Review of the Impacts of Land Use and Land Cover Change Effects in Coastal Zones

Thomas R Fisher

Horn Point Laboratory

University of Maryland-CES

NASA LCLUC Science Team meeting, 20-22 Nov 2002

LCLUC Conceptual Scheme

feedback

socio-economic drivers

land use/cover change

focus of talk

ecol/biogeochem consequences

Tools

observations

modeling

prediction

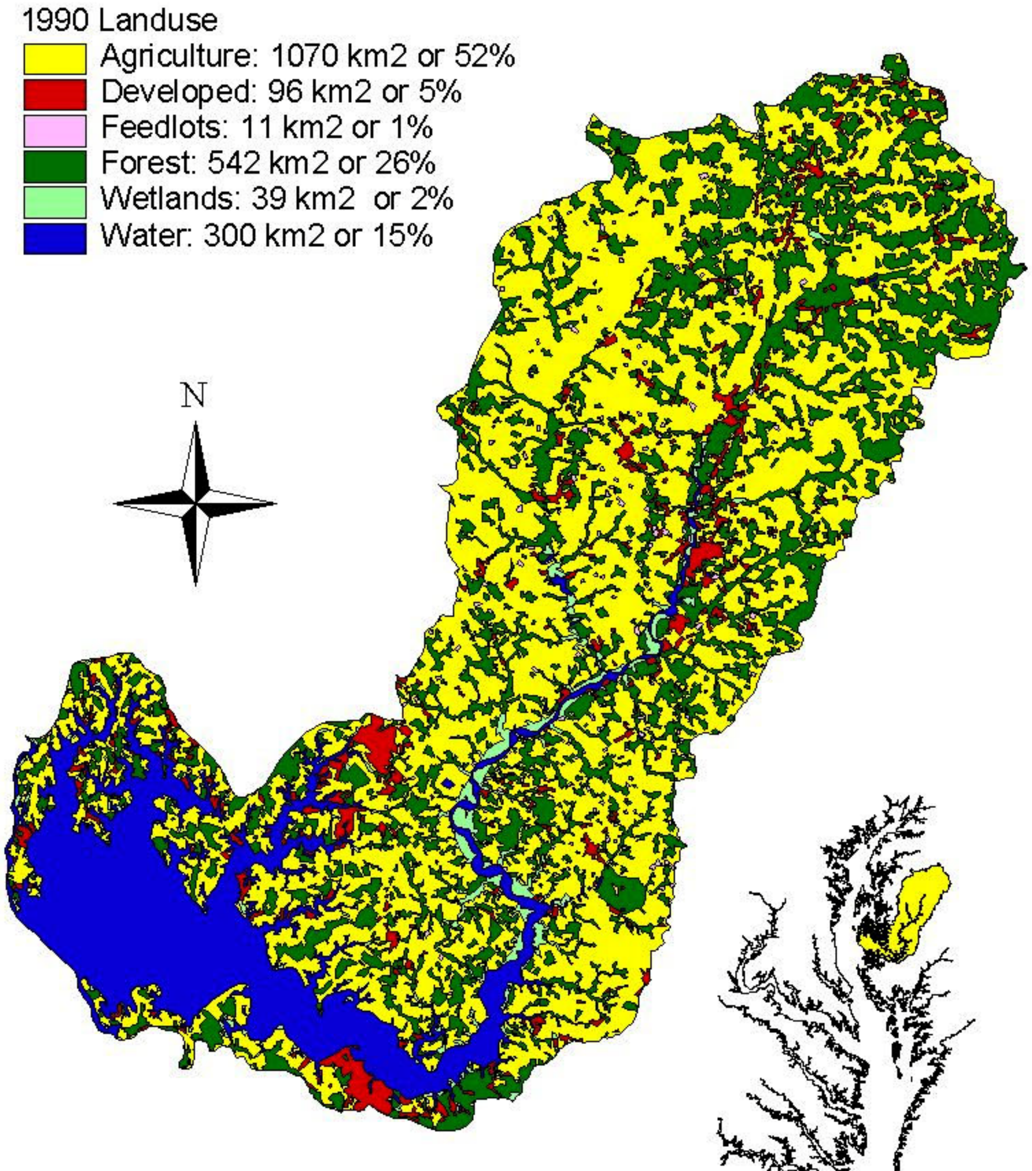
Topics:

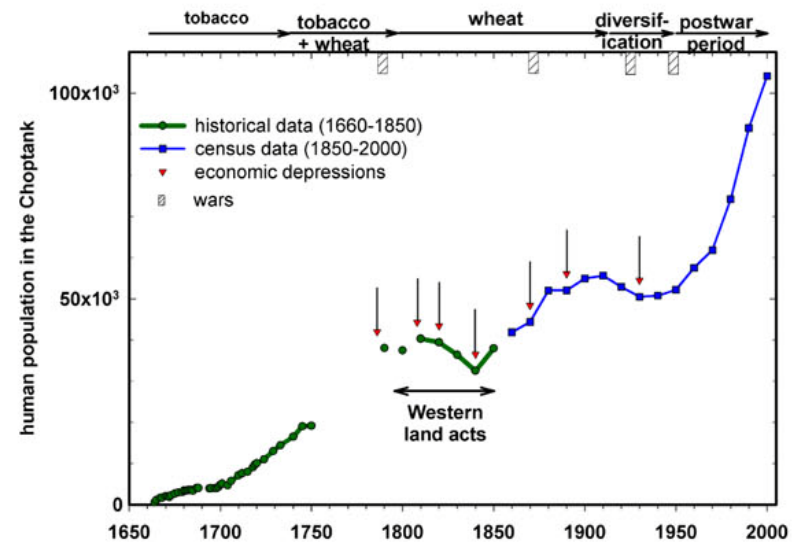
- Approaches
  - Direct experiments (usually deforestation)
    - Primarily hydrologic consequences
  - Space for time swaps
    - Based on spatial variations in land cover
- How does stream flow and chemistry vary with land cover/use?
- What does hydrochemical modeling tell us?

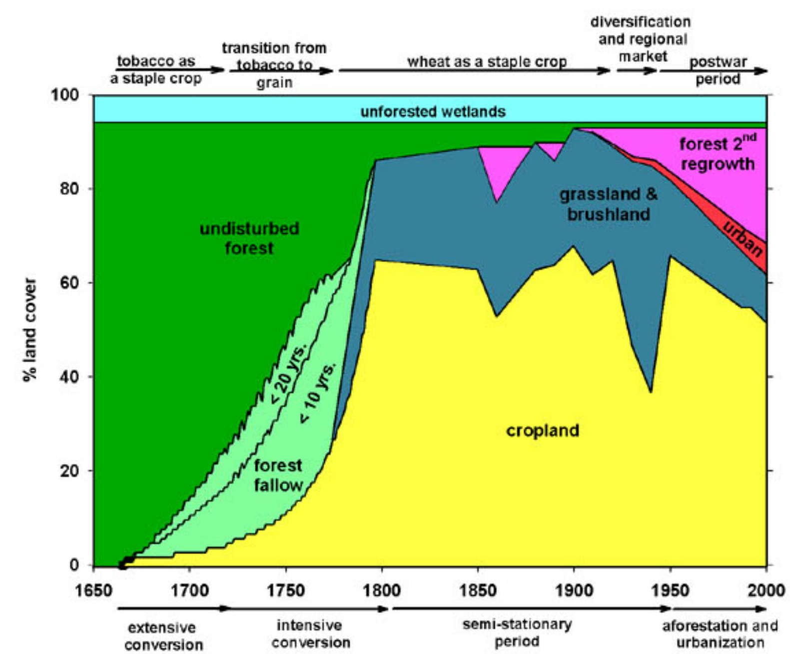
Historical Reconstructions

- **Socioeconomic drivers**
  - **historical data or records**
- **Land use/cover**
  - **maps, aerial photos, satellite imagery**
- **Biogeochemical consequences**
  - **data rarely available**

LULCC in the Choptank River Basin, MD







Benitez and Fisher, 2001

Focus of the talk:

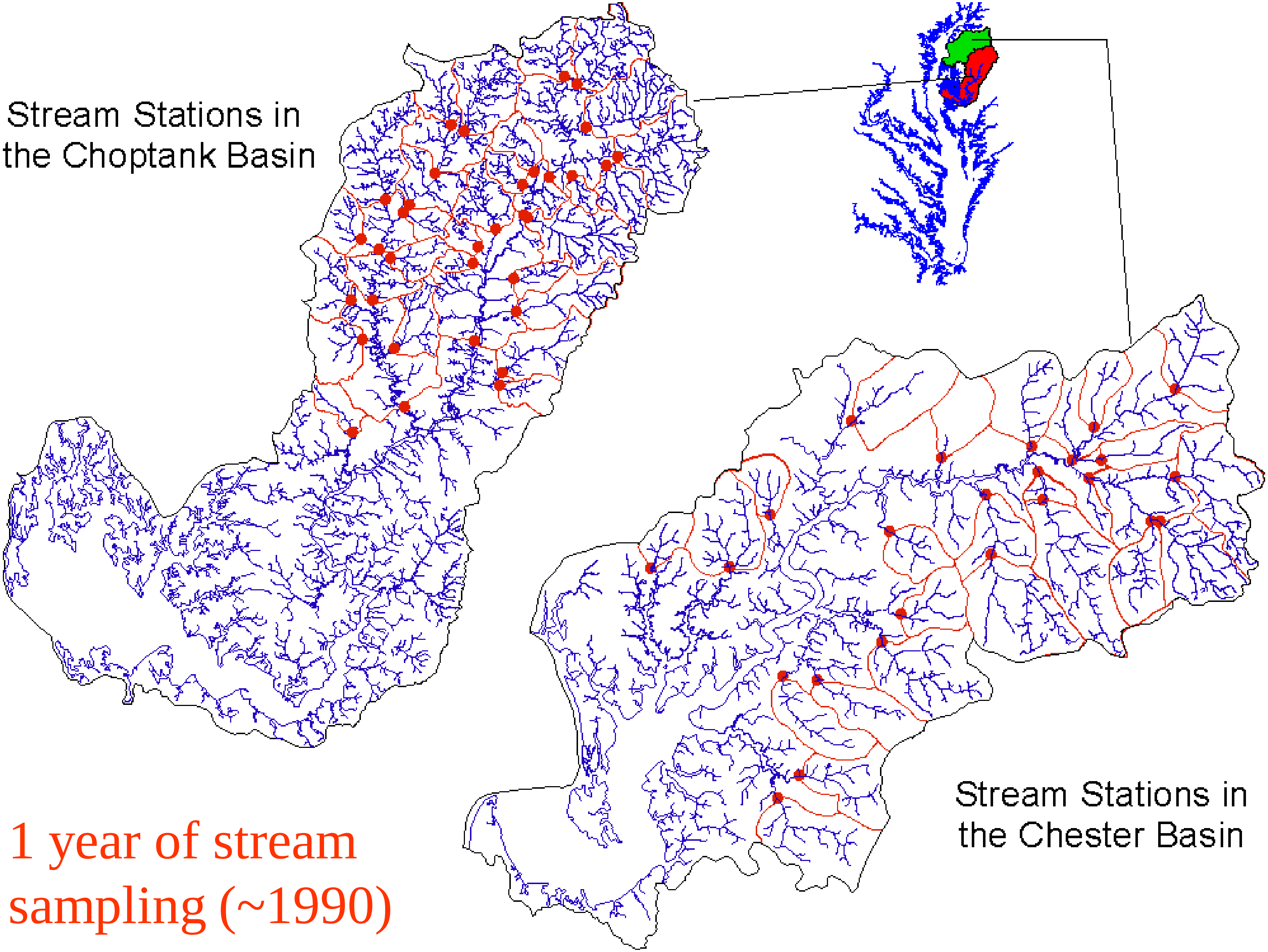
- Effects of changes in land use/cover on
  - export of materials from land to water
- Two components:
  - stream discharge (storm response, water yield)
  - “water quality” = conc. of diss. or part. materials
    - Low conc = good water quality
- Effects on soils

Approach:

- Ideal situation:
  - – monitoring WQ during land use/cover change
  - – rarely observed (no colonial water data)
  - – sediment cores reveal erosion and plant changes
    - Good validation data, but not spatially explicit
- Alternative: “space for time swaps”
  - – Use variations in space to infer trajectory of a time course
  - – Sample WQ in basins with varying amounts of land cover
  - – Substituting spatial variations for temporal ones

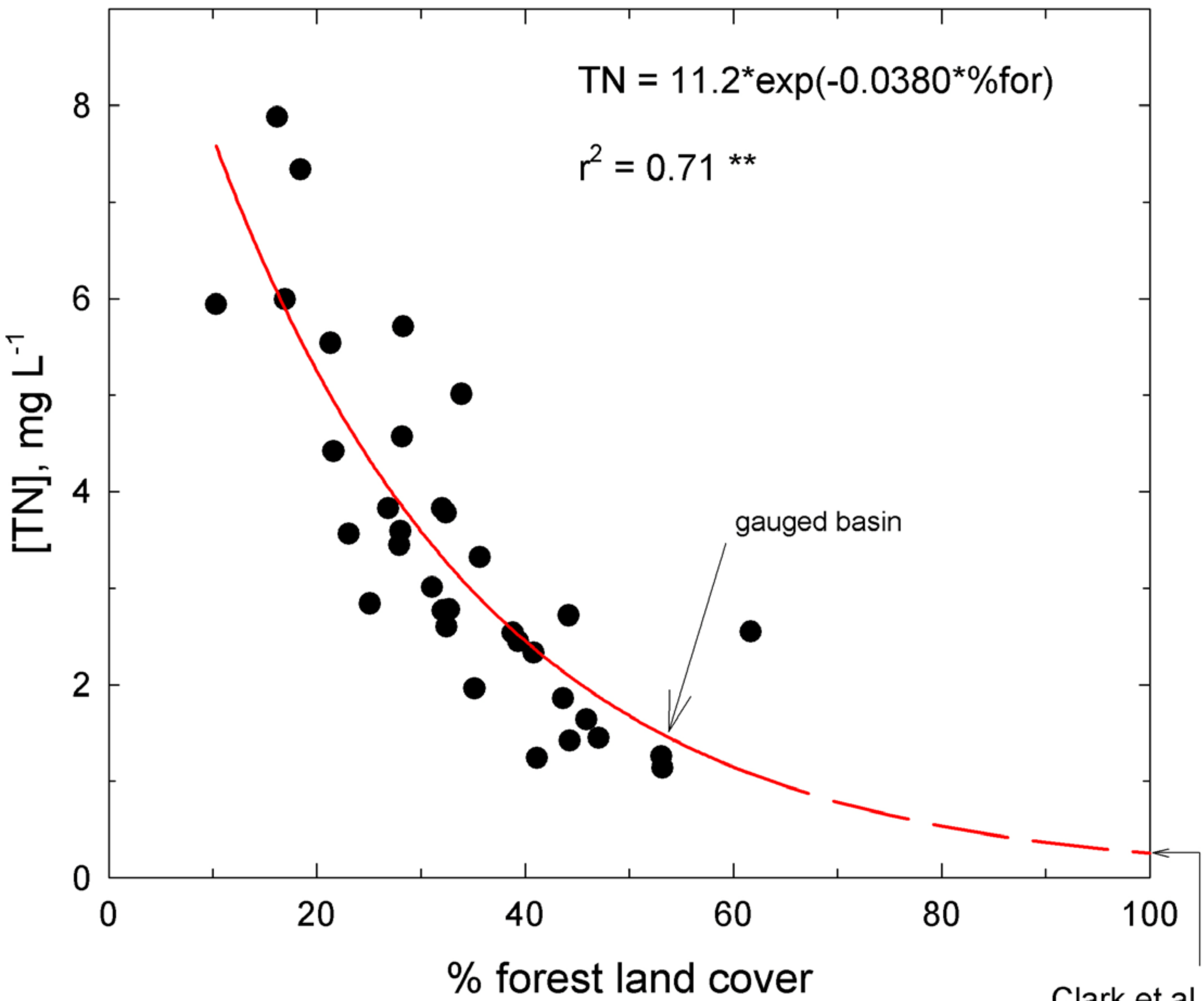
Approach (con't):

- Problems:
  - Assumes common temporal trajectory for all land cover conversions
    - sampling in space = sampling in time
  - Ignores real spatial heterogeneity with differing trajectories and histories



1 year of stream sampling (~1990)

Choptank River Basin

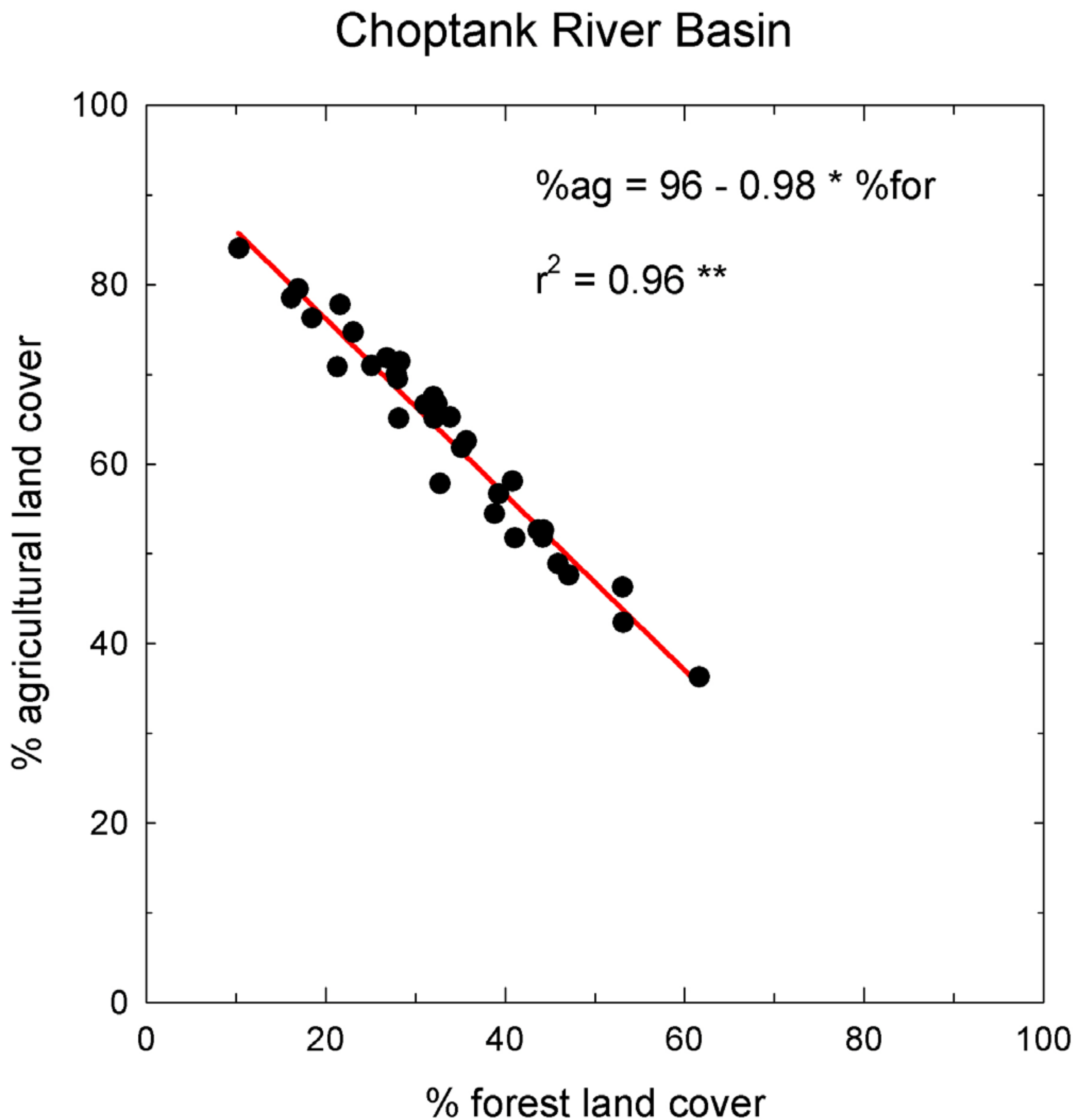


Clark et al. (2000):
TN in undeveloped
basins: 0.26 mg N L^{-1}

Lower forest cover is associated with higher N conc.

Extrapolation of regression line agrees with data for undeveloped basins.

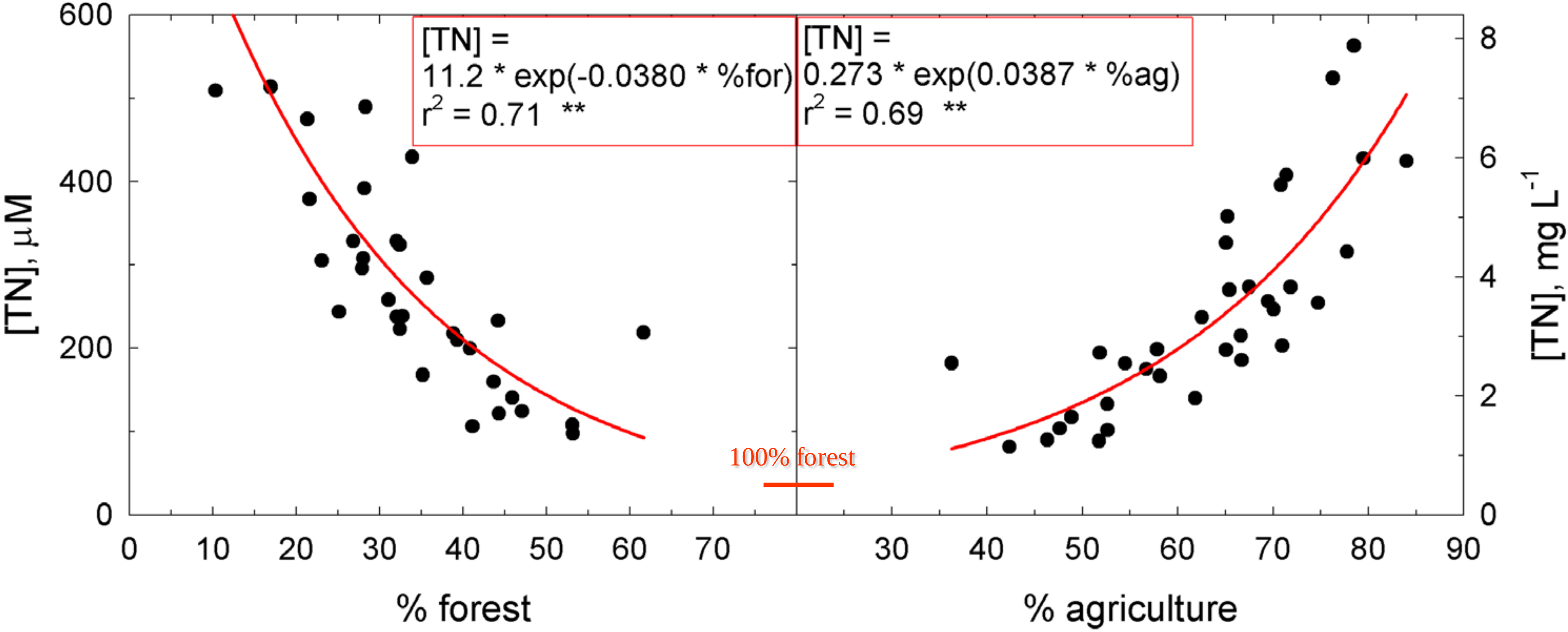
Data sources: Norton, MM and TR Fisher. 2000. Ecol. Engin. 14: 337-362
Clark et al. 2000. J. Amer. Water Res. Assoc. 36: 849-860



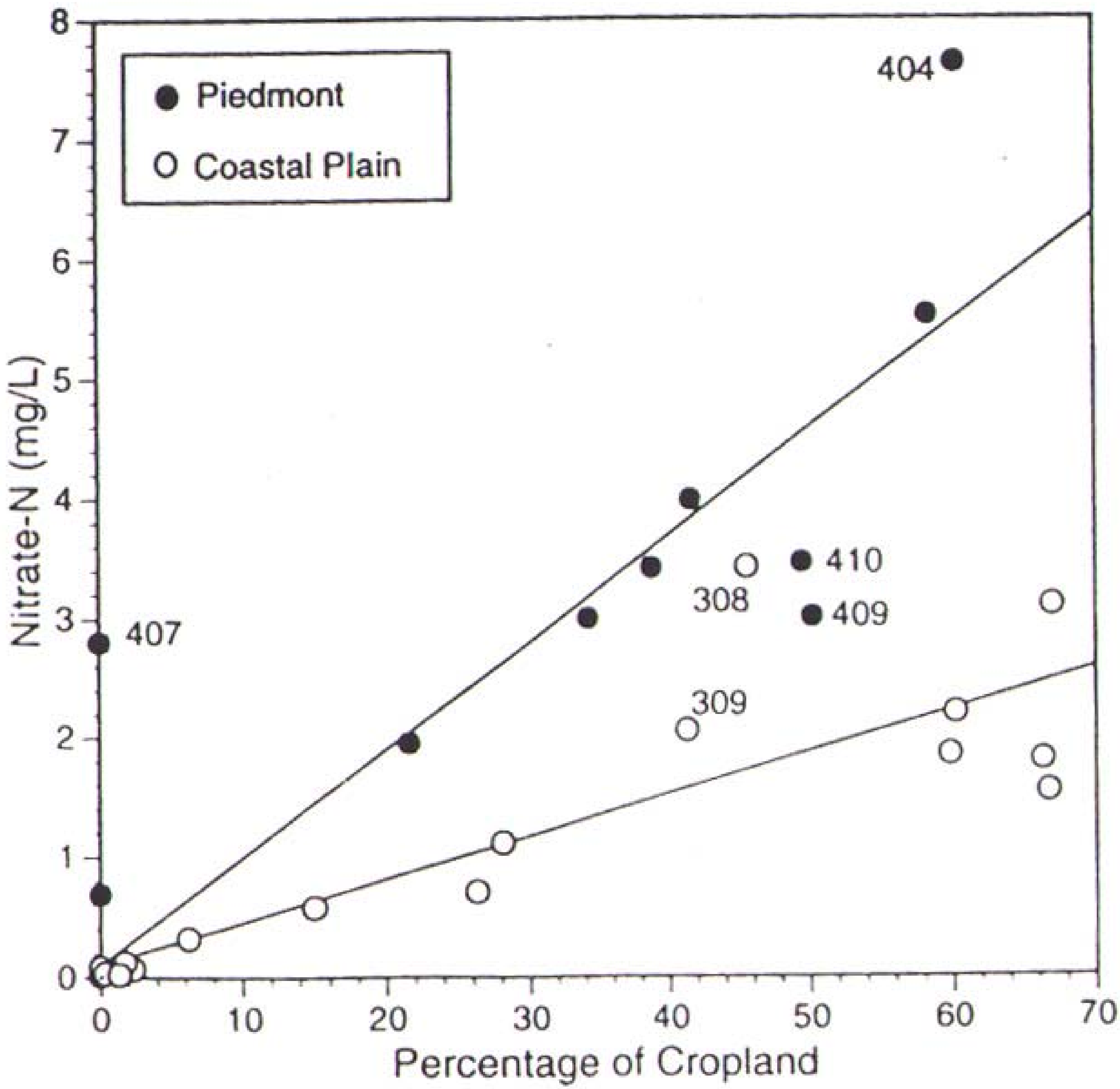
Data source: Norton, MM and TR Fisher. 2000. Ecol. Engin. 14: 337-362

The two main land covers are inversely correlated.

