Science Assessment to Support an Illinois Nutrient Reduction Strategy

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Technical Tasks

- develop a science based technical assessment of:
  - current conditions in Illinois of nutrient sources and export by rivers in the state from point and non-point sources
  - methods that could be used to reduce these losses and estimates of their effectiveness throughout Illinois
  - estimates of the costs of statewide and watershed level application of these methods to reduce nutrient losses to meet TMDL and Gulf of Mexico goals

Steps we will take

1. determine current conditions
2. identify critical watersheds
3. estimate potential reductions and costs
4. develop scenarios

1. Current Conditions

- nutrient (nitrate and total P) loads from major river basins of Illinois
  - estimates of point and non-point sources
  - compare 1980-1996 with 1997-2011
  - determine direction of loads
- determine current agricultural management practices across the state
  - nutrient inputs and management (fertilizers and manure)
  - current cropping practices
  - N and P loads and yields from water quality data

Point Source P Analysis

- began with IEPA's total P analysis
  - USEPA nutrient loading tool that is linked to the Integrated Compliance Information System (ICIS)
  - focused on larger point sources in state
    - IEPA focused on 108 sources (used IAWA request for data)
    - 42 facilities responded with P data
    - we added one additional facility (Decatur)
- also looked at the other majors and all minors
  - mostly used ICIS concentrations for total P
  - IEPA knowledge of industrial sources for total P concentrations
  - some industrial sources have shut down; actual number is currently less

Point Source N Analysis

- solicited total N and nitrate data from operators via IAWA
  - received useable data from 31 facilities (1.3 to 712 MGD, median 12 MGD)
  - most provided 5-years of data (2008 to 2012)
- total N 16.8 mg N/L; nitrate-N 14.9 mg N/L applied to other facilities in ICIS N database
  - average from typical plants in survey
  - applied to 392 sources in ICIS
  - all POTW's

Point Source N Loads

	Total N	Nitrate-N
	1000 tons N yr^{-1} (392 sources)	
State	39.6	34.1
Illinois River	34.1	29.2
Green River	0.05	0.04
Big Muddy	0.55	0.49
Kaskaskia River	1.00	0.88
Little Wabash	0.22	0.20
Rock River	1.79	1.58
Vermilion River	0.70	0.62
Embarras River	0.27	0.24
All other basins	0.94	0.80
State (David and Gentry, 2000)	39.0	
State consumption of N (David et al., 2010)	56.0	

Point Source P Loads

	Total P (1000 tons P yr^{-1})	
	(all, 1660 sources)	(majors, 263)*
State	8.16	7.54
Illinois River	6.62	6.25
Green River	0.01	0.01
Big Muddy	0.10	0.08
Kaskaskia River	0.23	0.18
Little Wabash	0.08	0.06
Rock River	0.46	0.41
Vermilion River	0.10	0.09
Embarras River	0.05	0.03
All other basins	0.51	0.43
State (David and Gentry, 2000)	6.67	
State consumption of P (Jacobson et al., 2011)	5.92	

*this number is from ICIS 2009, some are no longer operational

Riverine fluxes

- used USGS flow data and IEPA and USGS nutrient data for 1980 through 2011
- eight major rivers in state (drain 74% of state)
  - assumed to represent all of the state
- used both linear interpolation for total N, nitrate-N, dissolved reactive P (DRP), and total P; USGS WRDTS for nitrate-N, DRP, and total P
- Rock River contribution by difference in stations or by assuming outlet represents Illinois well

Load Estimators

- no standard method, unless you have a concentration every day
  - much argument about various methods
- interpolation is simple, and works well for larger rivers and nutrients such as nitrate-N
- for P, interpolation has limitations at high flows, when most P loss occurs (Royer et al., 2006)
  - Weighted Regressions on Time, Discharge, and Season is newer USGS approach (Hirsch et al., 2010)

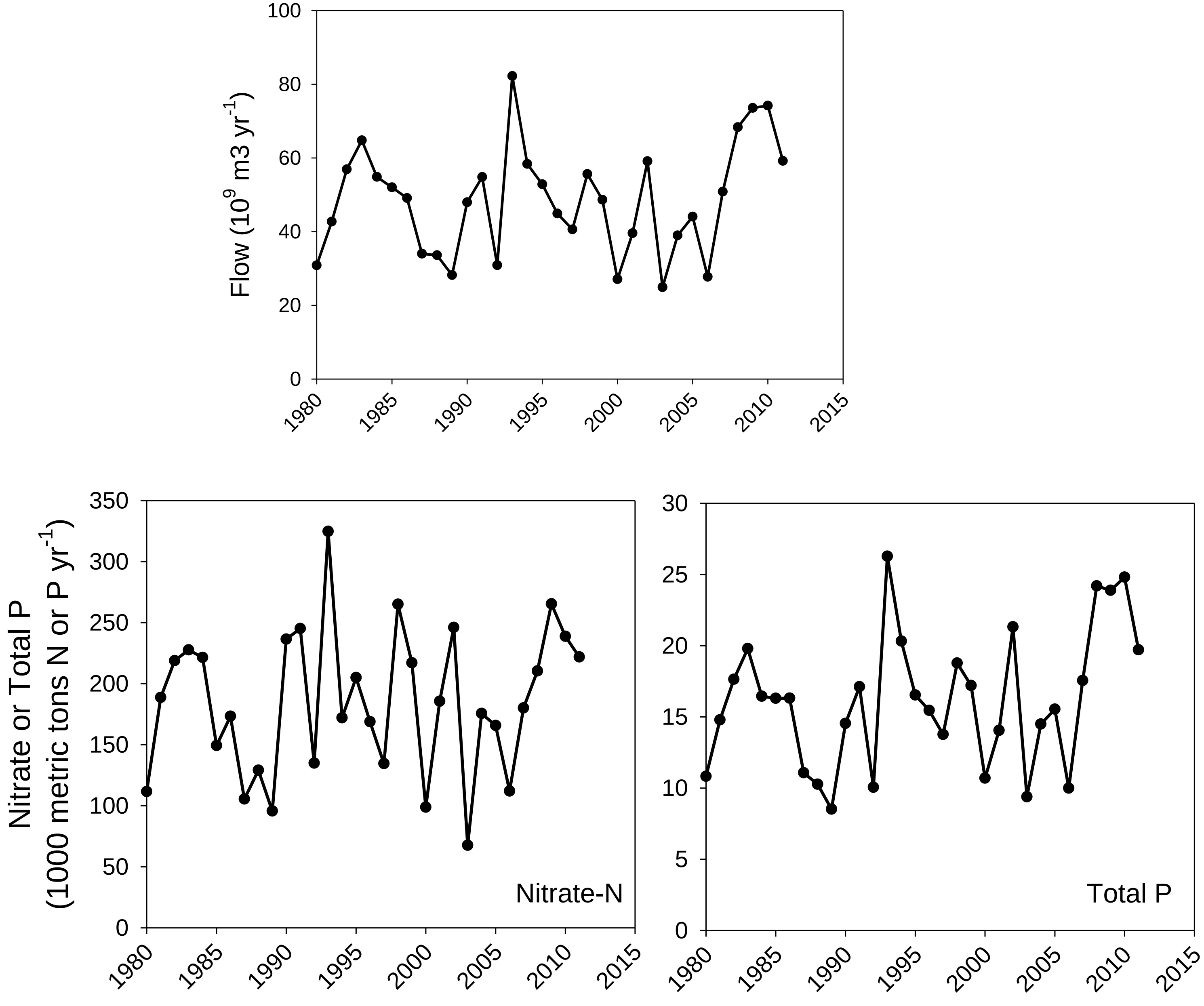
Riverine fluxes continued

- interpolation and WRDTS gave similar results for nitrate-N; for DRP and total P WRDTS gave higher estimates for smaller rivers
  - Illinois River nearly the same for both nitrate-N and total P with either method
  - Rock River best estimated by difference between upstream and downstream sites
- we used interpolation for nitrate-N and total N, WRDTS for DRP and total P for final estimates

Riverine N and P Fluxes

	Water	Nitrate-N	Total N	DRP	Total P
	10^9 m^3 yr^{-1}	1000 tons N or P yr^{-1}			
David & Gentry (2000)	47		244		14.2
1980-1996	48.2	183	239	7.0	15.4
1997-2011	48.8	186	243	8.4	17.0
Point sources		34.1	39.6		8.2
		Percent of 1997-2011 load			
Point sources		18.4	16.3		48
David & Gentry (2000)			16		47

