NUTRIENTS IN WATER:
TRANSPORT, TRENDS, AND BIOLOGICAL RESPONSE

Jeff Frey

Indiana-Kentucky Water Science Center

USGS science for a changing world

December 14, 2016

WHAT ARE NUTRIENTS?

- Elements required for growth in plants and animals
- **Macronutrients** (6): C, H, O, **N**, **P**, S
- **Micronutrients** (20): B, F, Na, Mg, **Si**, Cl, K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Se, Mo, Sn, I

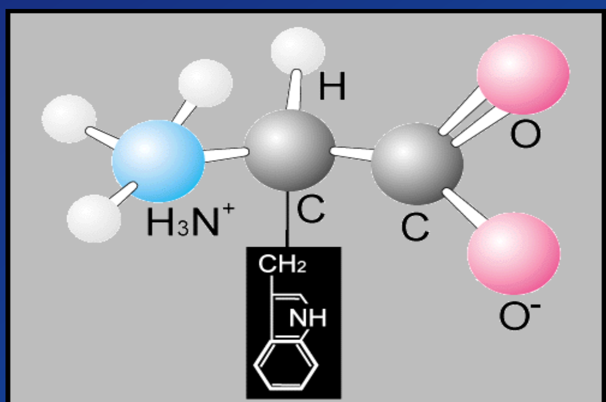
- Most macro- and micronutrients are generally readily available and rarely limit growth
  - Exceptions: **N**, **P**, and to a lesser extent **Si**

NITROGEN AND PHOSPHORUS

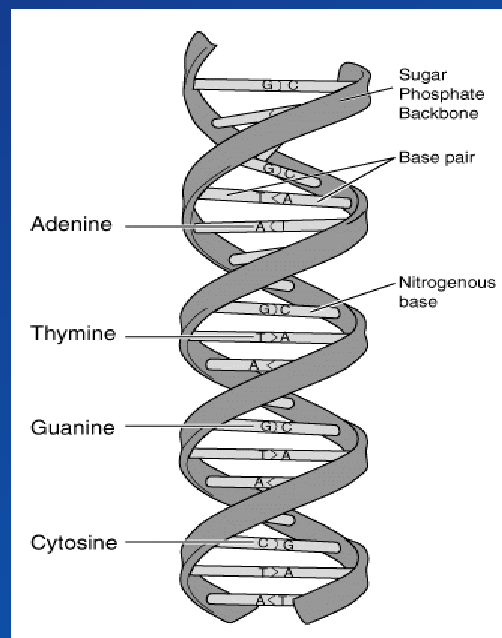
Nitrogen: amino acids (all proteins), nucleic acids (DNA, RNA)

Phosphorus: nucleic acids, organelle walls (P-lipids), energy molecules (ADP/ATP/NADP)

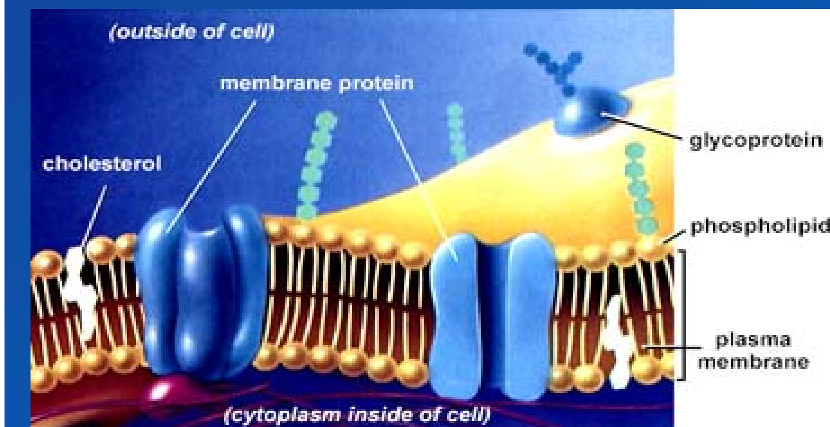
From Michael Paul, Tetratech



A. Acid (Tryptophan)



DNA



Phospholipid Bilayer

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NUTRIENT PRIMER

NUTRIENT SOURCES

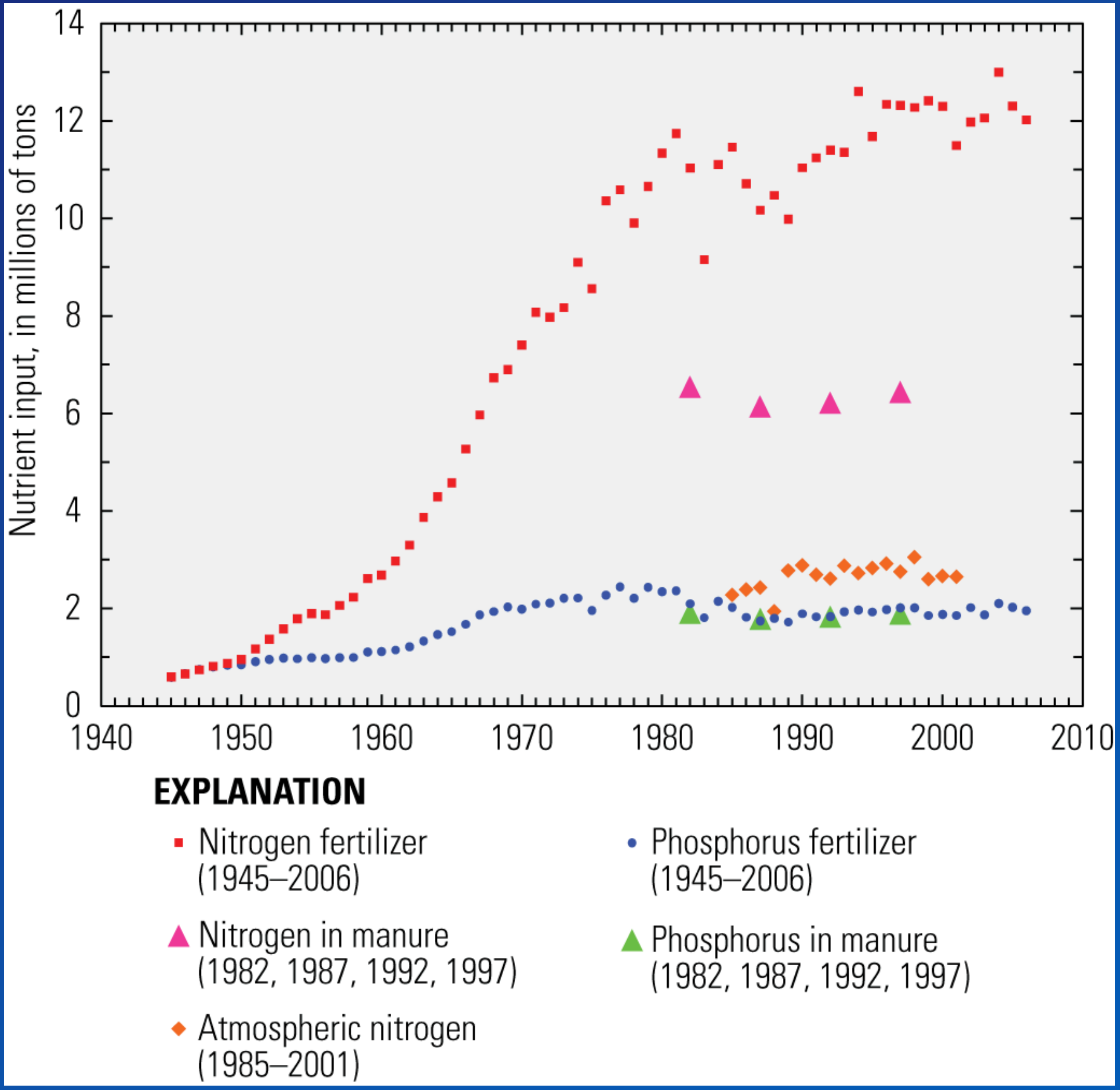
Agricultural

- Fertilizers
- Animal feed lots
  - Confined
  - Unconfined
- Septic systems

Urban

- Waste Water Treatment Plants
- Lawn fertilizers
- Industry

Natural occurrences



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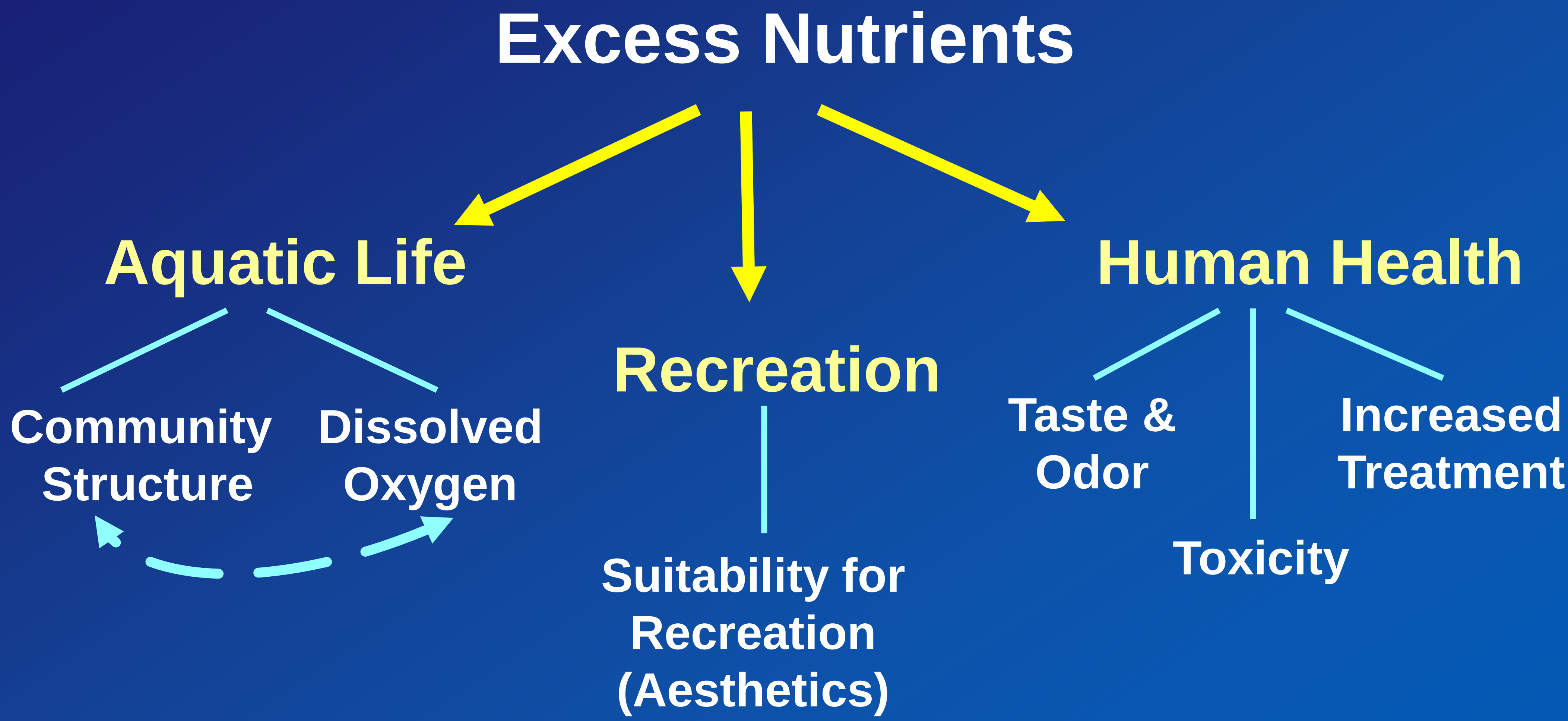
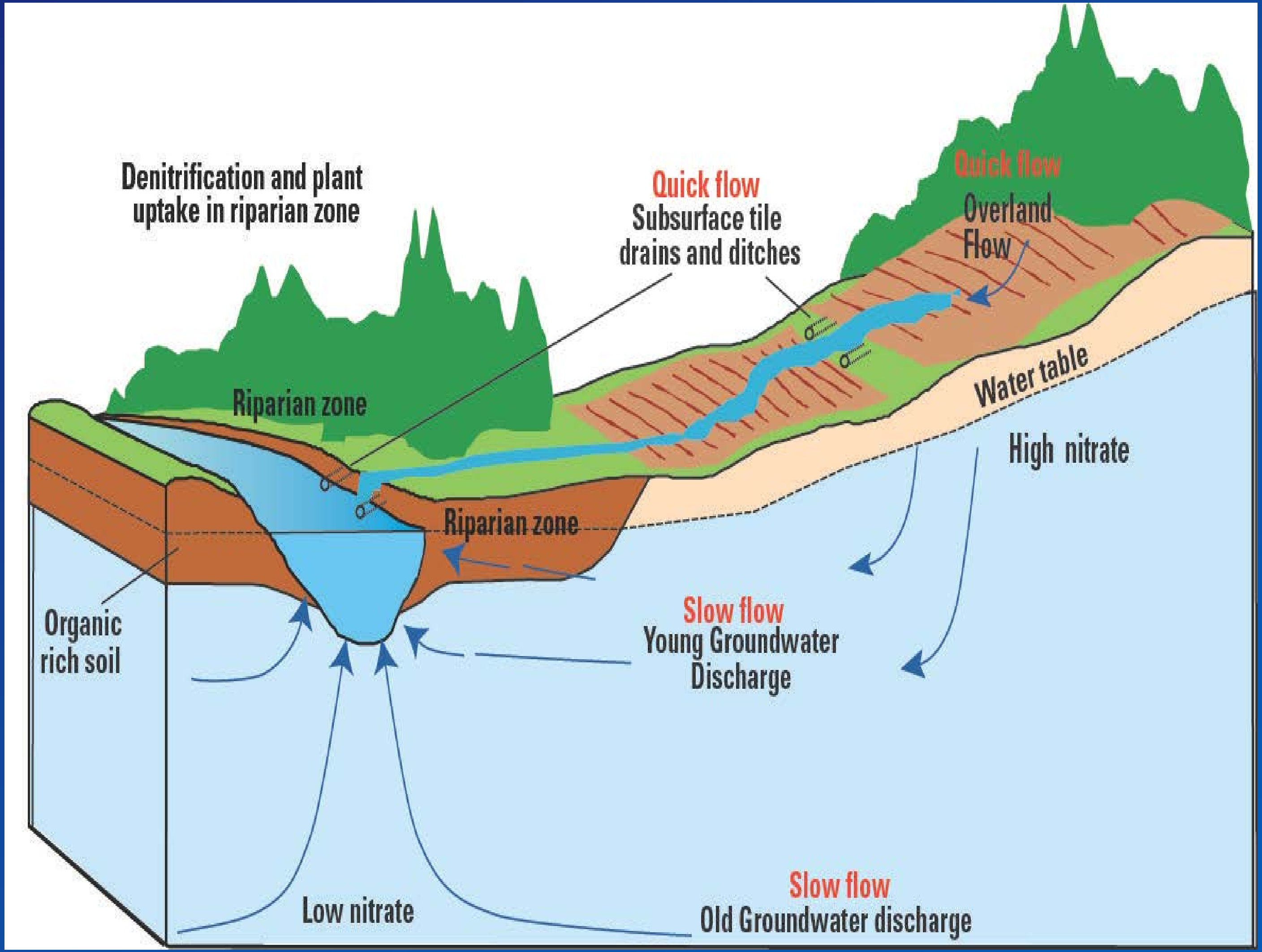
IMPACTS OF EXCESS NUTRIENTS

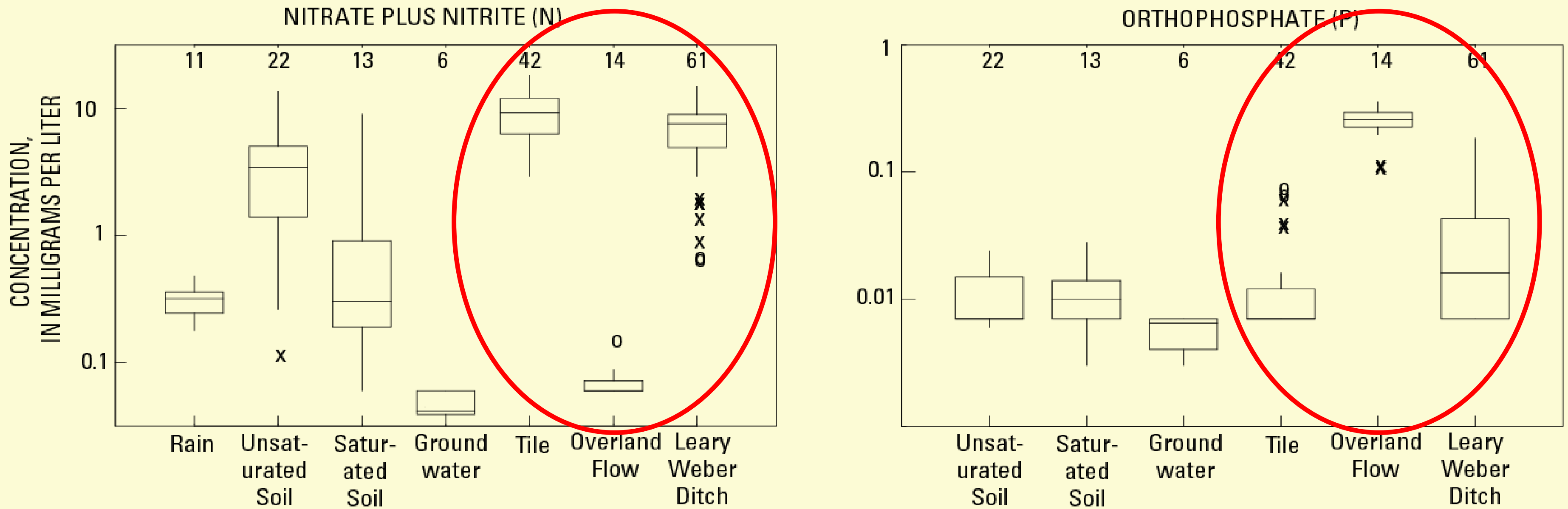


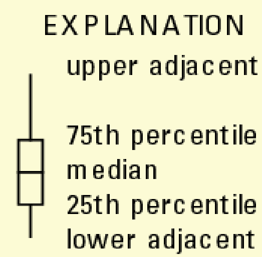
HOW DO NUTRIENTS GET INTO STREAMS?

- Hydrology
  - Fast
  - Slow
- Chemistry
  - Dissolved
    - Nitrogen
  - Particulate
    - Phosphorus



How Do Nutrients Get Into Streams?





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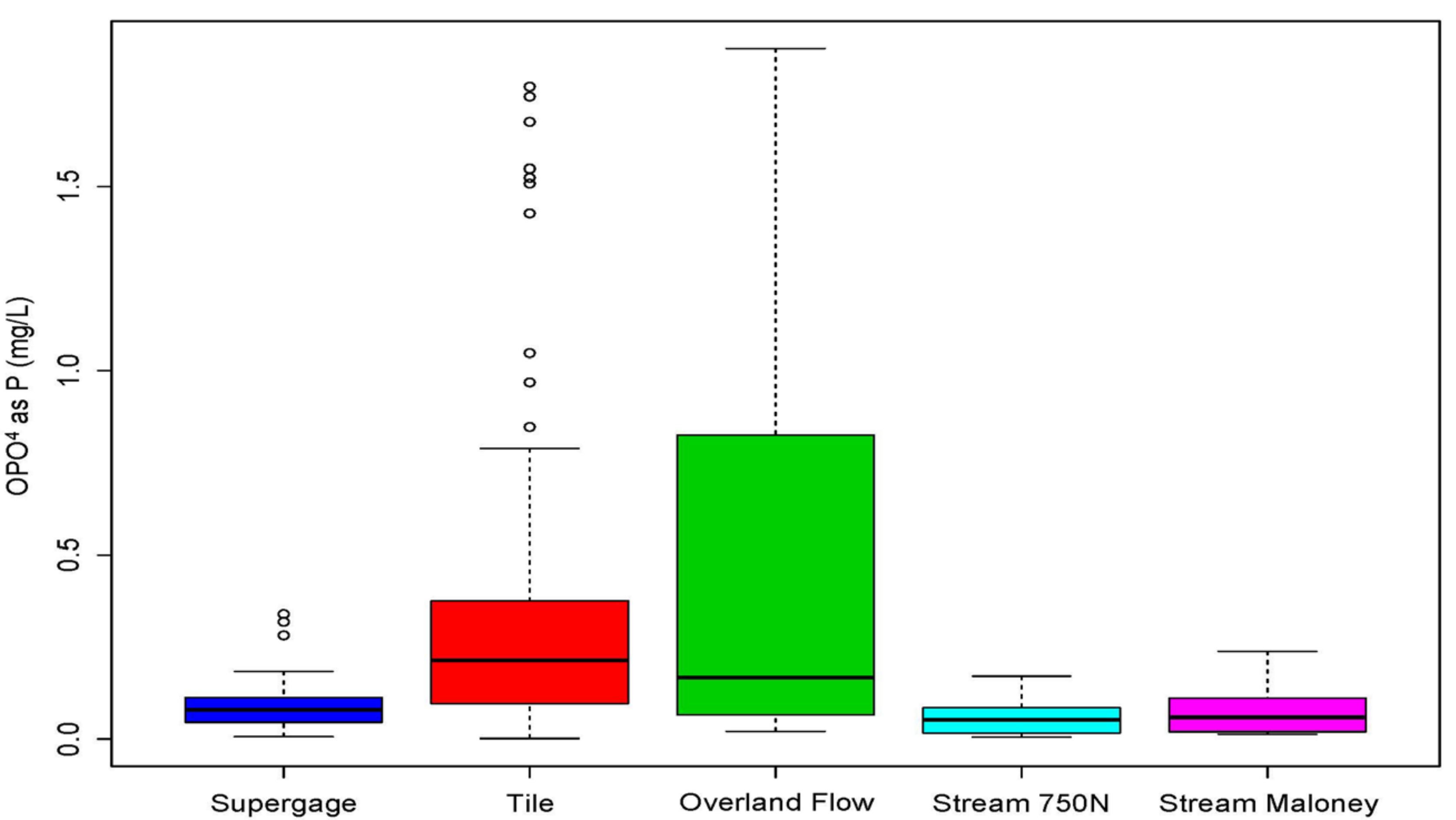
Case Study: Sugar Creek

Orthophosphate is higher in tiles at School Branch

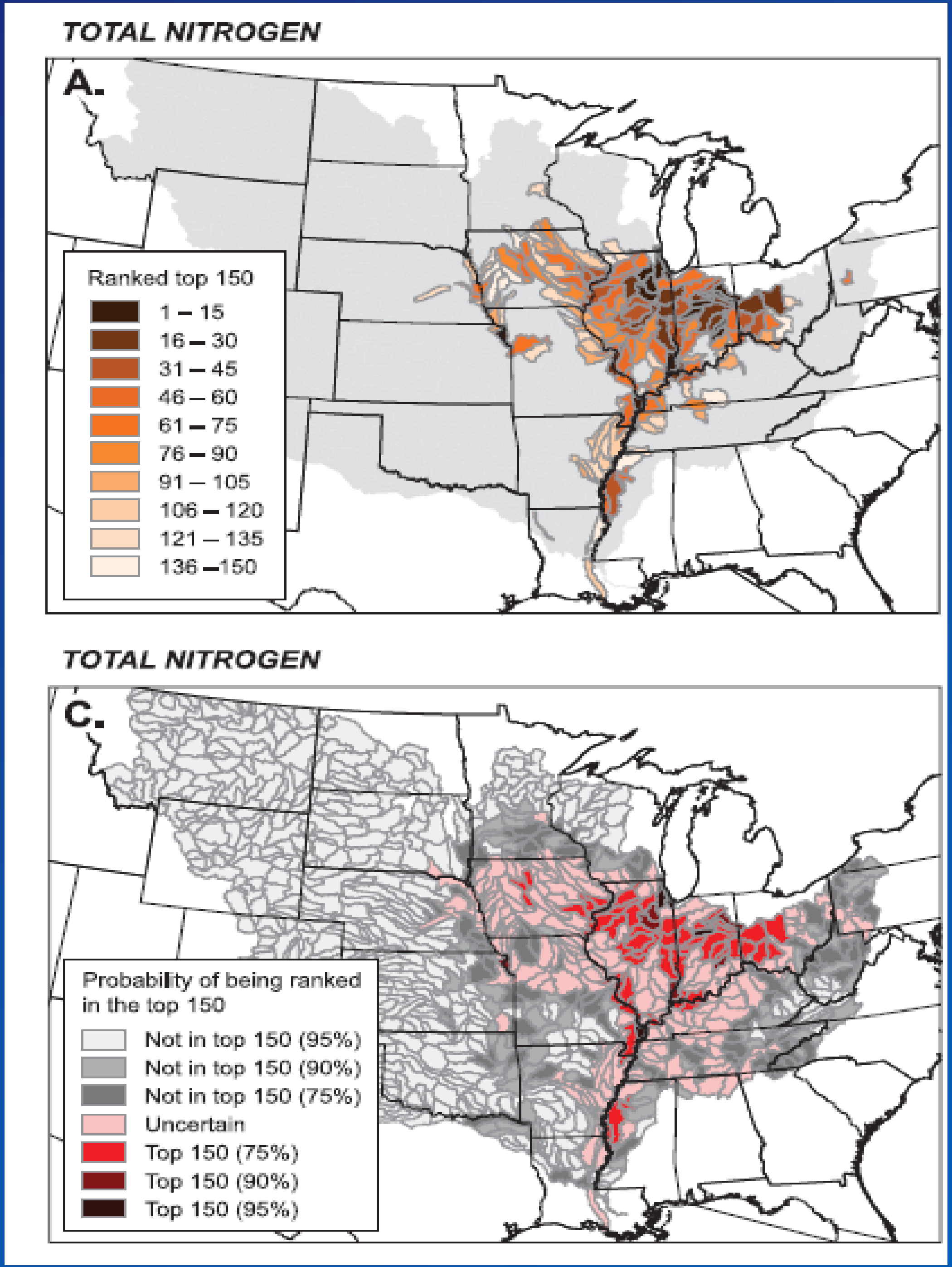


Provisional Data Analysis

WHERE ARE THE NUTRIENT "HOTSPOTS"?