Effect of Land Use in the Choptank River Basin

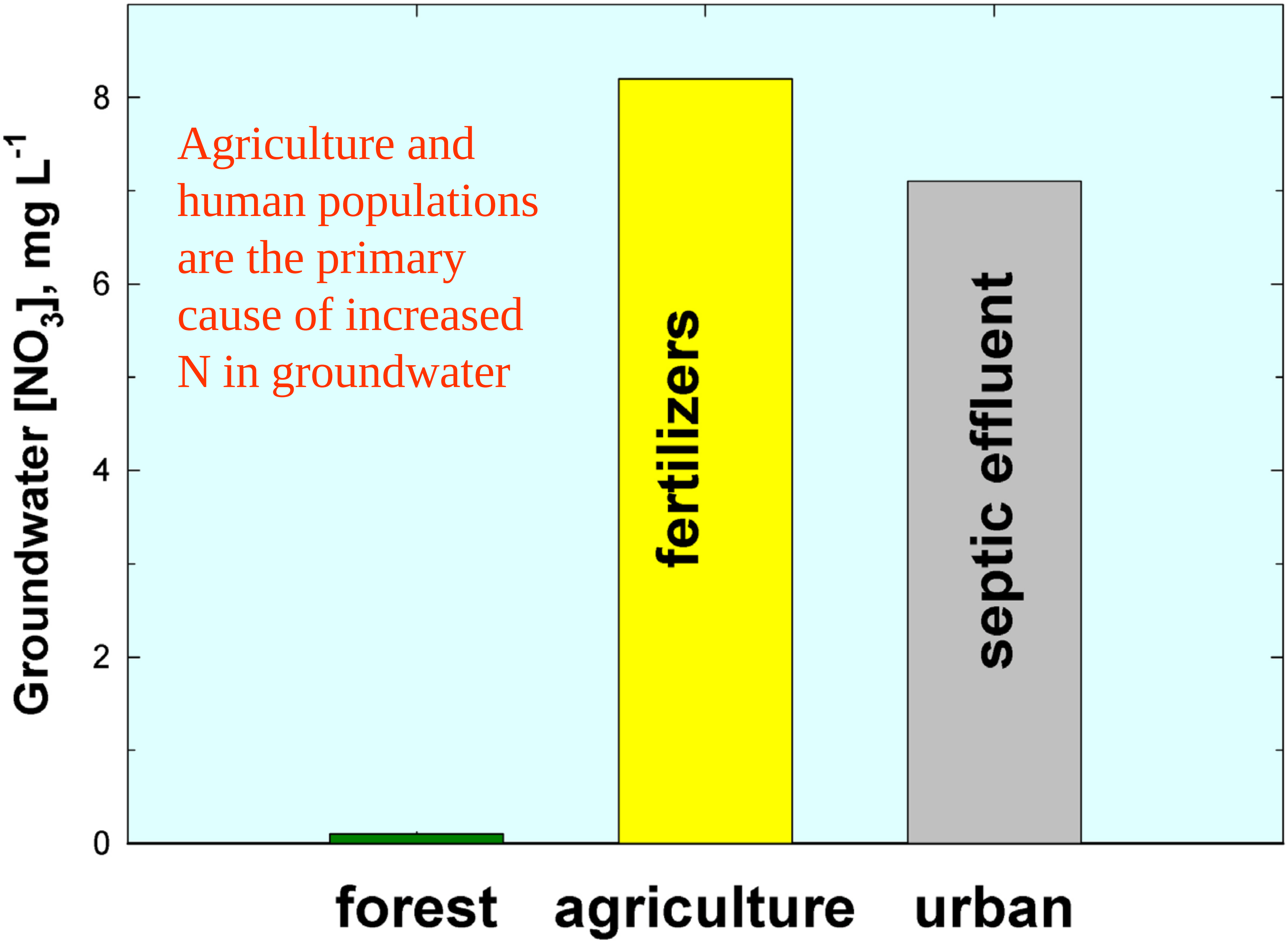


Increasing agriculture and decreasing forest result in higher total N in streams, primarily as nitrate .



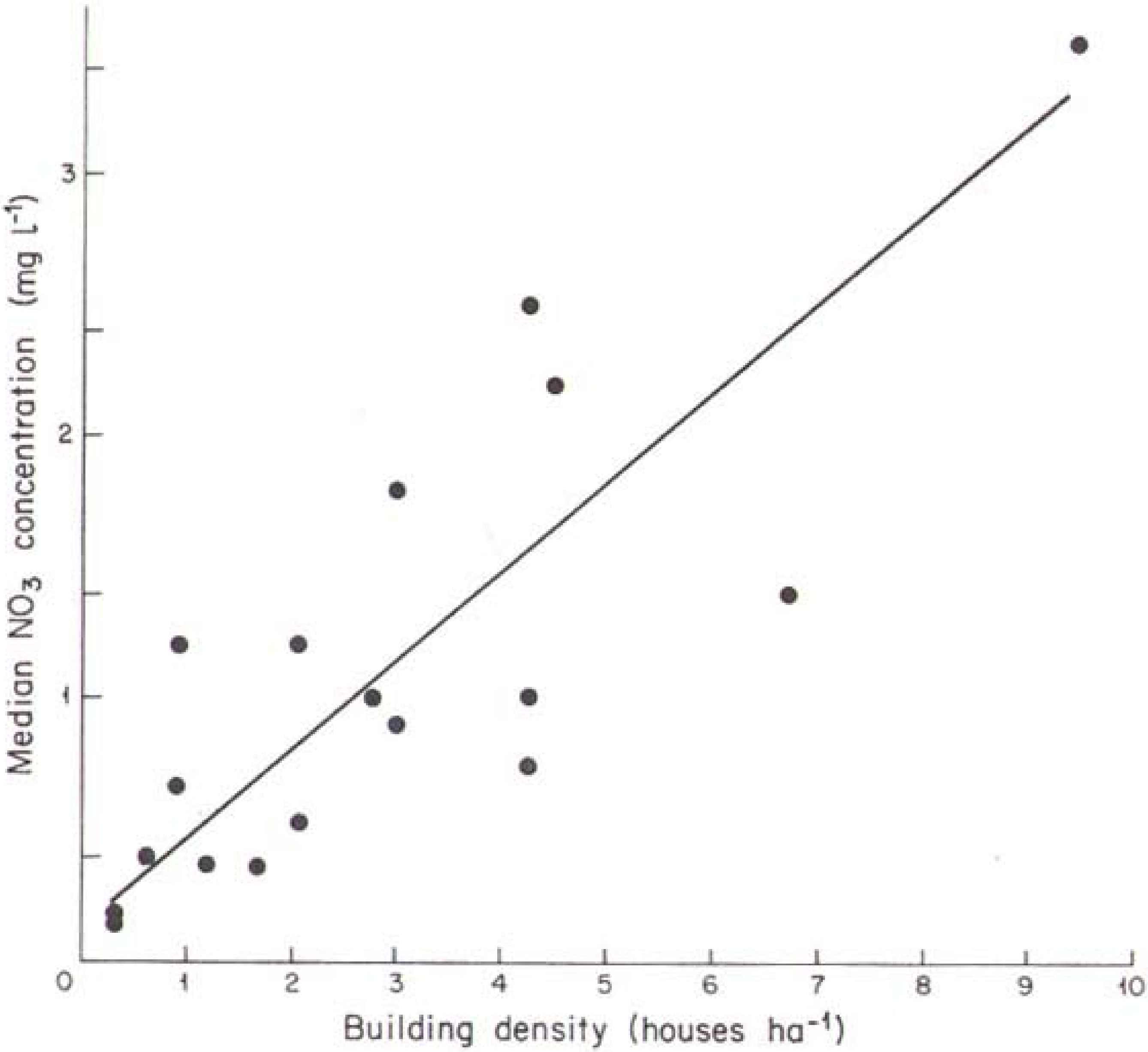
Increasing agriculture may have a more linear relationship with stream N over a narrower range of % ag and exhibit geological effects (Jordan et al 1997).

Hamilton et al. (1993)

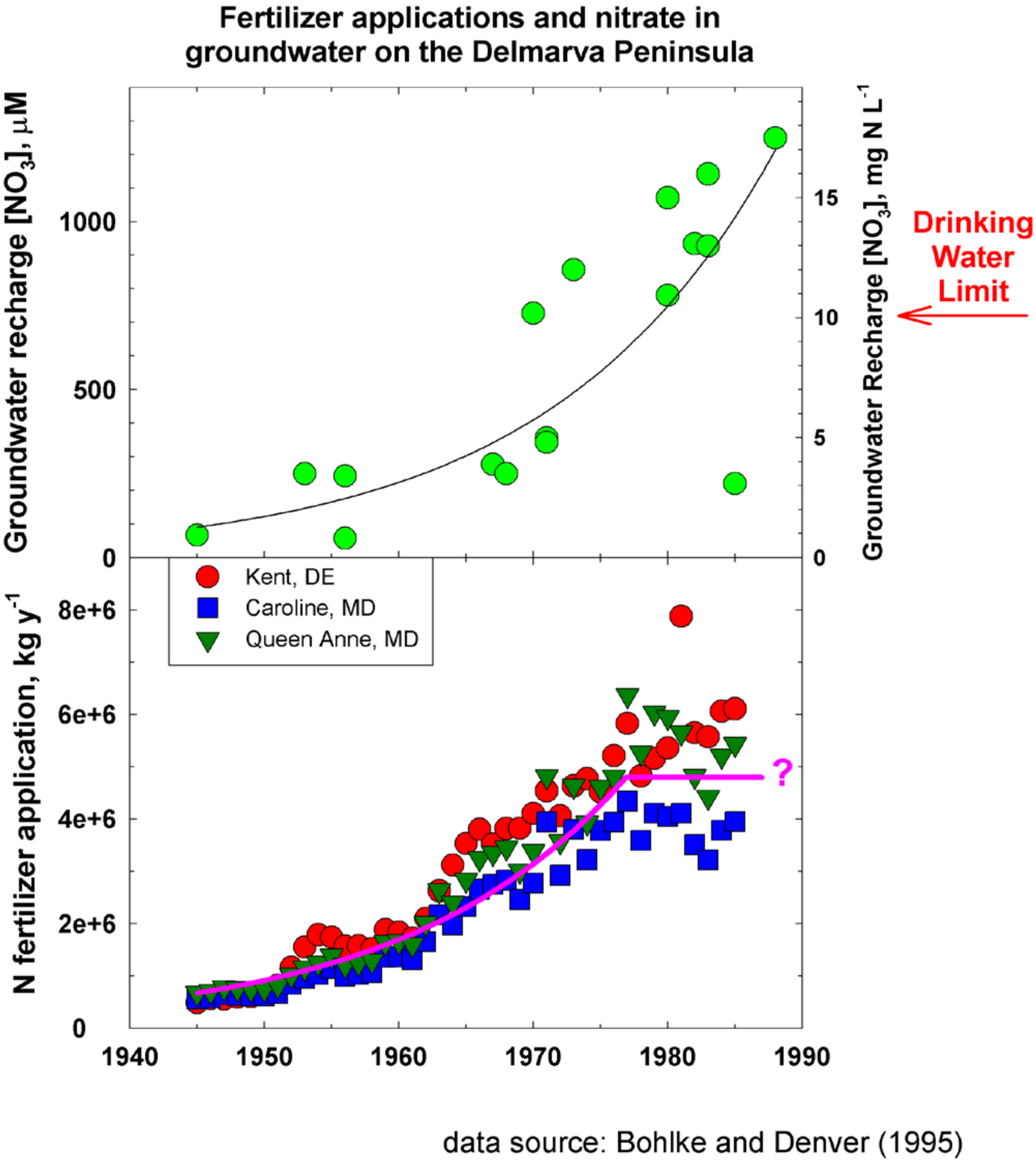


Couplings of Watersheds and Coastal Waters

Cape Cod: Valiela et al. 1992

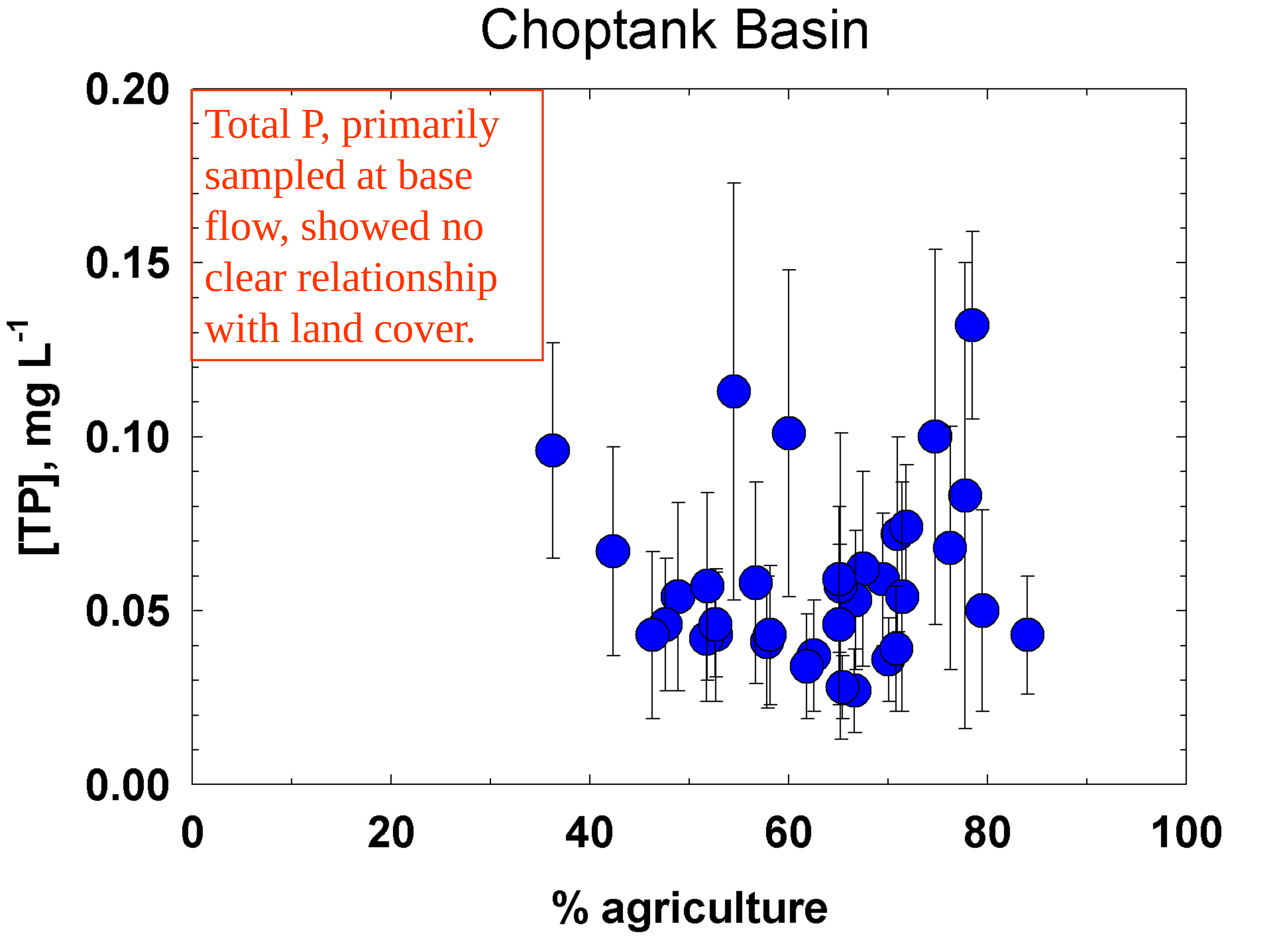


Groundwater nitrate increases with housing density in unsewered areas.



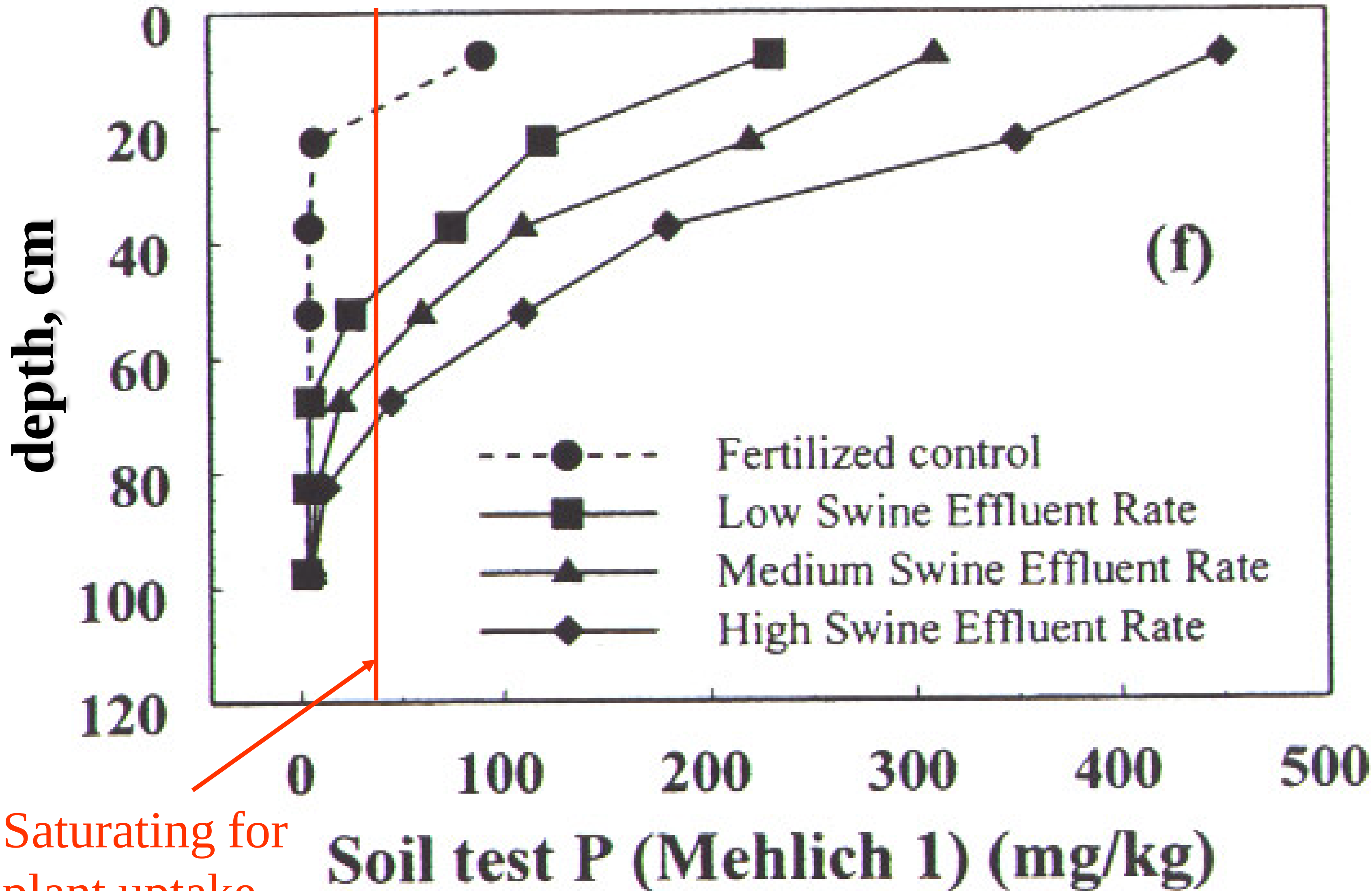
Groundwater nitrate has also increased exponentially over the same period

Fertilizer applications increased exponentially from 1945-1980

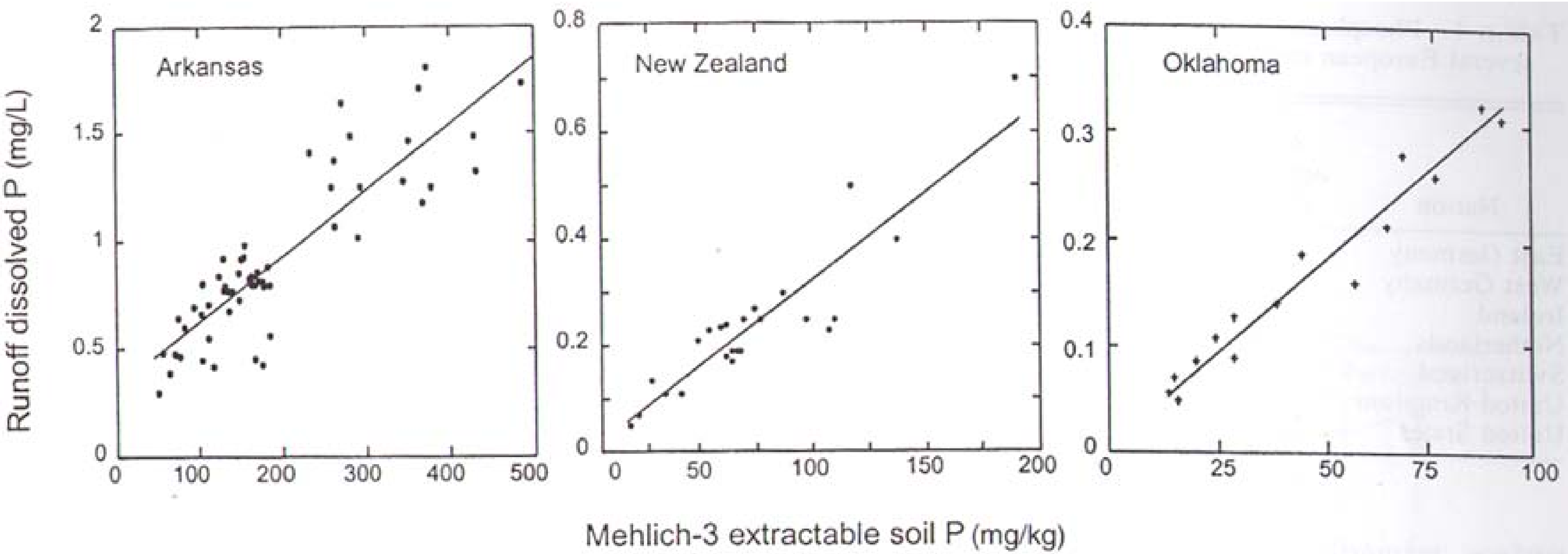


Choptank Basin
Total P, primarily sampled at base flow, showed no clear relationship with land cover.
0.20
0.15
0.10
0.05
0.00
[TP], mg L-1
0
20
40
60
80
100
% agriculture