Flow and Nutrient Loads



Trends through time

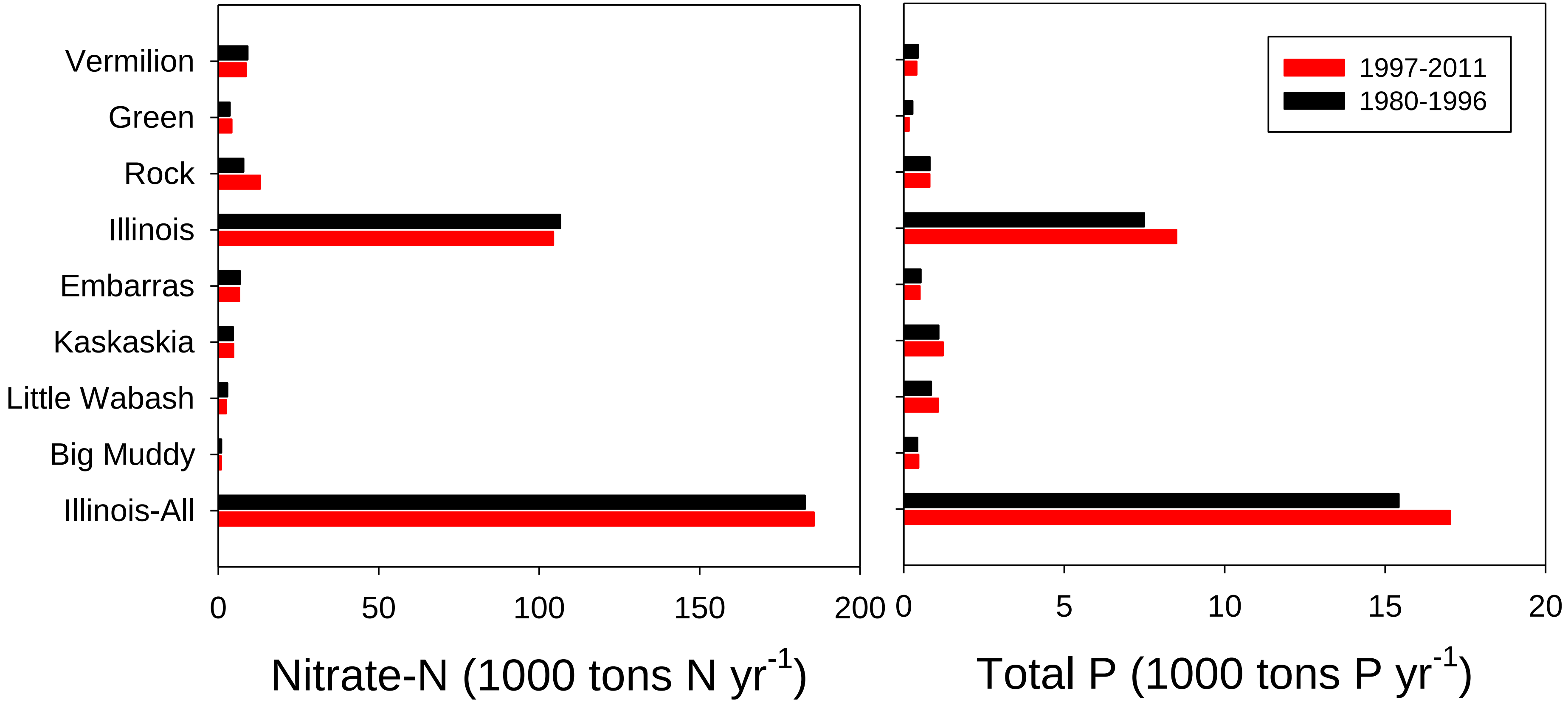
- no significant trend for flow using linear regression of annual volume

- regression model with flow and time
  - for nitrate, R^2=0.77, flow $p < 0.0001$, year not significant
  - for total P, R^2=0.97, flow and year both significant at $p < 0.0001$
  - for DRP, R^2=0.96, flow and year both significant at $p < 0.0001$

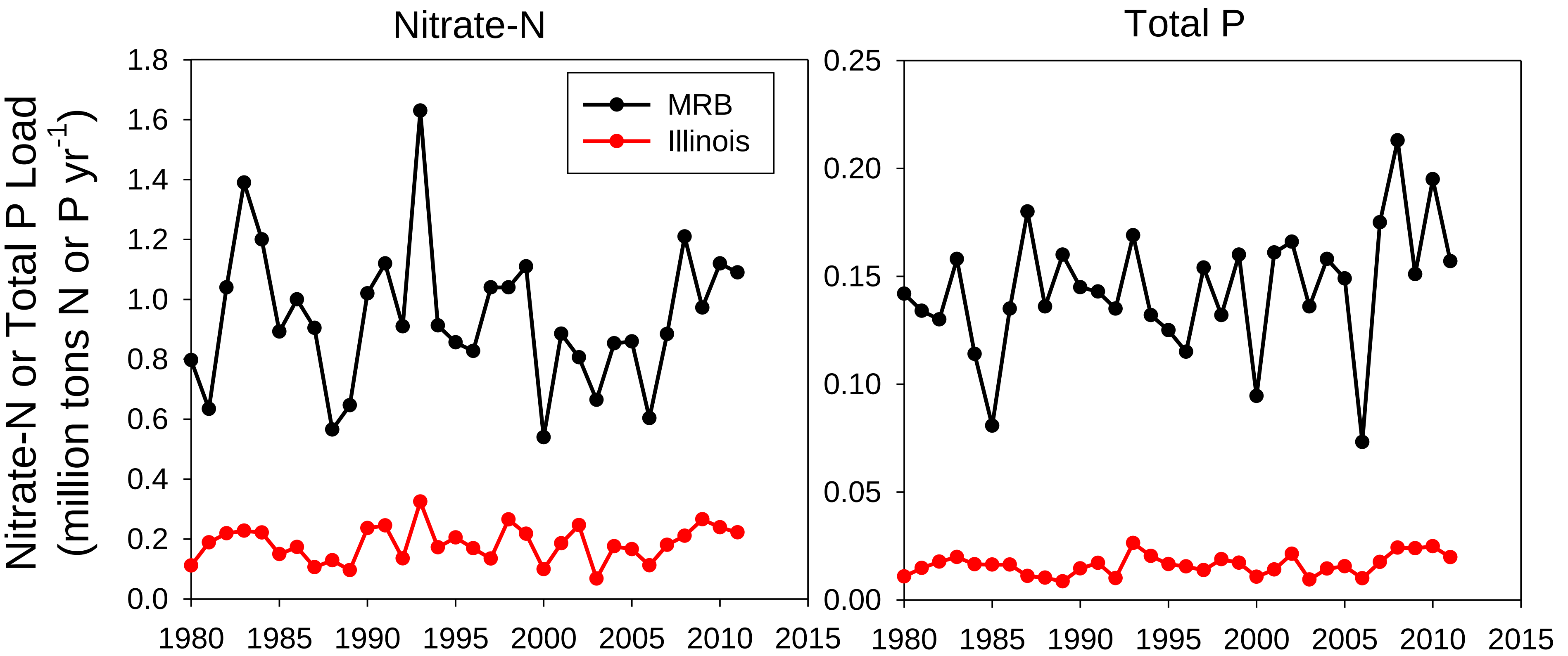
Riverine N and P loads (1997-2011)

	Nitrate-N	Total P
	1000 tons N or P yr^{-1}	
State	186	17.0
Illinois River	104	8.5
Green River	4.1	0.2
Big Muddy	9.0	0.5
Kaskaskia River	4.7	1.2
Little Wabash	2.5	1.1
Rock River	13	0.8
Vermilion River	8.6	0.4
Embarras River	6.6	0.5

