



# **Evaluating changes in water quality with respect to non-point sources and best management practices**

**poster presented at the 2014 American Geophysical Union Meeting  
San Francisco, CA**

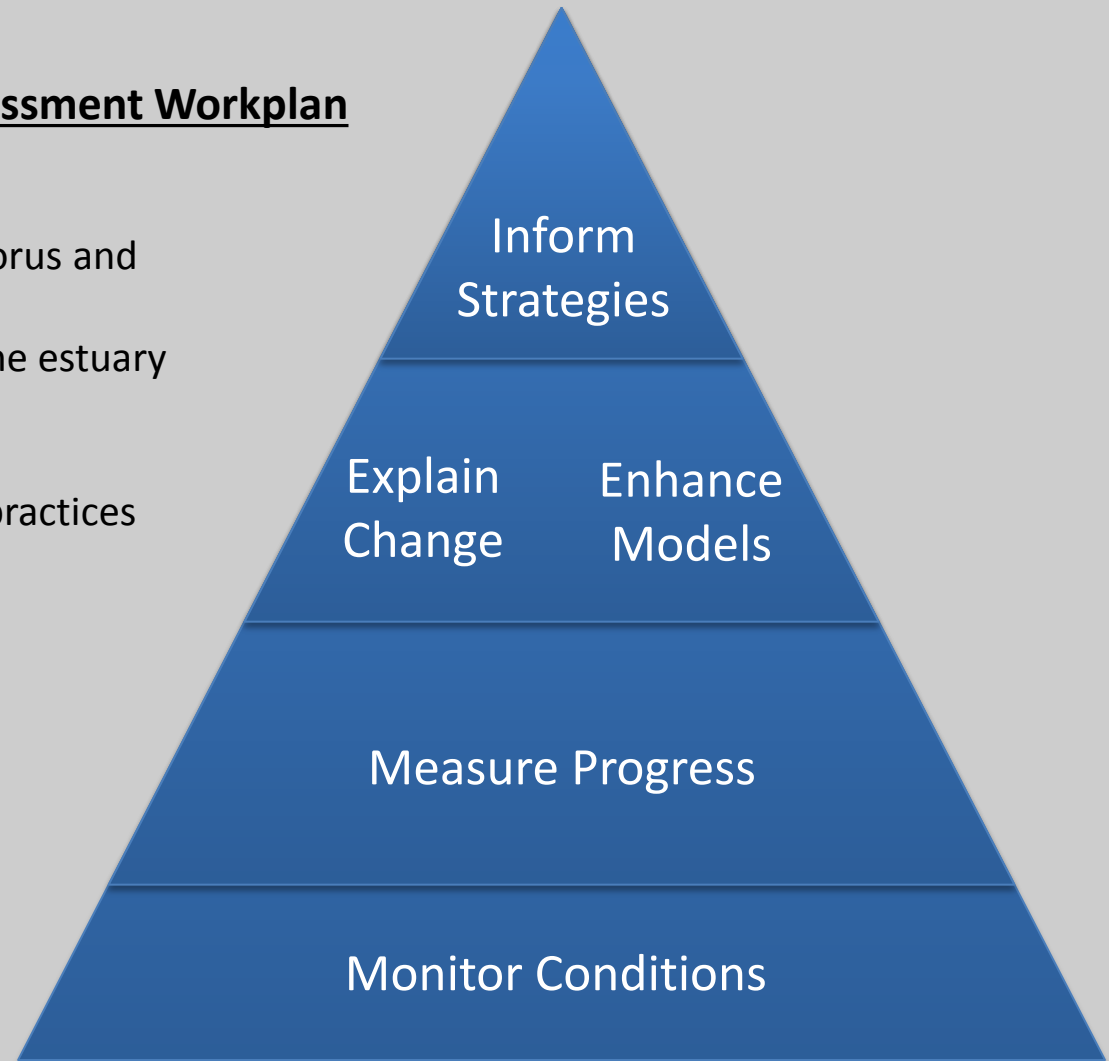
March 23, 2015  
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# Using Monitoring Data To Measure Progress and Explain Change

## STAR Workplan Elements

### Elements of STAR Mid-Point Assessment Workplan

1. Measure progress
  - Trends of nitrogen, phosphorus and sediment in the watershed.
  - Trends of water quality in the estuary
2. Explain water-quality changes
  - Response to management practices
3. Enhance CBP models
4. Inform management strategies
  - WIPs
  - Water-quality benefits



# Using Monitoring Data To Measure Progress and Explain Change

## comparative analysis generates hypotheses

### **Compare patterns in loads across watersheds**

- What do similar watersheds have in common?
- Which one of these is not like the others?