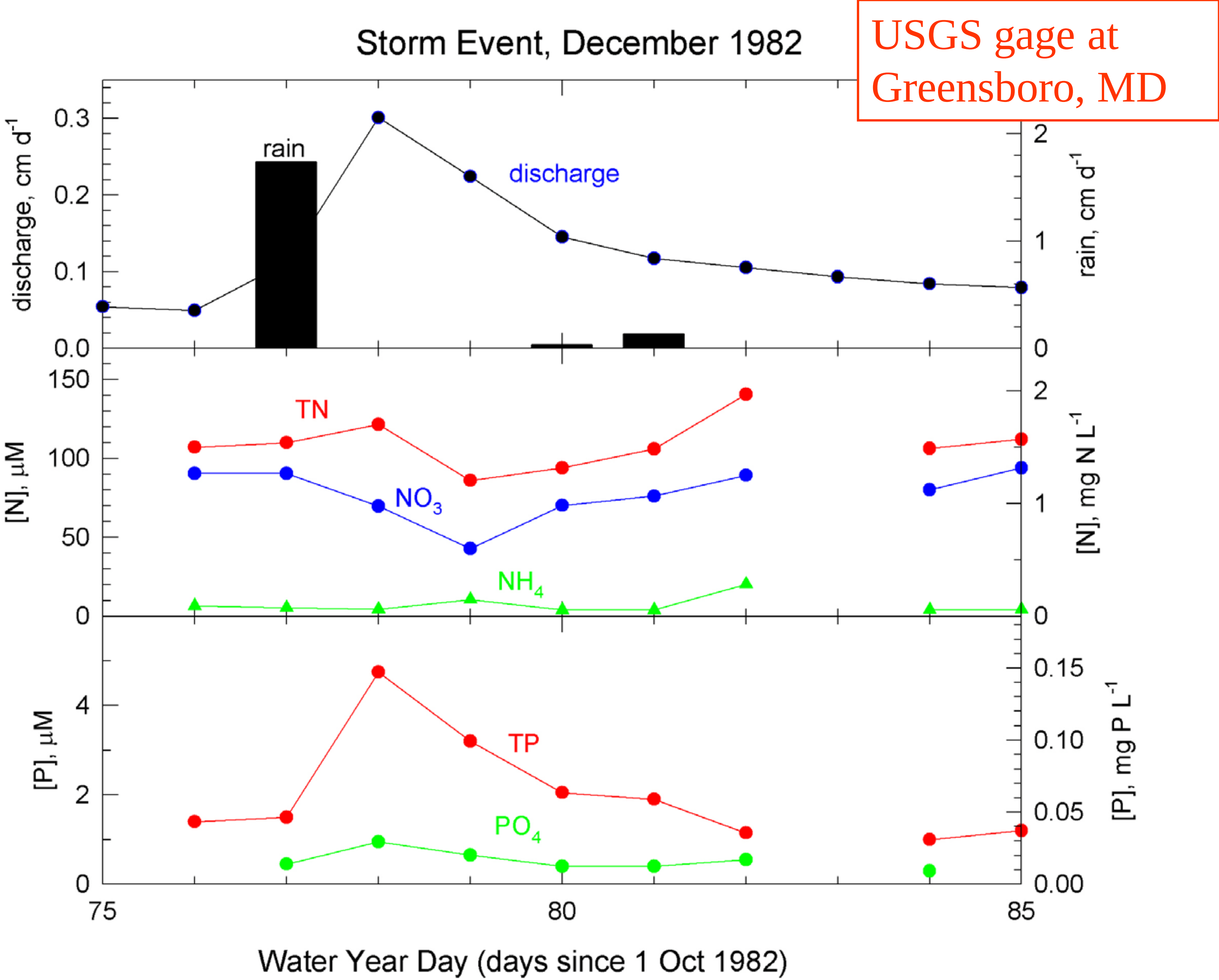
Source: Sims et al. 1998



Saturating for plant uptake



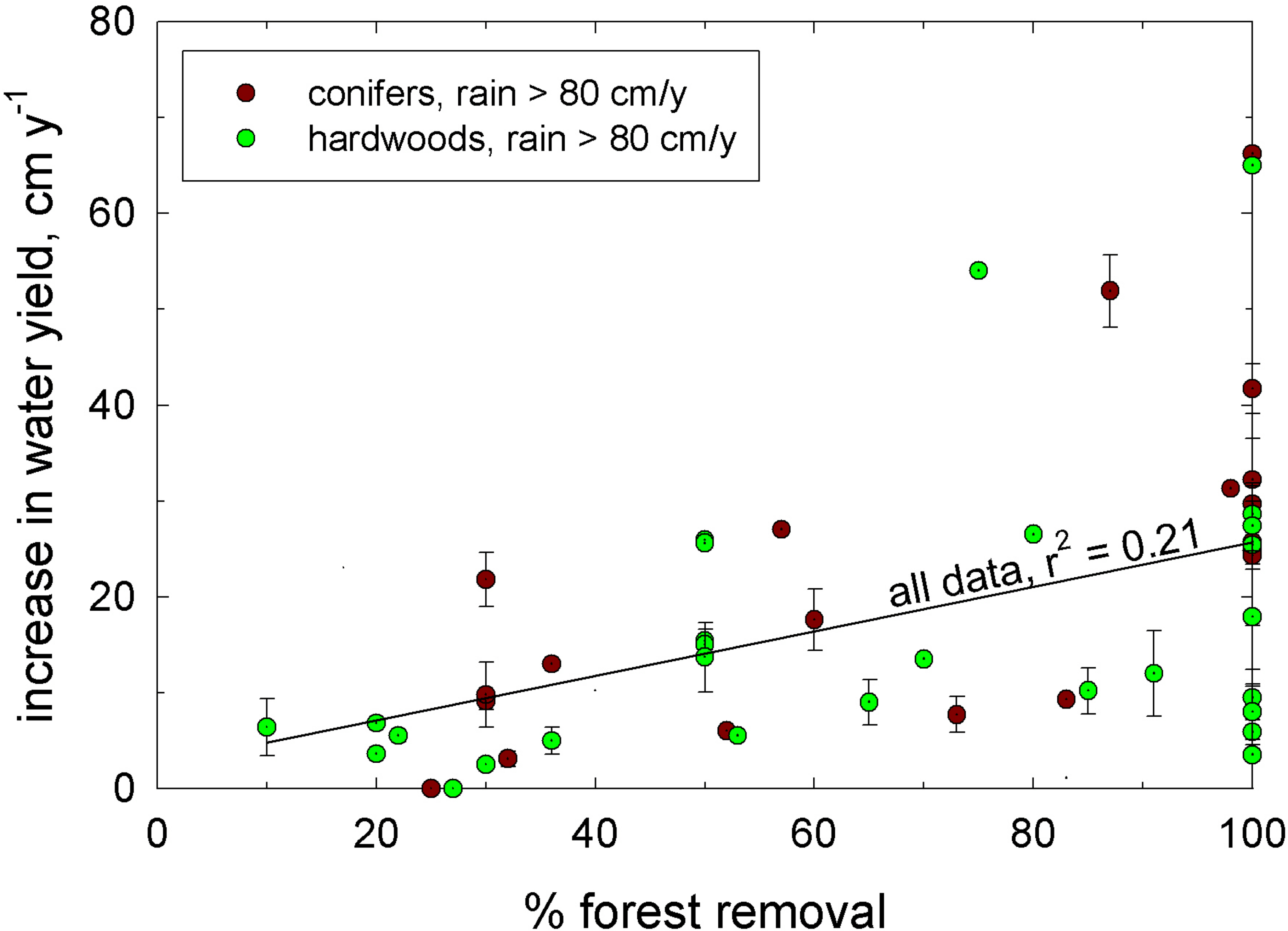
Increases in soil P lead to increased leaching of P in overland flow. Source: Carpenter et al. 1998


USGS gage at Greensboro, MD
Storm Event, December 1982
discharge, cm d-1
rain, cm d-1
rain
discharge
0.0
0.1
0.2
0.3
0
1
2
[N], µM
[N], mg N L-1
TN
NO3
NH4
0
50
100
150
0
1
2
[P], µM
[P], mg P L-1
TP
PO4
0
2
4
0.00
0.05
0.10
0.15
75
80
85
Water Year Day (days since 1 Oct 1982)

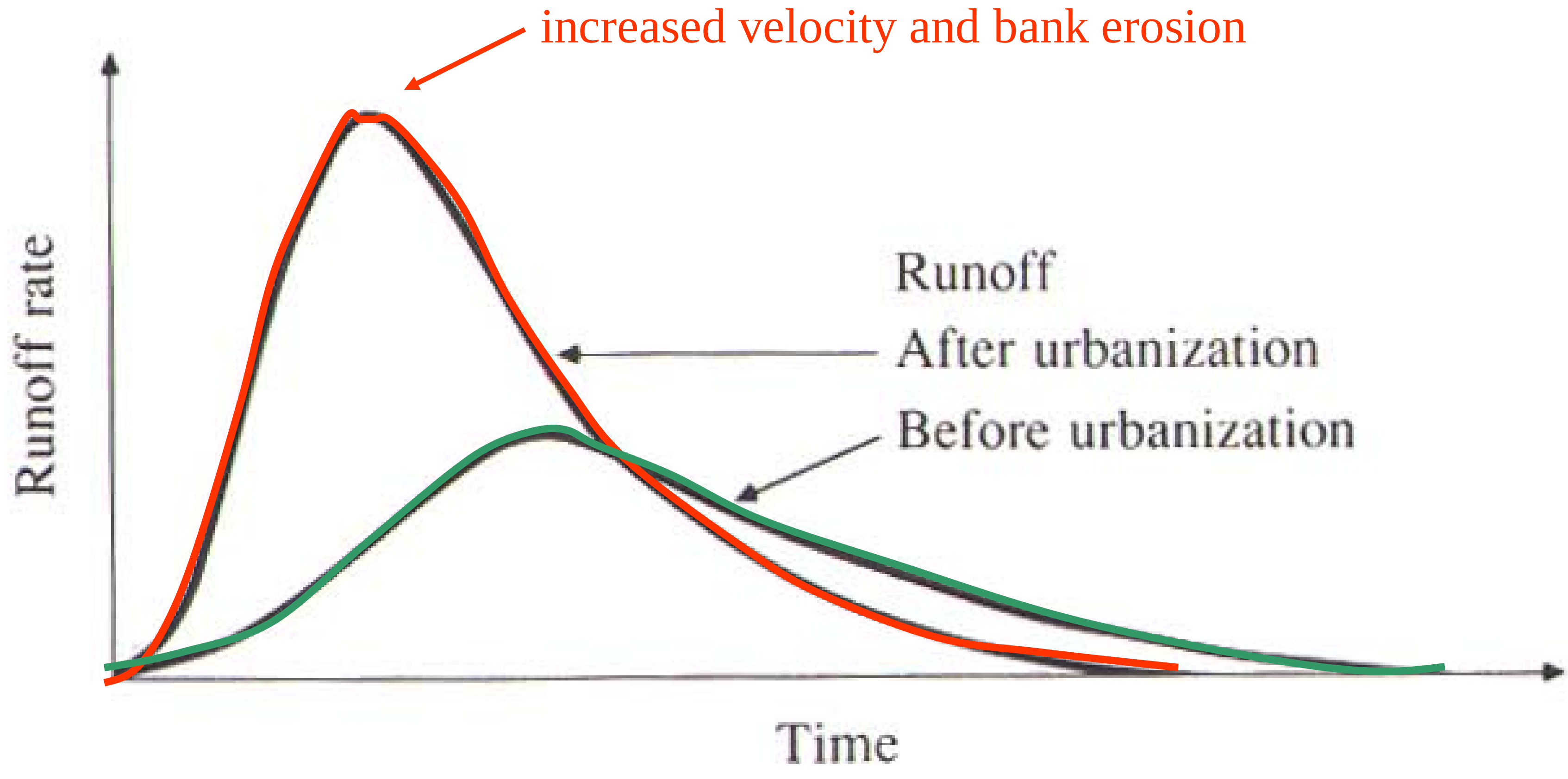
Hydrology (some direct experiments)

- Forest removal and urbanization
  - Increased rate of response to a storm and loss of baseflow
    - Less capacity to retain water (= lower baseflow)
  - Total volume of water increased
    - Less evapotranspiration (= more stormflow)

Source: Bosch and Hewlett 1982

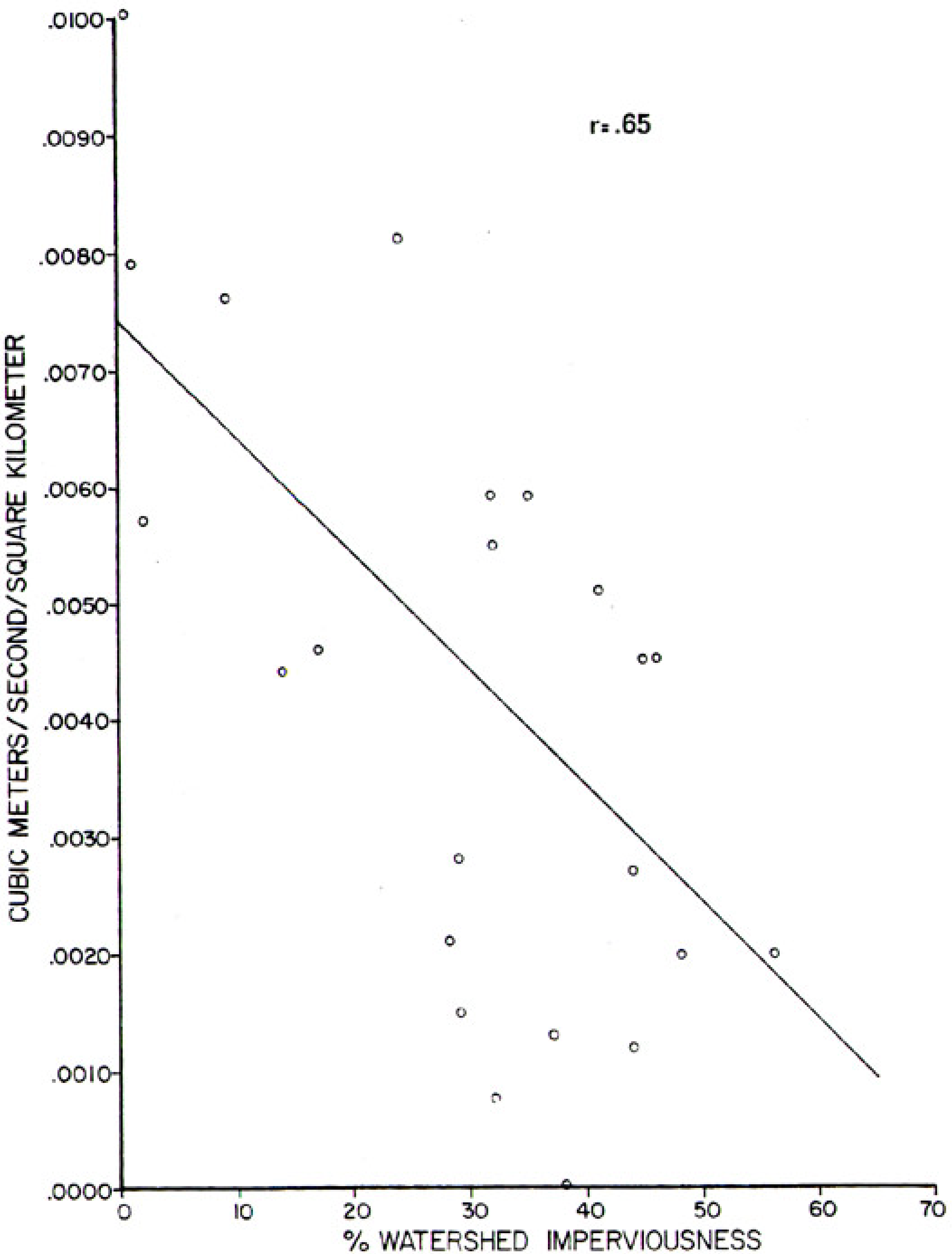


Urbanization increases stream velocity and total runoff



The effect of urbanization on storm runoff.

Source: Chow et al. 1988

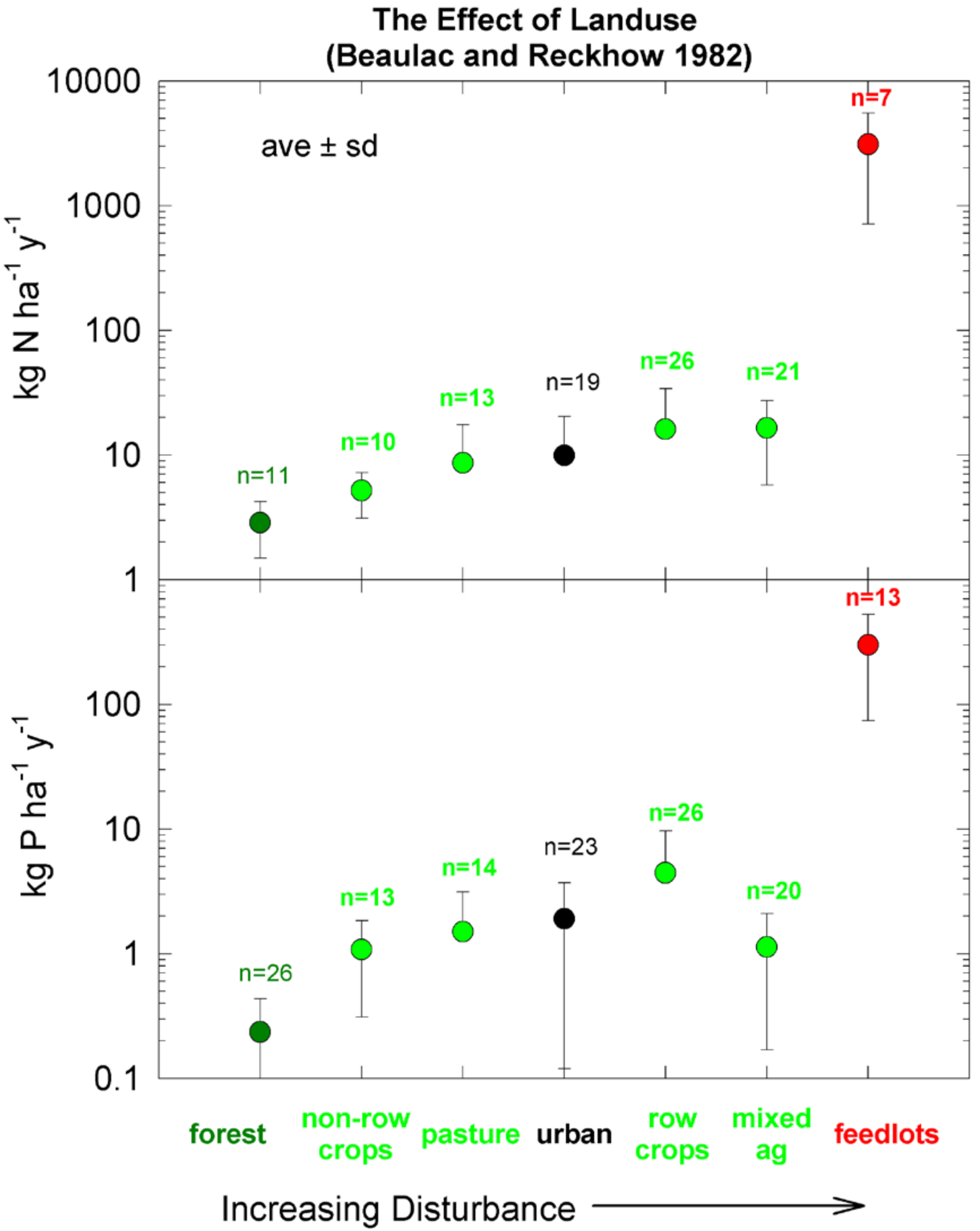


Impervious surfaces decrease stream baseflow between events.

Source: Klein 1979

Watershed export

- Export = water flow * concentration
  - Increased rates of water flows
  - Increased concentrations in stream water
- Conversion from forest to ag to urban
  - Exports greatly increased
- Often normalized per unit area watershed
  - kg ha^{-1} y^{-1} (area yield coefficients)

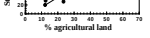


Agriculture and human populations are the primary cause of increased mobility of N and P in watersheds and export in streams.

Useful estimates from classified imagery.

Other relationships with land use:

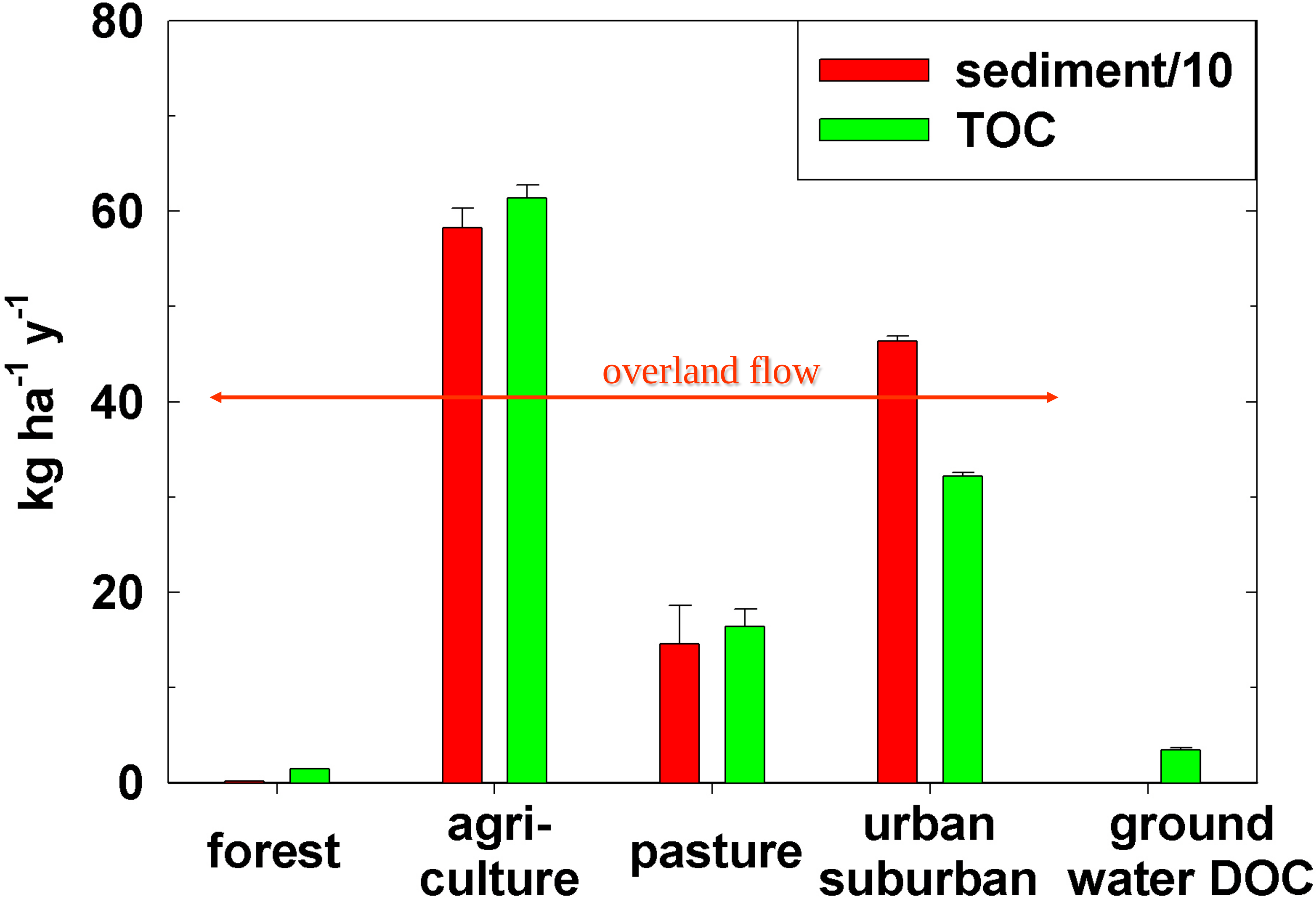
- Potassium and agriculture
- Urban and ag land uses (C, sed)
- EMAP surveys of land cover effects (NO_3^-, Cl^-)



New England basins

Source: Driscoll and Whitall, unpub.

