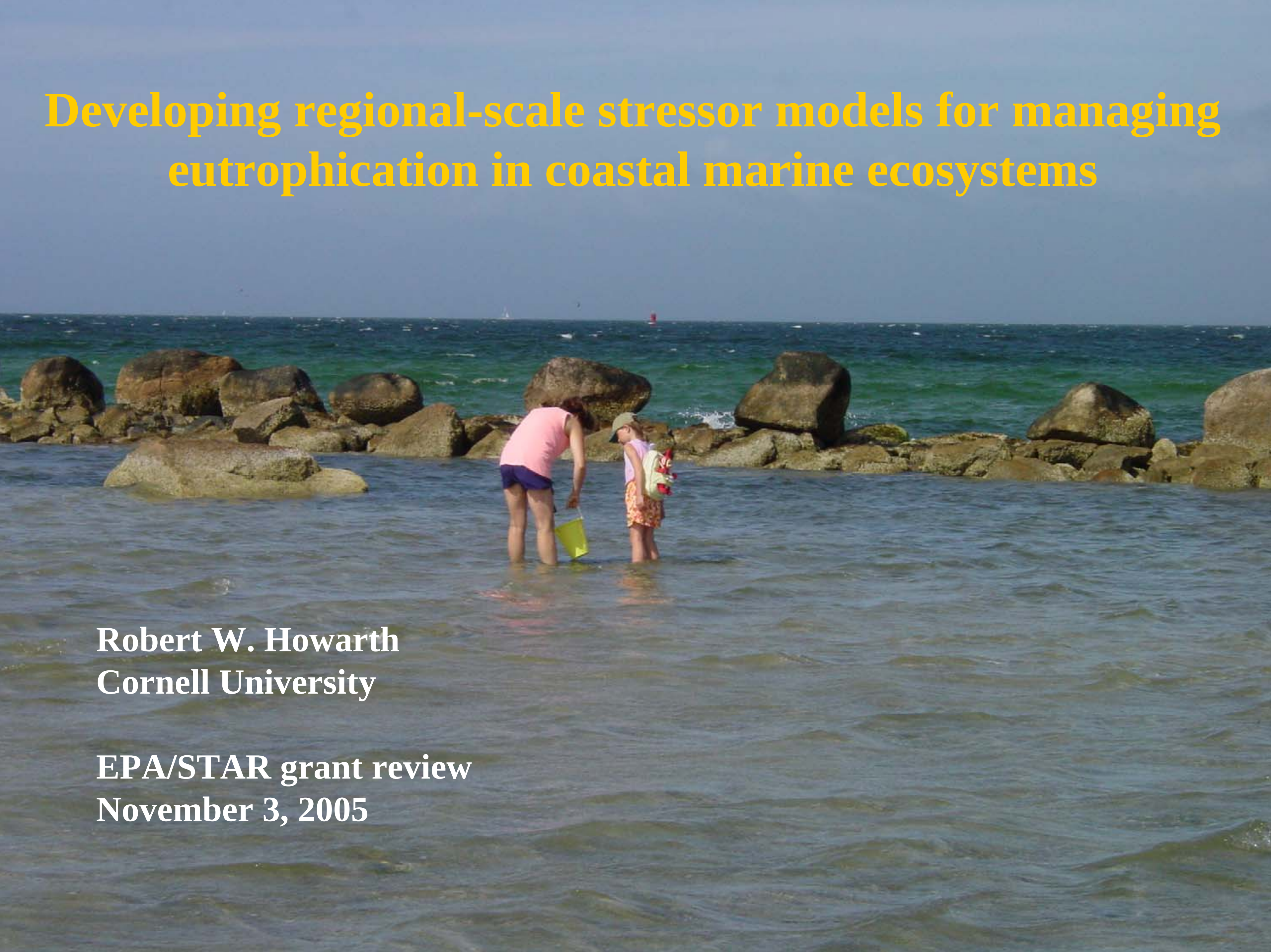
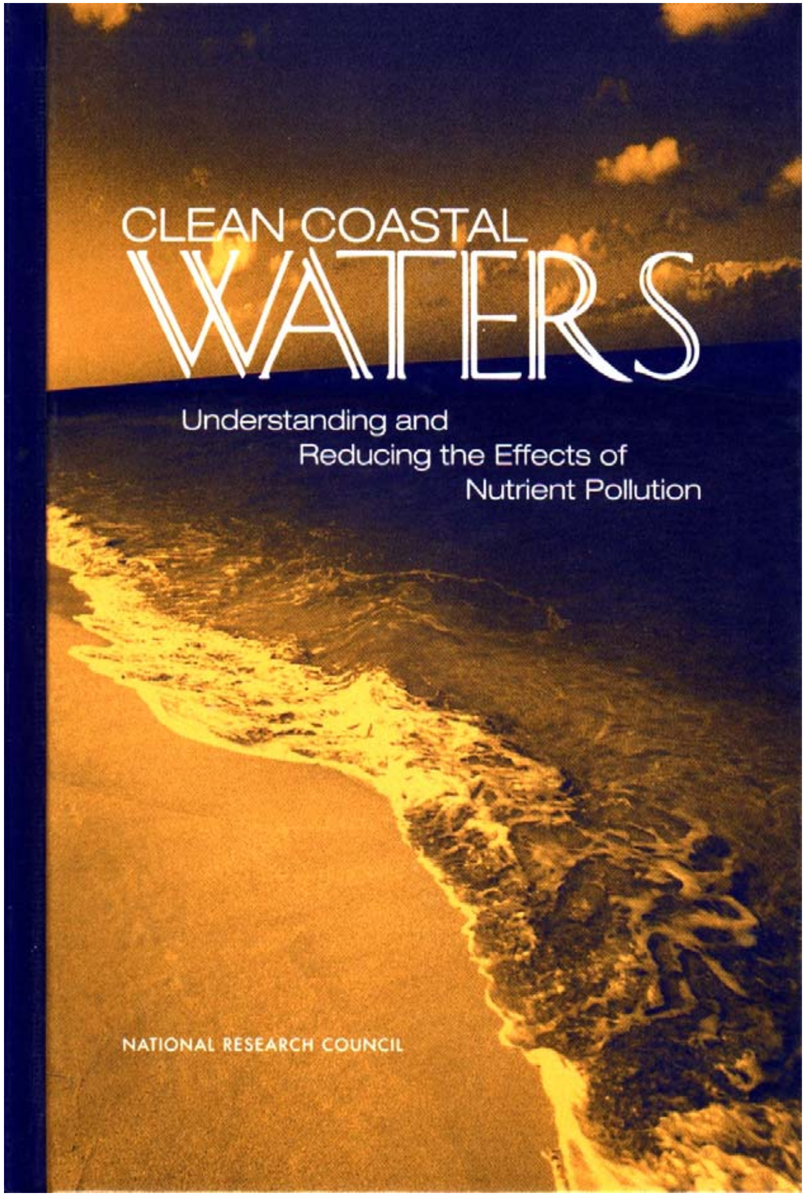


Developing regional-scale stressor models for managing eutrophication in coastal marine ecosystems

Robert W. Howarth
Cornell University

EPA/STAR grant review
November 3, 2005



CLEAN COASTAL
WATERS
Understanding and
Reducing the Effects of
Nutrient Pollution

NATIONAL RESEARCH COUNCIL

Nitrogen is the largest pollution problem in the coastal waters of the US. Two thirds of coastal rivers and bays are moderately to severely degraded from nitrogen pollution.

<u>Priority recommendations</u>:

- **Improve models for determining how management actions may affect nitrogen fluxes from watersheds, and how these may be affected by climate variability and change.**

- **Develop a classification scheme for the sensitivity of estuaries to nitrogen inputs, as an aid for management decisions.**

National Academy of Science’s Committee on Causes and Management of Coastal Eutrophication (1998-2000)

Principal Investigator:

Robert Howarth, Cornell (biogeochemistry, ecosystem science)

Key Personnel and consultants:

Dennis Swaney, Cornell (watershed modeling)

Roxanne Marino, Cornell (coastal marine biogeochemistry, ecosystem science)

Elizabeth Boyer, Univ. of California at Berkeley (watershed hydrology)

Don Scavia, Univ. of Michigan (water quality modeling)

Merryl Alber, Univ. of Georgia (ecology of southeastern rivers and estuaries)

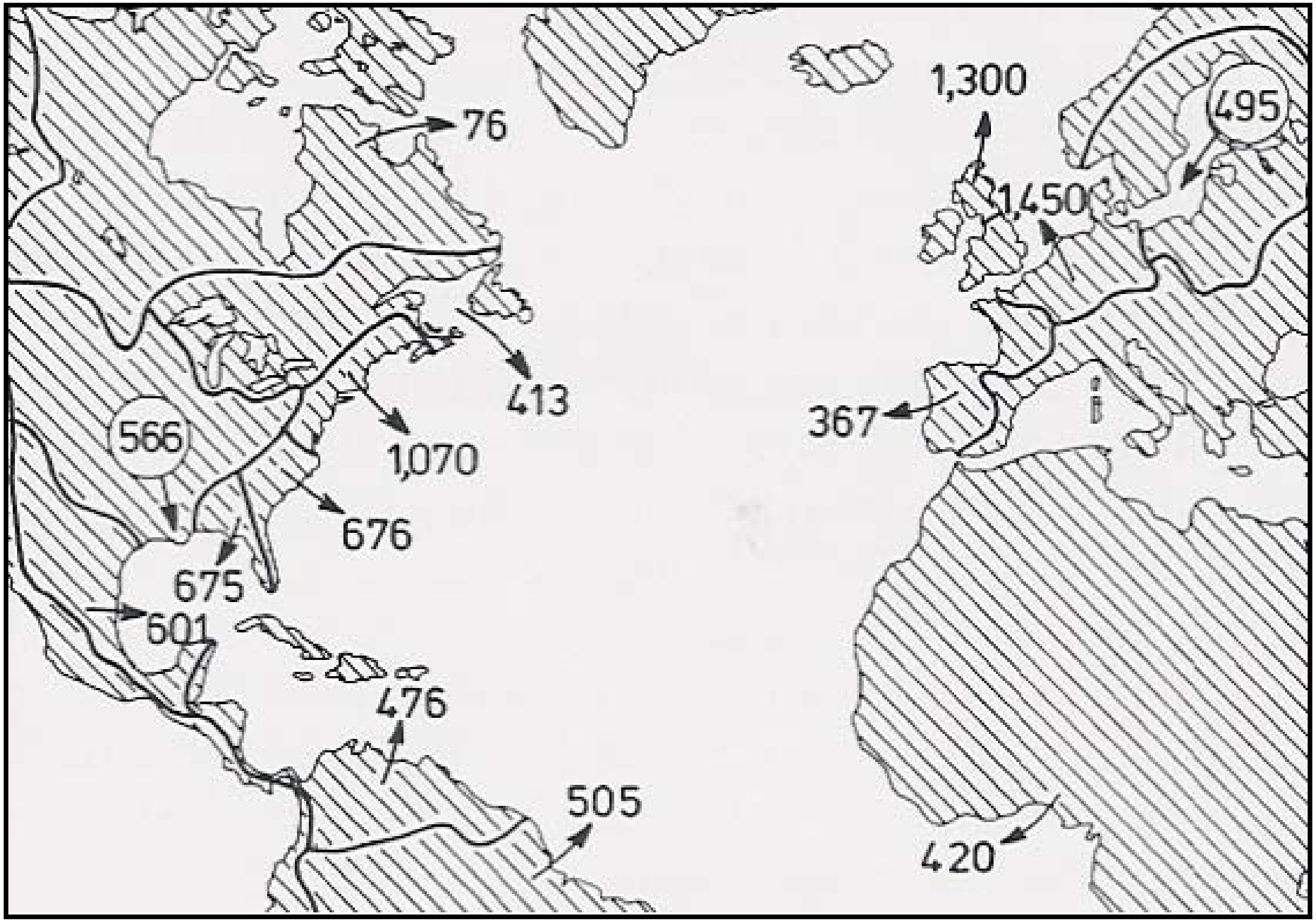
Two distinct parts of our research (from NRC 2000):

1) Understanding differential sensitivity of estuaries to nutrient inputs (poster by Dennis Swaney).
2) Modeling nutrient fluxes from large watersheds (effects of climate and climate change, land use change, and management practices).

Our modeling involves two approaches:

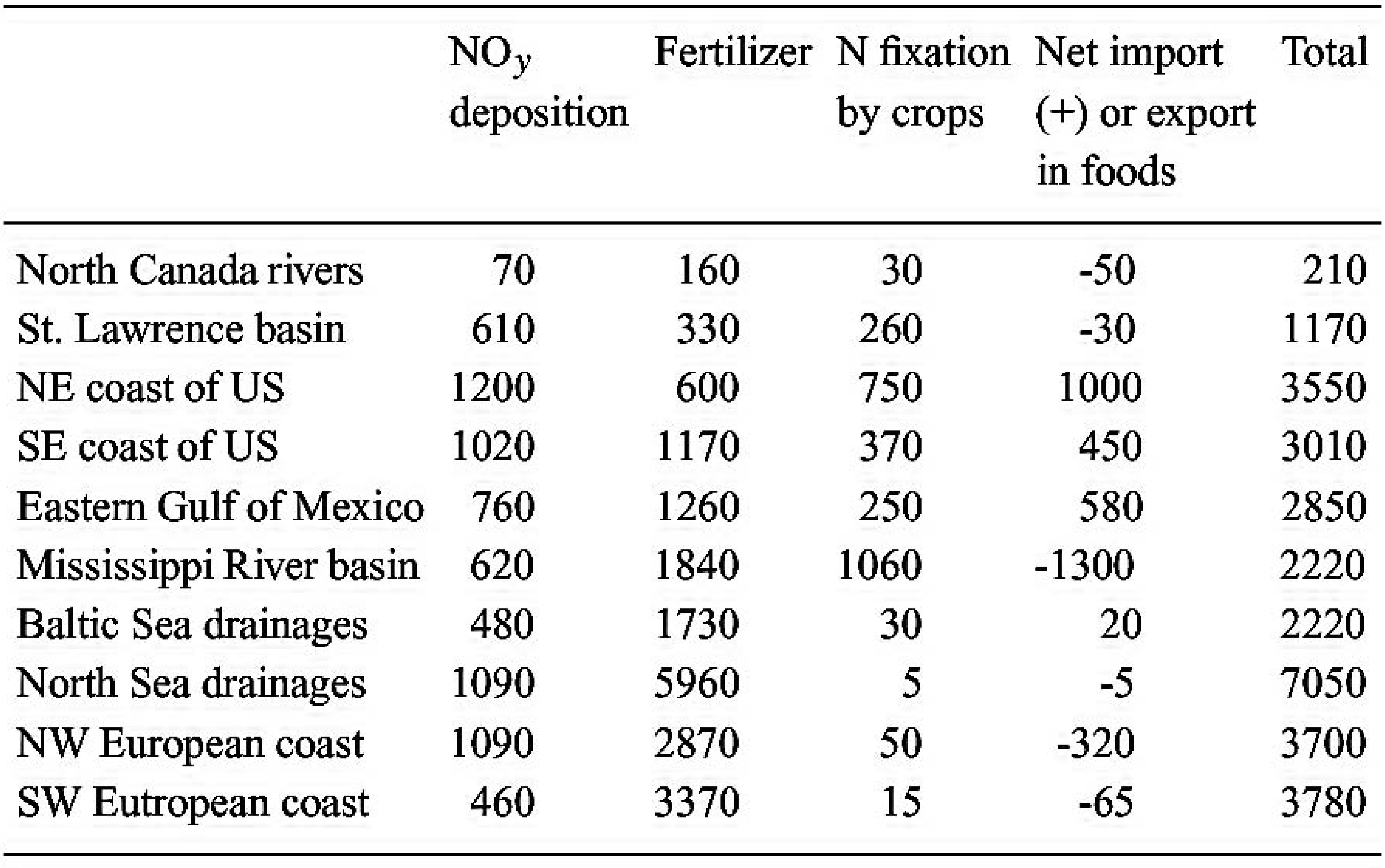
1. Mass balance, statistical approach.
2. Simulation modeling.