### **Where we see interesting patterns:**

- What can the models tell us about inputs and fluxes in these watersheds?
- What can data on nutrient sources and inputs tell us?
- How does this information compare with estimates of the effects of BMP implementation?

### **Integration of several complex datasets is required. Four components discussed here:**

1. Environmental setting/watershed characteristics
2. Water quality monitoring (nutrient fluxes)
3. Models
4. Nutrient sources/inputs and BMP implementation

# Using Monitoring Data To Measure Progress and Explain Change

## comparative analysis generates hypotheses

### Evaluating changes in water quality with respect to non-point source nutrient management strategies in the Chesapeake Bay watershed



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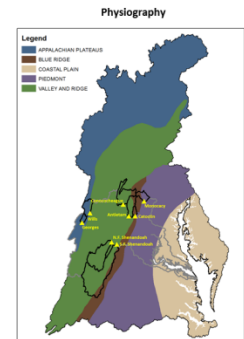
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#### I. Background

Chesapeake Bay is a eutrophic ecosystem with periodic hypoxia and anoxia, algal blooms, diminished submerged aquatic vegetation, and degraded stocks of marine life. Of the 5 major tributaries in its 64,000 mile watershed, the Potomac River is estimated to be the largest contributor of phosphorus (27%) and the 2nd largest contributor of nitrogen (22%) to the Bay. Knowledge of the effectiveness of actions taken across the watershed to reduce nitrogen (N) and phosphorus (P) loads to the bay (i.e. "best management practices" or BMPs) is essential to its restoration. A better understanding of the effects of BMPs on Potomac River nutrient loads will benefit restoration efforts across the Chesapeake watershed. To explore the relation of changes in nonpoint source inputs and BMP implementation to changes in water quality, a subset of 8 watersheds draining to the Potomac River were selected for a comparative study. Watersheds within the Potomac basin were selected based on the availability of long-term monitoring data.

Distinguishing the effects of non-point source BMP implementation from nutrient load reductions attributable to changes in other factors such as point-source (e.g. wastewater treatment plants and other industrial and municipal operations) inputs, land use change, and atmospheric deposition requires compilation and comparison of an array of complex datasets including water quality, land use, point source discharges, and BMP implementation.

#### Watershed Characteristics



Physiographic characteristics affect the hydrology of a region, thus the transport of pollutants from the landscape to local streams and rivers.

**The Appalachian Plateau** is a region of flat-lying to gently folded rocks. The high relief in the area (often exceeding 500 ft) is due to erosion by streams and rivers. Aquifer material is composed of fractured sedimentary rocks. Water yielding rocks are typically sandstones and, occasionally, coal seams.

**The Valley and Ridge** province is formed by a band of mountains and high plateaus (lower in elevation than the Appalachian region). Sedimentary rocks underlie the changing topography. The deep limestone soils make this region extremely fertile for farm fields.

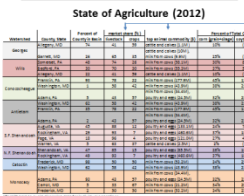
**The Blue Ridge** region consists of a narrow line of low mountains with ancient hard rocks, making it the most rugged of the provinces. The area is underlain by metamorphic, igneous, sedimentary, and carbonate rocks.

**The Piedmont** is characterized by gently rolling hills, underlain by metamorphic and igneous rocks with an overburden of unconsolidated material known as regolith.



Land use is a key factor driving patterns of N and P loads across the Chesapeake Bay watersheds.

Land use change from 1984-2006 was ~1% for the sub-watersheds identified here.

