At the watershed scale . . .

…we know relatively little about the relative effectiveness of practices to retain or prevent mobilization of sediment

…or even about the relative contributions from different sources of sediment

Challenges in demonstrating watershed-scale effects

- High spatial heterogeneity and temporal variability (especially for sediment)
- Transport strongly driven by events in time and space
- Watersheds are complex
  - Multiple sediment sources
  - Multiple management practices
- Difficult to create a signal observable above high variability

Demonstrating vs. accounting

- Test hypotheses
- Few variables with good data
- Simple models
- Estimate uncertainty

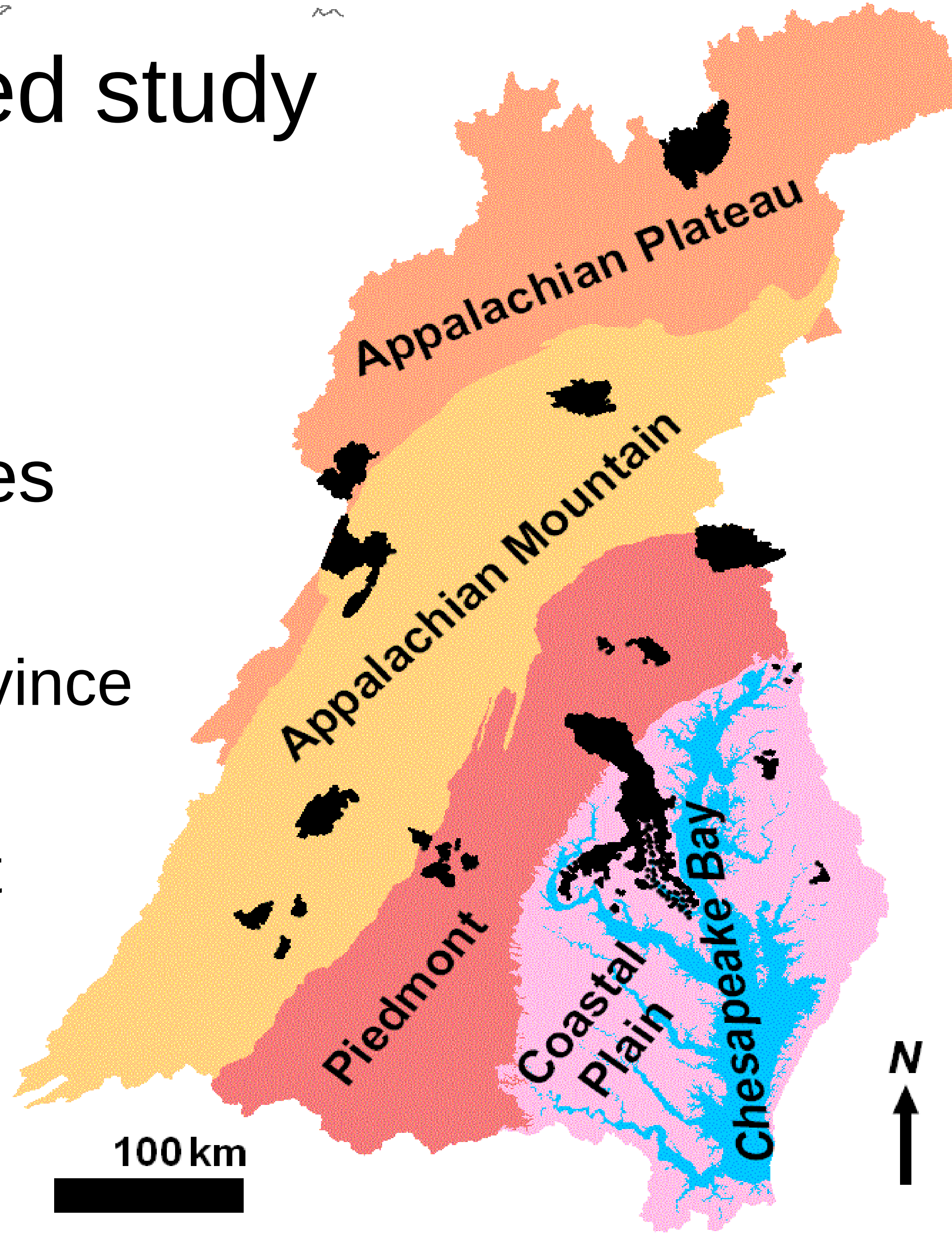
- Research models

- Summarize knowledge
- All variables of interest (BPJ)
- Complex models
- Often not

- Accounting models (like CPB WM)

SERC watershed study

- Watershed-scale
- Top-down
- Measure discharges
- Effects of
  - Physiographic province
  - Land use
  - Land management
  - BMPs