Average nitrogen fluxes from landscape (1980s)



Kg N km^{-2} year^{-1} (Howarth et al. 1996)

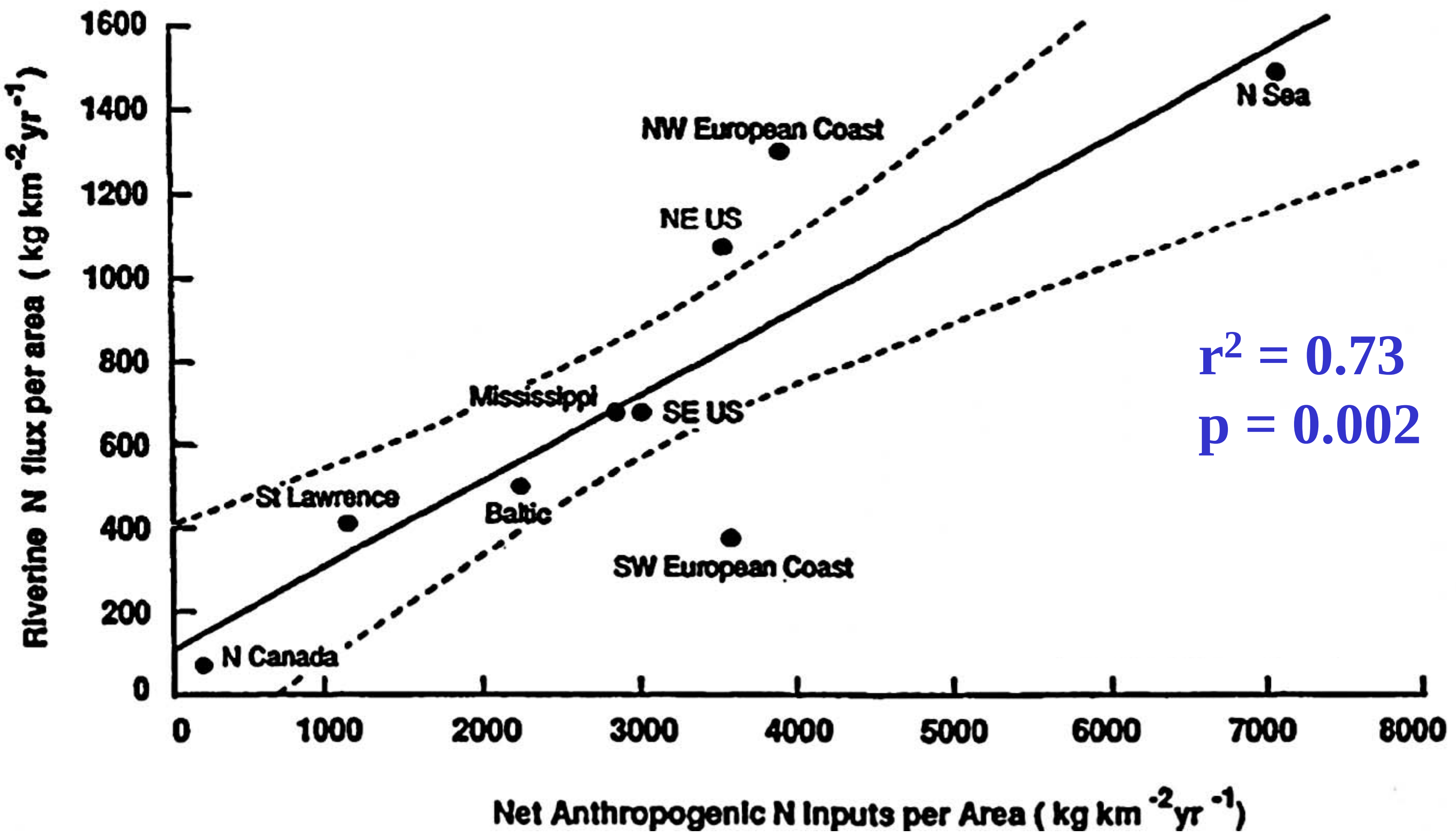
North Atlantic Ocean region: net anthropogenic N inputs



	NO$_y$ deposition	Fertilizer	N fixation by crops	Net import (+) or export in foods	Total
North Canada rivers	70	160	30	-50	210
St. Lawrence basin	610	330	260	-30	1170
NE coast of US	1200	600	750	1000	3550
SE coast of US	1020	1170	370	450	3010
Eastern Gulf of Mexico	760	1260	250	580	2850
Mississippi River basin	620	1840	1060	-1300	2220
Baltic Sea drainages	480	1730	30	20	2220
North Sea drainages	1090	5960	5	-5	7050
NW European coast	1090	2870	50	-320	3700
SW Eutropean coast	460	3370	15	-65	3780

Howarth et al. 1996

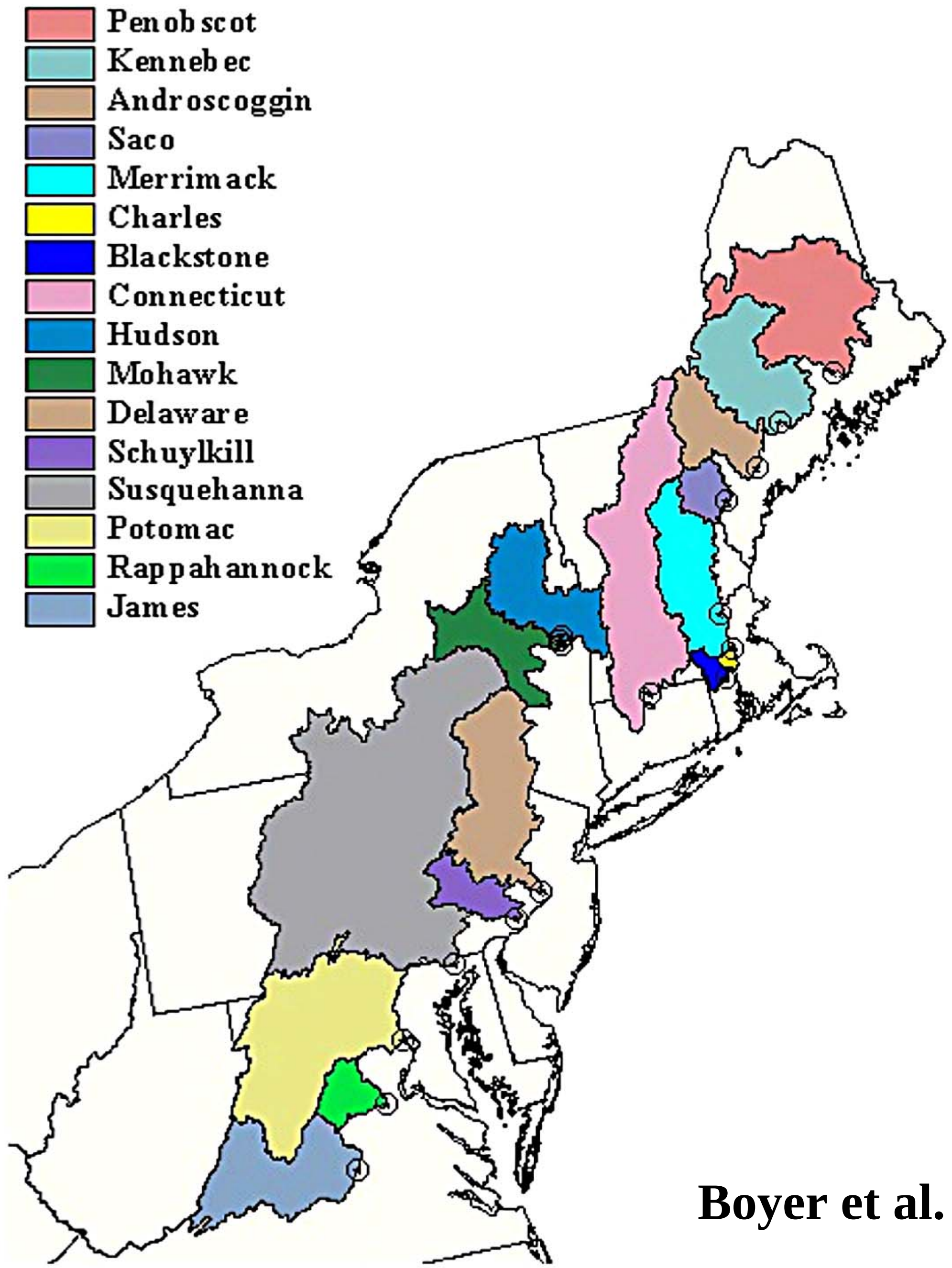
North Atlantic Ocean regions: human inputs of N are related to riverine N export, with ~ 20% of inputs exported to coast.



$r^2 = 0.73$
$p = 0.002$

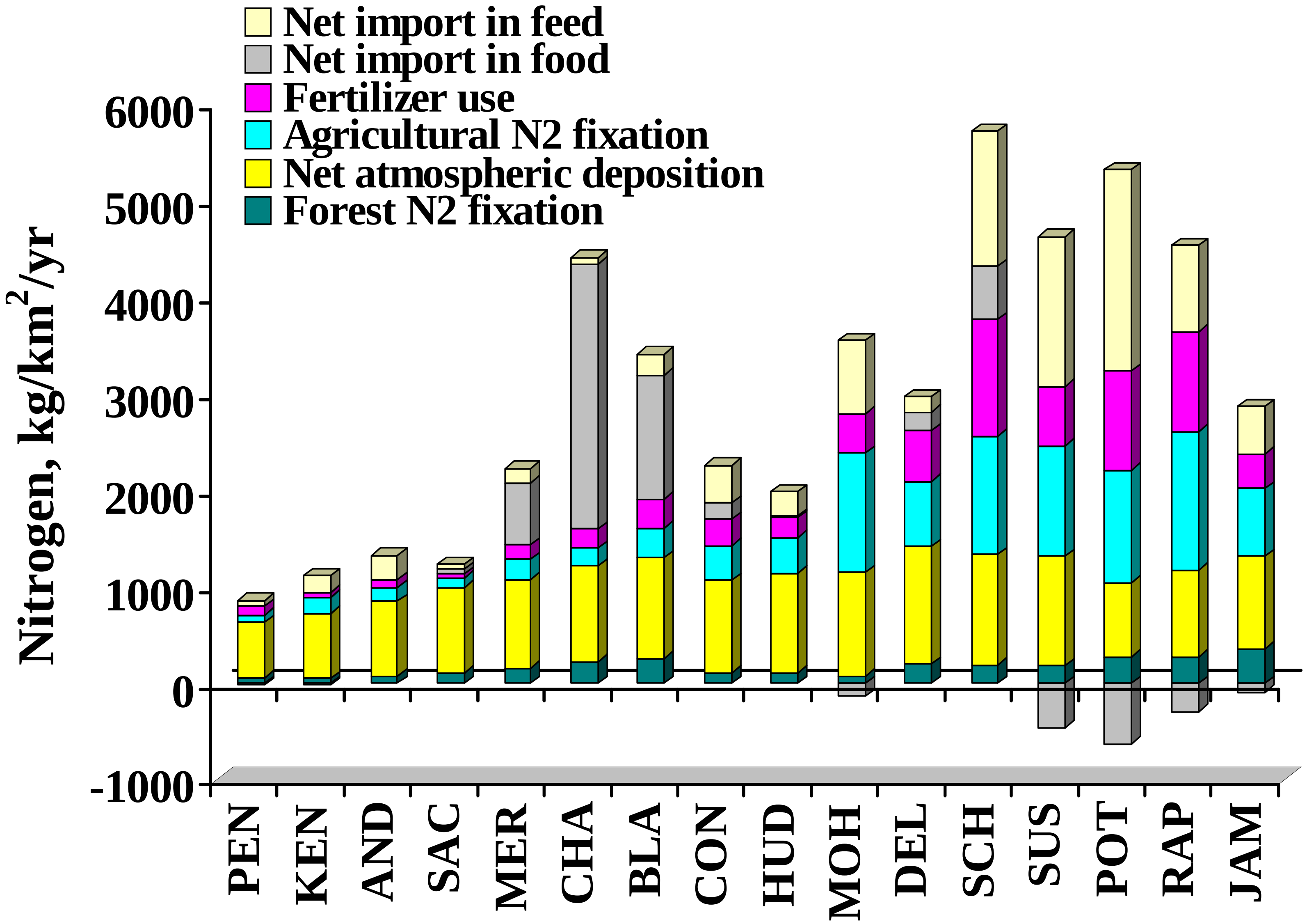
Howarth et al. 1996

Smaller scale analysis: 16 watersheds in northeastern US



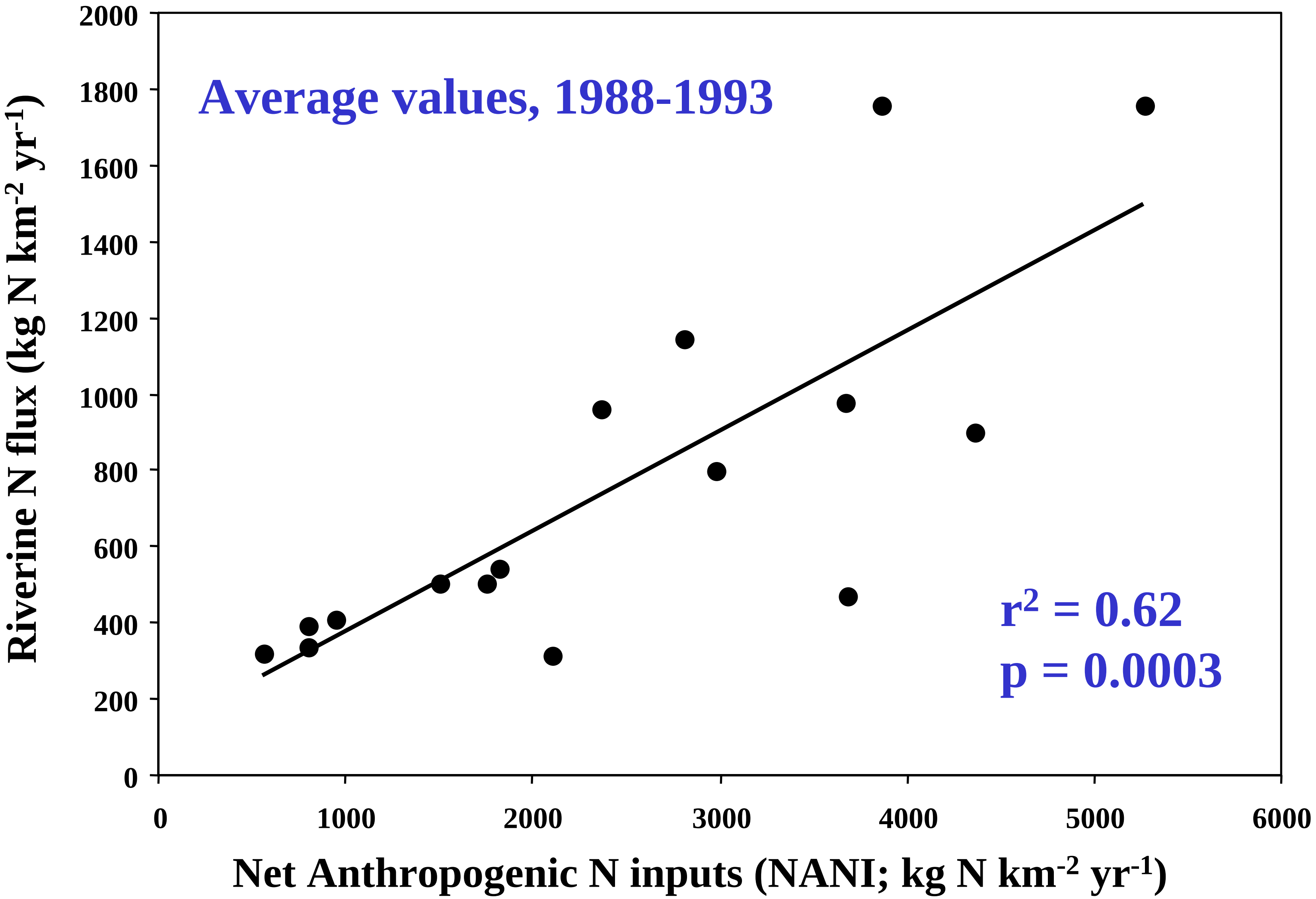
Boyer et al. 2002

Northeaster US watershed nitrogen inputs (1988-1993)