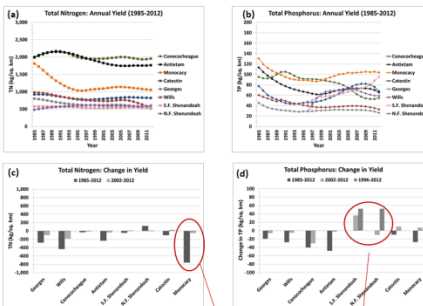


Economics influence agricultural practices

- Agricultural practices, fertilizer application, and irrigation requirements vary across crop types
- Some crops may be "leakier" than others

#### II. Results from Monitoring Data

##### Yields (a,b) and changes in yields (c,d) of N and P from 1985-2012



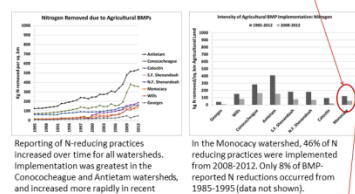
Water quality data collected from USGS long-term water quality monitoring gages were analyzed using the recently developed "Weighted Regressions on Time, Discharge, and Season" (WRTDS) statistical method. N and P loads were estimated using data for the 1985-2012 time period, and converted to yields for comparison across watersheds.

Comparison of changes over time across basins raises questions for further investigation. For example:

- Did the ~40% decrease in N yield from the Monocacy watershed between 1985- and 1995 correspond with any changes in agricultural practices, or non-point management actions occurring prior to or during that time period?
- Can data on P sources (inputs) to the Shenandoah sub-watersheds explain increased P yields from 1997 (and possibly earlier) to 2012? Were there identifiable differences in practices, independent of natural factors, that might explain why P yields from the S.F. Shenandoah increased in the past 10 years while yields from the N.F. Shenandoah remained relatively stable (or decreased slightly)?
- Can temporal and spatial patterns in anthropogenic N and P sources explain the similarities and differences over time between yields from the Conococheague and Antietam watersheds, which respond closely in physiography, geography, and land use?

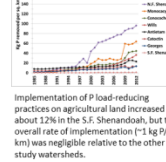
#### IV. BMPs and Interacting Factors

##### Intensity of BMP Implementation on agricultural lands



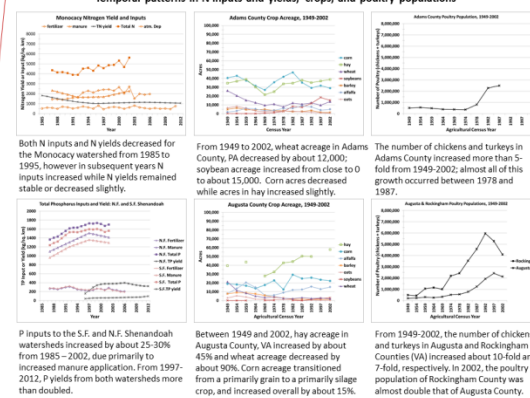
Reporting of N-reducing practices increased over time for all watersheds. Implementation was greatest in the Conococheague and Antietam watersheds, and increased more rapidly in recent years.

In the Monocacy watershed, 46% of N reducing practices were implemented from 2008-2012. Only 8% of BMP-reported N reductions occurred from 1985-1995 (data not shown).



In contrast, estimated P load reductions due to reported BMP implementation in the N.F. Shenandoah increased by 97 kg P/kg. km of agricultural land in the same time period; more than any other watershed.

##### Monocacy and Shenandoah Watersheds: Temporal patterns in N inputs and yields, crops, and poultry populations



Both N inputs and N yields decreased for the Monocacy watershed from 1985 to 1995, however in subsequent years N inputs increased while N yields remained stable or decreased slightly.

From 1949 to 2002, wheat acreage in Adams County, PA decreased by about 12,000 soybean acreage increased from close to 0 to about 15,000. Corn acres decreased while acres in hay increased slightly.

The number of chickens and turkeys in Adams County increased more than 5-fold from 1949-2002; almost all of this growth occurred between 1978 and 1987.

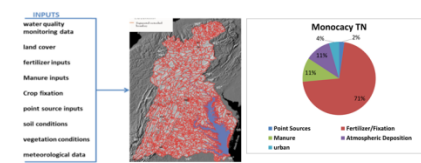
P inputs to the S.F. and N.F. Shenandoah watersheds increased by about 25-30% from 1985-2002, due primarily to increased manure application. From 1997-2012, P yields from both watersheds more than doubled.