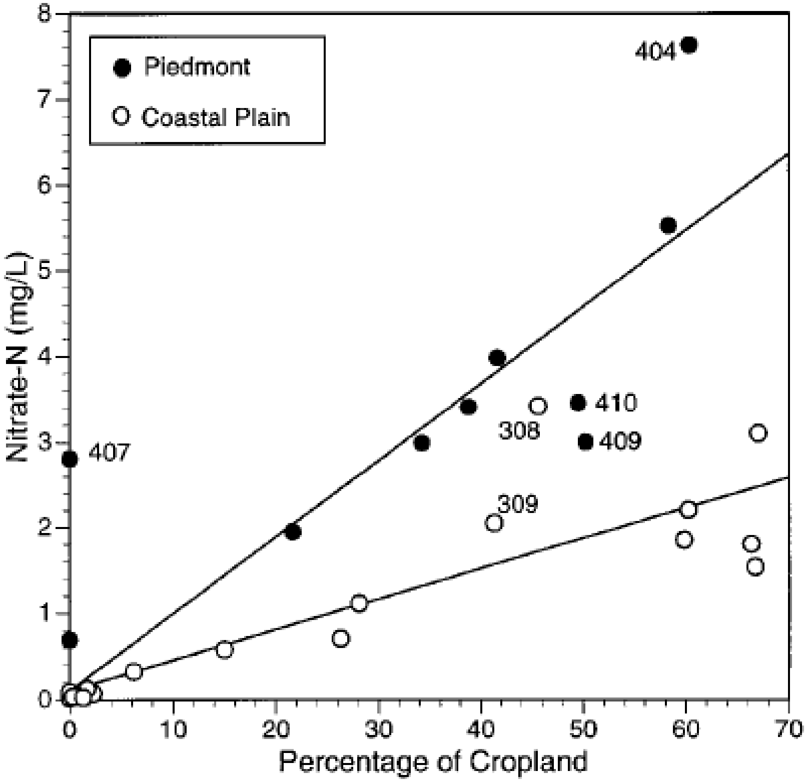


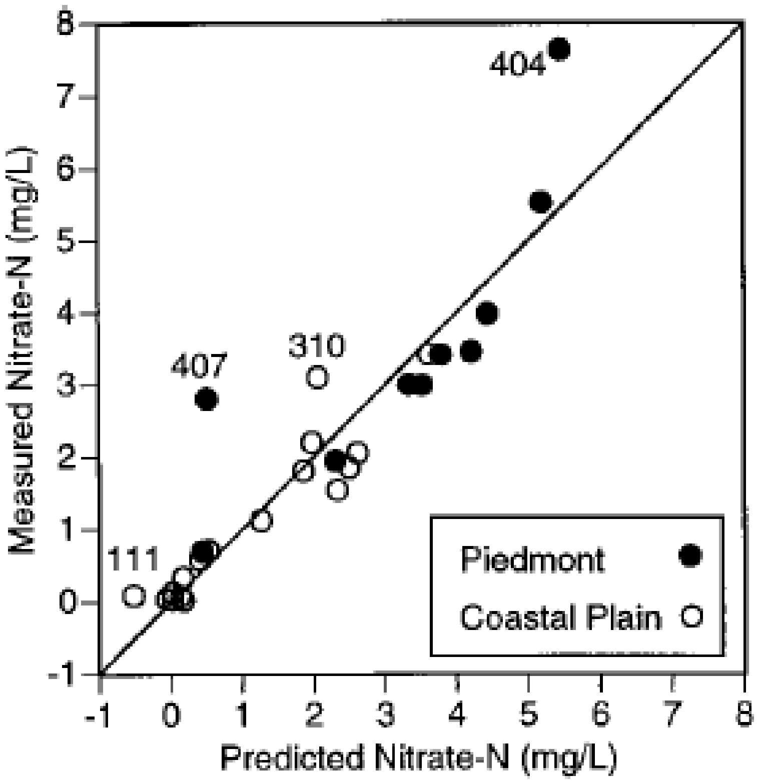
WATER RESOURCES RESEARCH, VOL. 33, NO. 11, PAGES 2579–2590 NOVEMBER 1997

Relating nutrient discharges from watersheds to land use and streamflow variability

Thomas E. Jordan, David L. Correll, and Donald E. Weller
Smithsonian Environmental Research Center, Edgewater, Maryland

N concentration strongly related to cropland & base flow index…





…sediment and P, not so much

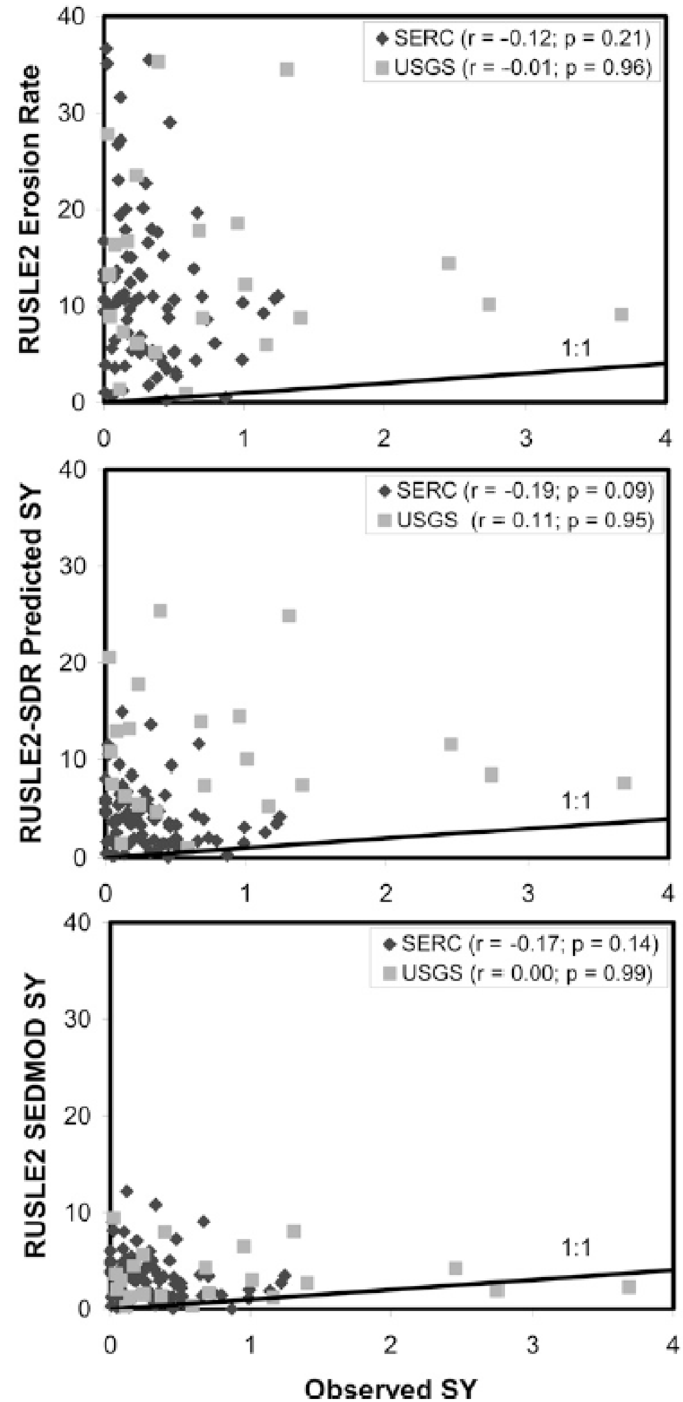
Jordan et al. 1987 *Water Res. Res.* 33:2579–2590

Empirical Models Based on the Universal Soil Loss Equation Fail to Predict Sediment Discharges from Chesapeake Bay Catchments

Kathleen B. Boomer,* Donald E. Weller, and Thomas E. Jordan Smithsonian Environmental Research Center

Predicted sediment yield (mass/area) vs. observed

- Overprediction
- Hugh scatter
- Lack of correlation



Boomer et al. 2008 *J. Environ. Qual.* 37:79–89

Insights from model comparison…

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

Vol. 49, No. 1 AMERICAN WATER RESOURCES ASSOCIATION February 2013

USING MULTIPLE WATERSHED MODELS TO PREDICT WATER, NITROGEN, AND PHOSPHORUS DISCHARGES TO THE PATUXENT ESTUARY[1]

Kathleen M.B. Boomer, Donald E. Weller, Thomas E. Jordan, Lewis Linker, Zhi-Jun Liu, James Reilly, Gary Shenk, and Alexey A. Voinov[2]

Relative Predictably: Flow>TN> TP

- For models that had published calibration results,
  - the *performance of the calibrated model was better for water discharge than for TN load and worst for TP load*
- For all three time frames that we considered (average annual, annual time series, and monthly),
  - *performance metrics were best for flow, intermediate for TN, and worst for TP*;
  - and the *ranges of estimates among models were narrowest for flow, intermediate for TN, and widest for TP*
- Nutrient release, transport, and removal are strongly driven by temporally episodic and spatially heterogeneous factors, making them hard to model

Boomer et al. 2013 *JAWRA* 49:15-39

Fits of Chesapeake SPARROW models (R2)

Model	N	P	Sediment
Flux (mass)	0.98	0.95	0.83
Yield (mass/area)	0.86	0.73	0.57
Concentration	?	?	?

