Nutrients in Illinois Waters (& Sources)

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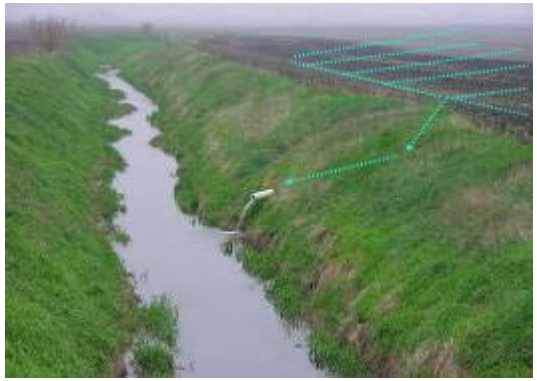
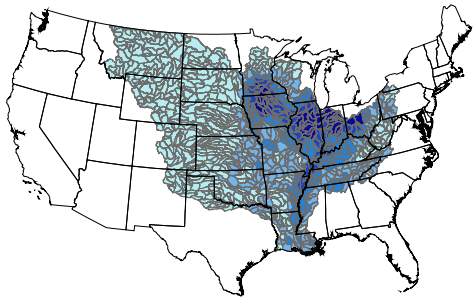
Nutrient Summit

September 13, 2010





Acknowledgements

- Greg McIsaac
- Lowell Gentry
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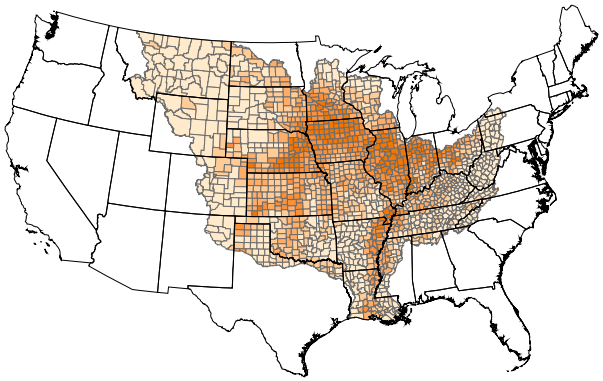
- Corey Mitchell
- Linda Jacobson

What I will cover

- N and P sources, balances, and riverine exports in the Mississippi River Basin (MRB), focusing on Illinois
  - what is going to the Gulf
- importance of modified hydrology (tile drainage)
- timing of flow and nutrients
- response of streams & rivers to nutrients (local effects)

Recent County Level Analysis

- all counties in MRB (1768)
- 1997 to 2006 annual data on fertilizer, crops, animals, people, deposition
- predictive model from watersheds applied to all MRB counties
- for both N and P



Components of Nitrogen Mass Balances

- net nitrogen inputs (NNI)

  = inputs – outputs

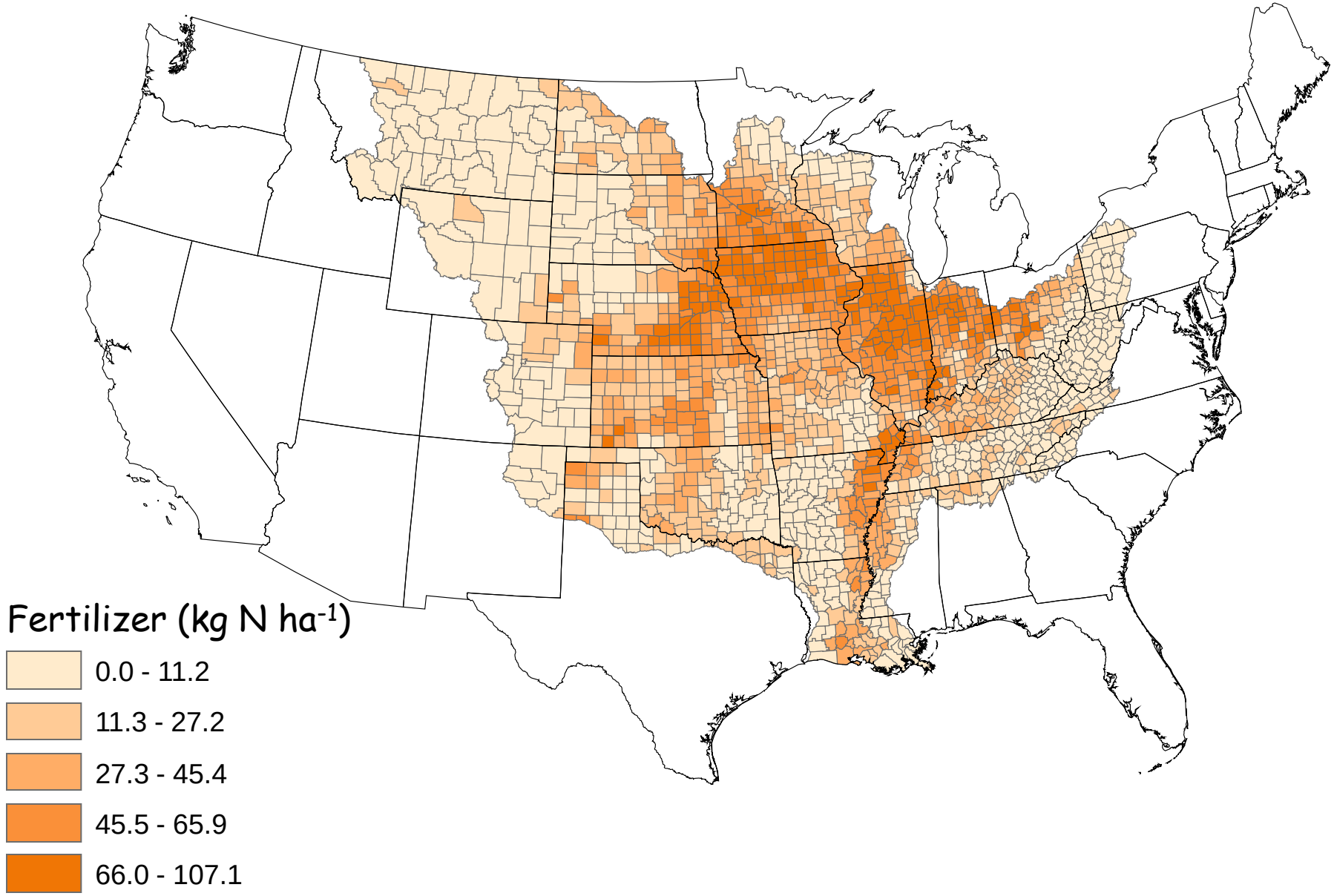
  inputs (deposition, fertilizer, fixation)

  outputs (grain harvest - human + animal consumption)

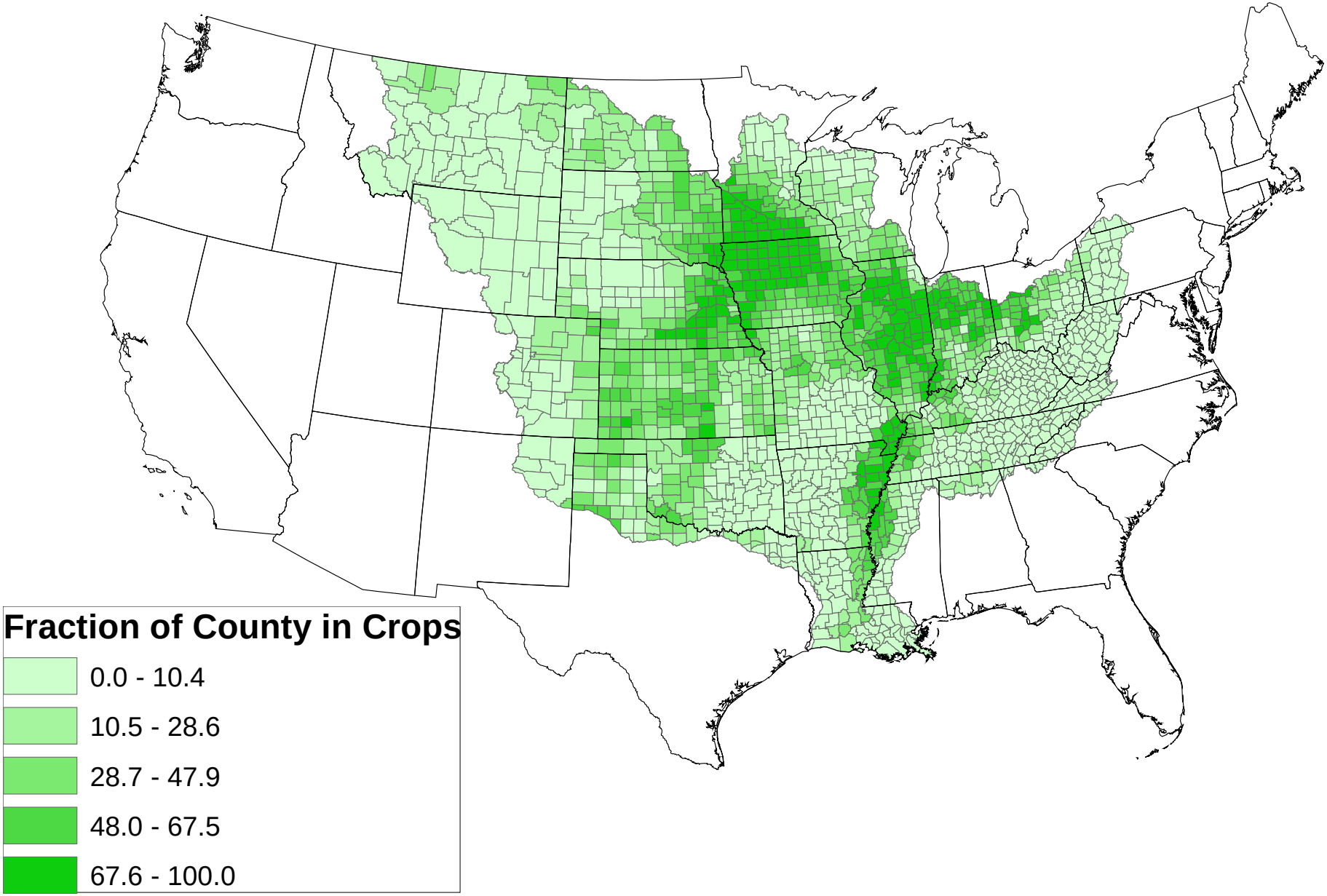
- NNI is N available for leaching, denitrification, adding to soil N pools

- data from agricultural statistics (crops and animals), fertilizer industry, assumptions about N in various components