Between 1949 and 2002, hay acreage in Augusta County, VA increased by about 45% and wheat acreage decreased by about 90%. Corn acreage transitioned from a primarily grain to a primarily silage crop, and increased overall by about 15%.

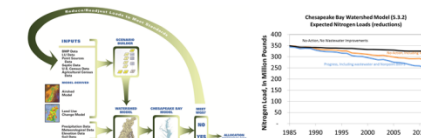
From 1949-2002, the number of chickens and turkeys in Augusta County and Rockingham Counties (VA) increased about 10-fold and 7-fold, respectively. In 2002, the poultry population of Rockingham County was almost double that of Augusta County.

#### III. Results from Models

##### The SPARROW Chesapeake Bay Model



##### The Suite of Chesapeake Bay Program Models used for TMDL development and implementation



The Phase 5.3 Chesapeake Watershed TMDL Model simulates Chesapeake watershed land use, river flows, and the associated transport and fate of nutrient and sediment loads to the Chesapeake Bay, in conjunction with models of the Chesapeake ained and estuary, it provides estimates of management actions needed to protect water quality, achieve Chesapeake water quality standards, and restore aquatic living resources in the Chesapeake Bay.

SPARROW (Spatially Referenced Regression On Watershed Attributes) models are statistical tools that can be used to explain in-stream measurements of water quality in relation to up-stream sources and watershed processes. The SPARROW Chesapeake Bay model was constructed to attribute 2002-year N and P loads at USGS long-term monitoring sites to inputs from atmospheric deposition, fertilizer, manure, urban, point-source, and select natural sources. SPARROW attributed 71% of nitrogen yields from the Monocacy River watershed to inputs from fertilizer, and about half of P loads from the N.F. Shenandoah to inputs from manure application.