Boyer et al. 2002

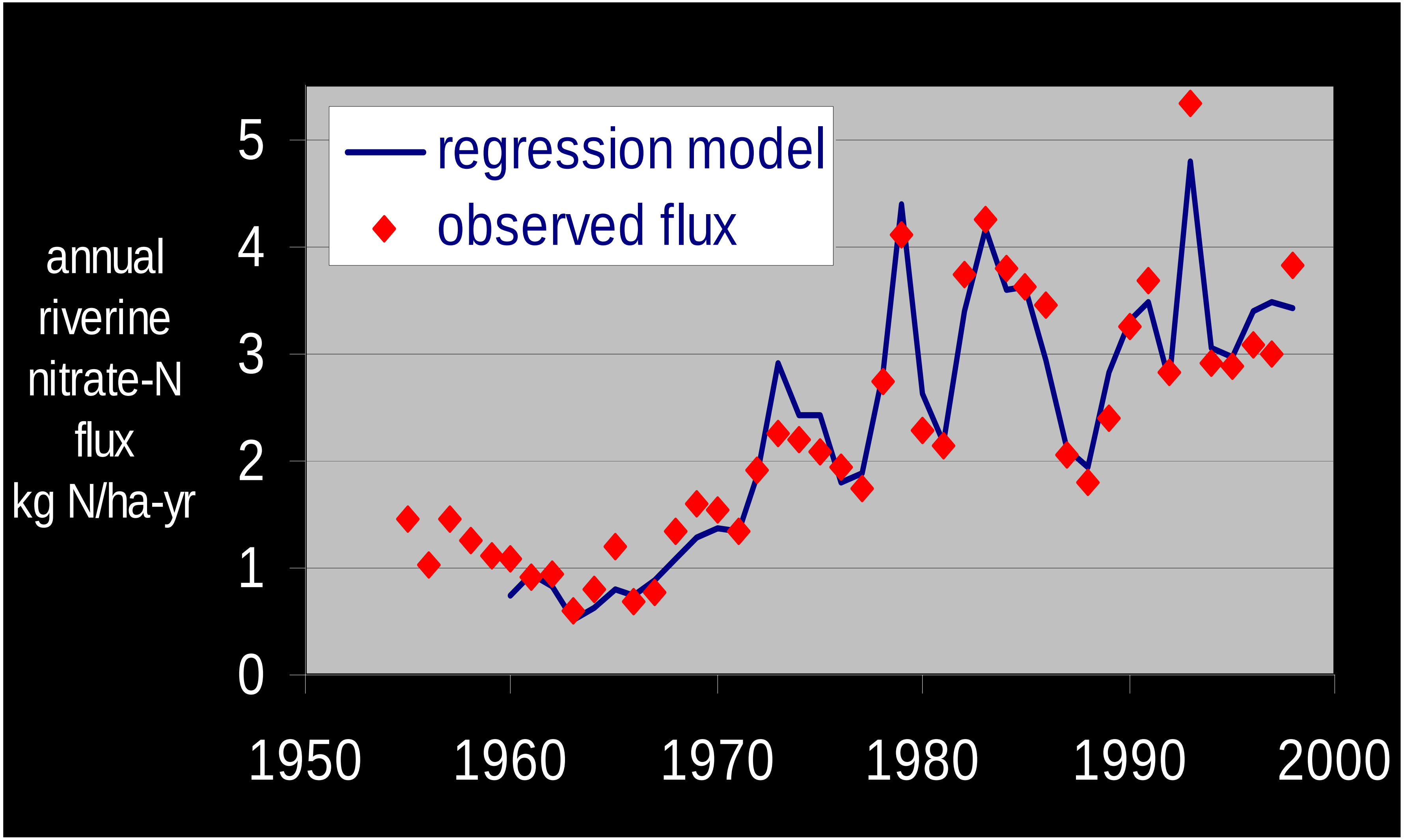
Approximately 25% of nitrogen inputs are exported in rivers.



(based on Boyer et al. 2002)

N fluxes are governed by sources and sinks –
<u>at the time scale of 5 years to decades</u>.

Mississippi River Nitrate N Flux: observed and modeled using annual water yield and Net N Input for the Mississippi River Basin (McIsaac et al. 2001)



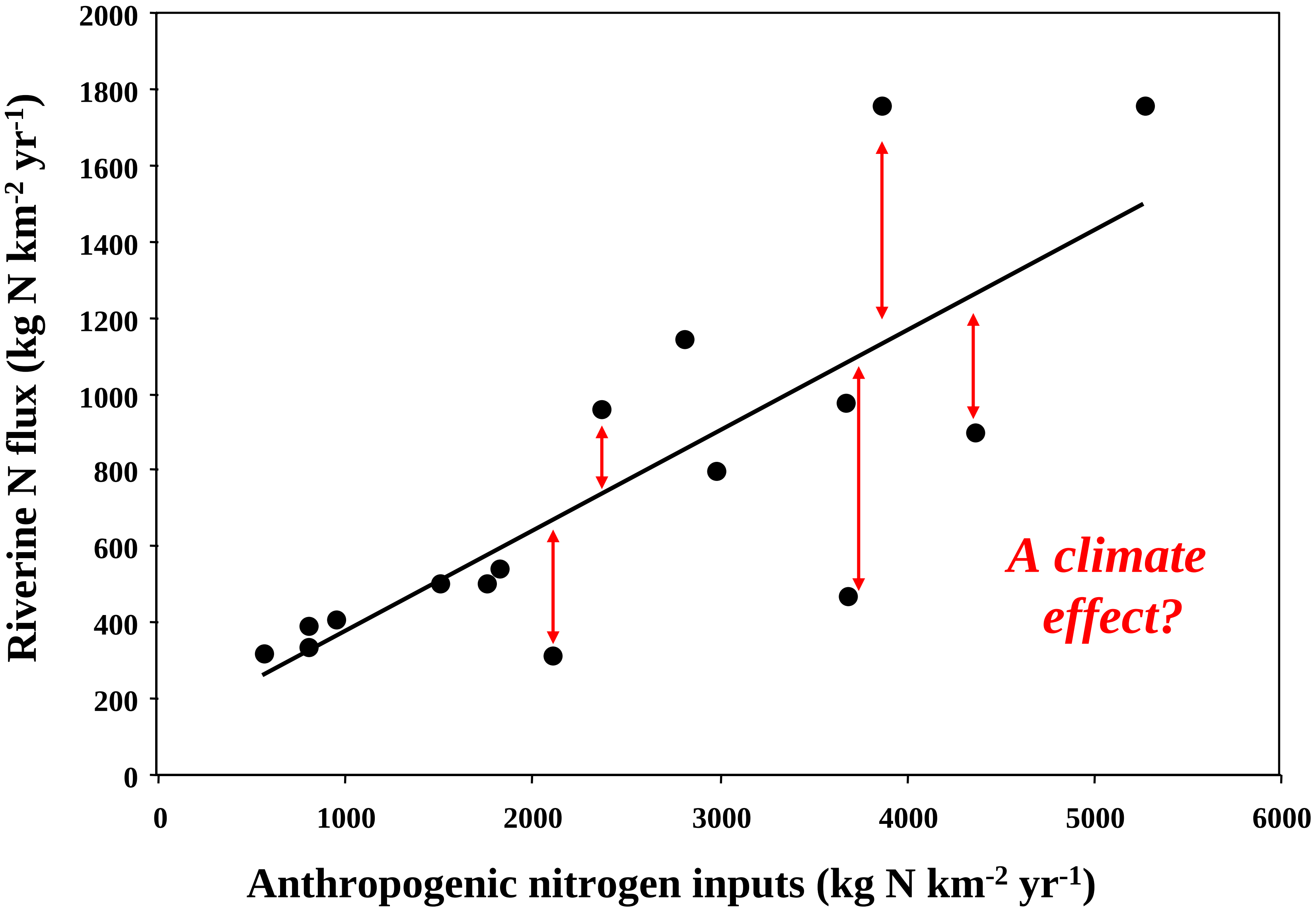
N fluxes are governed by sources and sinks – <u>at the time scale of 5 years to decades</u>.

But clearly a climate influence at shorter time scales, with nitrogen temporarily stored in soils and aquifers in dry years and flushed out in wet years.

N fluxes are governed by sources and sinks –
<u>at the time scale of 5 years to decades</u>.

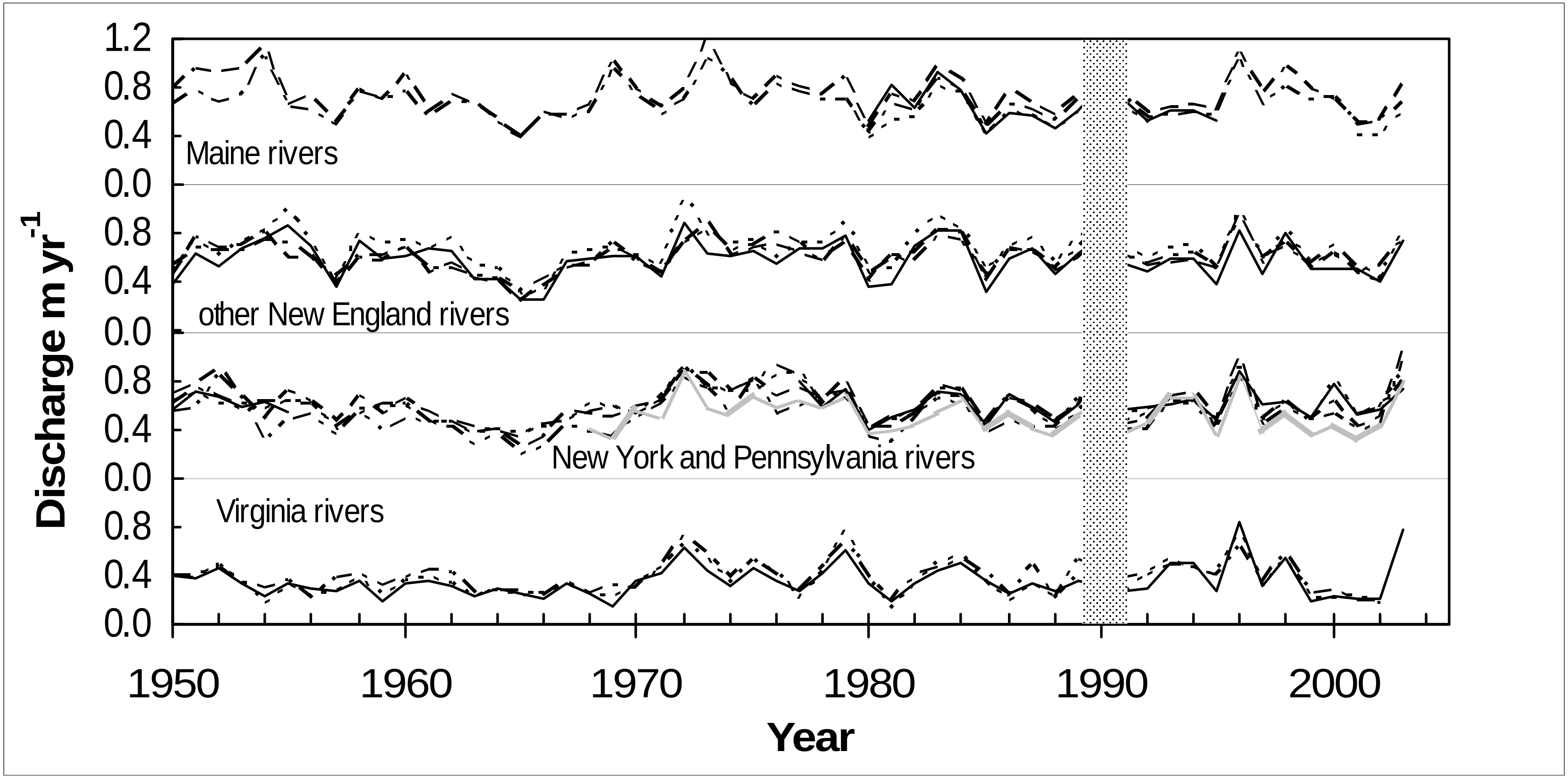
But clearly a climate influence at shorter time scales, with nitrogen temporarily stored in soils and aquifers in dry years and flushed out in wet years.

Is there also a climate effect over longer time scales? That is, does climate influence long-term sinks of nitrogen in the landscape (denitrification or storage in soils or biomass)?



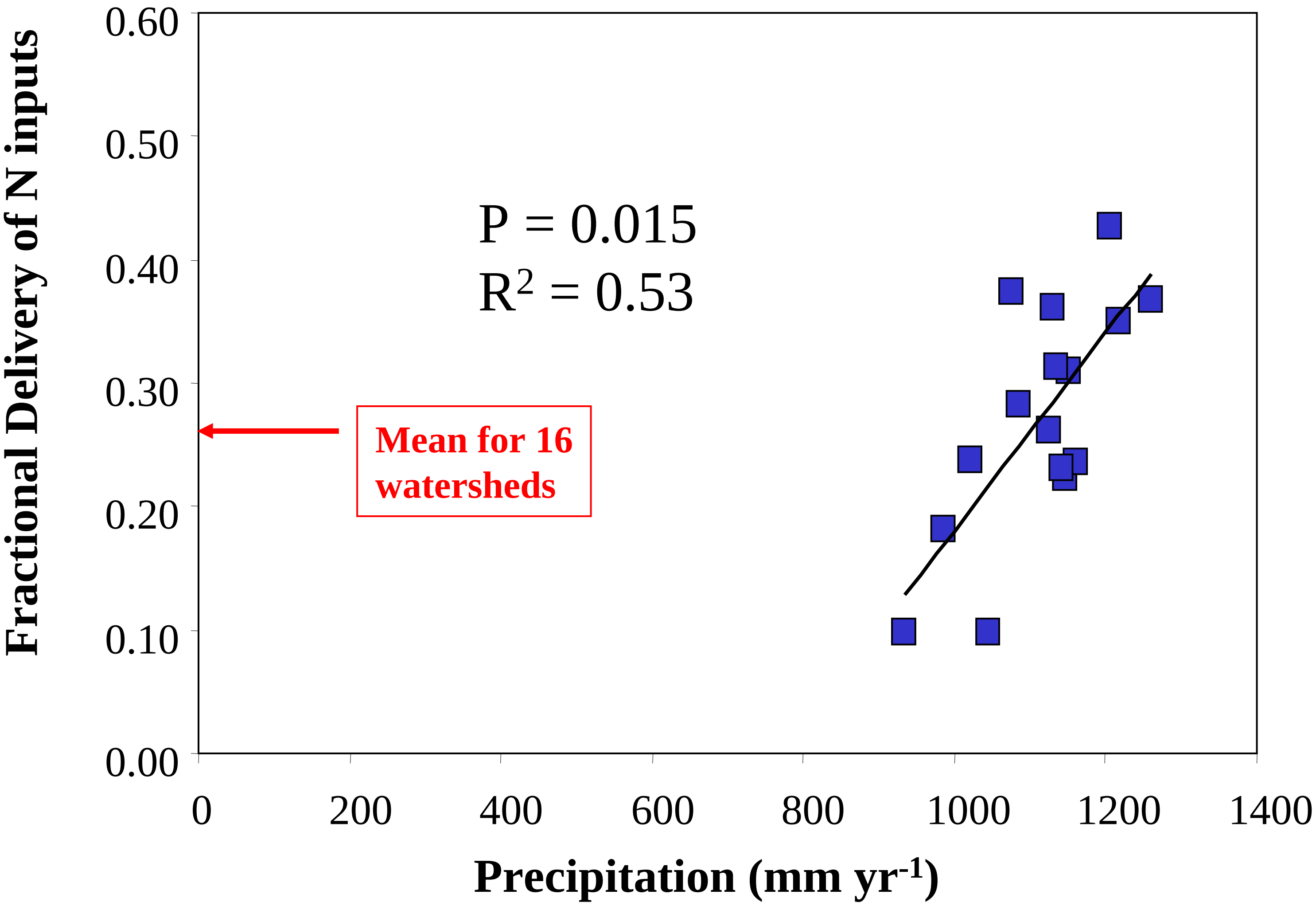
A climate effect?

Study period



Evaluate the fractional delivery of nitrogen inputs to the landscape in downstream river fluxes to the coast.

