Land Cover – Nutrient Export Relationships in Space and Time

James Wickham
US EPA
Office of Research &Development
Research Triangle Park, NC

2010 AWRA Spring Specialty Conference

GIS & Water Resources VI

Orlando, FL

March, 29-31, 2010

Background

There has been a 5- to 14-fold in nitrogen yield for major rivers of the northeastern US since the pre-industrial period (Howarth et al. 1996).

There has been a two-fold increase in nitrogen and a significant increase in phosphorus in the Mississippi River (and the Gulf of Mexico) since 1900 (Rabalais et al. 1996).

Howarth et al. 1996. Biogeochemistry 35: 75-139
Rabalais et al. 1996. Estuaries 19: 386-407

Background

There has been a 5- to 14-fold in nitrogen yield for major rivers of the northeastern US since the pre-industrial period (Howarth et al. 1996).

There has been a two-fold increase in nitrogen and a significant increase in phosphorus in the Mississippi River (and the Gulf of Mexico) since 1900 (Rabalais et al. 1996).

Problem Statement

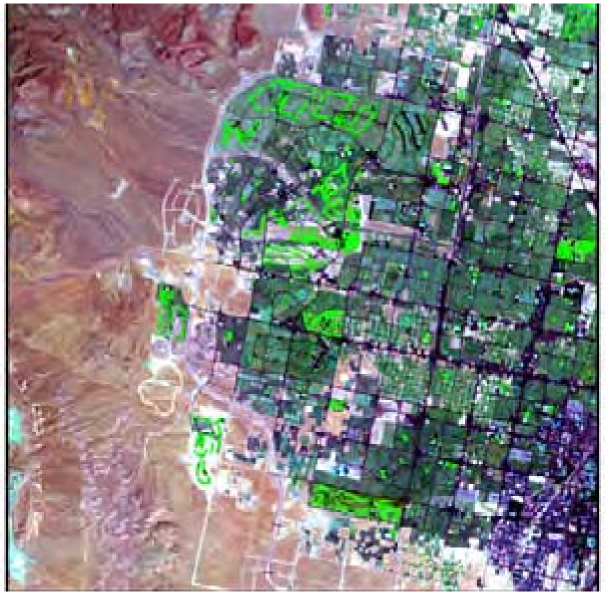
How do we measure change over more contemporary time periods (5, 10, 25 years)?

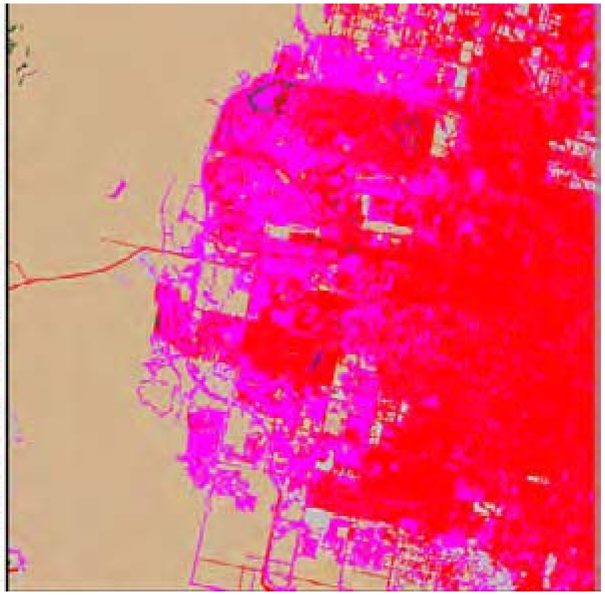
Howarth et al. 1996. Biogeochemistry 35: 75-139
Rabalais et al. 1996. Estuaries 19: 386-407

We know the landscape is changing …

Las Vegas, NV


1992


2001


magenta = change

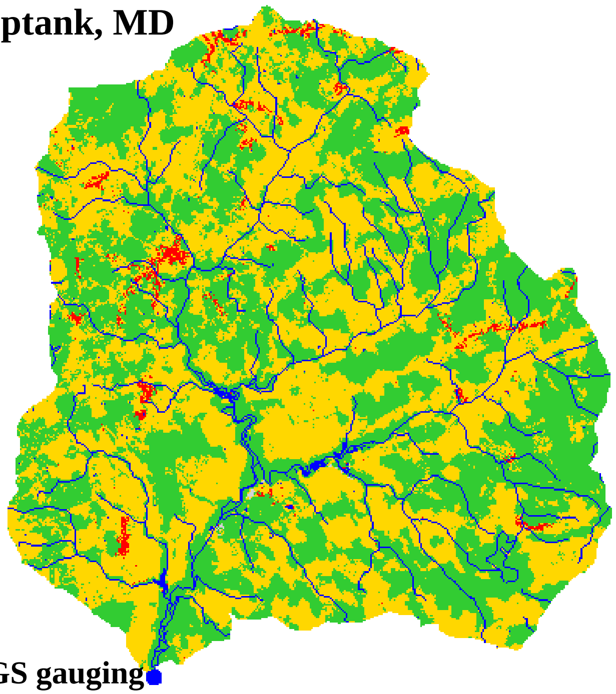
… And we know the change has an impact

Land Cover	Nitrogen	Phosphorus
Forest	2.45	0.09
Range	0.56	0.06
Agriculture	11.92	0.68
Developed	9.25	1.35