#### V. Discussion

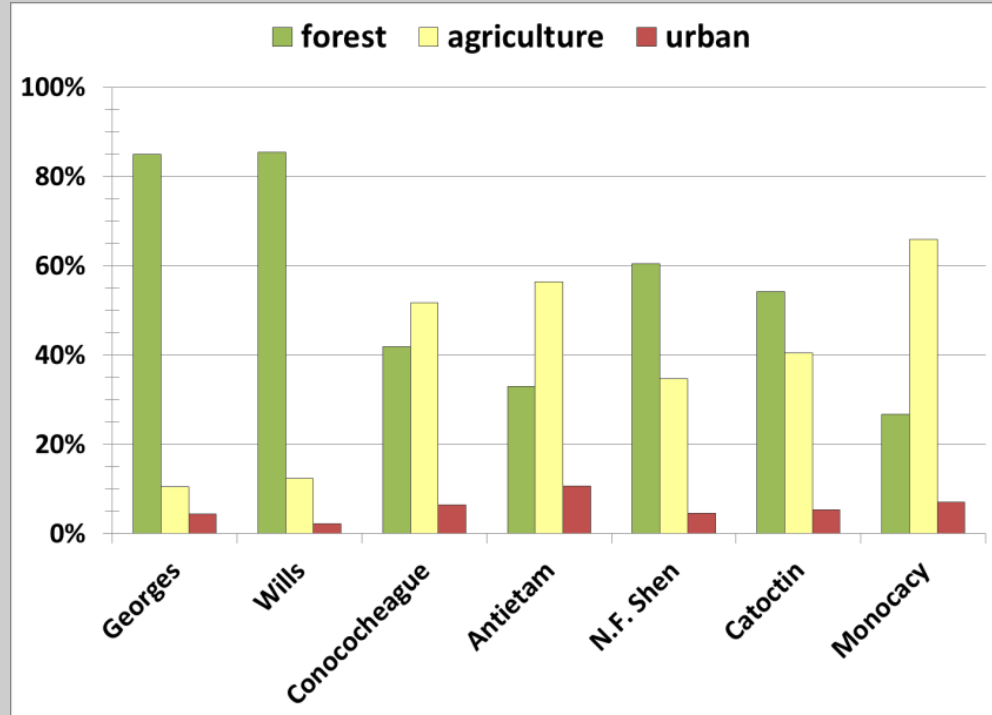
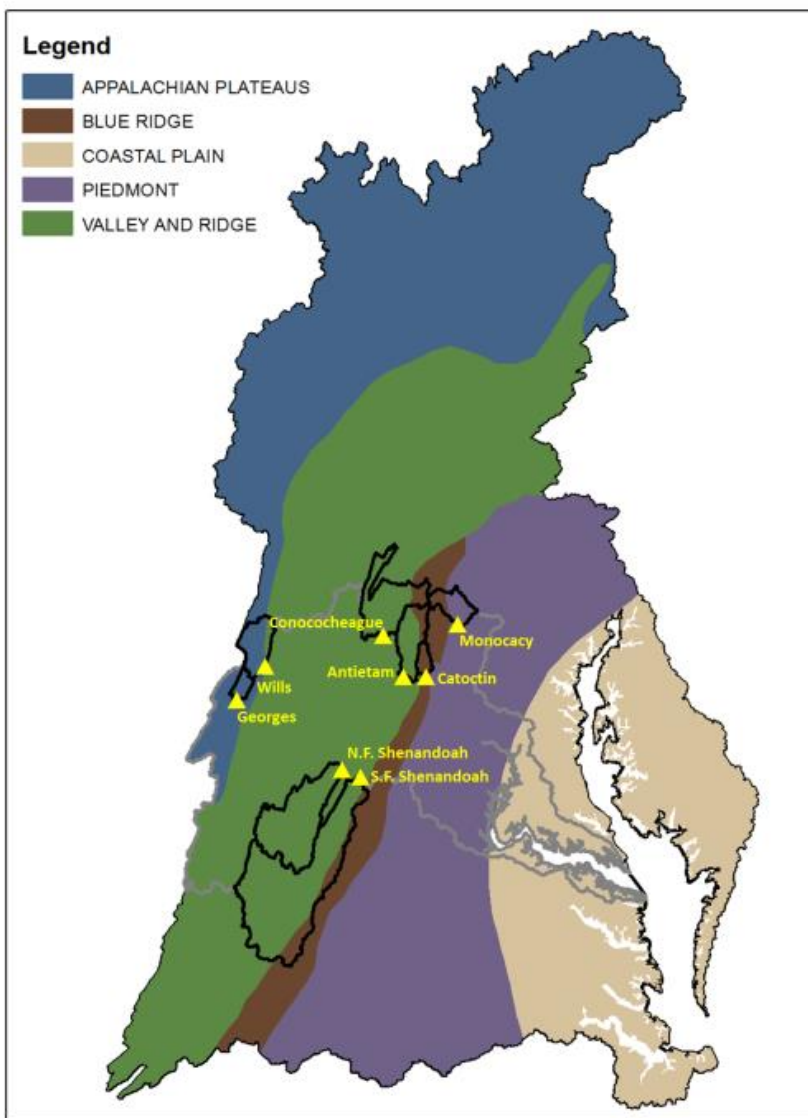
Comparison of water quality yields over time identified watersheds with contrasting patterns of change, and generated questions for further study. For example, the rapid decrease in N yields from the Monocacy watershed suggests that a distinct change in N inputs may have occurred there—but not in the other watersheds—prior to 1995. Similarly, the increase in P yields from the Shenandoah watershed during a time when P yields decreased across the other 6 watersheds suggest that temporal patterns in the factor(s) driving Shenandoah P yields contrasts with patterns of these factors in the other watersheds. However, differences in P yields may be due to north-south differences in environmental characteristics as well as to differences in P inputs.