Total Nitrogen

- Cornbelt states dominate
- Indiana has some of the highest ranked



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From: Roberson and others, 2009

WHERE ARE THE NUTRIENT "HOTSPOTS"?

Total Phosphorus

- Cornbelt states dominate BUT…
- Indiana less than other states
- WHY?

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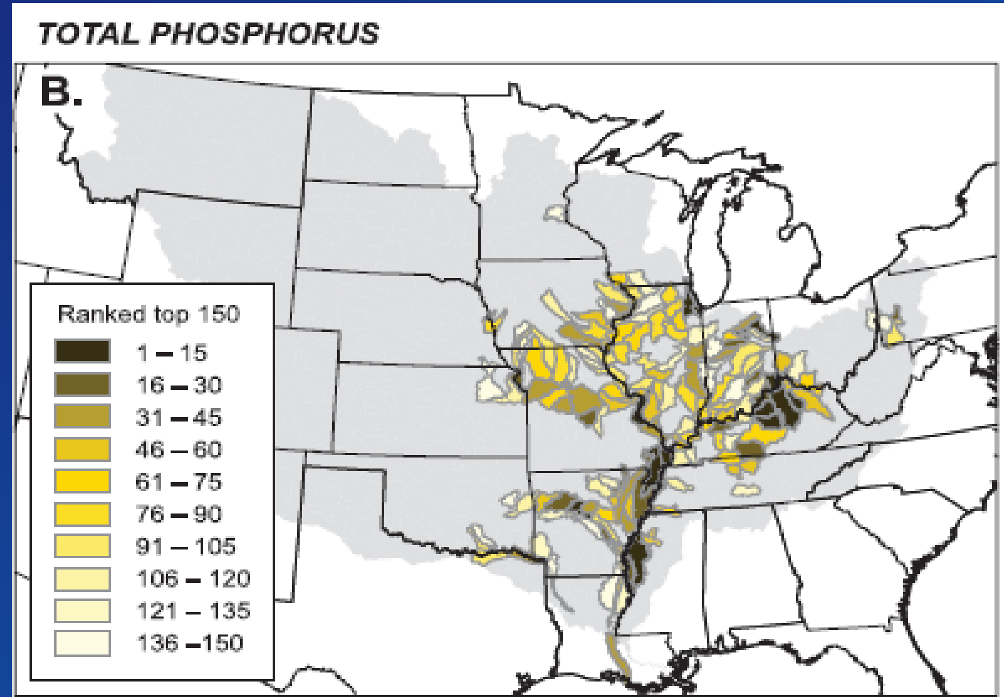
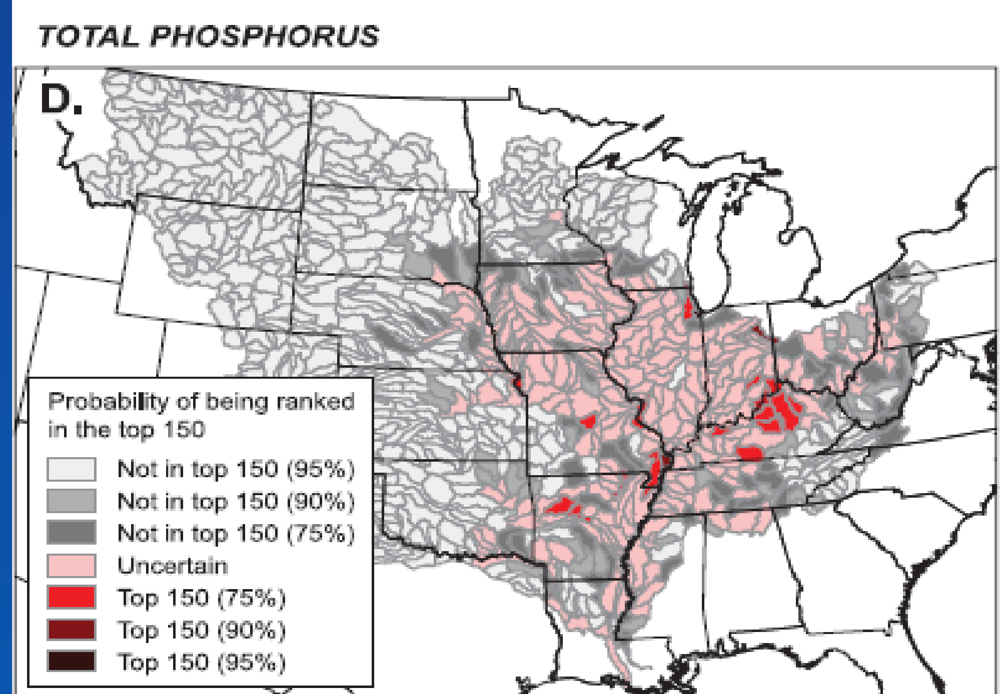
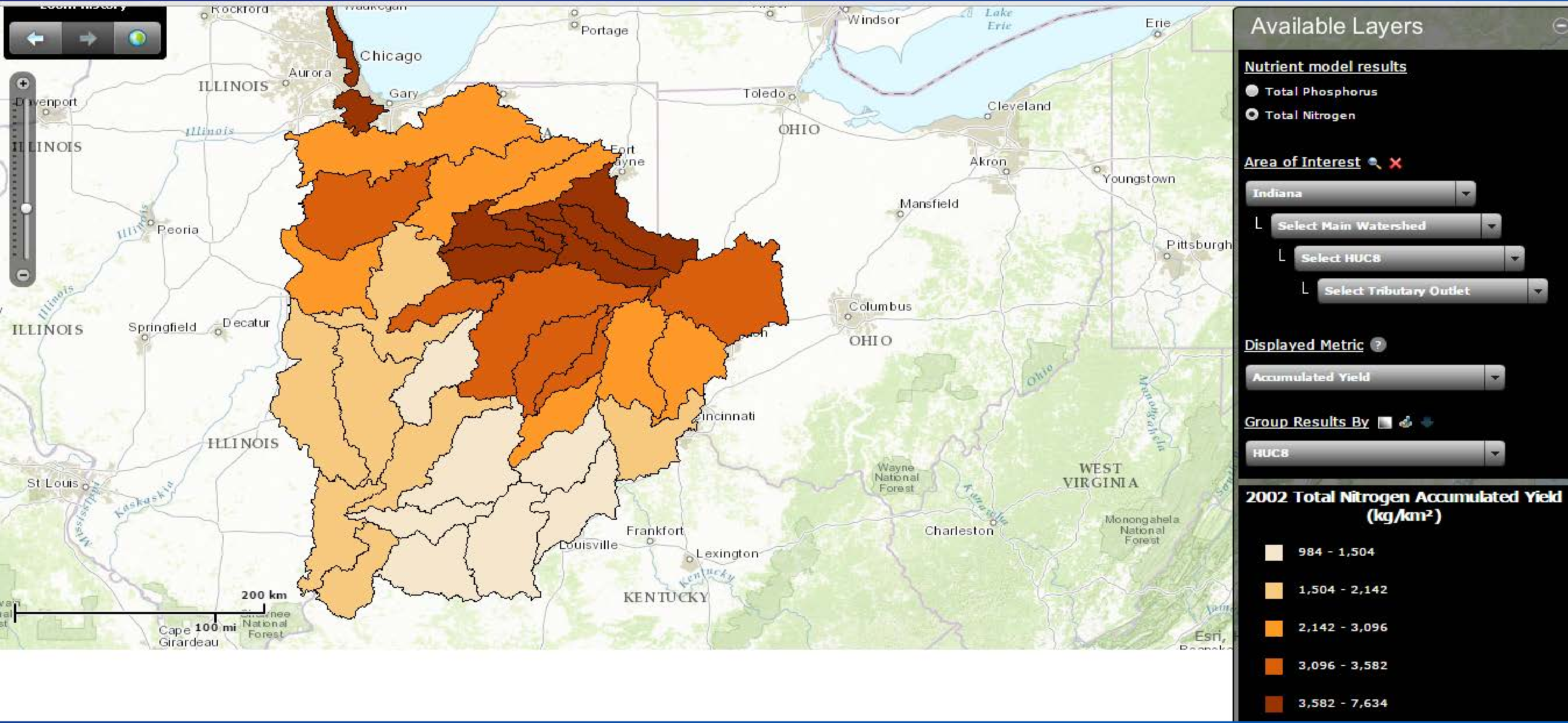
From: Roberson and others, 2009





Total Nitrogen: Yields greatest in agricultural and primarily Indiana basins



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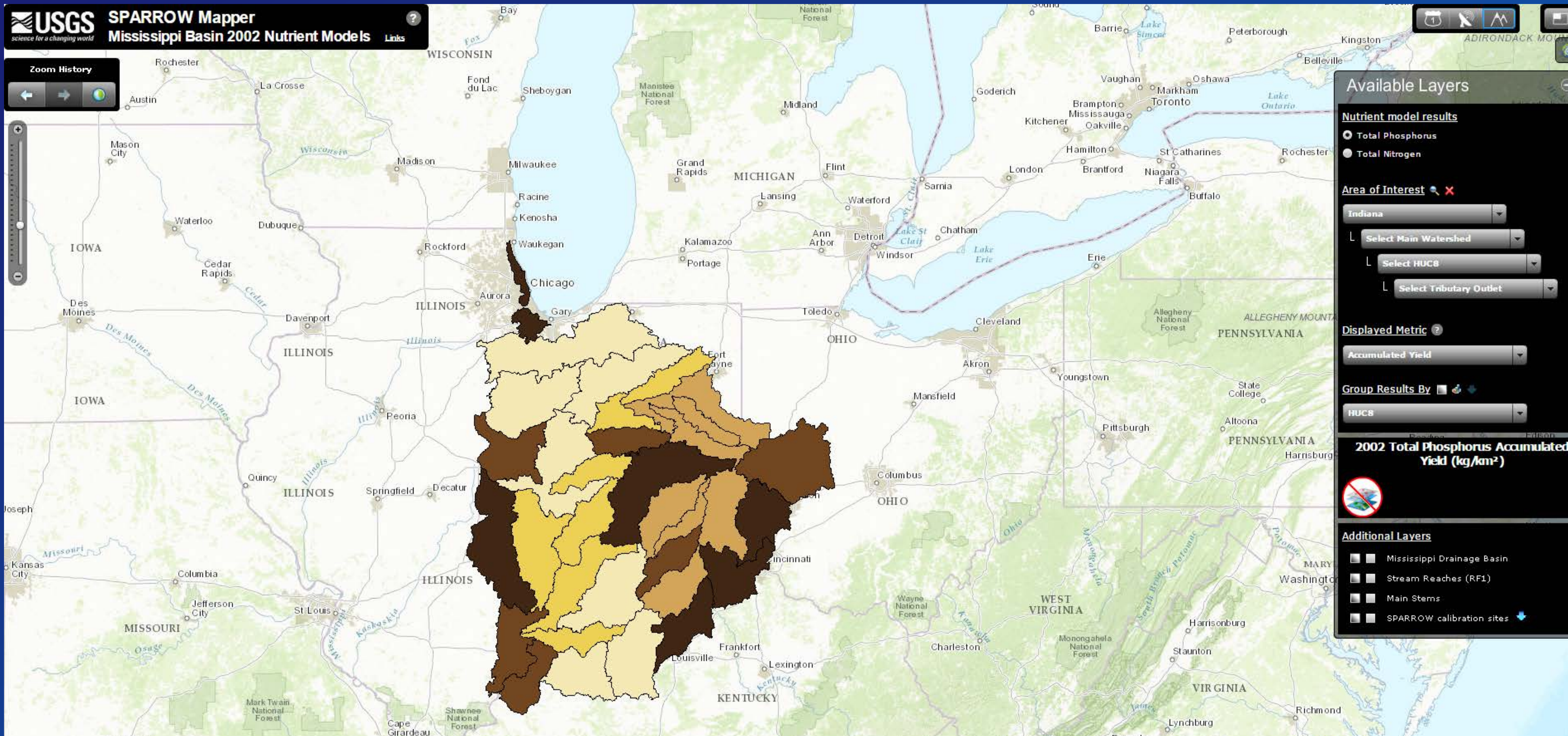
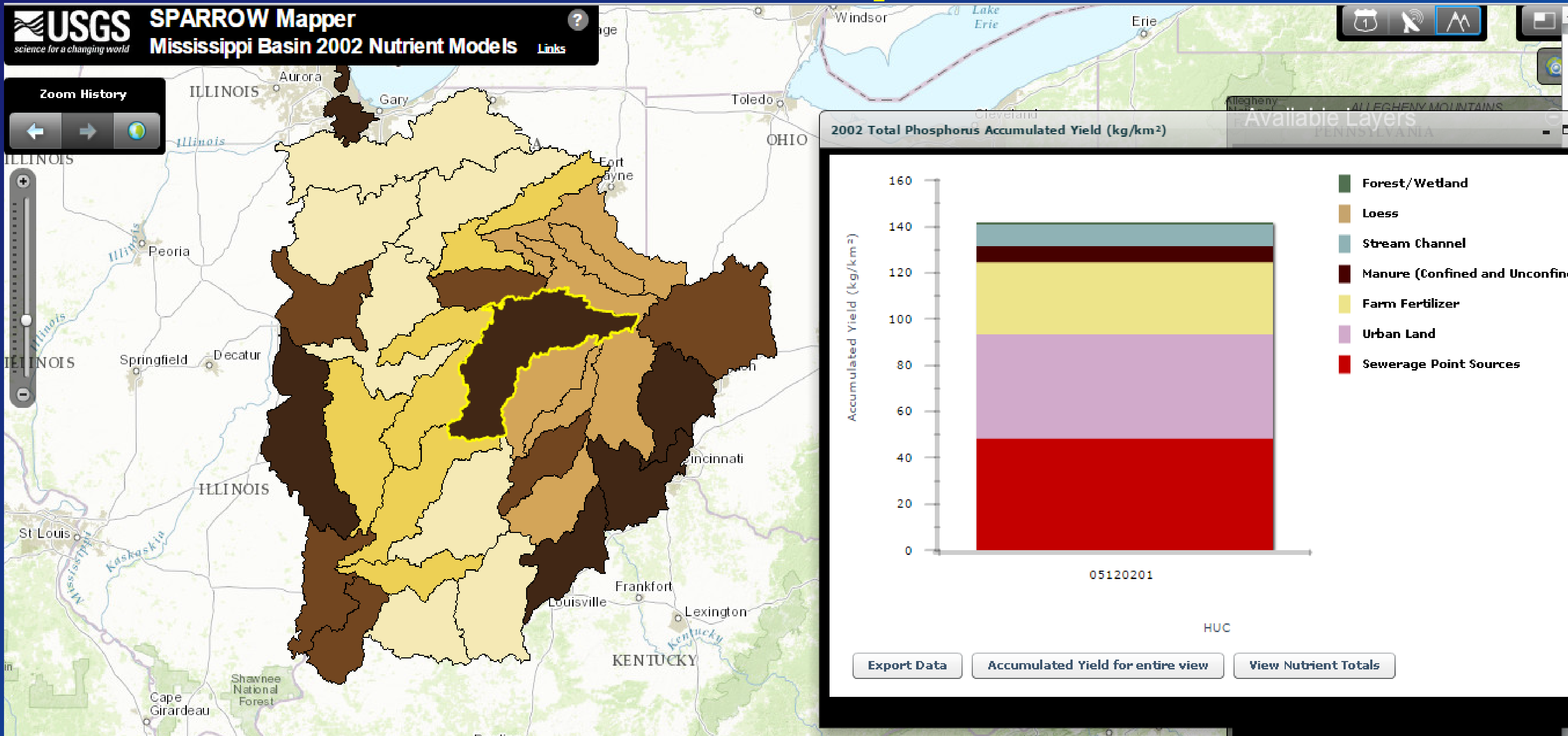
Total Phosphorus: Yields greatest in urban and Indiana border watersheds



Some watersheds are dominated by urban inputs



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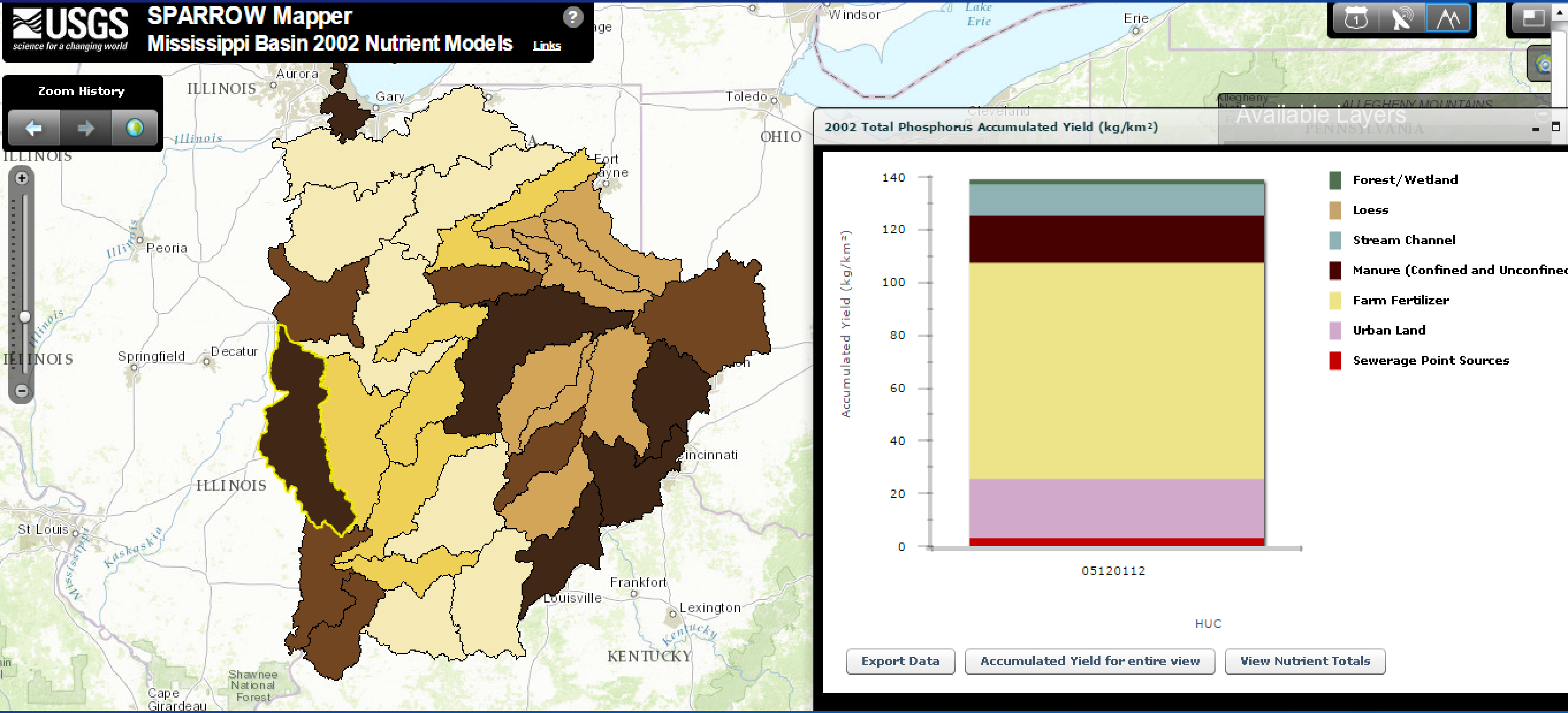
Upper White River Watershed (05120201)

The sources for P are primarily agriculture in some watersheds



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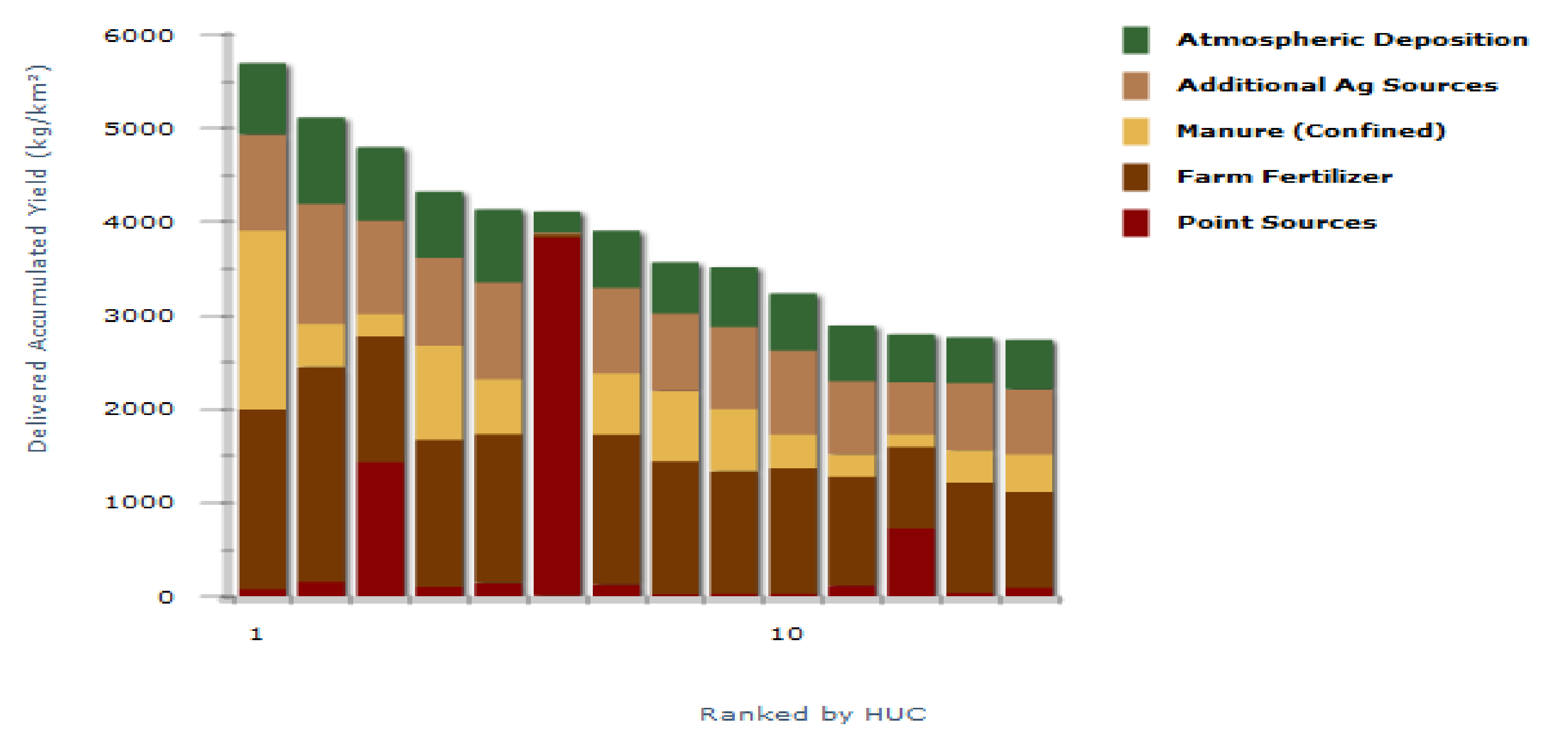
Embarrass Watershed (05120112)

