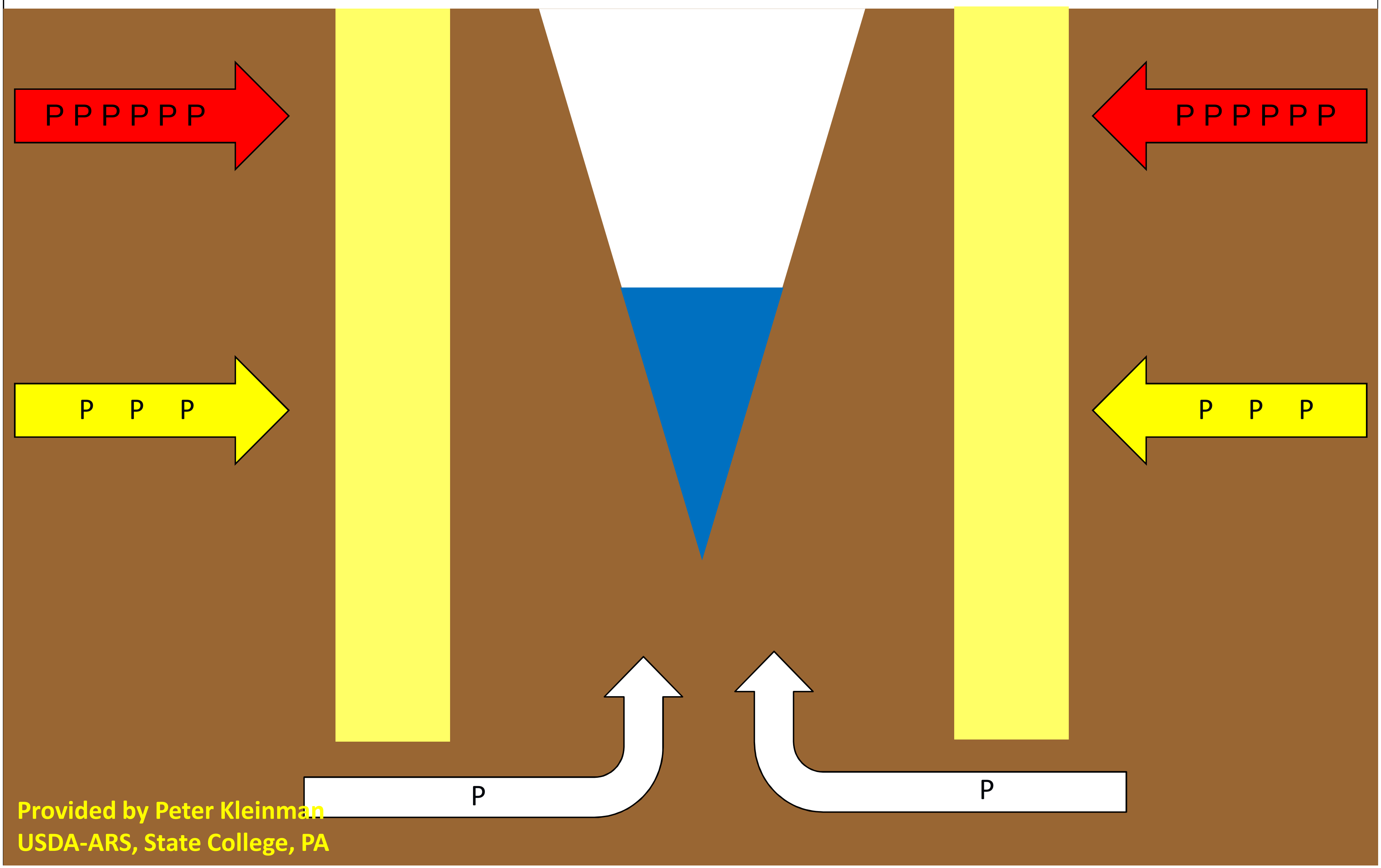
USDA-ARS, State College, PA

Gypsum Curtains




Provided by Peter Kleinman
USDA-ARS, State College, PA
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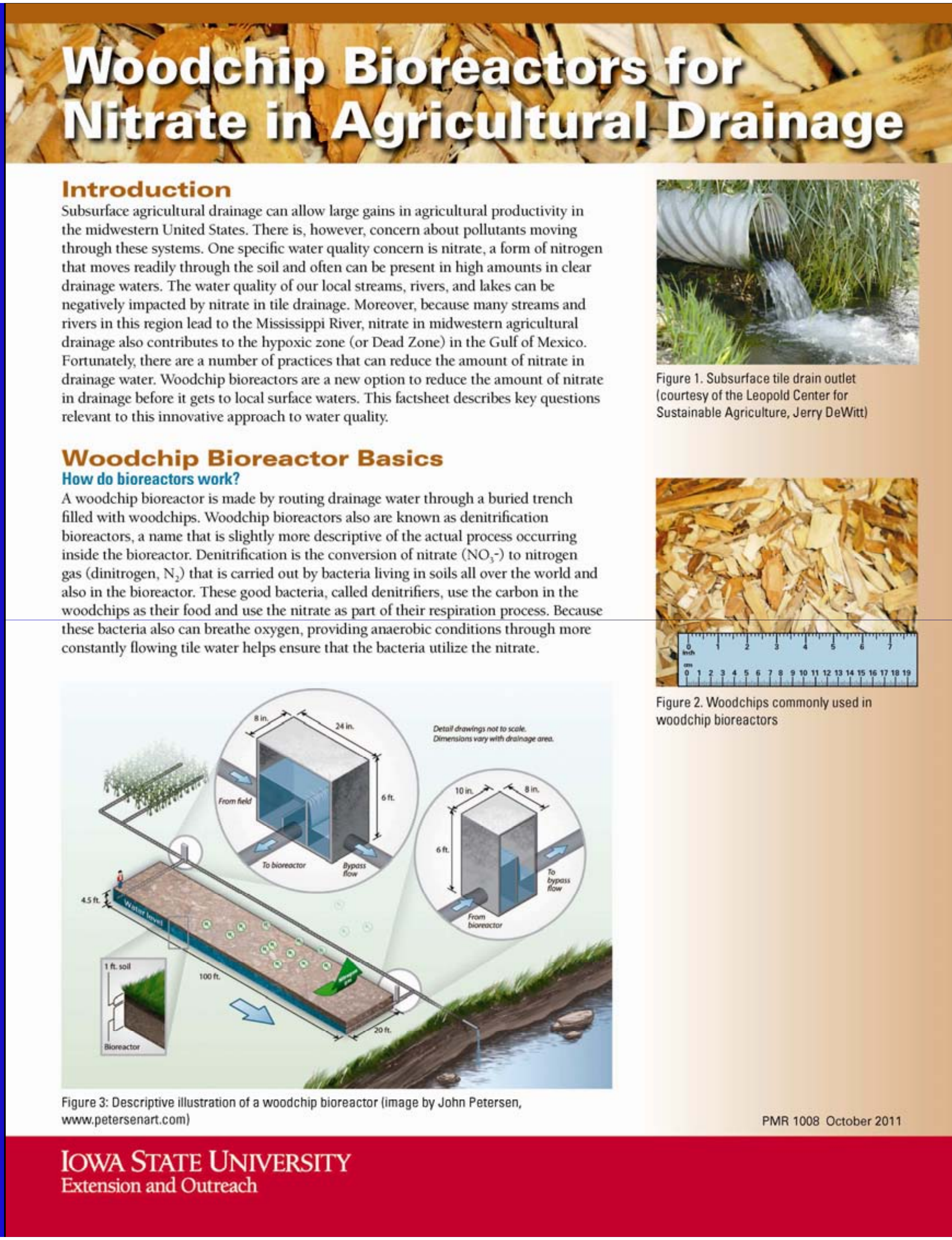


Woodchip Bioreactors for Nitrate in Agricultural Drainage

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.