Beualac MN, Reckhow KH. 1982. Water Resource Bull 18: 1013-1024
Frink CR. 1991. J. Env. Qual. 20: 717-724
Wickham et al. 2008. Env. Manage. 42: 223-231

… but the problem is variance ('ya gotta learn to love it …)

Upper Choptank, MD



USGS gauging station 01491000

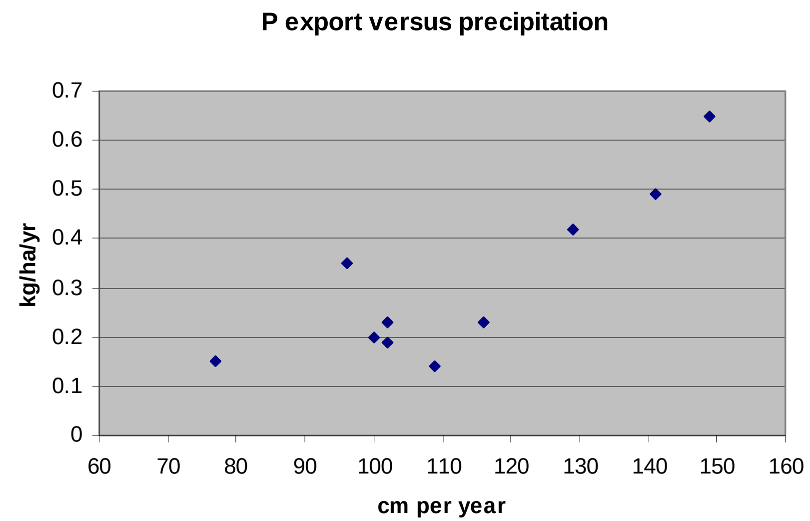
Date	Precipitation (cm/yr)	N export (kg/ha/yr)	P export (kg/ha/yr)
1981	102	3.21	0.23
1982	102	5.06	0.19
1983	129	**8.17**	0.42
1984	141	**11.50**	**0.49**
1985	109	2.89	0.14
1986	77	5.09	0.15
1987	100	5.77	0.20
1988	96	3.30	0.35
1989	149	**9.44**	**0.65**
1990	116	**7.42**	0.23

Fisher et al. 1998. Water, Air & Soil Poll. 105: 387-397
Linker et al. 1996. Water, Env. & Tech. 8:48-52

4x and 4.5x differences in annual N and P export but little change in land cover

… but the problem is variance ('ya gotta learn to love it …)

Date	Precipitation (cm/yr)	N export (kg/ha/yr)	P export (kg/ha/yr)
1981	102	3.21	0.23
1982	102	5.06	0.19
1983	129	**8.17**	0.42
1984	141	**11.50**	**0.49**
1985	109	2.89	0.14
1986	77	5.09	0.15
1987	100	5.77	0.20
1988	96	3.30	0.35
1989	149	**9.44**	**0.65**
1990	116	**7.42**	0.23



… but the problem is variance ('ya gotta learn to love it …)

Change detection is a problem for most of the popular water-quality models

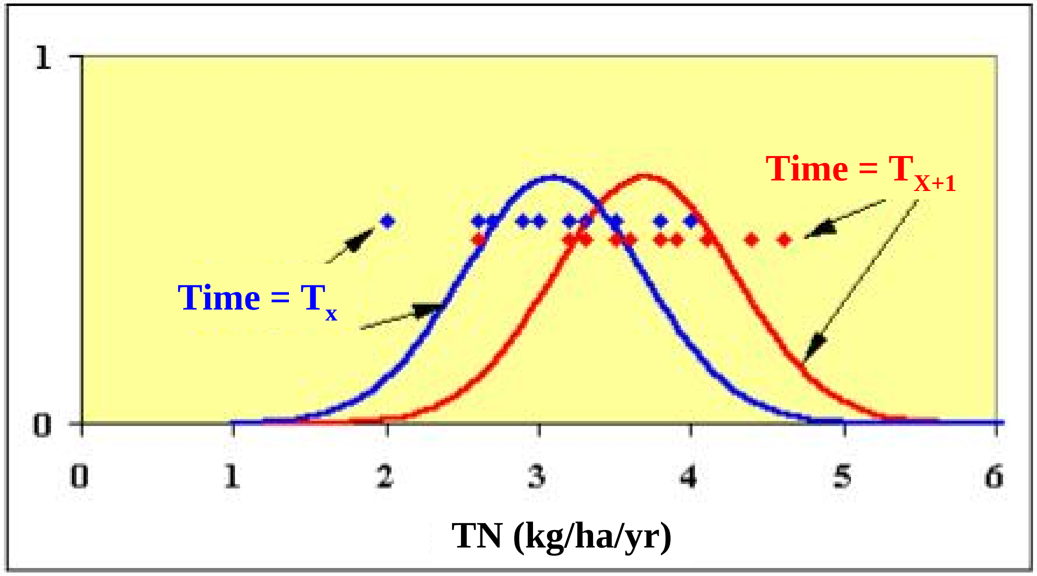
1) SPARROW is a static model (S. Qian, AWRA 2010, WQ Modeling II)