Hudson River Subbasins

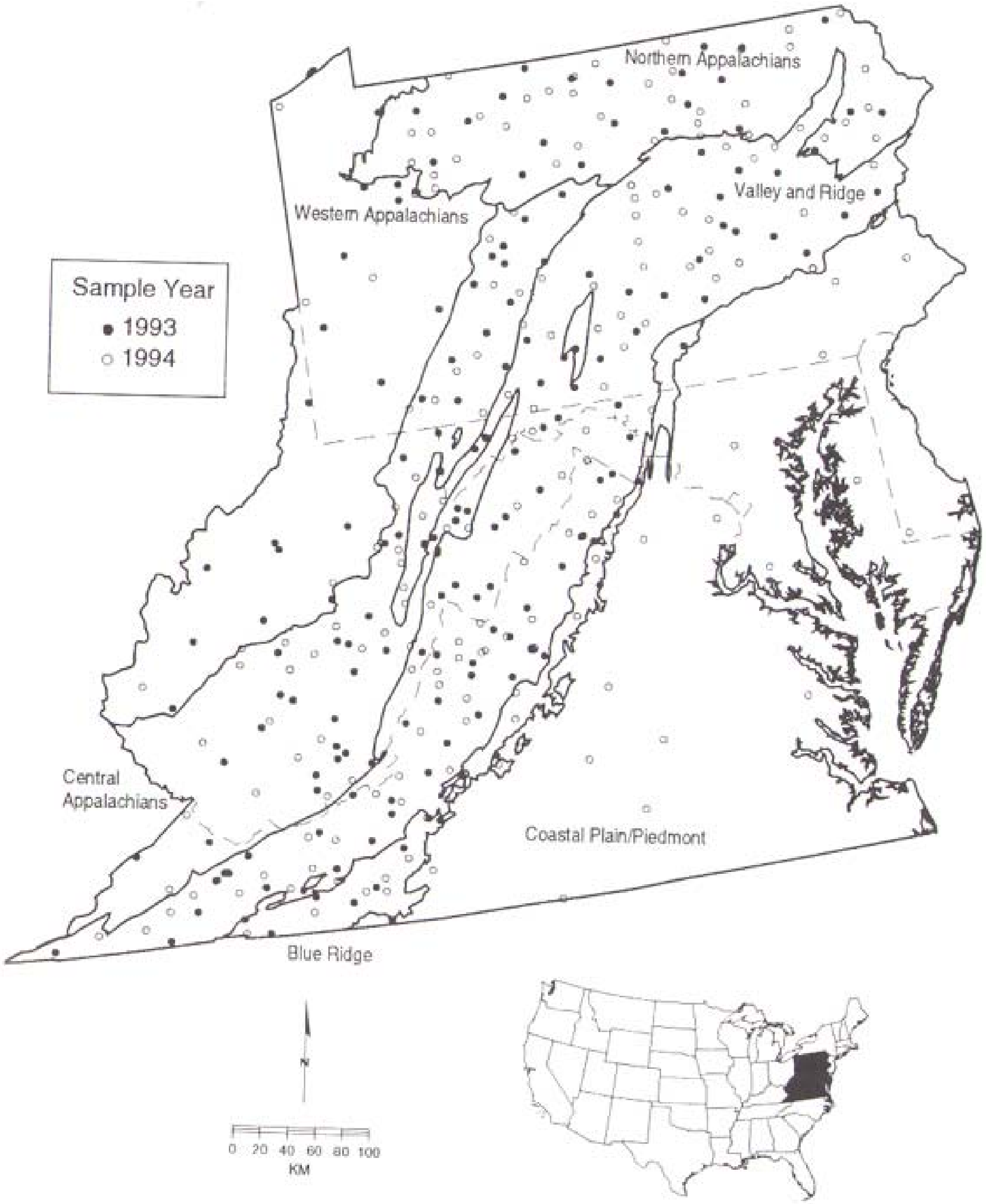


source: Howarth et al. 1991

EPA EMAP strategy:

- Sample a stream once in time
- Sample extensively in space
- Use land cover to understand stream chemistry

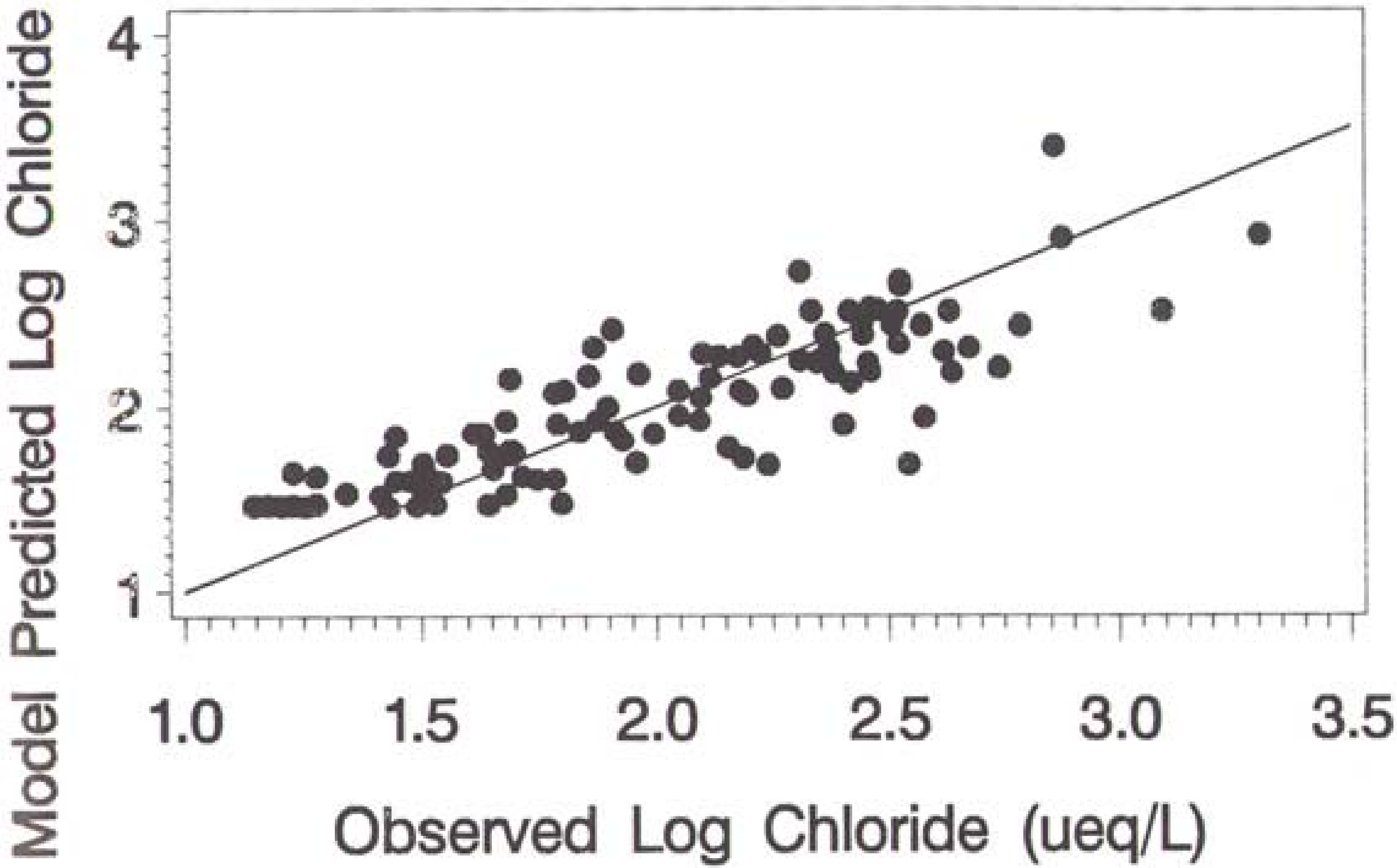
$$\log(\text{conc}) = a_1(\text{LULC}_1) + \ldots + a_n(\text{LULC}_n) + \text{error}$$



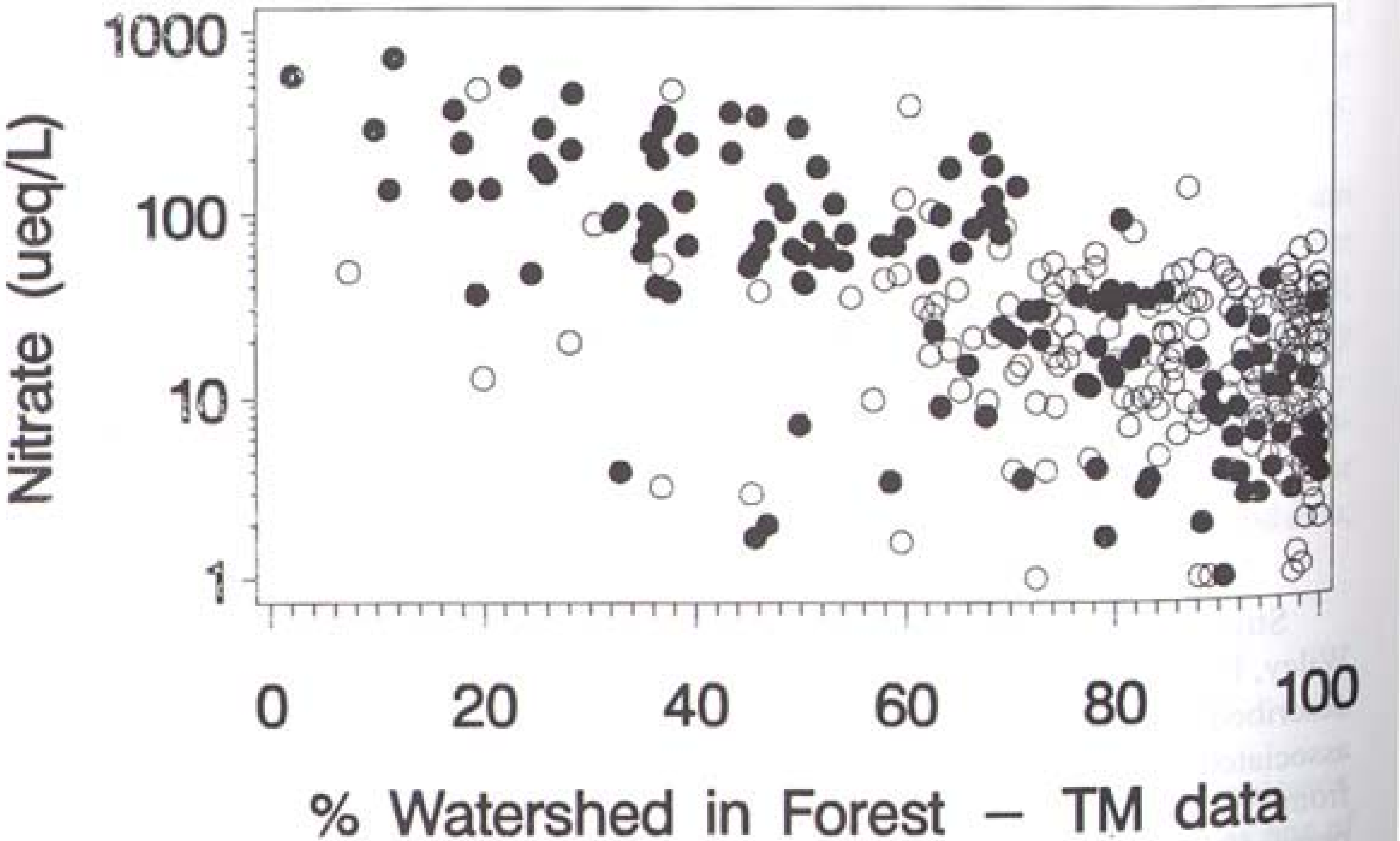
Location of sample sites in 1993 and 1994 EMAP stream surveys.

EPA Region III:

Intensive spatial sampling, single stream water sample.



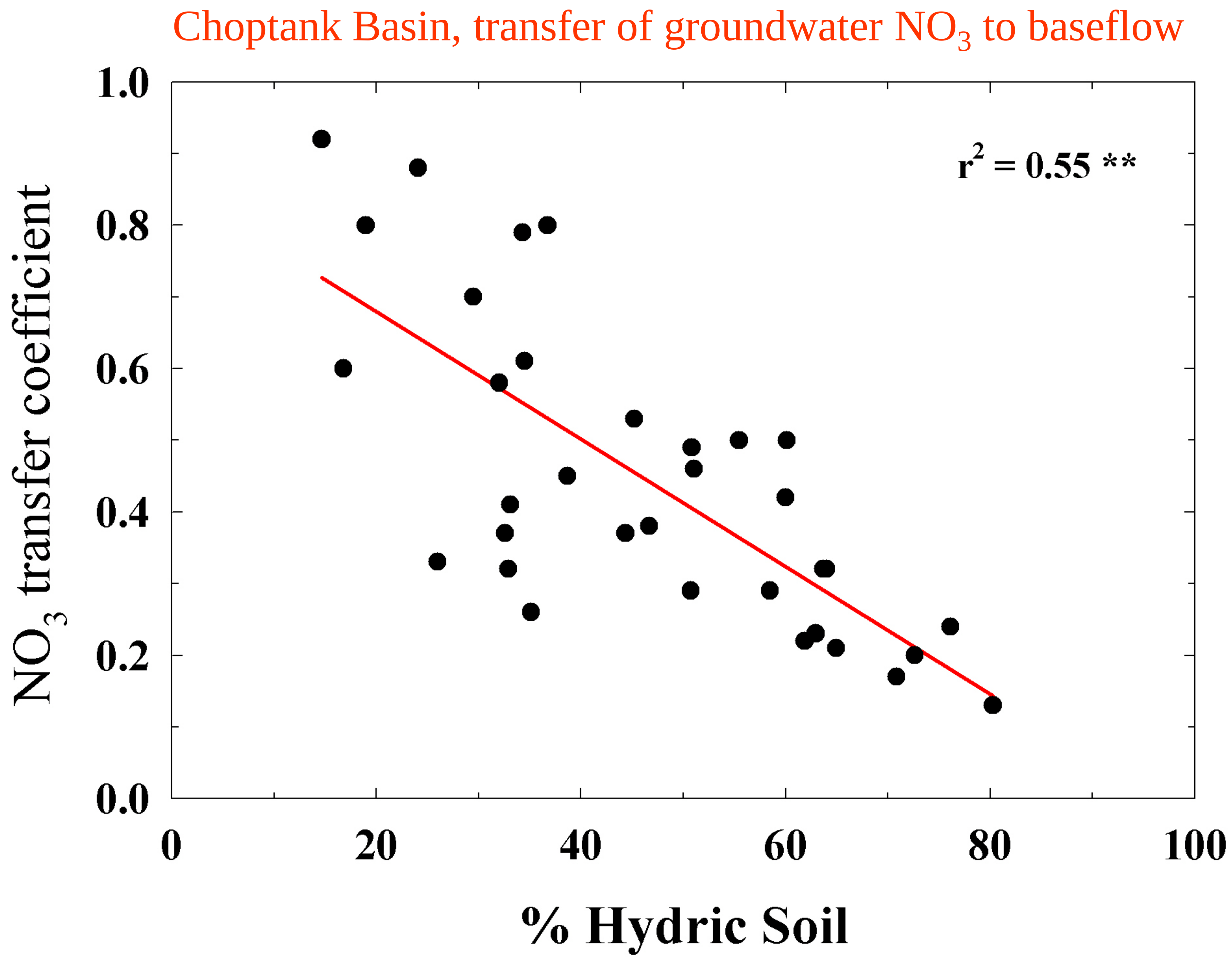
[Cl^-] was primarily associated with urban areas and road salt applications. Modeled values agreed well with observed.



$[NO_3^-]$ was exponentially associated with forested land, much as we observed in the Choptank.

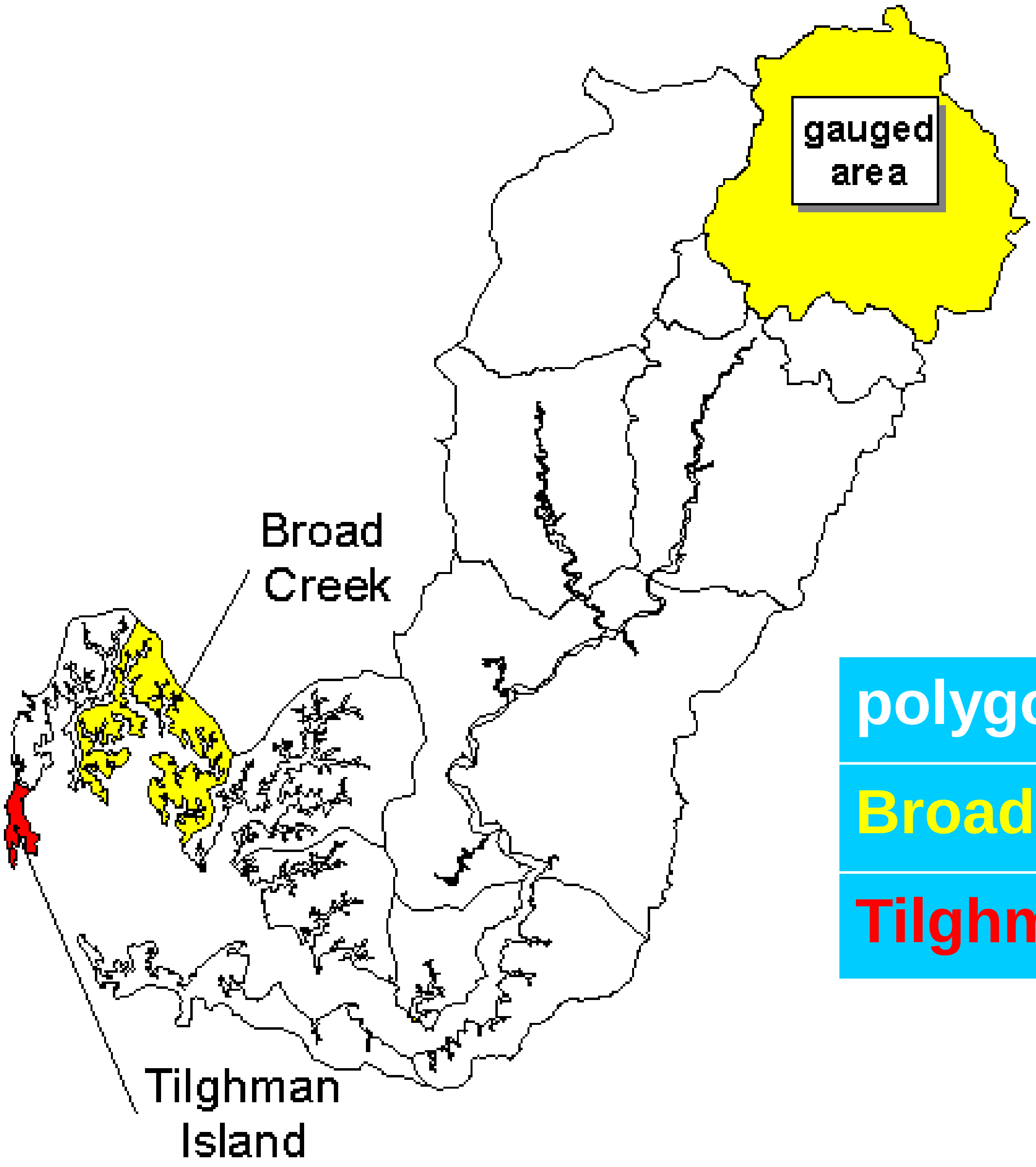
Relationships with soils:

- N transfer coefficient in Choptank subbasins
  - – Use land cover to estimate [NO_3] in groundwater
  - – Compare with [NO_3] in stream base flows
    - Base flows are derived from groundwater flows
  - – Base flow [NO_3] < estimated groundwater [NO_3]
    - Some NO_3 is lost as groundwater moves to streams

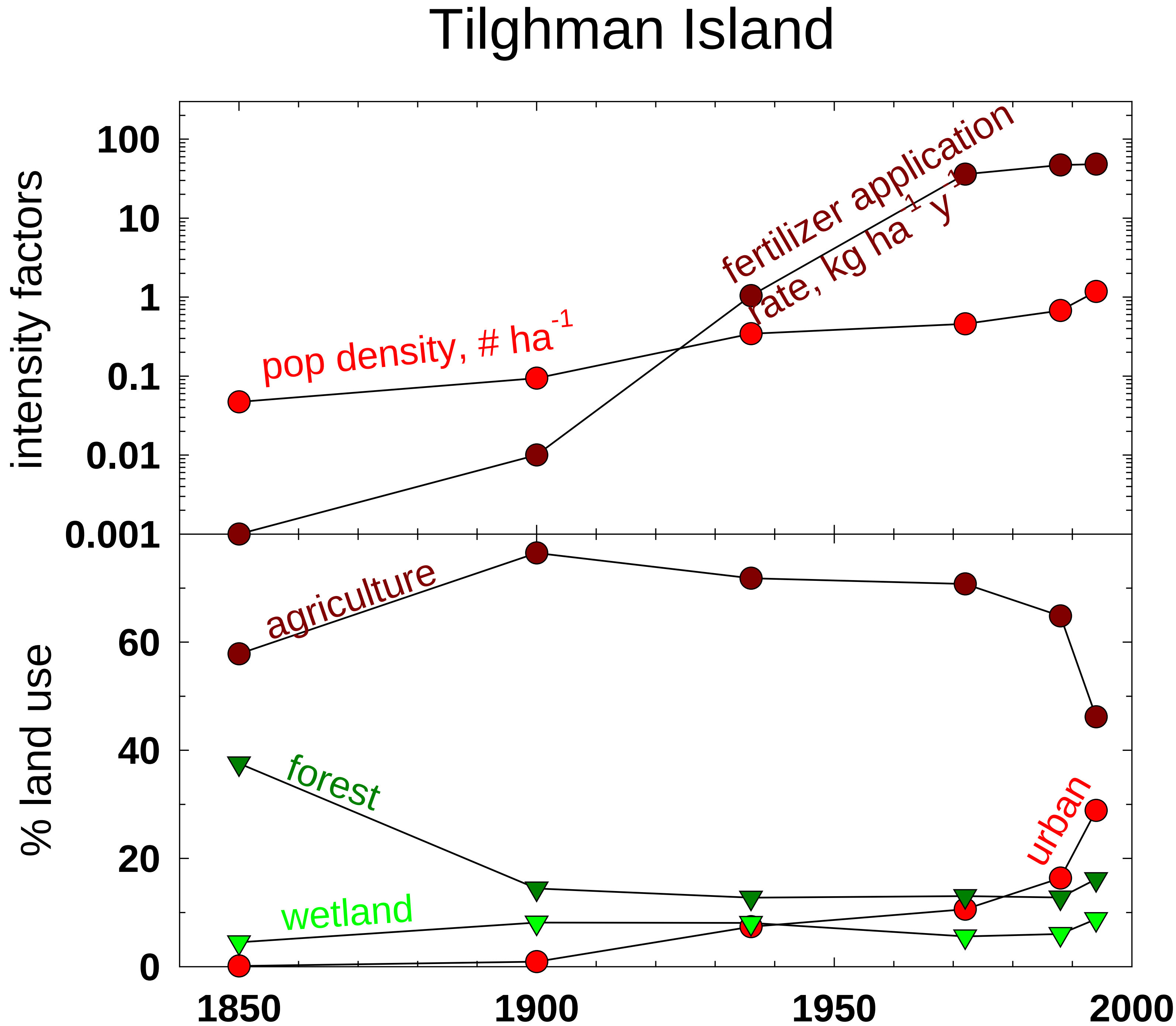

Choptank Basin, transfer of groundwater NO3 to baseflow
r2 = 0.55 **
1.0
0.8
0.6
0.4
0.2
0.0
NO3 transfer coefficient
0
20
40
60
80
100
% Hydric Soil

What can we learn from hydrochemical modeling?