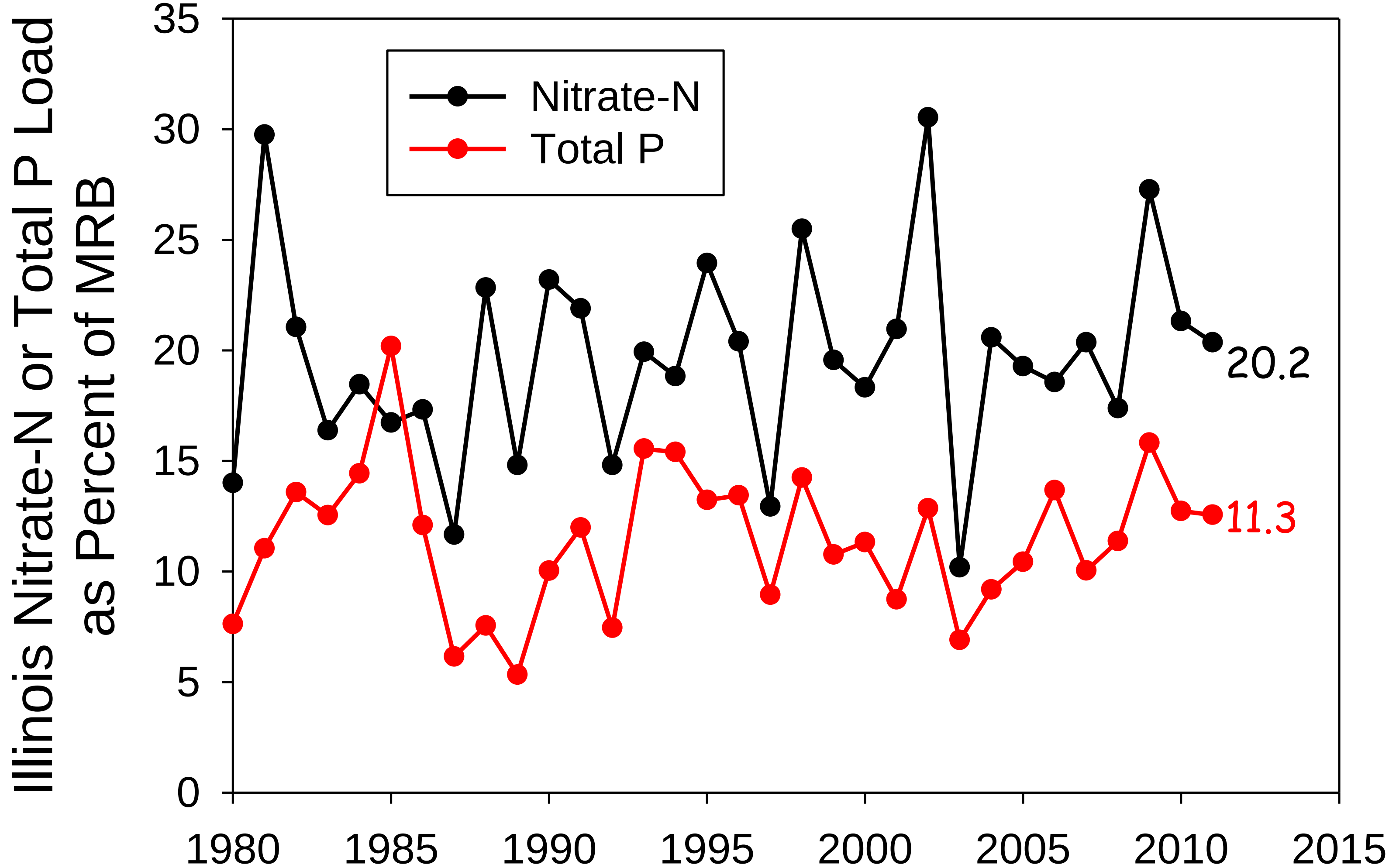
Riverine Loads through Time



Illinois Compared with MRB

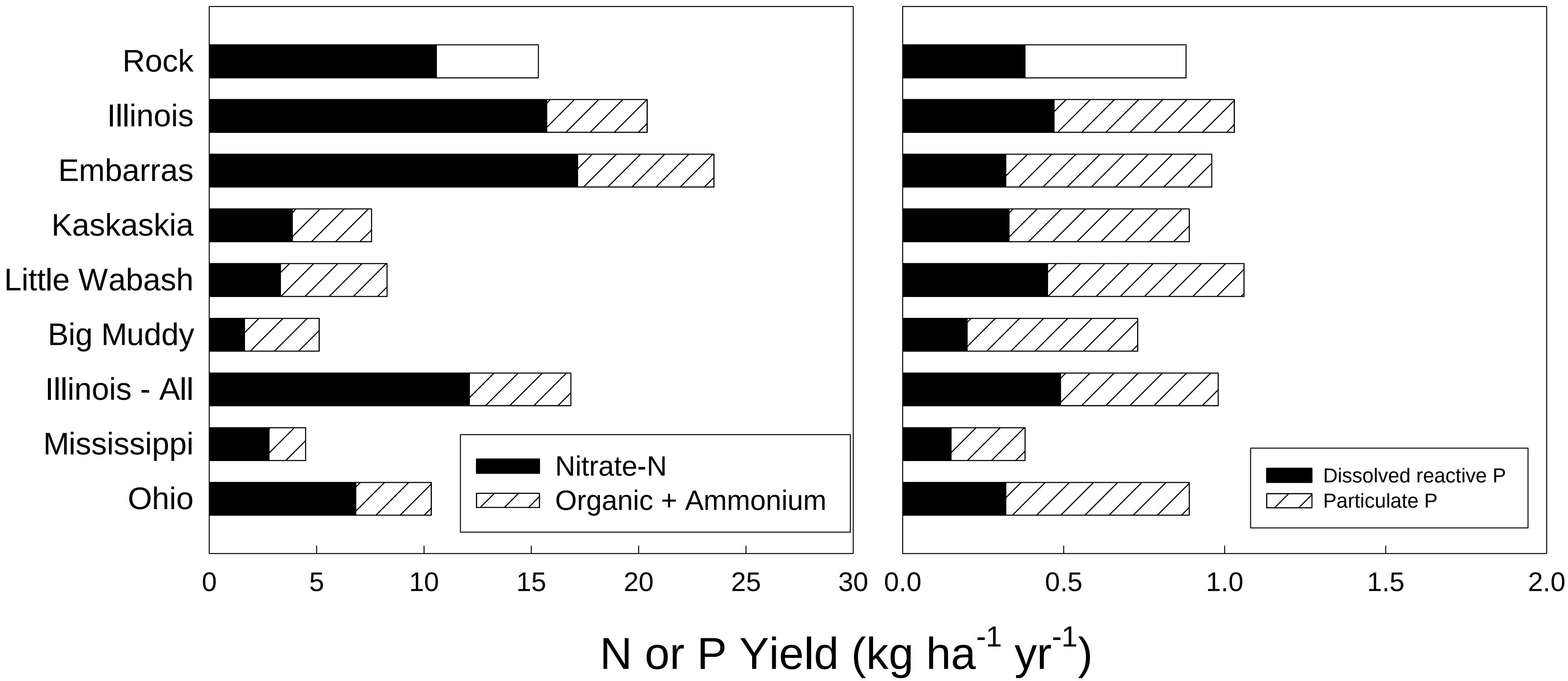


Illinois as % of MRB



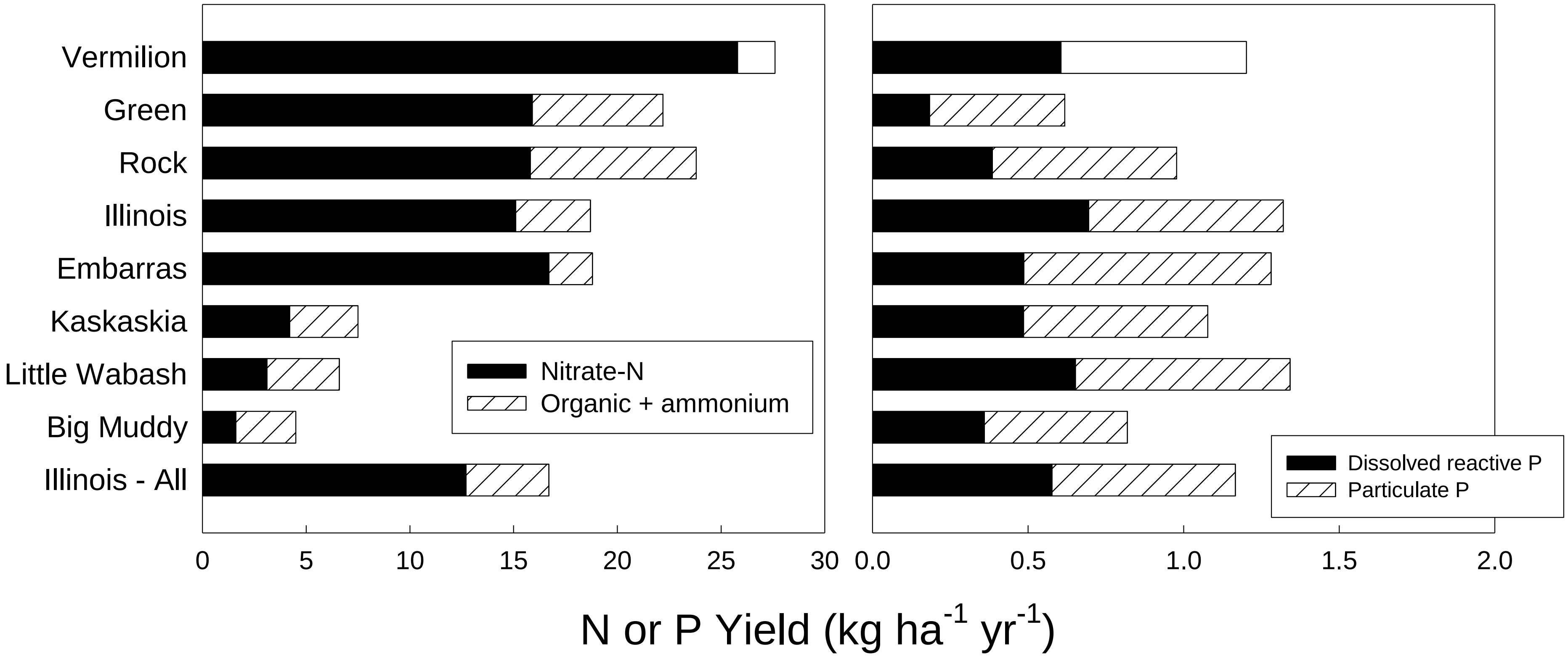
David and Gentry (2000) 15% for total N, 10% for P