For Total Nitrogen agricultural sources predominate



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NUTRIENTS CHANGE SEASONALLY

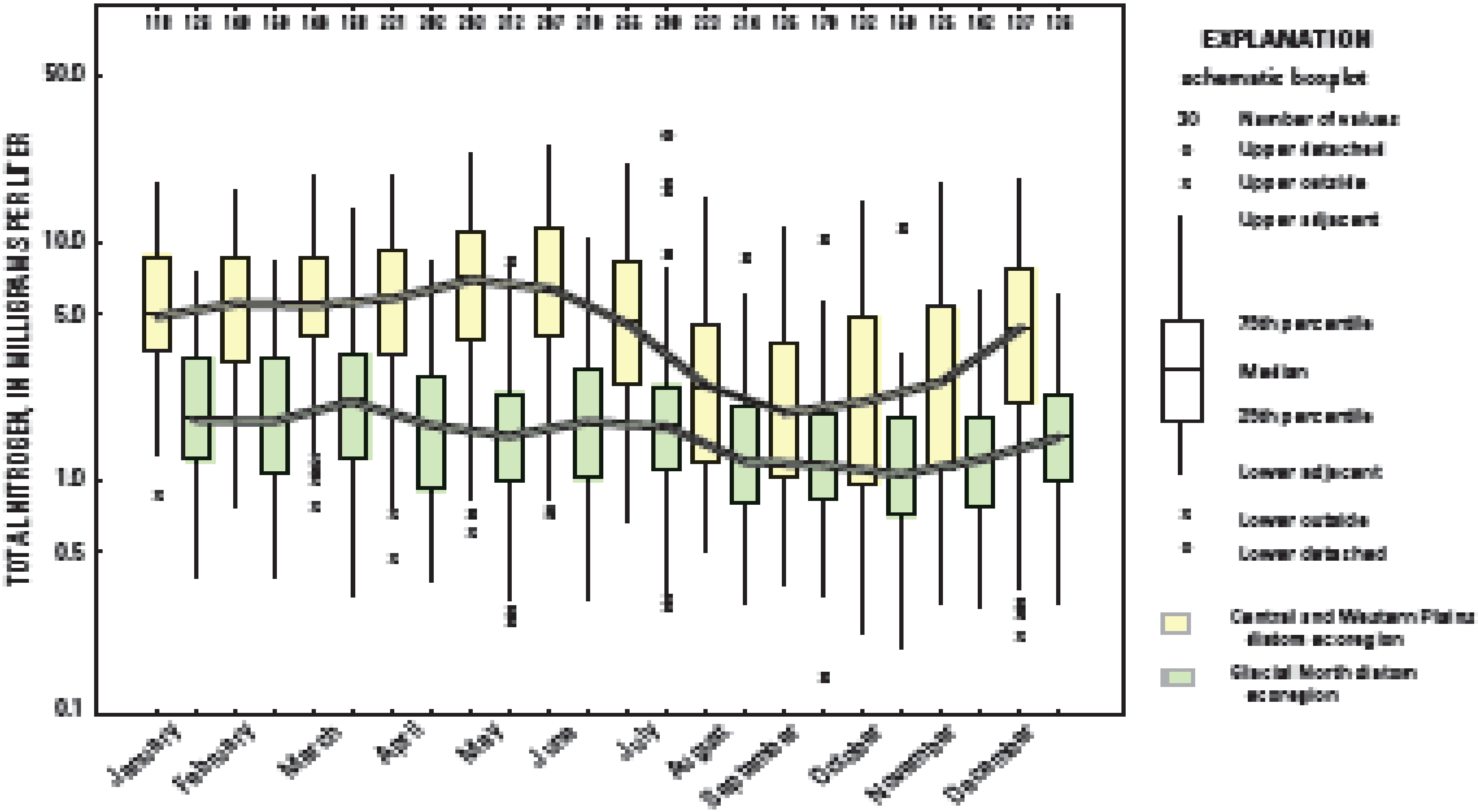
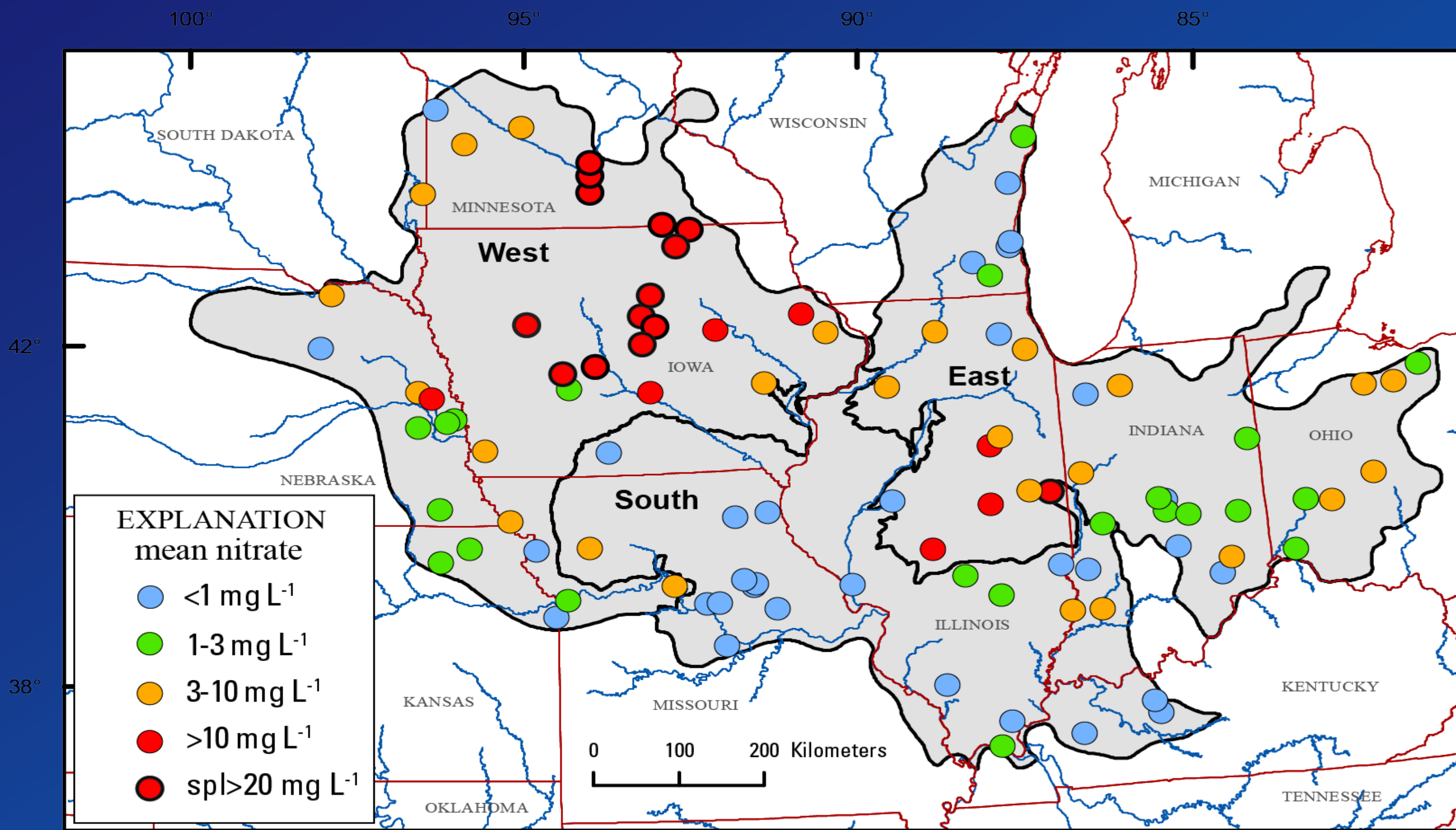


Figure 6. Monthly concentrations of total nitrogen at the 64 sites within Central and Western Plains and Glacial North diatom ecoregions used to determine nutrient categories.

Total Nitrogen

Historically high nitrate in some streams



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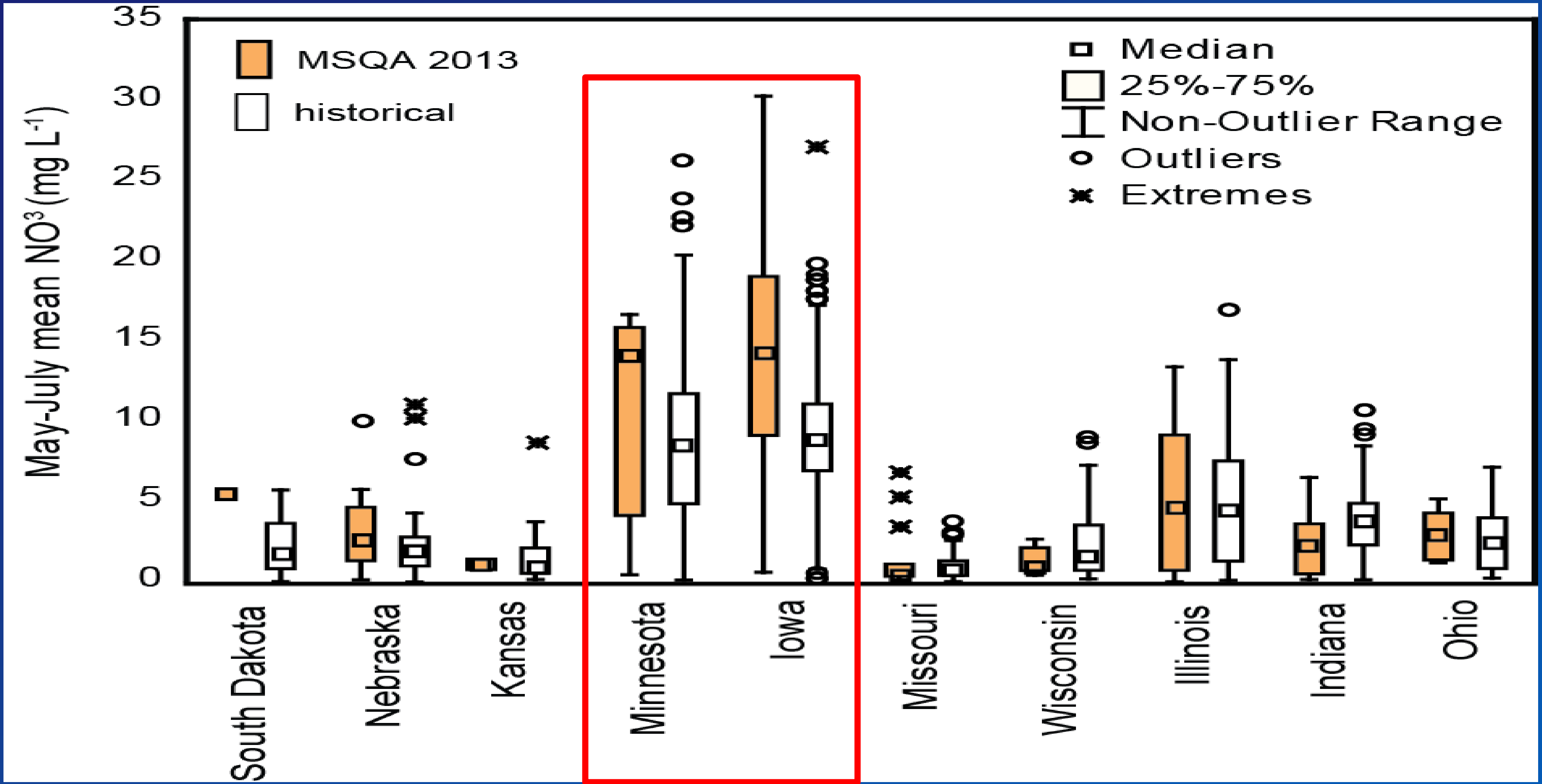
Historically high, but 2013 was higher than normal in the west



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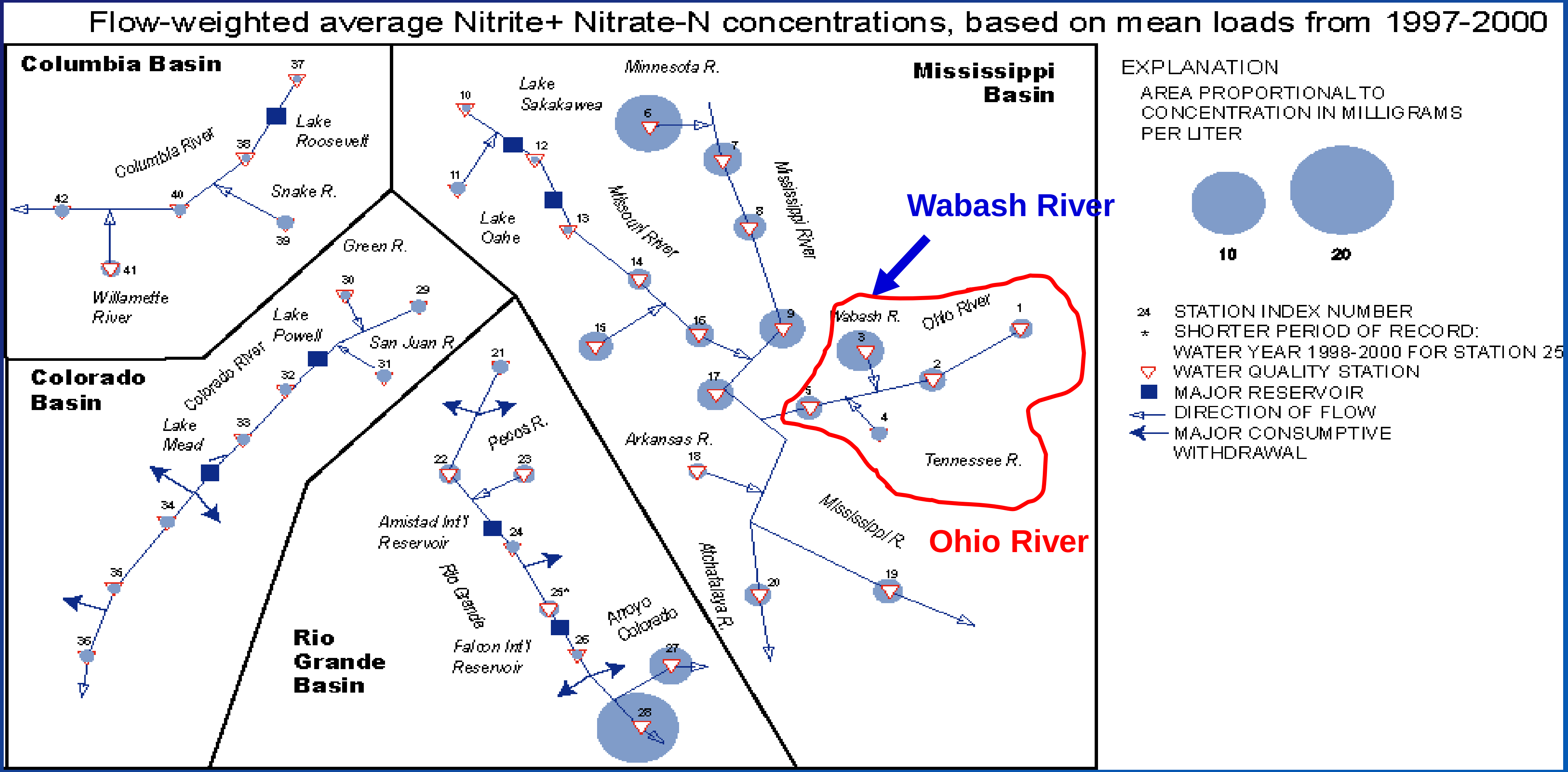
WHAT DOES INDIANA CONTRIBUTE DOWNSTREAM?



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Major Sub-basins of the Mississippi River

Super Gage Equipment

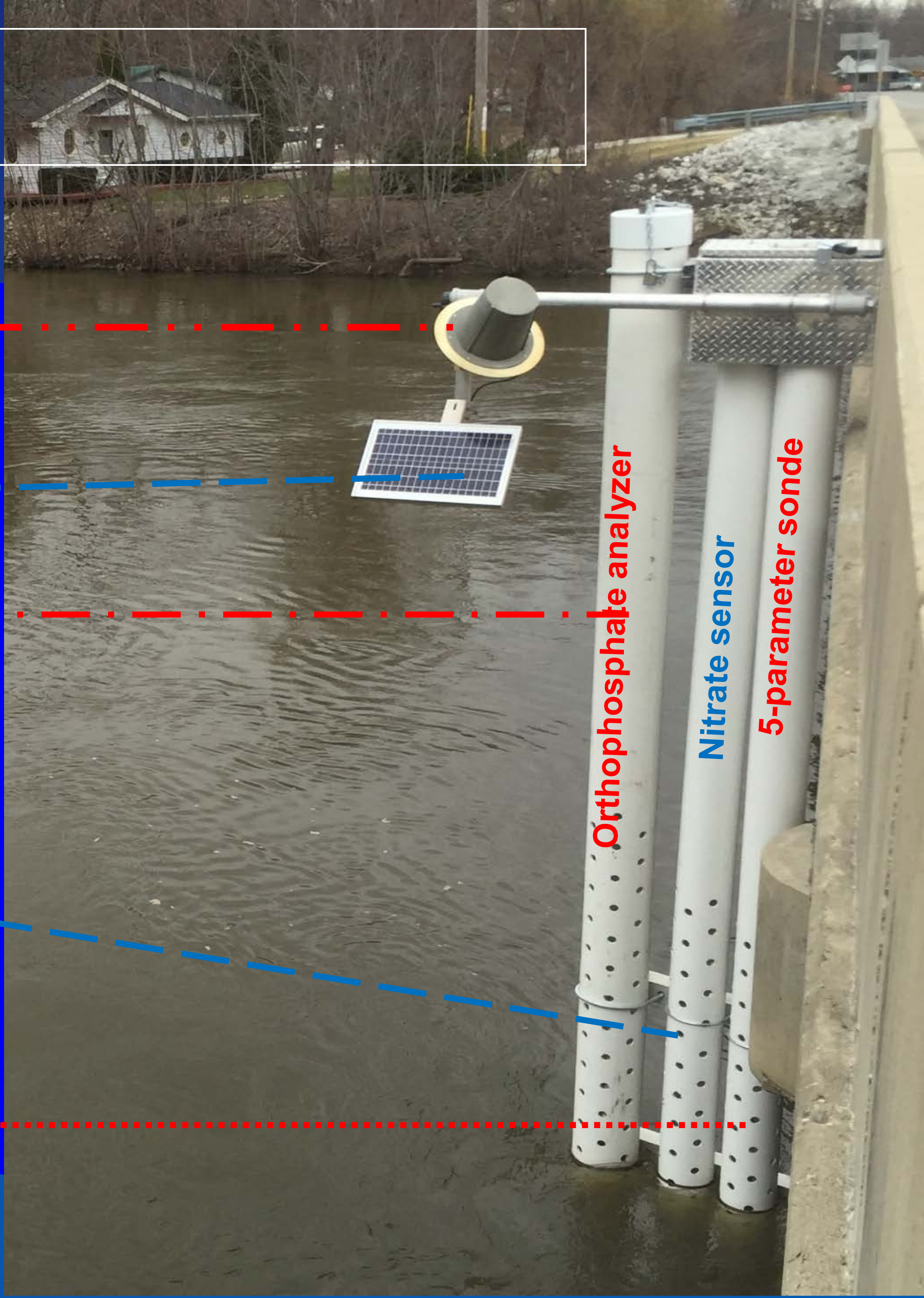
Satellite telemetry and GPS

Solar panel

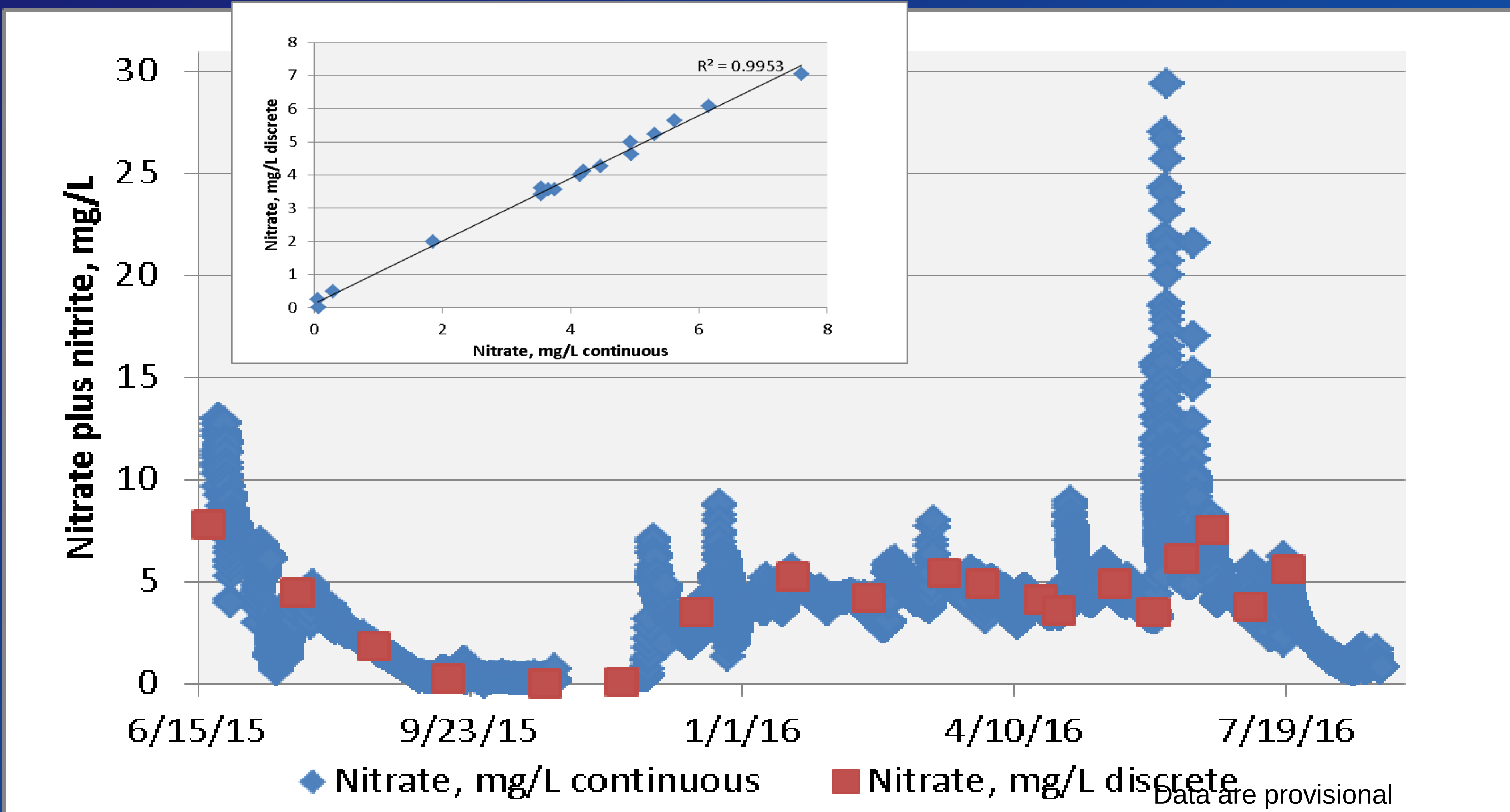
Orthophosphate analyzer

Nitrate sensor

Water-quality sonde



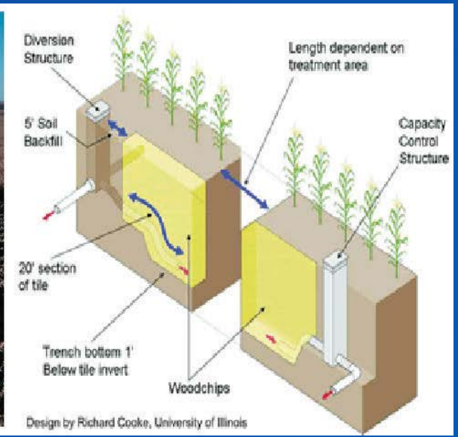
Discrete nitrate data corresponds well with continuous nitrate data



Data are provisional

HOW DO WE KEEP NUTRIENTS OUT OF STREAMS?

- Nutrient inputs
  - Nutrient management plans
- Transport of nutrients and sediment
  - Conservation tillage
  - Cover crops
  - Buffers
- Transformation of nutrients
  - Wetlands
  - Bioreactors
  - 2-stage ditches



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BEST MANAGEMENT PRACTICES (BMPS)

HOW DO WE KEEP NUTRIENTS OUT OF STREAMS?

- **Nutrient inputs**
  - **Nutrient management plans**
- **Transport of nutrients and sediment**
  - **Conservation tillage**
  - **Cover crops**
  - **Buffers**
- **Transformation of nutrients**
  - **Wetlands**
  - **Bioreactors**
  - **2-stage ditches**

NRCS
Healthy Soils System

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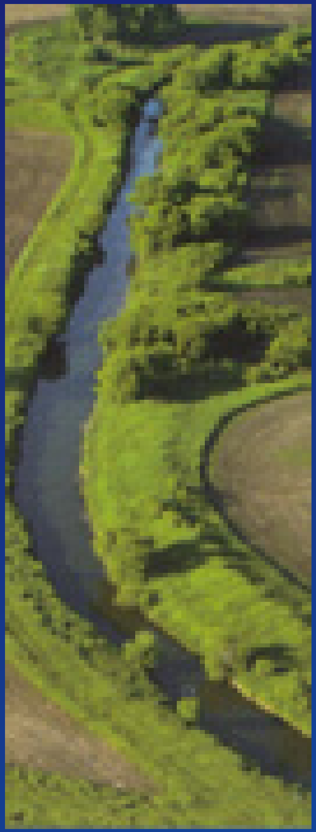
BEST MANAGEMENT PRACTICES (BMPS)

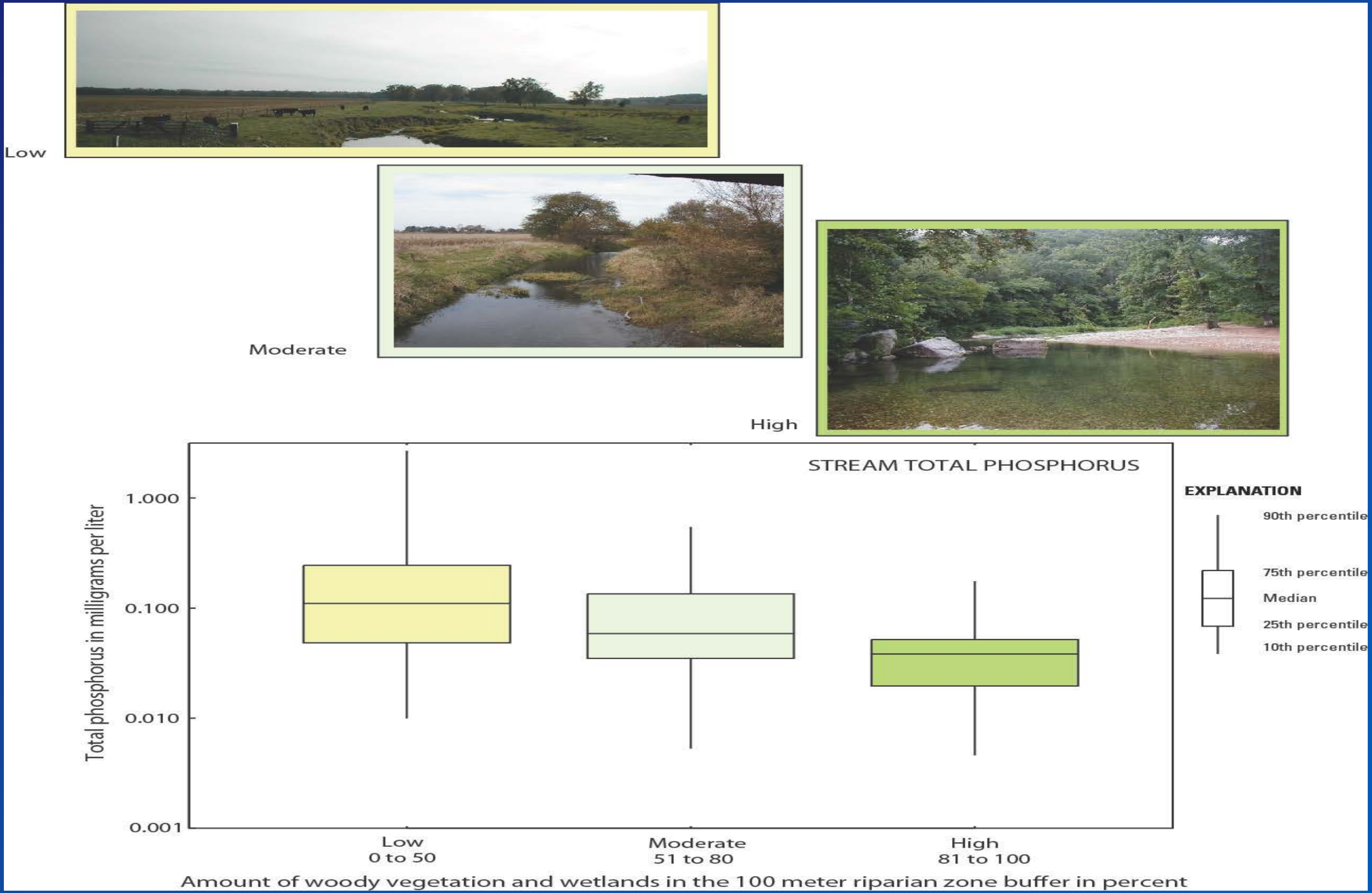
What are agricultural management practices?