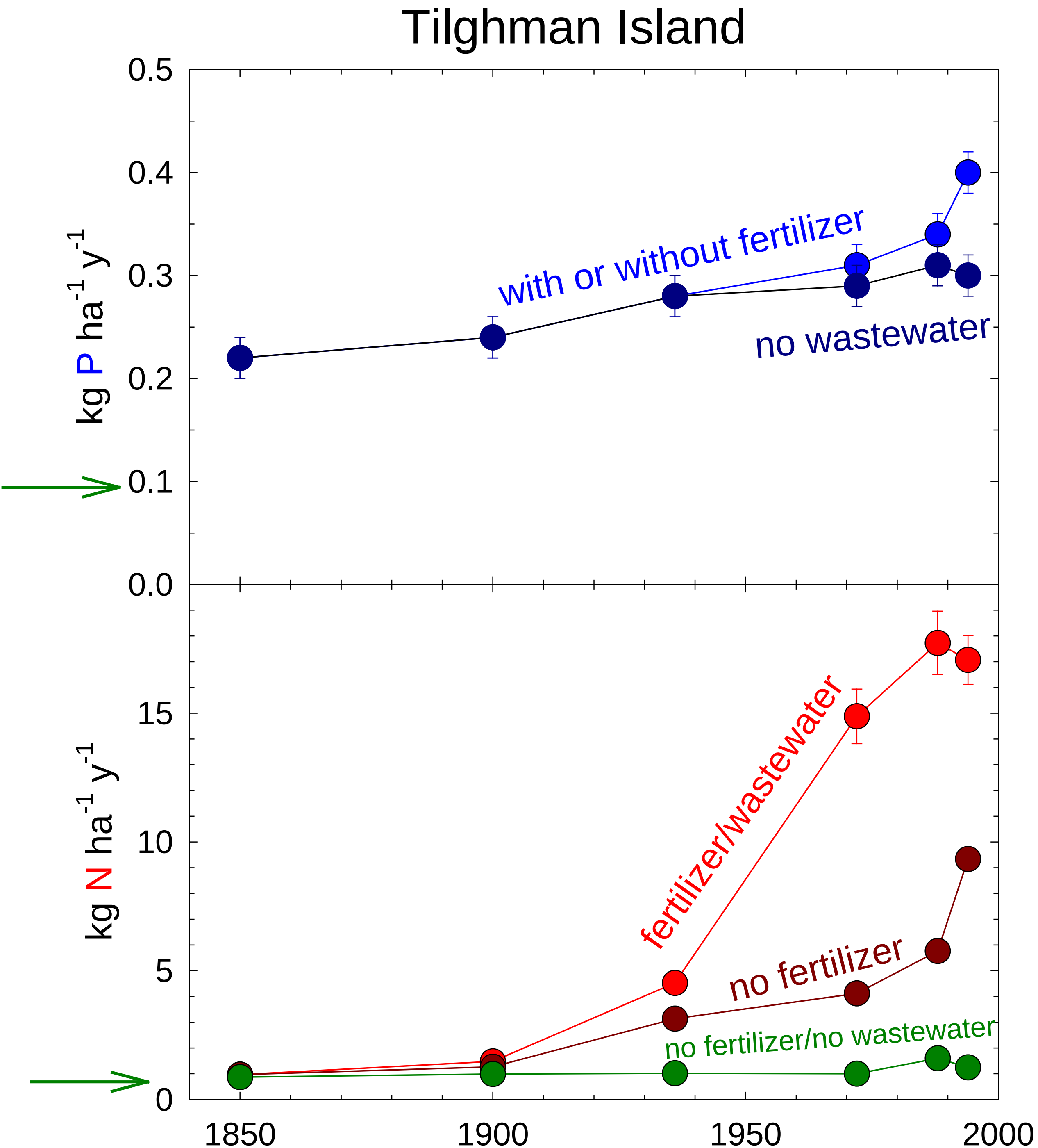
- Calibrate model to current conditions
- Model experiments
  - Withhold fertilizers
  - Eliminate human wastewaters
  - Compare with all forested condition



polygon	% urban	% ag
Broad Cr.	2	77
Tilghman	29	46



Tilghman Island
intensity factors
100
10
1
0.1
0.01
0.001
fertilizer application rate, kg ha-1 y-1
pop density, # ha-1
% land use
60
40
20
0
agriculture
forest
wetland
urban
1850
1900
1950
2000

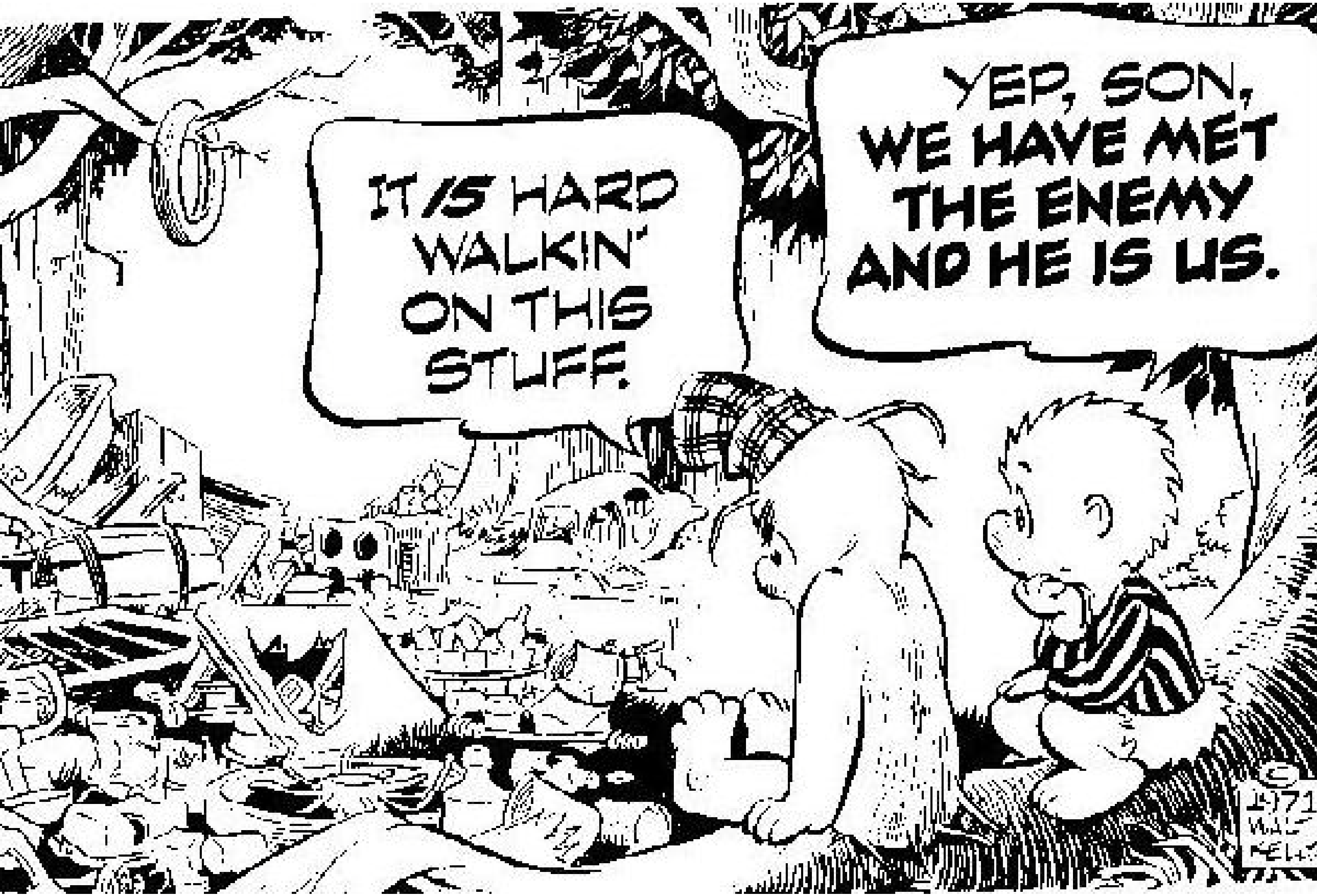


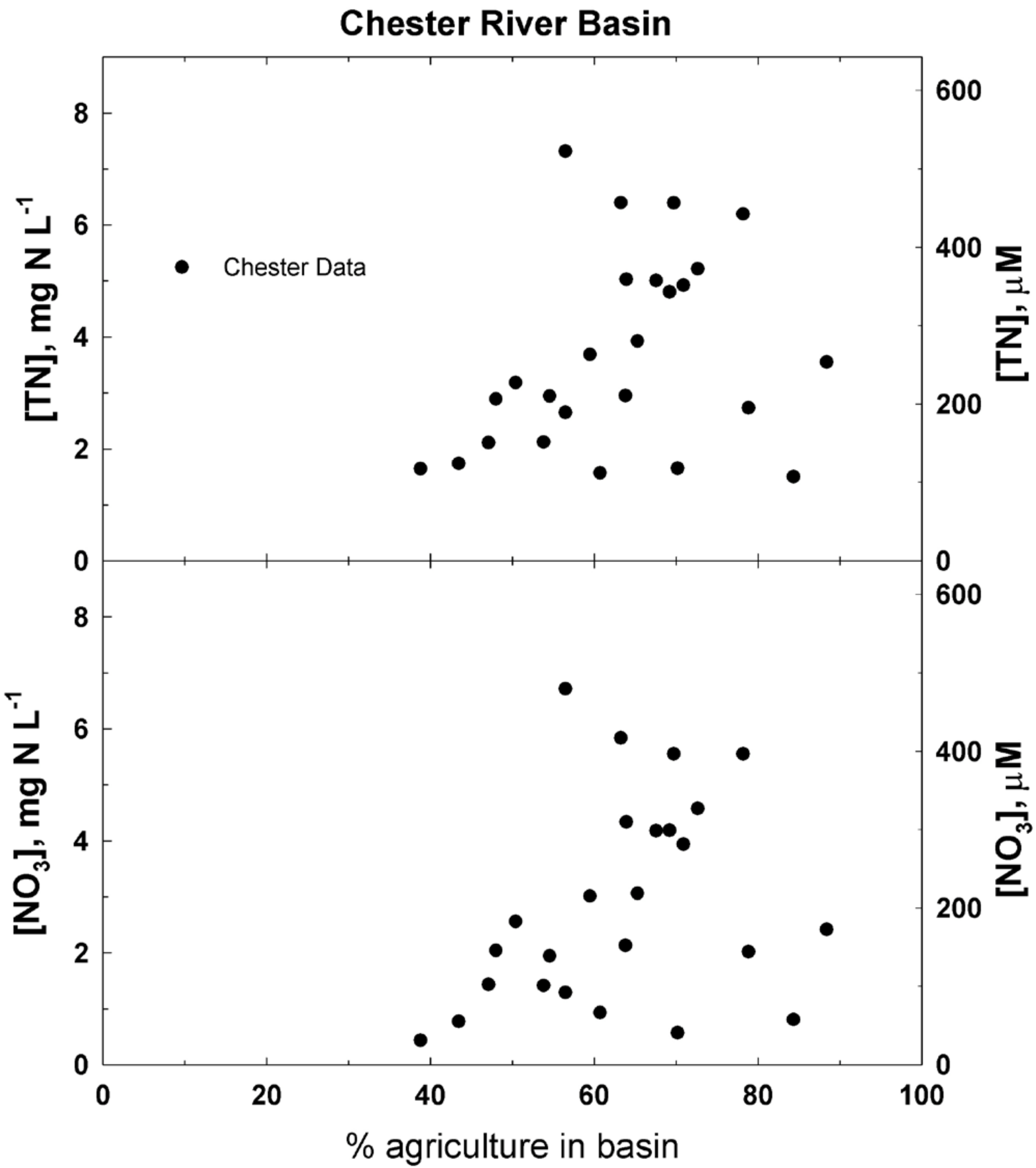
1. Large wastewater effect: ~50% increase
2. Current P export 400% of forested scenario

1. Strong fertilizer effect: 200-300% increase
2. Strong wastewater effect: 500-900%
3. Current N export ~20 X forested scenario

Summary of land use effects

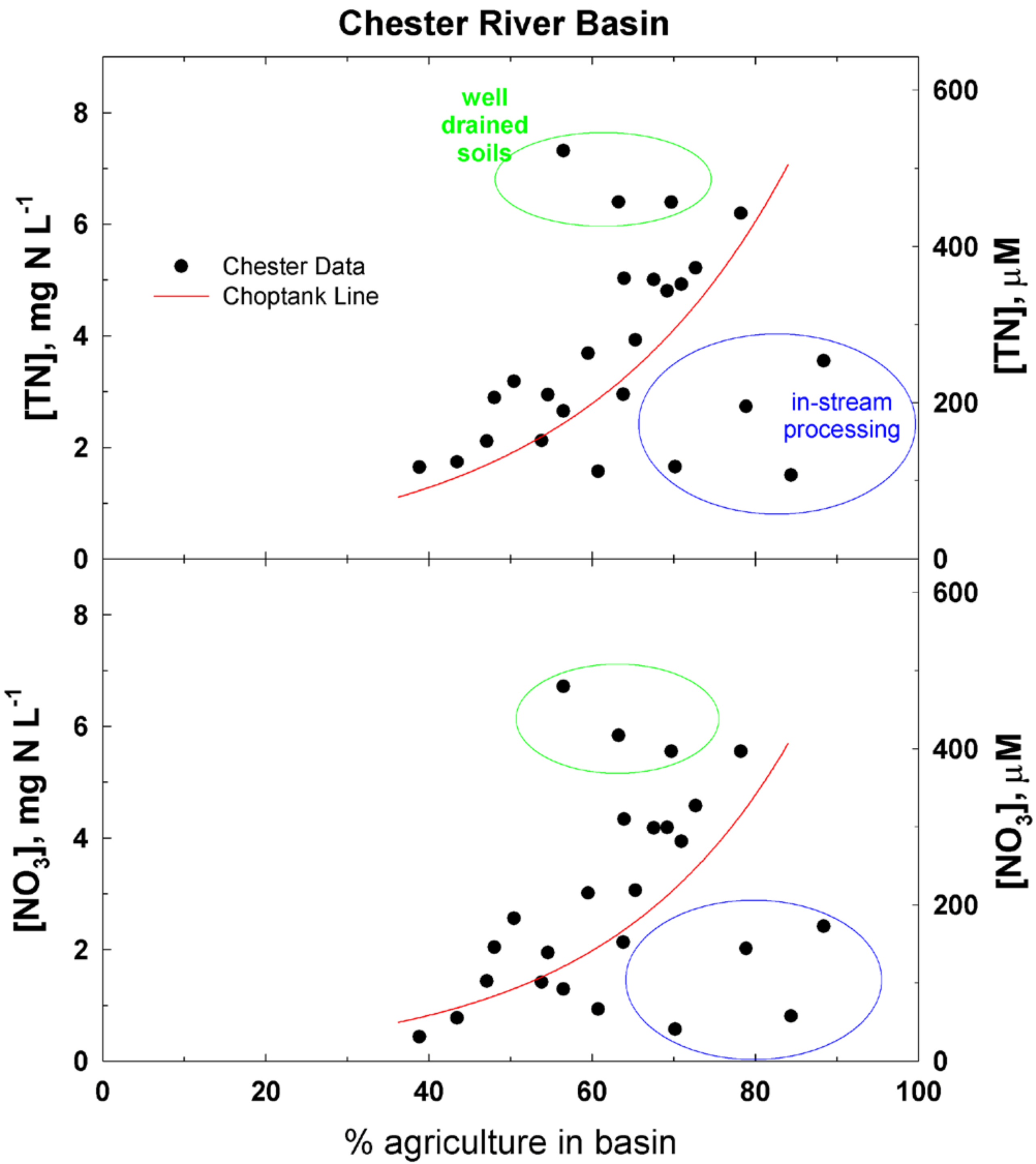
- Of all land covers, forests have the lowest water yields and export of materials
  - Highly retentive
- Agriculture increases N and K losses via enrichment of groundwater K^+ and NO_3^-
- Soils moderate ag N losses and accumulate P
  - Release P from surface materials during storm events
- Urban and agricultural areas export 10-100 x sediment and C as forested areas
- Urban areas increase water yields, export NaCl from road salt use, and increase NO_3^- in groundwaters


IT IS HARD WALKIN' ON THIS STUFF.
YEP, SON, WE HAVE MET THE ENEMY AND HE IS US.
© 1971

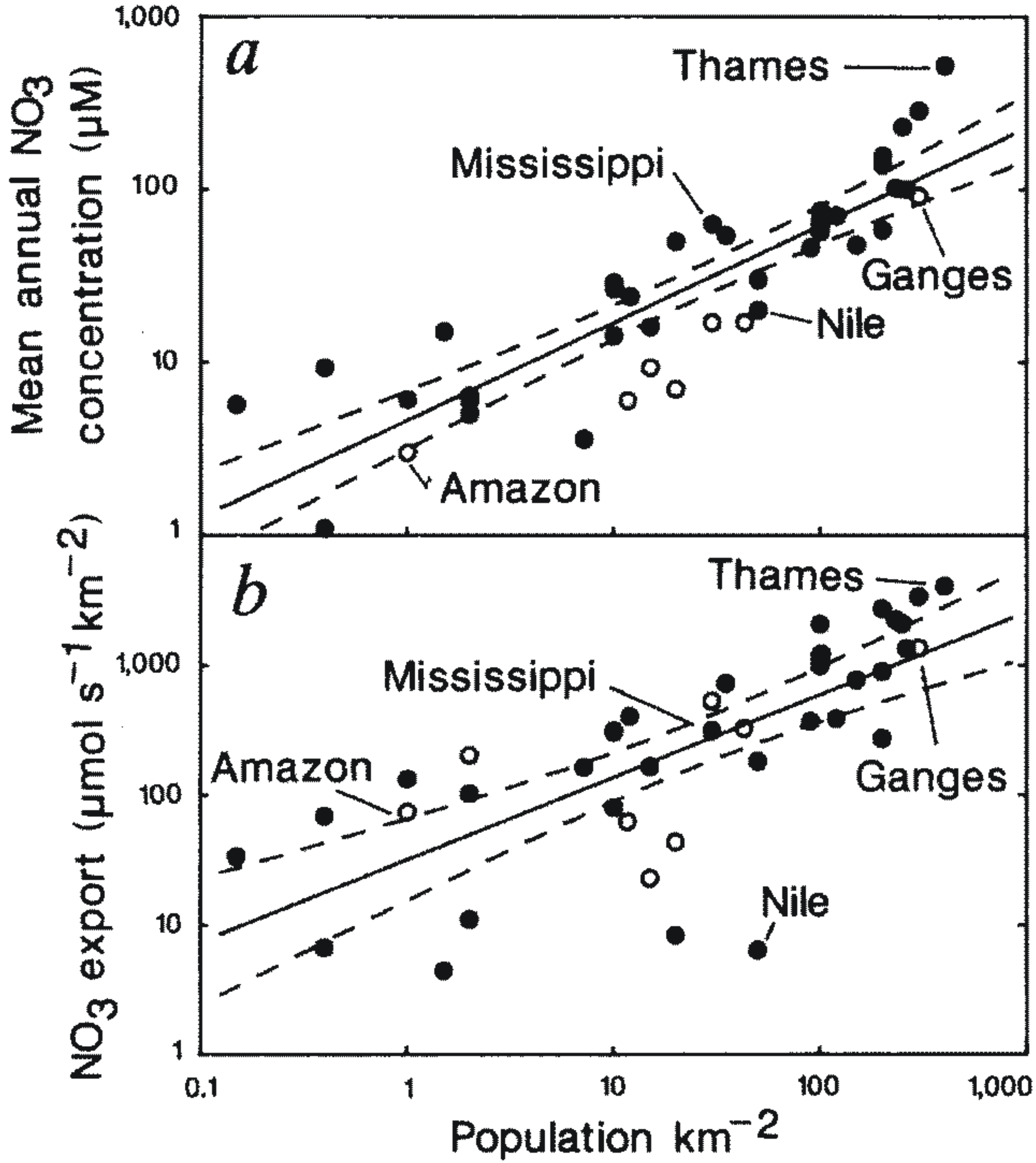


TN and NO_3 data from the Chester were similar to those in the Choptank, but there is no clear relationship with agriculture.

Why this difference?

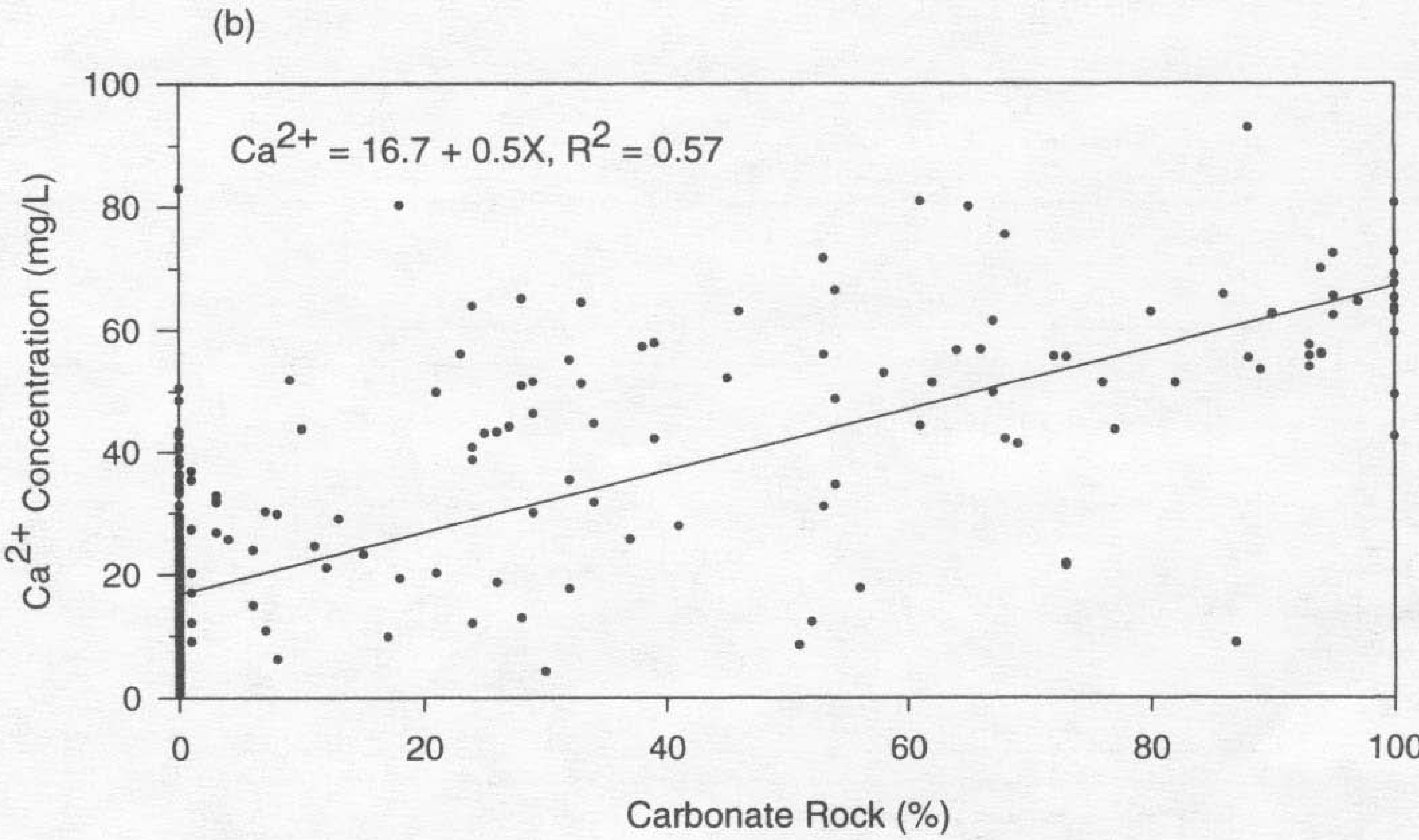


Four of the stations were tidal in summer, and in-stream loss of NO_3 reduced annual concentrations. Three other stations had unusually well-drained soils, leading to greater leaching losses of NO_3.



The activities of human populations increase nitrate concentrations in rives and N export from large river basins.