N and P Yields for State, 1980 to 1997

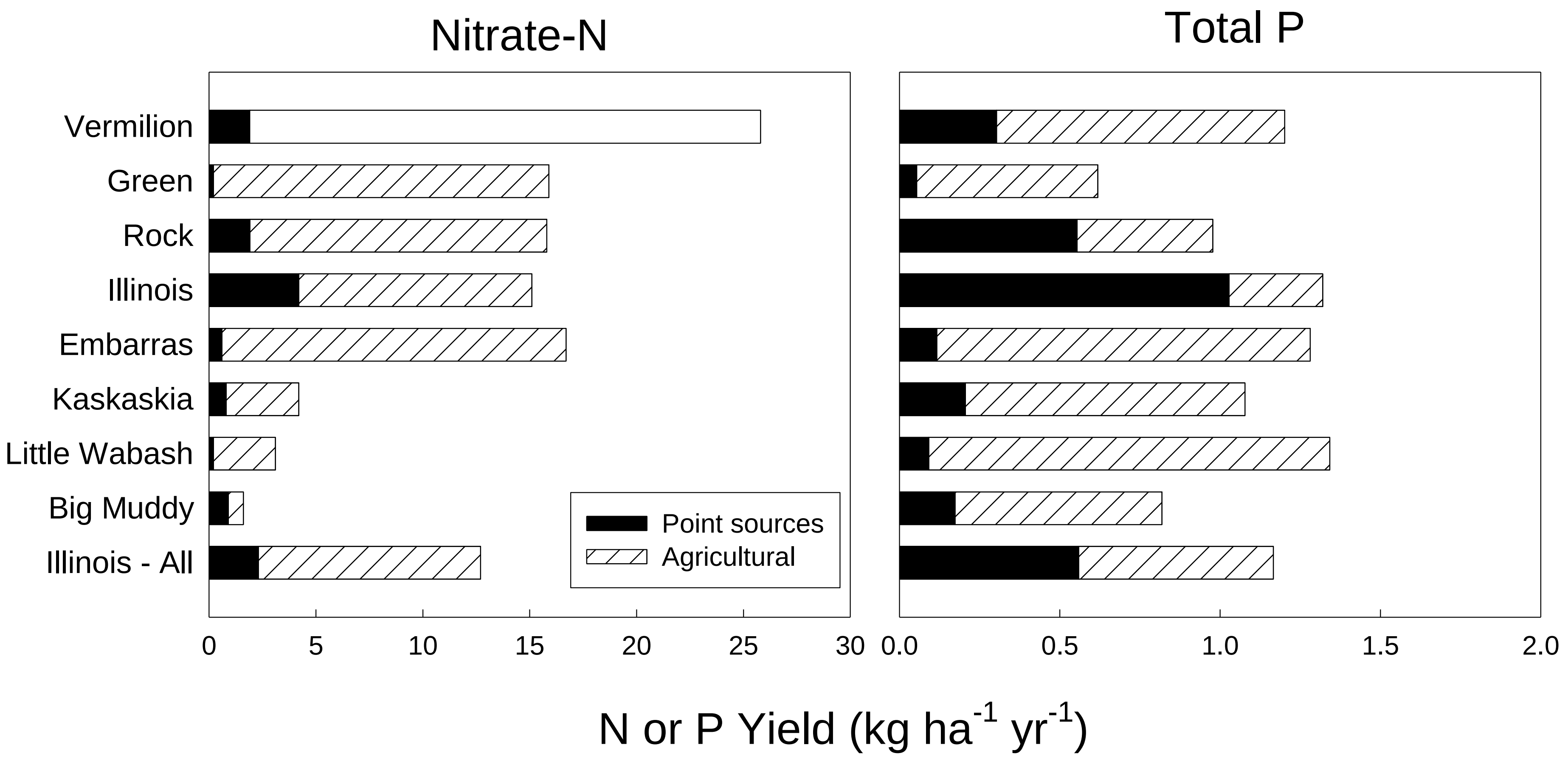


From David and Gentry (2000)

N and P Yields for State, 1997 to 2011



Point and agricultural sources
(1997-2011)



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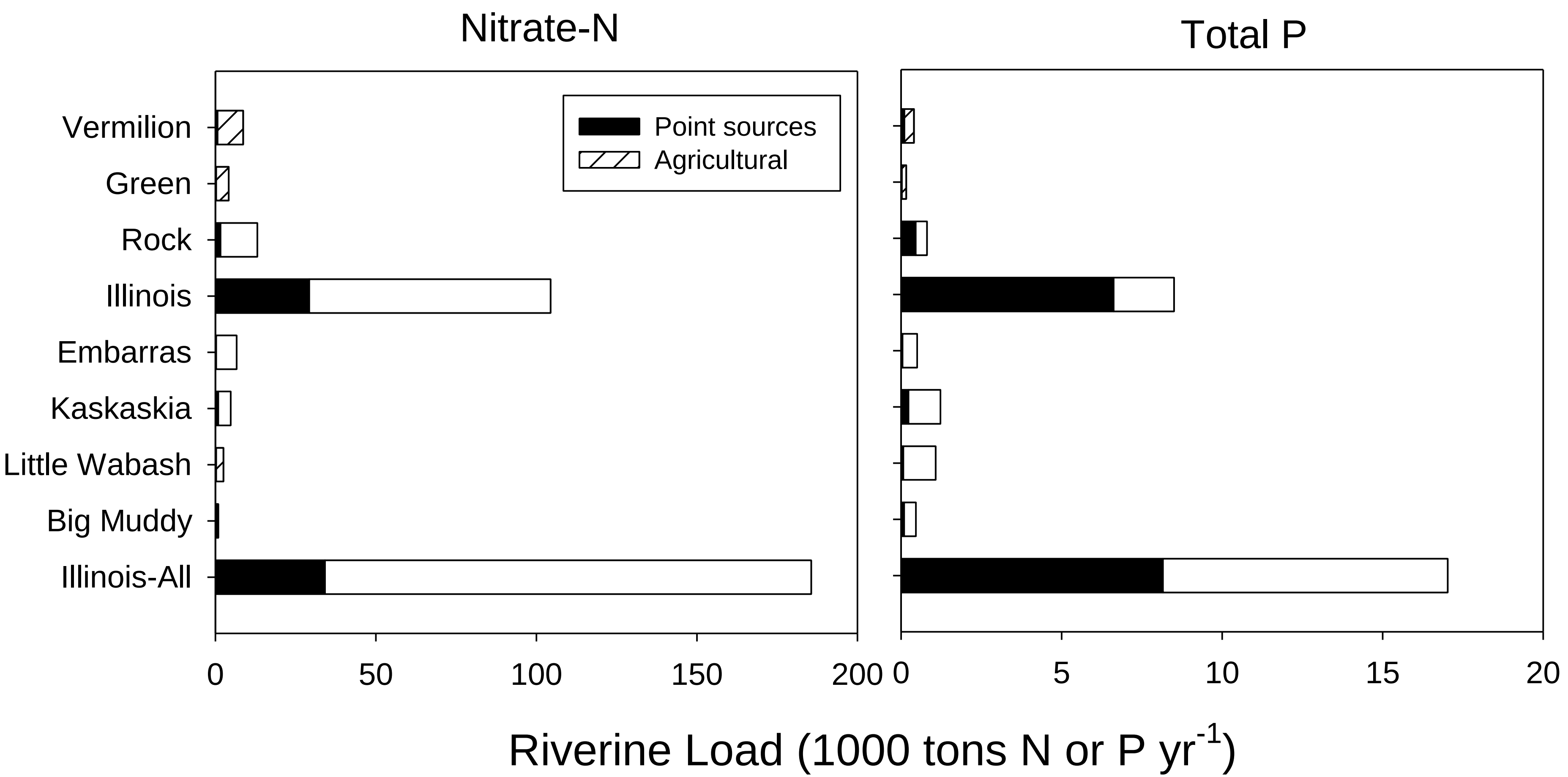
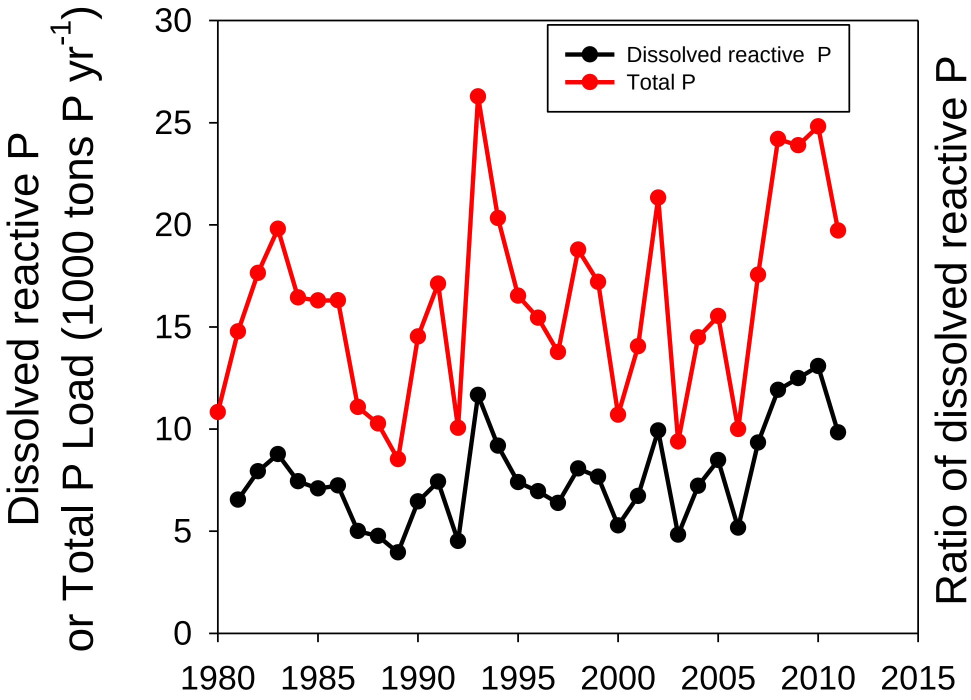
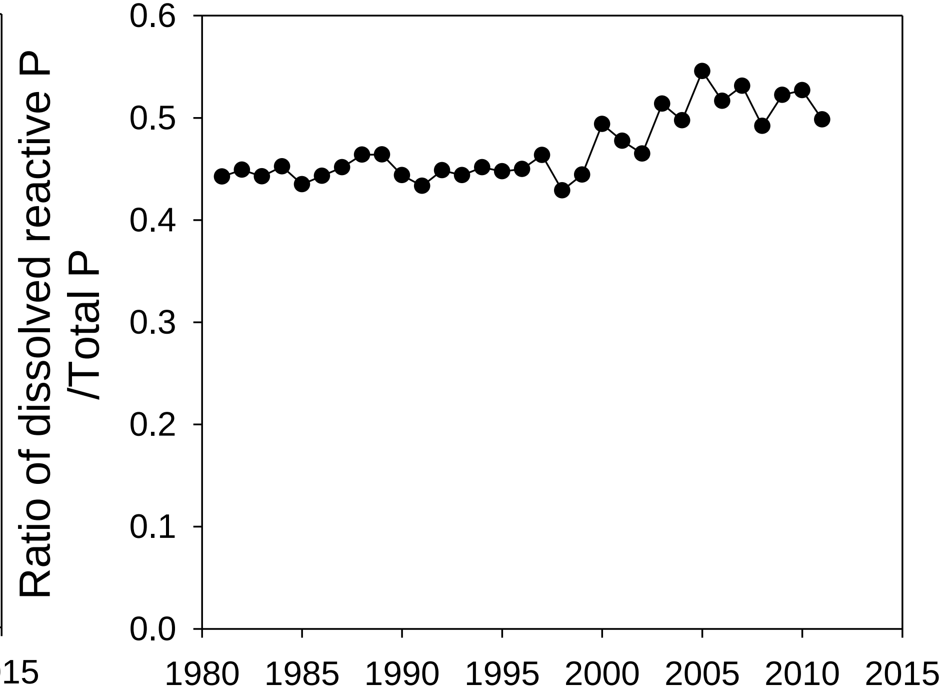