2) HSPF requires many years of in-stream monitoring data (Shenk & Linker 2002. Proc. of the Water Env. Fed. pp. 225-237).

3) Temporal applications of SWAT have not focused on changes in nutrient yields (see Gassman et al. 2007. TASABE 504:1211-1250.)

N & P Export Change Detection

To detect change in N and P export over shorter time horizons, treat the yields as distributions, and test for changes in the N and P distributions.



Methods

1) Compile TN and TP yields for watersheds with homogenous land cover.
2) Fit land-cover specific TN and TP data to statistical models
3) Apply statistical models to temporal land cover to determine if there was a significant change in *distributions* over time.

Methods

1) Compile TN and TP yields for watersheds with homogenous land cover.
2) Fit land-cover specific TN and TP data to statistical models
3) Apply statistical models to temporal land cover to determine if there was a significant change in distributions over time.

Ingredients

- Primary TN & TP data -- NASQAN, HBN, Reckhow (1980), Panuska & Lillie (1995)
- Temporal land cover – NLCD retrofit (Fry et al. 2008 [mrlc.gov])
- Watershed – 12-digit watershed boundary data set (North Carolina)

Methods

1) Compile TN and TP yields for watersheds with homogenous land cover.
2) Fit land-cover specific TN and TP data to statistical models
3) Apply statistical models to temporal land cover to determine if there was a significant change in distributions over time.

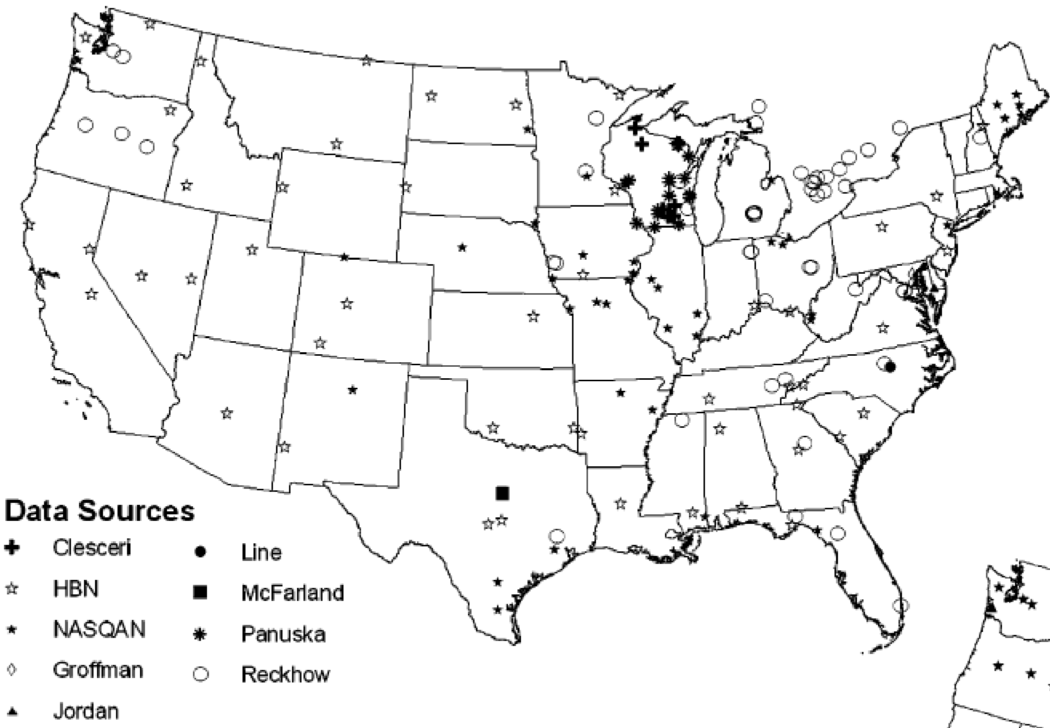
Ingredients

- Primary TN & TP data -- NASQAN, HBN, Reckhow (1980), Panuska & Lillie (1995)
- Temporal land cover – NLCD retrofit (Fry et al. 2008 [mrlc.gov])
- Watershed – 12-digit watershed boundary data set