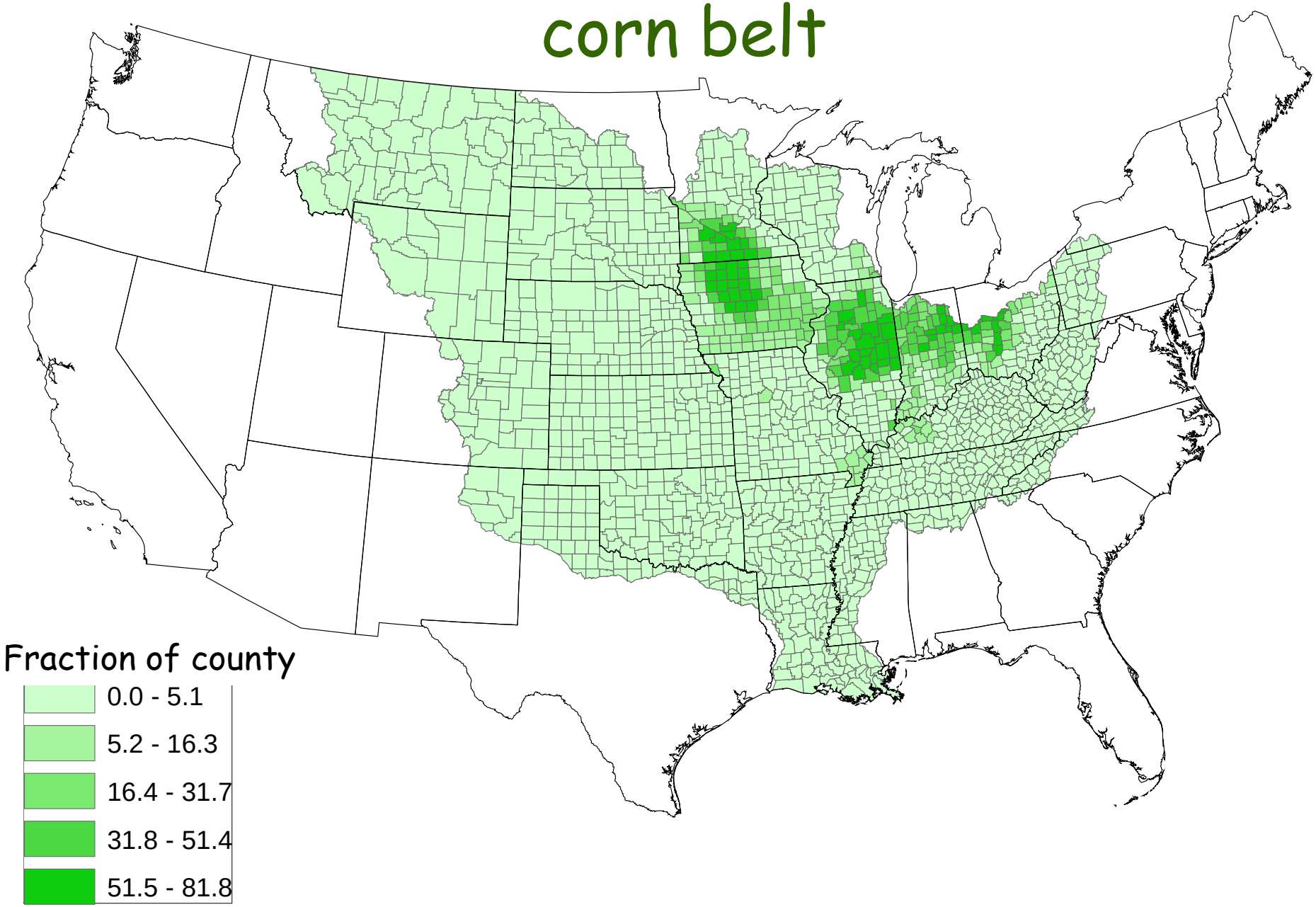
Annual N Fertilizer Applications



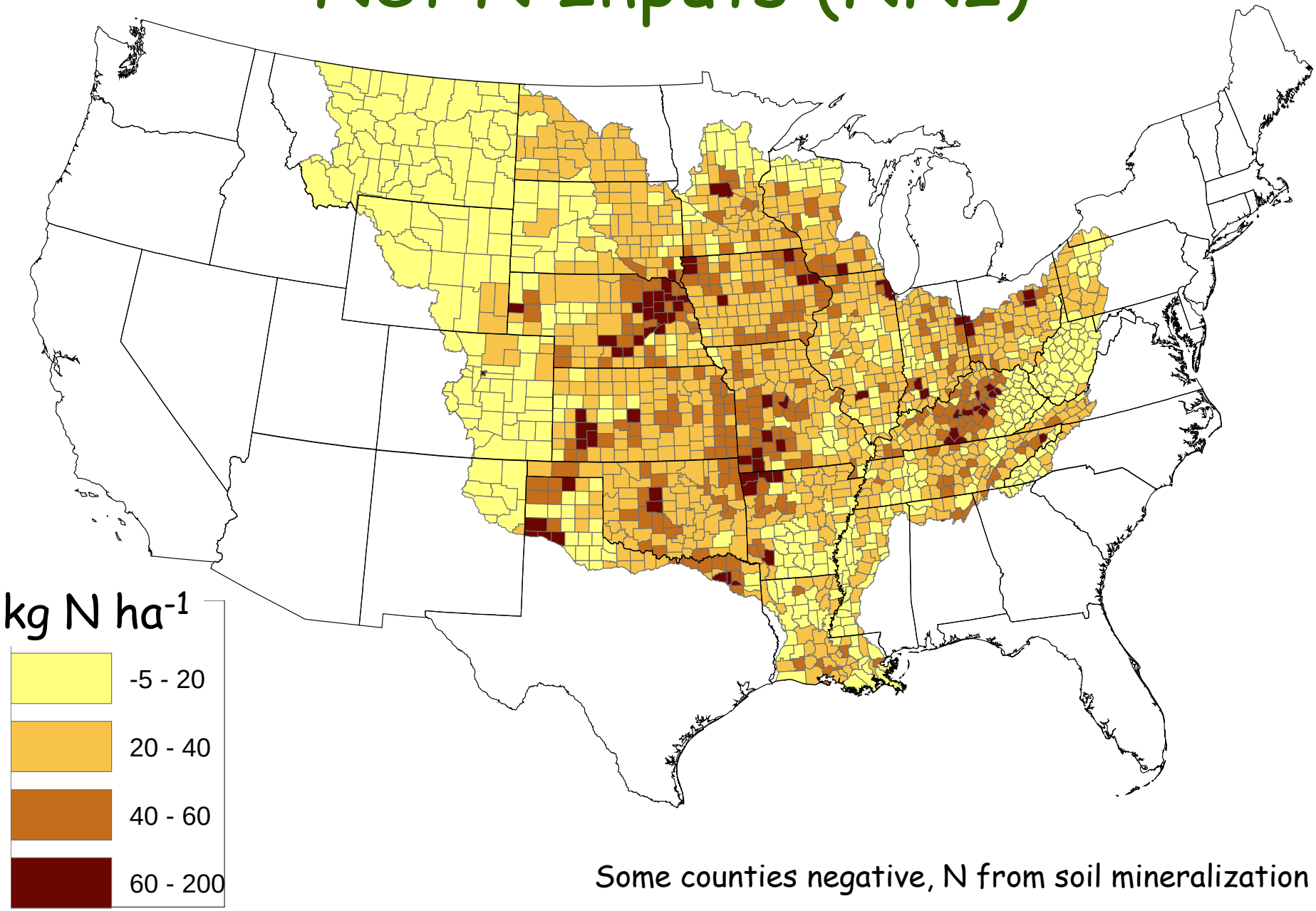
Fraction of County in Row Crops



Tile drainage is concentrated in the corn belt



Net N Inputs (NNI)

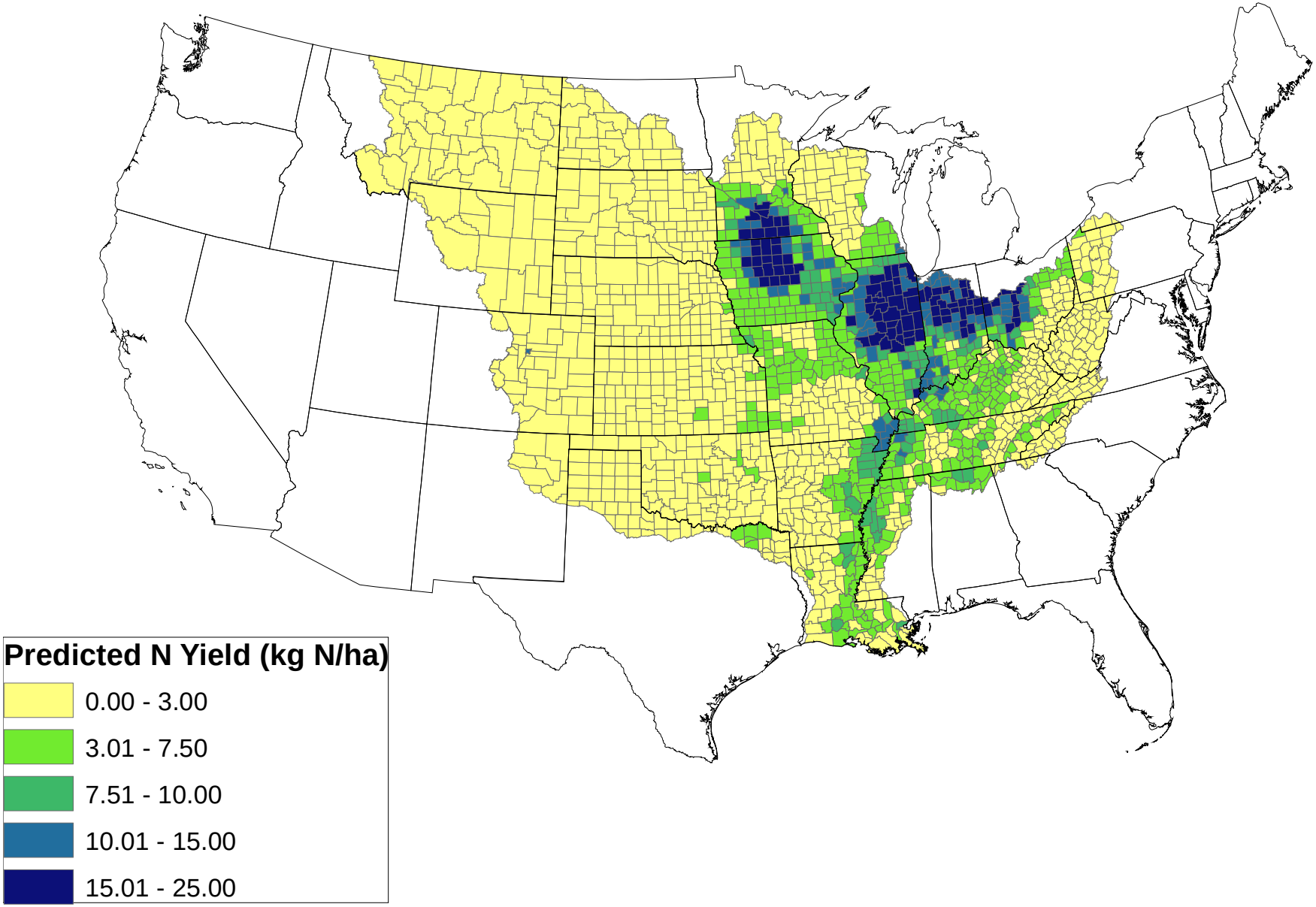


Some counties negative, N from soil mineralization

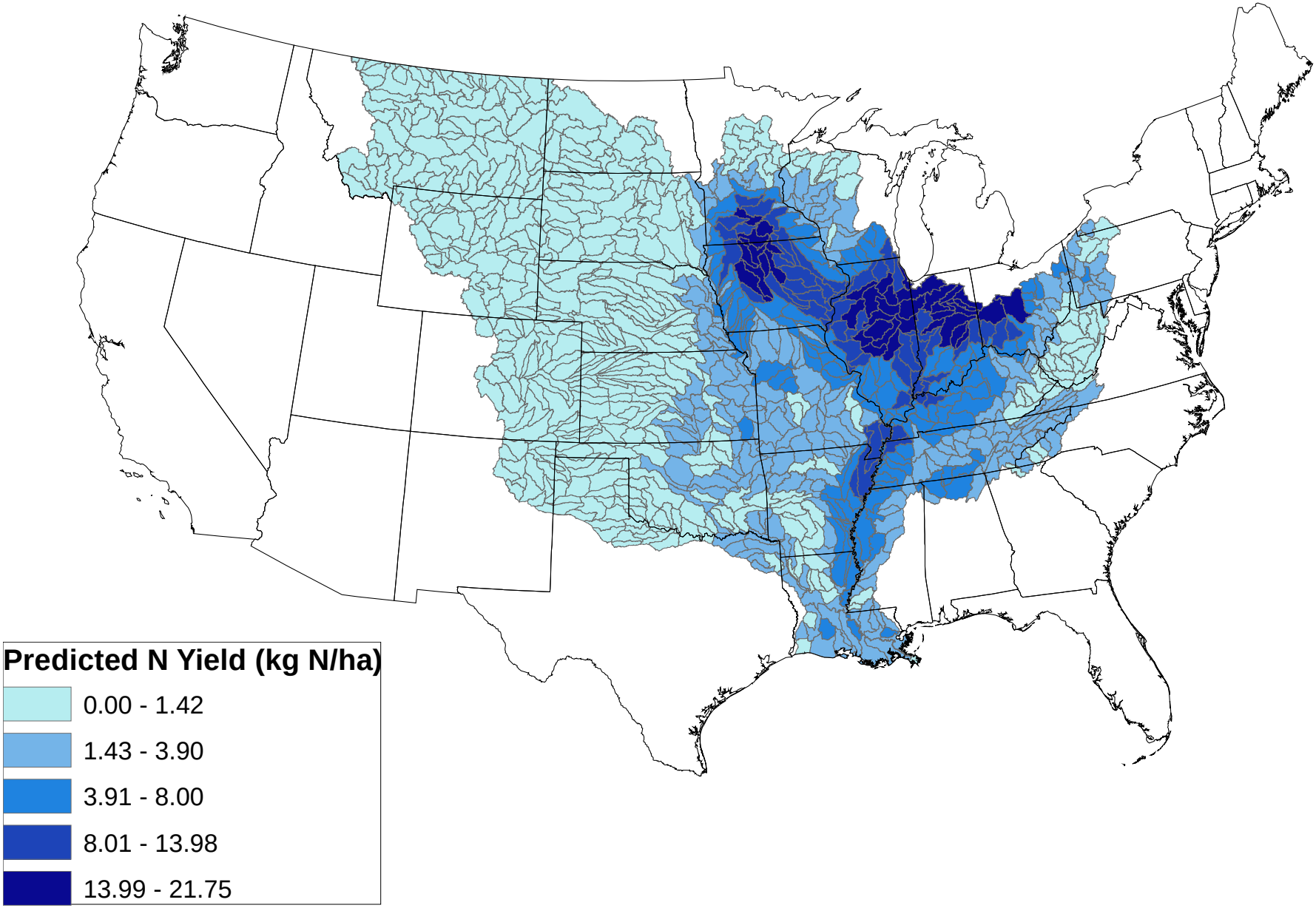
Watershed Data

- 153 from across basin
- January to June nitrate-N concentrations and flow
  - typically about 40 concentrations for a given location
- median watershed size was 1982 km^2
  - 79 to 50,360 km^2
- nonlinear model has flow* fertilizer (76%), human consumption (7%), and fraction of county tile drained (17%)