Buffer Strips

Case Study: Sugar Creek

PHOSPHORUS DECREASES AS CROPLAND IN THE RIPARIAN BUFFER INCREASES



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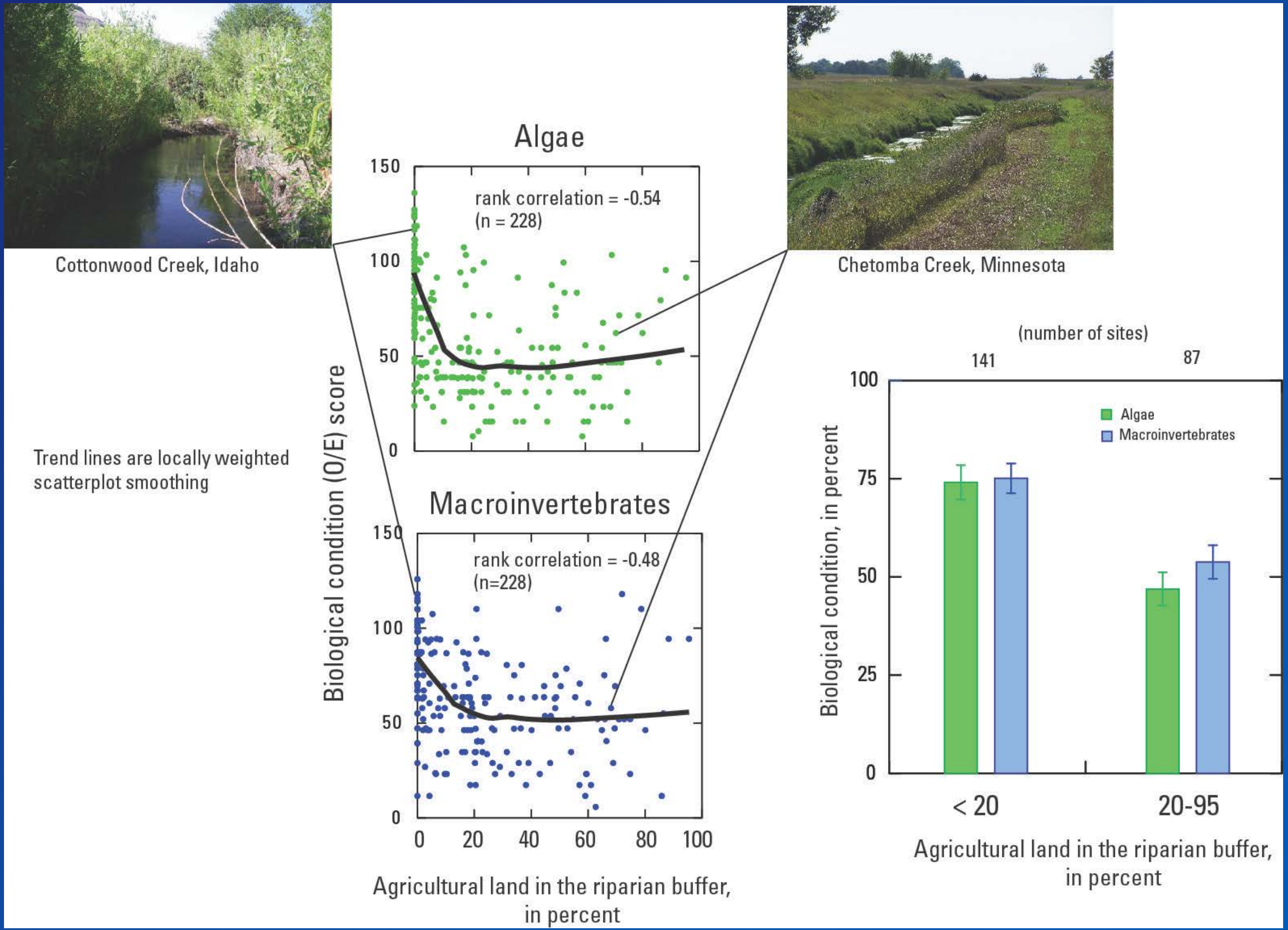
THE HEALTH OF THE STREAM DECLINES AS THE AMOUNT OF CROPLAND IN THE RIPARIAN BUFFER INCREASES



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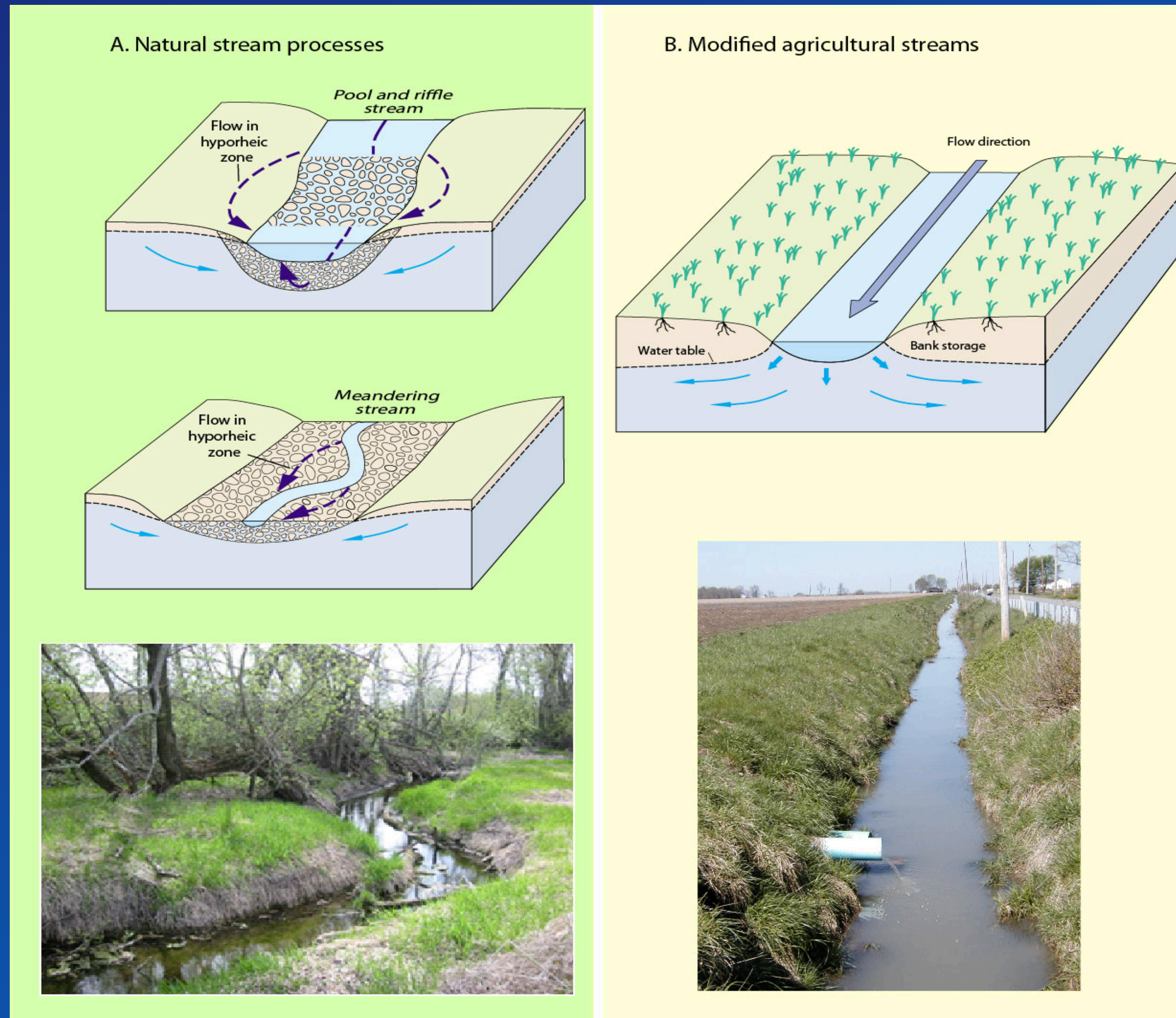
MODIFIED STREAMS HAVE DECREASED NATURAL ABILITY TO REMOVE NITROGEN

Denitrification

- Contact time with bacteria
- Slower velocity



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Has Water Quality Improved with the Implementation of Agricultural Management Practices?

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Case Study: Sugar Creek

Which agricultural management practices work?

Conservation tillage

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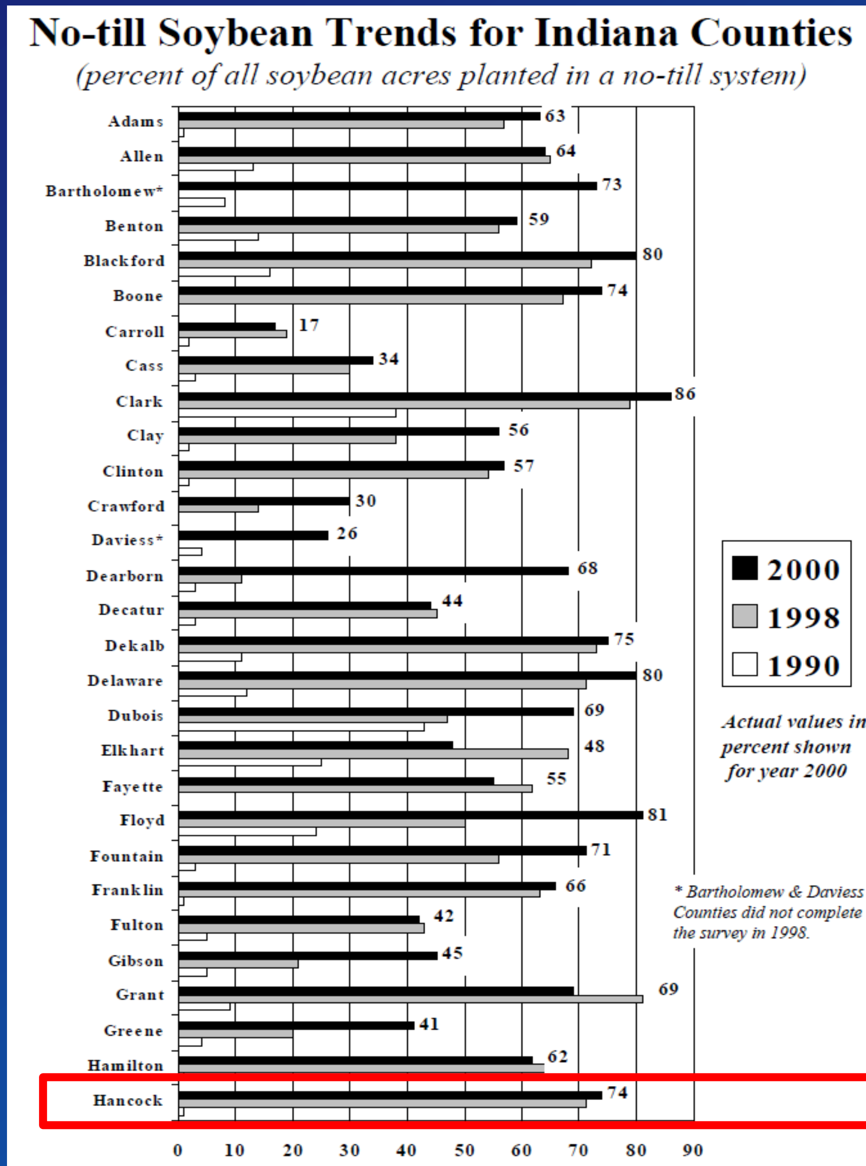
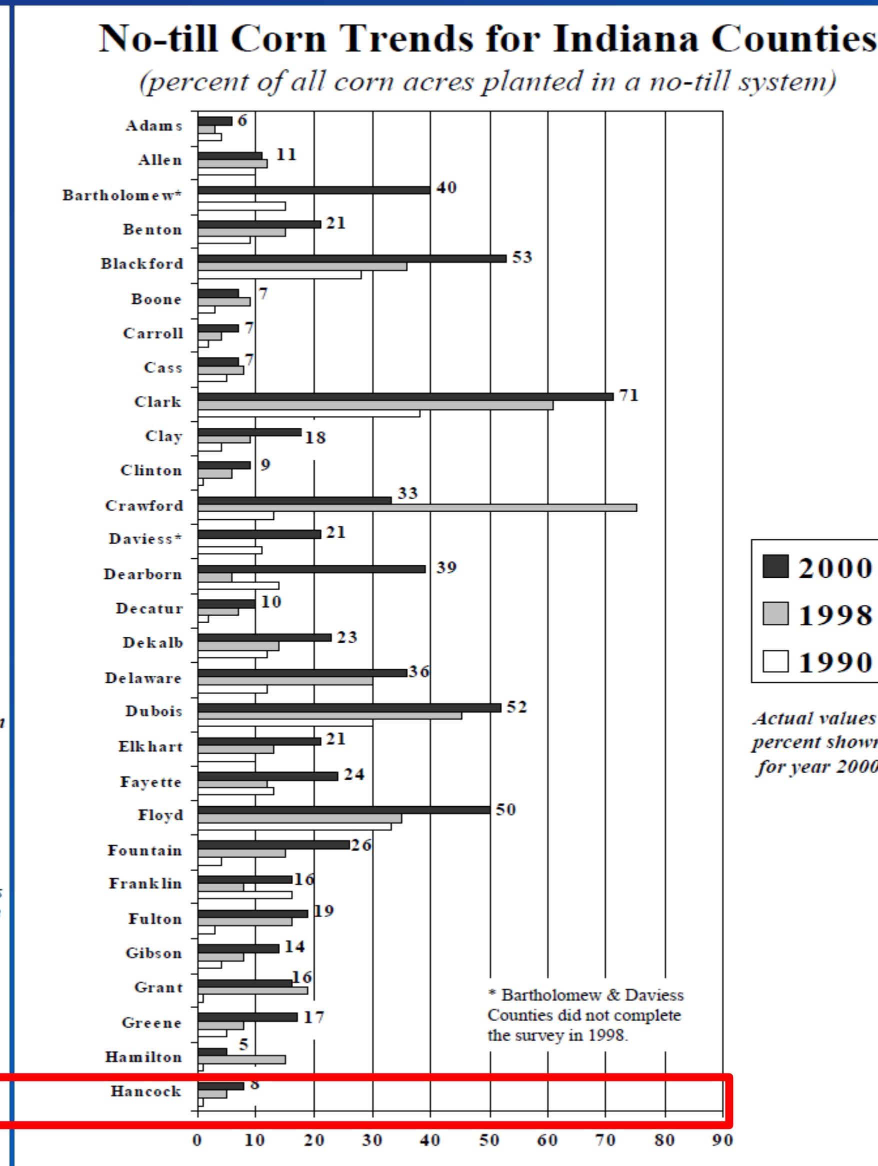
Case Study: Sugar Creek

No Till Conservation Tillage Increased Through the 1990's

From Evans & others, 2000 (CTIC)

- Transect data
- Randomly selected
- Repeated
- "Window survey"





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No Till Conservation Tillage Increased Through the 1990's

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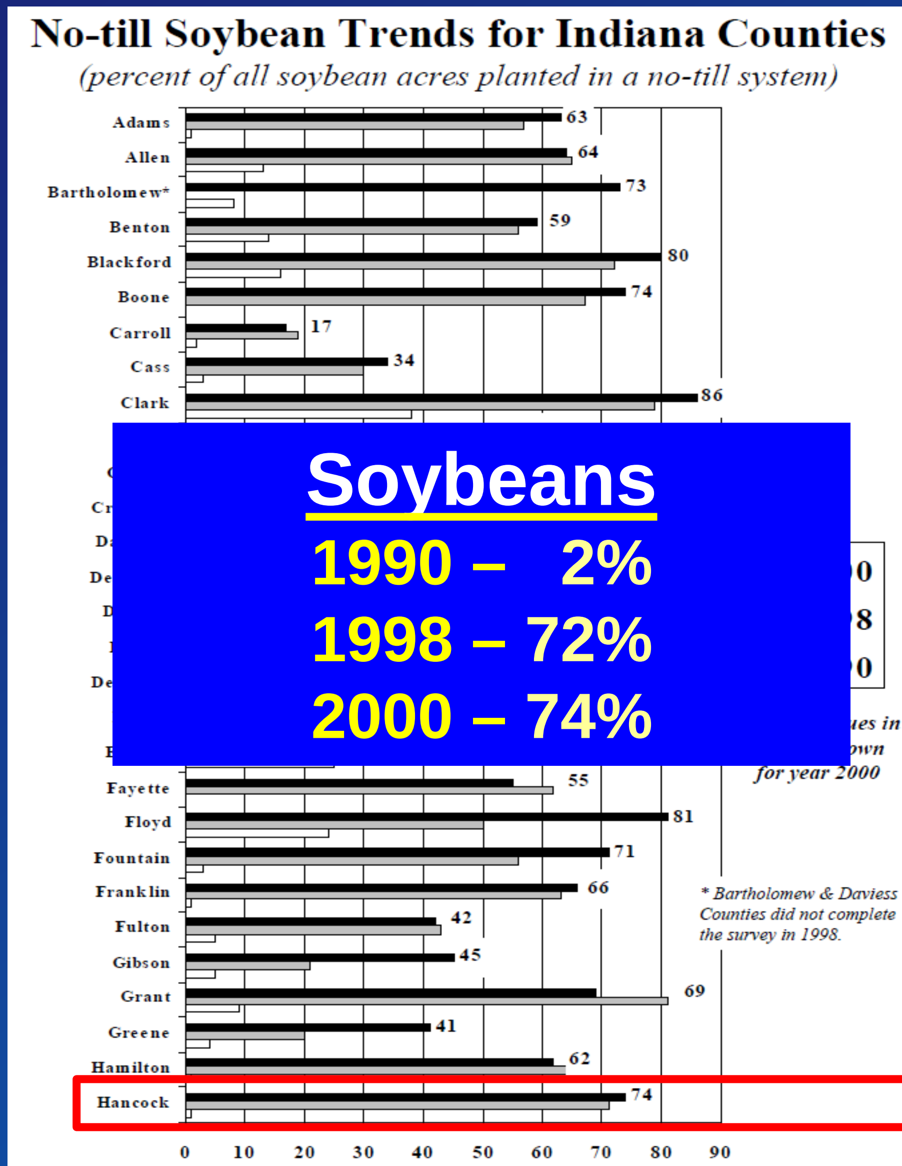

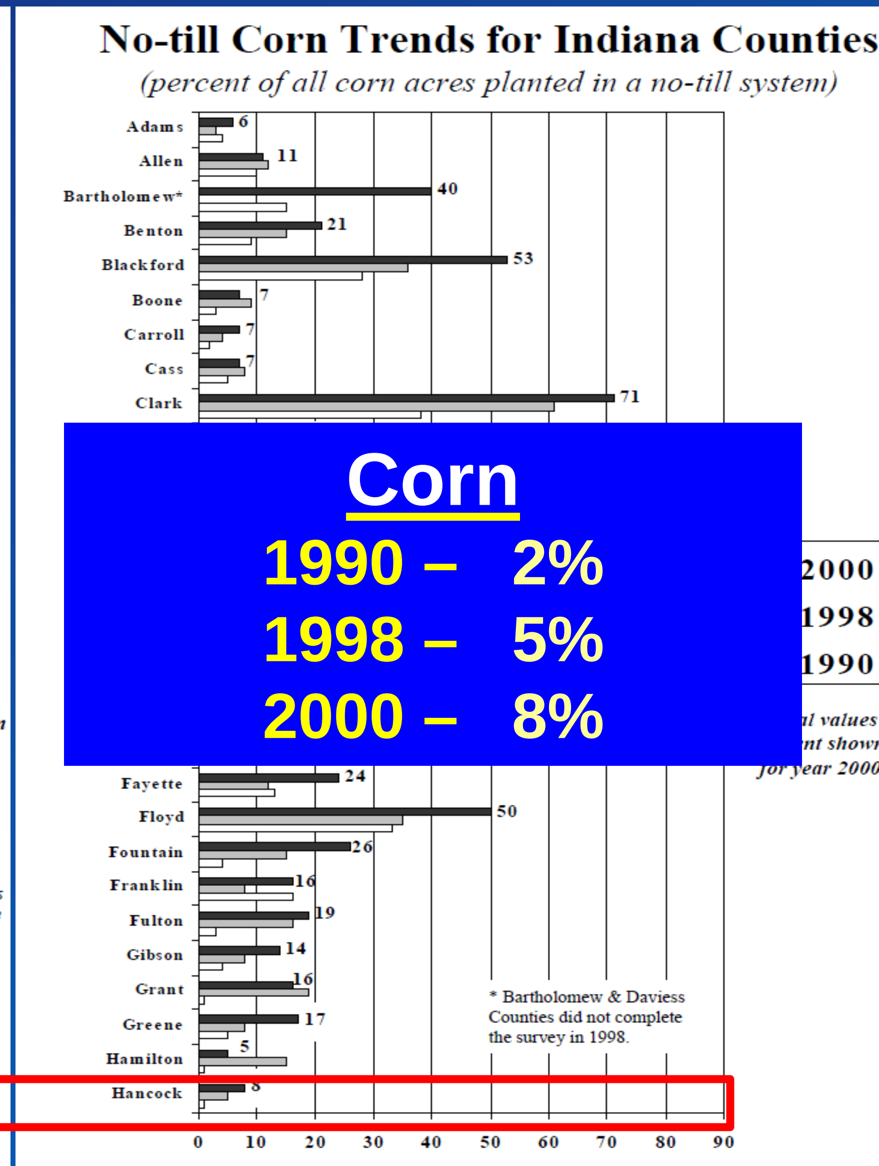

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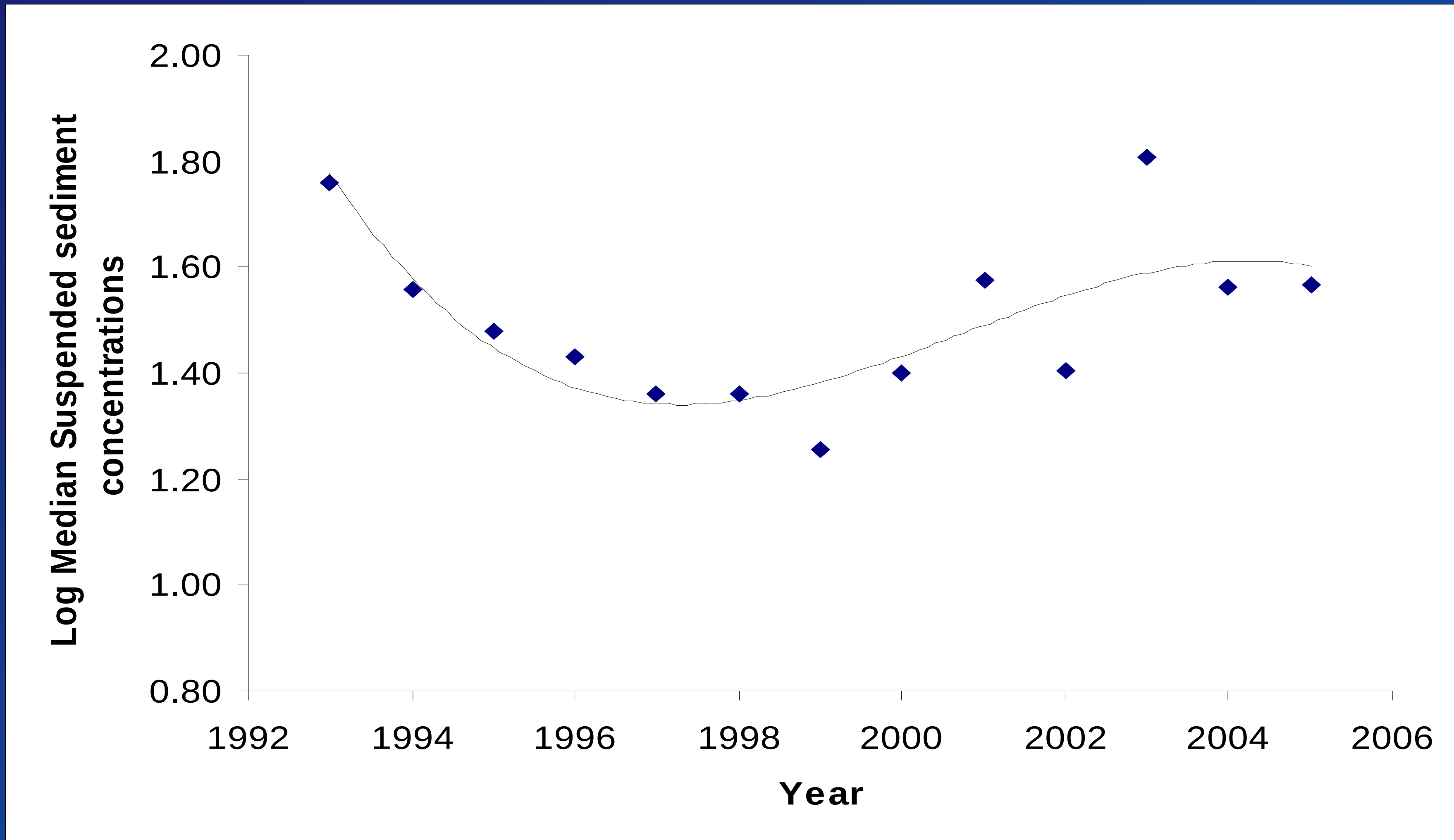
Sediment Concentrations over Time