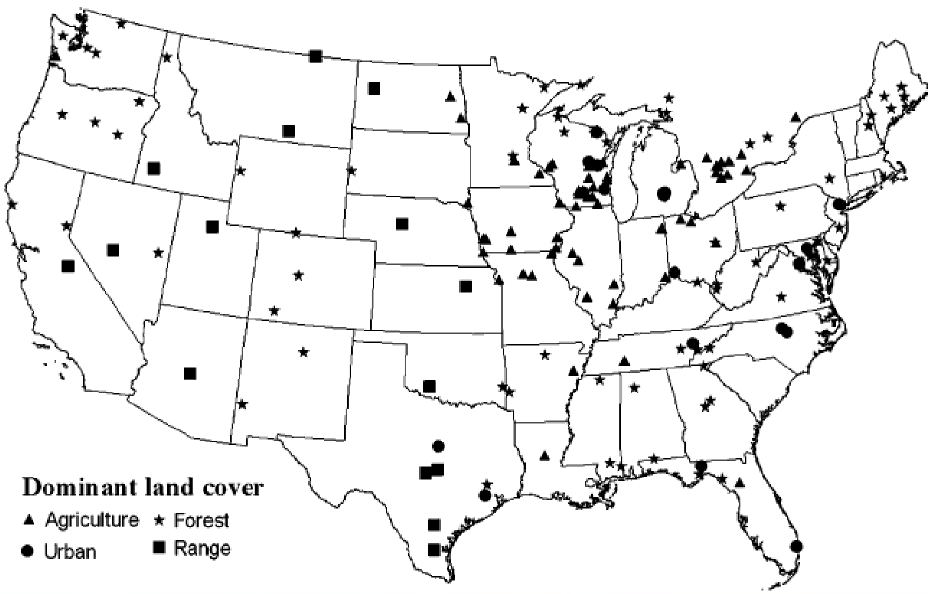
Significance

Output (per watershed & per chemical) compared to stochastic variability in model for P_{50} and $P_{90.}$ Significance = greater that stochastic for both P_{50} and P_{90} (10,000 reps).