Fractional delivery = (river flux) / (N inputs)



$P = 0.015$

$R^2 = 0.53$

Mean for 16 watersheds

Under long-term steady state conditions, watersheds with wetter climates export a higher percentage of the nitrogen inputs.

(10% export in watersheds with less precipitation; 40% export in watersheds with greater precipitation).

Under long-term steady state conditions, watersheds with wetter climates export a higher percentage of the nitrogen inputs.

(10% export in watersheds with less precipitation; 40% export in watersheds with greater precipitation).

The influence of climate must be on nitrogen sinks in the landscape.

Best Guestimates of the sinks for nitrogen inputs to the landscape that are not exported in rivers from Northeastern US Watersheds (van Breemen et al. 2002)

- 27% accumulated in soils and forest biomass
- 73% denitrified (57% in landscape, 16% in rivers)

Influence of climate on N storage in soils and biomass?

Within the moisture gradient in northeastern US, would expect no influence on N (or C) storage (Christy Goodale).

Influence of climate on N storage in soils and biomass?

Within the moisture gradient in northeastern US, would expect no influence on N (or C) storage (Christy Goodale).

Or maybe more N and C storage in the wetter watersheds? … <u>the opposite of our result</u>.

Influence of climate on denitrification?? Might also expect more denitrification where precipitation and discharge are greater (due to more waterlogged soils)…..

On the other hand, denitrification might be less where precipitation and discharge are greater due to shorter water-residence time (less opportunity for denitrification in low-order streams and riparian wetlands).

We tentatively conclude that there is greater export of nitrogen inputs from watersheds where climate is more wet due to less denitrification (due to shorter water residence time).

Suggests importance of protecting riparian wetlands and low-order streams.

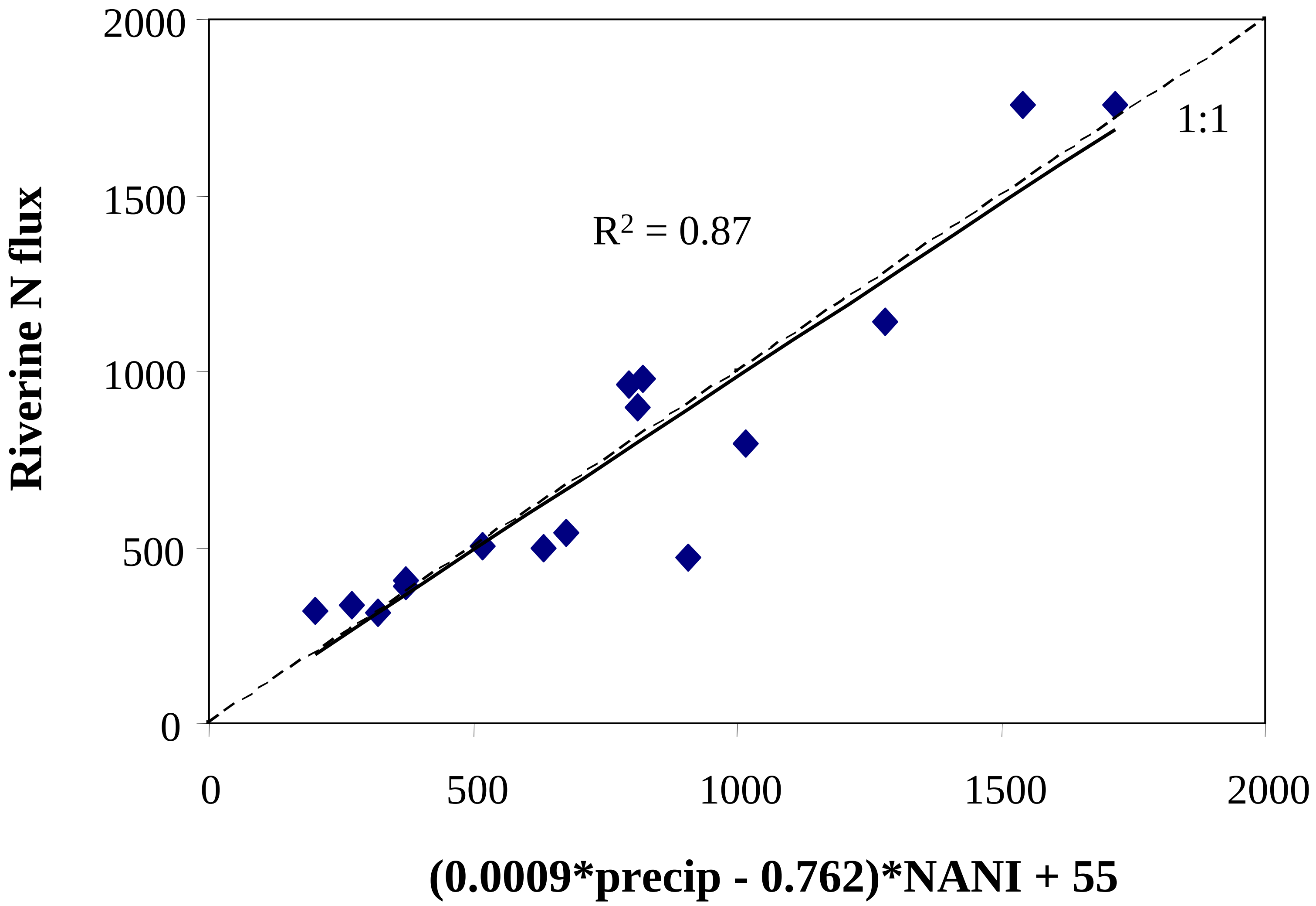
Predictive equation for river nitrogen flux (R) as a function of nitrogen inputs (N_i) and fractional delivery of these inputs, based on precipitation (P).

$$R = \underbrace{(0.00095 * P - 0.762)}_{\text{fractional delivery term}} * N_i + 55$$

<u>Summary statistics</u>:

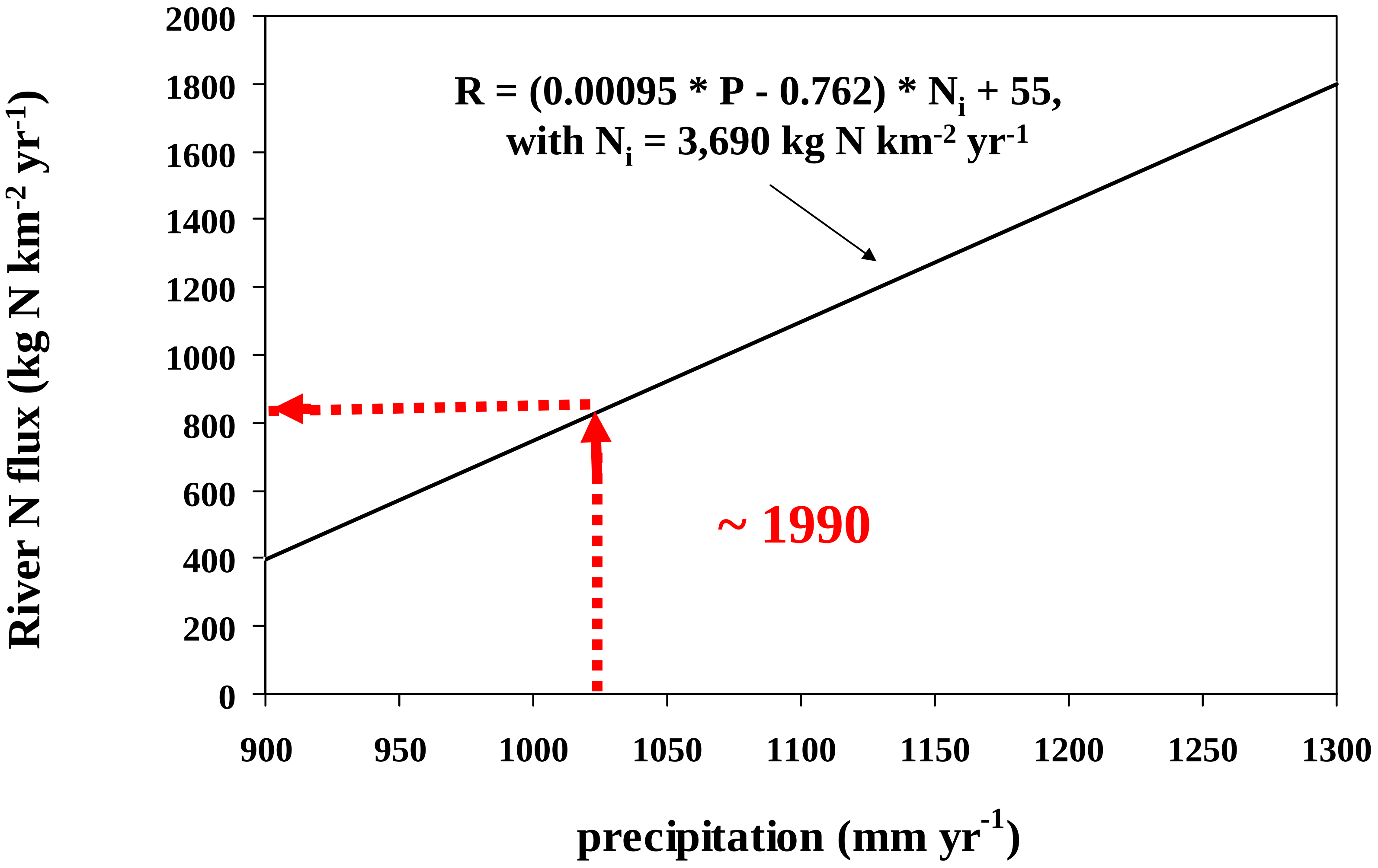
Adjusted $r^2 = 0.87$
$p < 0.000001$

Both N_i and $(N_i)(P)$ terms are highly significant
($p = 0.002$ and 0.0002, respectively)



2000
1500
1000
500
0
0
500
1000
1500
2000
Riverine N flux
(0.0009*precip - 0.762)*NANI + 55
R2 = 0.87
1:1

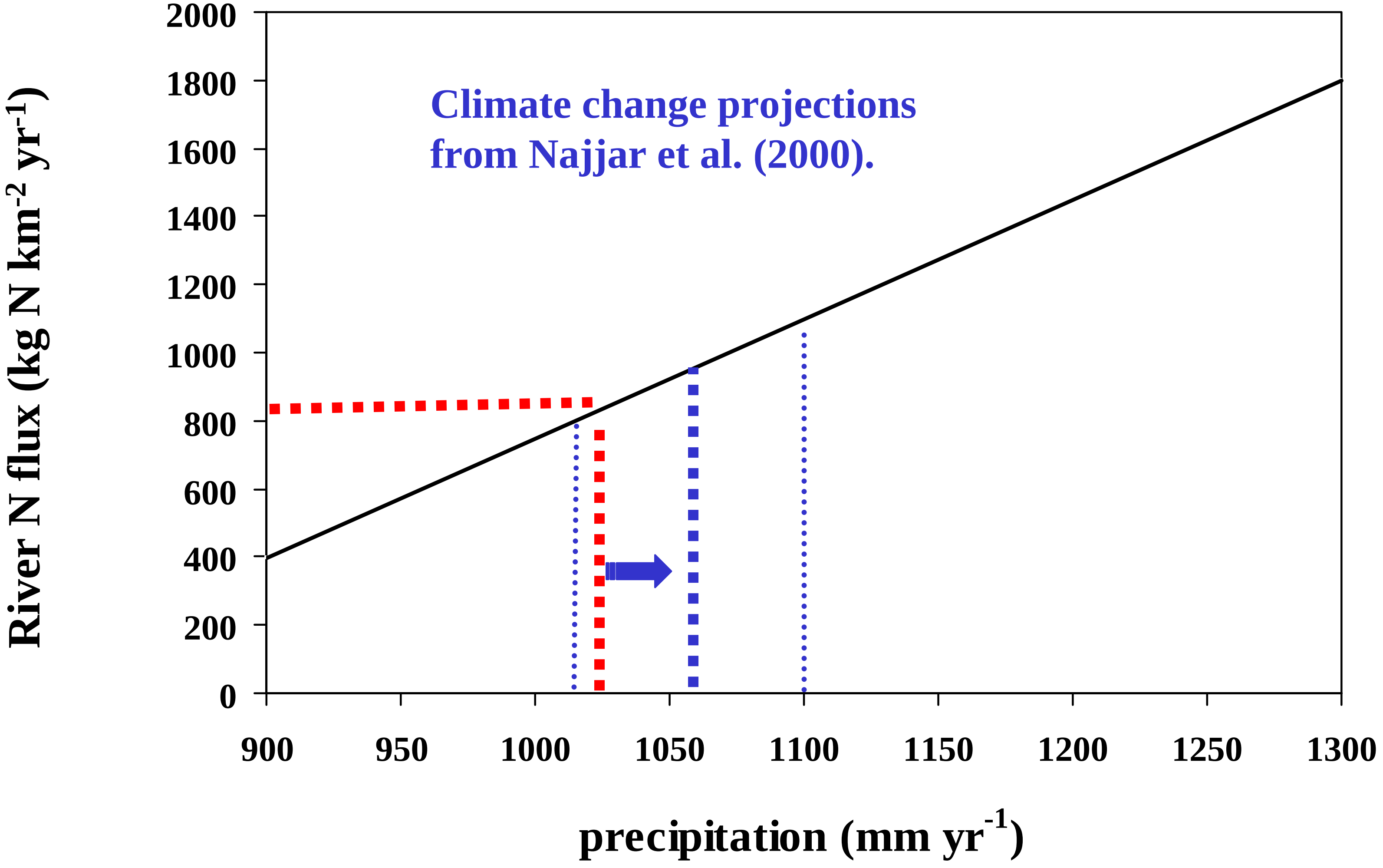
Susquehanna River: Relation between precipitation and river N flux.



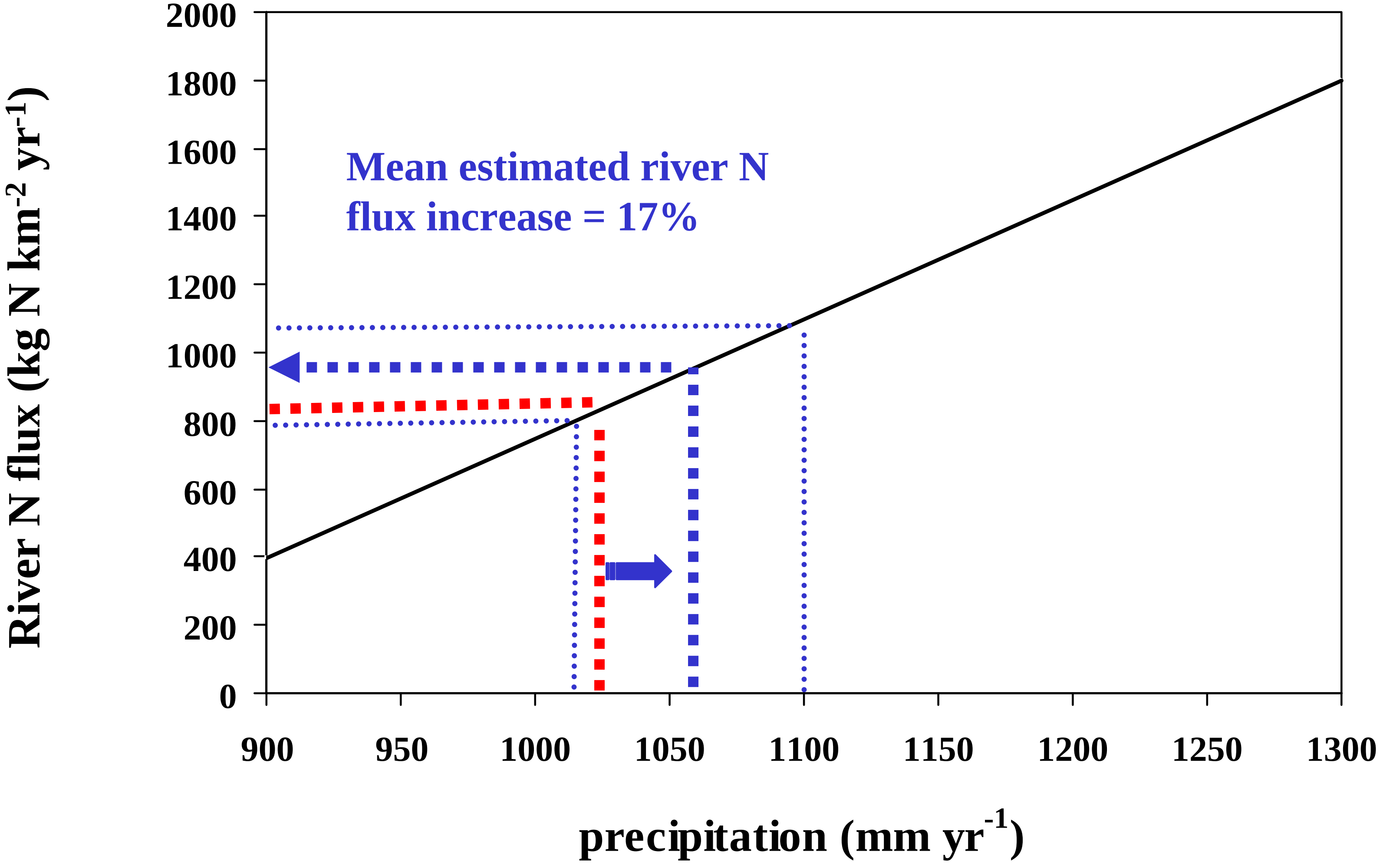
$R = (0.00095 * P - 0.762) * N_i + 55$,
with N_i = 3,690 kg N km^{-2} yr^{-1}

~ 1990

Susquehanna River: Estimated change by 2030 (mean and range).