Dissolved Reactive P versus Total P

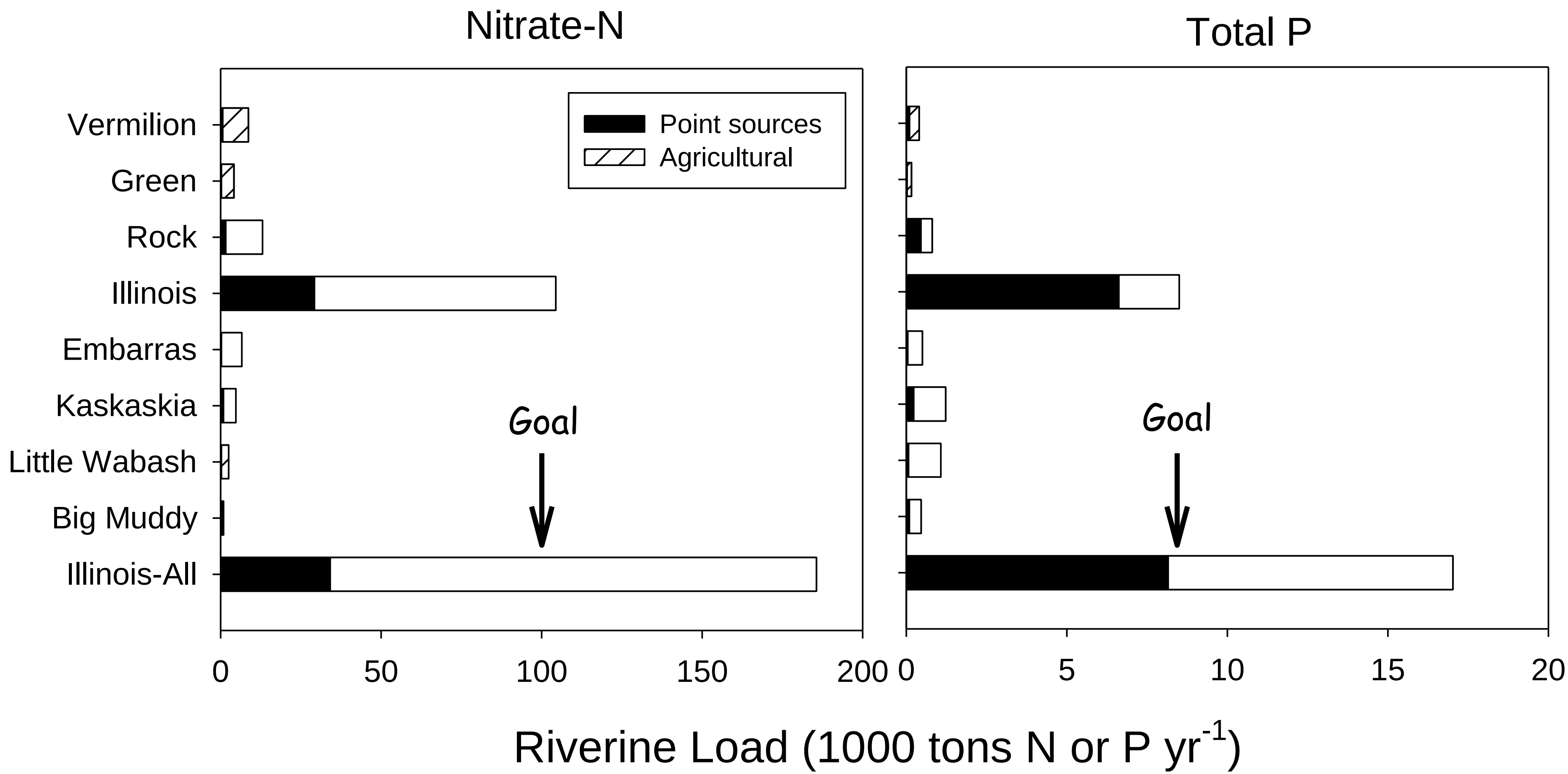




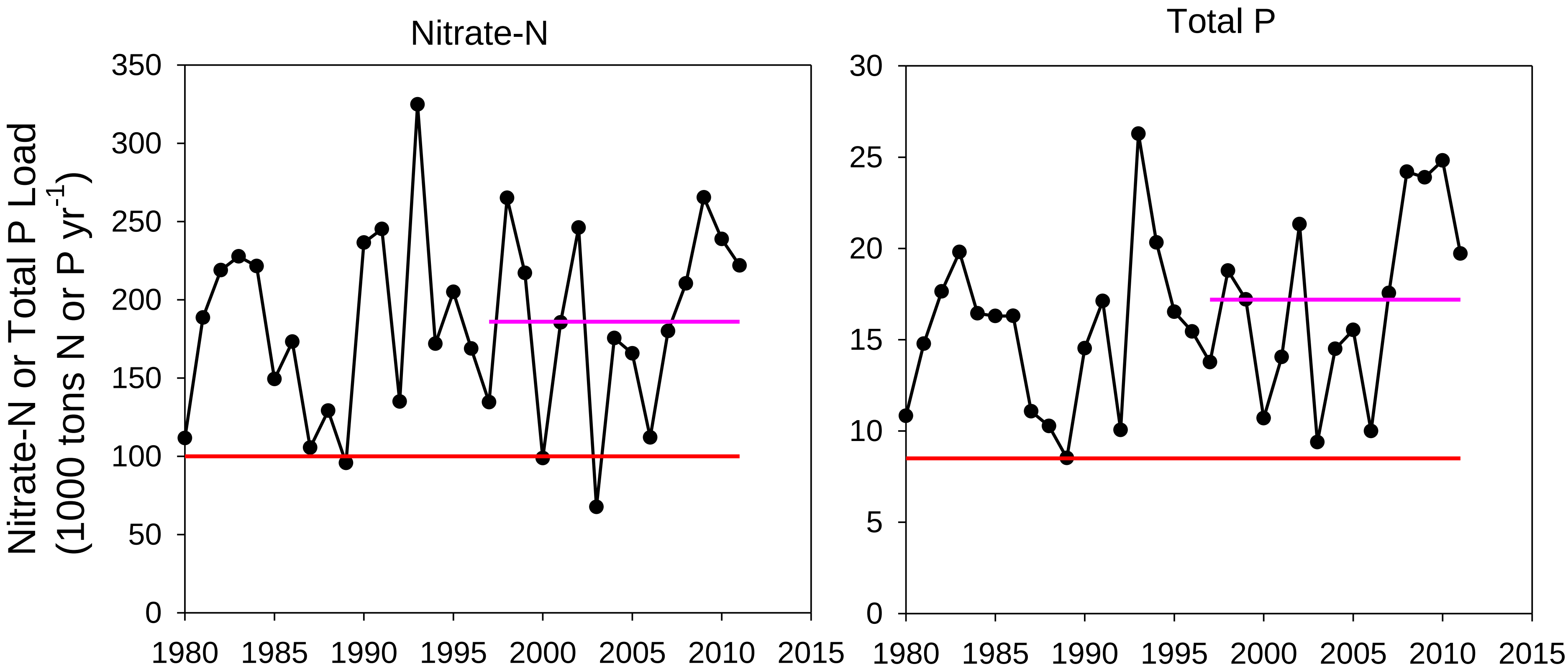
Goal or Target

- 45% reduction in 1980 to 1996 loads
  - nitrate-N target of 100,000 tons N yr^{-1}
  - total P target of 8,500 tons P yr^{-1}
- larger reductions needed from 1997 to 2011 average loads
  - 186,000/86,000 tons N as nitrate-N needed (46%)
  - 17,000/8,500 tons total P needed (50%)
- example reduction for point source P
  - all majors P reduction to 1 mg P/L limit, 0.7 mg P/L average would give a 4,800 ton P reduction