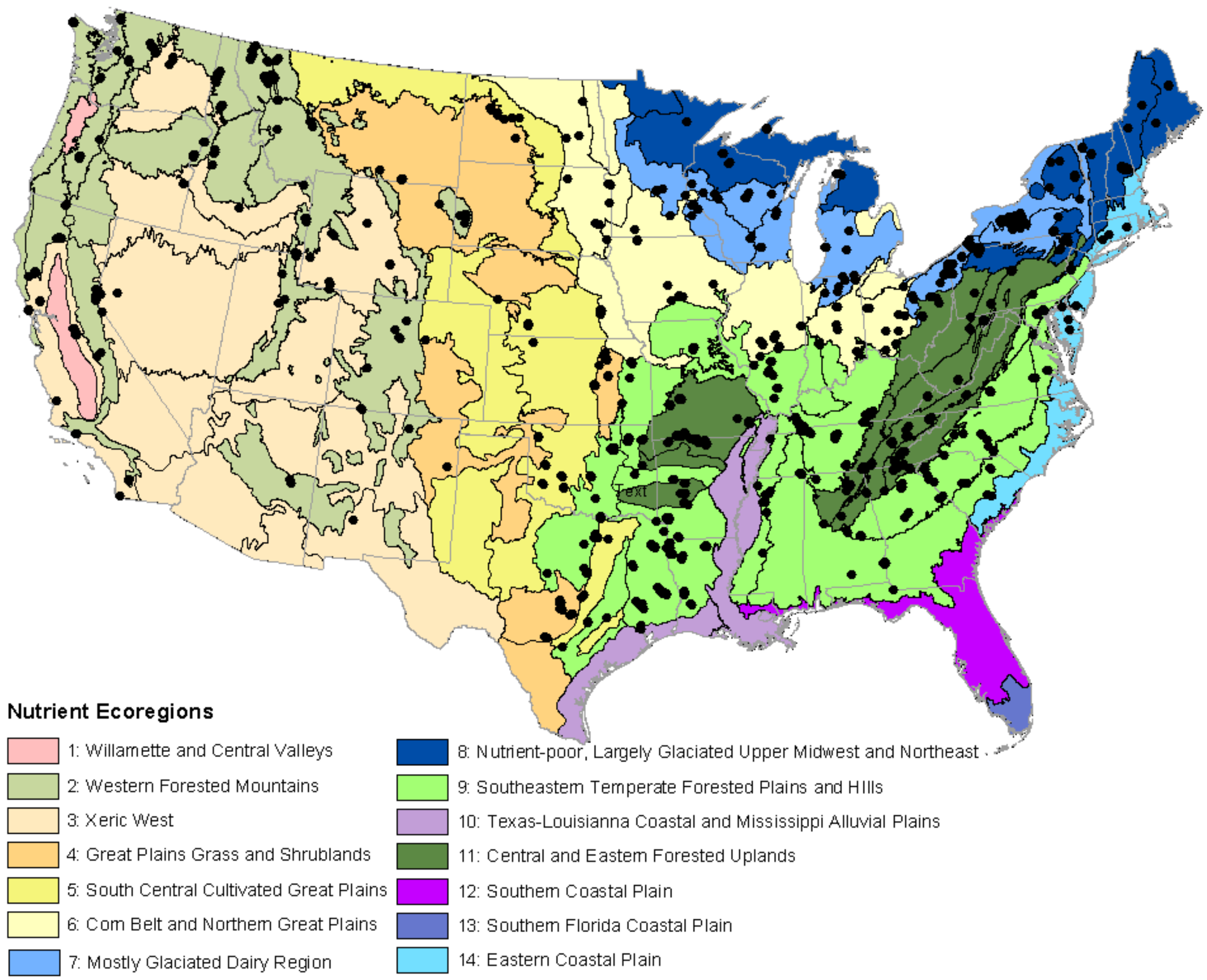
TN & TP Data



1228 observations spread across 167 sites.



Geographic Variability



Wickham et al. (2005)

Geographic Variability

$$Y_{ijk} = u + ECO_i + LC_{j(i)} + E_{k(ij)}$$

Nested design

- **land cover tested within each ecoregion, not averaged across ecoregions.**
- **ecoregions tested relative to the variance of the land-cover classes they contain.**

Output

- **R^2 – total variance explained by both together**
- **estimates of variance component of ecoregion, land cover, error**
- **F-tests of ecoregions and land cover**
  - **ecoregion variance tested after accounting for land cover**

Notes

- **Watersheds were given an alternate ecoregion assignment when close to border**
- **Adjustments for unbalanced design**

Source	Expected Mean Square	Term	N	P
Nutrient ecoregion	$\sigma^2_e + 3.2071\,\sigma^2_{l(r)} + 22.78\,\sigma^2_r$	σ^2_r	0.1371 (8%)	0.001010 (12%)
land-cover composition	$\sigma^2_e + 11.518\,\sigma^2_{l(r)}$	$\sigma^2_{l(r)}$	0.8575 (47%)	0.003254 (41%)
error	σ^2_e	σ^2_e	0.8216 (45%)	0.003732 (47%)

Nitrogen

Source	DF	Sum of Squares	Mean Square	F-value	p-value
model	71	1794.6750	25.2771	30.76	<0.0001
- ecoregion	10	69.4320	6.9432	1.94[a]	0.0496
- land cover	61	652.5974	10.6983[a]	13.02	<0.0001
error	856	703.3623	0.8216		
Corrected Total	927	2498.0373			
$R^2 = 0.72$					

Phosphorus

Source	DF	Sum of Squares	Mean Square	F-value	p-value
model	71	3.9428	0.0555	14.88	<0.0001
- ecoregion	10	0.3613	0.0361	2.75[b]	0.0050
- land cover	61	2.2860	0.0378[b]	10.04	<0.0001
error	856	3.1946	0.0037		
corrected total	927	7.1374			
$R^2 = 0.55$					

Wickham et al. (2005)