Controls of phosphorus delivery

- Poor performance & high uncertainty suggests models do not capture the dominant source, transport, & delivery processes
- Most watershed models assume hillslope erosion is the proximal sediment source
- Hillslope erosion poorly predicts loads
- There is a critical need to study other processes
  - gully erosion
  - seepage erosion
  - stream bank erosion
  - in-stream erosion and deposition
  - floodplain deposition

Boomer et al. 2013 *JAWRA* 49:15-39

Models differ in attributing sources

TABLE 16. Percentages of Predicted Average Annual TN and TP Discharges from the Bowie Basin Allocated to Cropland and Developed Land by Nine Model Implementations.

	TN		TP	
Model	**Agriculture**	**Developed Land**	**Agriculture**	**Developed Land**
MDP90	37	50	51	46
MDP97	31	58	44	54
SPARROW87	63	27	30	37
SPARROW92	56	40	27	55
SPARROW97	71	25	26	52
SERC	49	36	46	44
SERCLM	66	27	50	34
CBP4	25	54	21	52
CBP5	32	50	30	56
Model average	48	41	36	48

Boomer et al. 2013 *JAWRA* 49:15-39

Demonstrating watershed-scale effects

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

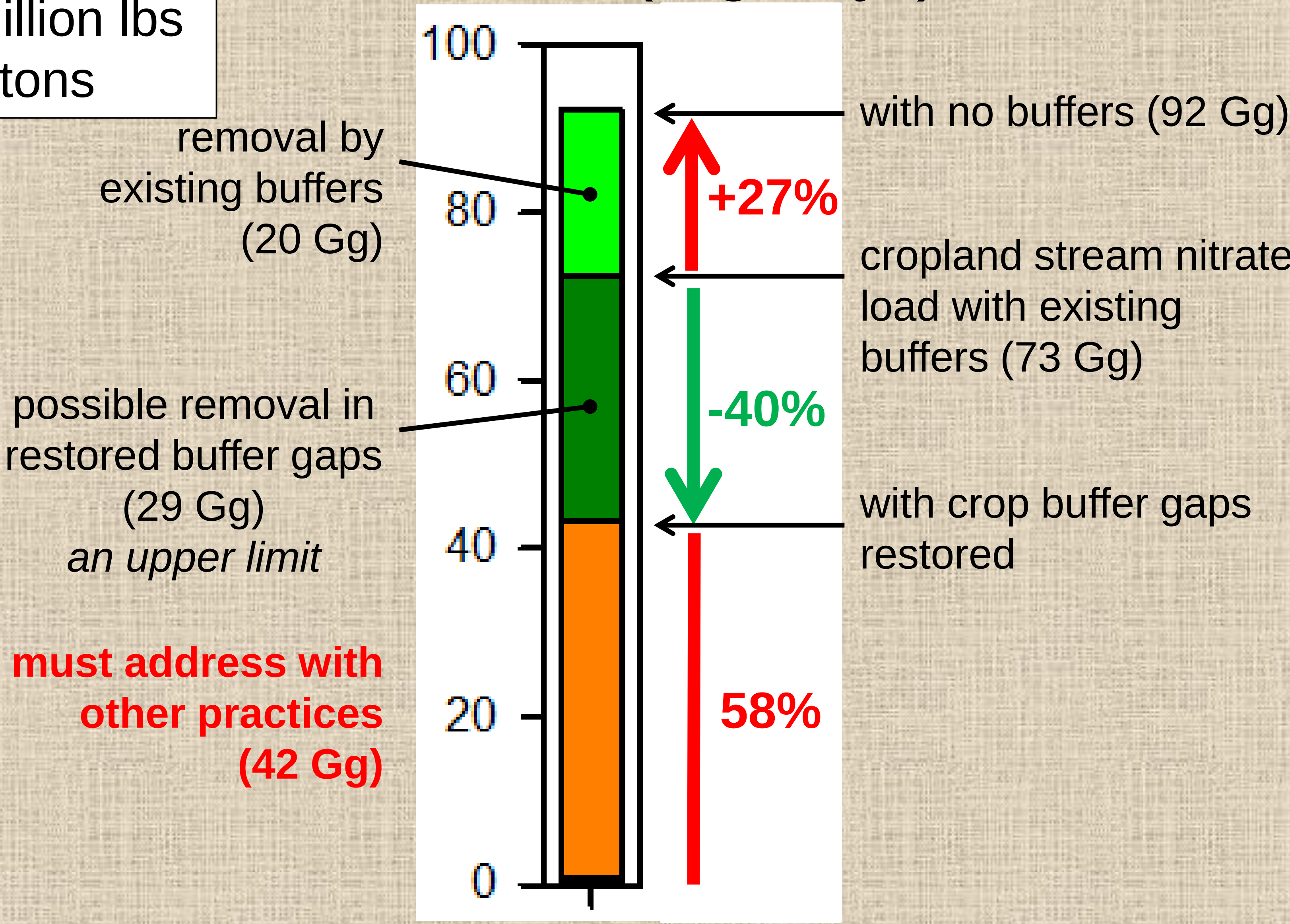
Vol. 50, No. 3 AMERICAN WATER RESOURCES ASSOCIATION June 2014

CROPLAND RIPARIAN BUFFERS THROUGHOUT CHESAPEAKE BAY WATERSHED: SPATIAL PATTERNS AND EFFECTS ON NITRATE LOADS DELIVERED TO STREAMS[1]

Donald E. Weller and Matthew E. Baker[2]

Bay-wide buffer effects on nitrate load *to streams* (Gg N/yr)