Point and agricultural sources
(1997-2011)



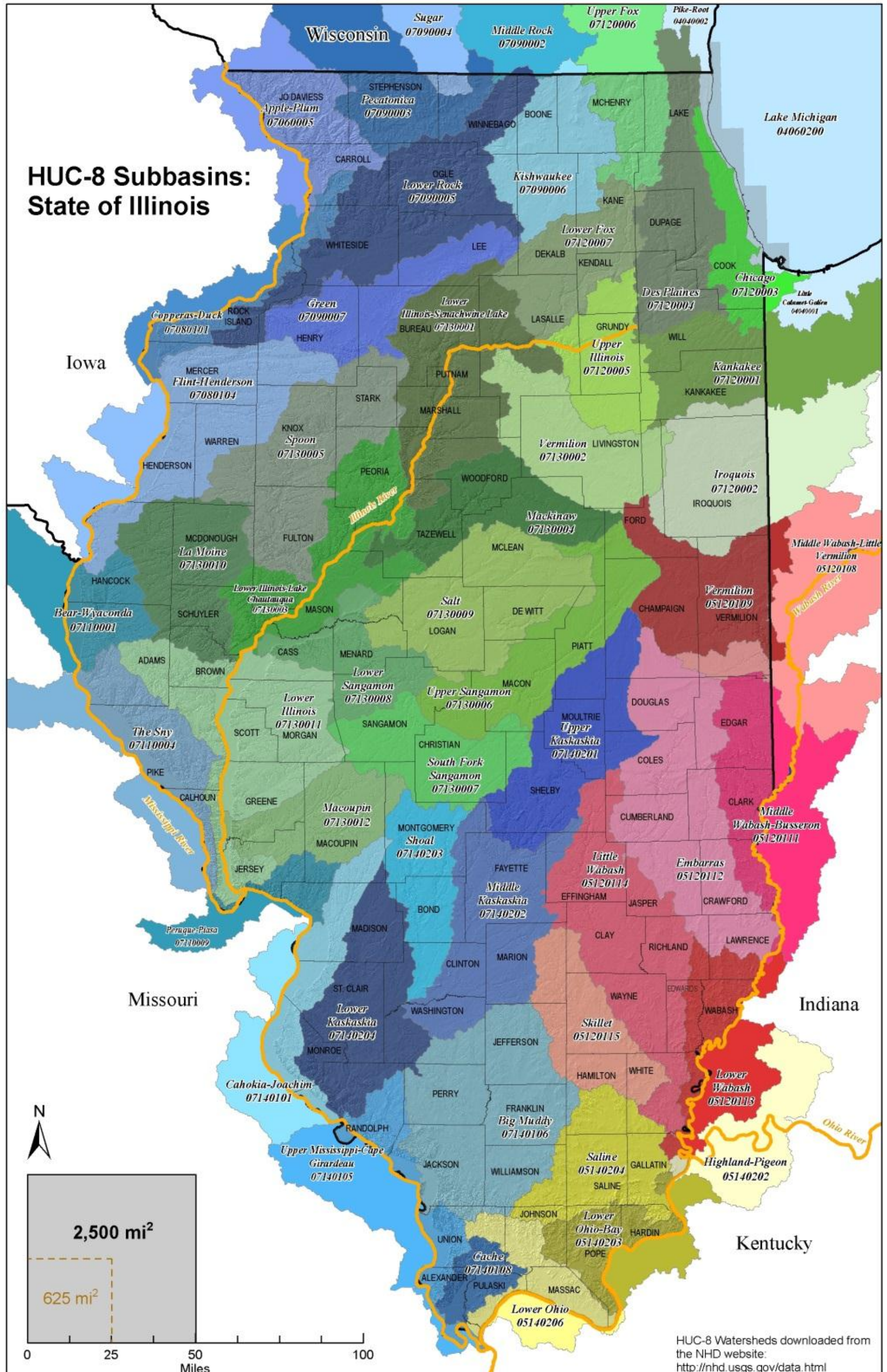
Nitrate-N and Total P Targets



Red line is target, purple is average 1997 to 2011

2. Critical Watershed Identification

- identify 8 digits HUCs with the highest nutrient yields and loads to the Gulf of Mexico
- identify watersheds with nutrient impaired water bodies (303d list)
- determine overlap
- estimate point and non-point sources of N and P within watersheds



HUC-8 Subbasins: State of Illinois
Wisconsin
Sugar 07090004
Middle Rock 07090002
Upper Fox 07120006
Pike-Root 04040002
Lake Michigan 04060200
JO DAVIESS
Apple-Plum 07060005
STEPHENSON
Pecatonica 07090003
WINNEBAGO
BOONE
MCHENRY
LAKE
CARROLL
OGLE
Lower Rock 07090005
Kishwaukee 07090006
KANE
DUPAGE
Lower Fox 07120007
DEKALB
KENDALL
WHITESIDE
LEE
COOK
Chicago 07120003
Little Calumet-Galien 04040001
Des Plaines 07120004
Copperas-Duck 07080101
ROCK ISLAND
Green 07090007
HENRY
Lower Illinois-Senachwine Lake 07130001
BUREAU
LASALLE
GRUNDY
WILL
Upper Illinois 07120005
Iowa
MERCER
Flint-Henderson 07080104
PUTNAM
Kankakee 07120001
KANKAKEE
STARK
MARSHALL
KNOX
Spoon 07130005
WARREN
Vermilion 07130002
LIVINGSTON
HENDERSON
PEORIA
WOODFORD
Iroquois 07120002
IROQUOIS
Illinois River
Mackinaw 07130004
FORD
MCDONOUGH
FULTON
TAZEWELL
MCLEAN
La Moine 07130010
Middle Wabash-Little Vermilion 05120108
HANCOCK
Lower Illinois-Lake Chautauqua 07130003
Vermilion 05120109
Wabash River
Bear-Wyaconda 07110001
SCHUYLER
MASON
Salt 07130009
DE WITT
CHAMPAIGN
VERMILION
LOGAN
CASS
MENARD
PIATT
ADAMS
BROWN
Lower Sangamon 07130008
Upper Sangamon 07130006
MACON
DOUGLAS
Lower Illinois 07130011
SANGAMON
MOULTRIE
EDGAR
The Sny 07110004
SCOTT
MORGAN
CHRISTIAN
Upper Kaskaskia 07140201
COLES
PIKE
South Fork Sangamon 07130007
SHELBY
CLARK
CALHOUN
GREENE
Macoupin 07130012
Mississippi River
MONTGOMERY
Shoal 07140203
CUMBERLAND
Middle Wabash-Busseron 05120111
MACOUPIN
JERSEY
FAYETTE
Little Wabash 05120114
Embarras 05120112
Middle Kaskaskia 07140202
EFFINGHAM
JASPER
CRAWFORD
BOND
Peruque-Piasa 07110009
MADISON
CLAY
LAWRENCE
RICHLAND
CLINTON
MARION
EDWARDS
ST. CLAIR
WAYNE
WABASH
Missouri
Indiana
Lower Kaskaskia 07140204
WASHINGTON
Skillet 05120115
JEFFERSON
MONROE
HAMILTON
WHITE
Lower Wabash 05120113
Cahokia-Joachim 07140101
PERRY
FRANKLIN
Big Muddy 07140106
RANDOLPH
Ohio River
Upper Mississippi-Cape Girardeau 07140105
Saline 05140204
GALLATIN
Highland-Pigeon 05140202
JACKSON
WILLIAMSON
SALINE
JOHNSON
Lower Ohio-Bay 05140203
HARDIN
Kentucky
UNION
POPE
Cache 07140108
ALEXANDER
PULASKI
MASSAC
Lower Ohio 05140206
N
2,500 mi²
625 mi²
0
25
50
100
Miles
HUC-8 Watersheds downloaded from the NHD website: http://nhd.usgs.gov/data.html