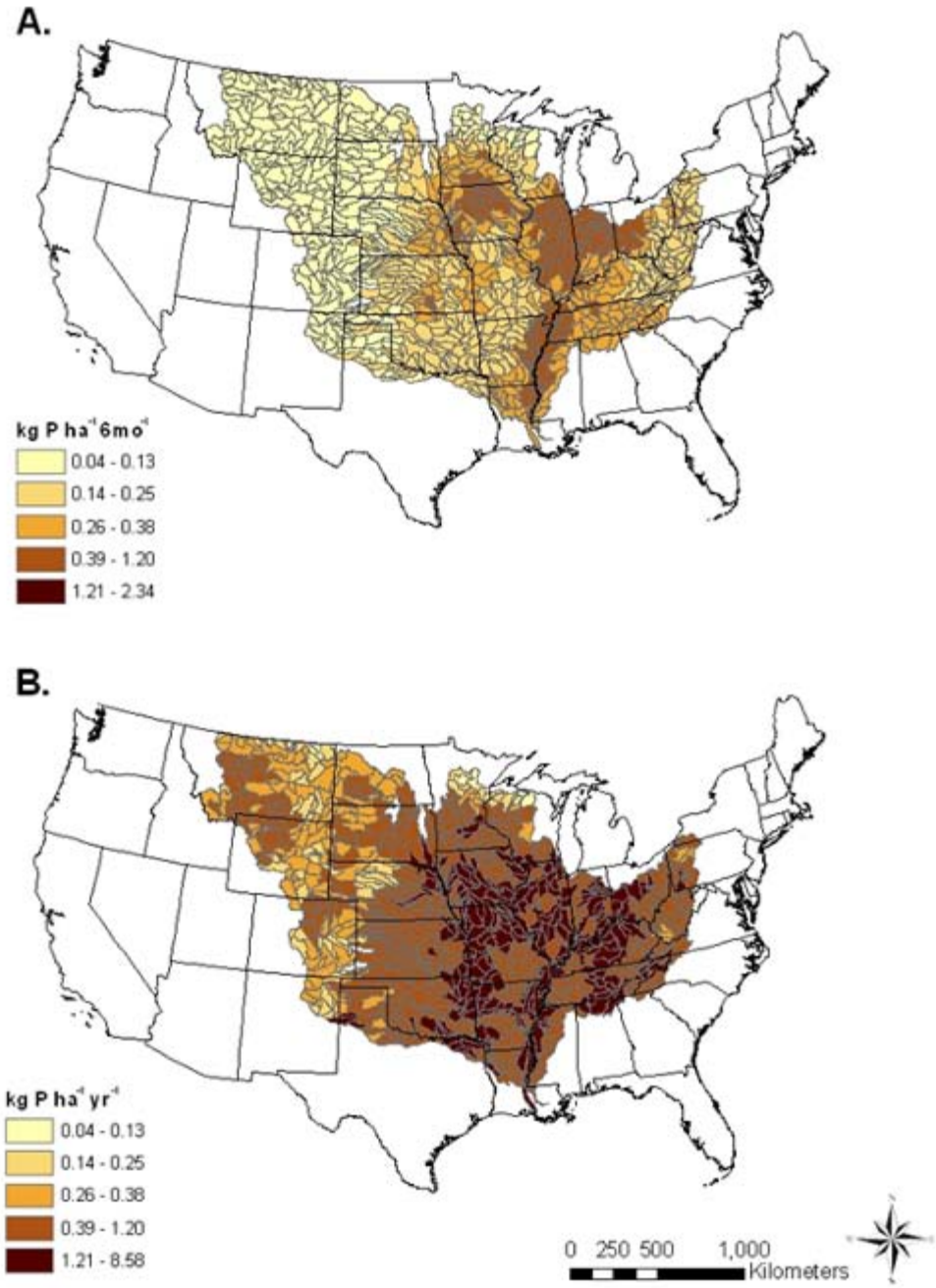
Modeled January to June Nitrate Export



January to June Nitrate-N Yield



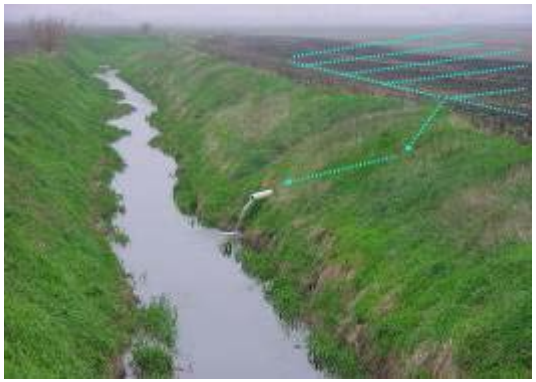
P Yields in MRB from our analysis (A) and SPARROW (B)



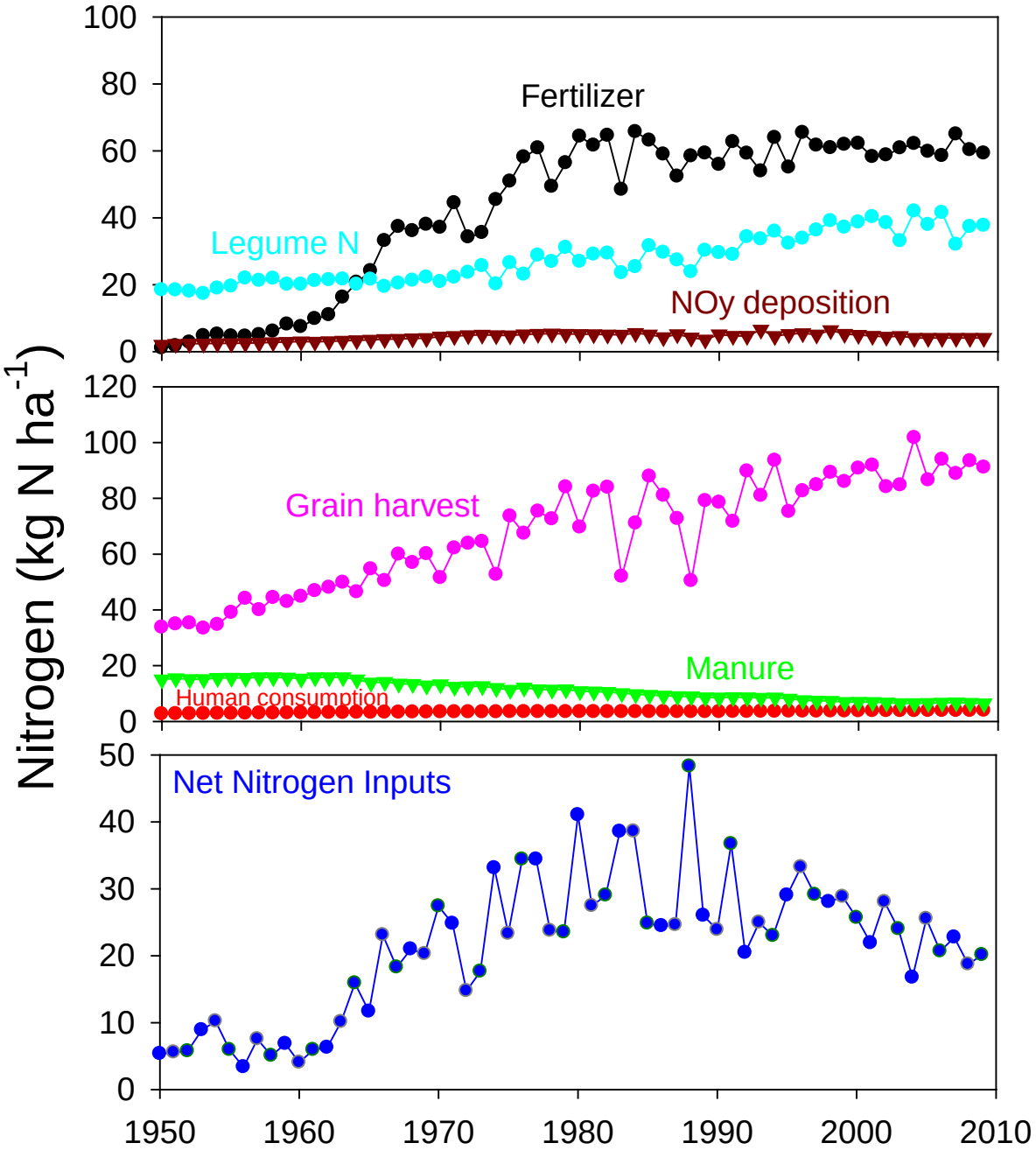
Sources of Nutrients in Illinois

- agriculture
  - surface runoff
  - tile drainage
  - many watersheds > 90% row cropped
  - animal agriculture less important

- sewage effluent
  - Illinois has ~ 12.9 million people
  - dominates upper Illinois River
  - generally, no N or P removal technology used



Illinois N budget



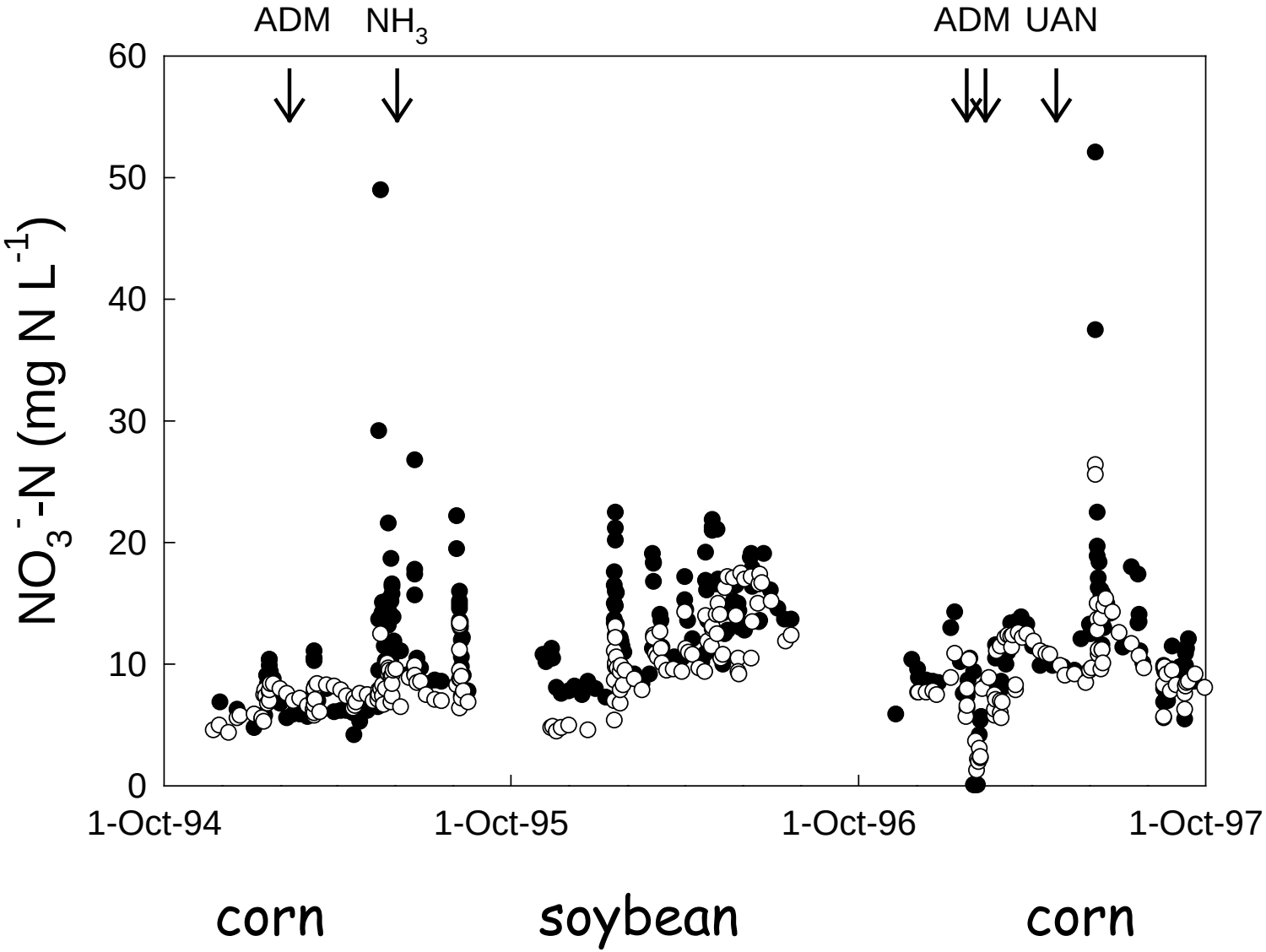
Linking N balances to N Export

- hydrology overwhelming factor
  - tile drainage, channelization
- can look at watershed N export as a fraction of net N inputs
  - most studies have found this to be about 25%
  - however in MRB we know it is larger in critical areas
  - can be > 100% in Illinois tile drained watersheds