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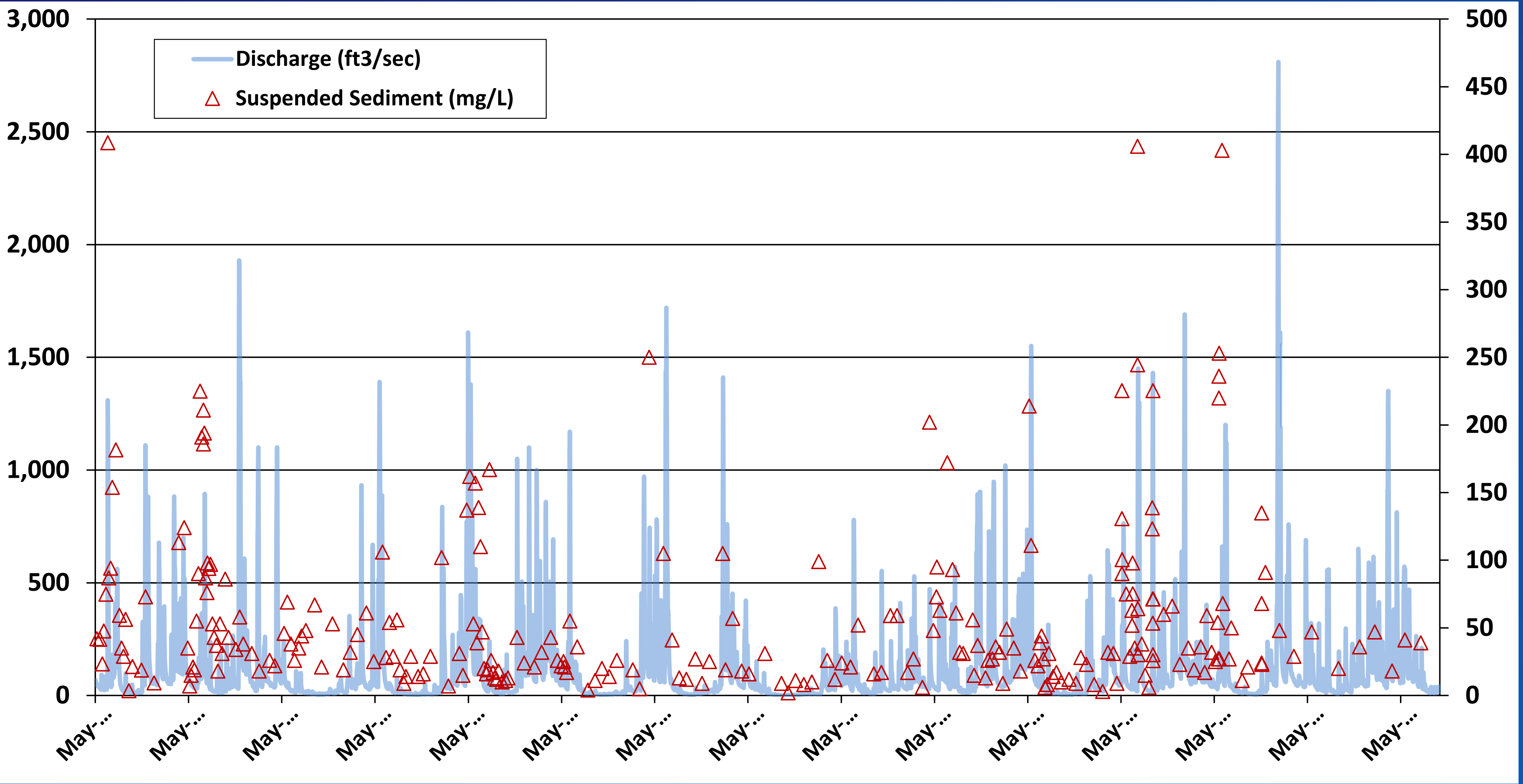
Case Study: Sugar Creek

Sediment Concentrations over Time



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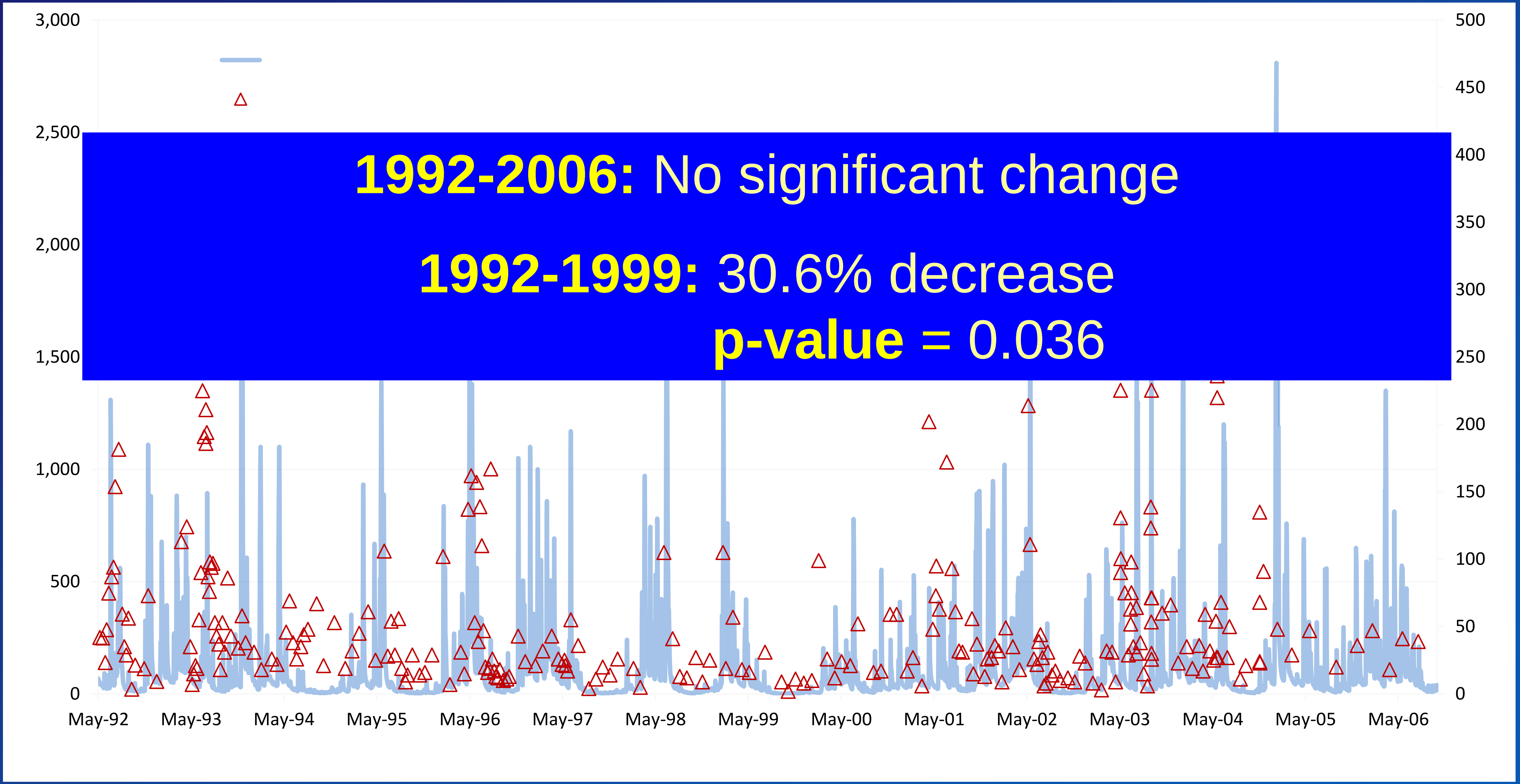
Case Study: Sugar Creek

Sedimentation Concentrations over Time



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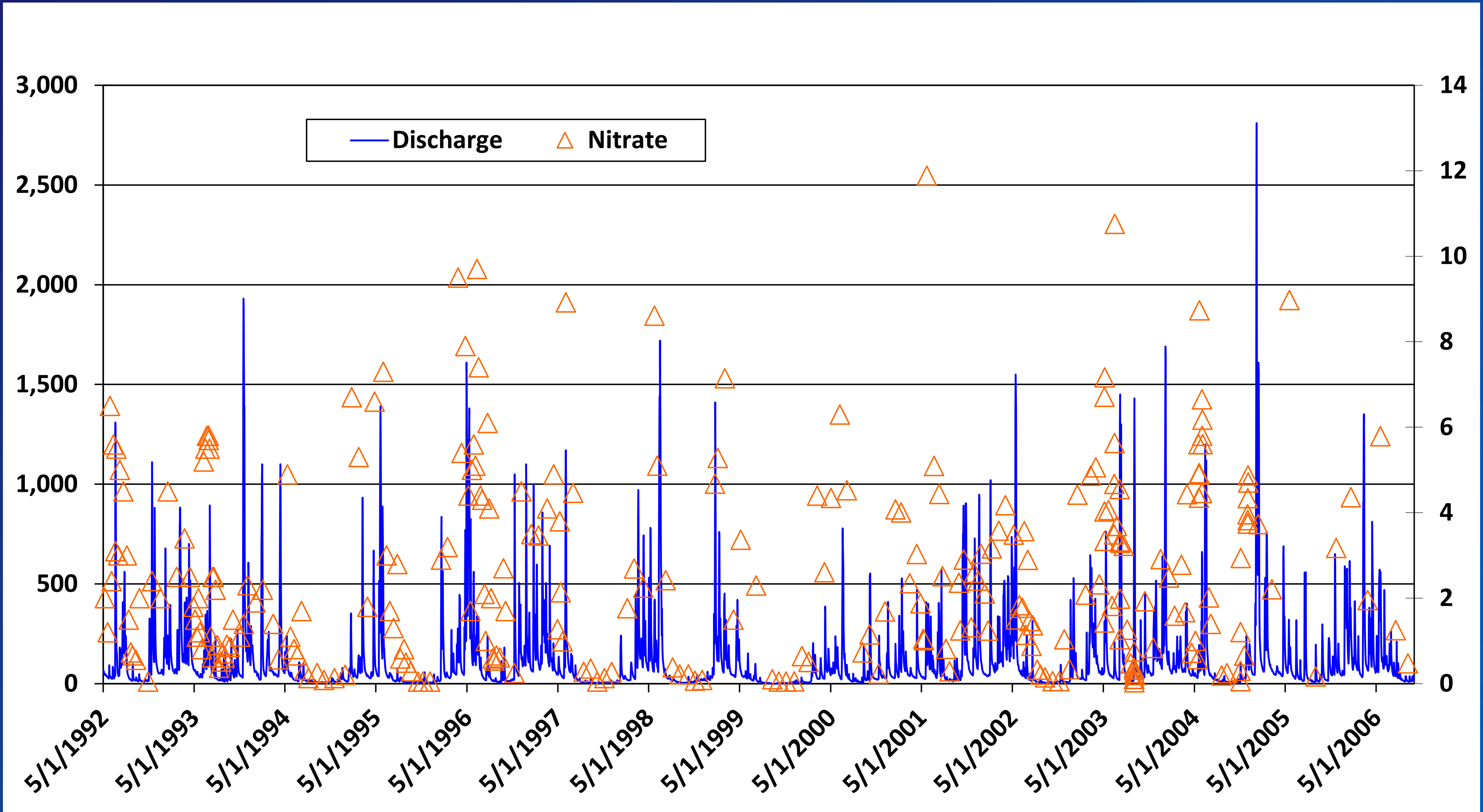
Case Study: Sugar Creek

Nitrate Concentrations over Time



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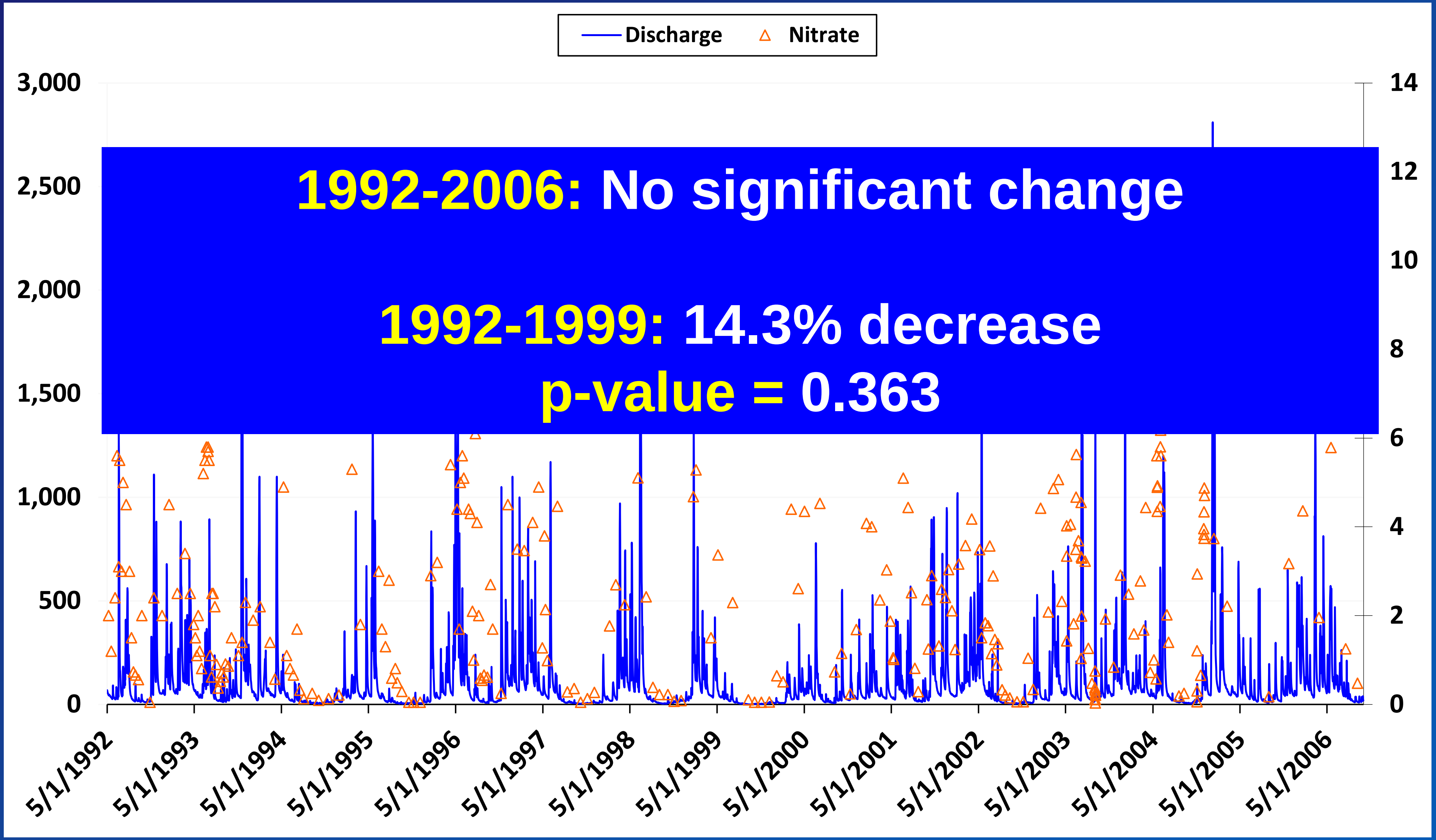
Nitrate Concentrations over Time



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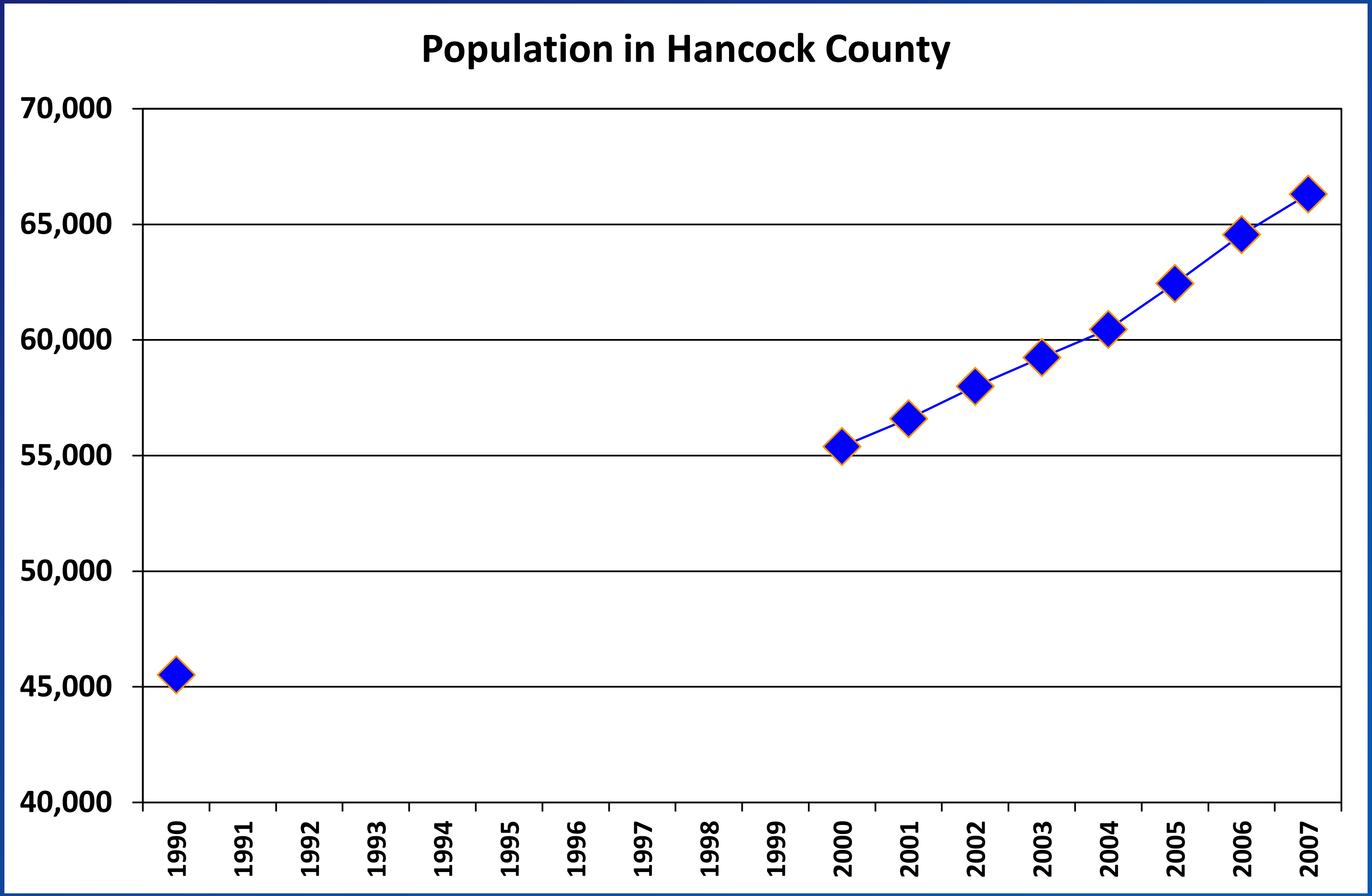
Case Study: Sugar Creek

Population in Hancock County Has Rapidly Increased



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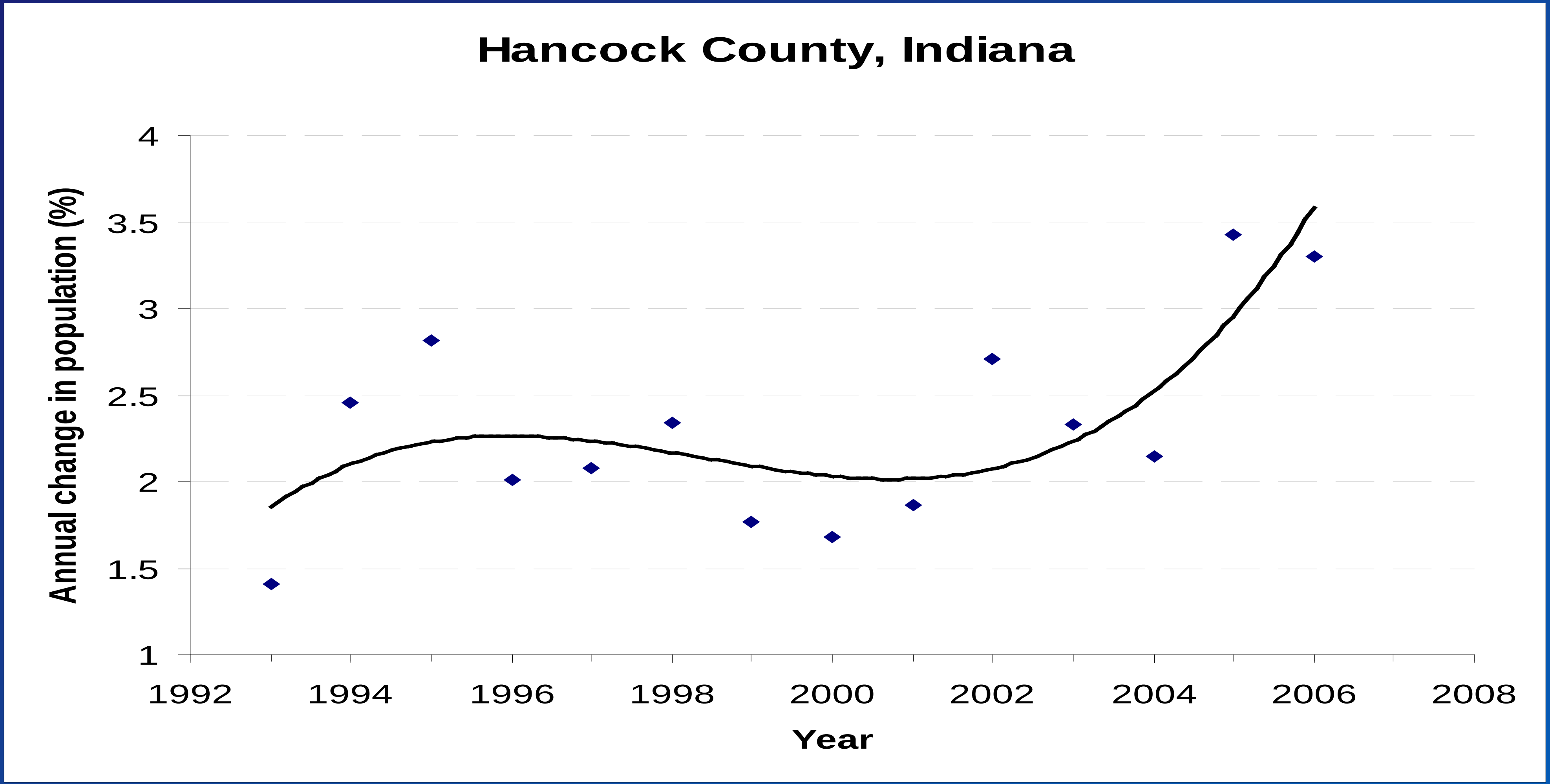

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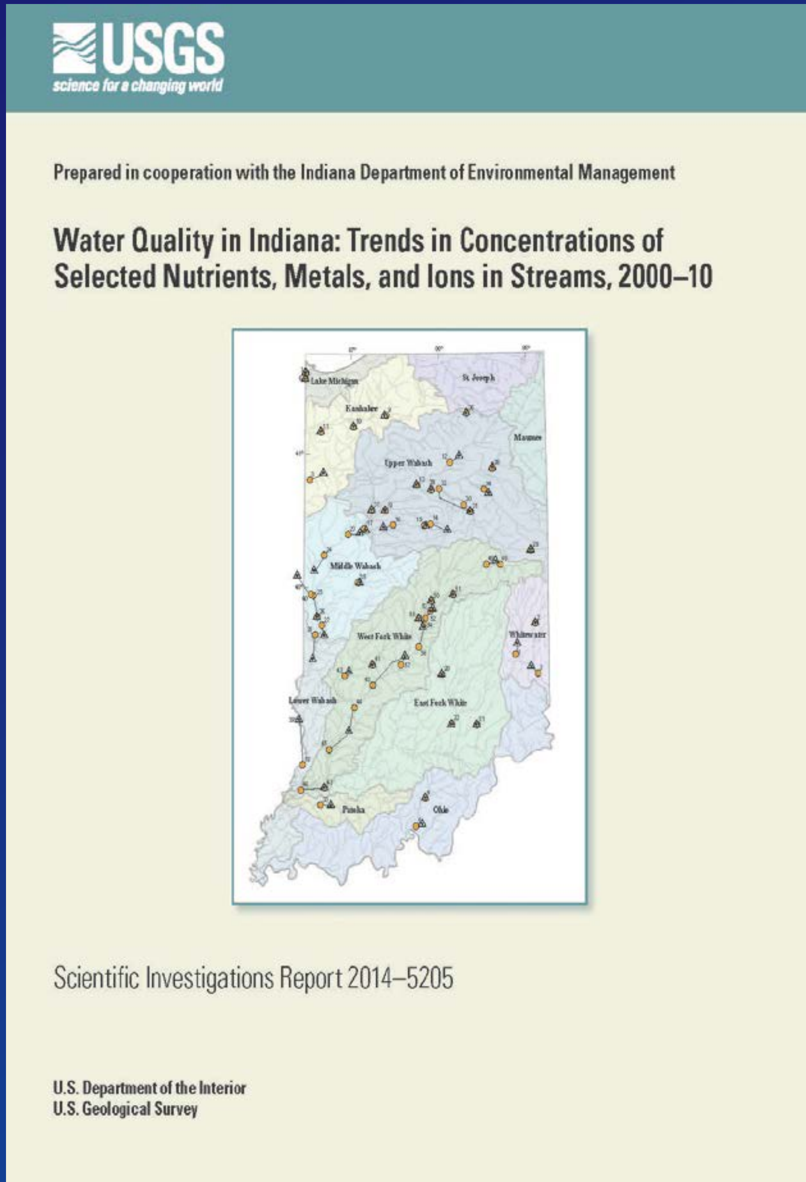
Case Study: Sugar Creek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Prepared in cooperation with the Indiana Department of Environmental Management