3. Estimate Potential Reductions and Costs

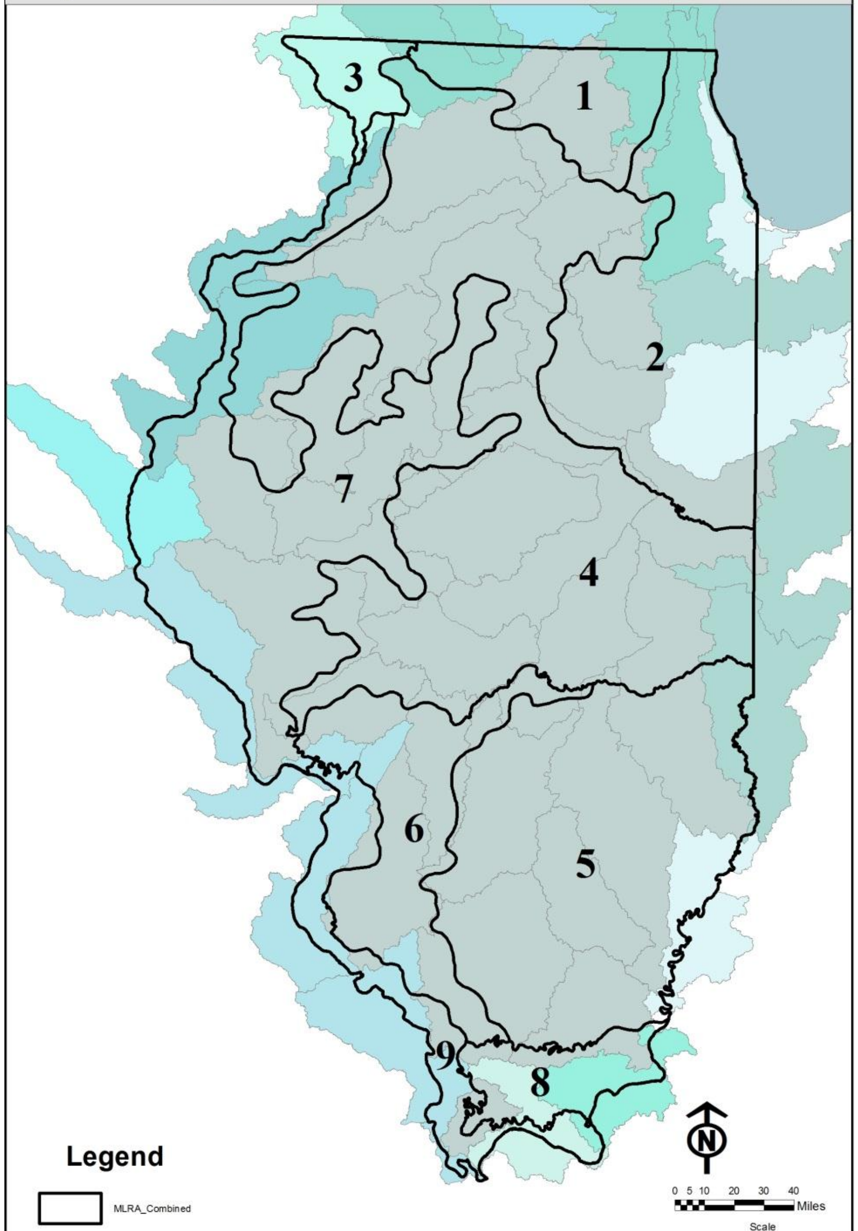
- estimate field-level effectiveness of various agricultural management practices
  - utilize SAB, Iowa, and Lake Bloomington Project estimates
  - knowledge in Illinois
- determine possible point source reductions
- estimate costs
  - Gary Schnitkey (agricultural economist) will lead
  - initial investments
  - likely to annualize costs over 25 years

Combined MLRA's

Major Land Resource Areas (MLRAs) in Illinois, showing combinations to be used for analysis (15 combined into 9). Bold MLRAs are the numbers that will be used throughout our analysis.

		Landscape		Climate		
MLRA	**Description**	**Elevation m (ft)**	**Local Relief m (ft)**	**Precipitation mm (inches)**	**Annual Temperature °C (°F)**	**Freeze Free Days**
95B	Southern Wisconsin and Northern Illinois Drift Plain	200 to 300 (660 to 980)	8 (25)	760 to 965 (30 to 38)	6 to 9 (43 to 48)	170
97	Southwestern Michigan Fruit and Truck Crop Belt	200 to 305 (600 to 1000)	2 to 5 (5 to 15)	890 to 1,015 (35 to 40)	8 to 11 (47 to 52)	200
98	Southern Michigan and Northern Indiana Drift Plain	175 to 335 (570 to 1,100)	15 (5)	735 to 1,015 (29 to 40)	7 to 10 (44 to 50)	175
110	Northern Illinois and Indiana Heavy Till Plain	200 (650)	3 to 8 (10 to 25)	785 to 1,015 (31 to 40)	7 to 11 (42 to 52)	185
105	Northern Mississippi Valley Loess Hills	200 to 400 (660 to 1,310)	3 to 6 (10 to 20)	760 to 965 (30 to 38)	6 to 10 (42 to 50)	175
108A	Illinois and Iowa Deep Loess and Drift, Eastern Part	200 to 300 (660 to 985)	1 to 3 (3 to 10)	890 to 1,090 (35 to 43)	8 to 12 (47 to 54)	195
108B	Illinois and Iowa Deep Loess and Drift, East-Central Part	200 to 300 (660 to 985)	1 to 3 (3 to 10)	840 to 990 (33 to 39)	8 to 12 (47 to 54)	185
113	Central Claypan Areas	200 (660)	1.5 to 3 (5 to 10)	915 to 1,170 (36 to 46)	11 to 14 (51 to 57)	205
115A	Central Mississippi Valley Wooded Slopes, Eastern Part	100 to 310 (320 to 1,020)	3 to 15 (10 to 50)	1,015 to 1,195 (40 to 47)	11 to 14 (53 to 57)	210
114B	Southern Illinois and Indiana Thin Loess and Till Plain, Western Part	105 to 365 (350 to 1,190)	3 to 15 (10 to 50)	940 to 1,170 (37 to 46)	11 to 14 (52 to 56	210
115C	Central Mississippi Valley Wooded Slopes, Northern Part	130 to 270 (420 to 885)	3 to 6 (10 to 20)	865 to 1,015 (34 to 40)	9 to 13 (48 to 55)	200
120A	Kentucky and Indiana Sandstone and Shale Hills and Valleys, Southern Part	105 to 290 (345 to 950)	Varies widely	1,145 to 1,370 (45 to 54)	13 to 14 (55 to 58)	210
115B	Central Mississippi Valley Wooded Slopes, Western Part	100 to 310 (320 to 1,020)	3 to 15 (10 to 50)	965 to 1,220 (38 to 48)	12 to 14 (53 to 57)	205
131A	Southern Mississippi River Alluvium	0 to 100 (0 to 330	Max 5 (15)	1,170 to 1,525 (46 to 60)	14 to 21 (56 to 69)	210 (North)
134	Southern Mississippi Valley Loess	25 to 185 (80 to 600)	3 to 6 (10 to 20)	1,195 to 1,525 (47 to 60)	14 to 20 (57 to 68)	215 (North)

Combined MLRAs for Illinois (Overlayed with HUC 8s & Counties)



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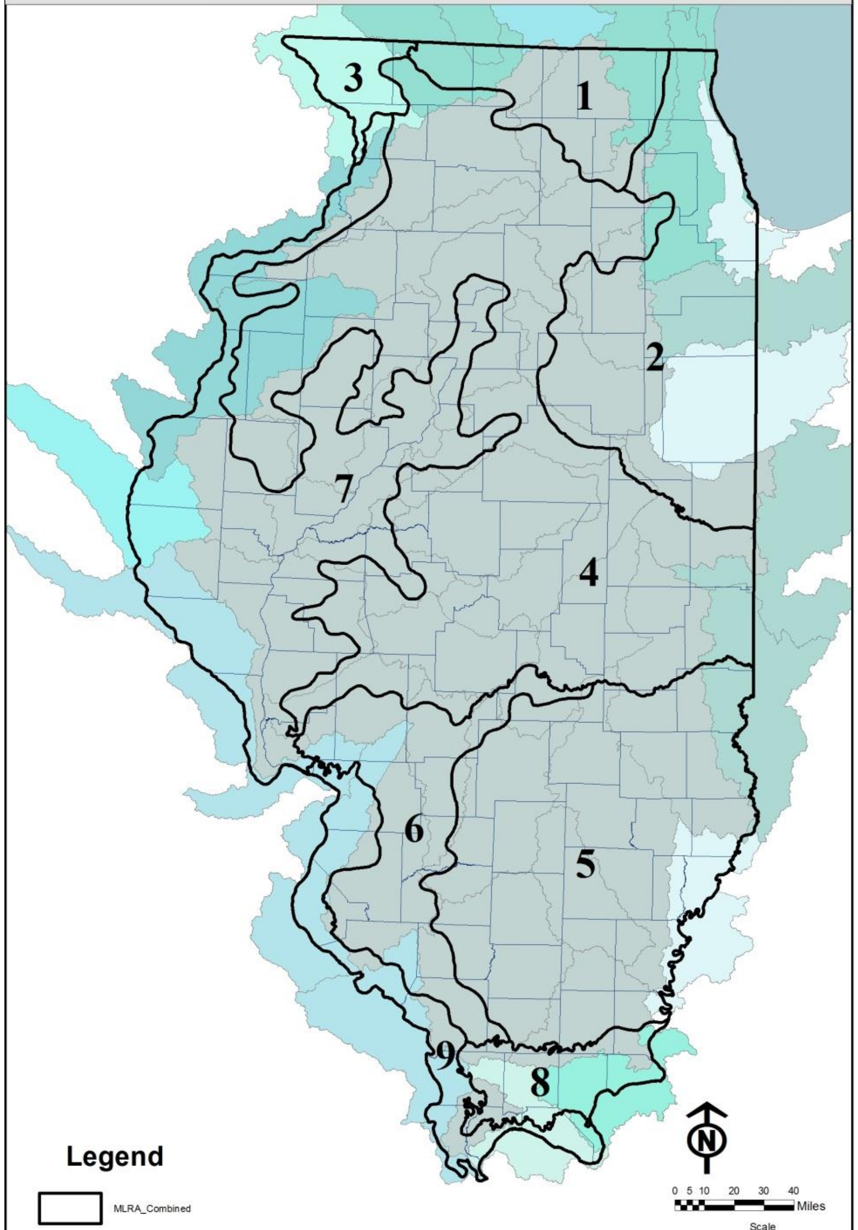