Source: Peierls et al (1992)

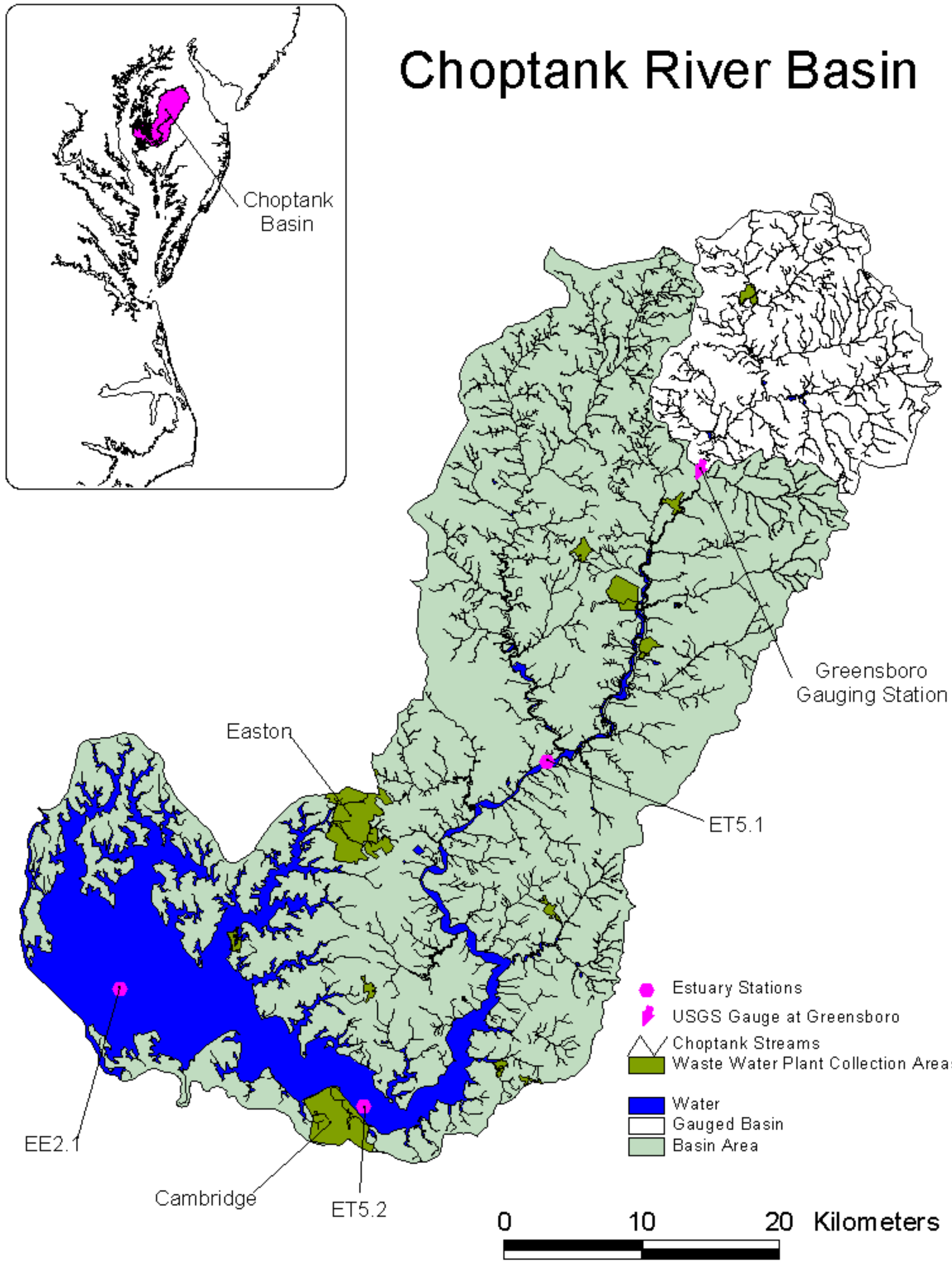


Source: Liu et al (2000)

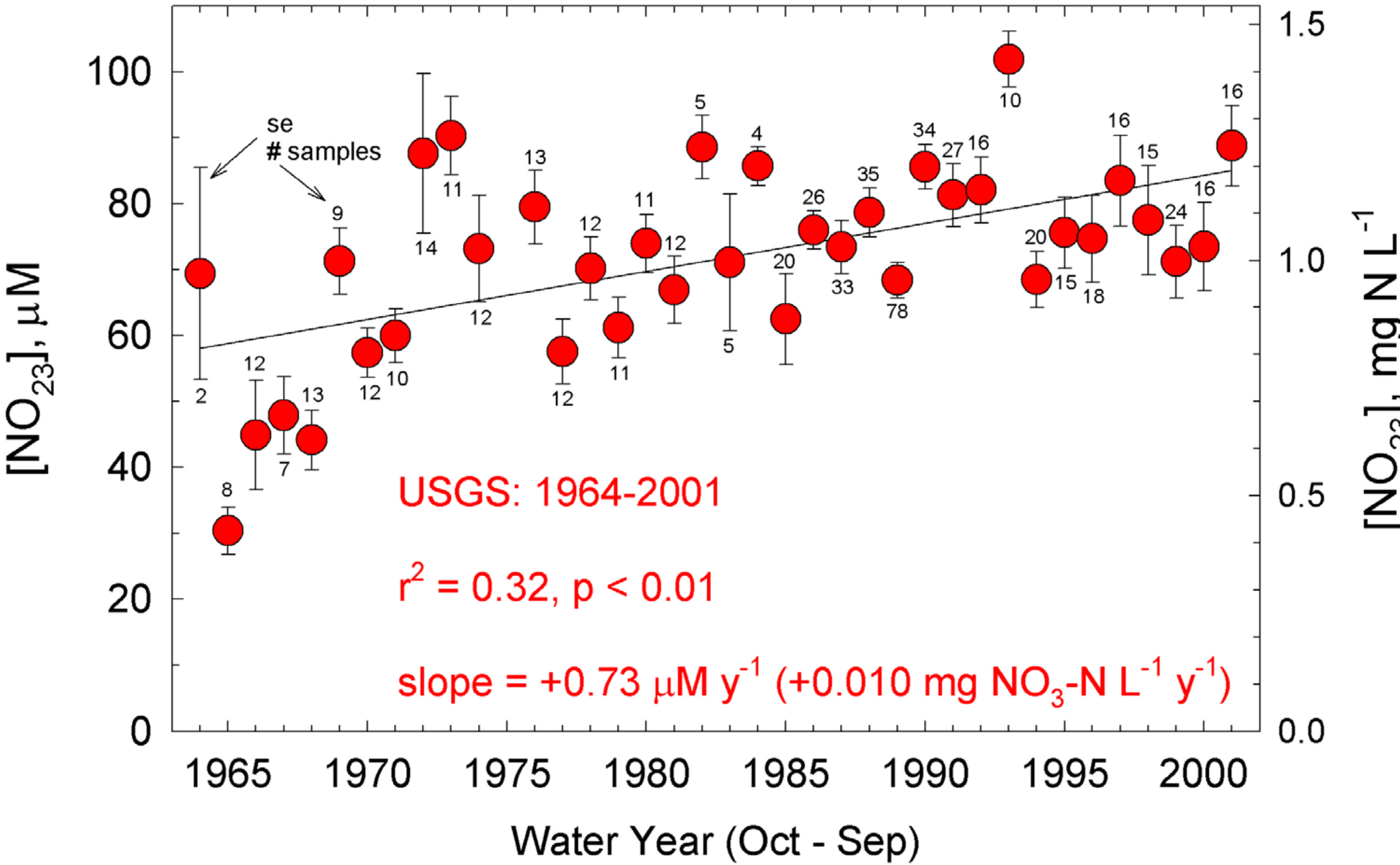
Choptank example

- Degraded water quality now observed
  - EPA 303d list of impaired waters
- Short history of observations
- Little undisturbed information available

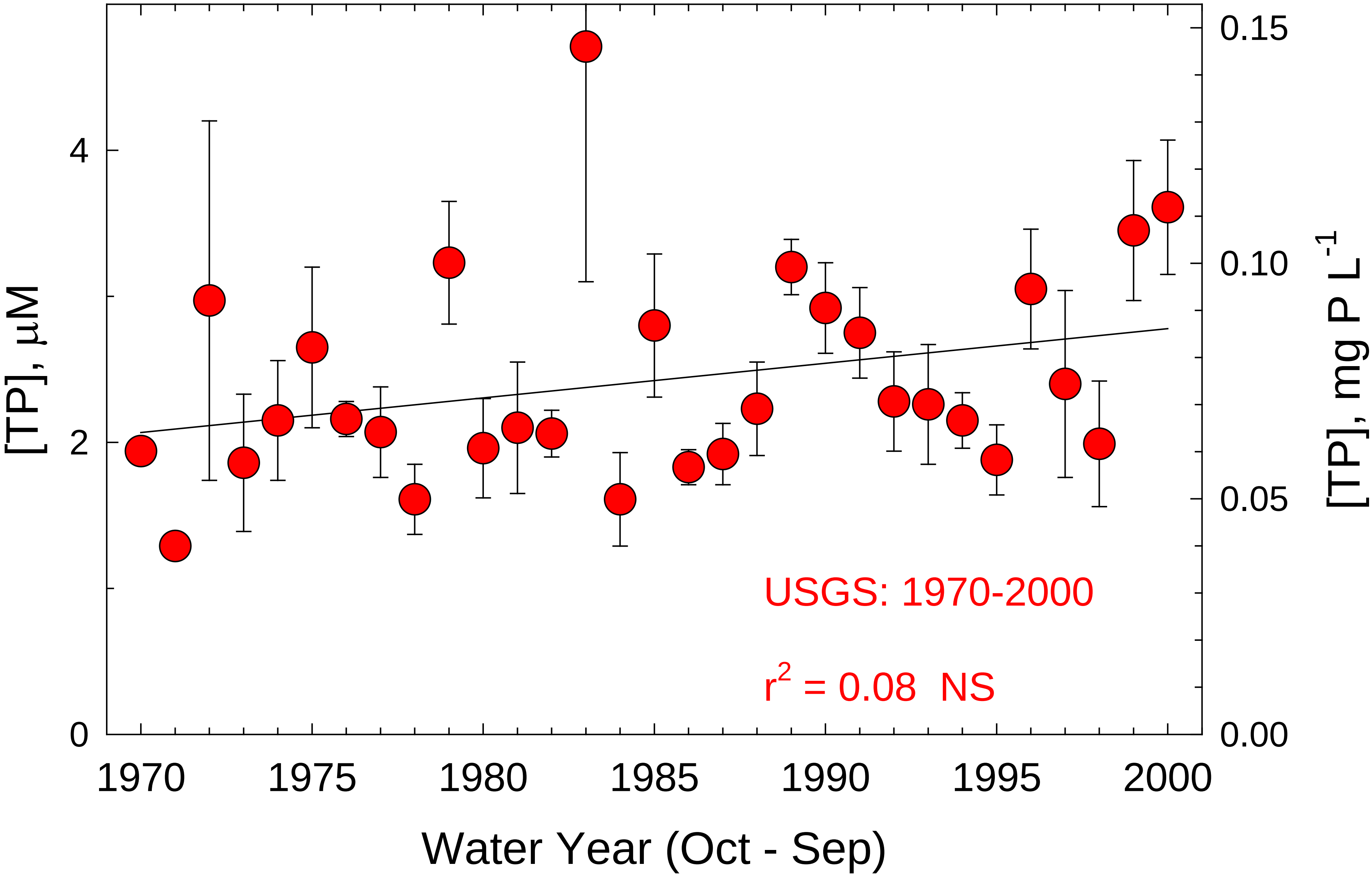
Choptank River Basin

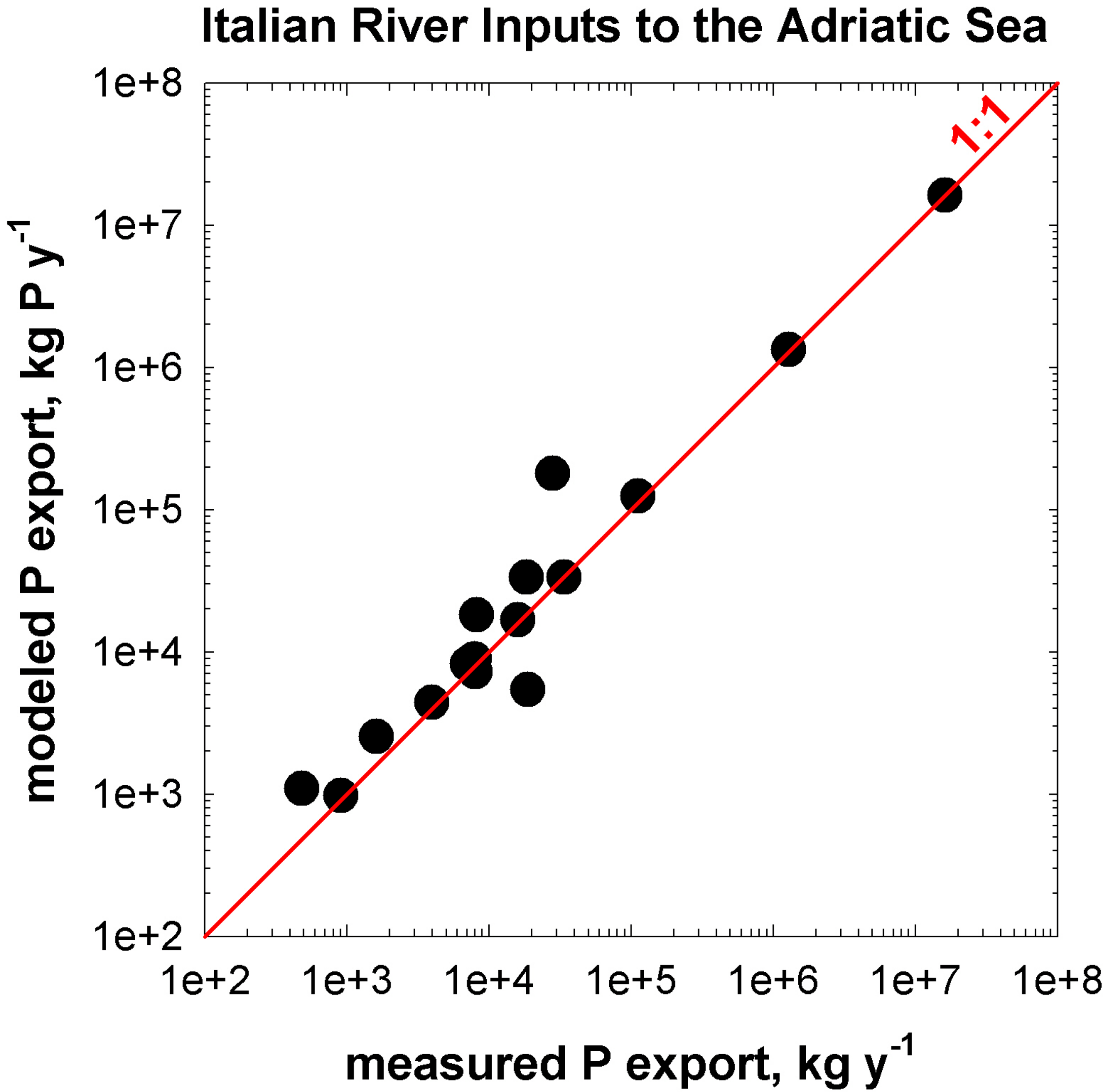


Choptank River near Greensboro



Choptank River near Greensboro

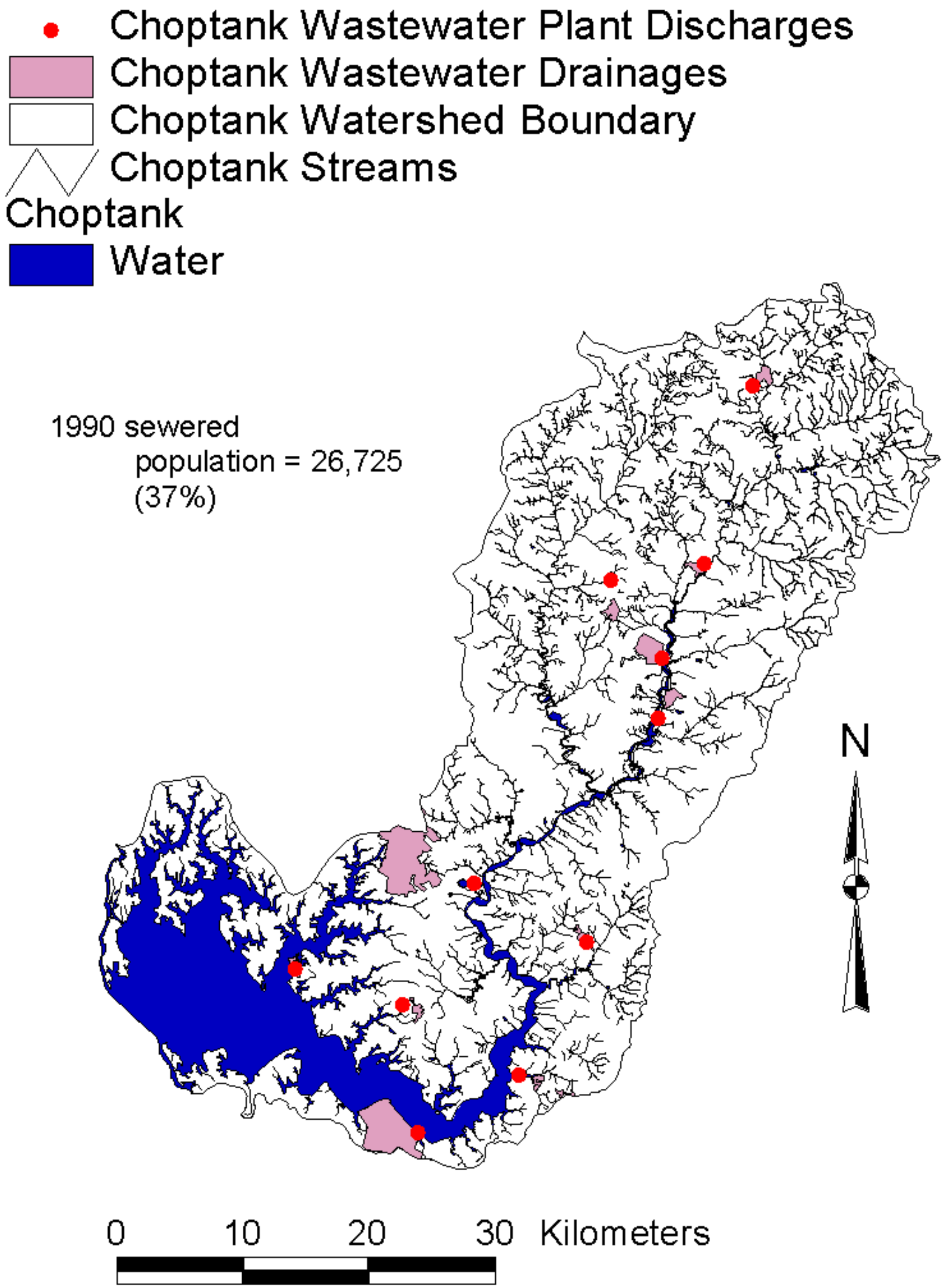




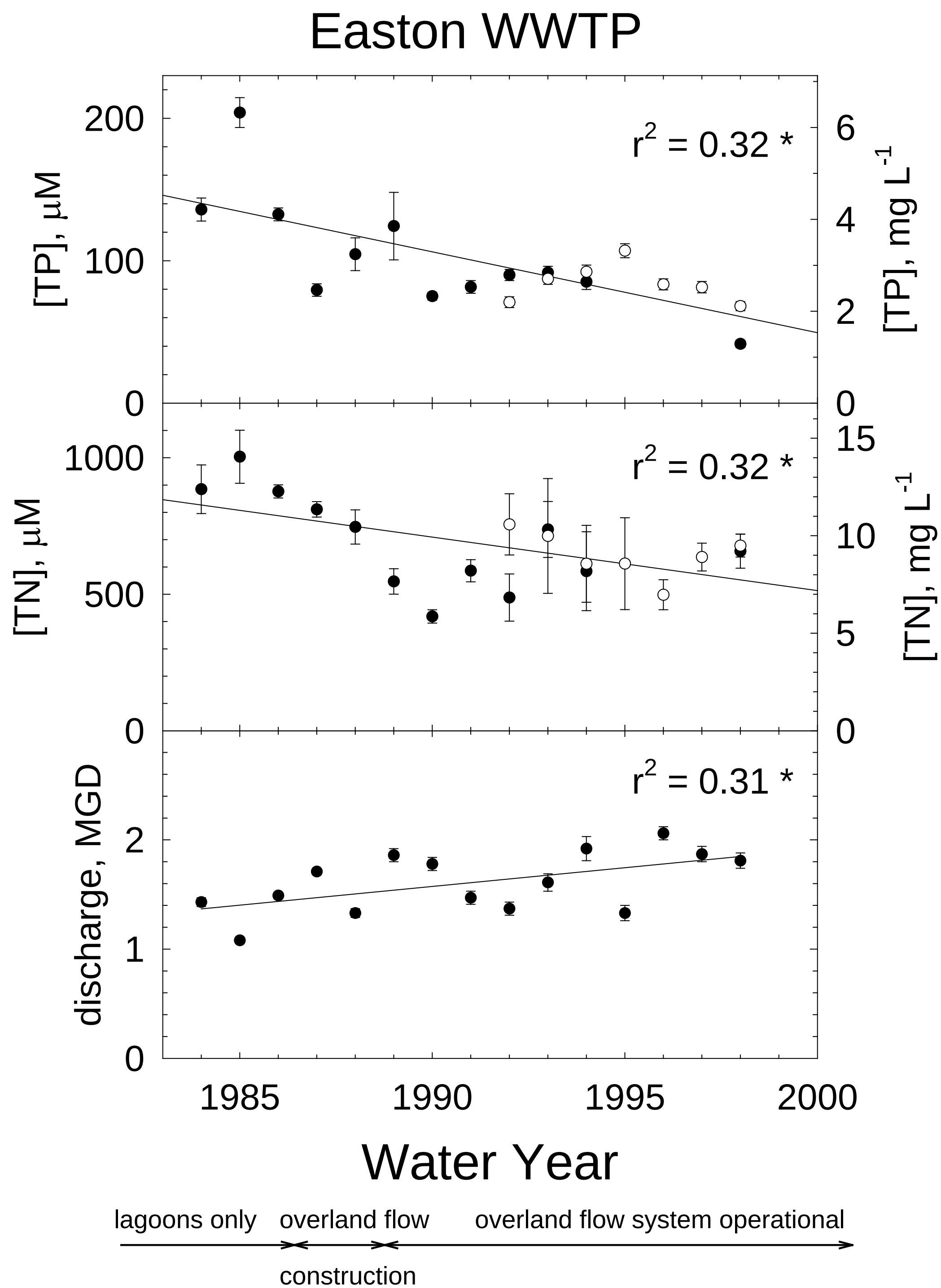
Source: Marchetti and Verna (1992)

Application of area yield coefficients to land cover yielded good agreement with observed river export.

What about wastewater (sewage) inputs to the Choptank?

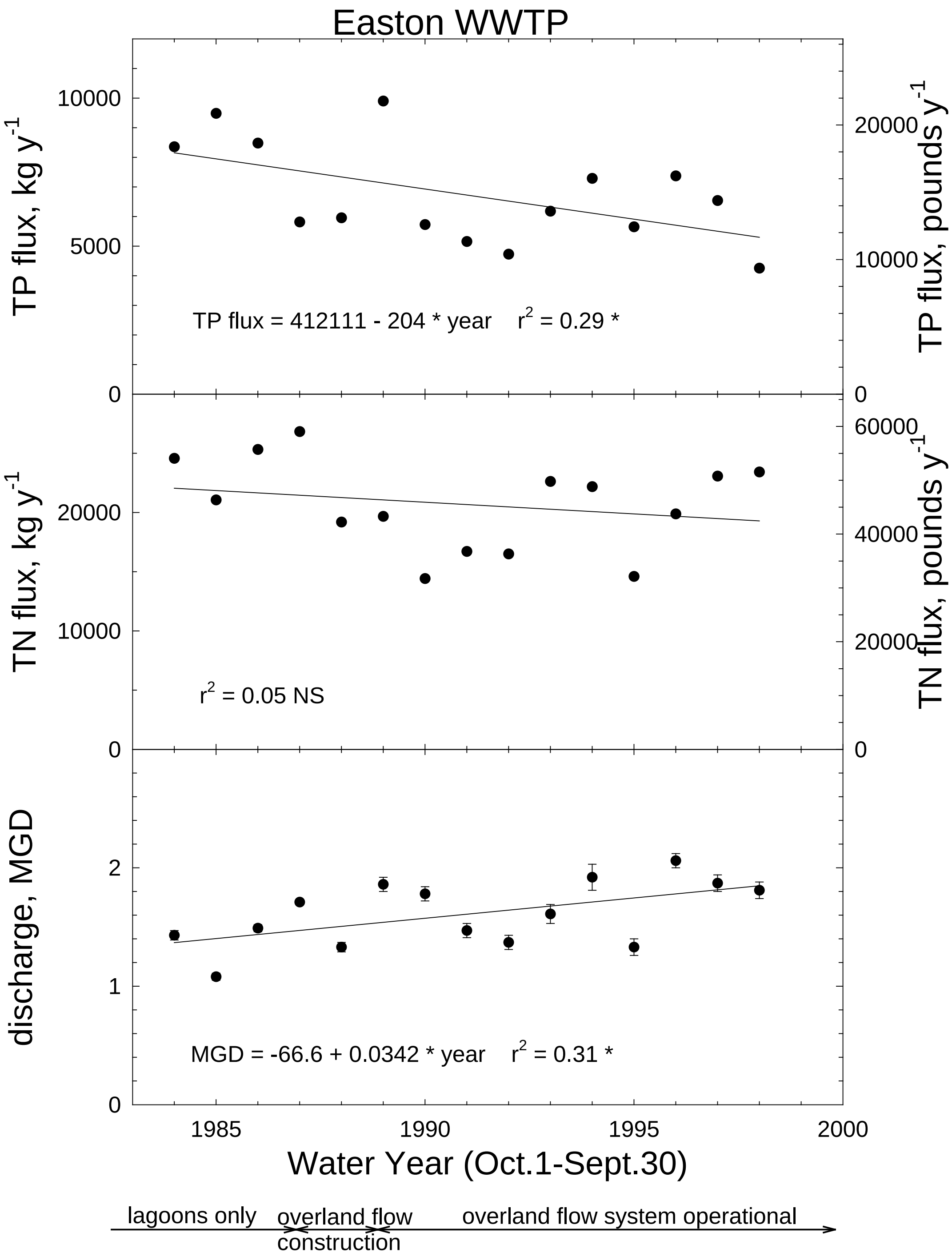


There is about 5-7 millions of gallons of sewage entering the Choptank per day from 11 licensed WWTPs.