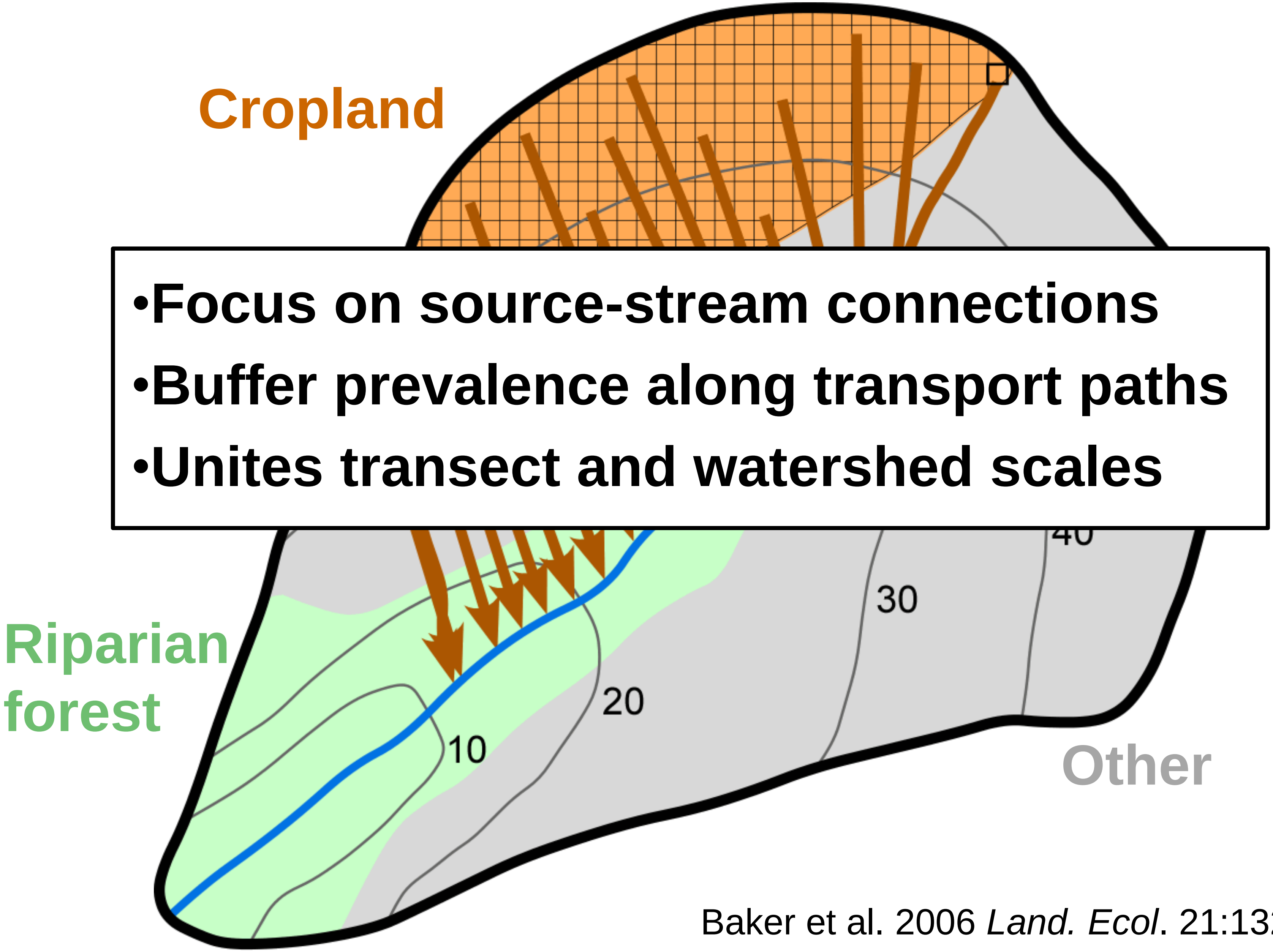
1 Gg
2.2 million lbs
1100 tons



Weller & Baker 2014 *JAWRA* 50:696-712

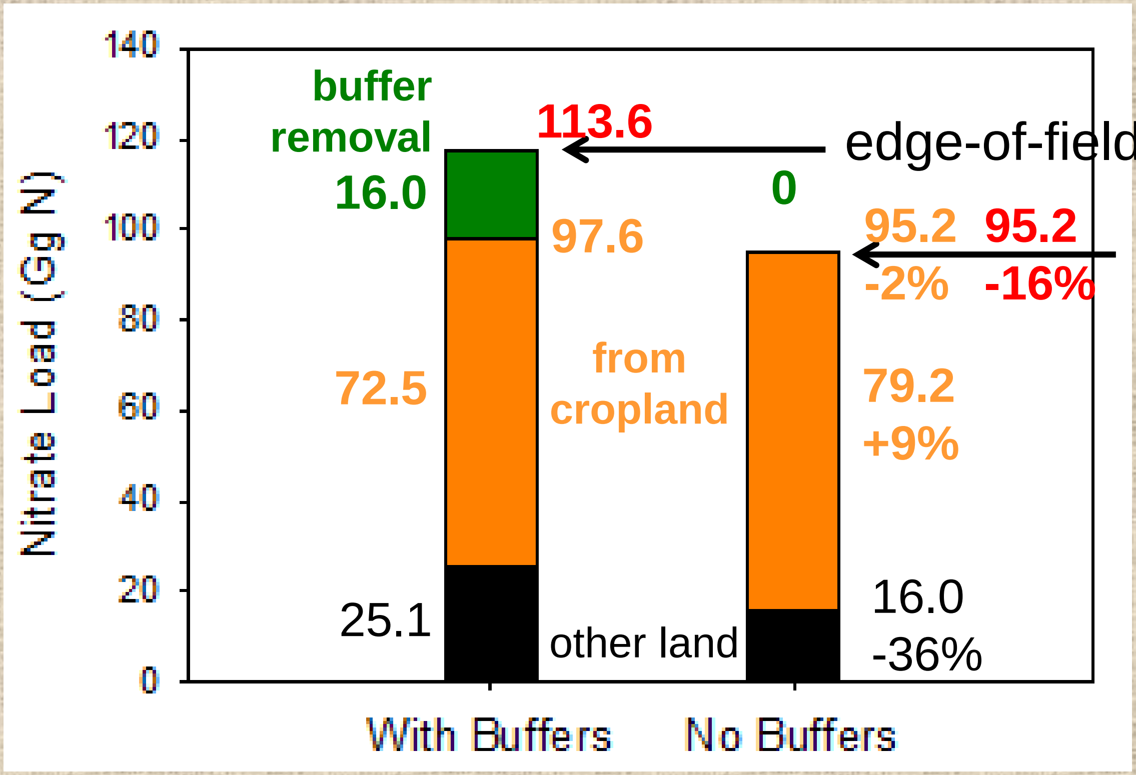
Accounting for source-sink connections

- Focus on source-stream connections
- Buffer prevalence along transport paths
- Unites transect and watershed scales



Baker et al. 2006 *Land. Ecol*. 21:1327-1345

Applying an appropriate model



Models without buffers can predict stream levels, but mislead about sources & fates.