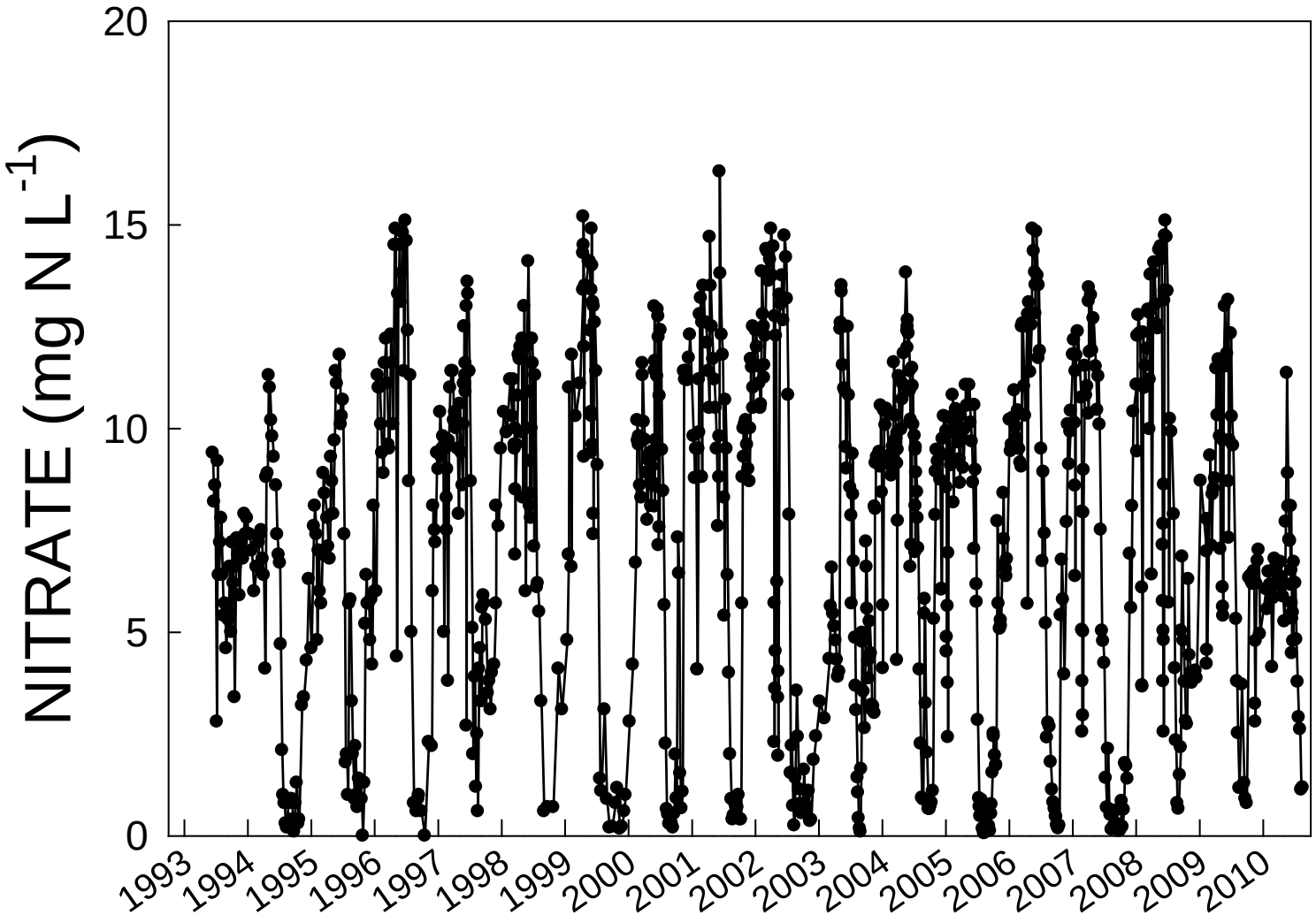
Drainage by tiles and ditches

Embarras River - Camargo

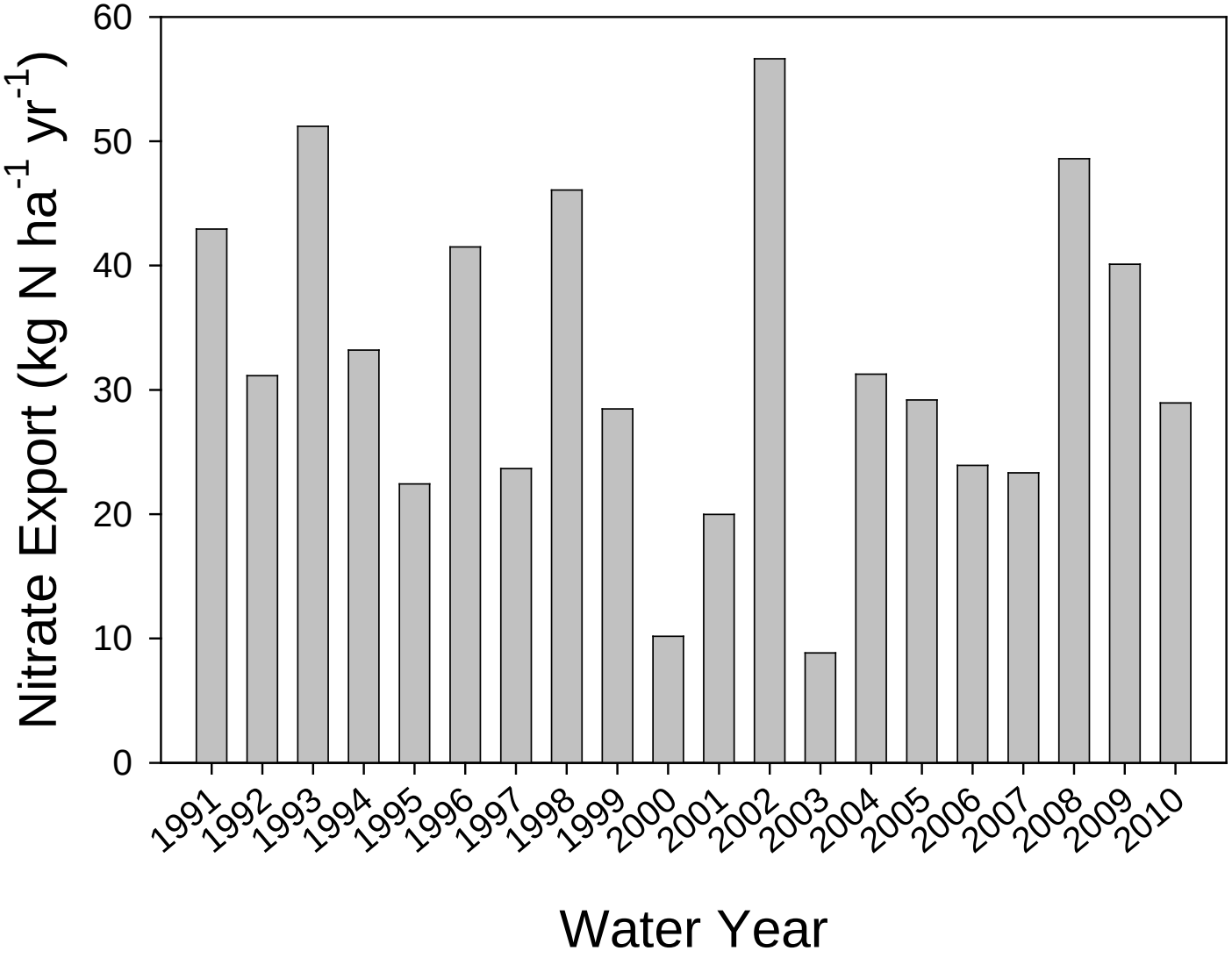
Tile nitrate concentrations



Embarras River



Embarras River



Components of Phosphorus Mass Balances

- net P inputs

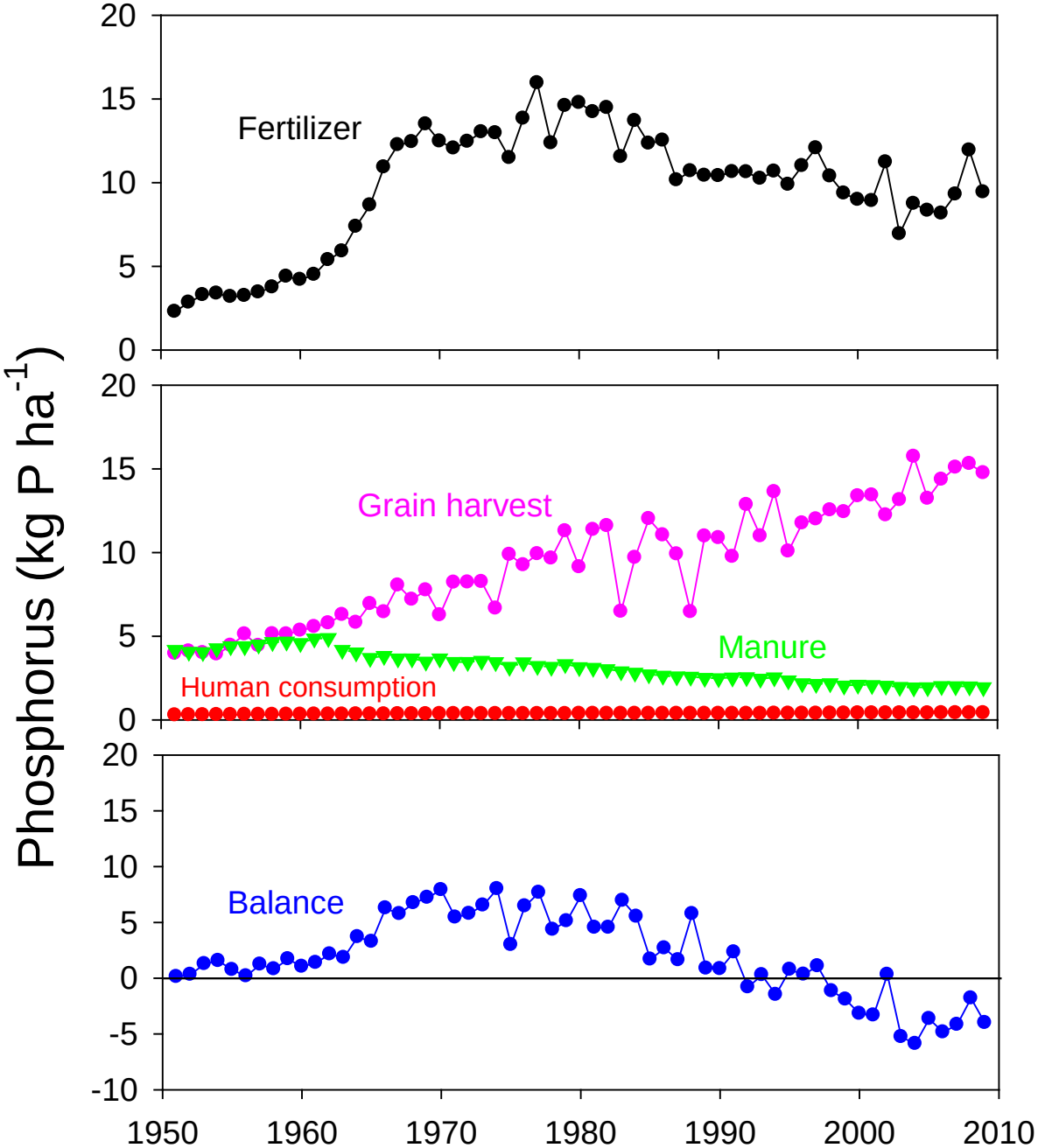
  = inputs – outputs

  inputs (fertilizer)

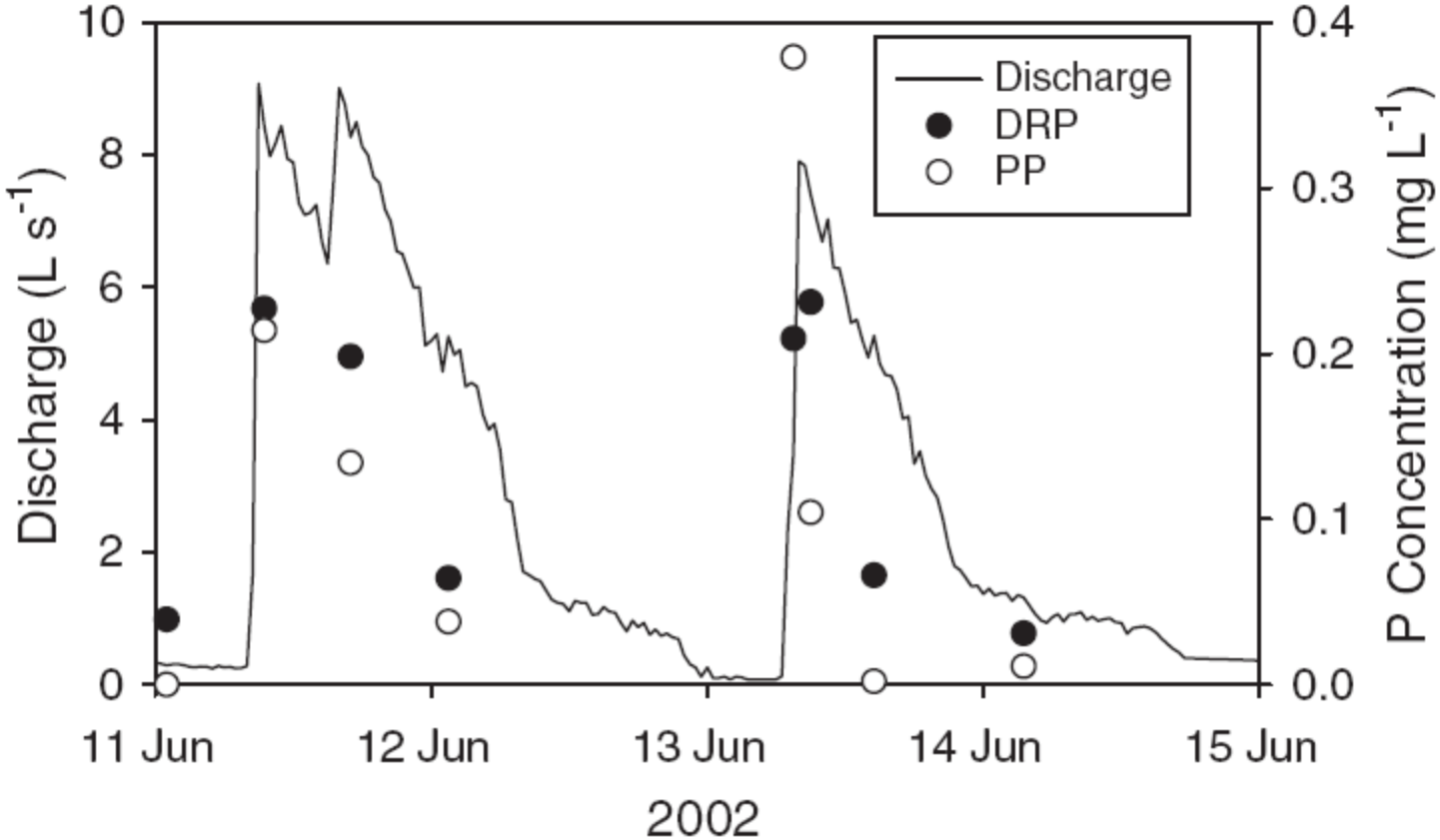
  outputs (grain harvest - human and animal consumption)