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

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 2. Woodchips commonly used in woodchip bioreactors

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

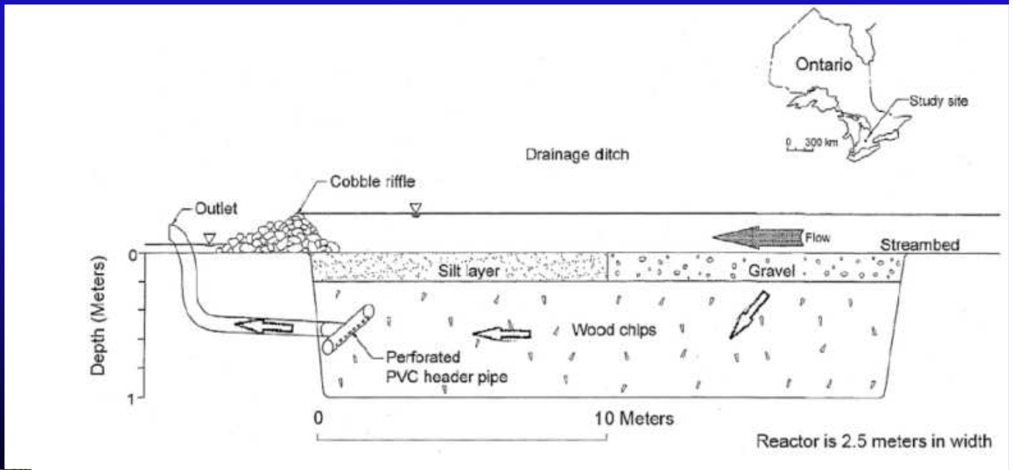
PMR 1008 October 2011

IOWA STATE UNIVERSITY
Extension and Outreach

New Bulletin on Woodchip Bio-reactors from Iowa State University

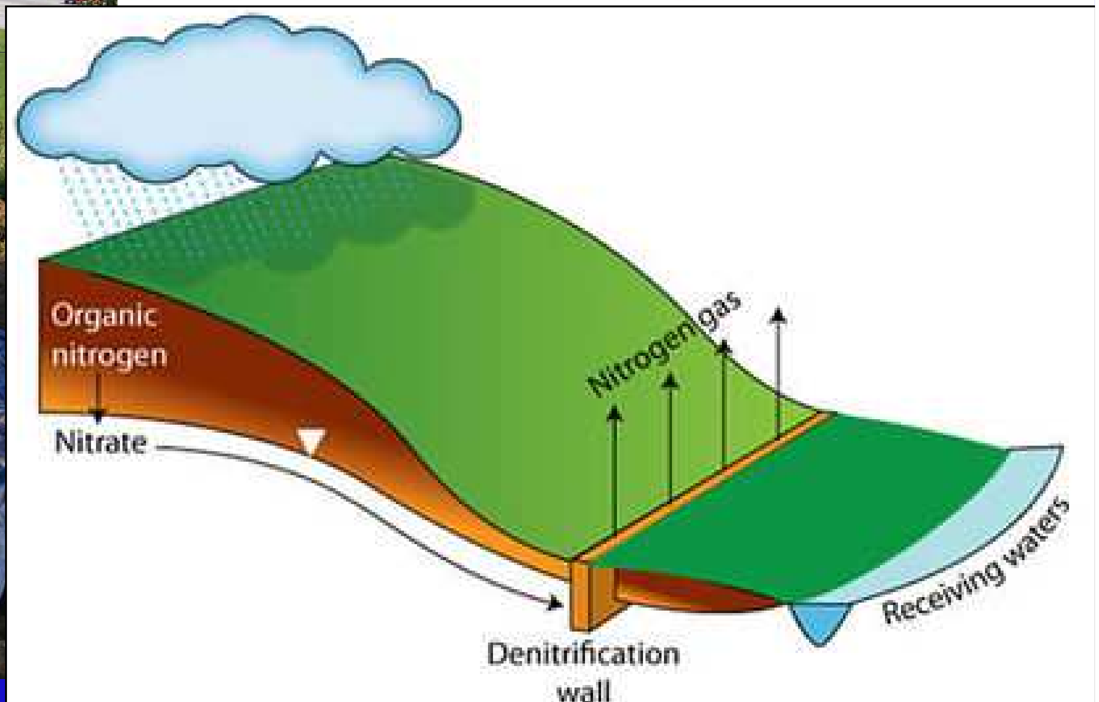
Denitrifying Bioreactors

1. Streambed (in-stream) bioreactors
2. Denitrification Wall
3. Denitrification Bed



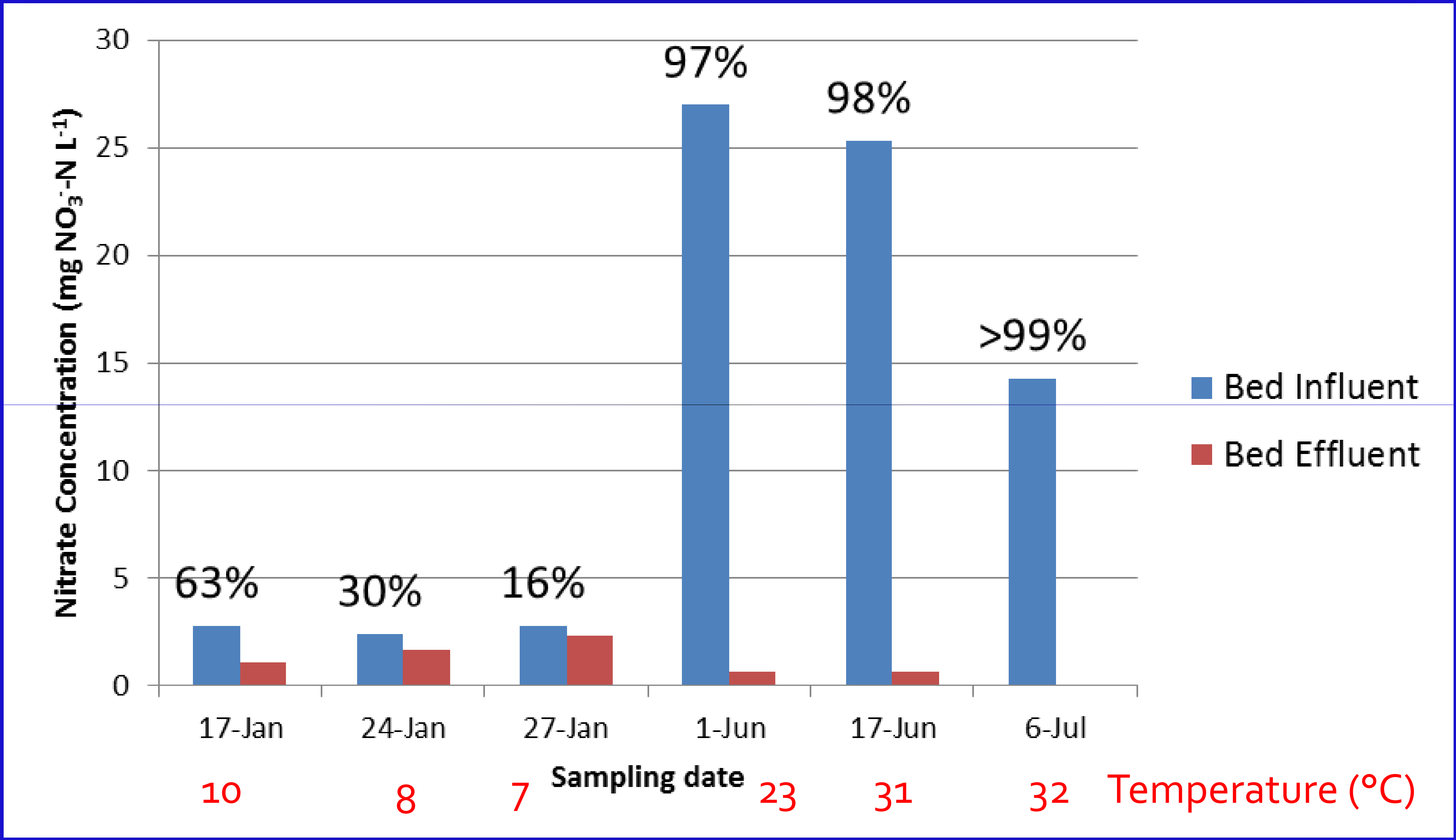
. 1. Design sketch of Avon streambed bioreactor (adapted from Robertson and Merkley, 2009).