Geographic Variability

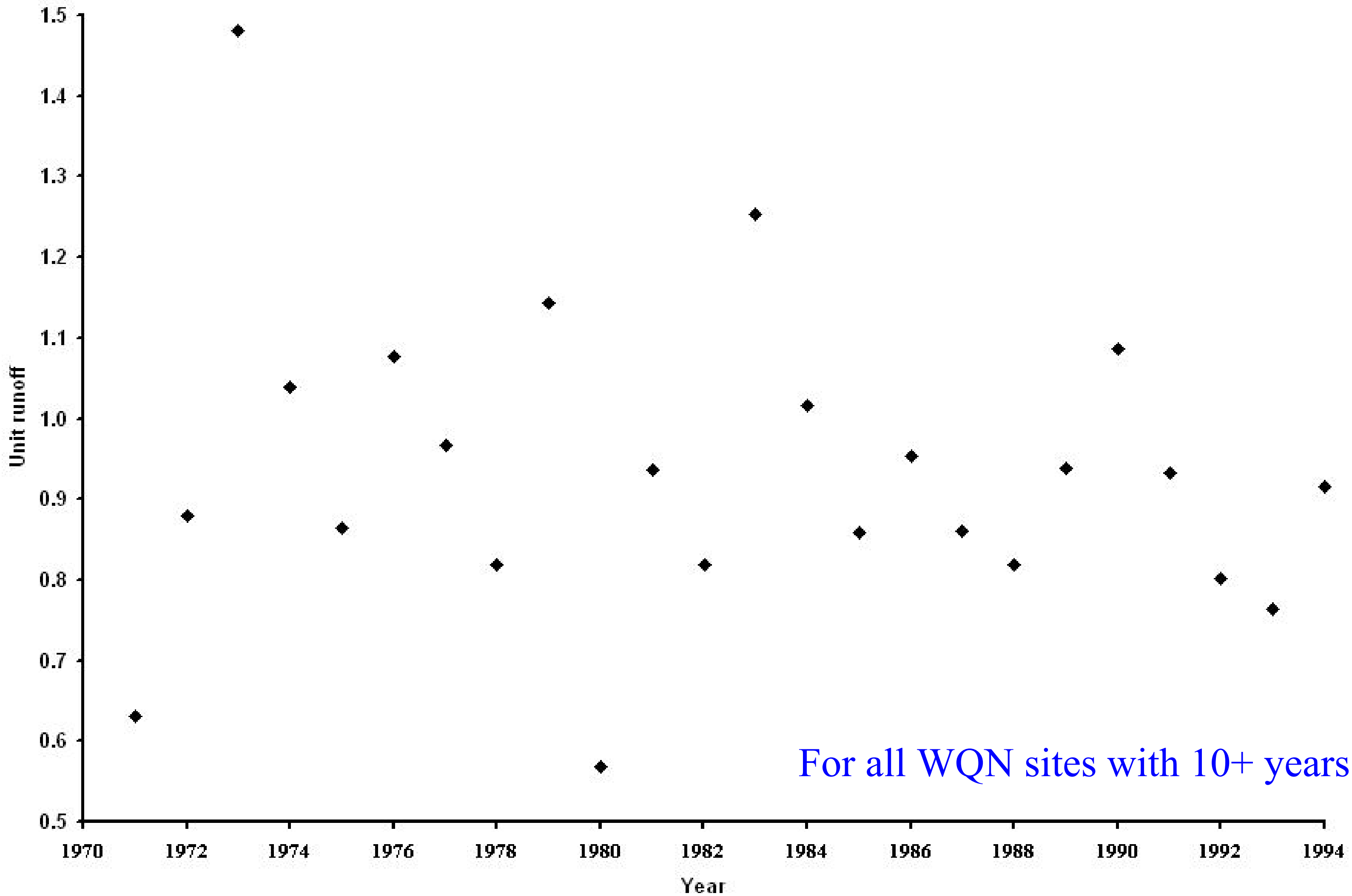
HBN/SPARROW estimates of background concentrations by nutrient ecoregion

Ecoregion	No. Obs.
2	23
8	10
9	9

	DF	Sum of Squares	Mean Square	F value	p value
Nitrogen					
Ecoregion	2	46831.06	23415.52	0.91	0.4099
Error	39	1000722.79	25659.56		
Corrected Total	41	1047553.85			
$R^2 = 0.045$					
Phosphorus					
Ecoregion	2	145.96	72.98	0.44	0.6476
Error	39	6477.05	166.08		
Corrected Total	41				
$R^2 = 0.022$					

Source: Smith RA, Alexander RB, Schwarz, GE. 2003. *Environmental Science and Technology*, 37:3039-3047.

Temporal Variability



For all WQN sites with 10+ years of data

Data Source Variability

Check that TN and TP do not exhibit source effects (e.g., NASQAN vs. Reckhow)

	Panuska & Lillie (1995)	Reckhow et al. (1980)	USGS (WQN) 1998
Panuska & Lillie (1995)		0.2414	0.9053
Reckhow et al. (1980)			0.1284

Cell entries are t-values for null, $X_i = X_j$, from least-square means tests, where i and j are the data source. Test is for TP and agricultural land cover.

Results

1) Loss of natural vegetation produced significant changes in nutrient yields, and gain produced increases (expected).

Results

1) Loss of natural vegetation produced significant changes in nutrient yields, and gain produced increases (expected).

2) Sensitivity to changes was dependent on the amount of vegetation present at T1. Small losses of natural vegetation produced significant changes in TN and TP distributions when amount of T1 natural vegetation was high.

Results

1) Loss of natural vegetation produced significant changes in nutrient yields, and gain produced increases (expected).

2) Sensitivity to changes was dependent on the amount of vegetation present at T1. Small losses of natural vegetation produced significant changes in TN and TP distributions when amount of T1 natural vegetation was high.

3) TP changes had a distinct urban signal, whereas TN did not. The TP-urban relationship is evident in the monitored data (… and literature).

Results

1) Loss of natural vegetation produced significant changes in nutrient yields, and gain produced increases (expected).

2) Sensitivity to changes was dependent on the amount of vegetation present at T1. Small losses of natural vegetation produced significant changes in TN and TP distributions when amount of T1 natural vegetation was high.

3) TP changes had a distinct urban signal, whereas TN did not. The TP-urban relationship is evident in the monitored data (… and literature).