- net indicates additions or removals from soil
- little P (relative to N) is lost to streams, but it biologically important
- surface runoff and tile leaching

Illinois P budget

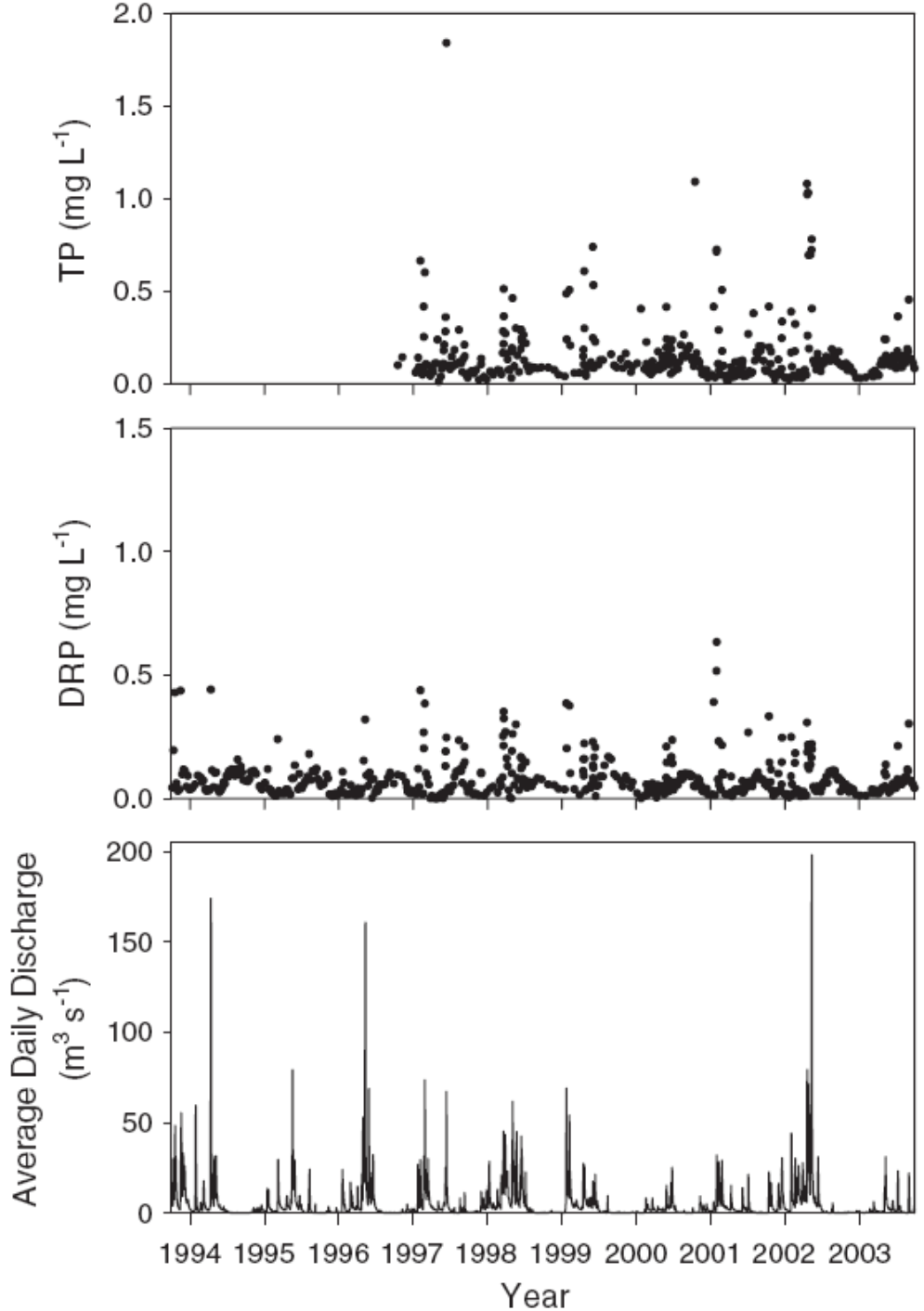


P from fields to rivers - tiles



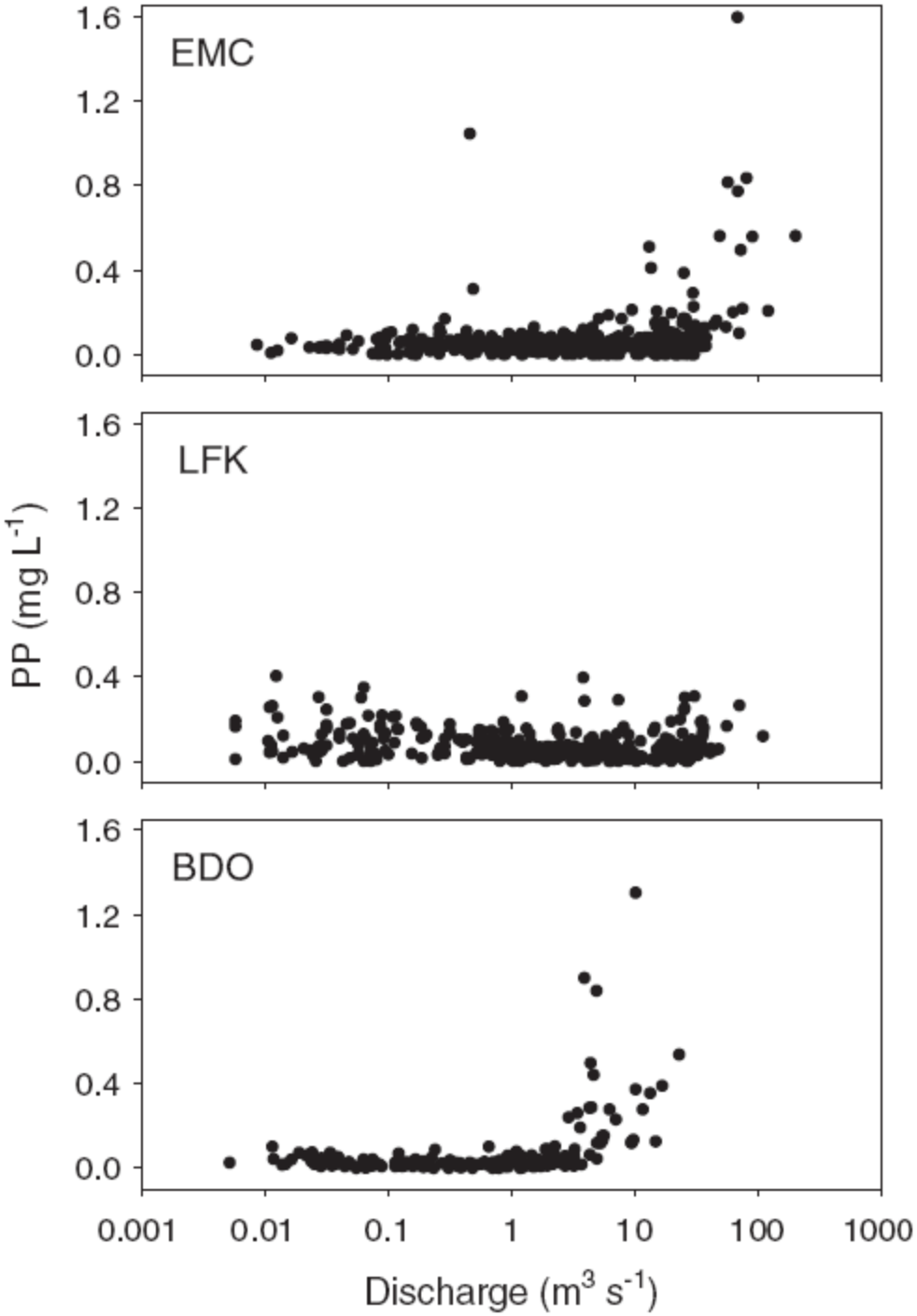
From Gentry et al. (2007)

P from fields to rivers – Embarras River



From Gentry et al. (2007)

Particulate P from fields to rivers



From Gentry et al. (2007)

Sewage Effluent –12.9 million people

16% of total N load statewide

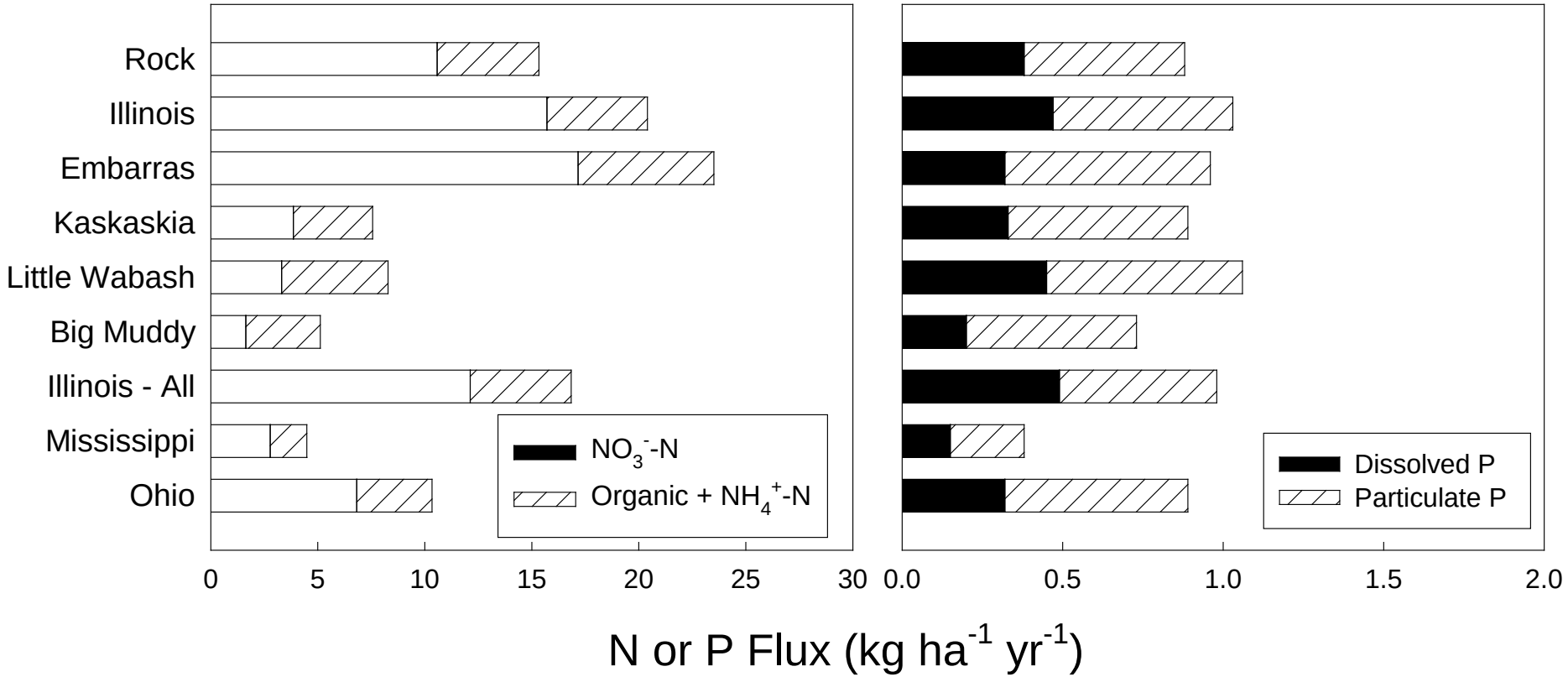
21% for Illinois River, 14% for others

47% of total P load statewide

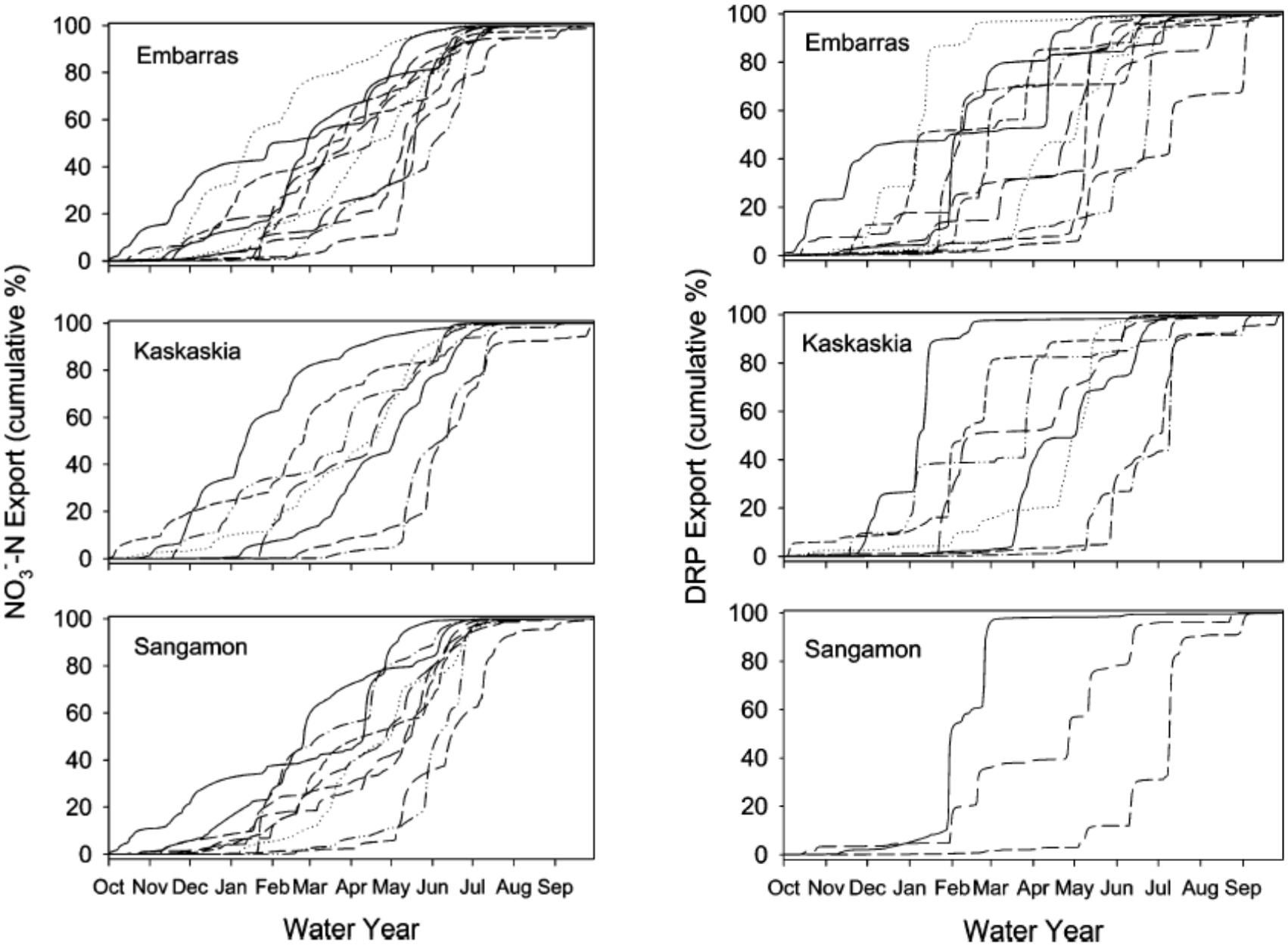
70% for Illinois River, 33% for others

From David and Gentry (2000)