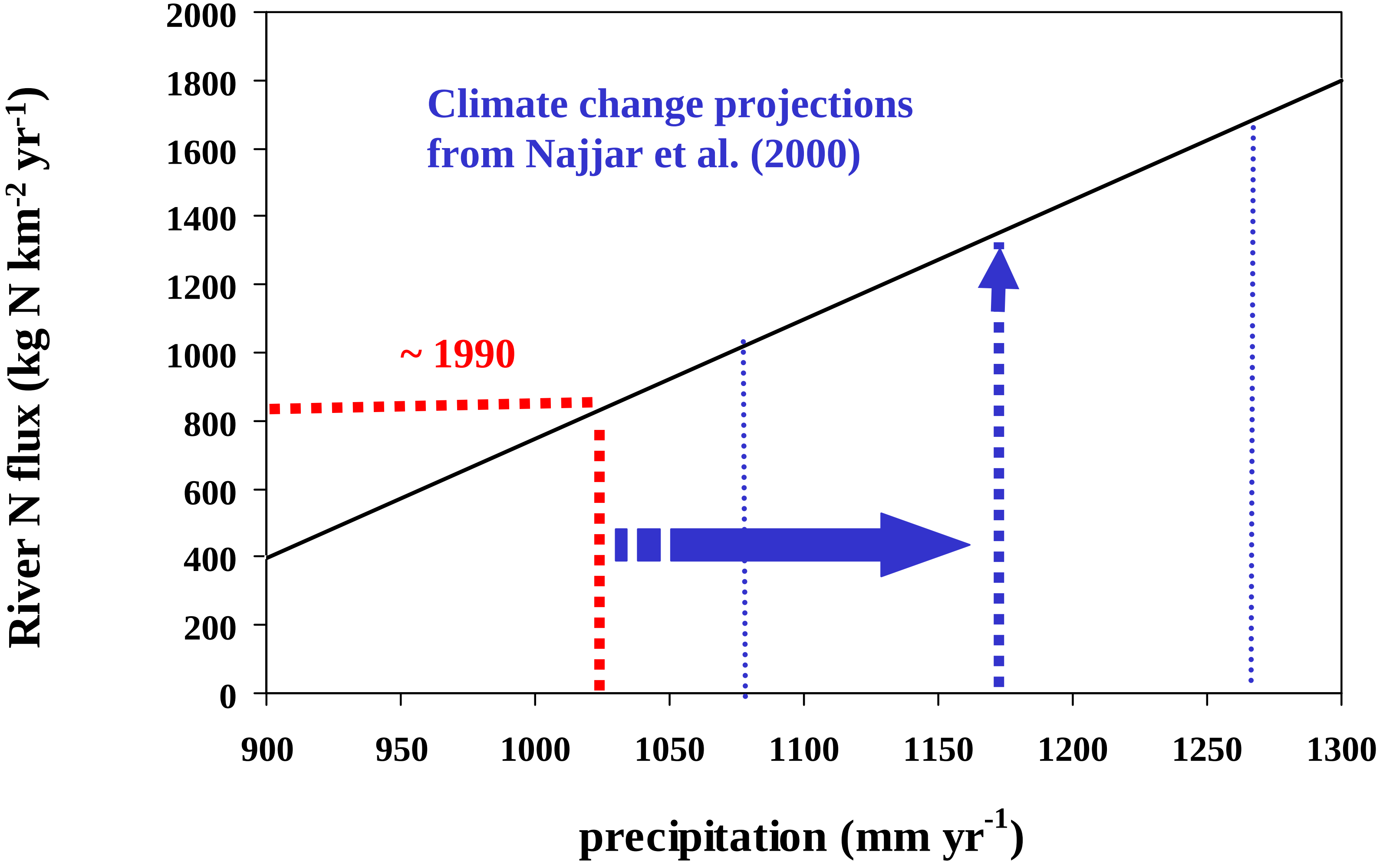


Susquehanna River: Estimated change by 2030 (mean and range).

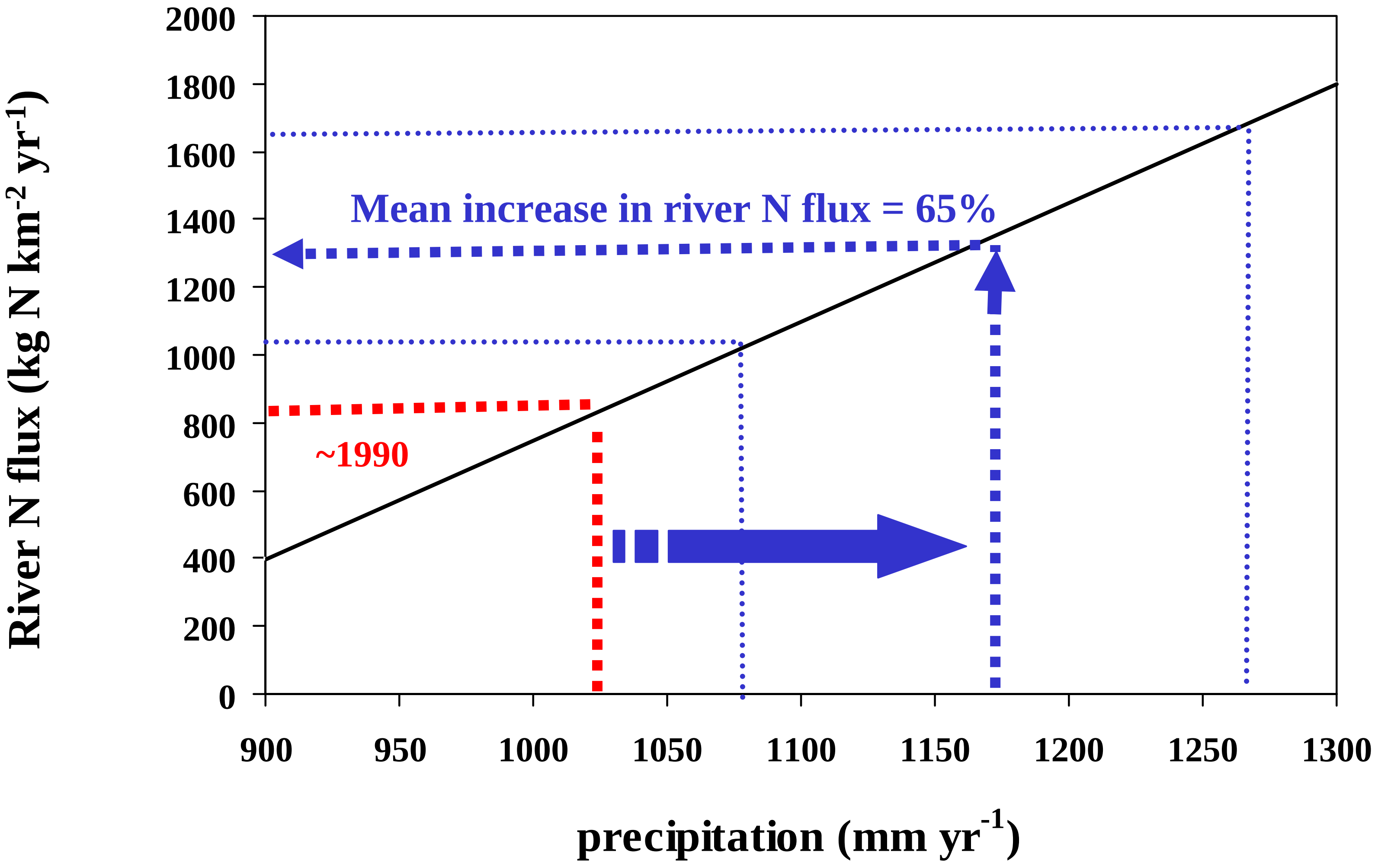


Mean estimated river N flux increase = 17%

Susquehanna River: Estimated change by 2095 (mean and range).



Susquehanna River: Estimated change by 2095 (mean and range).



Take-home points:

Nitrogen export from watersheds is driven by anthropogenic inputs of nitrogen to the landscape.

Climate influences the export of nitrogen inputs (~10% in drier watersheds; ~ 40% in wetter ones.

The influence of climate we observe is not simply due to short-term storage and flushing effects, but rather on sinks in the landscape.

Denitrification is probably greater sink of nitrogen in the drier watersheds, due to longer water residence times.

Future climate change will likely increase nitrogen fluxes in rivers where precipitation increases (and decrease nitrogen fluxes where precipitation decreases).

SCOPE/NANI approach highly predictive… accuracy as good as any other model (Alexander et al. 2002).

But not terribly responsive to management options.

And only address time periods of ~ 5 years or more; does not deal with shorter term variation from climate.

ReNuMa (Regional Nutrient Management) model

A semi-empirical,
semi-process-oriented approach to simulating
watershed-scale nutrient transport

Responsive to climate and to management options.

Based on GWLF, only with improved biogeochemistry.

- **Dynamic model with daily time step (requires daily temperature and precip data).**

- **Dissolved and particulate nutrients transported in surface flows, groundwater flow and sediment transport.**

- **“Lumped parameter” model (ie simulates multiple land use/land cover within watershed, but is not spatially explicit).**

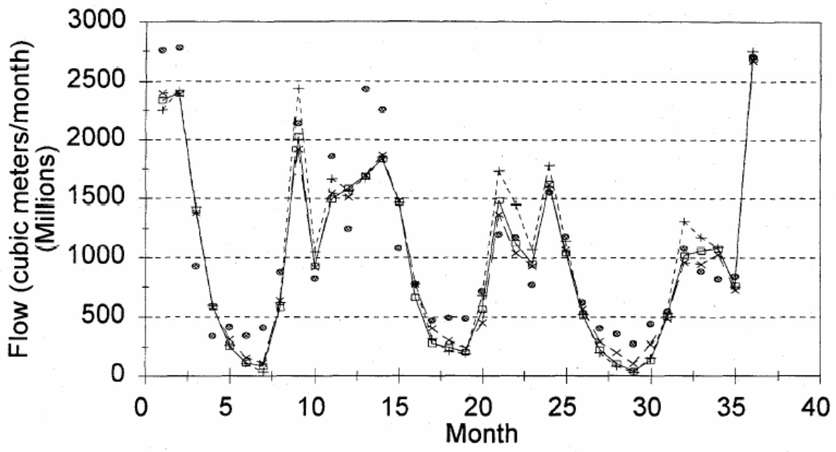
- **Uses empirical relationships originally developed for the USA (USCS runoff equation parameters, Universal Soil Loss equation parameters).**

- **Requires estimates of surface and groundwater nutrient concentrations or fluxes.**

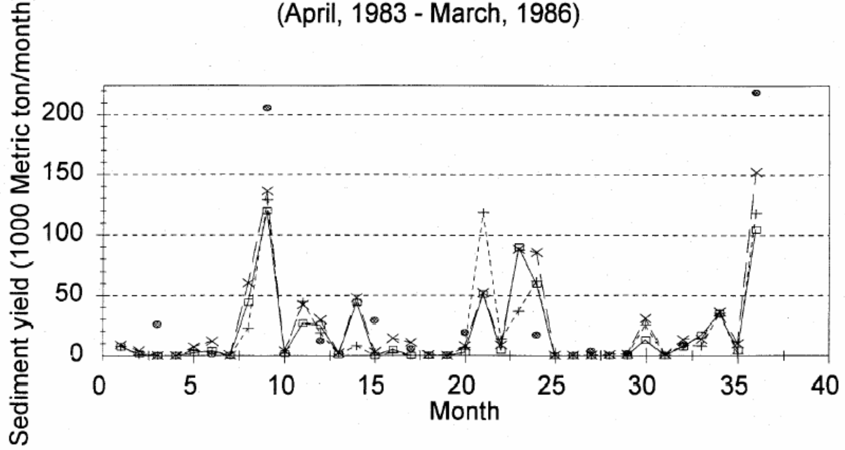
- **Runs in visual basic on Excel platform.**

Hudson River:
USGS data vs. model output

Monthly flow at Green Island, NY
(April, 1983 - March, 1986)



Monthly sediment yield at Green Island
(April, 1983 - March, 1986)

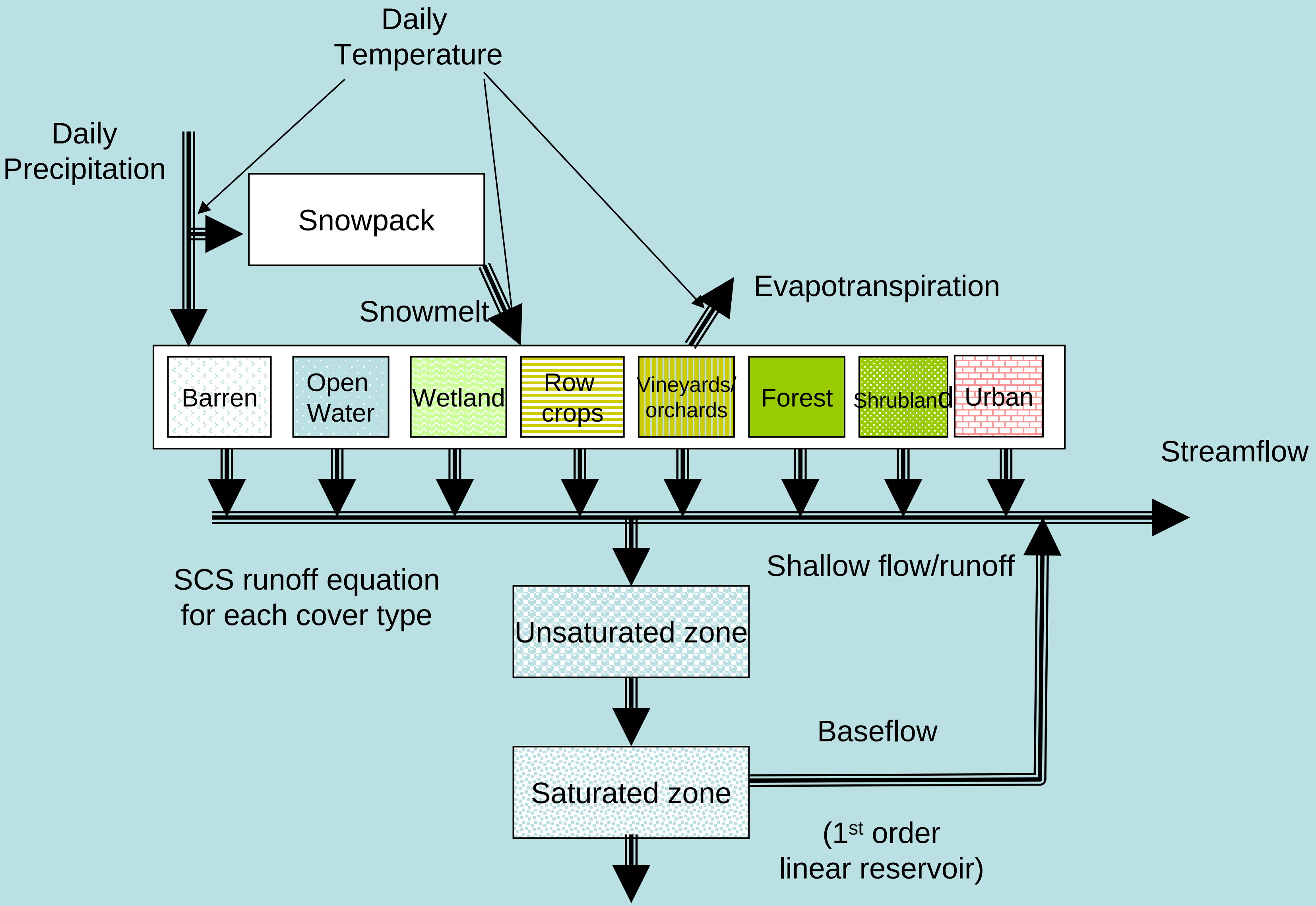


Swaney et al., 1996

The parent model (GWLF) does well with hydrology… It also predicts erosion well, and so does well with phosphorus fluxes.