Provided by Ehsan Ghani
Ohio State Univerisity



Schipper, Uni. of Waikato, New Zealand

Nitrate-N Concentration Percent Reduction



Provided by Ehsan Ghani
Ohio State Univerisity

In-stream or end-of-tile treatment Summary

- approximately 70% reduction in DRP over 2 years in New Zealand (McDowell et al., 2008)

- > 70% of DRP in milkhouse wastes removed with steel slag (Bird and Drizo, 2010)

- DRP concentrations reduced by 50 to 99% using in-stream gypsum (Penn et al., 2010)

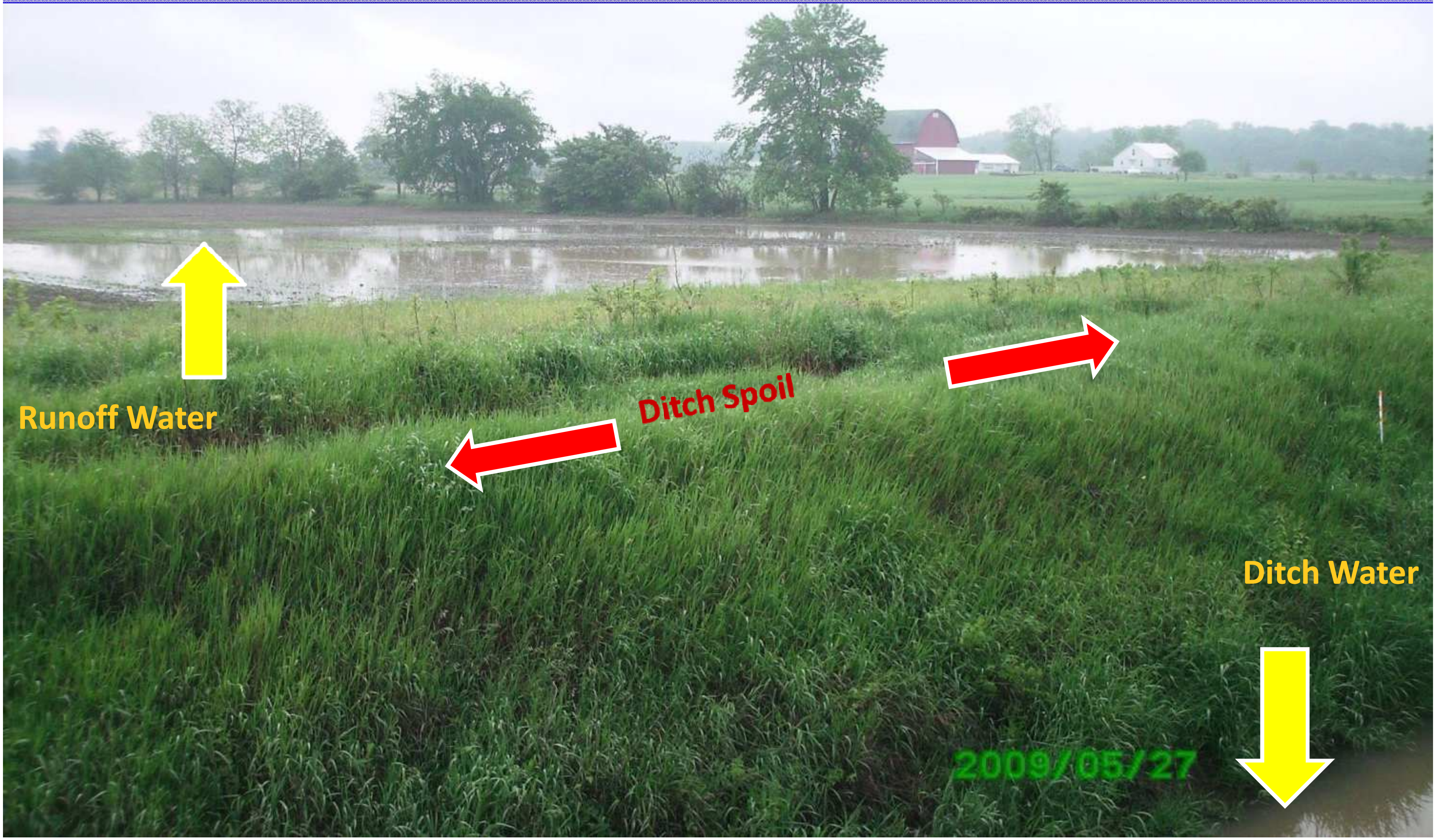
- 50% reduction in DRP concentrations and loads using end-of-tile filters (King et al., 2010)

- bioreactors enriched with steel slag (Brown et al., in progress)

- flow rate is limiting factor both in-stream and end-of-tile systems

Buffers

Ditch Spoil Blocks Flow to Drainage Ditch



Ditch Buffers

Vegetative buffer strips often placed adjacent to ag ditches

- Spoils are not removed
- No direct flow-path
- VBS *does not* diffuse concentrated flow
- DOES serve as a setback
- Who (Producer/Drainage board/Contractor) is responsible for dredged spoils?

Ditch Buffers

Photo taken ~100 ft looking upstream from previous photo

- Spoils removed
- There IS opportunity for filtration in these VBS's
- Corridor wide enough that we see slumps in the bank, so the channel is migrating toward a natural stream

Buffers (wooded, vegetative, and no buffers)

Objective

Compare nutrient concentrations in ditches/streams within the UBWC that have forested buffers, herbaceous buffers, and no buffers adjacent to them in an effort to evaluate if grassed buffers are an appropriate alternative to forested buffers for reducing nutrient losses

Experimental Design

- Three channelized streams without herbaceous riparian buffers

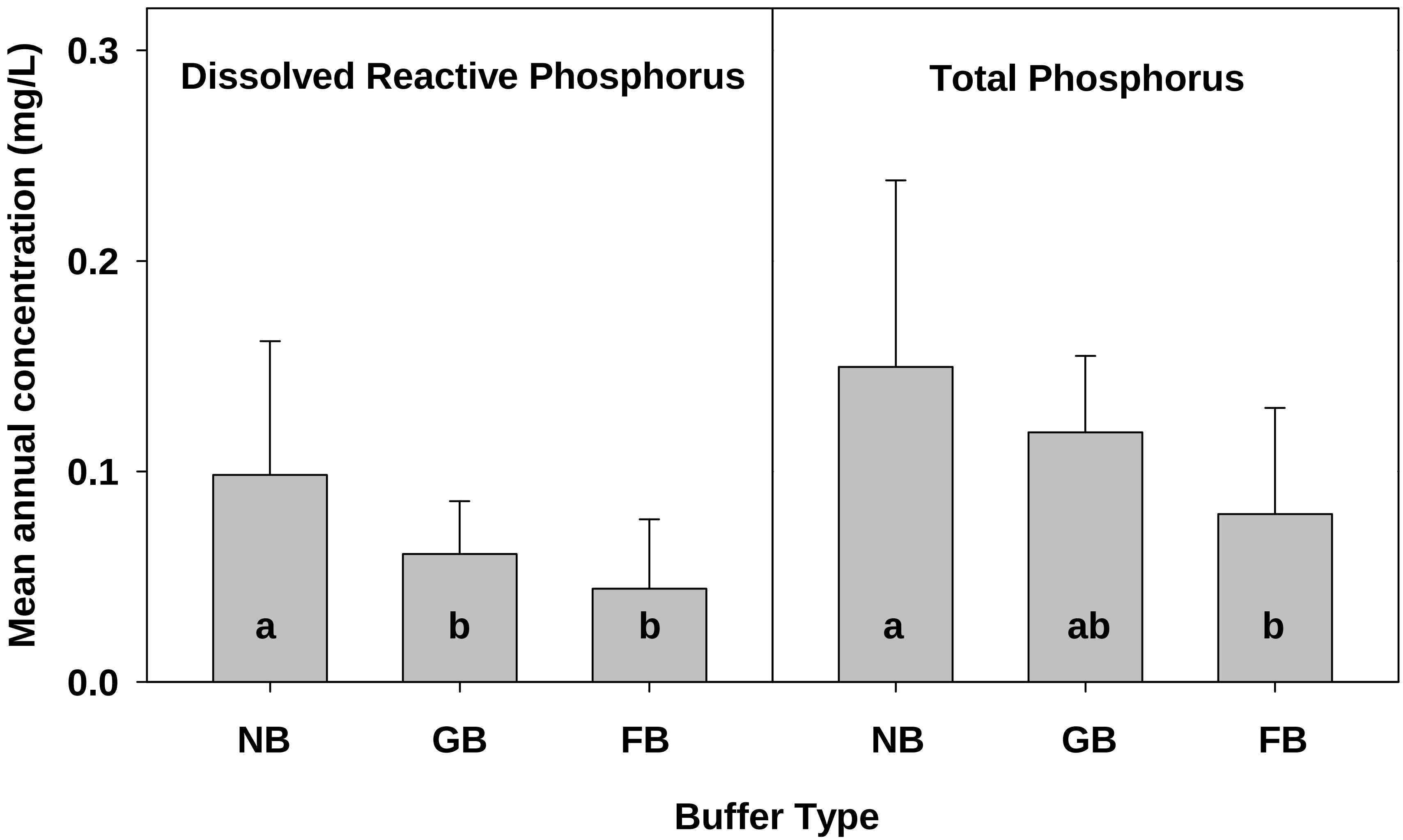
- Three channelized streams with herbaceous riparian buffers installed between 2003 and 2005

- Two unchannelized streams with remnant forest buffers.