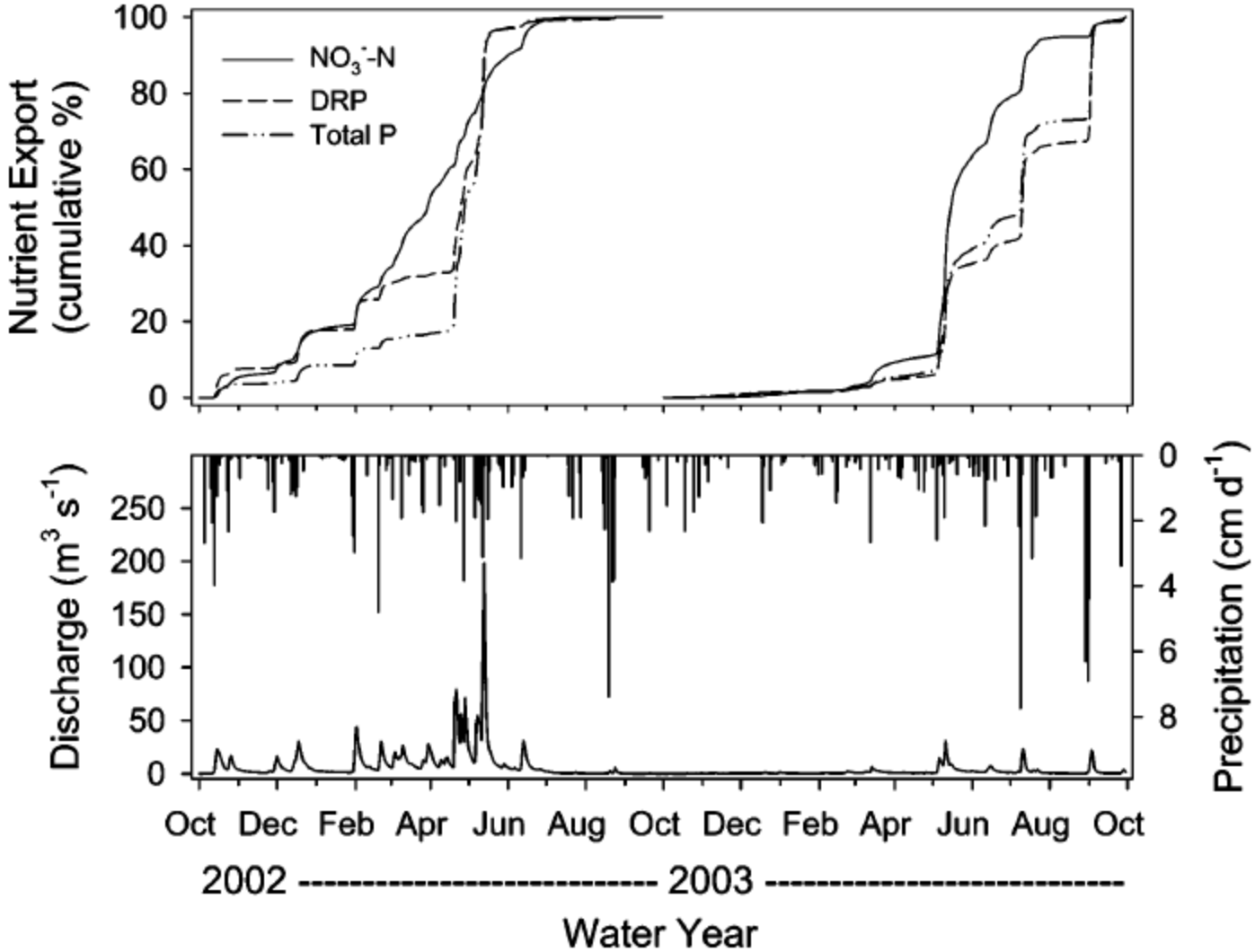
N and P Fluxes for State, 1980 to 1997



Nutrient Export Patterns



Importance of a Few Storm Events



N and P Inputs and River Export - Conclusions

- N balances don't relate well to nitrate loss across the entire MRB, or Illinois
- watersheds (counties) with high fertilizer inputs have high crop fractions (and corn acres) and tile drainage
  - all lead to riverine nitrate export
  - row crops (corn & soybean) on tile drained land much more important than manure, deposition, or sewage effluent
- P from both surface runoff and tiles
  - sewage effluent also important
- high winter/spring flow and nutrient losses are a challenge
- fall fertilizer N?

Will reducing nutrient loads (even by 45%) to the Gulf improve local water quality?

- not always clear in streams draining agricultural areas, and those with sewage effluent
- states such as Illinois, Iowa, Indiana, have few high quality streams
- difficult to find relationships between nutrients and biotic integrity
  - nearly all P concentrations above critical level
  - N relationships typically not found or very weak

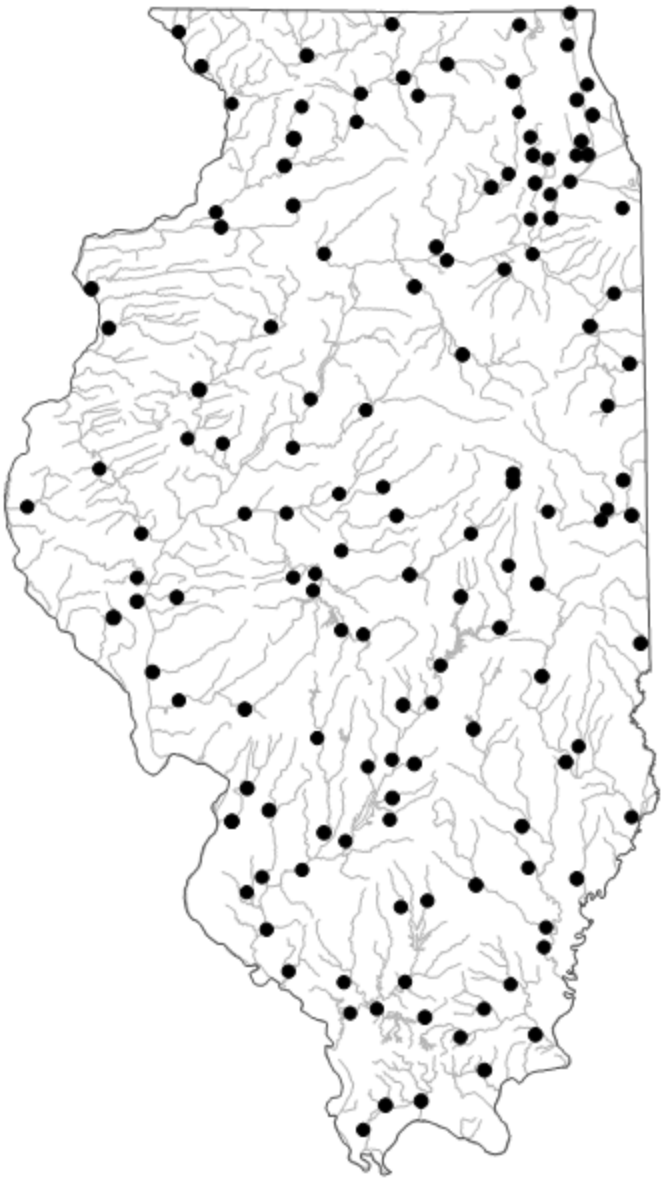
Operational Model

Light & Nutrients → Chlorophyll & O_2 respiration → Low Nighttime DO → Biotic impairment

- How strong is this relationship in Illinois streams?

- How might we modify the model to fit various categories of Illinois streams?

Extensive Sampling in 2004 and 2005



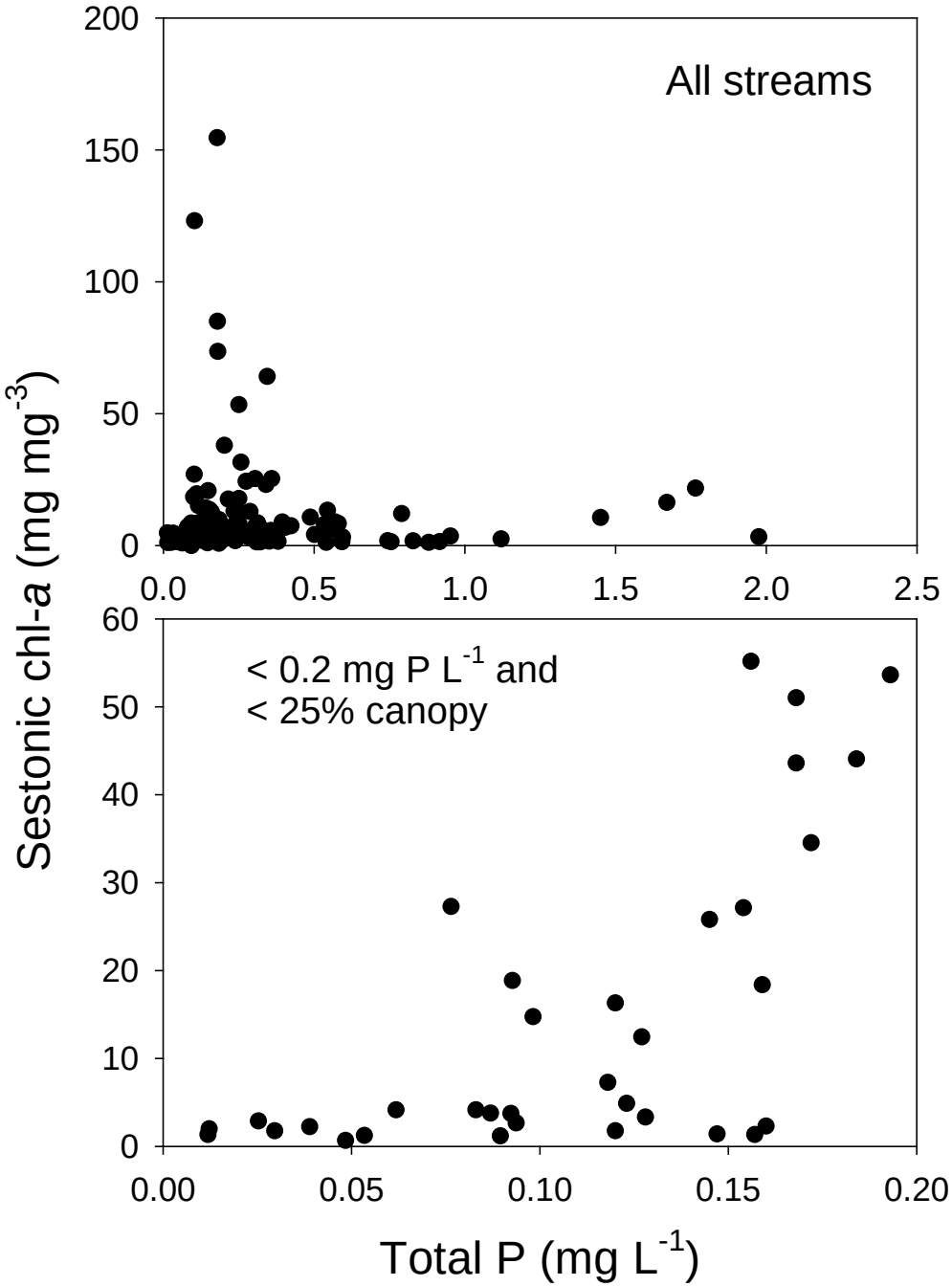
Nutrient Concentrations – seldom limiting

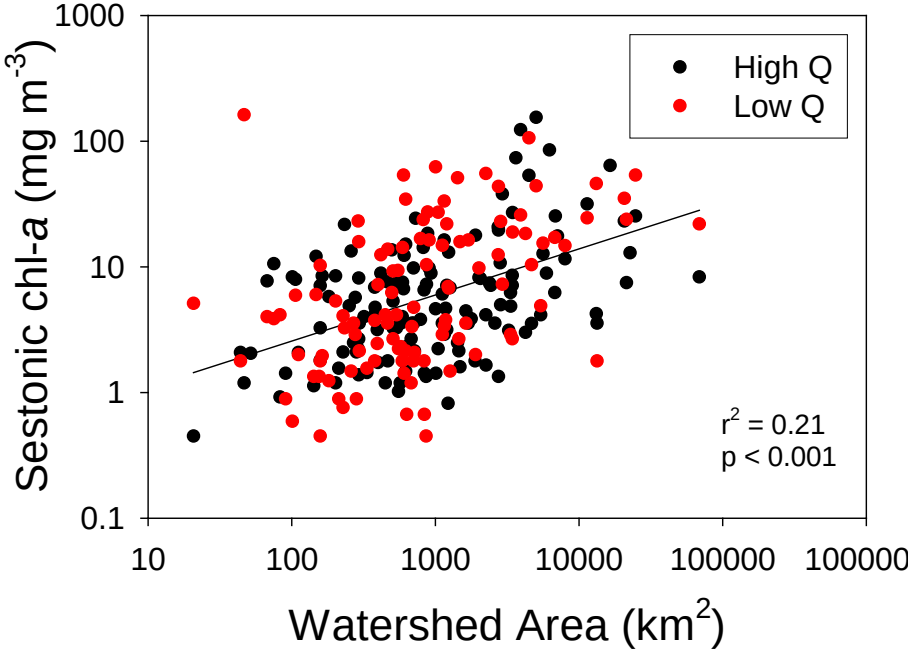
Table 1. Distribution of water chemistry values from the 2004 state-wide surveys.