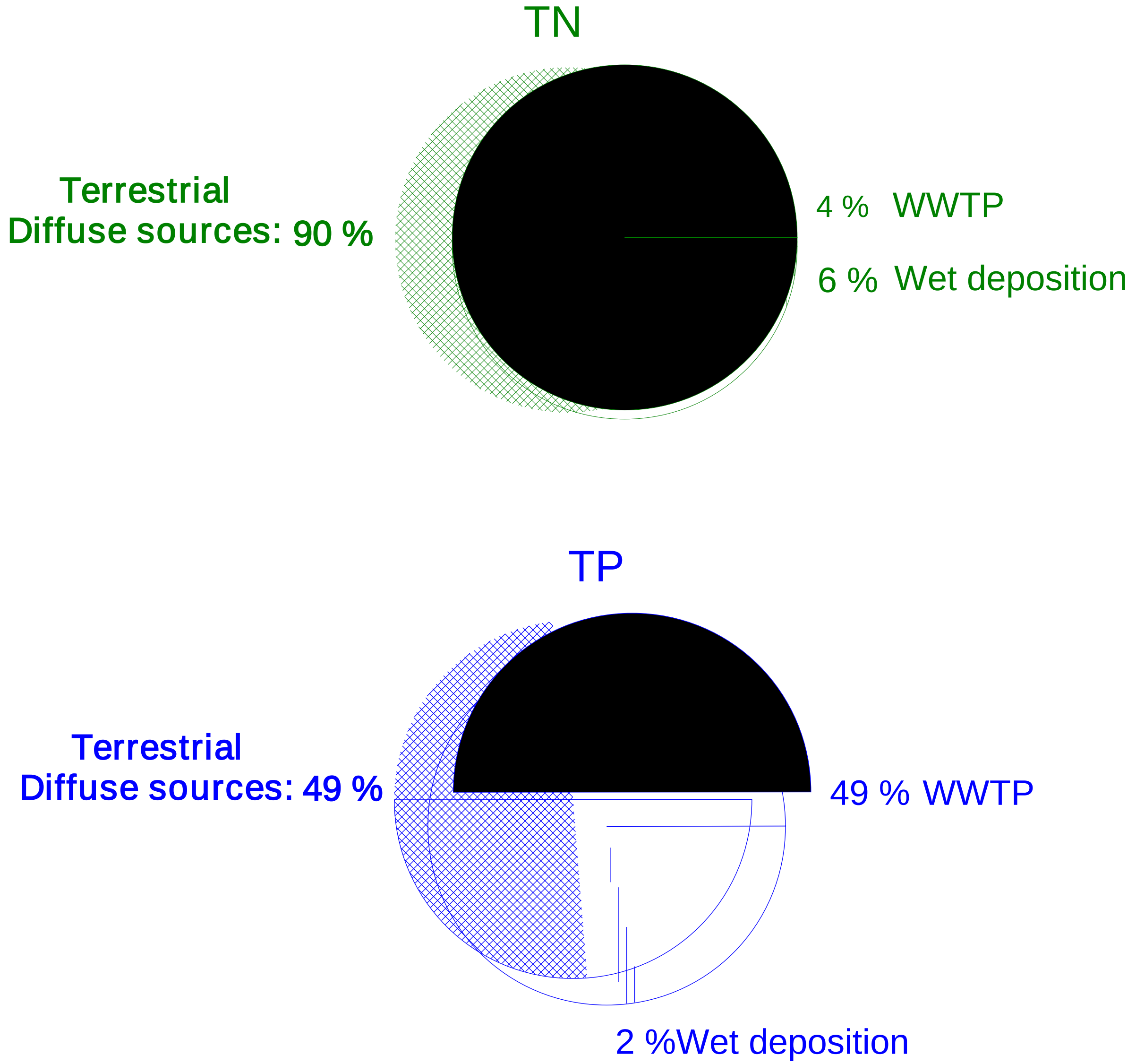
Concentrations of N and P have decreased over time due to plant management.

Discharge volumes have increased over time due to population growth



Despite increases in discharge volume, P fluxes are down, and N fluxes have remained stable due to improved WWTP management.

N and P Budgets for the Choptank Estuary

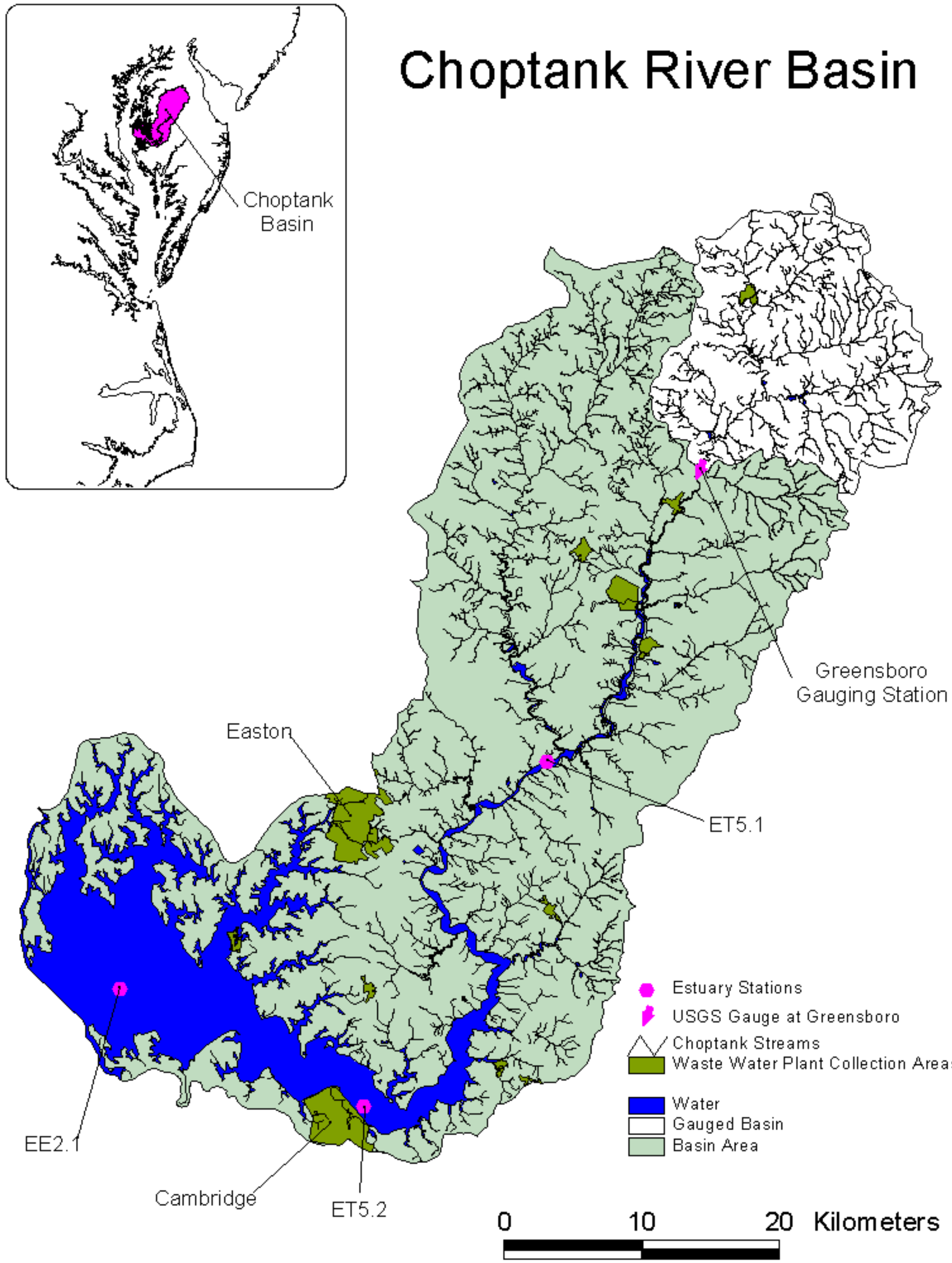


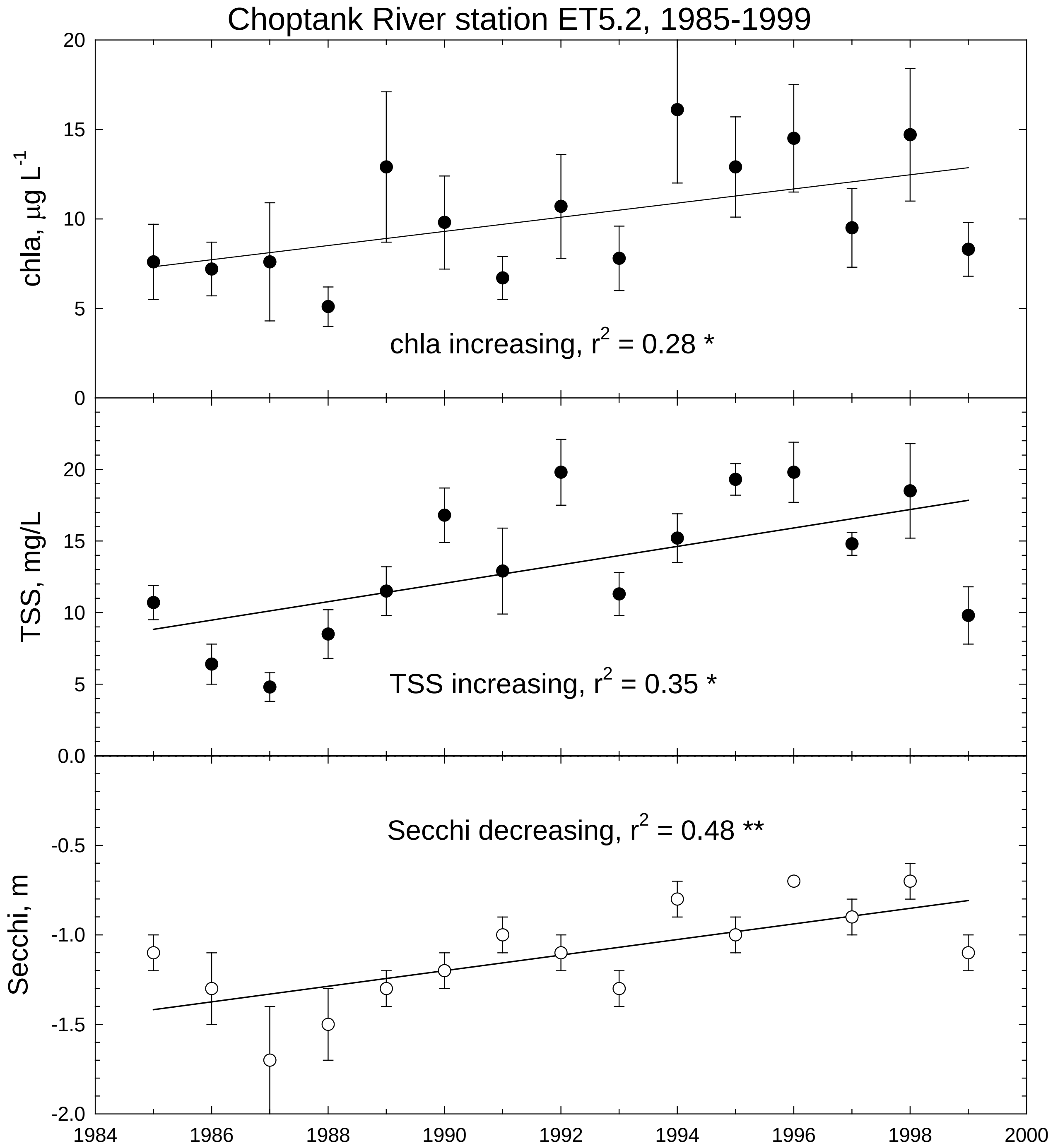
Agriculture is the primary source of N, and wastewater + agriculture are primary sources of P in the Choptank basin.

Source: Lee et al. 2000. *Biogeochem.* 56: 311-348

What has been happening to estuarine water quality in the Choptank?

Choptank River Basin





Algae and turbidity are increasing over time in the Choptank estuary

Effects of land use on water quality:

- Fertilizer applications have greatly increased nitrate in groundwater since 1950
- N concentrations in streams are elevated in basins dominated by agriculture
- Human wastewaters are high in P and are an important source if only secondary treatment is used
- The increasing size of human populations is a primary driver of eutrophication

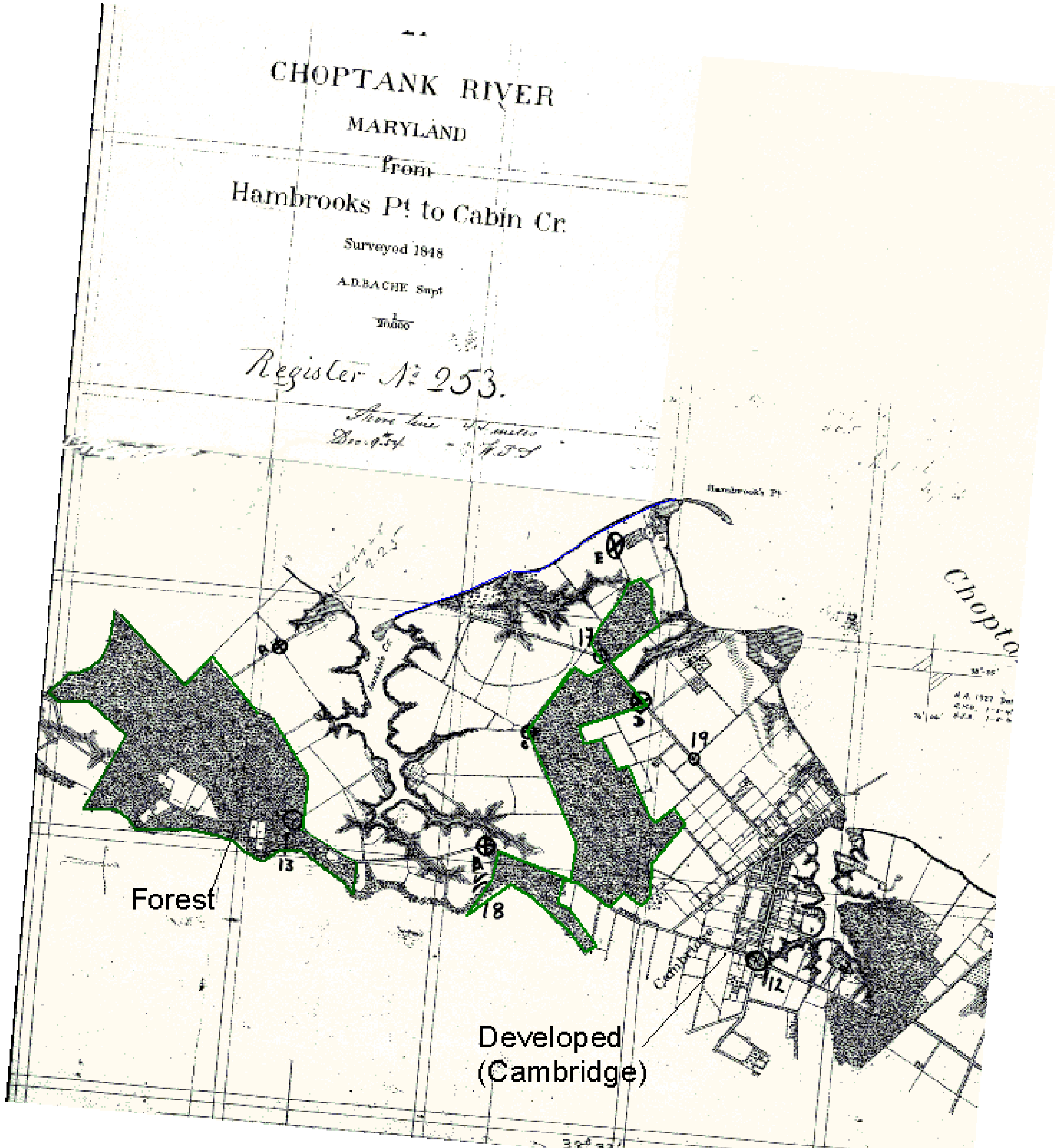
Management Recommendations:

- Tertiary treatment of wastewater
  - P removal will have more impact than N
- Target BMP application to high load subbasins dominated by agriculture
  - Winter cover crops
  - Stream buffers
  - Restored wetlands
- Integrate management of oysters, SAV, TSS, and nutrients
  - Let the benthic biota help improve WQ

How can we reconstruct the land use history of the Choptank basin?

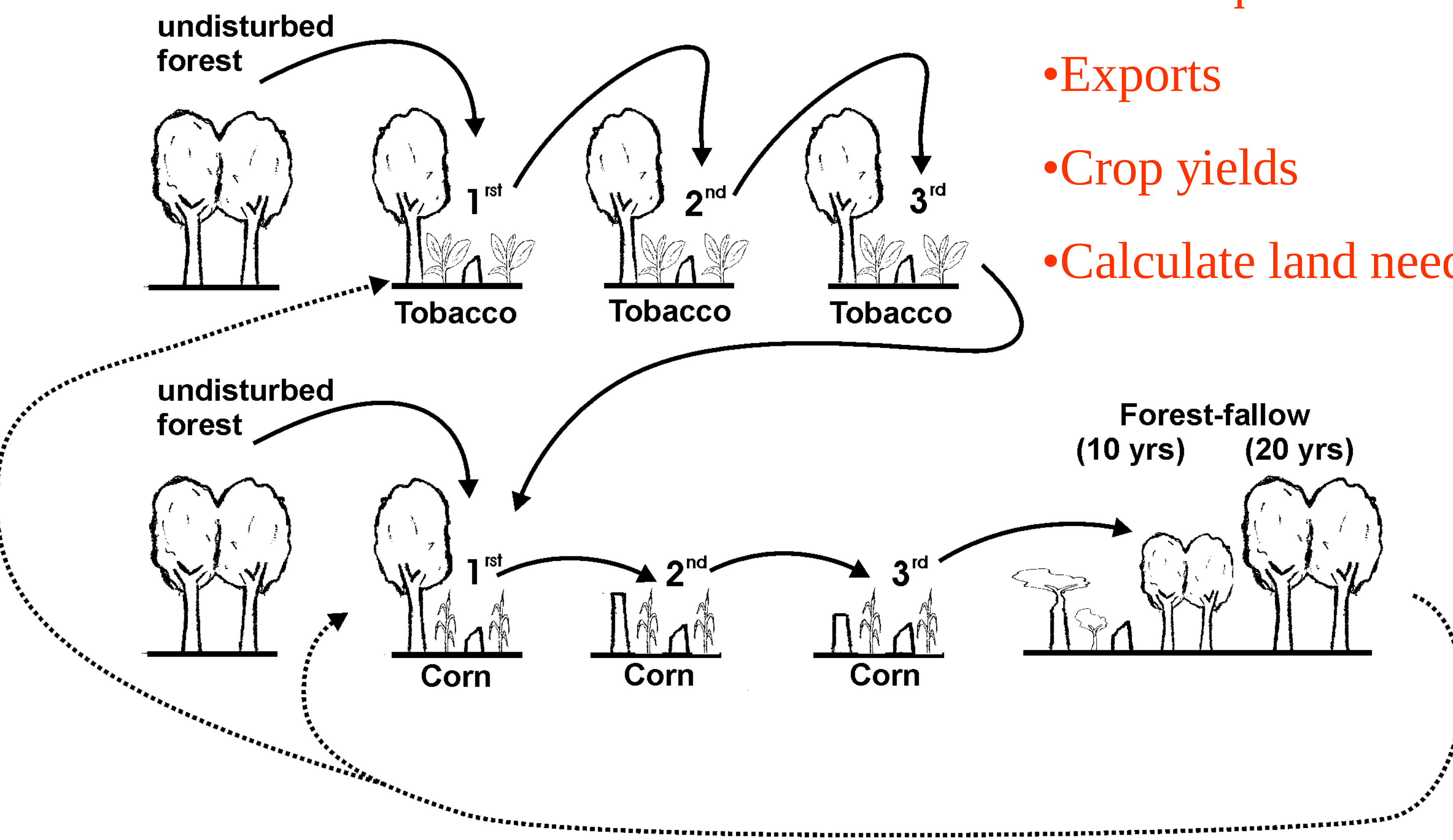
• Satellite imagery	after 1972
• Aerial photographs	after 1936
• Historical maps	after 1845
• Socioeconomic statistics	when available

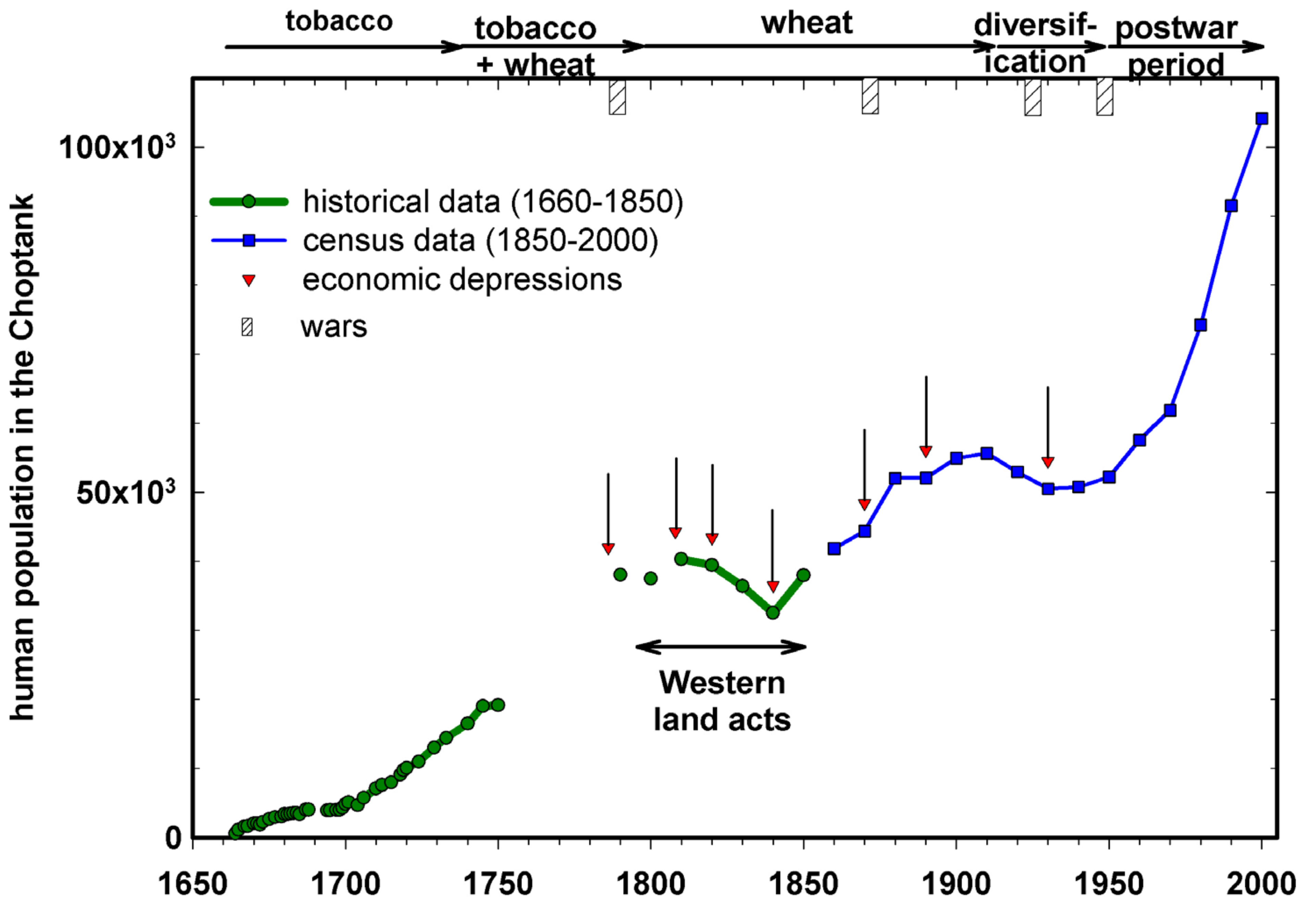

Y -1 1938
ANJ14- 76


CHOPTANK RIVER
MARYLAND
from
Hambrooks Pt to Cabin Cr.
Surveyed 1848
A.D.BACHE Supt
1/20000
Register No. 253.
Hambrook's Pt
Choptank
Forest
Developed
(Cambridge)