Agricultural Management by MLRA

Combined MLRA	Description	Corn (acres)	Soybean (acres)	Wheat (acres)	Drained acres (% of crop acres)	Corn yield (bushels /acre)	Soybean yield (bushels /acre)
MLRA 1	Northern Illinois drift plain	515,905	224,186	20,192	288,491 (39)	161	48
MLRA 2	Northeastern Illinois heavy till plain	1,532,100	1,111,885	42,404	2,063,695 (78)	150	39
MLRA 3	Northern Mississippi Valley	163,507	52,432	1,975	20,942 (10)	160	50
MLRA 4	Deep loess and drift	5,579,980	3,343,444	76,078	5,437,807 (61)	164	52
MLRA 5	Claypan	1,609,633	1,991,939	352,839	310,087 (9)	128	39
MLRA 6	Thin loess and till	664,242	689,773	161,180	226,971 (17)	130	42
MLRA 7	Central Mississippi Valley, Northern Part	2,058,853	1,288,686	73,884	1,284,588 (38)	155	49
MLRA 8	Sandstone and shale hills and valleys	83,969	115,244	10,658	49,565 (25)	103	33
MLRA 9	Central Mississippi Valley, Western Part	203,736	314,662	78,250	23,769 (5)	125	39
Sum		12,411,925	9,132,251	817,460	9,705,916 (43)		

Average crop acres and yields 2008 through 2012

Agricultural Management by MLRA

Combined MLRA	Description	Estimated corn fertilizer (lbs N/acre/yr)	Estimated corn fertilizer + manure (lbs N/acre/yr)	Row crops (acres)	Nitrate-N yield per row crop acre (lbs N/acre/yr)
MLRA 1	Northern Illinois drift plain	152	168	760,283	20.4
MLRA 2	Northeastern Illinois heavy till plain	158	164	2,686,389	25.0
MLRA 3	Northern Mississippi Valley	135	158	217,914	31.3
MLRA 4	Deep loess and drift	150	159	8,999,502	19.6
MLRA 5	Claypan	180	196	3,954,411	6.6
MLRA 6	Thin loess and till	156	170	1,515,195	7.4
MLRA 7	Central Mississippi Valley, Northern Part	155	169	3,421,423	24.5
MLRA 8	Sandstone and shale hills and valleys	209	219	209,871	3.9
MLRA 9	Central Mississippi Valley, Western Part	192	204	596,648	4.0
Sum		157	168	22,361,636	

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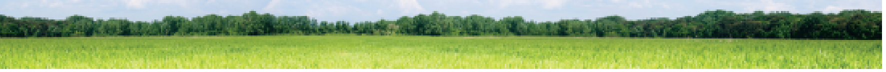

Iowa Strategy to Reduce Nutrient Loss: Nitrogen Practices

This table lists practices with the largest potential impact on nitrate-N concentration reduction (except where noted). Corn yield impacts associated with each practice also are shown as some practices may be detrimental to corn production. If using a combination of practices, the reductions are not additive. Reductions are field level results that may be expected where practice is applicable and implemented.

	Practice	Comments	% Nitrate-N Reduction[+]	% Corn Yield Change[++]
			Average (SD*)	Average (SD*)
Nitrogen Management	Timing	Moving from fall to spring pre-plant application	6 (25)	4 (16)
		Spring pre-plant/sidedress 40-60 split Compared to fall-applied	5 (28)	10 (7)
		Sidedress – Compared to pre-plant application	7 (37)	0 (3)
		Sidedress – Soil test based compared to pre-plant	4 (20)	13 (22)[**]
	Source	Liquid swine manure compared to spring-applied fertilizer	4 (11)	0 (13)
		Poultry manure compared to spring-applied fertilizer	-3 (20)	-2 (14)
	Nitrogen Application Rate	Nitrogen rate at the MRTN (0.10 N:corn price ratio) compared to current estimated application rate. (ISU Corn Nitrogen Rate Calculator – http://extension.agron.iastate.edu/soilfertility/nrate.aspx can be used to estimate MRTN but this would change Nitrate-N concentration reduction)	10	-1
	Nitrification Inhibitor	Nitrapyrin in fall – Compared to fall-applied without Nitrapyrin	9 (19)	6 (22)
	Cover Crops	Rye	31 (29)	-6 (7)
		Oat	28 (2)	-5 (1)
	Living Mulches	e.g. Kura clover – Nitrate-N reduction from one site	41 (16)	-9 (32)
Land Use	Perennial	Energy Crops – Compared to spring-applied fertilizer	72 (23)	
		Land Retirement (CRP) – Compared to spring-applied fertilizer	85 (9)	
	Extended Rotations	At least 2 years of alfalfa in a 4 or 5 year rotation	42 (12)	7 (7)
	Grazed Pastures	No pertinent information from Iowa – assume similar to CRP	85	
Edge-of-Field	Drainage Water Mgmt.	No impact on concentration	33 (32)	
	Shallow Drainage	No impact on concentration	32 (15)	
	Wetlands	Targeted water quality	52	
	Bioreactors		43 (21)	
	Buffers	Only for water that interacts with the active zone below the buffer. This would only be a fraction of all water that makes it to a stream.	91 (20)	

[+] A positive number is nitrate concentration or load reduction and a negative number is an increase.

[++] A positive corn yield change is increased yield and a negative number is decreased yield. Practices are not expected to affect soybean yield.

* SD – standard deviation. Large SD relative to the average indicates highly variable results.

** This increase in crop yield should be viewed with caution as the sidedress treatment from one of the main studies had 95 lb-N/acre for the pre-plant treatment but 110 lb-N/acre to 200 lb-N/acre for the sidedress with soil test treatment so the corn yield impact may be due to nitrogen application rate differences.

Water Quality Improvement Case Study: Assessment of the Lake Bloomington Watershed

Final Report, March 10, 2008

Nitrogen reduction practices (tile drainage)

Practice	Expected reduction (%)
nitrification inhibitors	10
spring vs. fall fertilization	20
recommended rate vs. above[1]	
no-till vs. conventional	0
cover crops	25
water table management	40
shallow or wide tiles	25
conversion to CRP	95
conversion to perennial crops	80
constructed wetlands (20:1)	50
bioreactors	no data available

Iowa Strategy to Reduce Nutrient Loss: Phosphorus Practices

Practices below have the largest potential impact on phosphorus load reduction. Corn yield impacts associated with each practice also are shown, since some practices may increase or decrease corn production. If using a combination of practices, the reductions are not additive. Reductions are field level results that may be expected where practice is applicable and implemented.

	Practice	Comments	% P Load Reduction[a]	% Corn Yield Change[b]
			Average (SD[c])	Average (SD[c])
Phosphorus Management Practices	Phosphorus Application	Applying P based on crop removal – Assuming optimal STP level and P incorporation	0.6[d]	0
		Soil-Test P – No P applied until STP drops to optimum	17[e]	0
	Source of Phosphorus	Liquid swine, dairy, and poultry manure compared to commercial fertilizer – Runoff shortly after application	46 (45)	-1 (13)
		Beef manure compared to commercial fertilizer – Runoff shortly after application	46 (96)	
	Placement of Phosphorus	Broadcast incorporated within 1 week compared to no incorporation, same tillage	36 (27)	0
		With seed or knifed bands compared to surface application, no incorporation	24 (46)	0
	Cover Crops	Winter rye	29 (37	-6 (7)
	Tillage	Conservation till – chisel plowing compared to moldboard plowing	33 (49)	0 (6)
		No till compared to chisel plowing	90 (17)	-6 (8)
Land Use Change	Perennial Vegetation	Energy Crops		
		Land Retirement (CRP)		
		Grazed pastures		
Erosion Control and Edge-of-Field Practices	Terraces			
	Buffers			
	Control	Sedimentation basins or ponds		

[a] - A positive number is P load reduction and a negative number is increased P load.
[b] - A positive corn yield change is increased yield and a negative number is decreased yield. Practi
[c] - SD – standard deviation. Large SD relative to the average indicates highly variable results.
[d] - Maximum and average estimated by comparing application of 200 and 125 kg P_2O_5/ha, respective requirements) (Mallarino et al., 2002).
[e] - Maximum and average estimates based on reducing the average STP (Bray-1) of the two highes (Mallarino et al., 2011a), respectively, to an optimum level of 20 ppm (Mallarino et al., 2002). Minimu
[f] - P retention in wetlands is highly variable and dependent upon such factors as hydrologic loading

IOWA STATE UNIVERSITY
Extension and Outreach

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Final Report, March 10, 2008

Phosphorus reduction practices

Practice	Expected reduction % Tile drainage	Surface runoff
recommended rate vs. above		5
subsurface vs. surface broadcast		20
cover crops	5	25
shallow or wide tiles	+	-
conversion to CRP	50	75
conversion to perennial crops	50	95
WASCOB installation		75
sedimentation basins		95[1]
riparian buffers		50[2]
constructed wetlands		20[3]

4. Develop Scenarios

- combine possible point source reductions and field level agricultural reductions
  - percent reduction by practice
  - costs of implementation
  - target 45% reductions in N and P
- scale-up to critical watersheds and statewide
- provide a range of scenarios to meet reduction targets
  - area needed by practice
  - initial investment and annualized costs