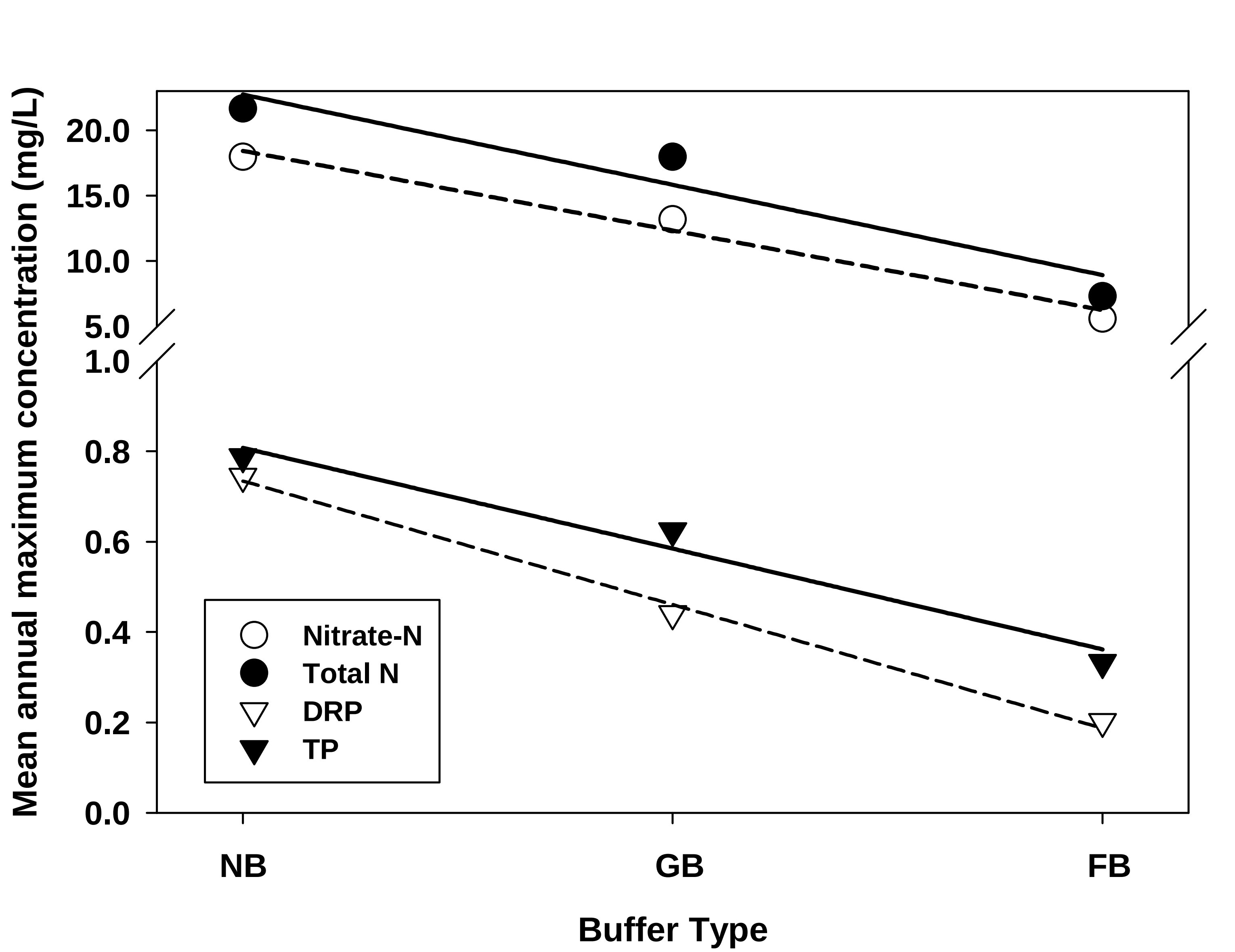
Sampling

Study period – 2006 through 2010

Weekly grab samples from center of stream



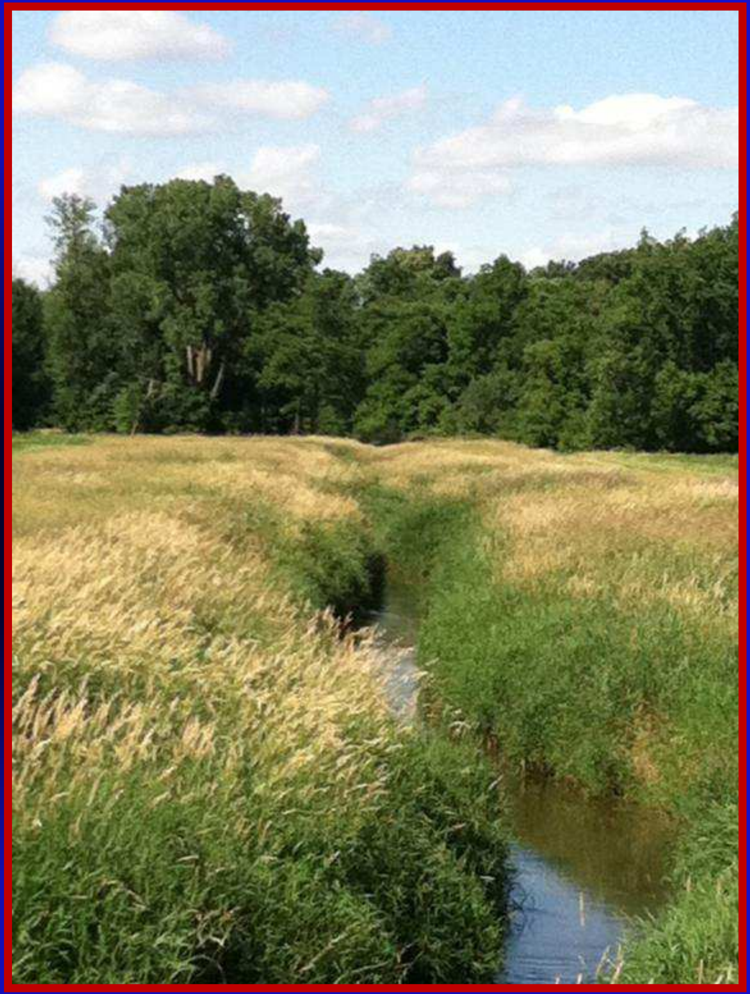
Mean annual (2006-2010) stream side nutrient concentrations for dissolved reactive phosphorus and total phosphorus for streams with no buffers (NB), grassed buffers (GB), and forested buffers (FB). Letters inside each box indicate significance; boxes with different letters indicates that mean values are significantly ($p < 0.05$) different.



Relationship between mean annual (2006-2010) maximum concentrations and buffer type.

Conclusions - Buffers

- Many buffers along streams serve predominately as setbacks
- Current buffering in Indiana watershed reduces TP loading by ~8% but could increase to 50% reduction if all field buffered (Mega $$$)
- FB>GB>NB
- Primarily addresses surface transport