Results from the Chesapeake SPARROW model suggest that fertilizer dominates modern N yields from the Monocacy, while manure is the dominant source of P yields in the Shenandoah watersheds. However, temporal patterns in fertilizer inputs increased in the Monocacy during the monitoring period. Lack of data prior to 1985 make it difficult to determine whether pre-1985 patterns in fertilizer and/or input drove this change. Temporal patterns in crop acreage since 1949 in Adams County, PA (which comprises 90% of the Monocacy watershed) did not reveal any obvious, large changes prior to 1995. The rapid increase in poultry populations between 1978 and 1987 would likely lead to larger rather than smaller N inputs to the Monocacy River. Implementation of BMPs in the Monocacy showed no dramatic increase prior to 1995; without more spatially explicit data on those practices it is difficult to discern whether the location or type of an individual practice could have had a relatively larger impact on yields in spite of the modest increase in BMPs overall. Integrating information on groundwater lag times derived from groundwater models might help to identify the most likely time period of interest: long lag times may indicate that the causes of decreased N yields occurred prior to the monitoring period.

The combination of increased manure-derived P inputs with a lack of BMP implementation may have contributed to increasing P yields from the S.F. Shenandoah watershed. P yields from the S.F. increased primarily in the past 10 years, while P yields from the N.F. decreased slightly over the same time period. BMP implementation also increased in the S.F. relative to the S.F. in recent years. The dramatic increase in the poultry populations of Augusta and Rockingham counties could have affected P yields from the S.F.

While comparison of temporal patterns in these datasets generates intriguing hypotheses for further study, care must be taken to avoid inferring causality from patterns such as those observed in the Shenandoah watersheds. Further analysis with both traditional and novel statistical and modeling methods are required to distinguish the effects of non-point source management actions from other drivers of water quality change, particularly given the need to integrate such diverse and complex datasets. Current and future work is focused on identifying and applying such approaches.

# 1. Watershed characteristics



- Land use is a key factor driving patterns of N and P loads across the Chesapeake Bay watershed.
- Land use change from 1984-2006 was  $\leq 1\%$  for the sub-watersheds identified here.

# 1. Watershed characteristics

- Economics influence agricultural practices

- Agricultural practices, fertilizer application, and irrigation requirements vary across crop types

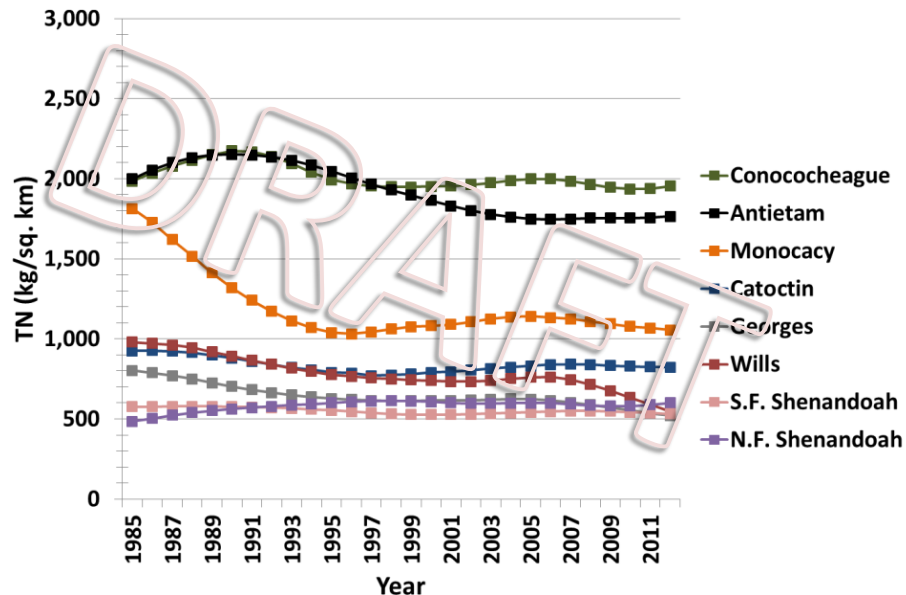
Watershed	County, State	Percent of County in Basin	market share (%)		top animal commodity (\$)	Percent of Total Crop Acres		
			livestock	crops		corn (grain+silage)	soybeans	forage
Georges	Allegany, MD	74	41	59	cattle and calves (1.1M)	10%	(D)	90%
	Garrett, MD	26	65	35	cattle and calves (10M), milk from cows (9.9M)	25%	(D)	71%
Wills	Somerset, PA	48	74	26	milk from cows (58.1M)	30%	8%	57%
	Bedford, PA	30	70	30	milk from cows (55.3M)	37%	5%	55%
	Allegany, MD	22	41	59	cattle and calves (1.1M)	10%	(D)	90%
Conococheague	Franklin, PA	93	78	22	milk from cows (177.9M)	45%	12%	38%
	Washington, MD	1	58	42	milk from cows (43.9M)	38%	21%	31%
	Adams, PA	5	43	57	milk from cows (34.4M), poultry and eggs (24.5M)	32%	23%	33%
Antietam	Washington, MD	62	58	42	milk from cows (43.9M)	38%	21%	31%
	Franklin, PA	35	78	22	milk from cows (177.9M)	45%	12%	38%
	Adams, PA	2	43	57	milk from cows (34.4M), poultry and eggs (24.5M)	32%	23%	33%
S.F. Shenandoah	Augusta, VA	45	88	12	poultry and eggs (133.1M)	24%	7%	65%
	Rockingham, VA	29	93	7	poultry and eggs (460.6M)	37%	10%	50%
	Page, VA	18	96	4	poultry and eggs (121.0M)	27%	4%	62%
	Warren, VA	5	63	37	cattle and calves (2.5M)	2%	(D)	97%
N.F. Shenandoah	Shenandoah, VA	47	85	15	poultry and eggs (85.5M)	28%	10%	62%
	Rockingham, VA	49	93	7	poultry and eggs (460.6M)	37%	10%	50%
Catoctin	Frederick, MD	98	50	50	milk from cows (53.2M)	34%	25%	31%
	Washington, MD	62	58	42	milk from cows (43.9M)	38%	21%	31%
Monocacy	Adams, PA	93	43	57	milk from cows (34.4M), poultry and eggs (24.5M)	32%	23%	33%
	Carroll, MD	5	33	67	milk from cows (21.2M)	34%	29%	26%
	Frederick, MD	2	50	50	milk from cows (53.2M)	34%	25%	31%