4) Influence of organic nitrogen (TKN) may explain why TN was less sensitive to change (primarily urbanization) than TP. TKN values tend to be high when TN values for forest and range are high.

Results

1) Loss of natural vegetation produced significant changes in nutrient yields, and gain produced increases (expected).

2) Sensitivity to changes was dependent on the amount of vegetation present at T1. Small losses of natural vegetation produced significant changes in TN and TP distributions when amount of T1 natural vegetation was high.

3) TP changes had a distinct urban signal, whereas TN did not. The TP-urban relationship is evident in the monitored data (… and literature).

4) Influence of organic nitrogen (TKN) may explain why TN was less sensitive to change (primarily urbanization) than TP. TKN values tend to be high when TN values for forest and range are high.

5) First study to split shrub from forest (four-class model)

Results

1) Loss of natural vegetation produced significant changes in nutrient yields, and gain produced increases (expected).

2) Sensitivity to changes was dependent on the amount of vegetation present at T1. Small losses of natural vegetation produced significant changes in TN and TP distributions when amount of T1 natural vegetation was high.

3) TP changes had a distinct urban signal, whereas TN did not. The TP-urban relationship is evident in the monitored data (… and literature).

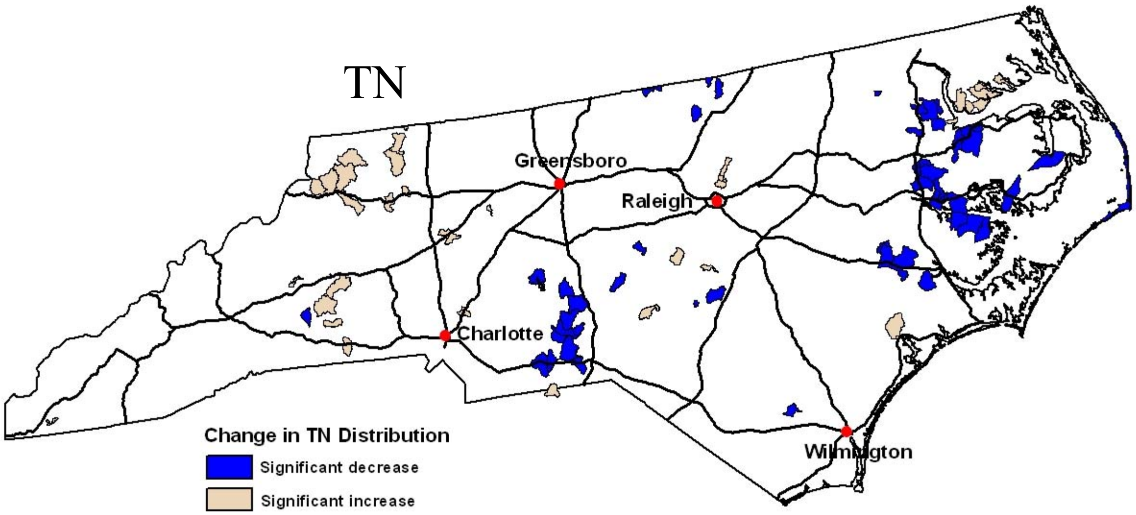
4) Influence of organic nitrogen (TKN) may explain why TN was less sensitive to change (primarily urbanization) than TP. TKN values tend to be high when TN values for forest and range are high.

5) First study to split shrub from forest (four-class model)