Wetlands

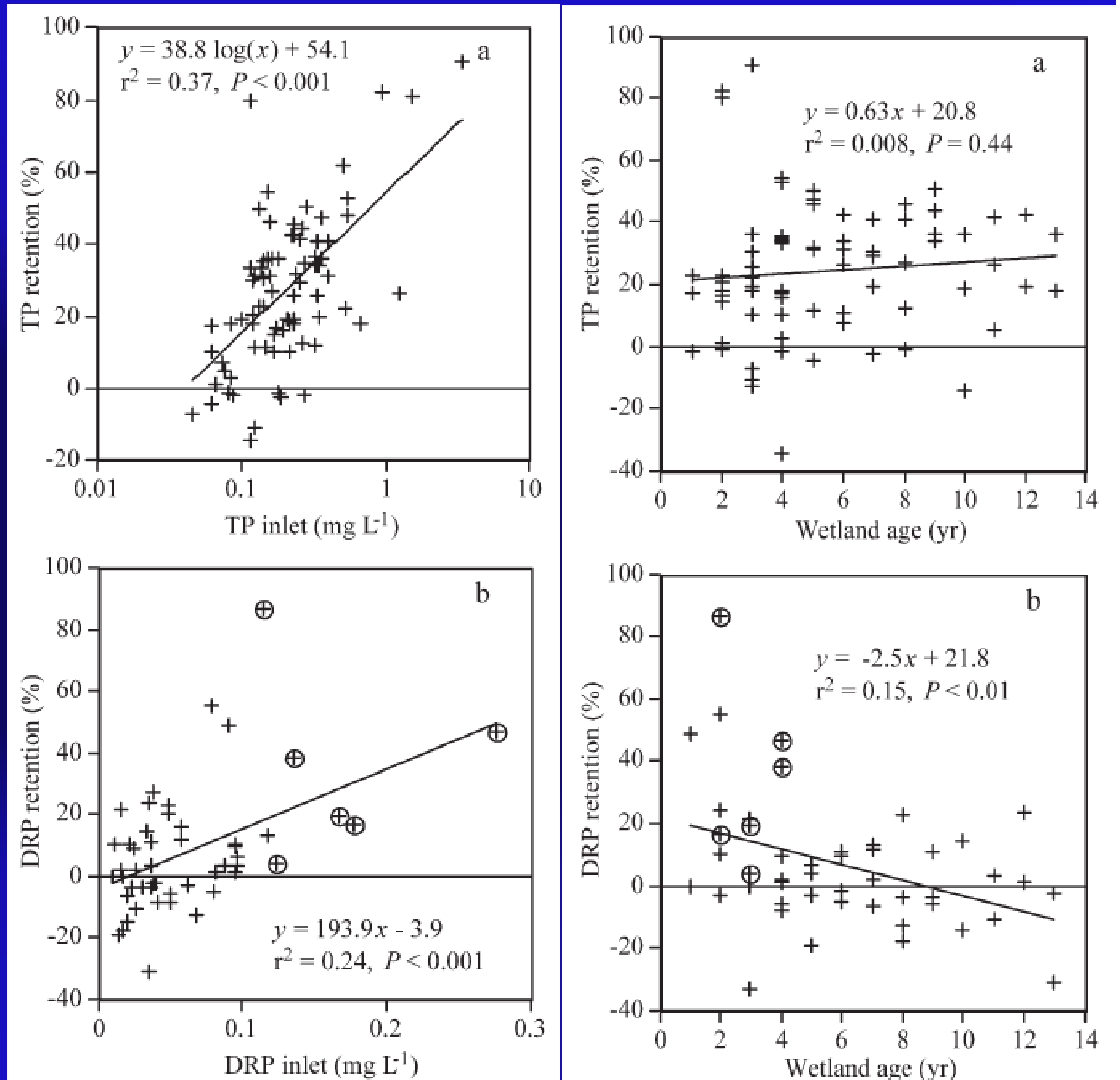
Braskerud et al. (2005):

- 17 constructed wetlands
- Sweden, Norway, Finland, Switzerland, USA (Illinois)
- Surface area (400 to 10000 m^2)

Dunne et al. (2007)

- Lake Apopka, FL
- Series of wetlands
- 0.9 g /m2/yr removal
- Approx. 28% removal efficiency

- Limited in addressing large flows



Ditch Design and Management

Nutrient Reductions in Vegetated Drainage Ditches

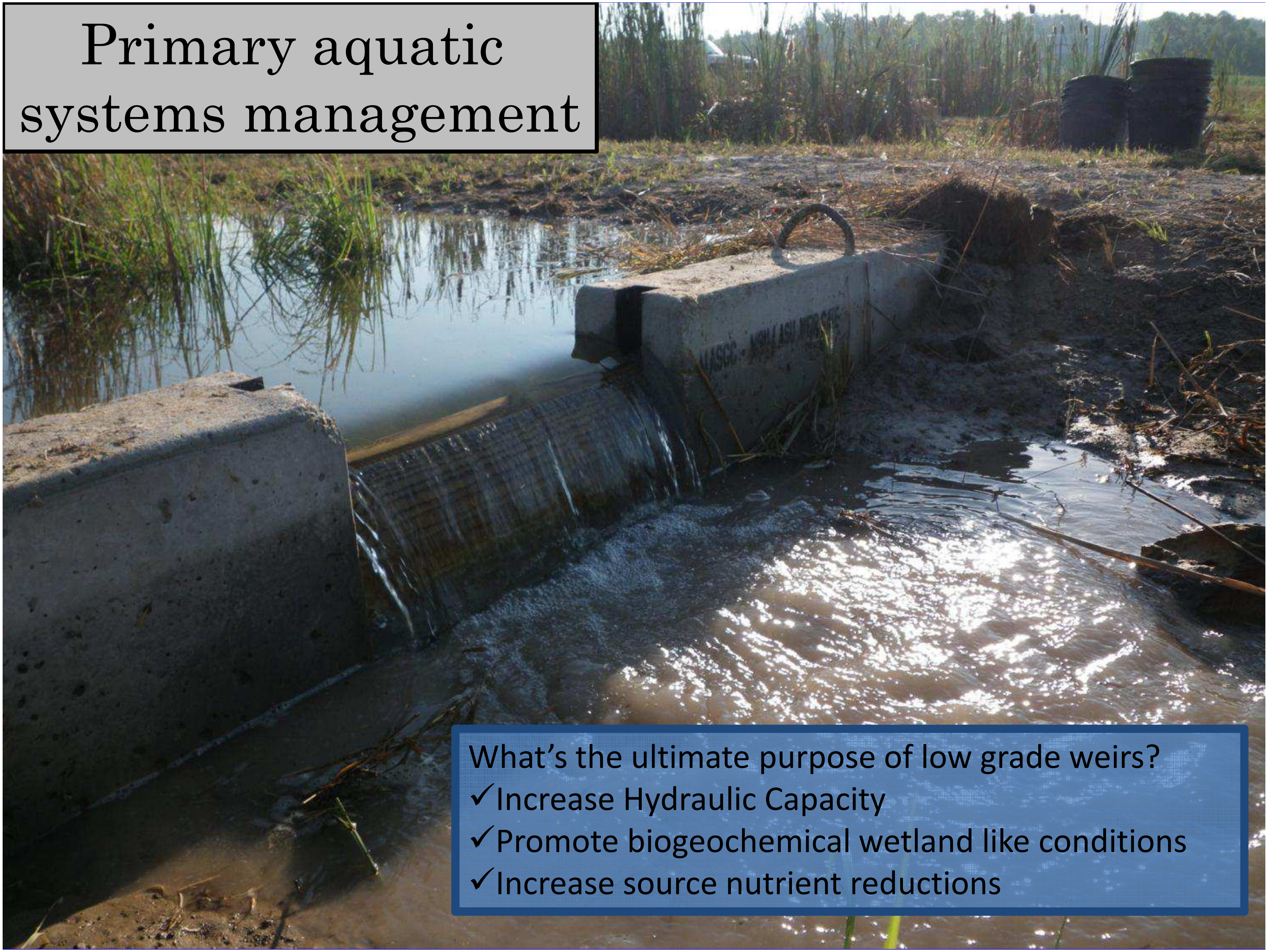
Over 2 years from cotton fields:
Phosphorus: 43% of dissolved P
and particulate / total P

Water / nutrient / sediment mixture amendment flow:
600 gallons/minute for 7 hr

	Load Reduction (%) Vegetated
DIP	99
TOP	60
TP	86

Provided by Robbie Kroger (MSU)