(D) Withheld to avoid disclosing data for individual operations

## 2. Water quality monitoring

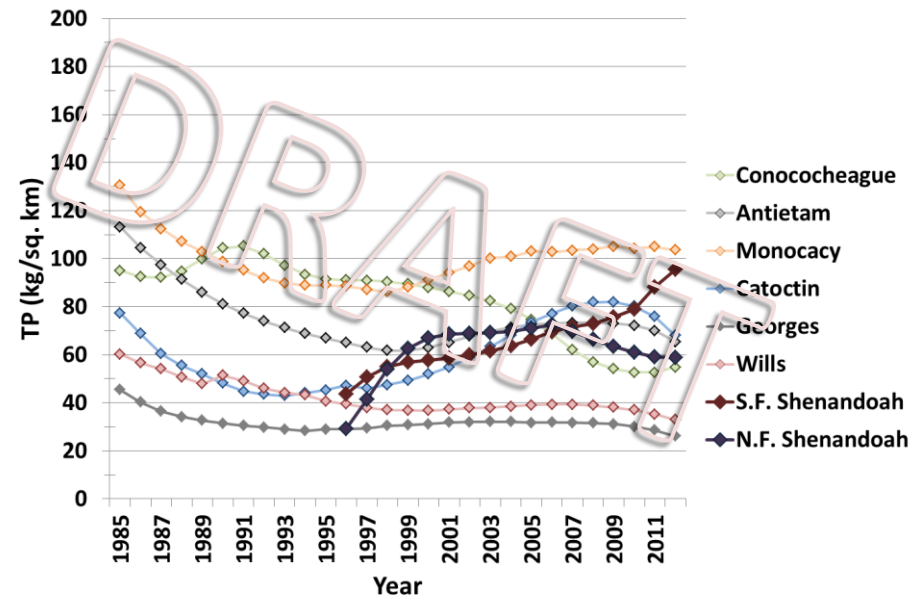
Comparison of changes over time across basins raises questions for further investigation.

Total Nitrogen: Annual Yield (1985-2012)



Can temporal and spatial patterns in anthropogenic N inputs explain the decrease in N yield from the Monocacy watershed from 1985-1995?