Weller & Baker 2014 *JAWRA* 50:696-712

Disclaimer:

Sediment practices that I am not an expert on

- Cover crops
- Stormwater management
- Streambank fencing
- Stream restoration
- Legacy sediment removal
- Floodplain restoration

Ways of demonstrating watershed scale effects

- Before and after studies
- Comparisons among watersheds

Effects of Agriculture on Discharges of Nutrients from Coastal Plain Watersheds of Chesapeake Bay

WATER RESOURCES RESEARCH, VOL. 33, NO. 11, PAGES 2579–2590 NOVEMBER 1997

VOL. 33 1997

Relating nutrient discharges from watersheds to land use and streamflow variability

Thomas E. Jordan, David L. Correll, and Donald E. Weller
Smithsonian Environmental Research Center, Edgewater, Maryland

Abstract. During a 1-year period we measured discharges of water, suspended solids, and nutrients from 27 watersheds having differing proportions of cropland in the Piedmont and Coastal Plain provinces of the Chesapeake Bay drainage. Annual flow-weighted mean concentrations of nitrate and organic N and C in stream water correlated with the relative proportions of base flow and storm flow. As the proportion of base flow increased, the concentration of nitrate increased and the concentrations of organic N and C decreased. This suggests that discharge of nitrate is promoted by groundwater flow but discharges of organic N and C are promoted by surface runoff. Concentrations of N species also increased as the proportion of cropland increased. We developed a statistical model that predicts concentrations of N species from the proportions of cropland and base flow. P concentrations did not correlate with cropland or base flow but correlated with the concentration of suspended solids, which differed among watersheds.

ABSTR eric
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Th e Universal Soil Loss Equation (USLE) and its derivatives are widely used for identifying watersheds with a high potential for degrading stream water quality. We compared sediment yields estimated from regional application of the USLE, the automated revised RUSLE2, and fi ve sediment delivery ratio algorithms to measured annual average sediment delivery in 78 catchments of the Chesapeake Bay watershed. We did the same comparisons for another 23 catchments monitored by the USGS. Predictions exceeded observed sediment yields by more than 100% and were highly correlated with USLE erosion predictions (Pearson r range, 0.73–0.92; $p < 0.001$). RUSLE2-erosion estimates were highly correlated with USLE estimates ($r = 0.87$; $p < 001$), so the method of implementing the USLE model did not change the results. In ranked comparisons between observed and predicted sediment yields, the models failed to identify catchments with higher yields (r range, –0.28–0.00; $p > 0.14$). In a multiple regression analysis, soil erodibility, log (stream fl ow), basin shape (topographic relief ratio), the square-root transformed proportion of forest, and occurrence in the Appalachian Plateau province explained 55% of the observed variance in measured suspended sediment loads, but the model performed poorly ($r2 = 0.06$) at predicting loads in the 23 USGS watersheds not used in fi tting the model. Th e use of USLE or multiple regression models to predict sediment yields is not advisable despite their present widespread application. Integrated watershed models based on the USLE may also be unsuitable for making management decisions.

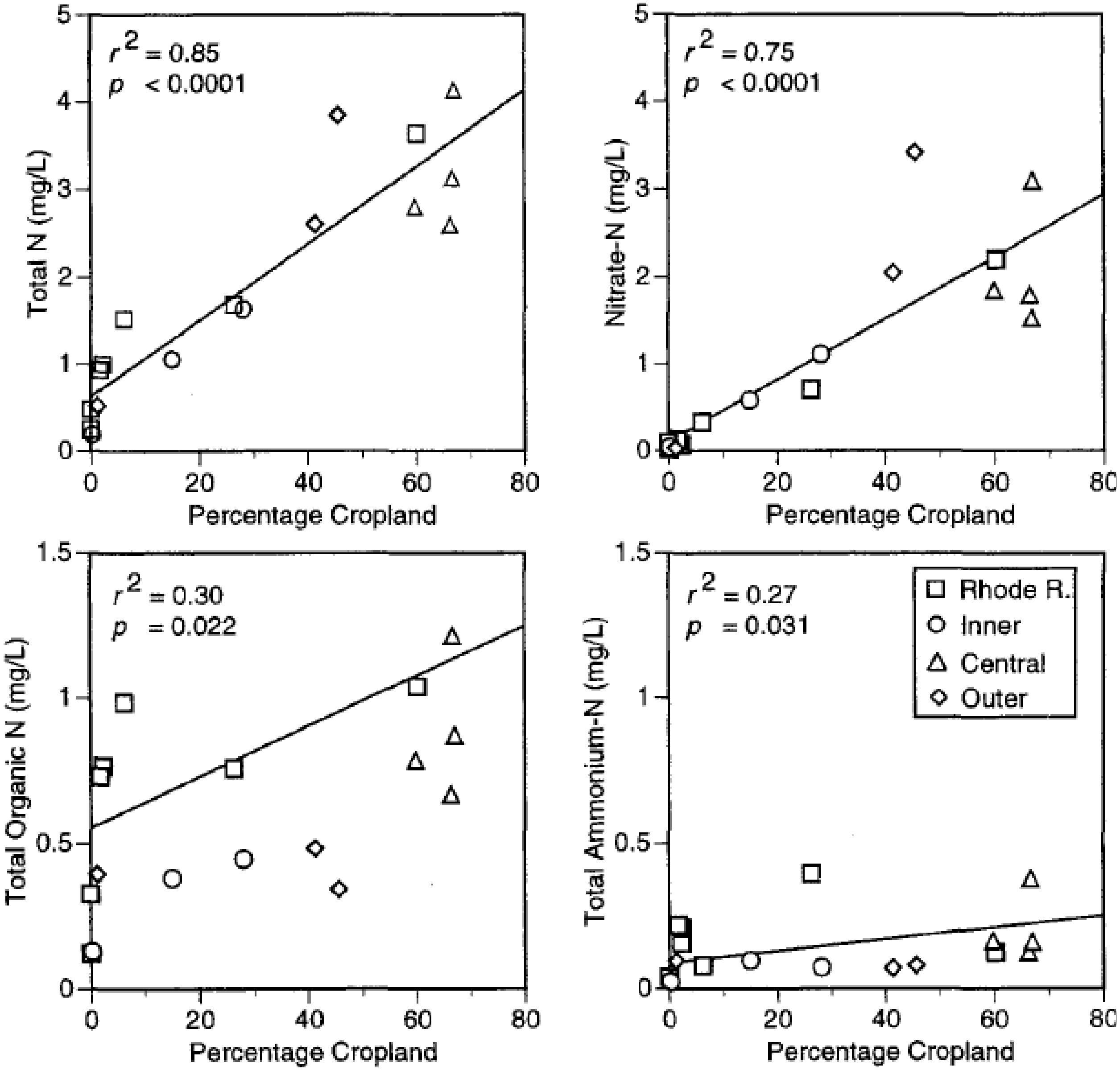
Boomer, K. B., D. E. Weller and T. E. Jordan (2008). "Empirical models based on the universal soil loss equation fail to predict sediment discharges from Chesapeake Bay catchments." J Environ Qual **37(1): 79-89.**

Table 3. Summary of Spearman rank correlations of Universal Soil Loss Equation–based predictions and annual average sediment yields observed by the Smithsonian Environmental Research Center (SERC) and USGS.