GWLF lacks some essential processes for nitrogen biogeochemistry, particularly atmospheric deposition and denitrification. We are adding these, plus more on agricultural management options, for ReNuMa.

ReNuMa: Hydrological Dynamics



Daily Temperature

Daily Precipitation

Snowpack

Snowmelt

Evapotranspiration

Barren

Open Water

Wetland

Row crops

Vineyards/ orchards

Forest

Shrubland

Urban

Streamflow

SCS runoff equation for each cover type

Shallow flow/runoff

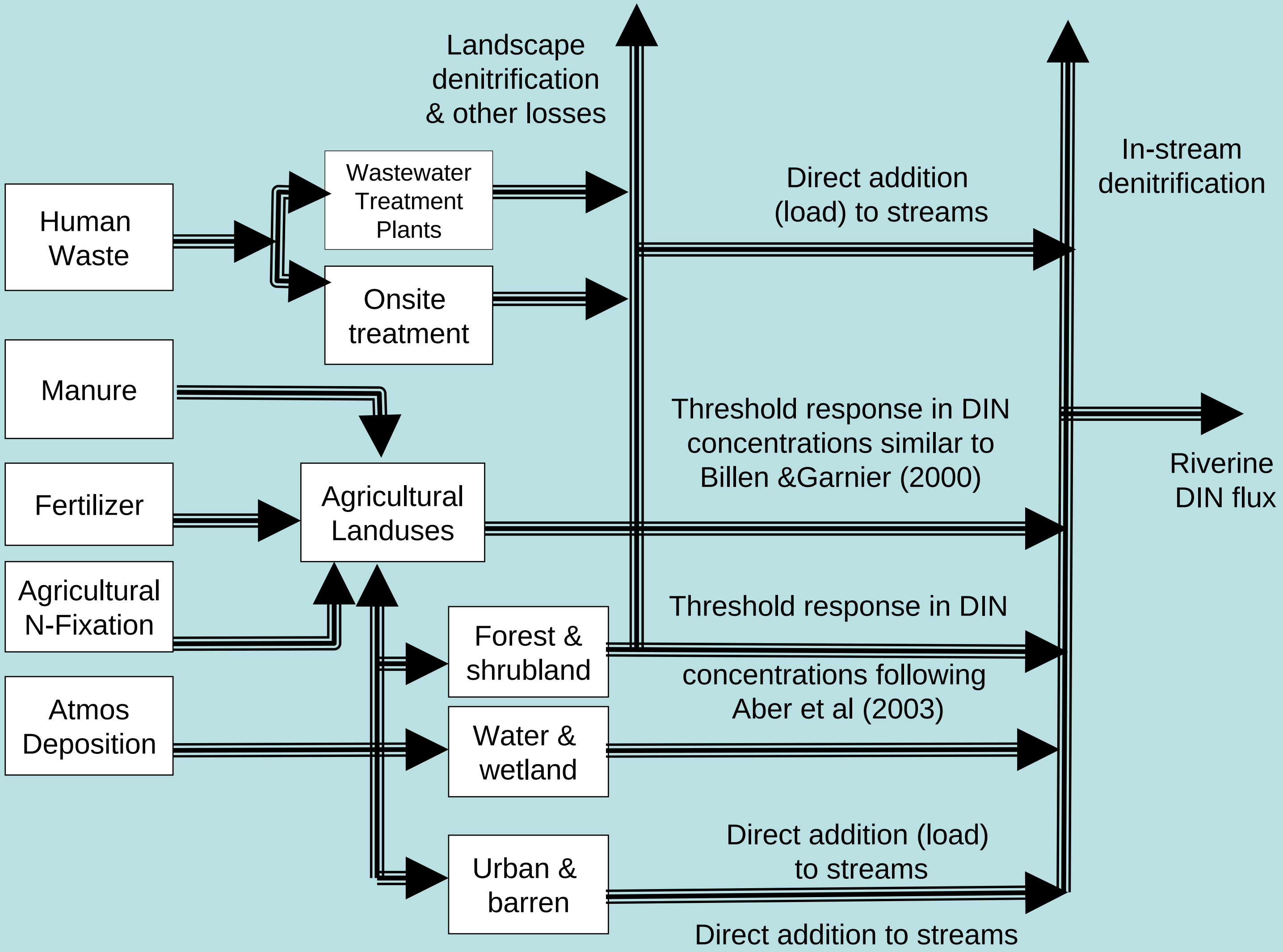
Unsaturated zone

Baseflow

Saturated zone

(1st order linear reservoir)

ReNuMa: Nitrogen Dynamics



Landscape denitrification & other losses

Human Waste

Wastewater Treatment Plants

Onsite treatment

Direct addition (load) to streams

In-stream denitrification

Manure

Fertilizer

Agricultural N-Fixation

Atmos Deposition

Agricultural Landuses

Threshold response in DIN concentrations similar to Billen &Garnier (2000)

Riverine DIN flux

Forest & shrubland

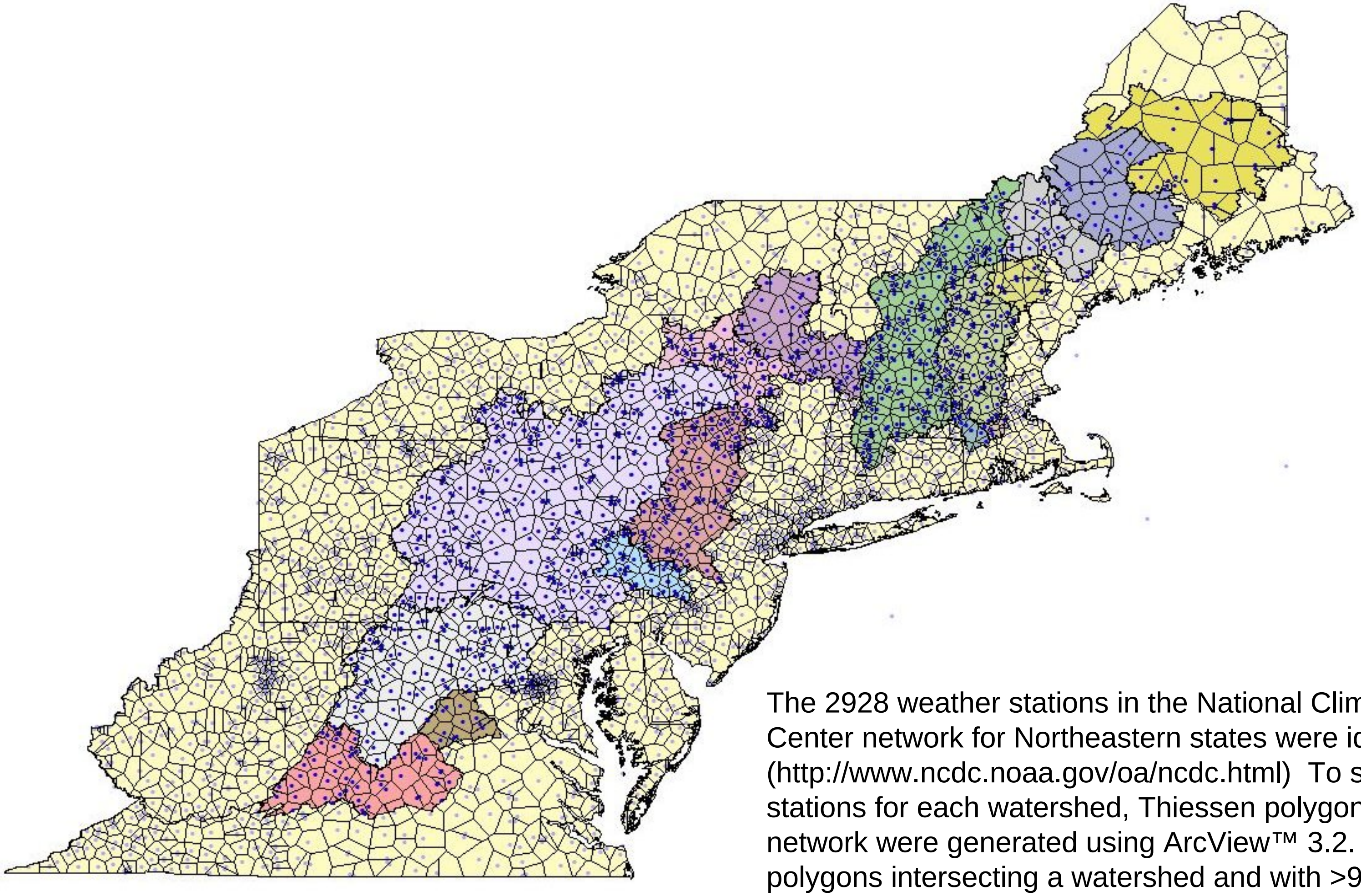
Water & wetland

Urban & barren

Threshold response in DIN concentrations following Aber et al (2003)

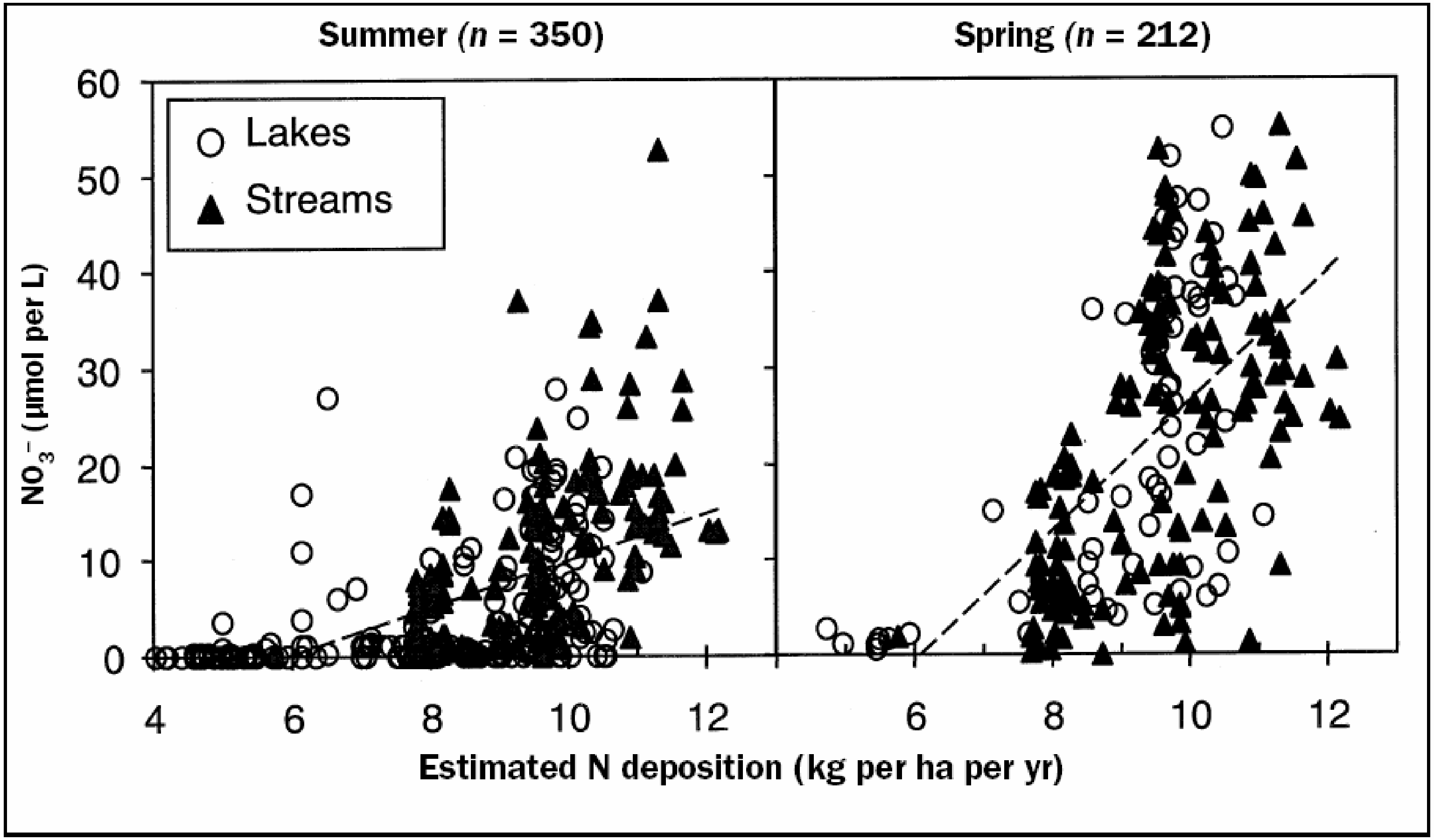
Direct addition (load) to streams

Direct addition to streams



The 2928 weather stations in the National Climate Data Center network for Northeastern states were identified (http://www.ncdc.noaa.gov/oa/ncdc.html) To select candidate stations for each watershed, Thiessen polygons for the network were generated using ArcView™ 3.2. Stations with polygons intersecting a watershed and with >95% complete records (daily temperature and precipitation) were averaged to obtain representative weather data for each watershed. Missing temperature data for each station were replaced with averages of the records preceding and following the missing interval; missing precipitation values were replaced with zero.

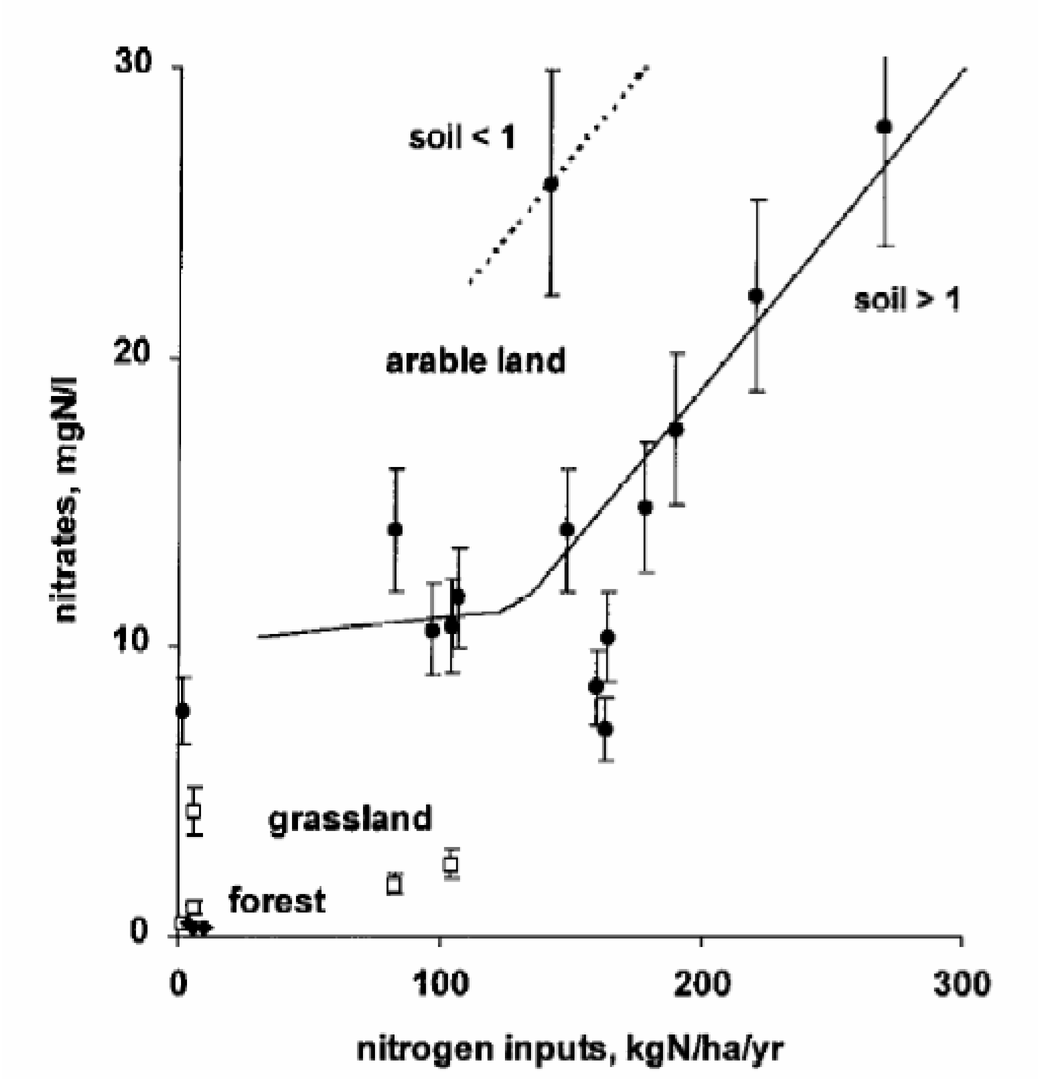
Export of atmospheric deposition from forests in northeastern US.