Water Quality in Indiana: Trends in Concentrations of Selected Nutrients, Metals, and Ions in Streams, 2000–10

Scientific Investigations Report 2014–5205

U.S. Department of the Interior
U.S. Geological Survey

Good news story: Nitrate is significantly decreasing.

http://pubs.usgs.gov/sir/2014/5205/

By Martin Risch, Aubrey Bunch, Aldo Vecchia, Jeffrey Martin, and Nancy Baker

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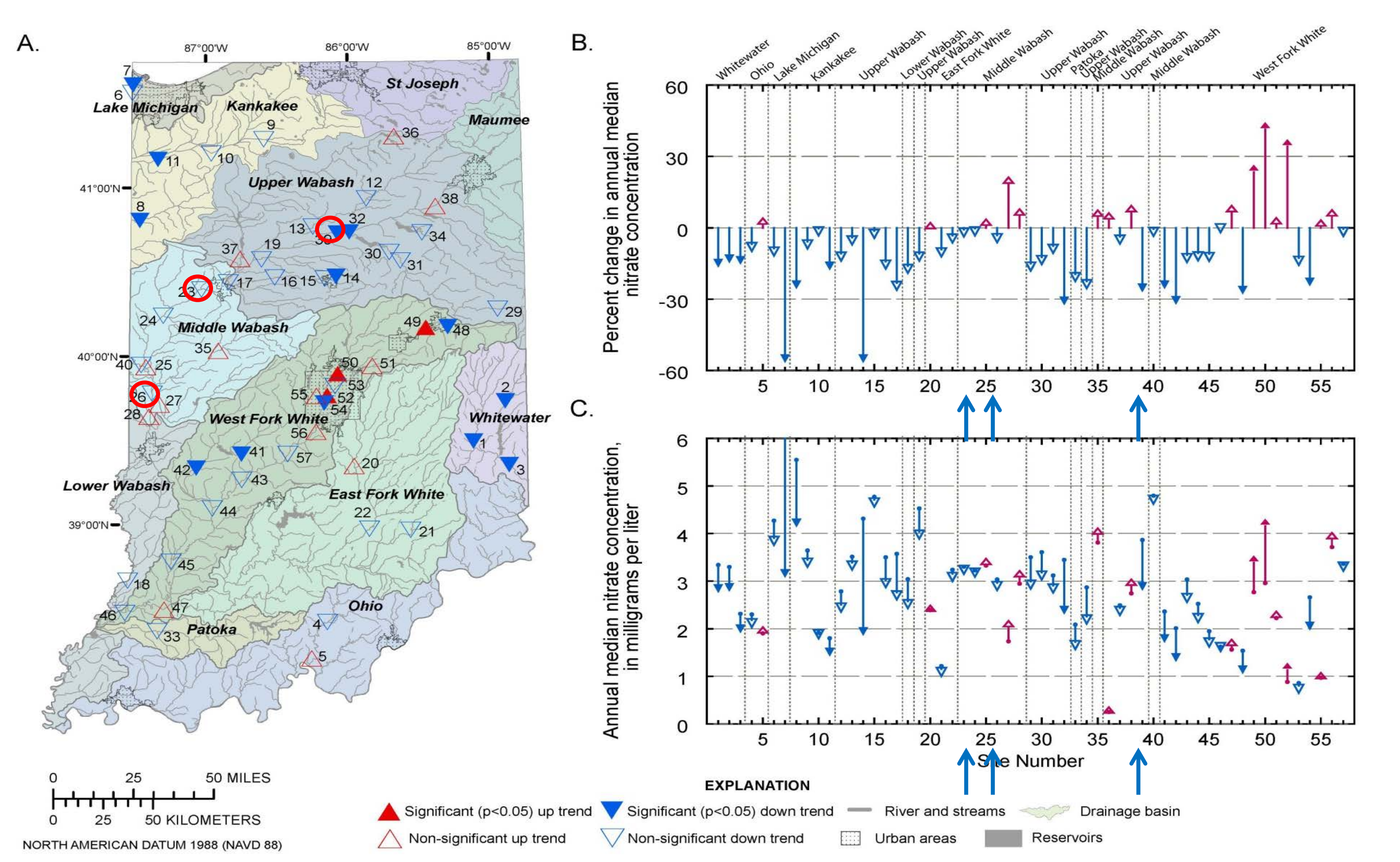

Nitrate: 74% percent of sites show decrease; statistically significant: 3 uptrends and 13 downtrends

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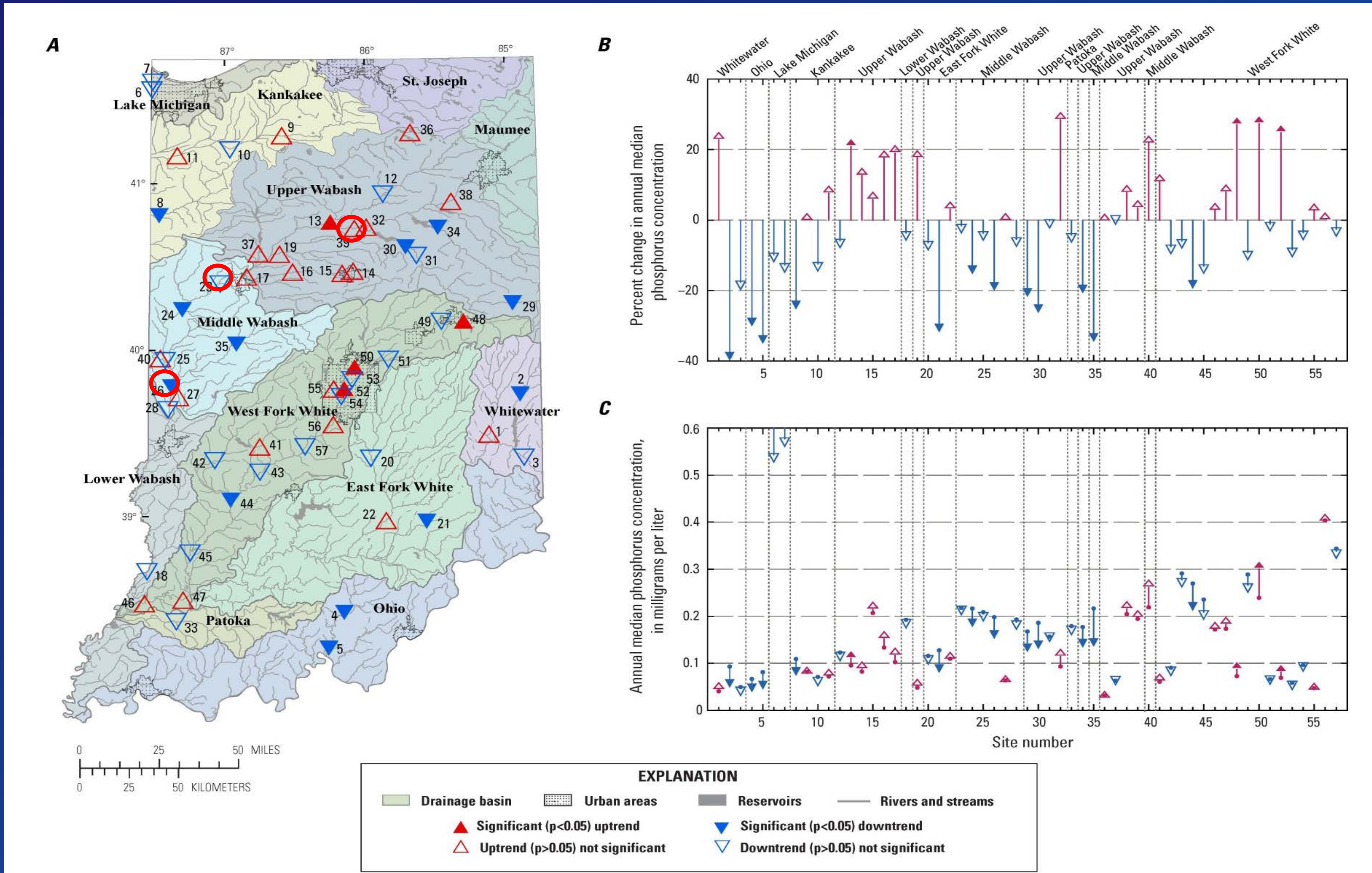

Total phosphorus: 58% percent of sites show decrease; statistically significant: 3 uptrends and 13 downtrends

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Iowa has seen similar downward trends in Nitrate between 2000-10

AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

10.1002/2013WR014829

Decadal surface water quality trends under variable climate, land use, and hydrogeochemical setting in Iowa, USA

Christopher T. Green[1], Barbara A. Bekins[1], Stephen J. Kalkhoff[2], Robert M. Hirsch[3], Lixia Liao[1], and Kimberlee K. Barnes[2]

[1]U.S. Geological Survey, Menlo Park, California, USA, [2]U.S. Geological Survey, Iowa City, Iowa, USA, [3]U.S. Geological Survey, Reston, Virginia, USA

Key Points:
- Weighted regression reveals N concentration trends independent of flow variations
- Flow-normalized N concentrations decreased in Iowa Rivers from 2000 to 2012
- Trends resulted from extreme flows interacting with hydrogeochemistry and land use

Supporting Information:
- Supporting tables and figures

Correspondence to:
C. T. Green,
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Citation:
Green, C. T., B. A. Bekins, S. J. Kalkhoff, R. M. Hirsch, L. Liao, and K. K. Barnes (2014), Decadal surface water quality trends under variable climate, land use, and hydrogeochemical setting in Iowa, USA, *Water Resour. Res.*, *50*, doi:10.1002/2013WR014829.

Received 1 OCT 2013
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Accepted article online 5 MAR 2014

Abstract Understanding how nitrogen fluxes respond to changes in agriculture and climate is important for improving water quality. In the midwestern United States, expansion of corn cropping for ethanol production led to increasing N application rates in the 2000s during a period of extreme variability of annual precipitation. To examine the effects of these changes, surface water quality was analyzed in 10 major Iowa Rivers. Several decades of concentration and flow data were analyzed with a statistical method that provides internally consistent estimates of the concentration history and reveals flow-normalized trends that are independent of year-to-year streamflow variations. Flow-normalized concentrations of nitrate+nitrite-N decreased from 2000 to 2012 in all basins. To evaluate effects of annual discharge and N loading on these trends, multiple conceptual models were developed and calibrated to flow-weighted annual concentrations. The recent declining concentration trends can be attributed to both very high and very low discharge in the 2000s and to the long (e.g., 8 year) subsurface residence times in some basins. Dilution of N and depletion of stored N occurs in years with high discharge. Reduced N transport and increased N storage occurs in low-discharge years. Central Iowa basins showed the greatest reduction in flow-normalized concentrations, likely because of smaller storage volumes and shorter residence times. Effects of land-use changes on the water quality of major Iowa Rivers may not be noticeable for years or decades in peripheral basins of Iowa, and may be obscured in the central basins where extreme flows strongly affect annual concentration trends.

1. Introduction

Abundant nitrogen (N) in surface waters can have harmful effects on human and environmental health. Agriculture is a primary source of excess N. In the United States (US), the intensification of agriculture has occurred in recent years as a result of food demands and promotion of biofuels crops to meet energy needs [*US Congress*, 2007]. Sustainable growth of agriculture requires evaluation of long-term effects of practices and environmental factors such as precipitation on N contamination. In this study, we examine long-term and recent trends in N and relate those changes to hydrogeochemical features of basins and conceptual models of responses to changing discharges and N-fertilization.

In the last decade, corn production has increased in the midwestern United States to satisfy demands for production of ethanol, now the most readily available alternative fuel in the US. Ethanol production in Iowa has increased over 700% from about 1.5 billion liters in 2003 to 14 billion liters in 2011 [*Hart et al., 2012*]. As corn prices increase, some of the most productive land has been continuously planted in corn in contrast to a corn-soybean rotation [*Secchi et al.*, 2011], and millions of acres of uncultivated lands have been brought into production [*Cox and Rundquist*, 2013]. A larger percentage of row-crop agriculture in a watershed has been shown to correlate with greater N concentrations in rivers and streams [*Schilling and Libra*, 2000; *Schilling and Spooner*, 2006]. Recent studies indicate that increased corn ethanol production can increase export of N to ocean ecosystems and cause eutrophication of surface waters [*Donner and Kucharic*, 2008; *Yang et al.*, 2012]. Whether specific conservation practices or environmental factors will modify the response of surface waters to increased corn planting is a critical question for midwestern states and other areas affected by agricultural intensification.

The state of Iowa is an important study area for the effects of agricultural intensification because of its long agricultural history, influence on regional water quality, and diverse hydrogeochemical landscape. Starting

Citation:
Green, C. T., B. A. Bekins, S. J. Kalkhoff, R. M. Hirsch, L. Liao, and K. K. Barnes (2014), Decadal surface water quality trends under variable climate, land use, and hydrogeochemical setting in Iowa, USA, *Water Resour. Res.*, *50*, doi:10.1002/2013WR014829.

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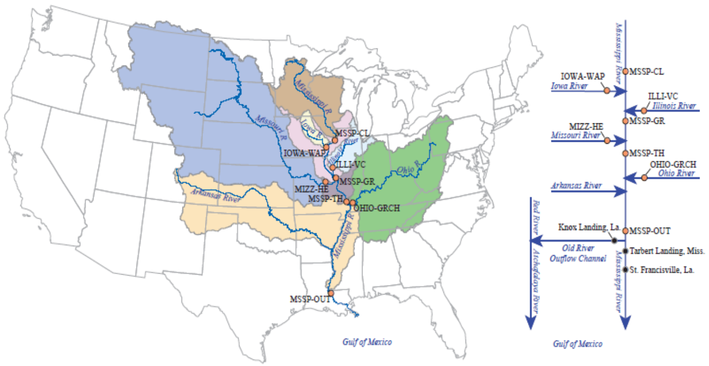
National Water-Quality Assessment Program

Nitrate in the Mississippi River and Its Tributaries, 1980–2010: An Update



Scientific Investigations Report 2013–5169

U.S. Department of the Interior
U.S. Geological Survey

http://pubs.usgs.gov/sir/2013/5169/

By Jennifer C. Murphy, Lori A. Sprague, and Robert M. Hirsch

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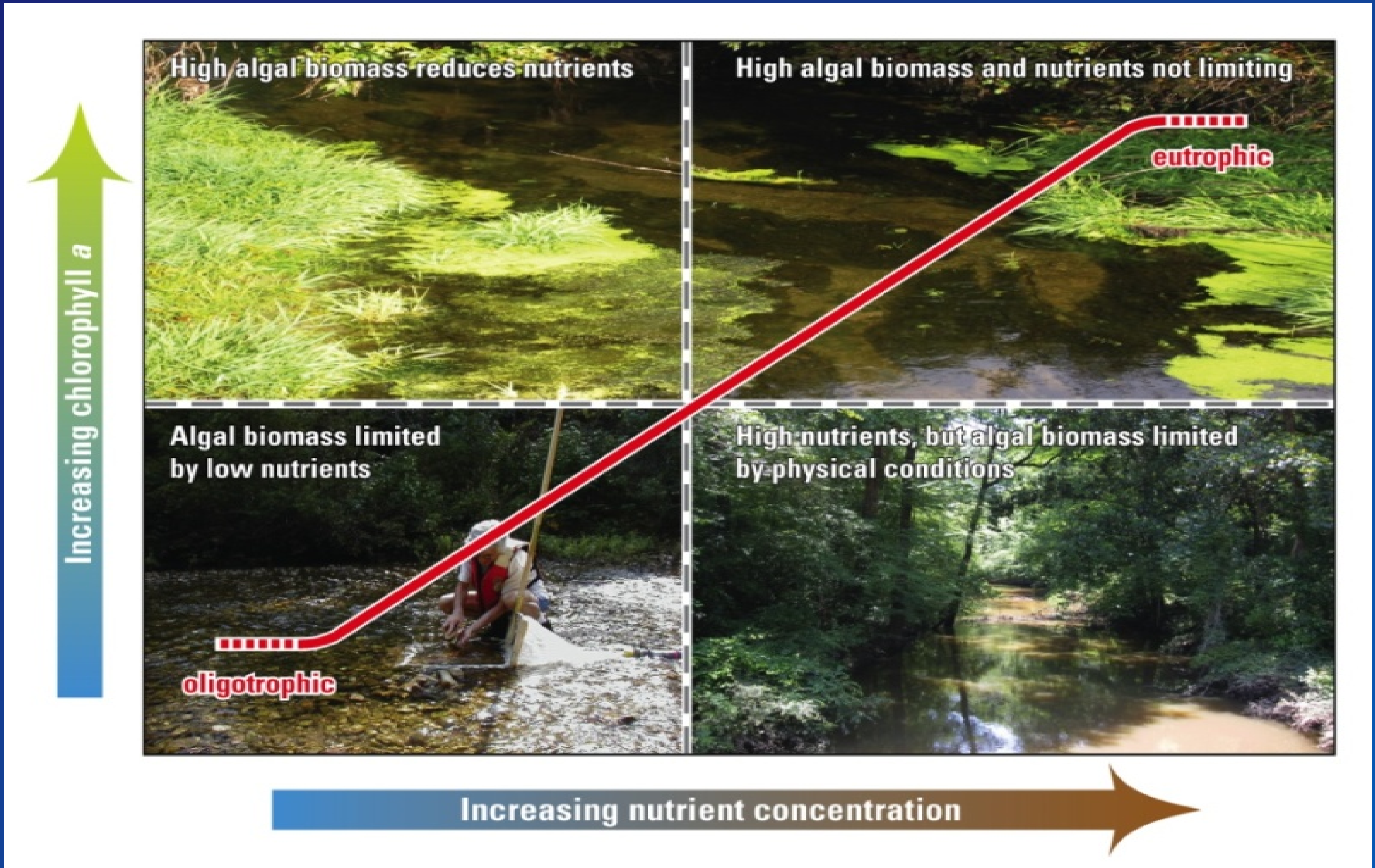
BIOLOGICAL COMMUNITIES CAN HELP SHOW LOW NUTRIENT SITES

WHY RELATIONS BETWEEN NUTRIENTS AND ALGAL BIOMASS ARE RARELY FOUND?

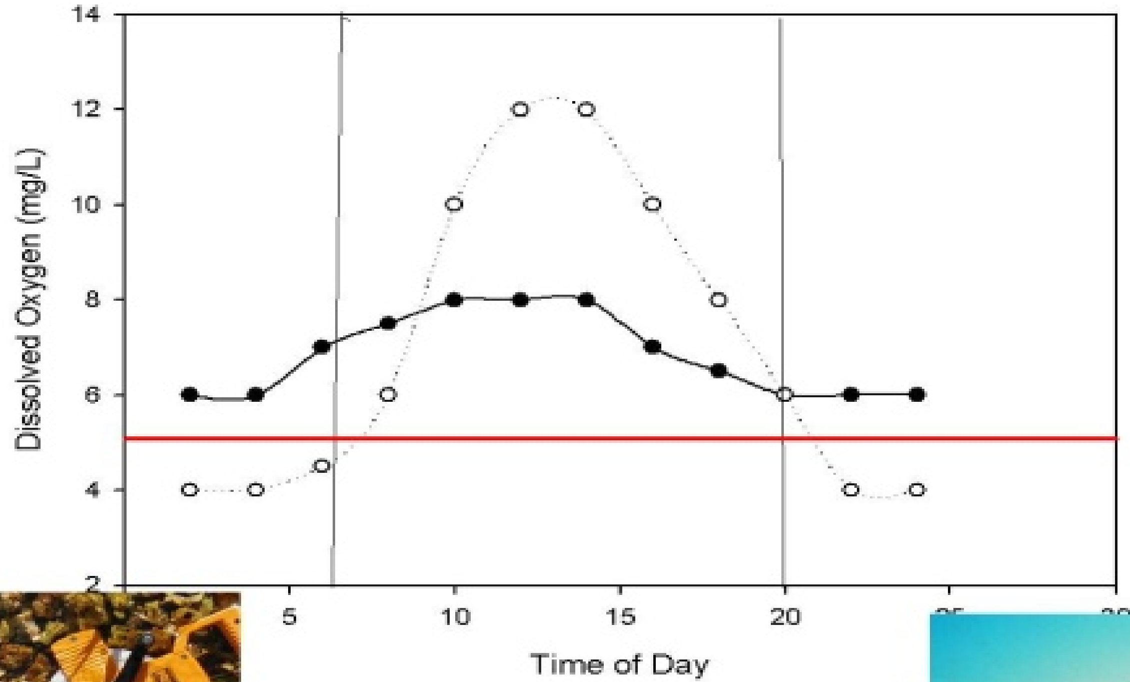


From Munn and others, 2010

THE LACK OF RELATIONS SUGGESTS BIOLOGICAL RESPONSES ARE NEEDED

- Invertebrate
- Fish
- Algae
  - States with Diatom IBI's: KY, MI, MT

Daily DO Fluctuations



States using:

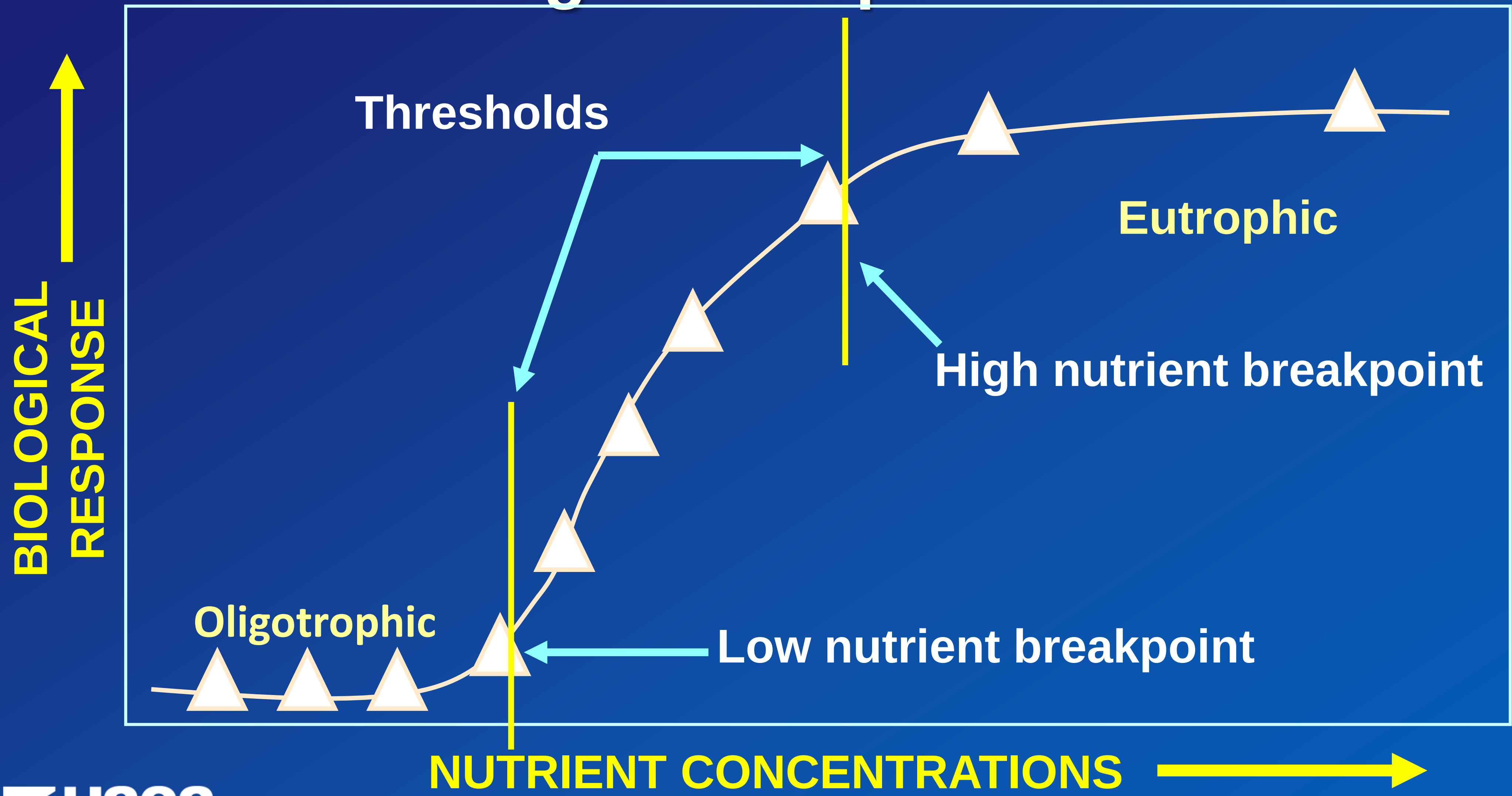
Ohio

Minnesota

Illinois

From Munn and others, in progress

A Conceptual Model:
Positive Biological Response to Nutrients



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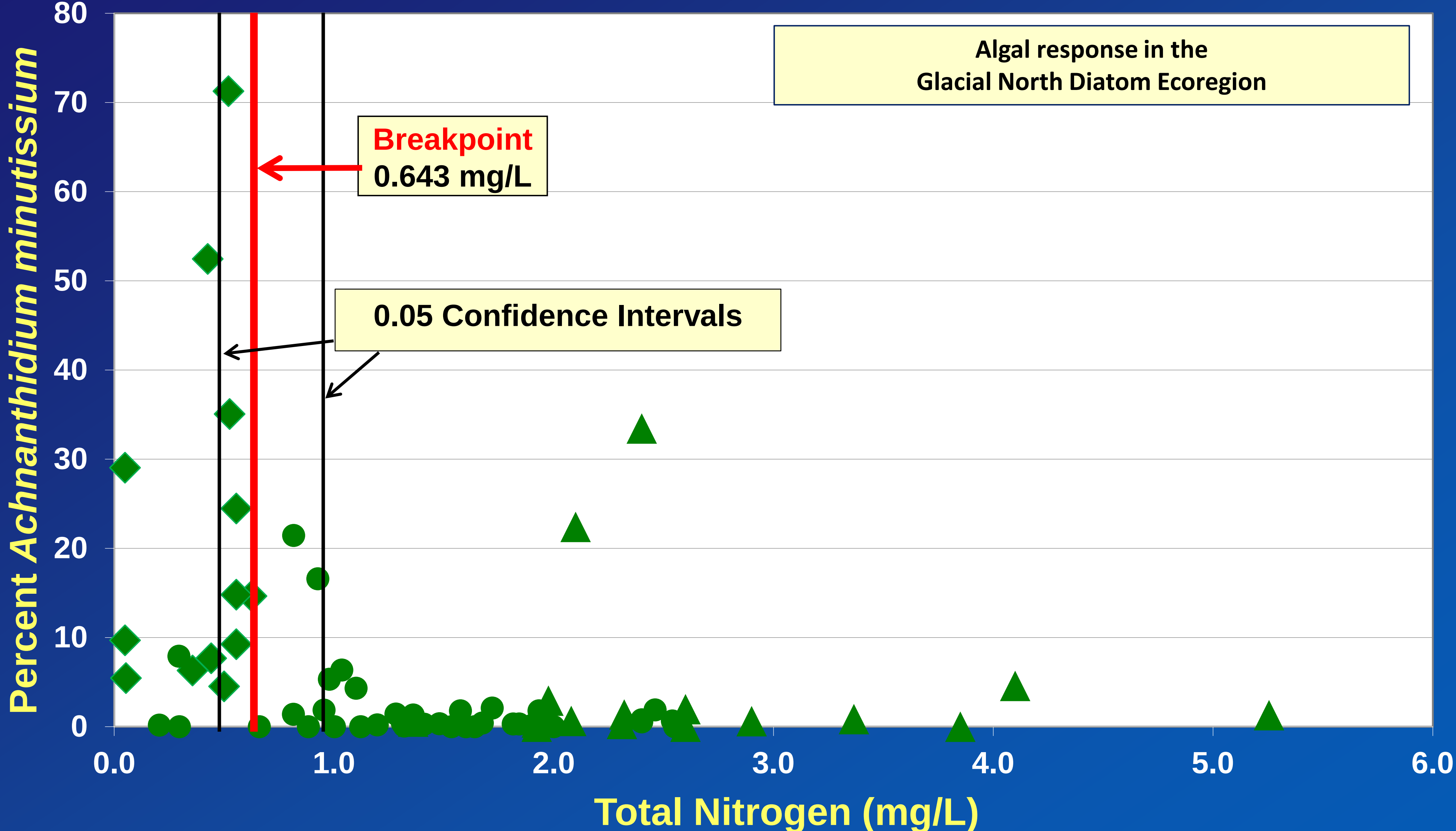
Nutrient Criteria Approaches: Stressor-Response

Example of Negative Response to Nutrients



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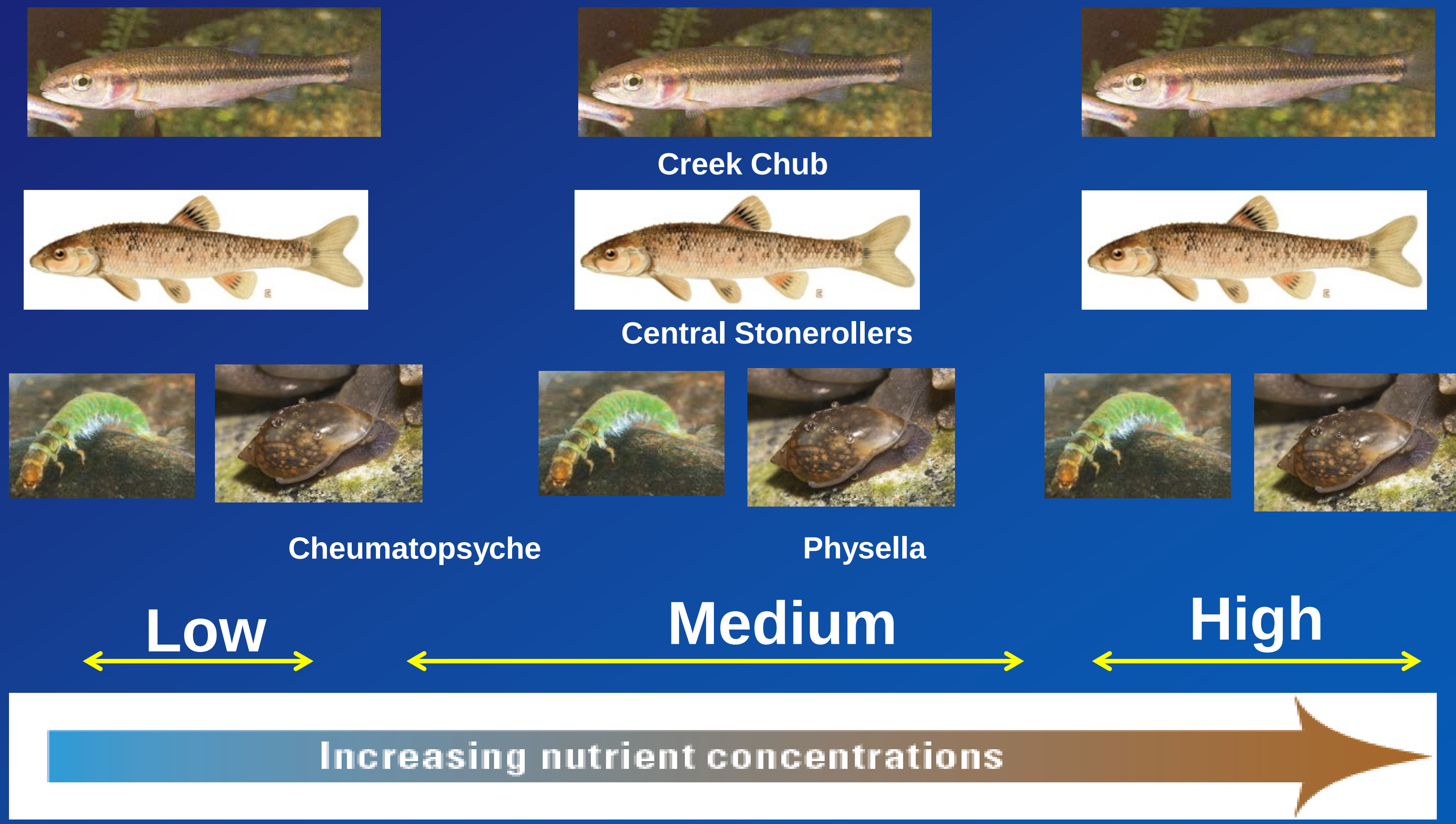
Nutrient Criteria Approaches: Stressor-Response

No Biological Gradient Based on Nutrient Concentrations



http://fish.dnr.cornell.edu
http://hbs.bishopmuseum.org
http://molluscs.at

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NUTRIENTS CAN BE REWARDING

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INDIANA WATER MONITORING COUNCIL

Indiana Water Monitoring Council

http://www.inwmc.org/

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PRIORITY PROJECTS

- **Optimization of:**
  - **Water-quality networks**
  - **Streamgages**

REMAINING ISSUES

- Is there a sufficient nutrient gradient to identify breakpoints?
- Can regional breakpoints be used across multiple states?
- Local vs Downstream Impacts: Account for downstream impacts
- There can be nutrient impairment even if there is a "good" IBI score

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APPROACHES FOR DEVELOPING NUTRIENT CRITERIA

Multiple approaches:

- Classification
- Reference condition
- Stressor – response
- Mechanistic models
- Literature and Best Professional Judgment
- Multiple lines of evidence

USEPA REQUIREMENTS FOR STATES

Numerical criteria

- Causal variables
  - TP
  - TN
- Response variables
  - Chl *a (periphyton and seston)*
  - Transparency/turbidity

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MULTIPLE LINES OF EVIDENCE

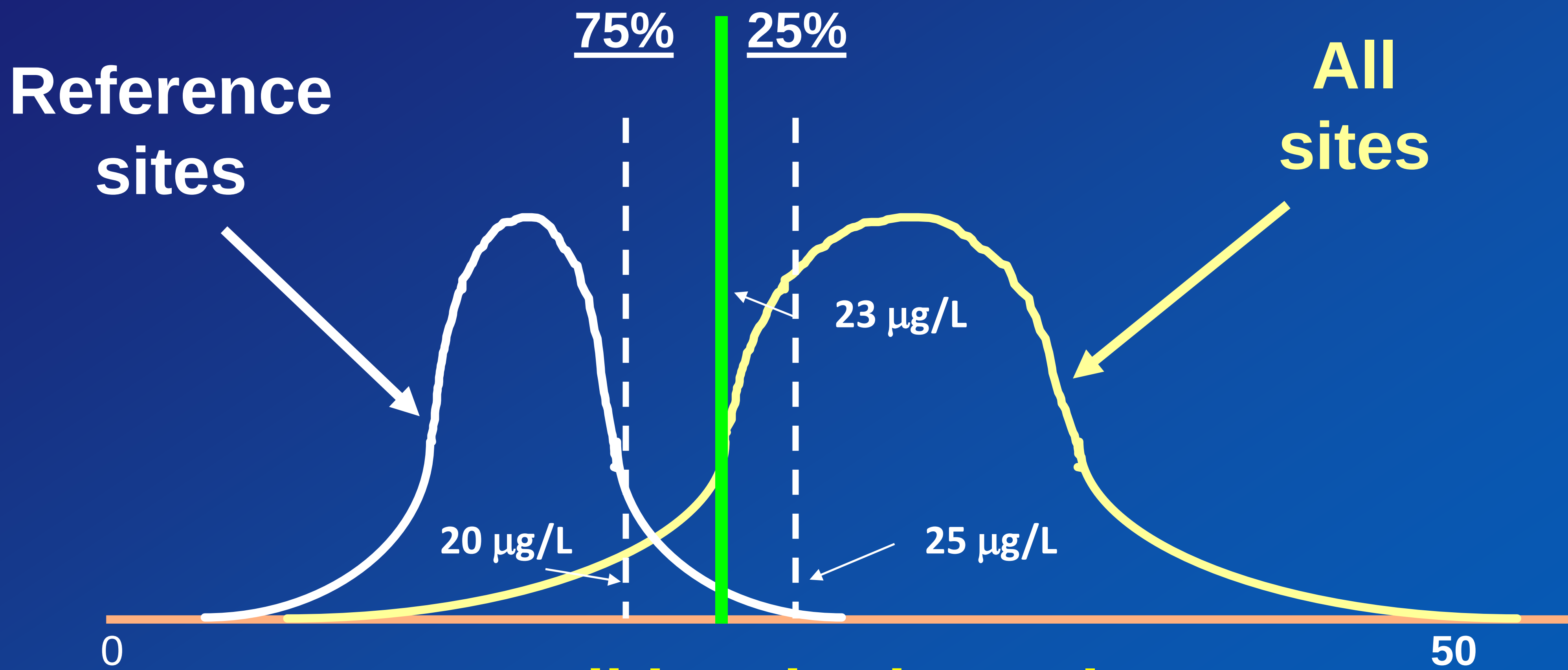
Biological Response

Study	Location	TN (mg/L) Low	TN (mg/L) High	TP (mg/L) Low	TP (mg/L) High
Smith Nutrient IBI (2007)	New York	0.34	1.40	0.018	0.065
NEET O/E	Midwest	0.58	1.34	0.026	0.100
Crain and Caskey (2010)	Kentucky wadable	--	--	0.032	--
Miltner (2010)	Ohio	--	--	0.038	--
Heiskary et al (2010)	Minnesota (North and Northwest)	--	1.77	0.040	
Robertson et al (2008)	Wisconsin (large rivers – inverts)	0.53	1.99	0.040	0.150
Robertson et al (2006)	Wisconsin (wadable streams – fish)	0.54	--	0.055	0.067
Frey et al (2011) wadable	Glacial North (MN, WI, MI)	0.60	1.20	0.030	0.100
NEET EPT richness	Midwest, West	0.60	--	0.052	0.174
Wang et al (2007)	Wisconsin	0.60	--	--	--
Miltner and Rankin (1998)	Ohio	0.61	1.65	0.060	0.170
Robertson et al (2006)	Wisconsin (wadable streams - inverts	0.61	1.11	0.088	0.091
Robertson et al (2008)	Wisconsin (large rivers) fish	0.63	1.97	0.079	0.139
Caskey et al (2010)	Indiana wadable	2.40	3.30	0.042	0.129
Heiskary et al (2010)	Minnesota (south)	1.77	3.60		
Frey et al (2011)	Central and Western Plains (IL, IN, OH)	1.70	3.50	0.075	0.133

Background nutrient concentrations or trophic levels

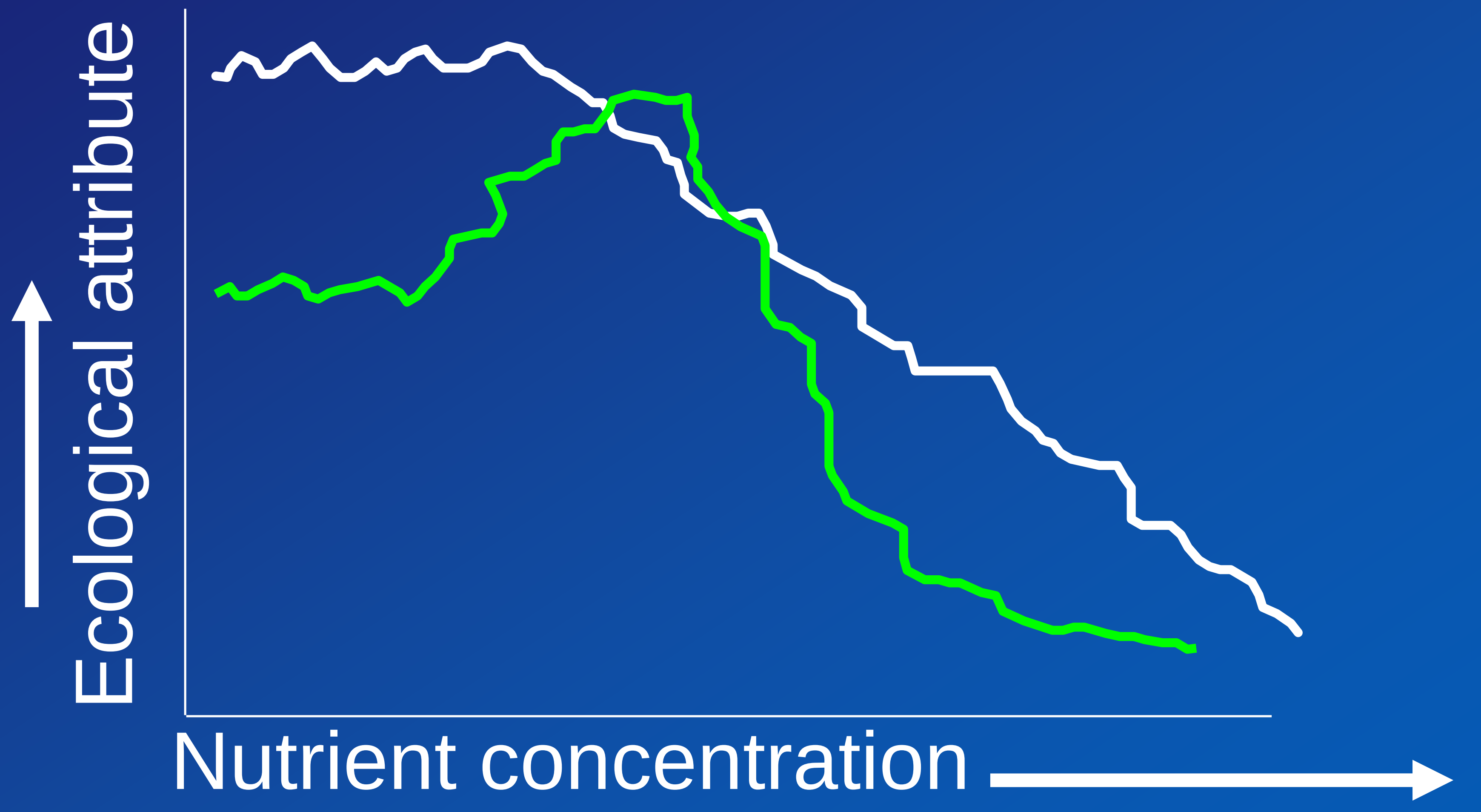
Study	Location	TN (mg/L) Low	TN (mg/L) High	TP (mg/L) Low	TP (mg/L) High
Dodds et al (1998)	National, 33rd and 66th percentiles	0.70	1.70	0.025	0.075
Robertson et al (2006)	Wisconsin (median reference) wadable	0.61	1.10	0.035	--
Robertson et al (2008)	Wisconsin (median reference) large rivers	0.40	0.70	0.035	--

FREQUENCY DISTRIBUTION APPROACH

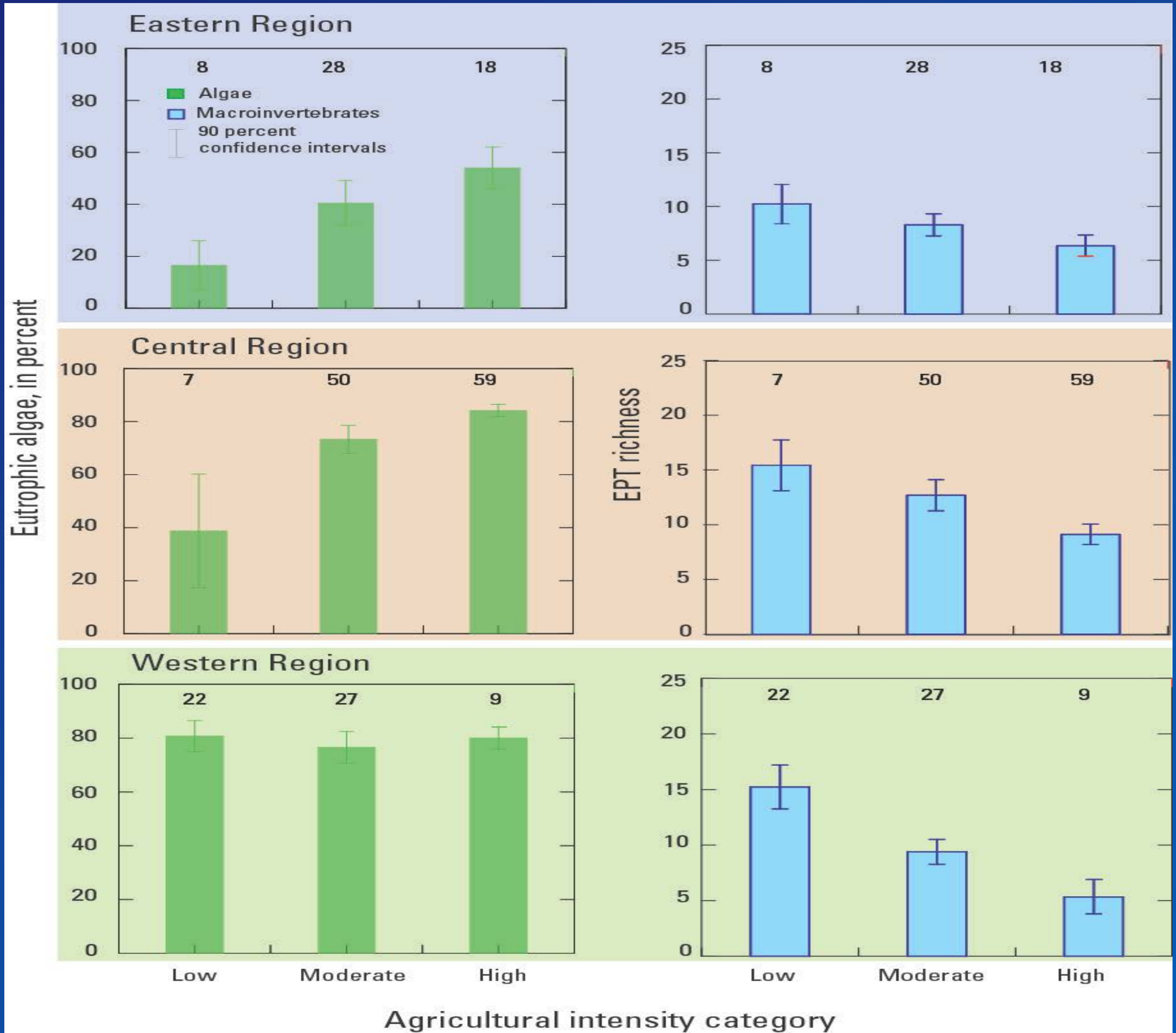


Possible criterion value

Effects Threshold Approach



BIOLOGICAL CONDITION IMPROVES AS AGRICULTURAL INTENSITY INCREASES



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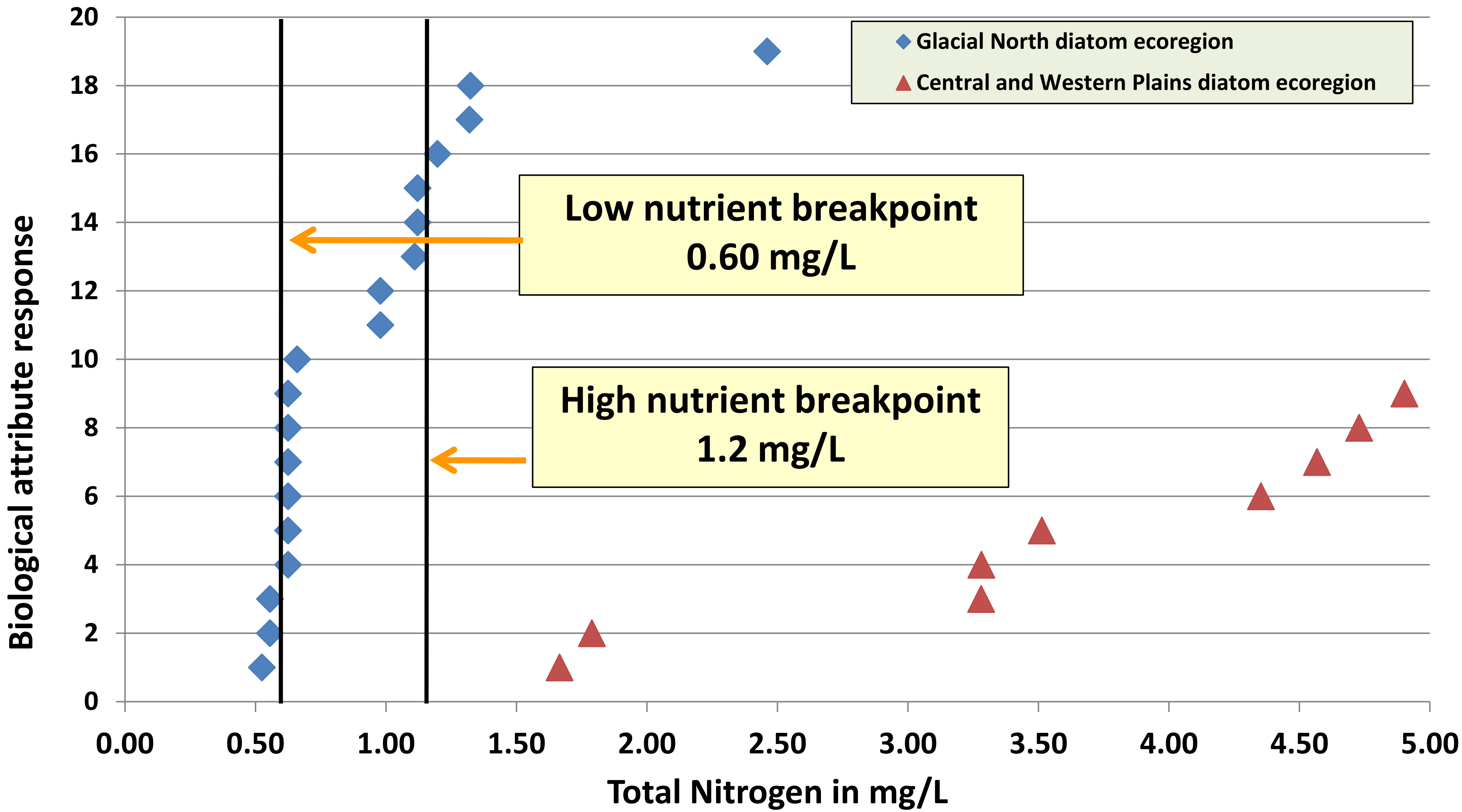
SIMILAR BREAKPOINTS ACROSS COMMUNITIES