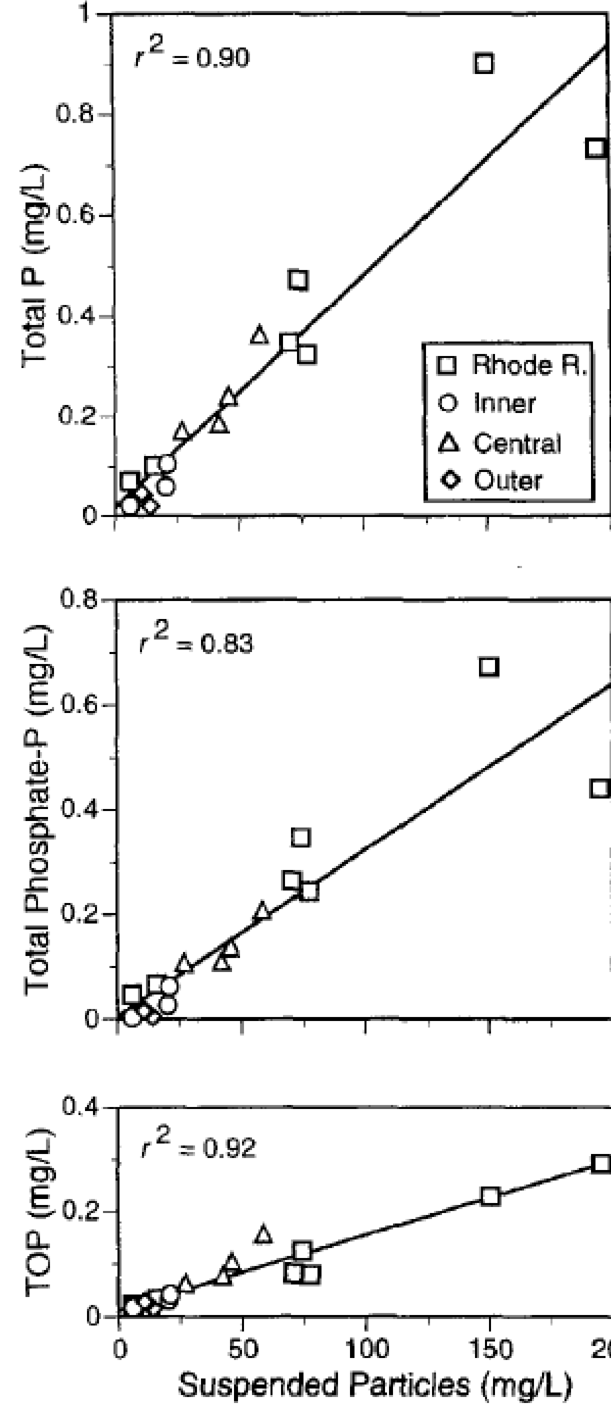
Model	SERC observed sediment yield ($n = 78$)		USGS observed sediment yield ($n = 23$)	
	r	*p*	*r*	*p*
Erosion model†				
USLE	−0.02	0.69	−0.22	0.32
RUSLE2	−0.12	0.21	−0.01	0.96
Sediment delivery model				
Vanoni, 1975	−0.11	0.34	−0.07	0.72
USDA Soil Conservation Service, 1986	−0.10	0.36	−0.02	0.94
Maner, 1958	−0.08	0.50	−0.28	0.20
Yagow, 1998	−0.13	0.28	na‡	na
Fraser, 1998 (RUSLE2)	−0.17	0.14	0.00	0.99

† RUSLE, revised Universal Soil Loss Equation; SCS, Soil Conservation Service; USLE, Universal Soil Loss Equation.

‡ This correlation was not assessed.



$r^2 = 0.85$
$p < 0.0001$
Total N (mg/L)
Percentage Cropland
$r^2 = 0.75$
$p < 0.0001$
Nitrate-N (mg/L)
Percentage Cropland
$r^2 = 0.30$
$p = 0.022$
Total Organic N (mg/L)
Percentage Cropland
$r^2 = 0.27$
$p = 0.031$
Total Ammonium-N (mg/L)
Percentage Cropland
Rhode R.
Inner
Central
Outer



$r^2 = 0.90$
Total P (mg/L)
Rhode R.
Inner
Central
Outer
$r^2 = 0.83$
Total Phosphate-P (mg/L)
$r^2 = 0.92$
TOP (mg/L)
Suspended Particles (mg/L)