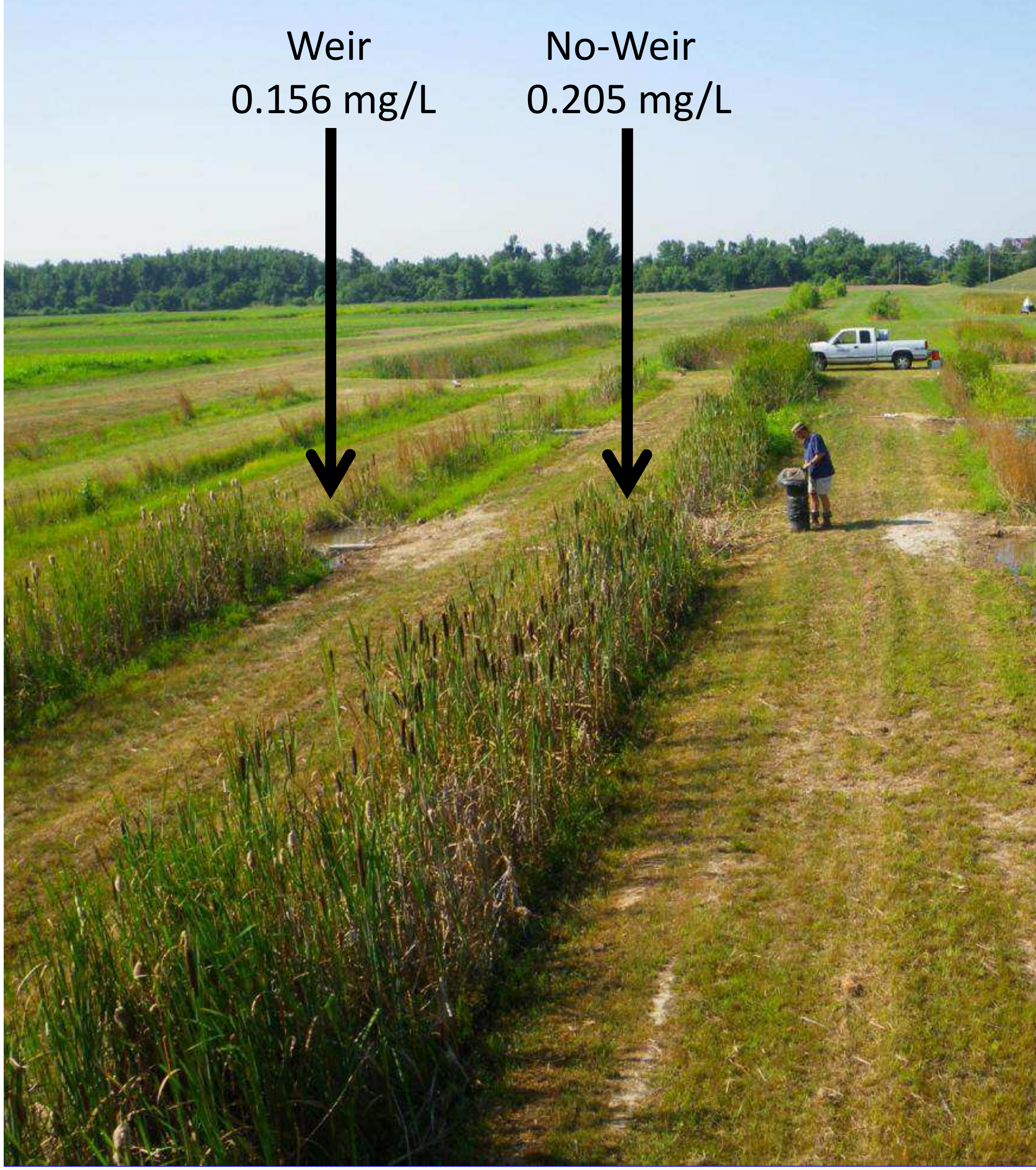
Primary aquatic systems management

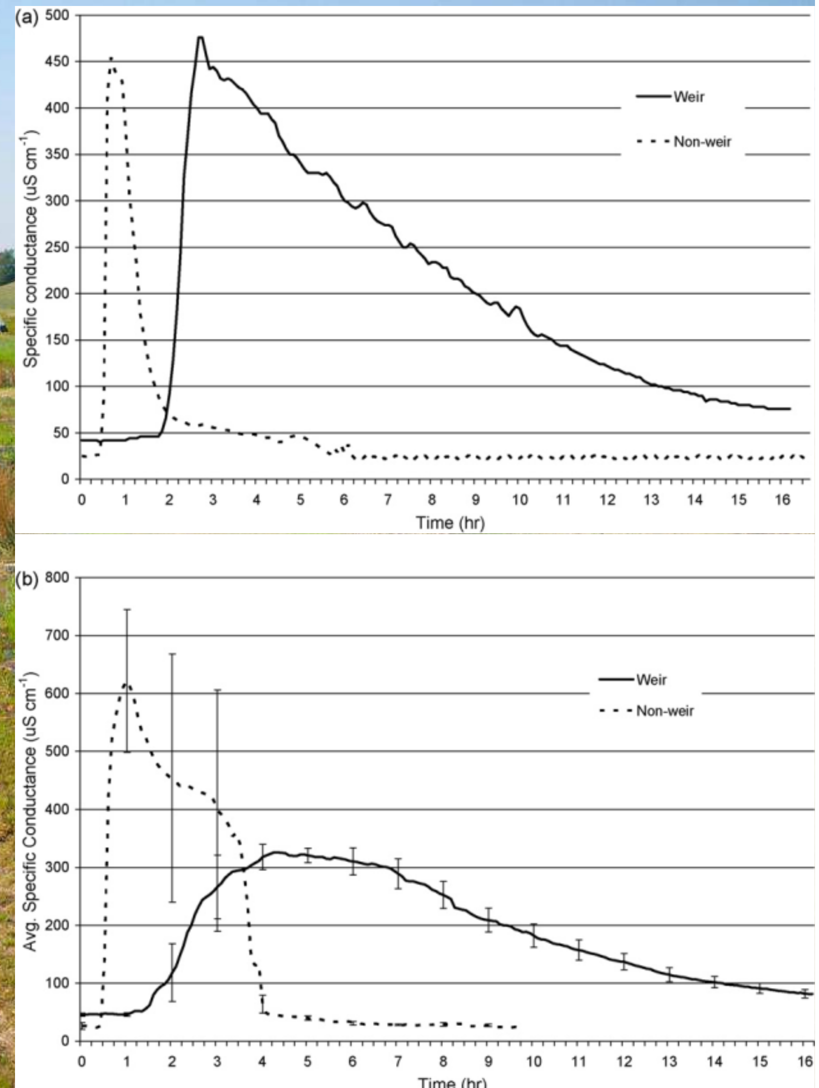


What’s the ultimate purpose of low grade weirs?

- ✓Increase Hydraulic Capacity
- ✓Promote biogeochemical wetland like conditions
- ✓Increase source nutrient reductions

Repeated Measures: significant time x treatment interaction ($F=3.285$; $P=0.042$)
Significantly higher concentrations in no-weir treatments ($P = 0.001$) at t = 120mins