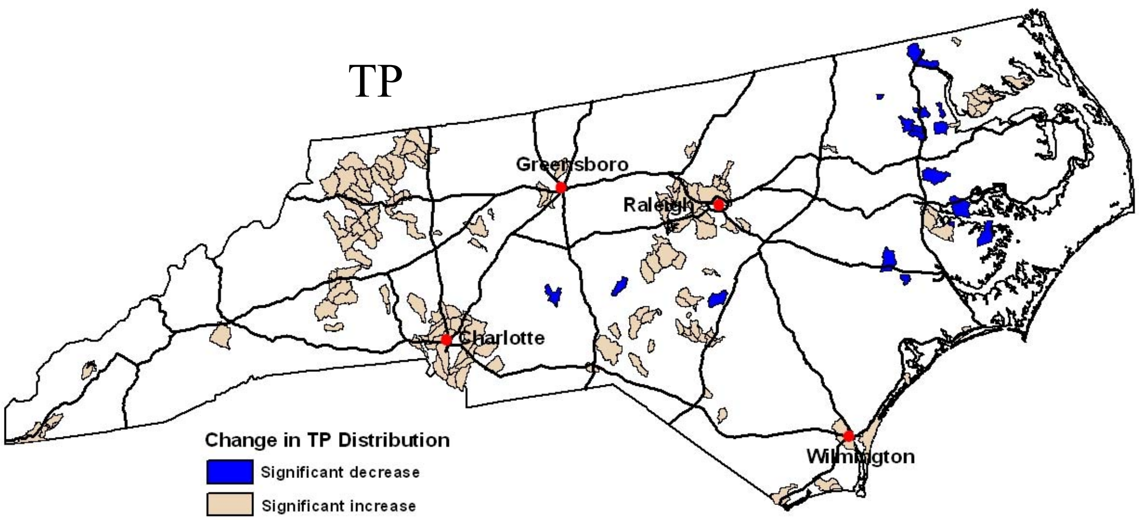
6) Don't forget about phosphorus …

Results

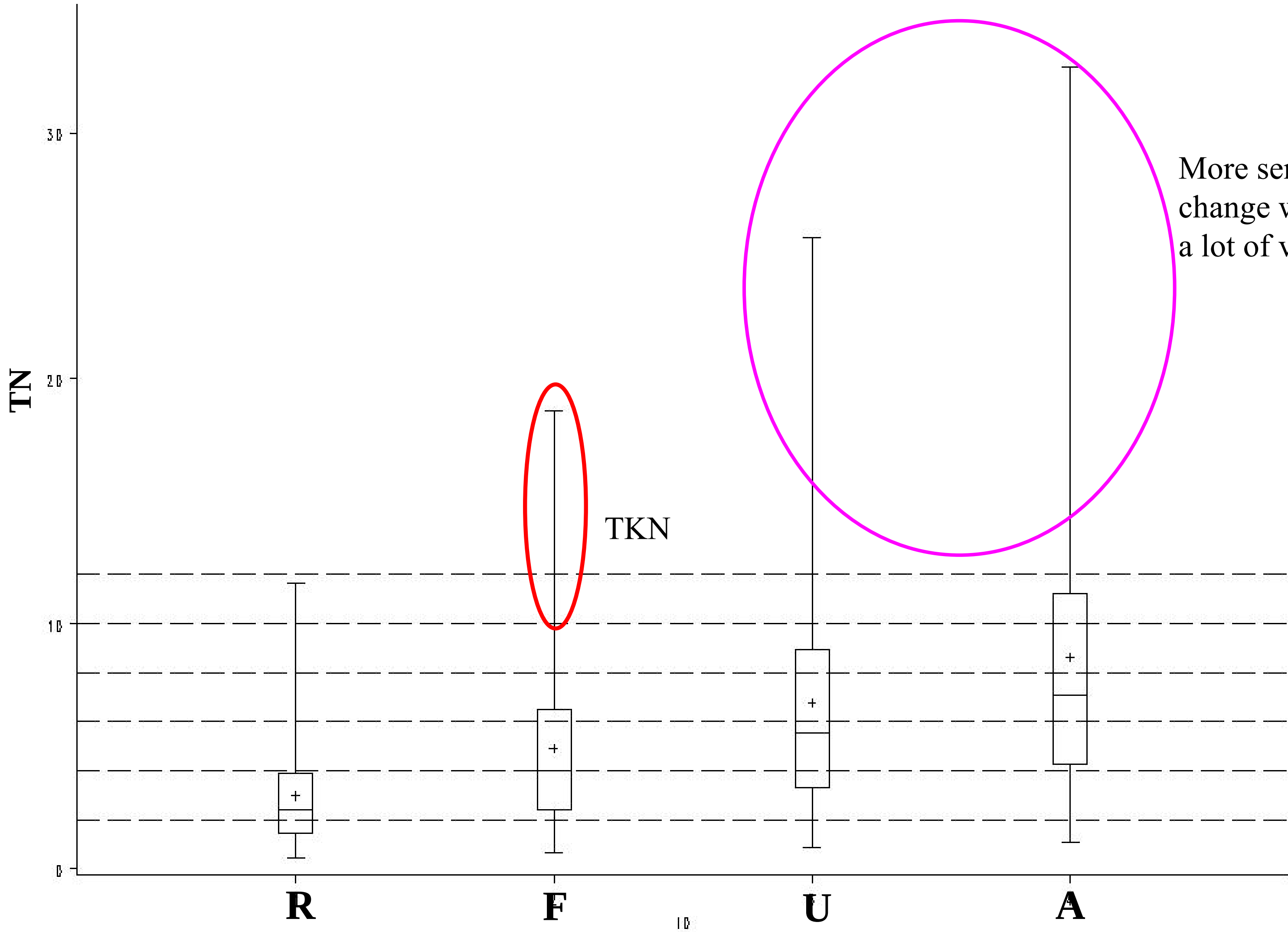
TN



TP



Results



More sensitive to change when there is a lot of vegetation

Questions?

Wickham JD, Wade TG, Riitters KH. 2008. Detection temporal change in watershed nutrient yields. Environmental Management 42:223-231.

Wickham JD, Riitters KH, Wade TG, Jones KB. 2005. Evaluating the relative roles of ecological regions and land-cover composition for guiding establishment of nutrient criteria. Landscape Ecology 20:791-798.