Land proportion vs. buffer model

R^2	0.741		0.756
AIC_c	159	Δ=31	128
Probability	0.0000004		0.9999996

1.5% improvement in R^2

AIC_c is 31 lower

AIC_c Interpretation

Support for weaker model

0-2 Substantial

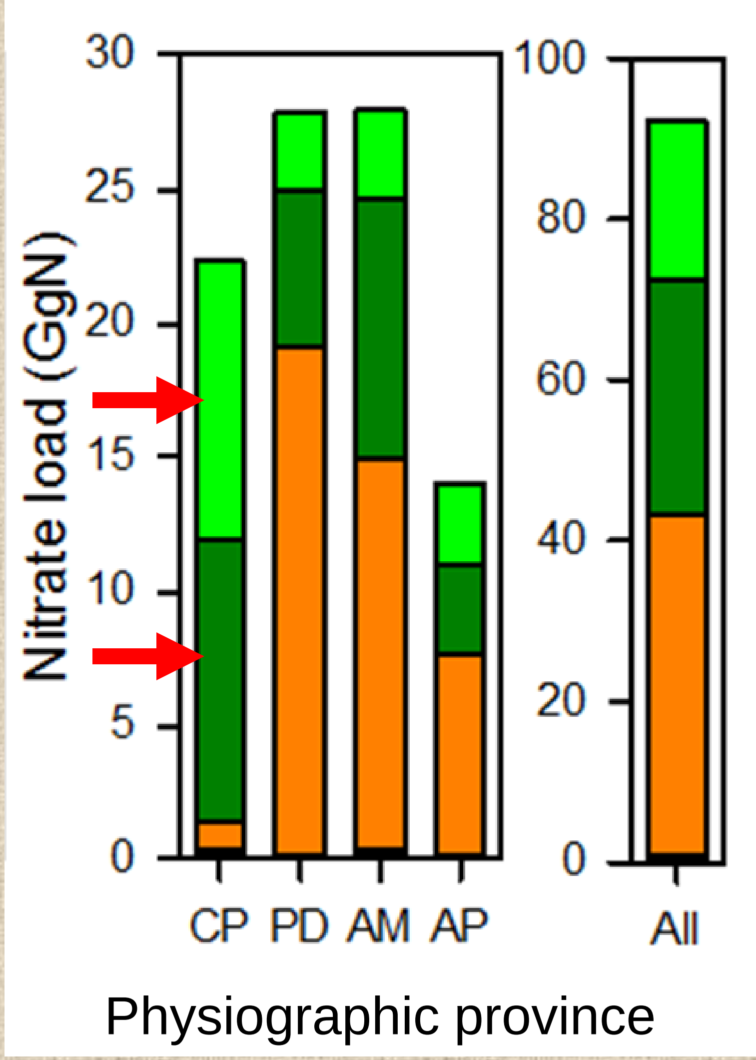
4-7 Considerably less

>10 Essentially none

Buffer model far more probable to be the correct one

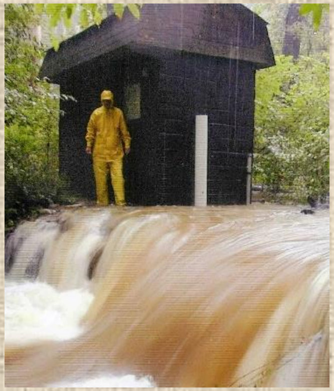
Weller & Baker 2014 *JAWRA* 50:696-712

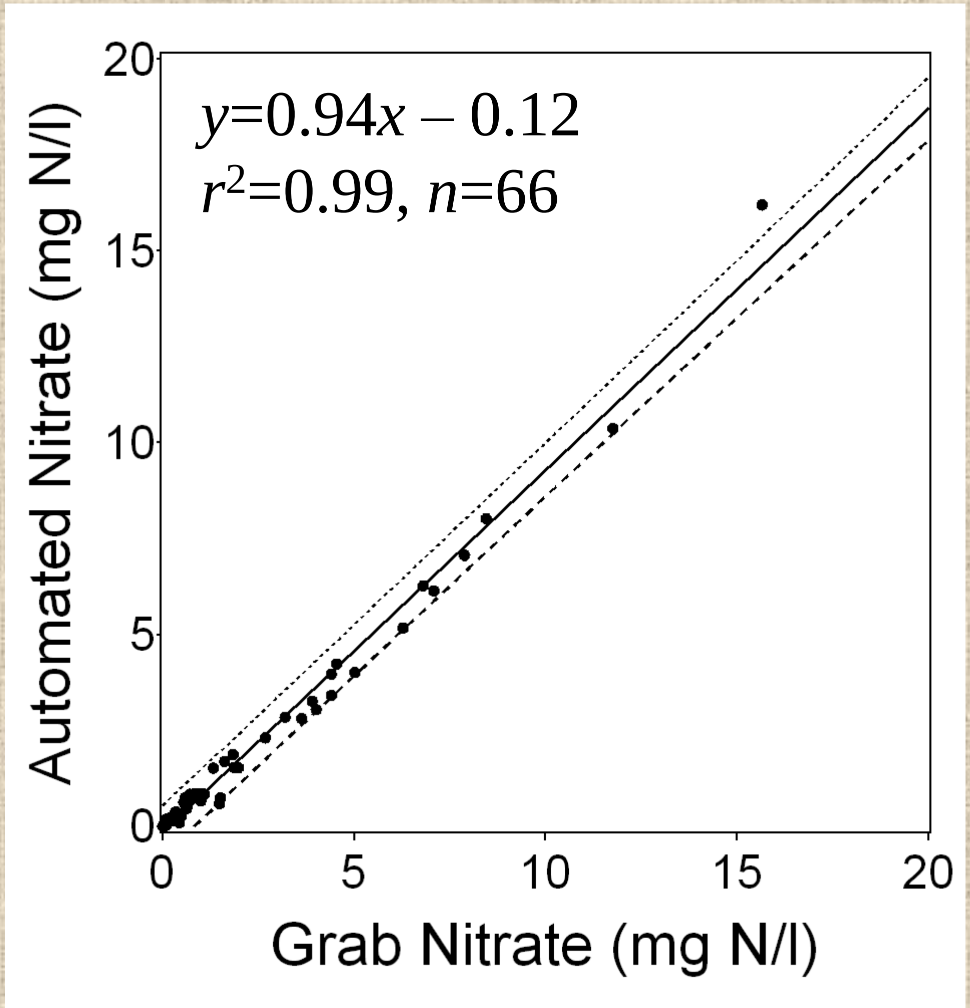
Differences among provinces



Weller & Baker 2014 *JAWRA* 50:696-712

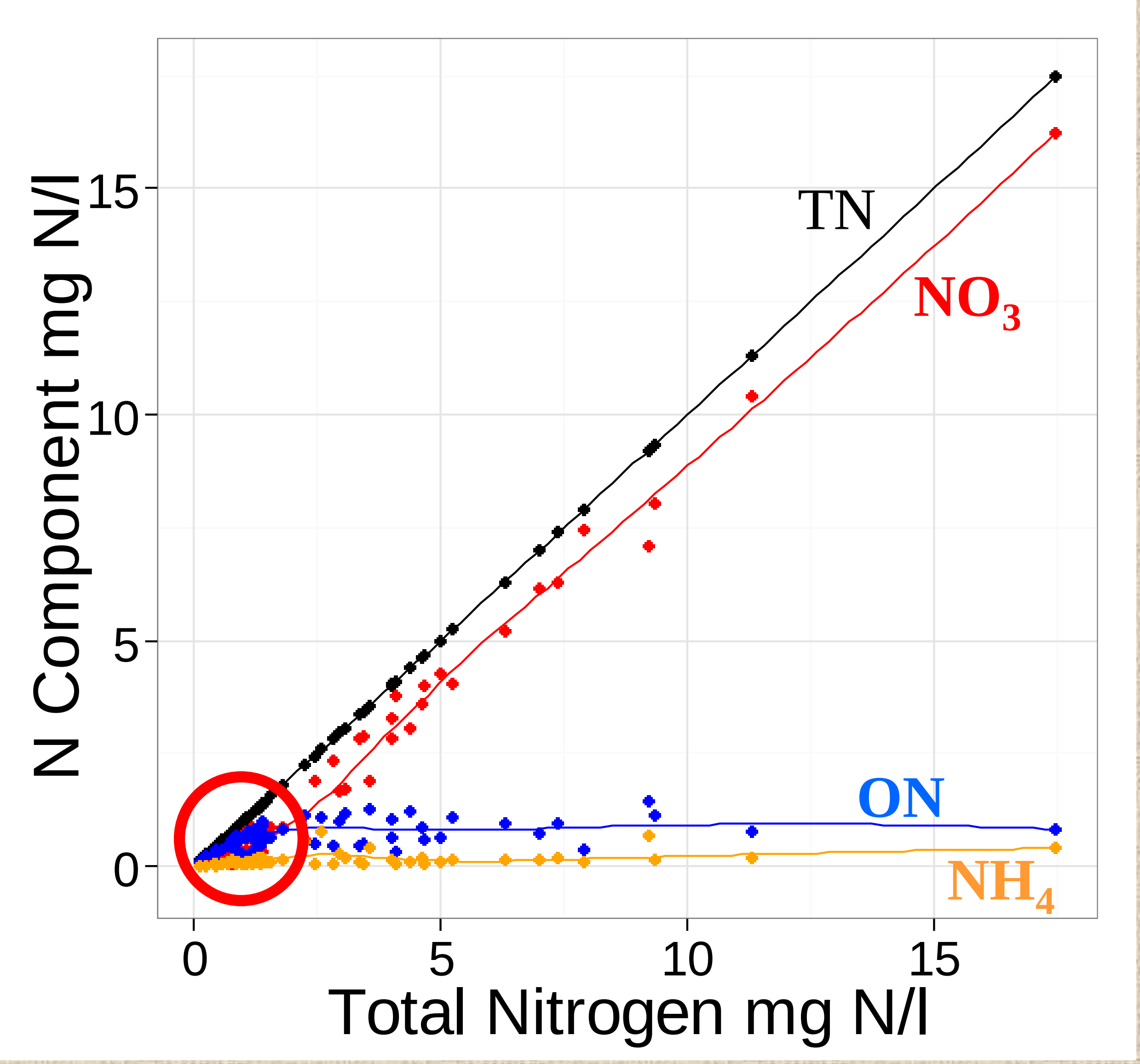
Seasonal baseflow nitrate sampling is a great N concentration indicator