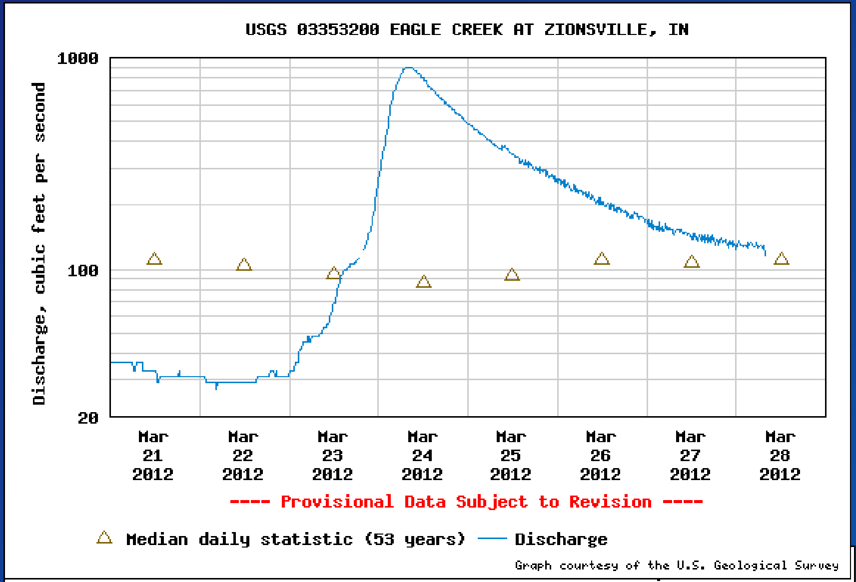


Super Gages

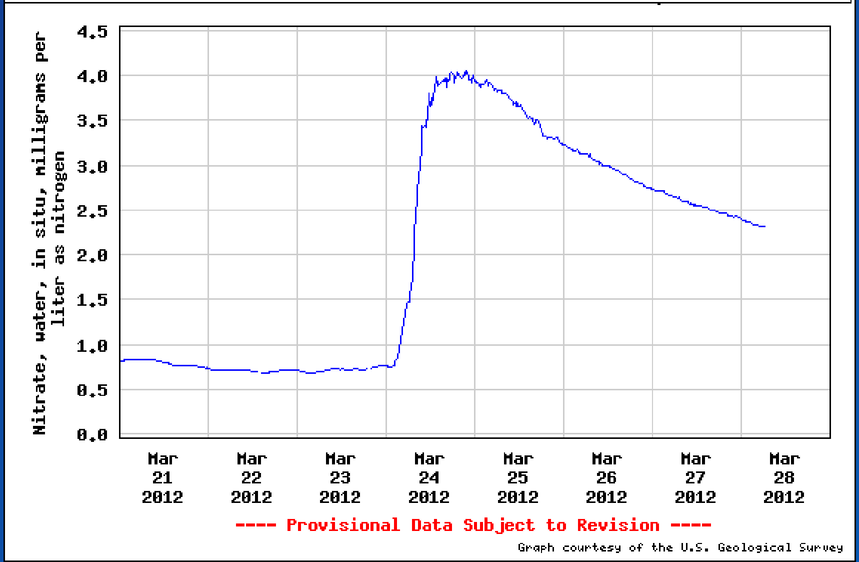
Eagle Creek at Zionsville, IN (03353200)

http://waterdata.usgs.gov/in/nwis/uv/?site_no=03353200&PARAmeter_cd=00400,00095,00010

Discharge



Nitrate



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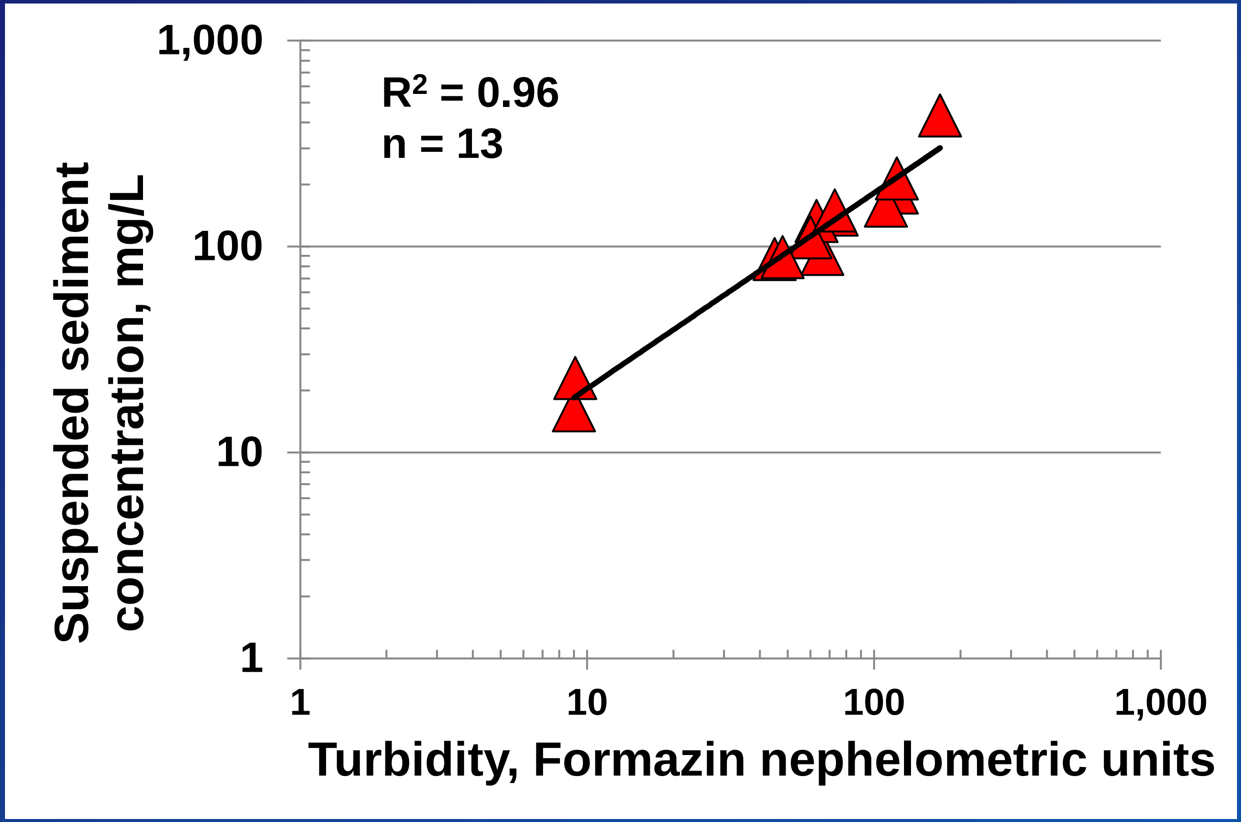
Surrogates

Suspended Sediment vs. Turbidity



White River at Hazleton, IN

Other uses:

- Phosphorus
- Algal biomass

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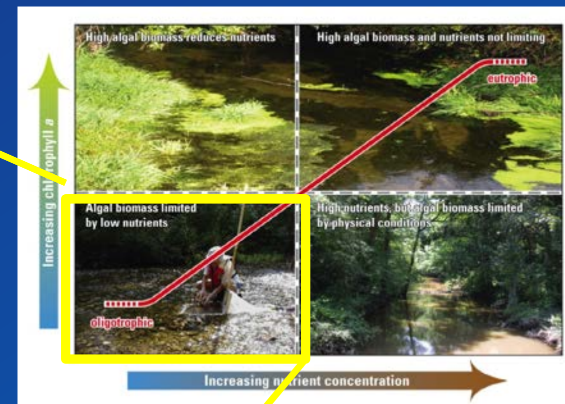
BIOLOGICAL COMMUNITIES CAN HELP SHOW LOW NUTRIENT SITES

- **Low nutrients, high algal biomass** (uptake sites)
  - Stonerollers
  - Creek chubs
- **Low nutrients, low algal biomass** (oligotrophic)
  - Longear sunfish
  - Spotfin shiners



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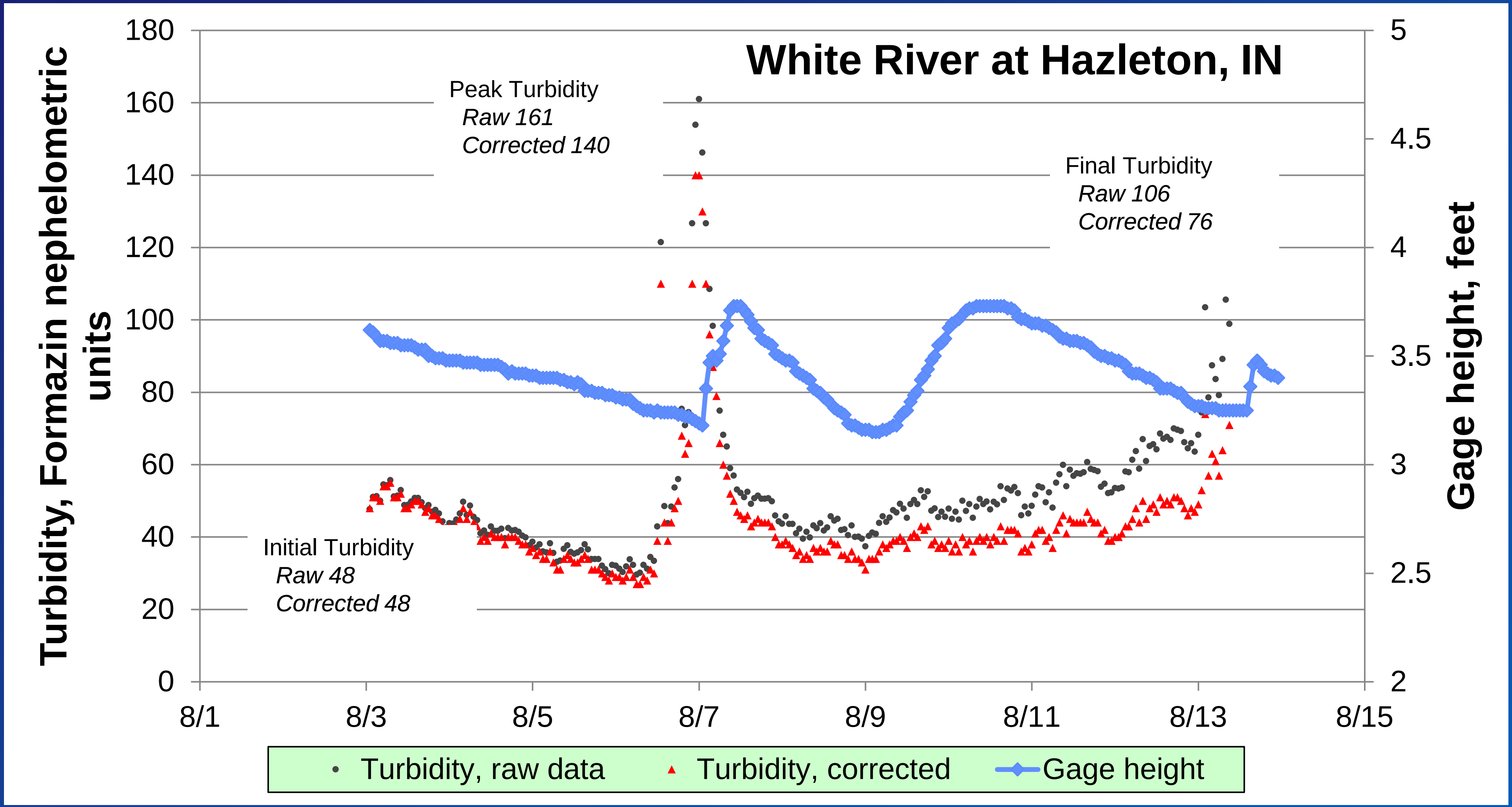
QA/QC leads to accurate data



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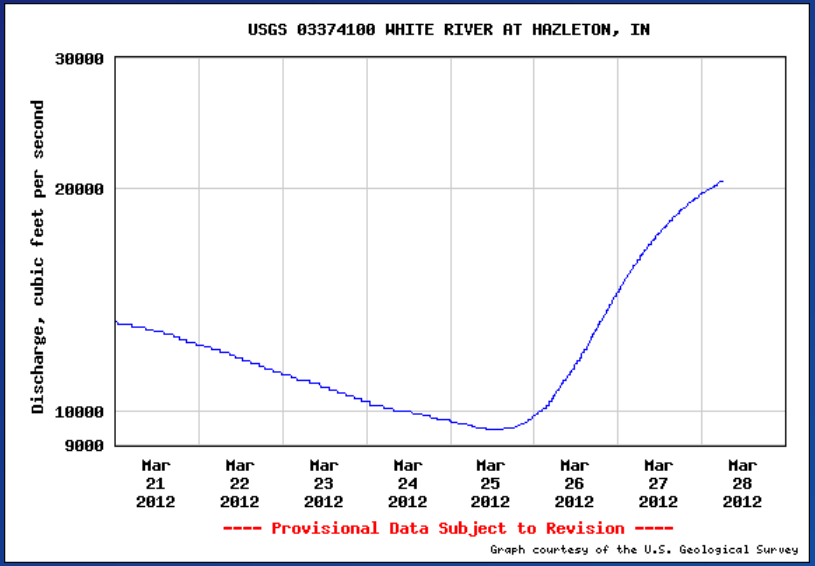
Super Gages

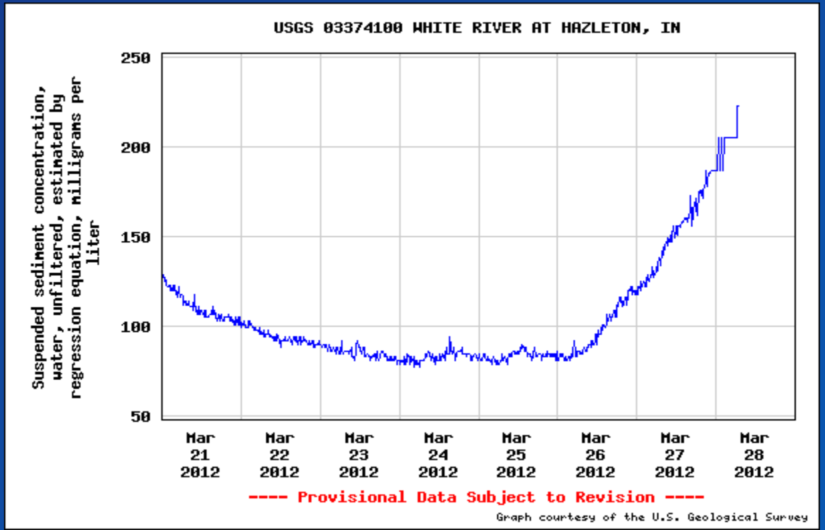
White River at Hazleton, IN (03374100)

http://waterdata.usgs.gov/in/nwis/uv/?site_no=03374100&PARAmeter_cd=00400,00095,00010

Discharge



Suspended sediment



http://www.ipcamhost.net/test_player.jsp?id=18&path=usgs-in

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NATURAL STREAMS

Reference or unimpacted streams

- Diverse instream habitat and extensive riparian buffers
  - Riffle-run-pool
- Low concentrations of:
  - Nutrients
  - Pesticides
  - Other stressor/ contaminants
- High dissolved oxygen
- Cooler temperatures

UNIMPACTED STREAMS

Reference or unimpacted streams

- **Diverse biological communities**
  - Sensitive species
  - More taxa
  - Stronger and more complex food web

- **Few unimpacted sites in the region of the Cornbelt we call Indiana**

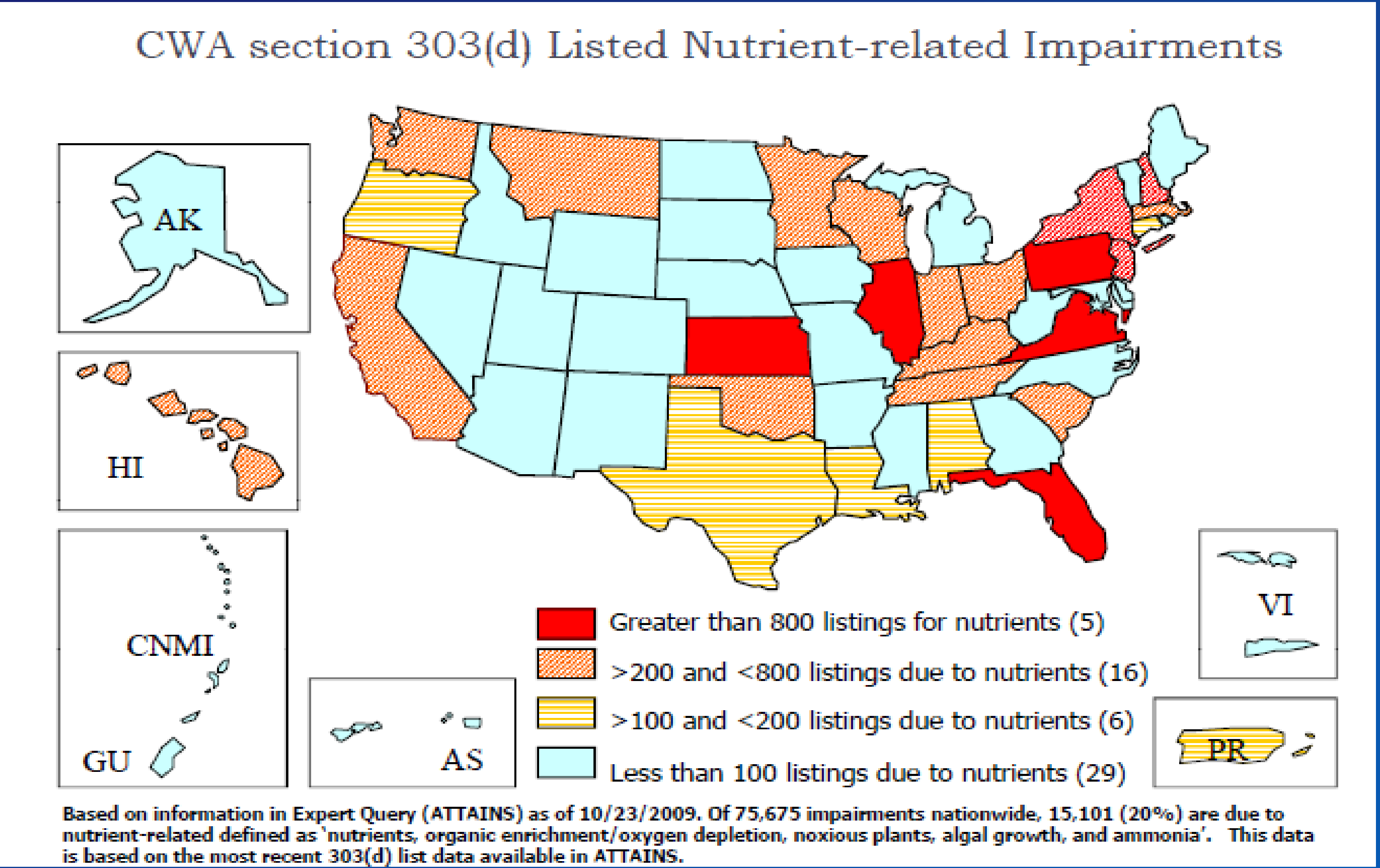
HOW ARE INDIANA STREAMS?

Impaired Streams

- Clean Water Act
  - 303d and 305b list
- 26 parameters
  - Acute
  - Chronic
- About 3,000 impaired reaches

Rank	IMPAIRMENT	2008	2010
	AGRICULTURAL AND URBAN IMPAIRMENTS		
1	E. COLI	930	979
	OIL AND GREASE	3	5
	PESTICIDES	1	1
	NUTRIENTS AND NUTRIENT RELATED IMPAIRMENTS		
5	DISSOLVED OXYGEN	78	163
6	NUTRIENTS	63	110
9	PHOSPHORUS	50	50
	ALGAE	20	20
	TASTE AND ODOR	12	12
	AMMONIA	6	8
	METALS AND MAJOR IONS		
2	PCBs (FISH TISSUE)	653	612
4	MERCURY (FISH TISSUE)	324	355
7	PCBs (WATER)	0	69
8	DIOXIN (WATER)	4	69
10	MERCURY (WATER)	0	47
	FREE CYANIDE	0	27
	PH	9	18
	CHLORIDE	14	16
	SULFATE	27	1
	TOTAL CYANIDE	15	0
	LEAD	4	0
	NICKEL	1	0
	COPPER	1	0
	BIOLOGICAL COMMUNITIES AND RELATED IMPAIRMENTS		
3	IMPAIRED BIOTIC COMMUNITIES	421	570
	TEMPERATURE	0	14
	SILTATION	3	3
	TOTAL DISSOLVED SOLIDS	42	0

HOW DOES INDIANA COMPARE?



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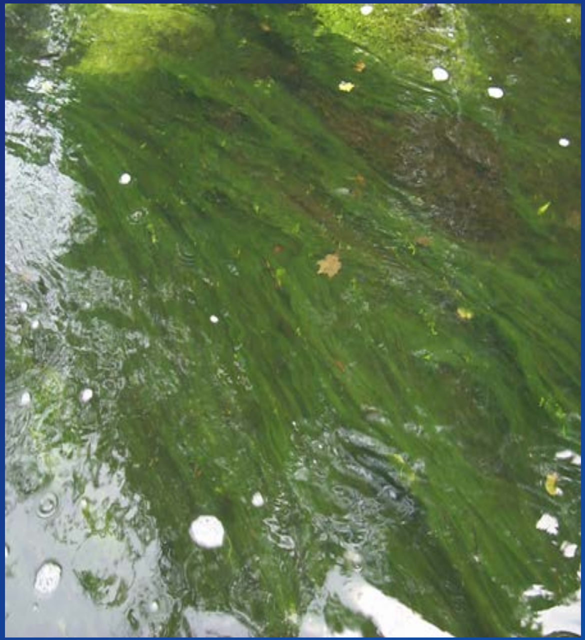
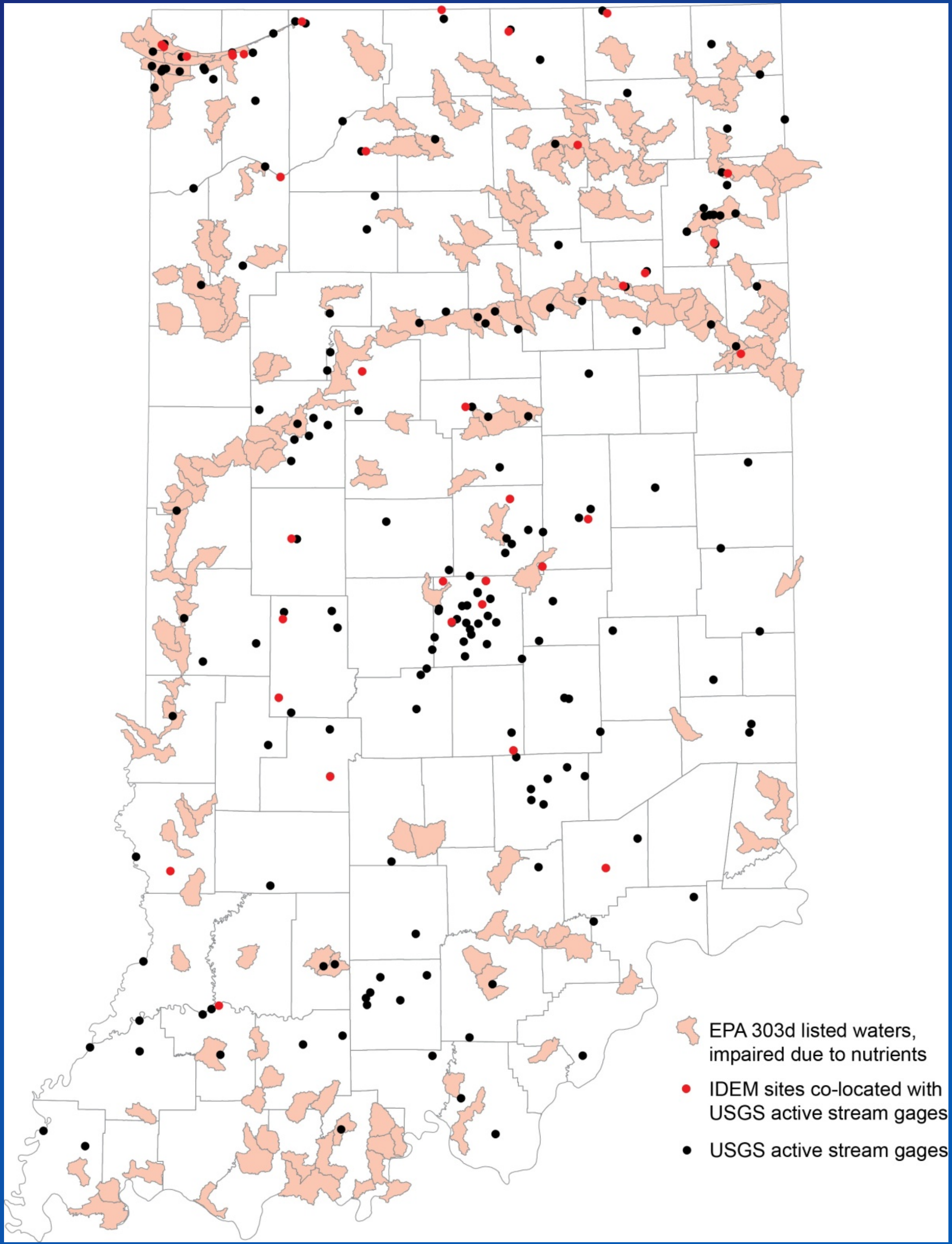
From Dana Thomas, USEPA

IMPAIRED STREAMS: NUTRIENTS





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303d listings