Note non-linear threshold response.

(Aber et al. 2003)

Export of nitrate from agricultural systems as a function of fertilizer input



(Billen & Garnier 2000)

Again, note threshold response.

Other new parameters in ReNuMa:

Denitrification in rivers based on water residence time (formulation of Seitzinger et al. (2002), scaled towards lower end of rates (van Breemen et al. 2002)

Denitrification in the landscape not yet added….. Will parameterize from the SCOPE/NANI approach and/or SPARROW results.

Will add more agricultural management practices (using meta-data analysis compiled by Laurie Drinkwater and Christina Tonitto).

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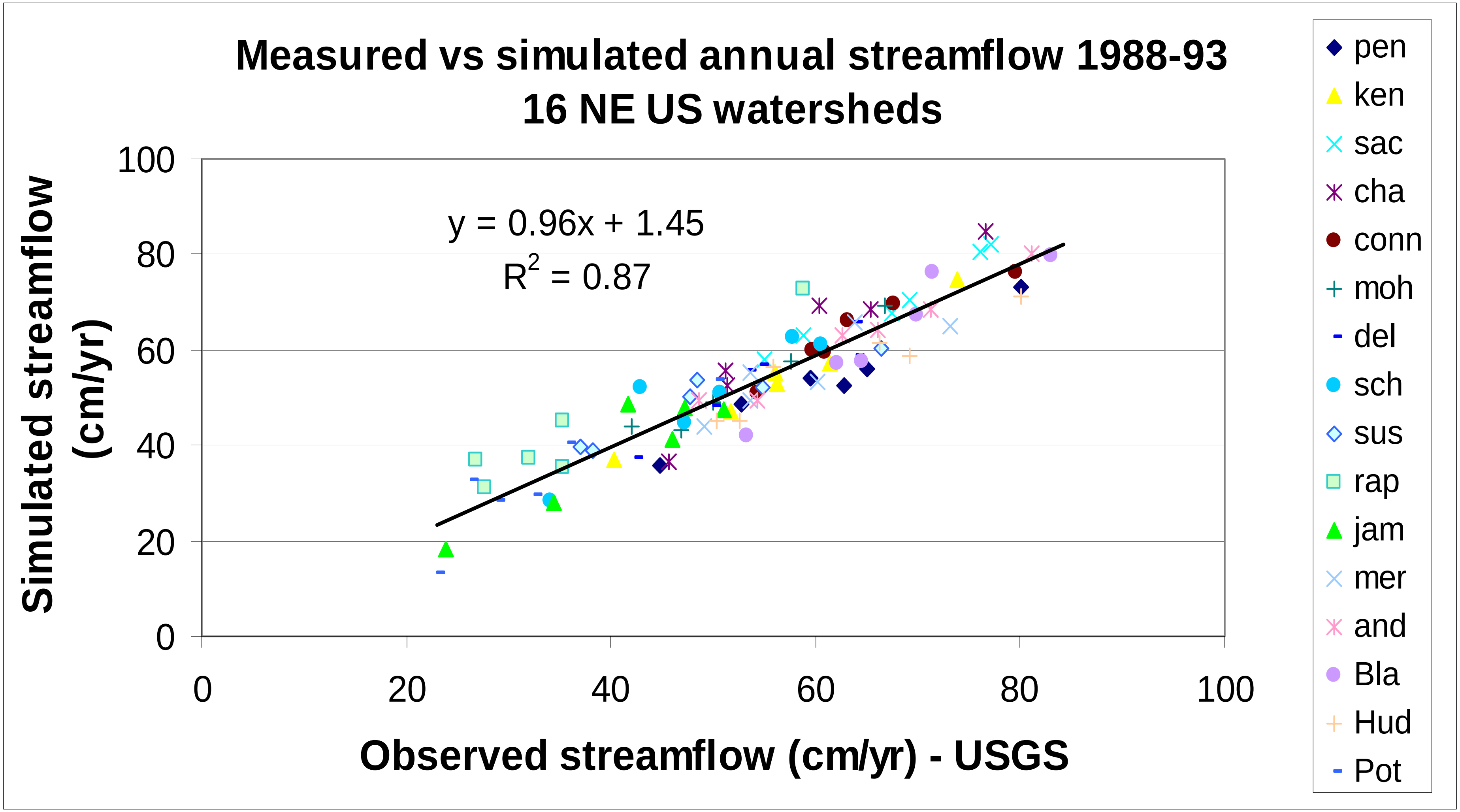
Denitrification in the landscape not yet added….. Will parameterize from the SCOPE/NANI approach and/or SPARROW results.

Will add more agricultural management practices (using meta-data analysis compiled by Laurie Drinkwater and Christina Tonitto).
Considered using data base in Chesapeake Bay model, but those are poorly documented…. And sometimes clearly wrong (ie, effect of no-till agriculture on nitrogen export).

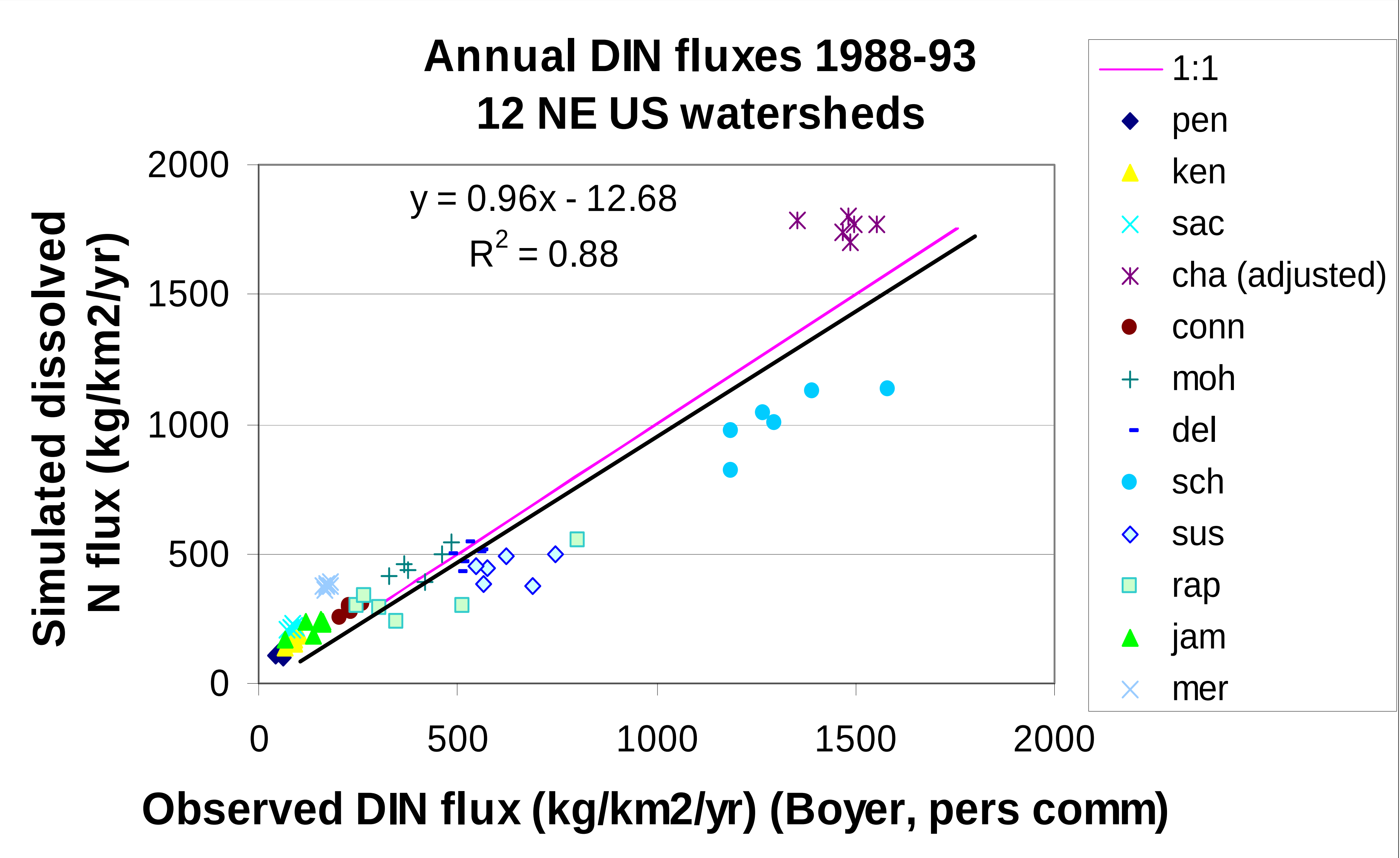
Effectiveness of BMPs for Reducing N and P pollution:

	phosphorus	nitrogen
Agricultural systems:		
No-till agriculture	very effective	not effective
Winter cover crops	effective	very effective
Perennial cropping systems	effective	very effective
Buffer strips along streams	effective	variable
Wastewater treatment:		
Conventional septic systems	very effective	not effective
2^o treatment plants	little effect	little effect
Chemical-precipitation advanced wastewater treatment plants	very effective	little effect
Denitrification advanced wastewater plants	effective	very effective

So far, ReNuMa model has not been calibrated at all…..



Minor adjustments to evaporative cover factor for the Androscoggin and Susquehanna rivers were the only changes made to baseline parameter values for the watersheds. While individual watersheds may exhibit some bias above or below observations (ie USGS annual streamflows http://waterdata.usgs.gov/nwis/), agreement over all years and across all watersheds was generally good.



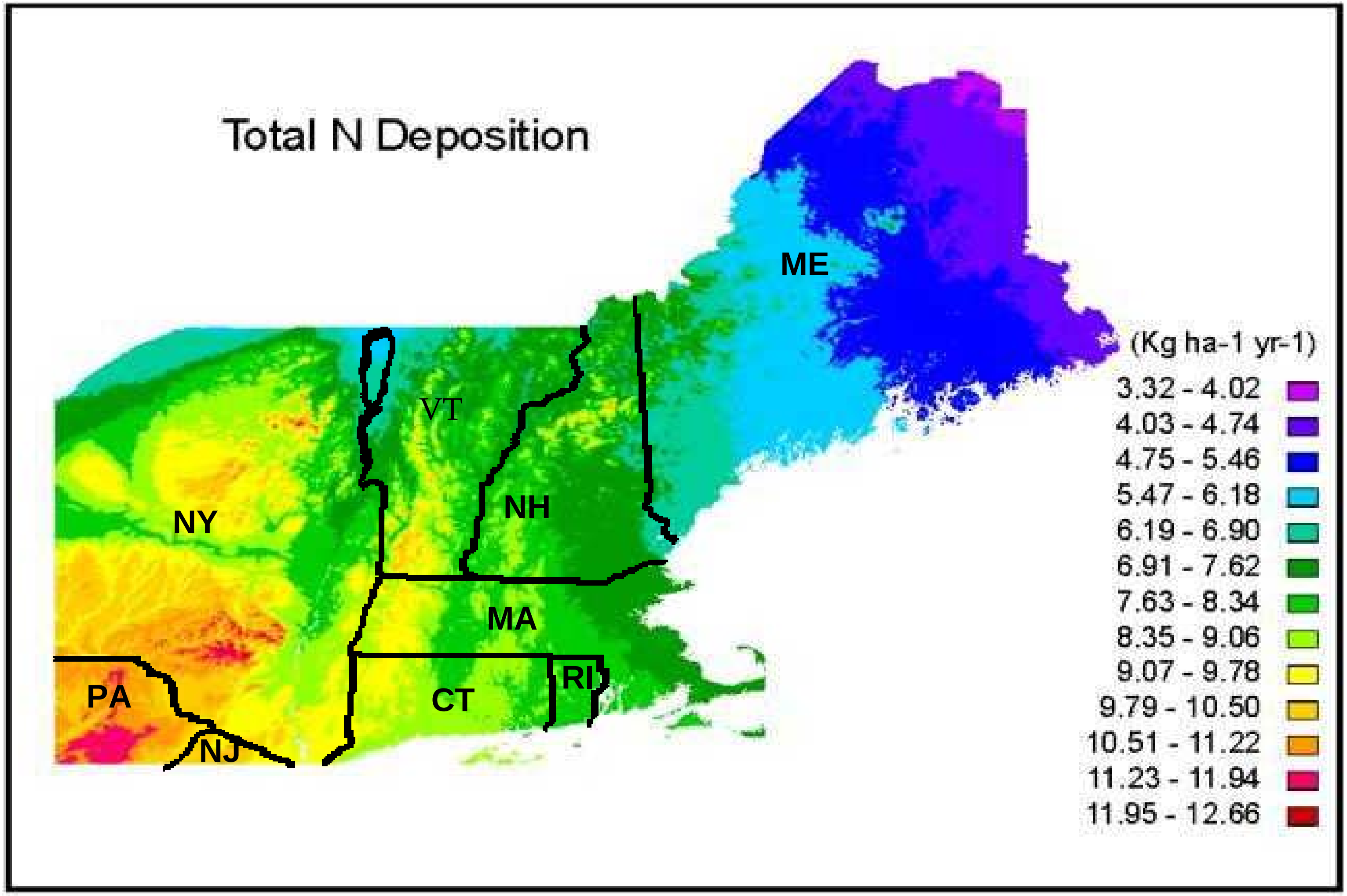
Annual DIN fluxes 1988-93
12 NE US watersheds

One other issue…..