Weller and Jordan *in prep.*

Really, it's the nitrate

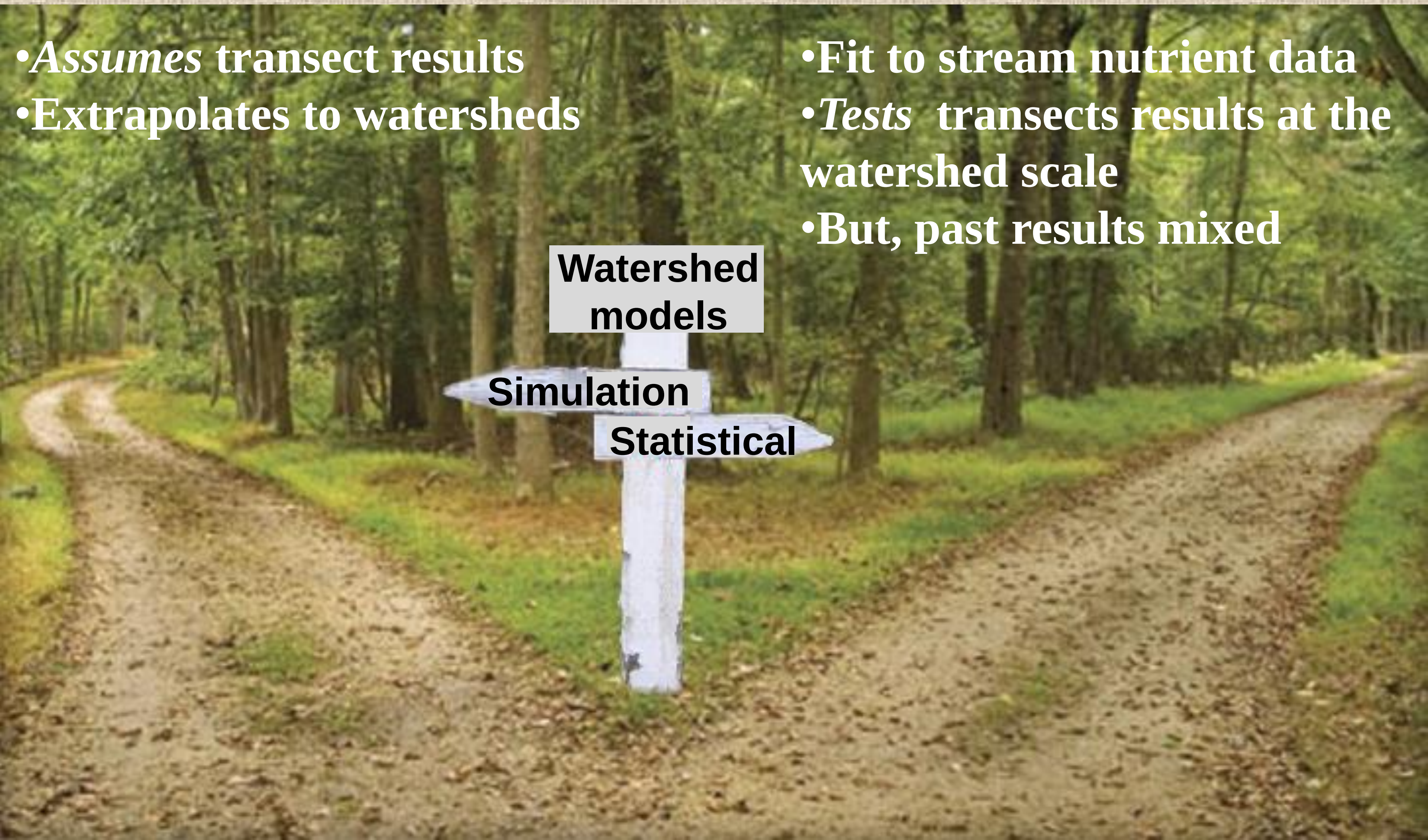


Weller and Jordan *in prep.*

"Scaling-up" from transects to watersheds

•*Assumes* transect results
•Extrapolates to watersheds

•Fit to stream nutrient data
•*Tests* transects results at the watershed scale
•But, past results mixed



If you had cancer and your doctor offered you a choice between an expensive medication with proven effectiveness and an inexpensive but untested medication that a panel of experts thought might work, what would you choose ?

VS.

Table 2. Statistical Significance p and Percentage of Variance Explained for Linear Models Relating Flow-Weighted Mean Concentrations of NO_3 to the Percentage of Cropland in the Watershed, the Base Flow Index, and the Province (Piedmont or Coastal Plain)

	Without 407		With 407	
Model Term	Variance Explained, %	p	Variance Explained, %	p
Percentage of cropland	51	0.0001	45	0.0001
Base flow index	69	0.0013	68	0.0003
Crop × base flow	85	0.0001	79	0.0019
Province	89	0.0085	86	0.0056
Crop × province	91	0.073	86	0.49
Base flow × province	93	0.065	87	0.13
Crop × base flow province	93	0.53	88	0.42

Each p value is for a particular model term. Each percentage of variance explained is for a model including the term on the line and all terms on previous lines. For all models that include terms on previous lines, $p < 0.0001$. Results are shown for models with and without the data from watershed 407, where NO_3 concentration was anomalously high.