Agricultural Ditch Design Approaches

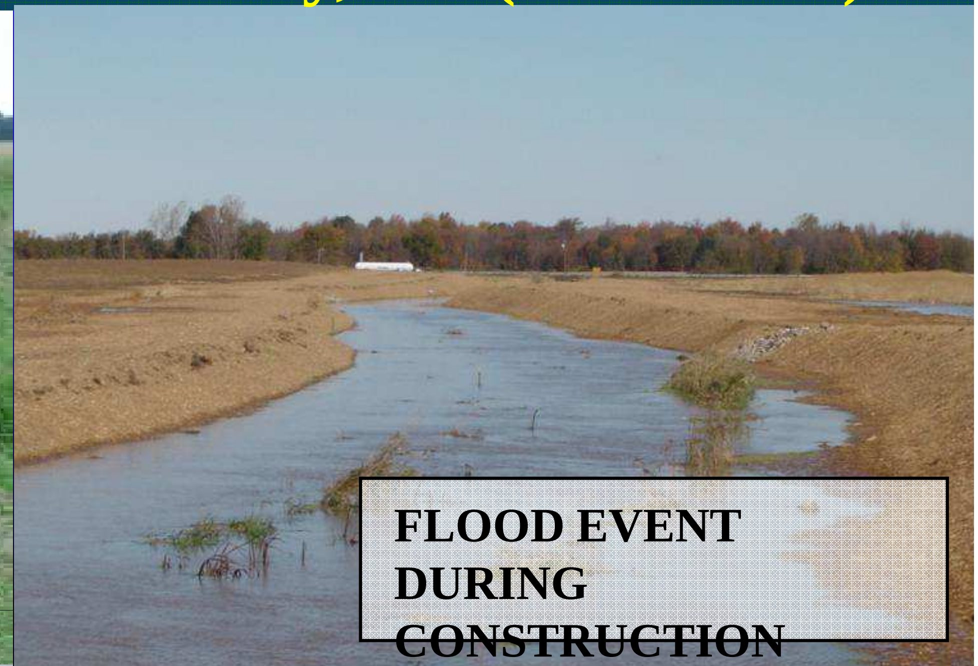
Trapezoidal Design

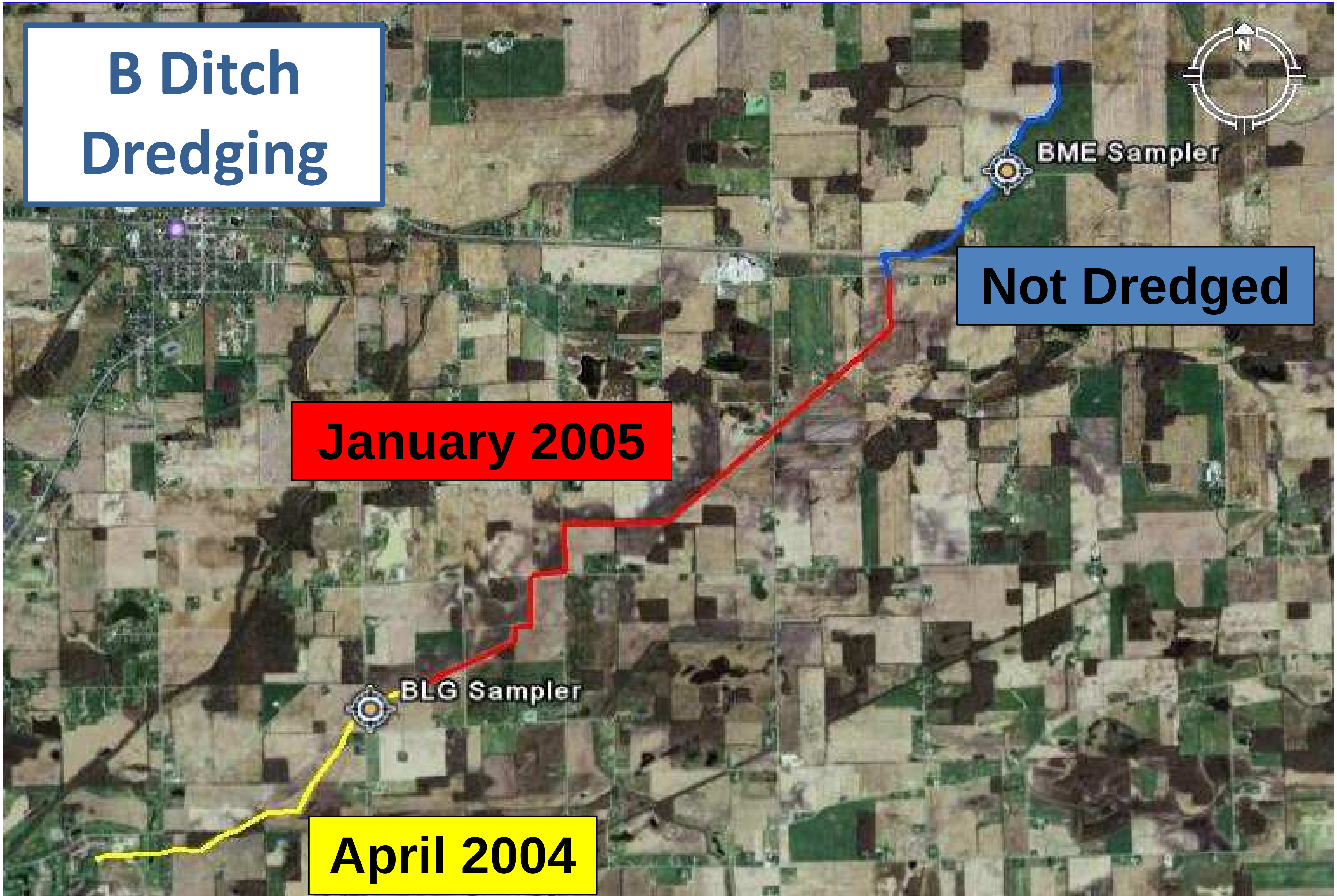
Two-Stage Design

Self-Forming Design

Provided by Jon Witter
Ohio State Univerisity

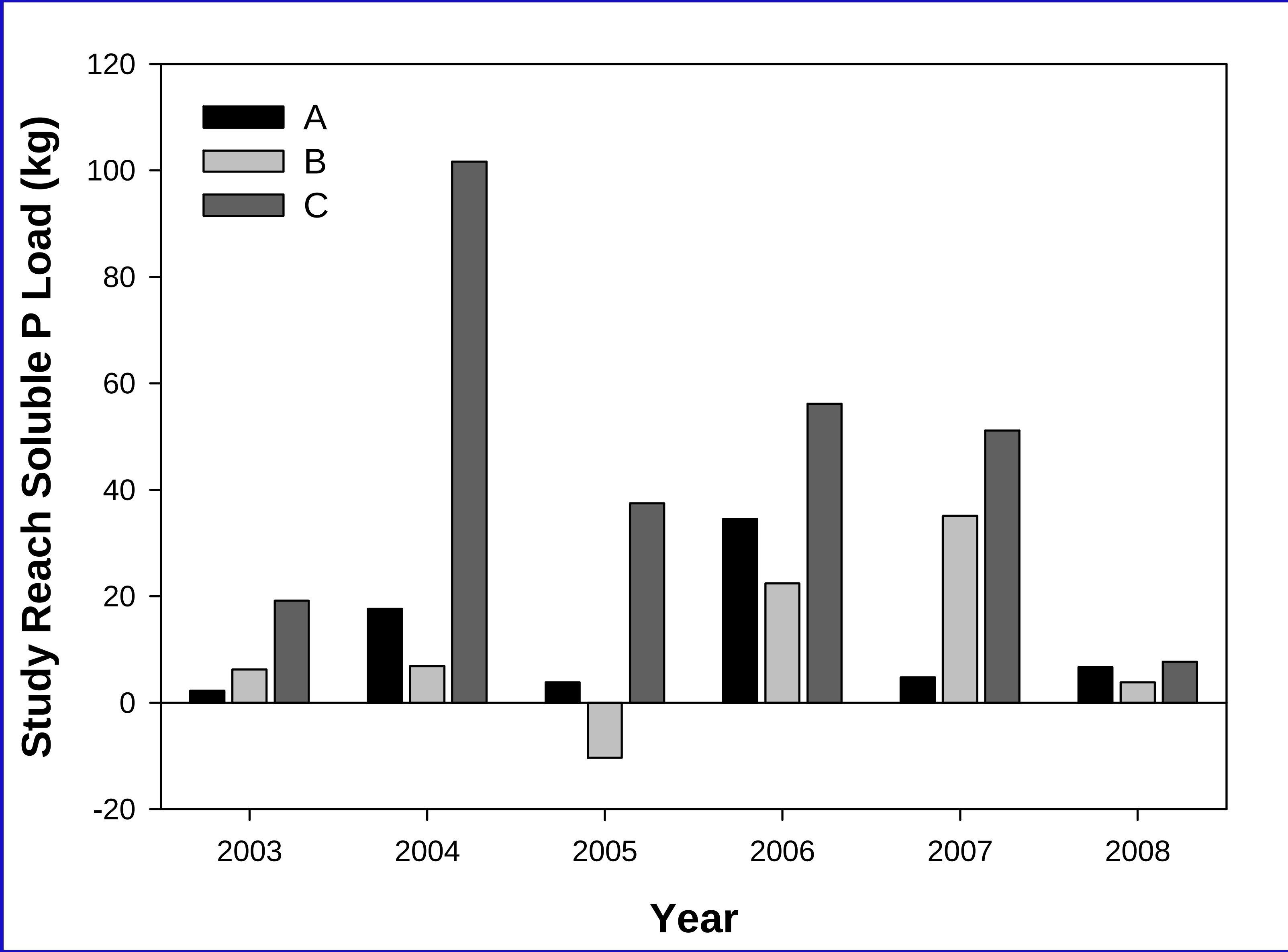
6 - Crommer Ditch, Hillsdale County, MI (Built 2003)