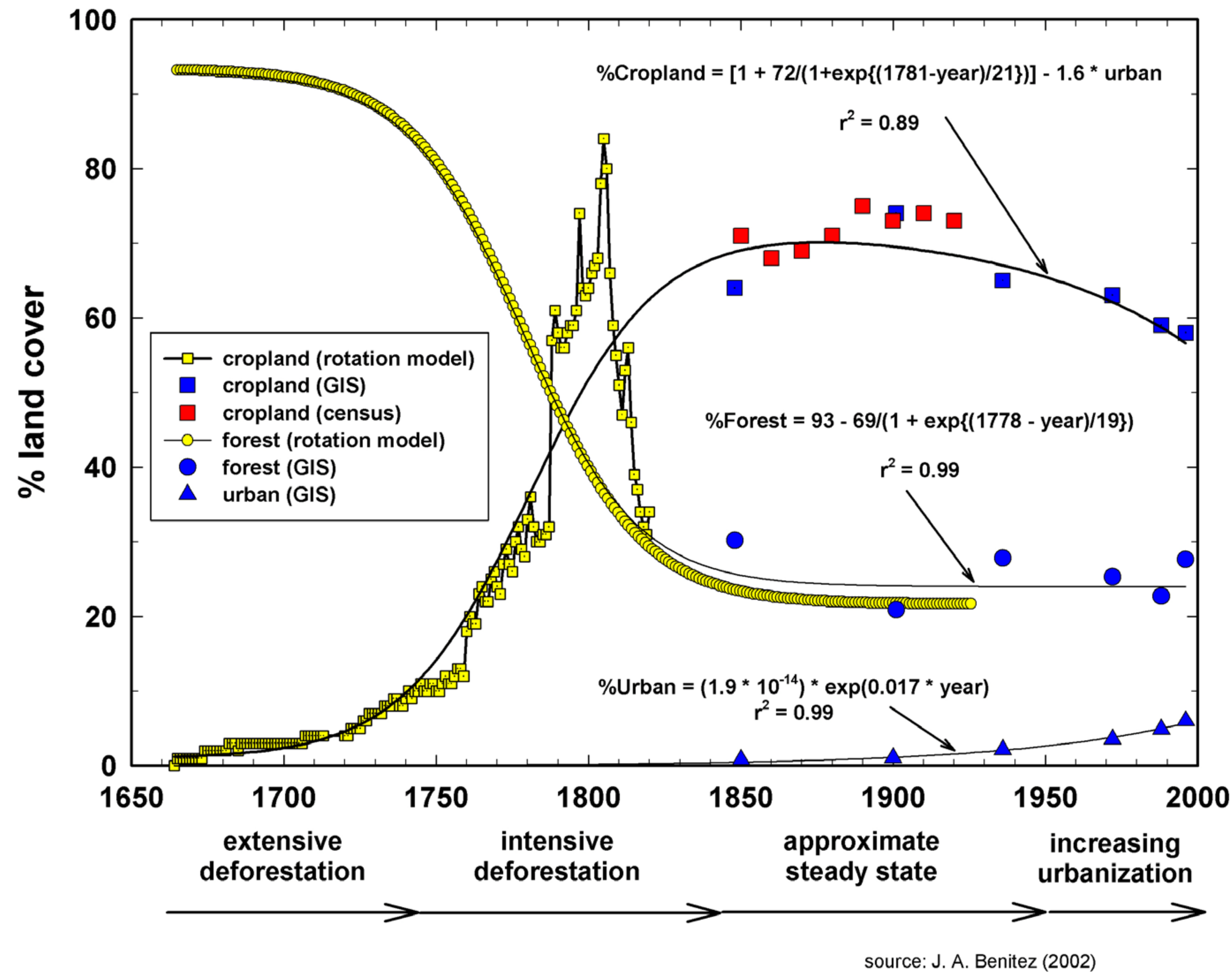
Socioeconomic Statistics

- •# people
- •Food requirements
- •Exports
- •Crop yields
- •Calculate land needed





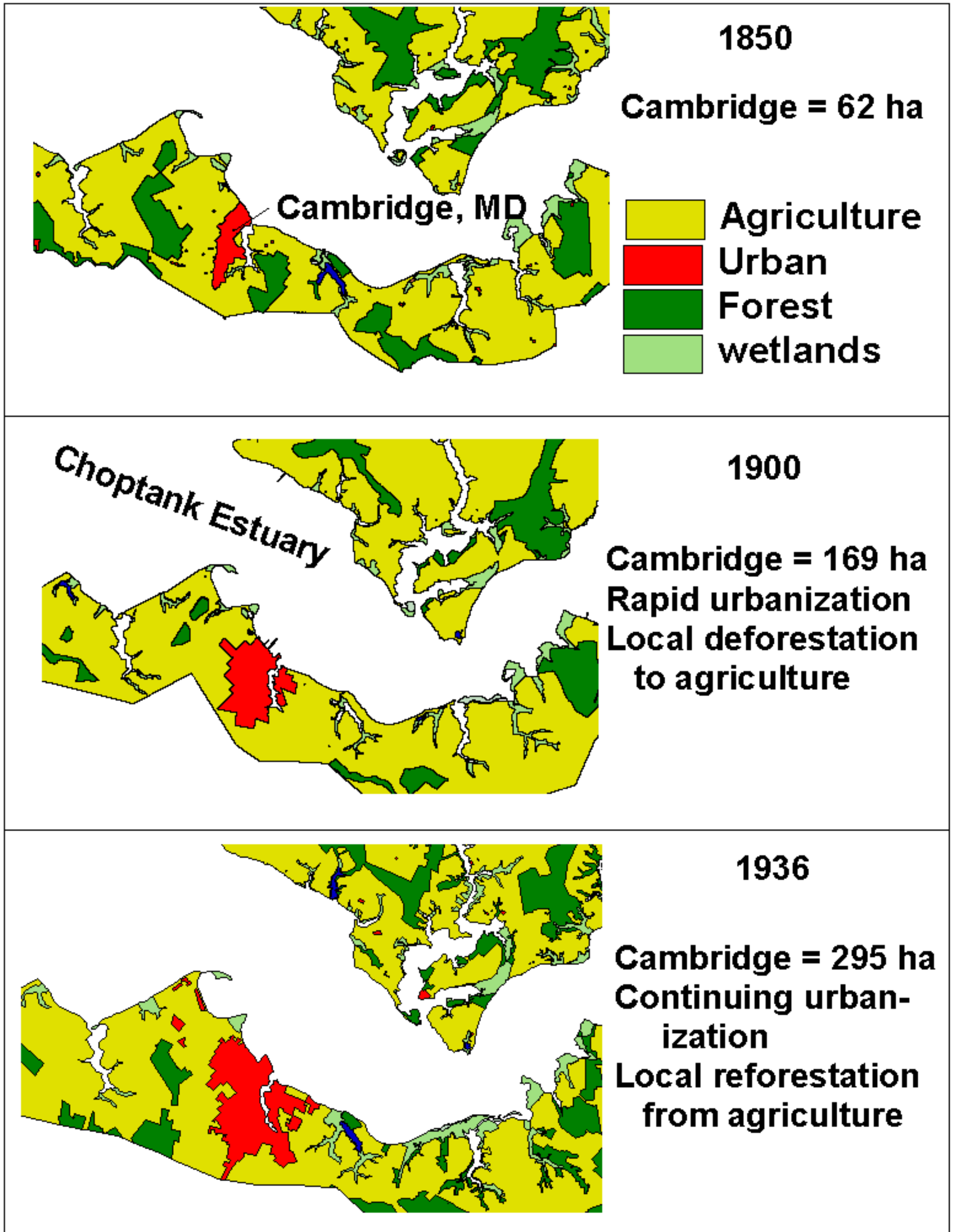
tobacco
tobacco + wheat
wheat
diversif-ication
postwar period
100x10³
50x10³
0
human population in the Choptank
historical data (1660-1850)
census data (1850-2000)
economic depressions
wars
Western land acts
1650
1700
1750
1800
1850
1900
1950
2000



% land cover
100
80
60
40
20
0
1650
1700
1750
1800
1850
1900
1950
2000
cropland (rotation model)
cropland (GIS)
cropland (census)
forest (rotation model)
forest (GIS)
urban (GIS)
%Cropland = [1 + 72/(1+exp{(1781-year)/21})] - 1.6 * urban
r2 = 0.89
%Forest = 93 - 69/(1 + exp{(1778 - year)/19})
r2 = 0.99
%Urban = (1.9 * 10-14) * exp(0.017 * year)
r2 = 0.99
extensive deforestation
intensive deforestation
approximate steady state
increasing urbanization
source: J. A. Benitez (2002)

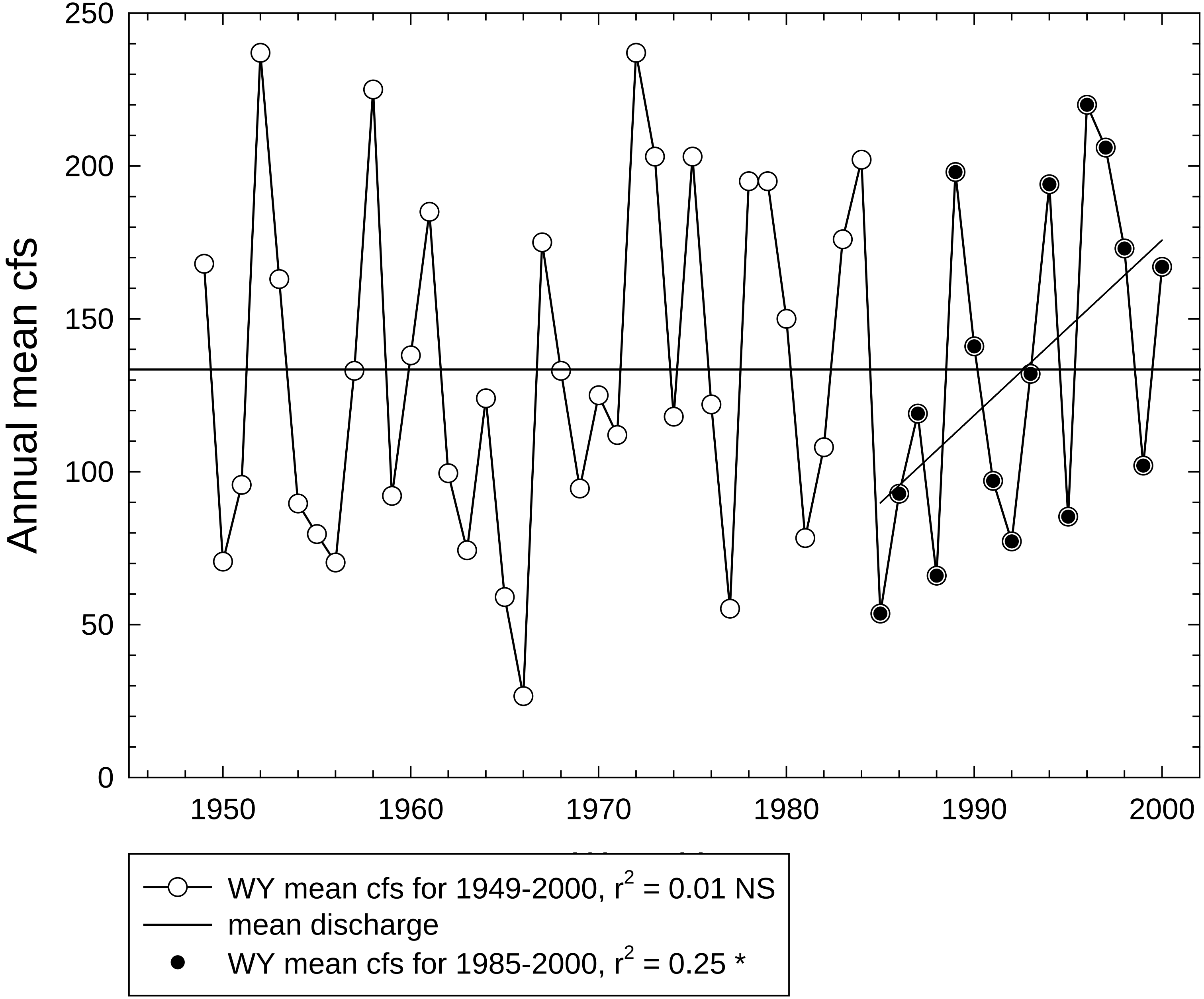
Summary of the land use history in the Choptank basin

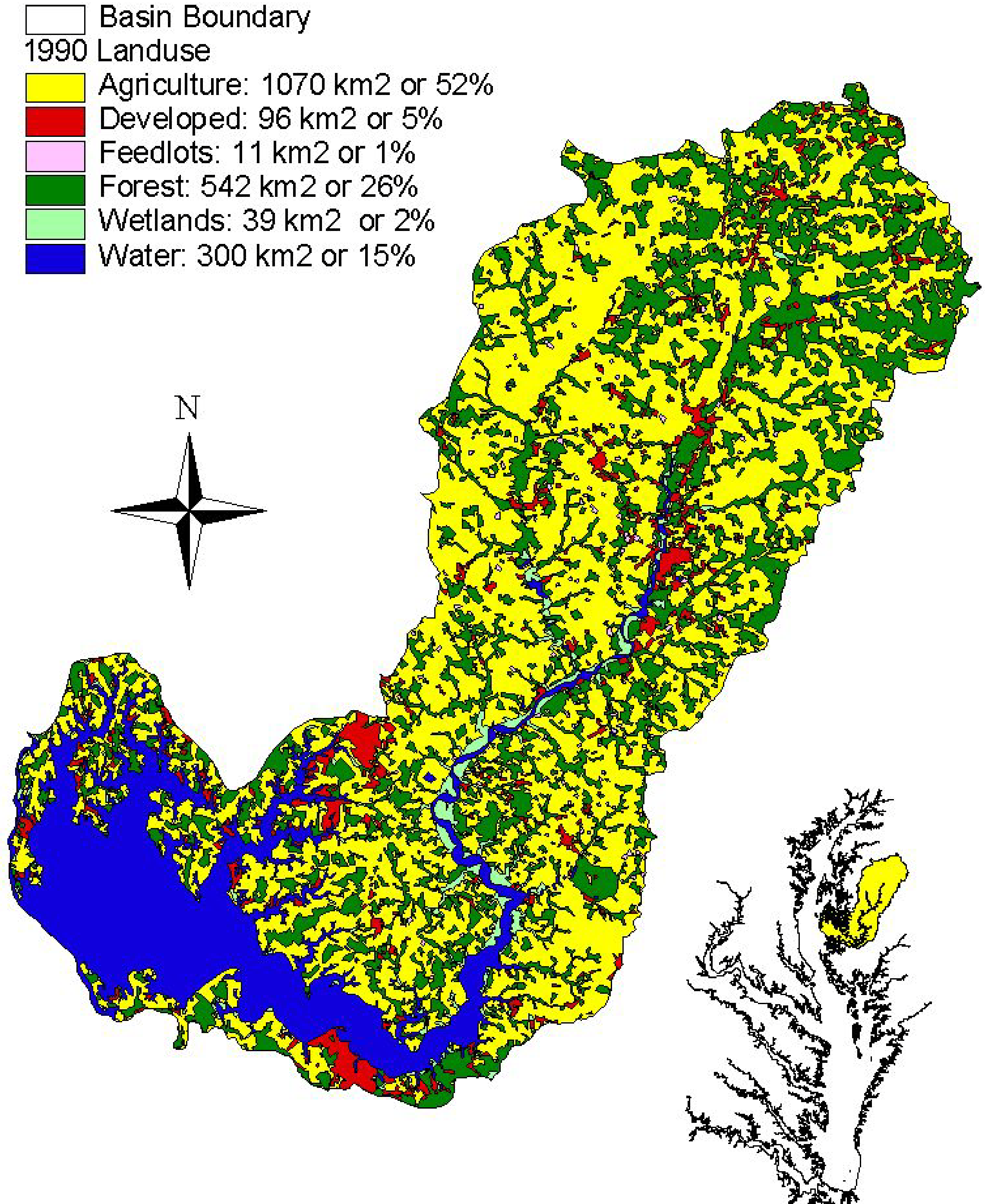
- Initial settling and tobacco production resulted in scattered deforestation
- After 1750, wheat production resulted rapid expansion of agriculture
- 1900 represented the agricultural maximum in the Choptank, about 75% of land use.
- Urban areas have been small, but growing exponentially with the human population



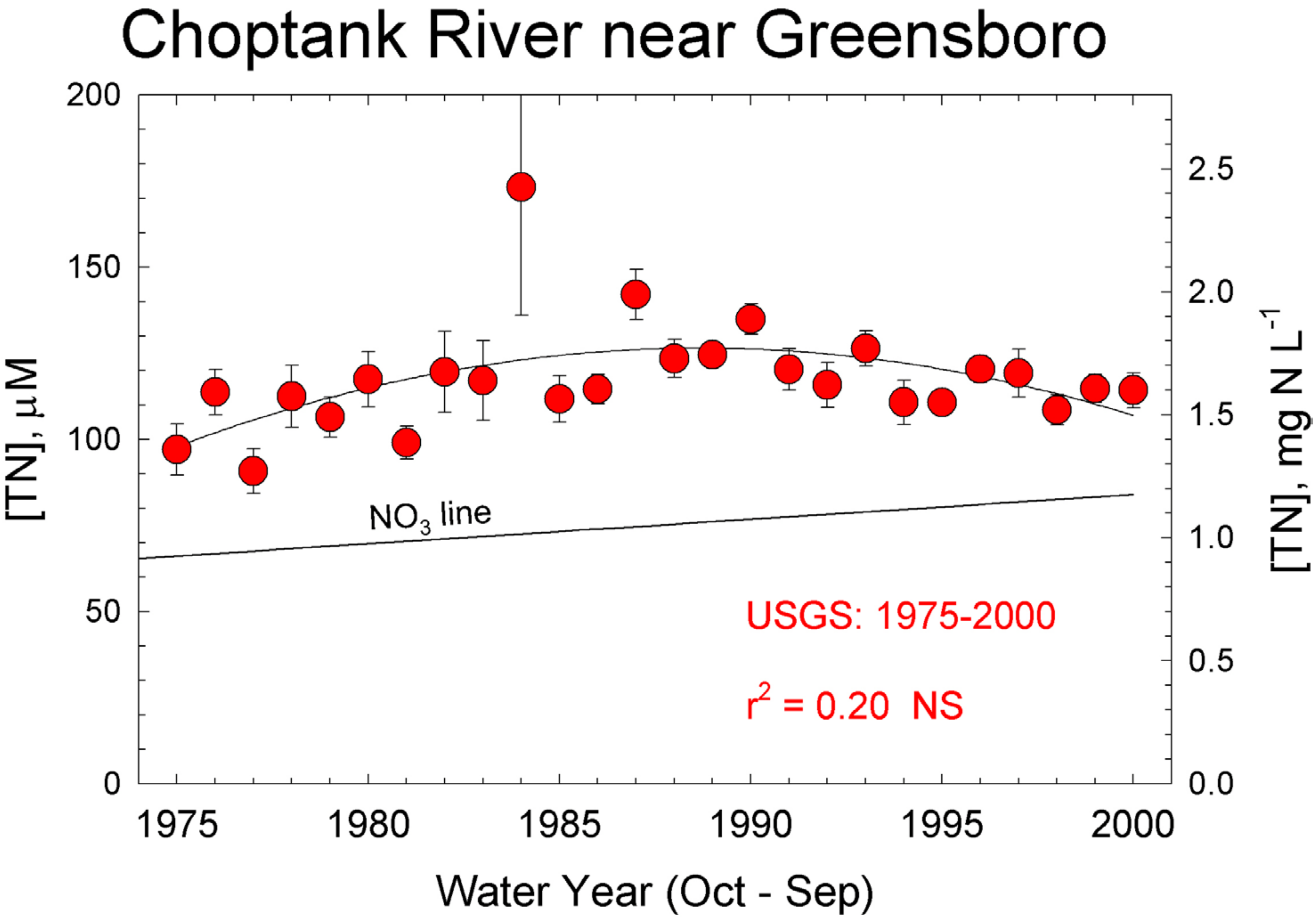
Exponential expansion (**urbanization**) of small towns was a consistent pattern observed in the GIS coverages of the Choptank basin.

Annual Discharge at Greensboro, MD (01491000)





Basin Boundary
1990 Landuse
Agriculture: 1070 km2 or 52%
Developed: 96 km2 or 5%
Feedlots: 11 km2 or 1%
Forest: 542 km2 or 26%
Wetlands: 39 km2 or 2%
Water: 300 km2 or 15%
N

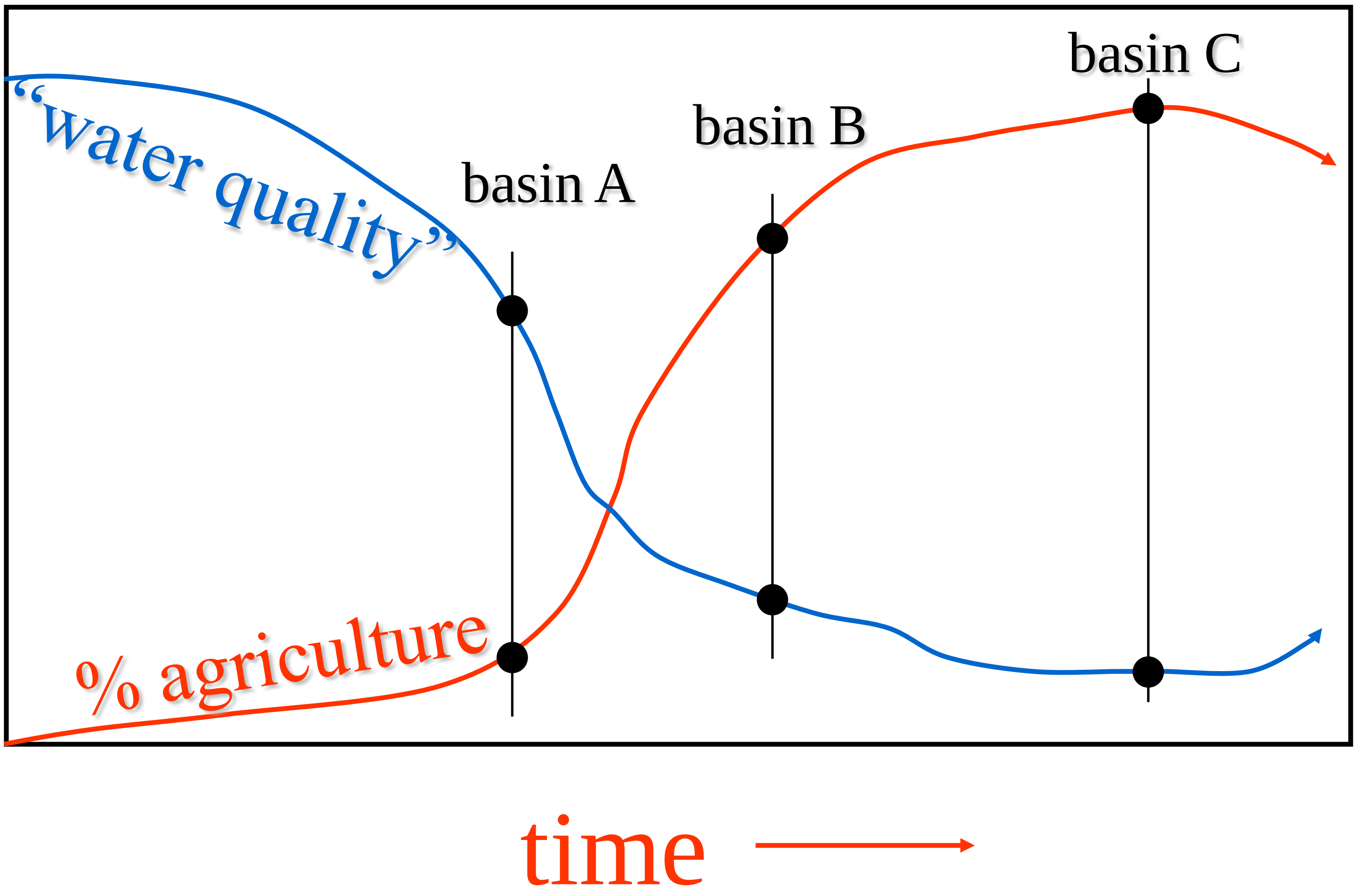


Choptank River near Greensboro
200
150
100
50
0
2.5
2.0
1.5
1.0
0.5
0.0
[TN], µM
[TN], mg N L-1
NO3 line
USGS: 1975-2000
r2 = 0.20 NS
1975
1980
1985
1990
1995
2000
Water Year (Oct - Sep)

Approach (con't):

- Assumption: spatially varying intensity can illustrate
  - **Trajectory**
  - **Consequences**
    - **Stream discharge (some direct observations)**
    - **Water quality**

Trajectories of LCLUC effects



Trajectories of LCLUC effects