	Minimum	25th Percentile	Median	75th Percentile	Maximum
High-Q† survey (May–July, $n = 138$)					
DRP‡ (mg L^{-1})	<0.005	0.038	0.069	0.156	1.9
Total P (mg L^{-1})	0.013	0.123	0.185	0.326	2.0
NH_4–N (mg L^{-1})	0.008	0.040	0.058	0.089	0.387
NO_3–N (mg L^{-1})	0.10	1.0	4.3	10.2	20.2
Total N (mg L^{-1})	0.37	2.2	5.6	11.0	20.9
Silica (mg L^{-1})	1.5	6.7	9.6	11.8	16.6
pH	7.0	7.7	7.9	8.1	8.7
Specific conductivity (μS cm^{-1} @ 25°C)	106	586	658	751	2240
Turbidity (NTU§)	<1	21	36	61	614
Low-Q survey (Sept., $n = 109$)					
DRP (mg L^{-1})	0.001	0.029	0.081	0.345	2.8
Total P (mg L^{-1})	0.007	0.112	0.168	0.456	2.8
NH_4–N (mg L^{-1})	0.002	0.011	0.022	0.042	0.696
NO_3–N (mg L^{-1})	<0.05	0.18	1.5	3.9	18.0
Total N (mg L^{-1})	0.21	1.0	2.5	5.0	18.7
Silica (mg L^{-1})	1.3	6.4	8.6	11.2	29.2
pH	6.8	7.6	7.9	8.2	8.9
Specific conductivity (μS cm^{-1} @ 25°C)	132	556	664	814	3246
Turbidity (NTU)	<1	10	18	29	159

From Royer et al. (2008)

Illinois Streams





From Royer et al. (2008)

Macroinvertebrate Results

- four major groups based on taxa dissimilarity
- habitat quality and nutrients responsible for separation
- streams with high quality habitats had low concentrations of nutrients
- biological integrity (forested > agricultural > urban)
- physical habitat degradation confounded with nutrients

From Heatherly et al. (2007)

Dissolved oxygen in Illinois streams

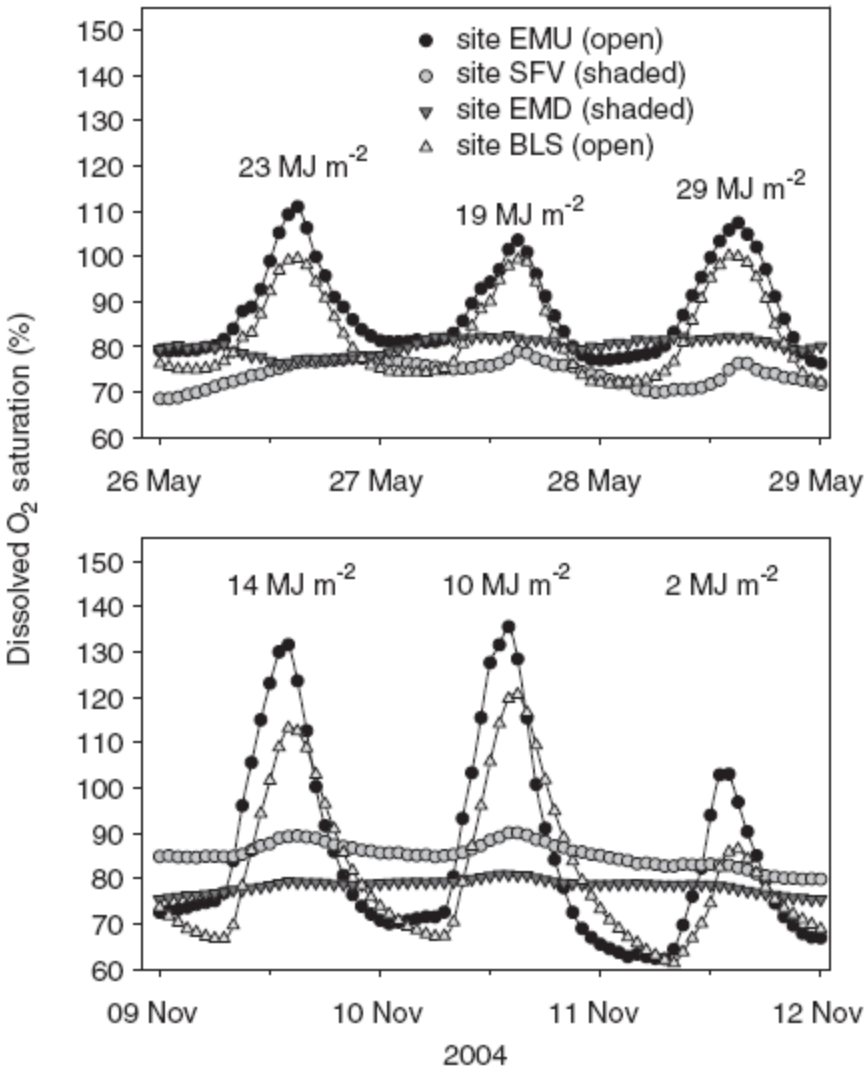
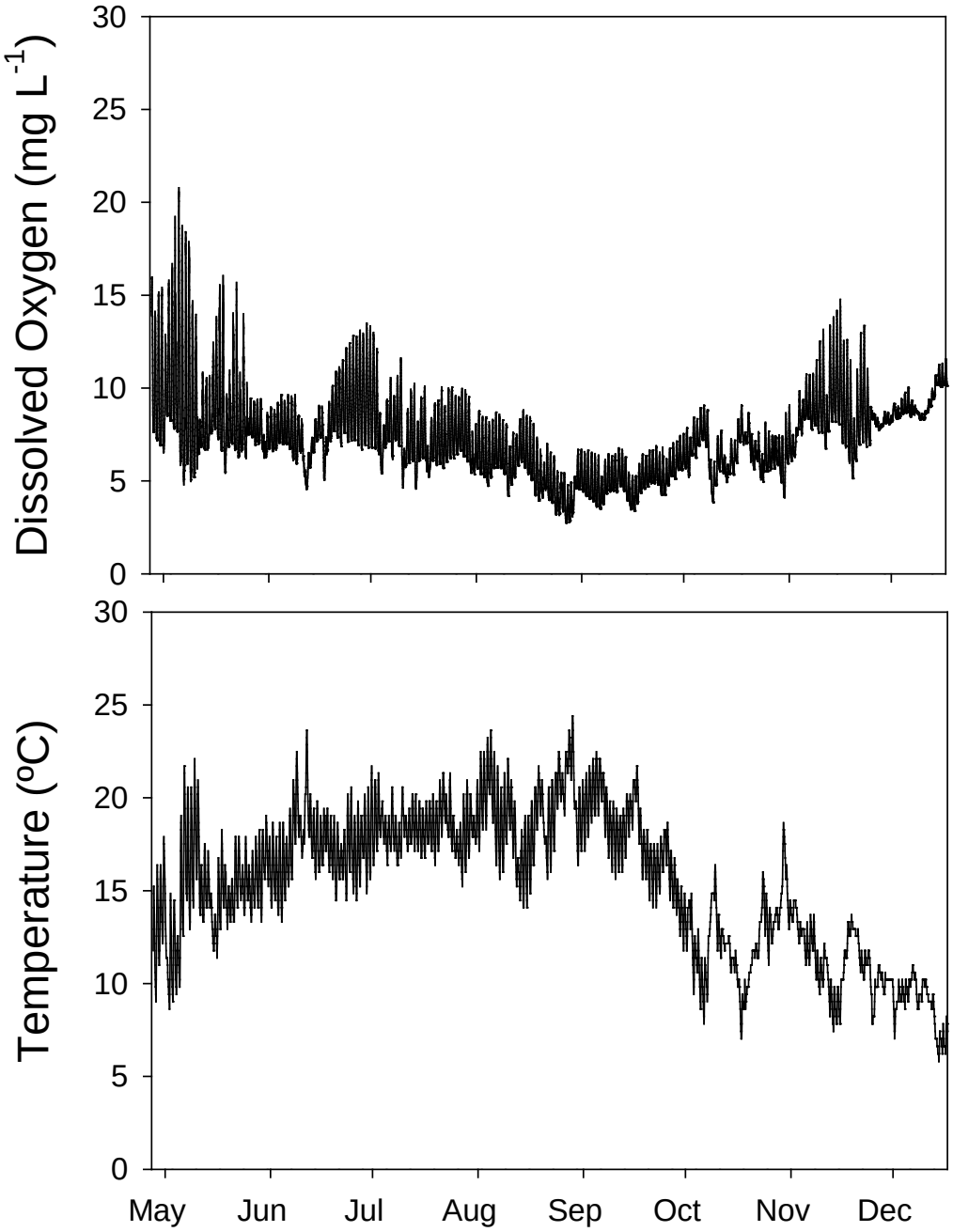


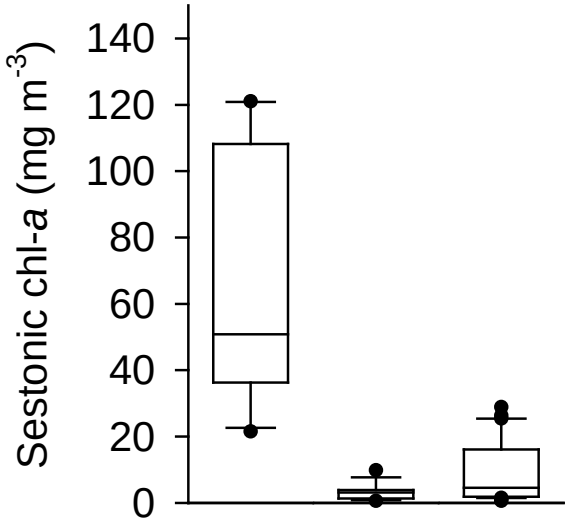
Fig. 6. Dissolved O_2 patterns during (upper) late May and (lower) early November 2004 in two open-canopy and two shaded agricultural streams. Daily solar radiation values were measured at Site BLS (open canopy) and do not reflect available light at the water surface for the shaded sites.

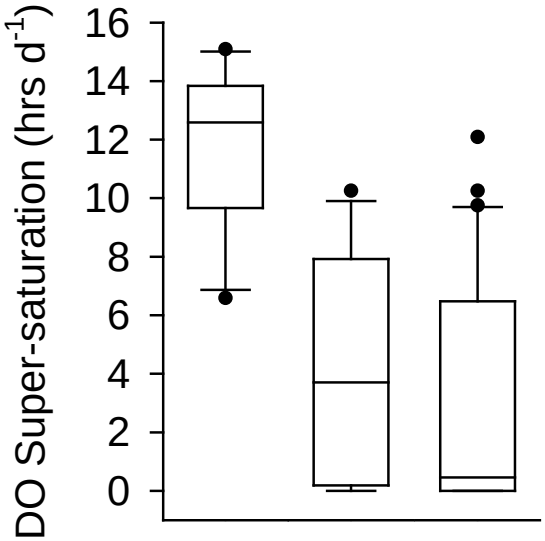
From Morgan et al. (2006)

Black Slough (small headwater stream)



Grouping streams for water quality

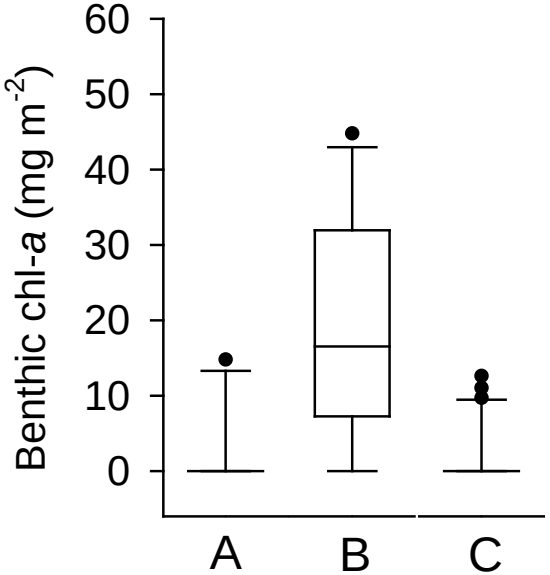


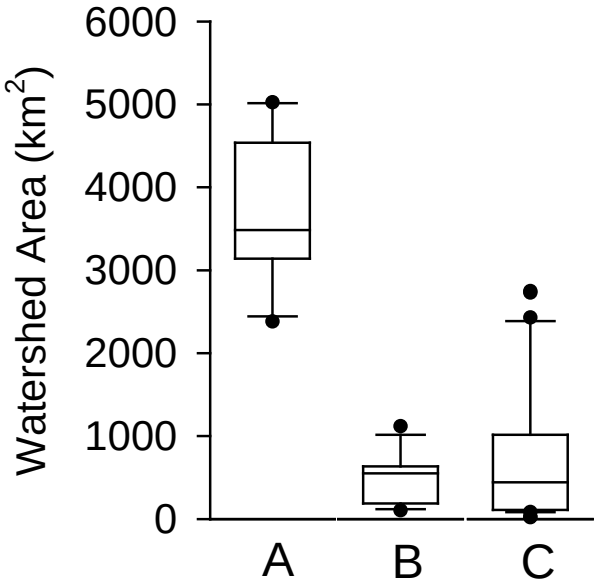


A

B

C





Nutrient Criteria with Complex Relationships

- correlations/regressions unlikely to work
  - much of the data are not normally distributed
- nutrient, chl-*a*, dissolved oxygen, and biotic integrity linked but not straightforward
  - is increased chl-*a* enough?
- can't study every site
- how to get overall relationships?