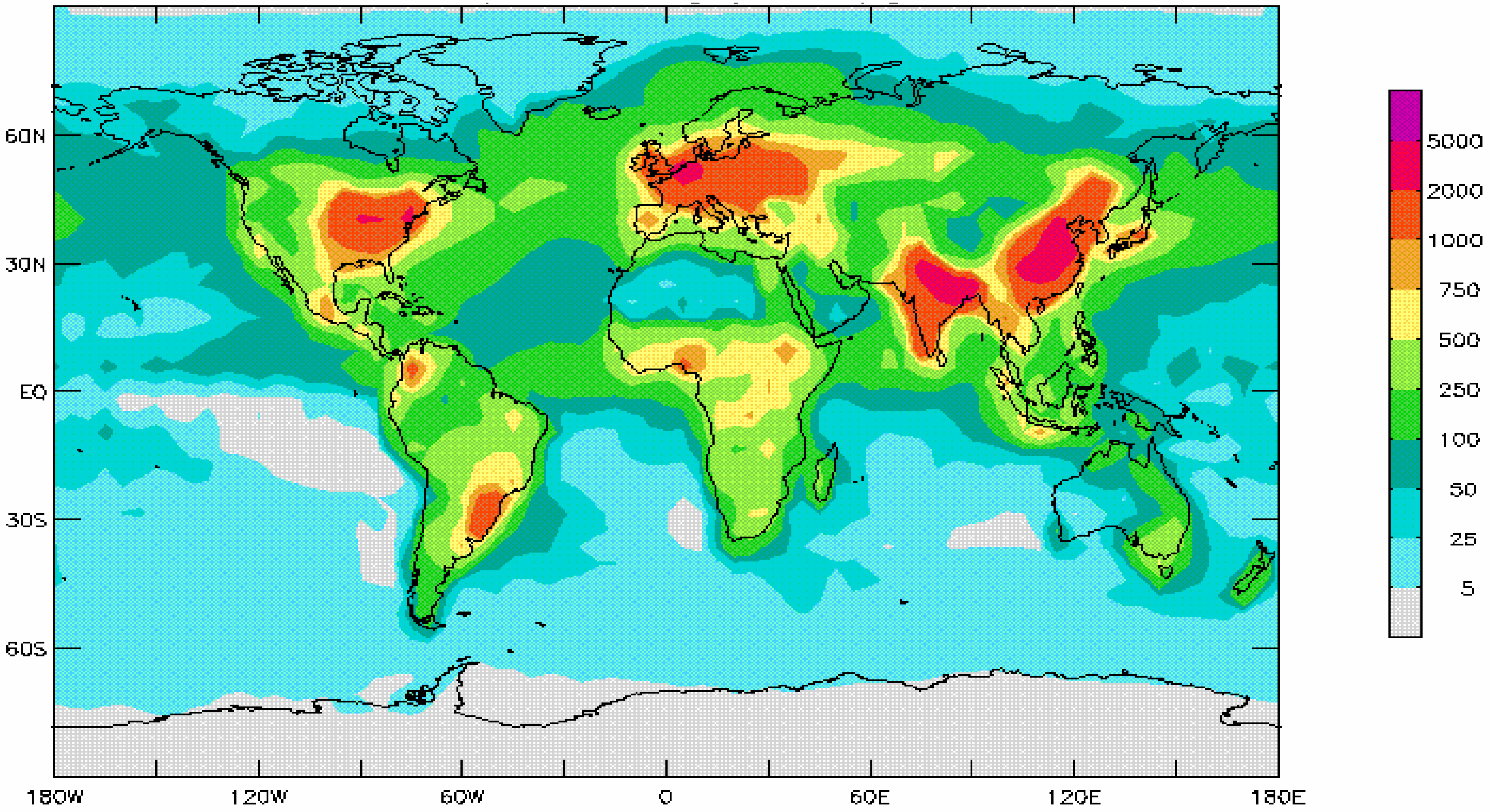
How to best estimate nitrogen deposition from the atmosphere at larger spatial scales, particularly for dry deposition, and especially for nitrogen gases (NO, NO_2, NH_3, HNO_3).

N Deposition in the US Northeast

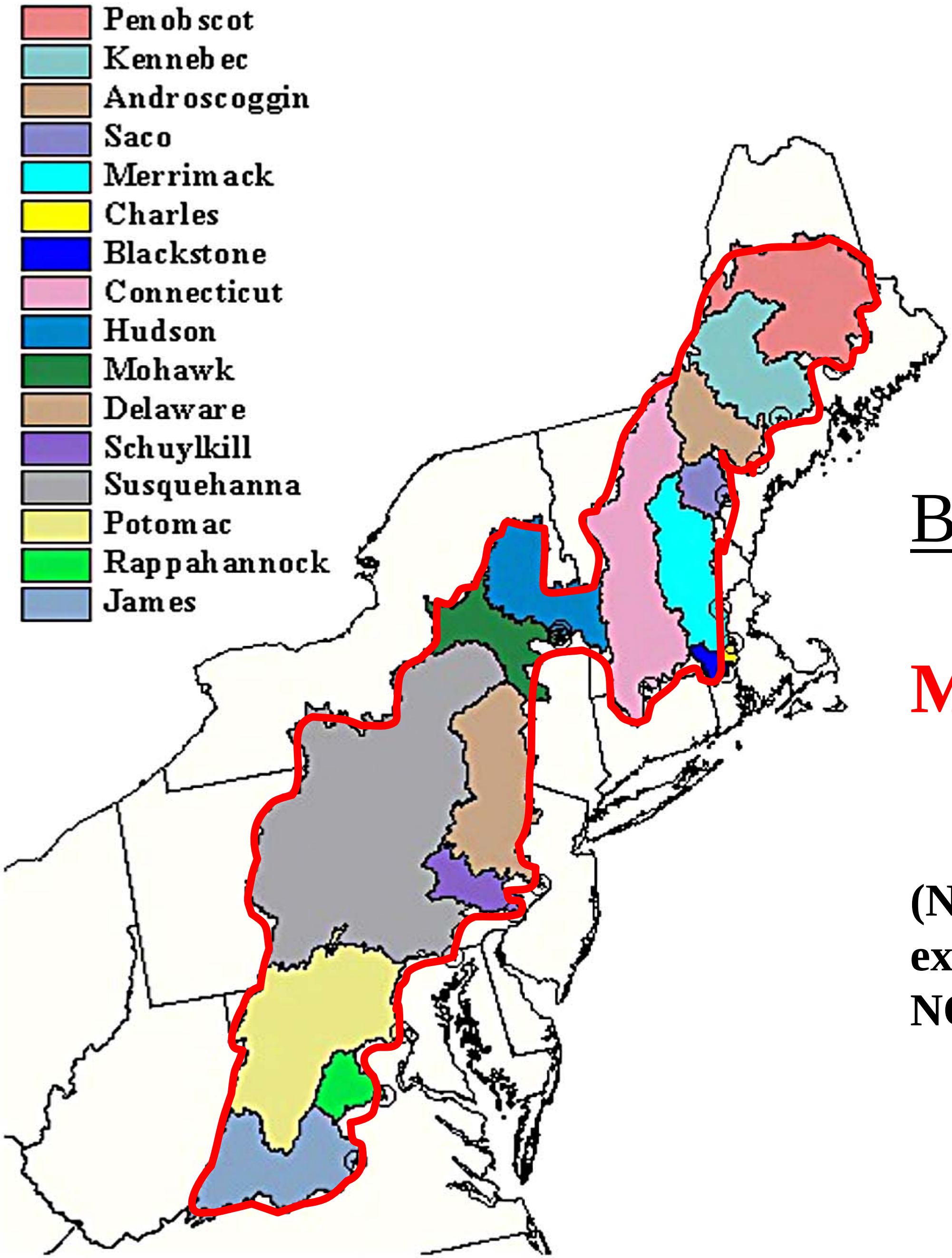
Provided by Scott Ollinger



1993 total nitrogen deposition (kg km^{-1} yr^{-1})



TM3 model of Dentener 2000 (Dentener, pers. comm.): deposition estimated from emission estimates and atmospheric reactions and advection.

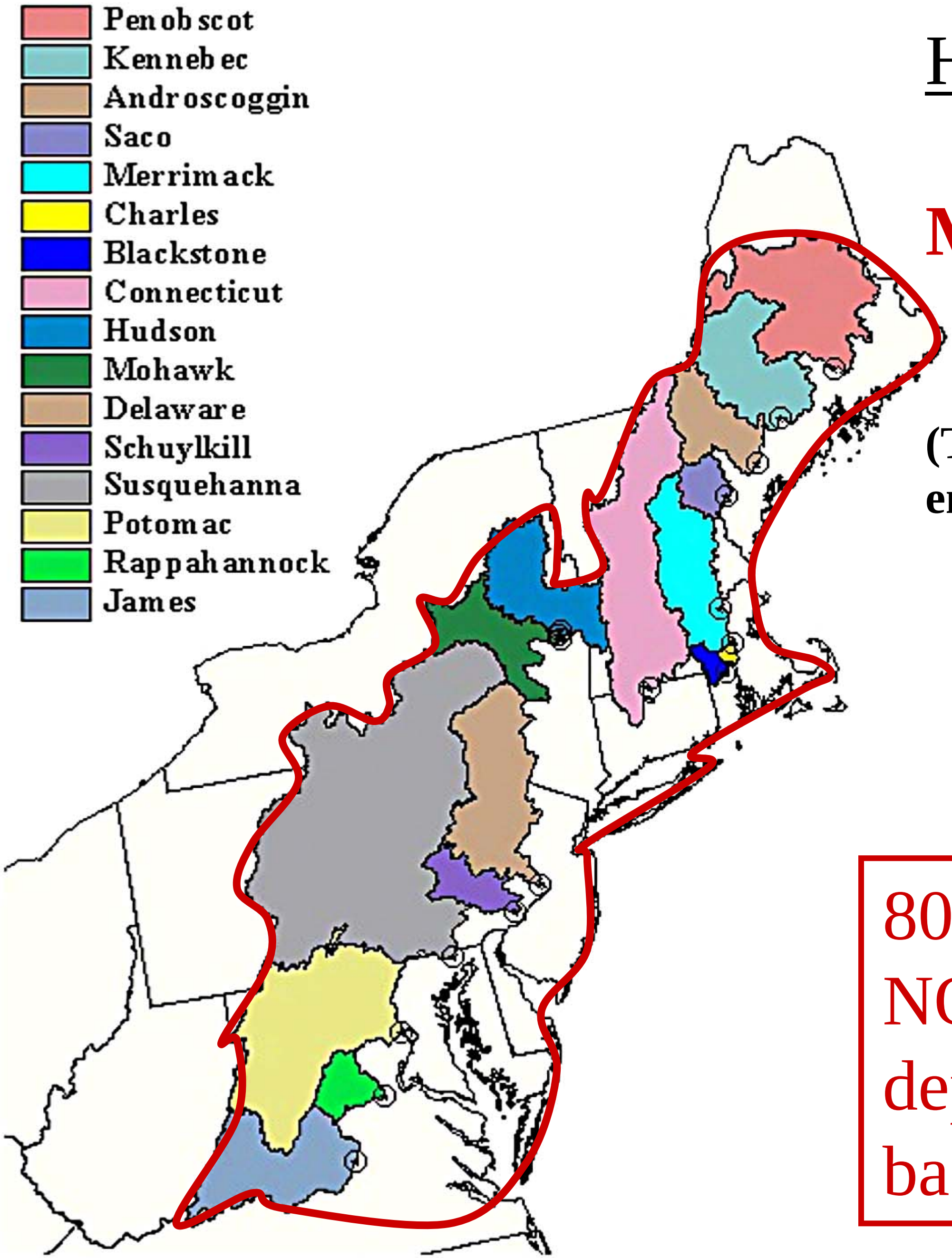


Boyer et al. (2002):

Mean for 16 watersheds:

~ 680 kg N km^{-2} yr^{-1}

(NADP monitoring data, with extrapolation for dry deposition; NOy deposition only)



Howarth et al. (1996):

Mean for entire northeast:

~ 1,200 kg N km^{-2} yr^{-1}

(TM3-type model estimate based on emissions, reaction, and advection)

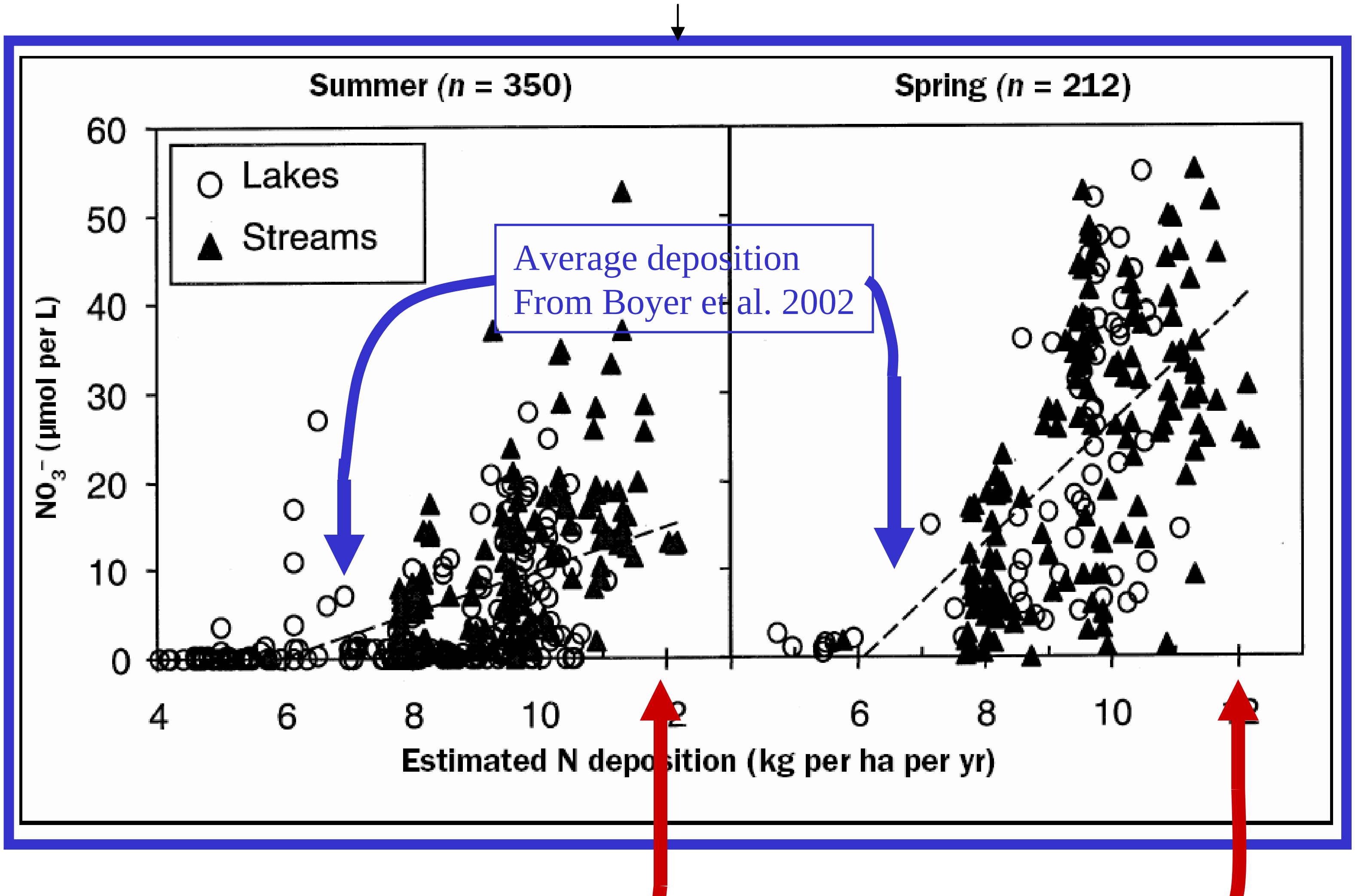
80% greater estimate of NOy atmospheric deposition using estimate based on emission data!

Explanation?

Dry deposition of gaseous nitrogen (NO, NO2) near emission sources? Very poorly monitored, but increasing evidence for this from many recent studies!

Underestimation of dry deposition of nitrogen fine particles, due to topographic effects? Poorly understood…..

(Aber et al. 2003)



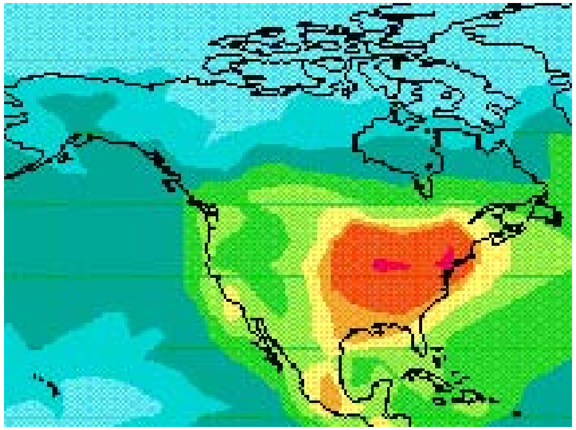
Average deposition
From Boyer et al. 2002

Average deposition from
Howarth et al. 1996

NCER
STAR
Science to Achieve Results

Grant # R830882

Thanks to EPA STAR Program!



North American Nitrogen Center

One of 5 regional centers of the International Nitrogen Initiative, established by the International Council of Science in 2003 (through SCOPE and the IGBP).

ini

www.eeb.cornell.edu/biogeo/nanc.nanc.htm

nitrogen@cornell.edu

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