Provided by Doug Smith
USDA-ARS, West Lafayette, IN

In-situ P loads for monitored study reaches



Provided by Doug Smith
USDA-ARS, West Lafayette, IN

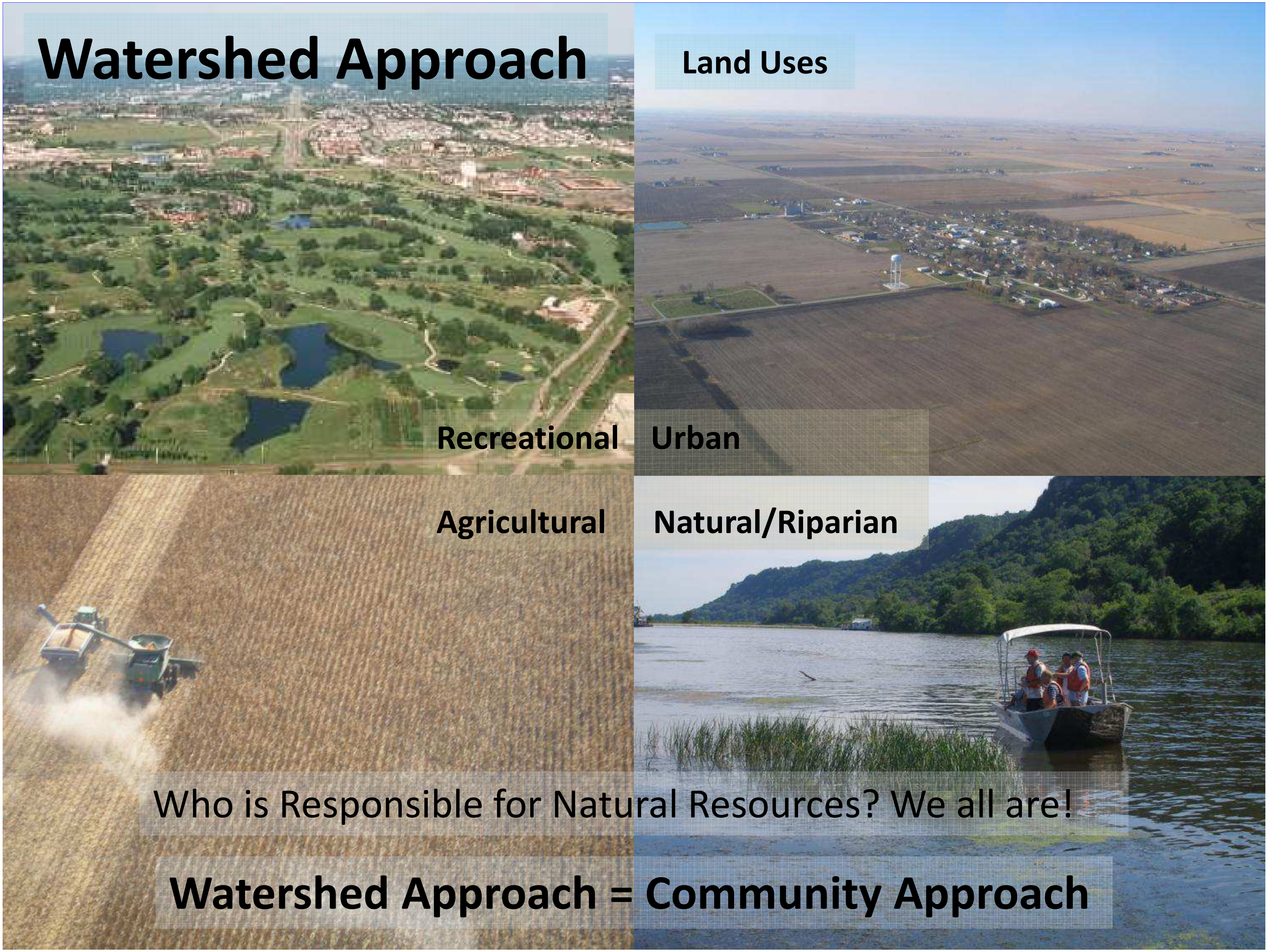
Ditch Design Summary

- vegetated drainage ditches or linear wetlands reduced DRP in growing season by 61% in MS (Kroger et al., 2008)

- two-stage and self-forming ditches (Powell et al., 2006)
  - promote interaction with the floodplain (Powell et al., 2007)
  - promote denitrification in the benches (Roley et al., 2011) suggesting may serve as a phosphorus sink, especially for particulate P (no research on soluble P)

- dredging reduced intermediate (approx 1 year) term total and soluble P losses (Smith and Huang, 2010)

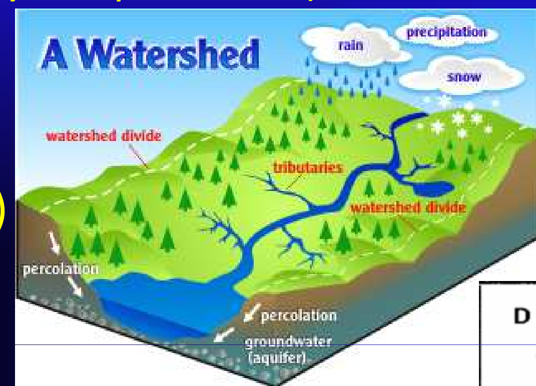



Watershed Approach
Land Uses
Recreational
Urban
Agricultural
Natural/Riparian
Who is Responsible for Natural Resources? We all are!
Watershed Approach = Community Approach

What Determines Watershed Condition and Response?
How Do We Measure and Monitor?
How Do Watersheds Function to Transport and Process Pollutants?

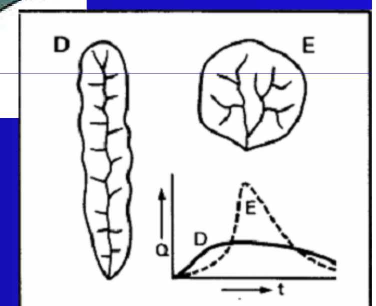
Uniqueness

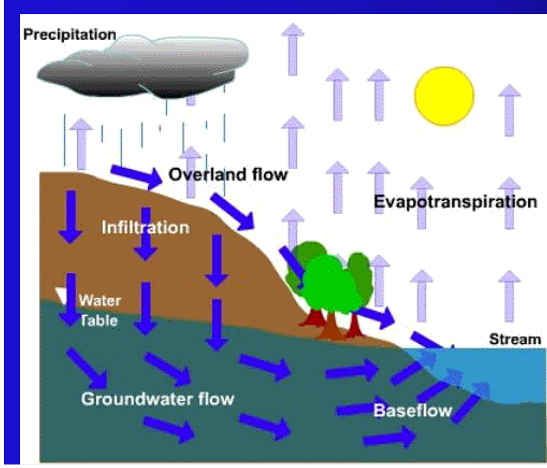
- Landscape and geomorphology (drainage density, shape factors)
- Management
- Soils and geological deposits
- Climate
- Hydrologic alteration (drainage, impoundments)

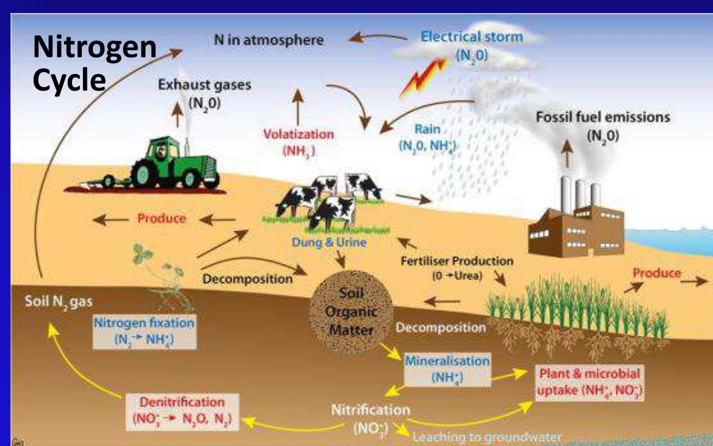


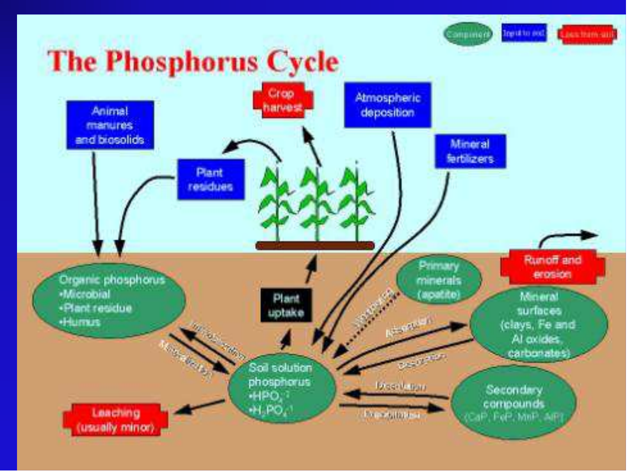
Complexity

- Lag time
- Seasonality
- Land use change
- Riparian function and processes
- Interacting cycles of water, carbon, and nutrients









Can We Avoid Unintended Consequences?
Agricultural Systems are Leaky!

Farmers provide society with food, feed, fiber, and fuel with economical efficiency!

How do we equilibrate between economic efficiency and ecological impact?

Requires a shift in scale:
More efficient agronomics need to be better combined with practices that provide healthier soils and approaches that effectively manage LANDSCAPES and their natural variability.

Integrate knowledge about landscape variability, hydrology, and ecosystem processes into production agriculture.

Accept that agricultural systems do leak – incorporate downstream approaches to minimize the impact of agriculture.

Kroger et al. (2012)

"Most stakeholders (e.g., scientists, managers, regulatory agencies), regardless of the landscape situation, when faced with P management will encounter three distinct problems:

1) substituting one P problem for another, for example, increasing dissolved P runoff from agricultural soils saturated with P, while retaining particulate P;

2) the persistence of P in field or within the management practice; and

3) the likelihood of persistent problems associated with P loss even if source control practices are successful".

Contact Information

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