Modifications to Original Model

Light & Nutrients → Chlorophyll & O_2 respiration → Low Nighttime DO → Biotic impairment

Light & Substrate appear more important than nutrients

(Nutrients generally not limiting)

Diel range in DO more consistently affected than the DO minima

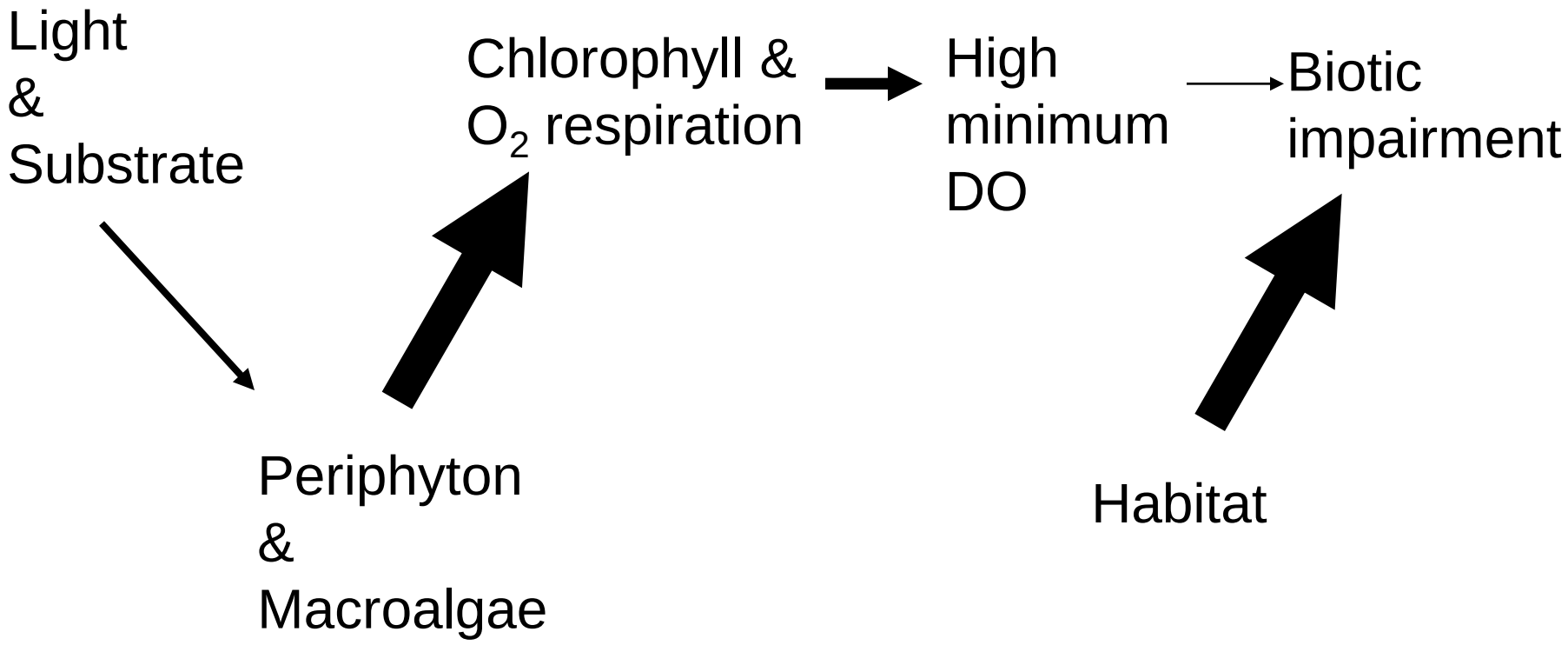
Physical habitat appears to play a much large role than nutrients

Small to medium streams

Modified Model for Illinois (1)

Small to medium streams

(in which nutrients are **almost** never limiting)



Medium streams

Modified Model for Illinois (2)

Medium streams

(in which nutrients are never limiting)

Limited by light, substrate, and/or time

Chlorophyll & O_2 respiration → Small Diel DO Range → Biotic impairment

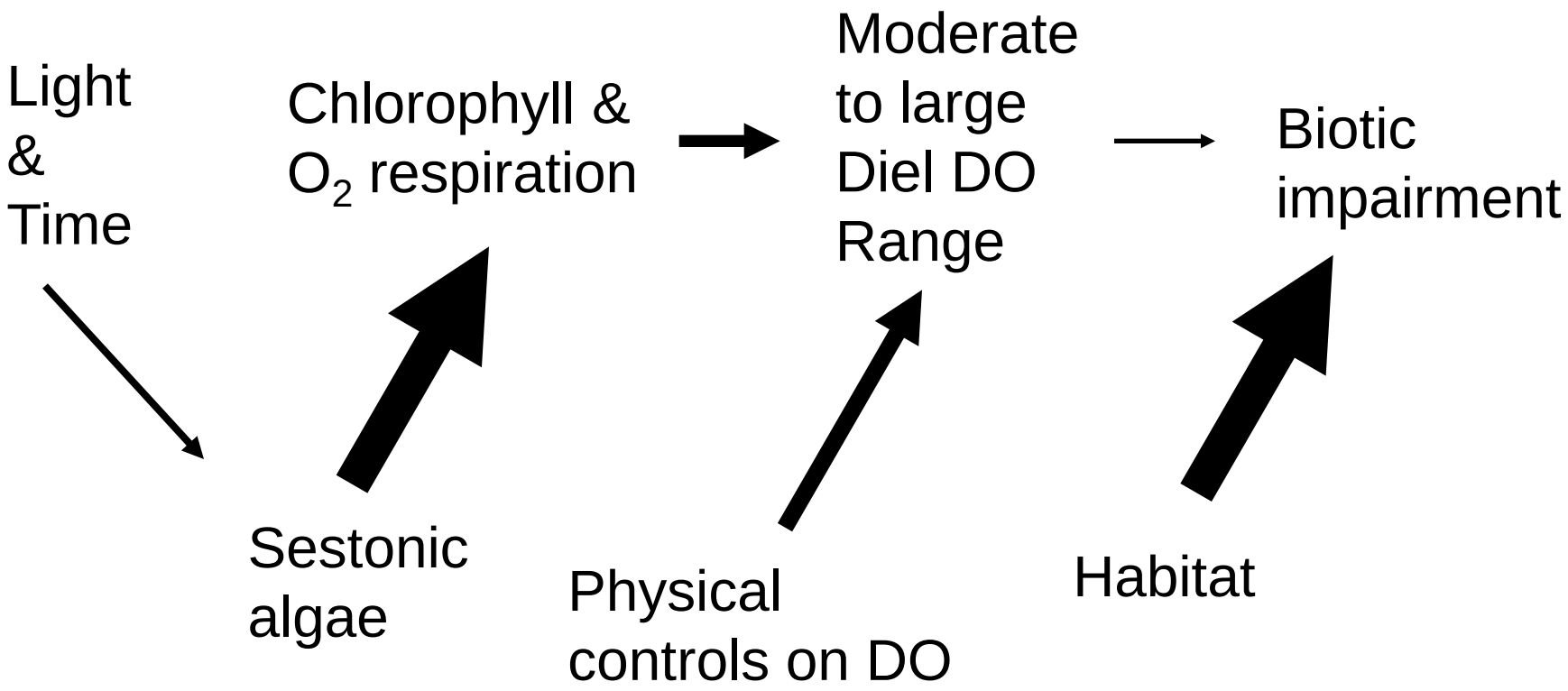
Limited Sestonic, Periphyton or Macroalgae

Habitat

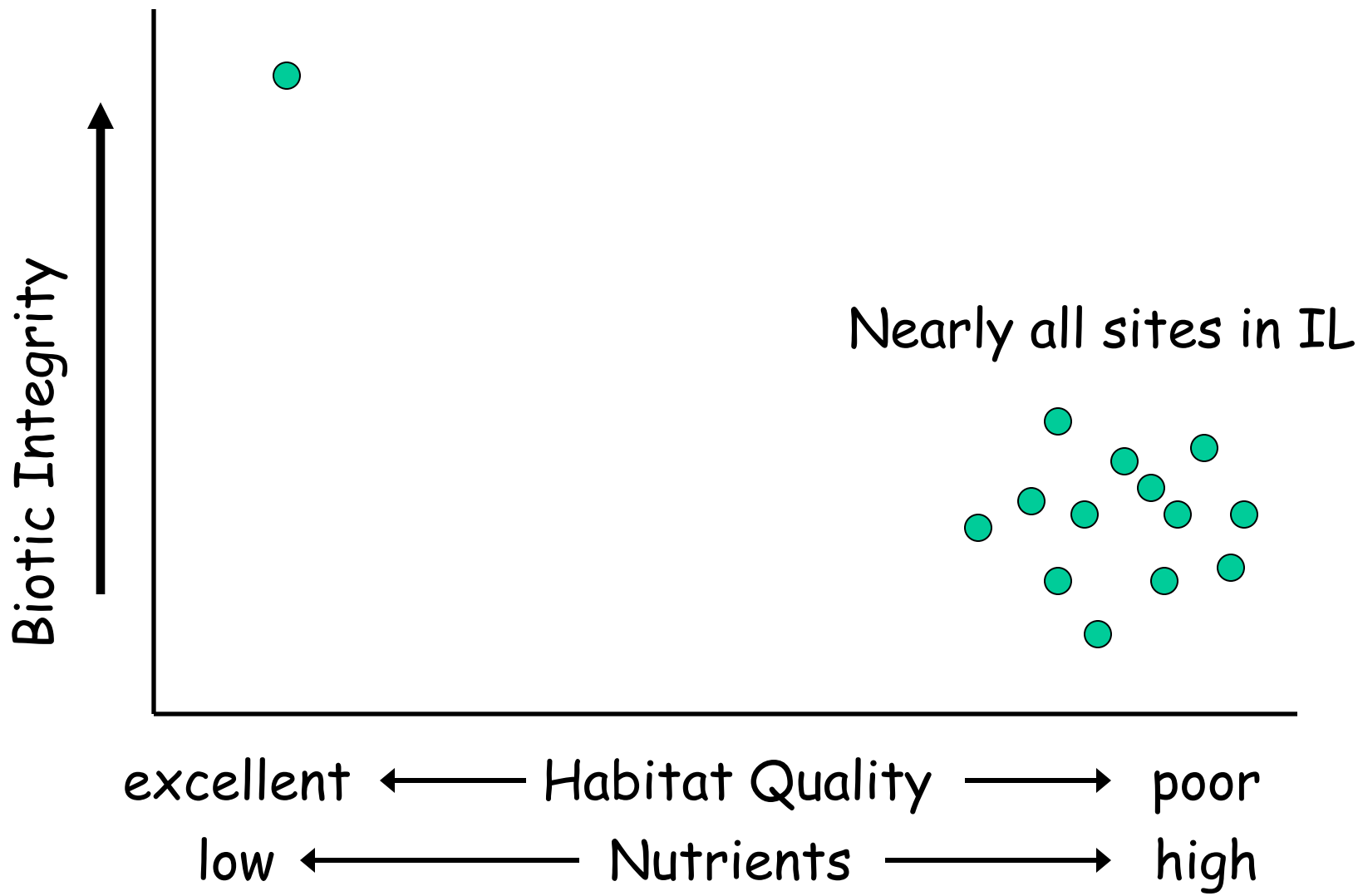
Medium to large rivers

Modified Model for Illinois (3)

Medium to large rivers
(in which nutrients are never limiting)



Nutrients and Biotic Integrity



Conclusions – Illinois Local Water Quality

- complex relationships at each step
  - many factors confounded
- nutrients almost never limiting algal biomass
- cluster analysis supports conceptual models
  - large river (sestonic, lower min DO, large diel range)
  - small streams with clear water (periphyton, high min DO)
  - many intermediate streams (little productivity, limited DO diel range)
- physical habitat (including sediment) major limit to biotic integrity throughout the state
  - improve habitat (reduce sediments), nutrients likely become more of a problem
  - relationships difficult to establish because Illinois lacks a wide range of conditions

Thank you