Total Phosphorus: Annual Yield (1985-2012)



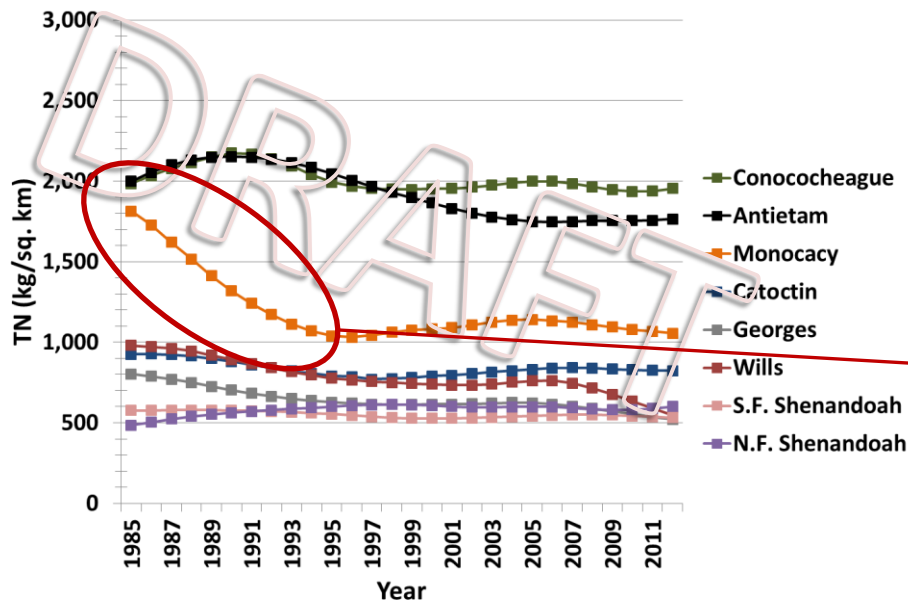
Can temporal and spatial patterns in anthropogenic N inputs explain the differences in P yields from the N.F. and S.F. Shenandoah watersheds from 1996 – 2012?



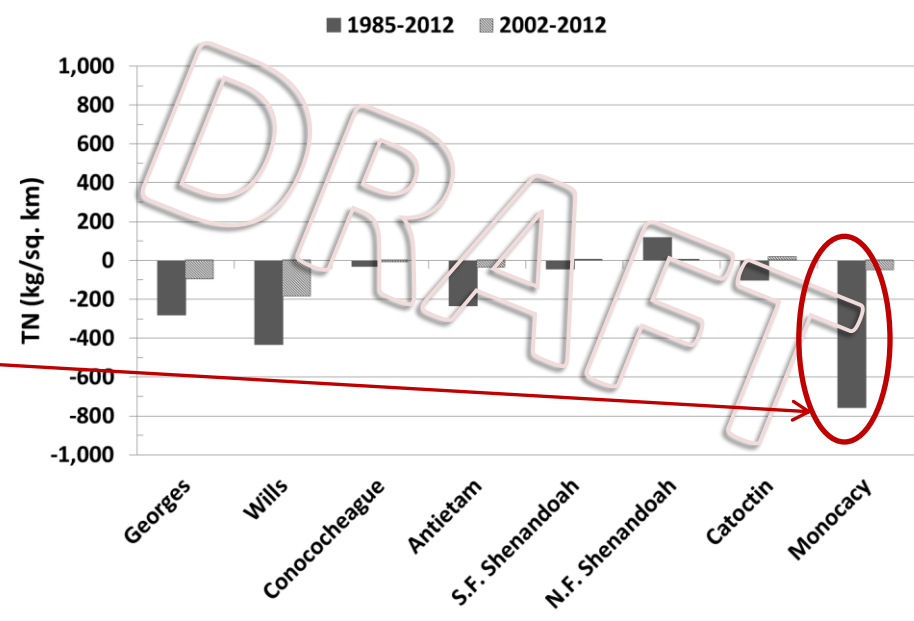
## 2. Water quality monitoring

Did the ~40% decrease in N yield from the Monocacy watershed between 1985- and 1995 correspond with any changes in agricultural practices or non-point management actions occurring prior to or during that time period?

Total Nitrogen: Annual Yield (1985-2012)



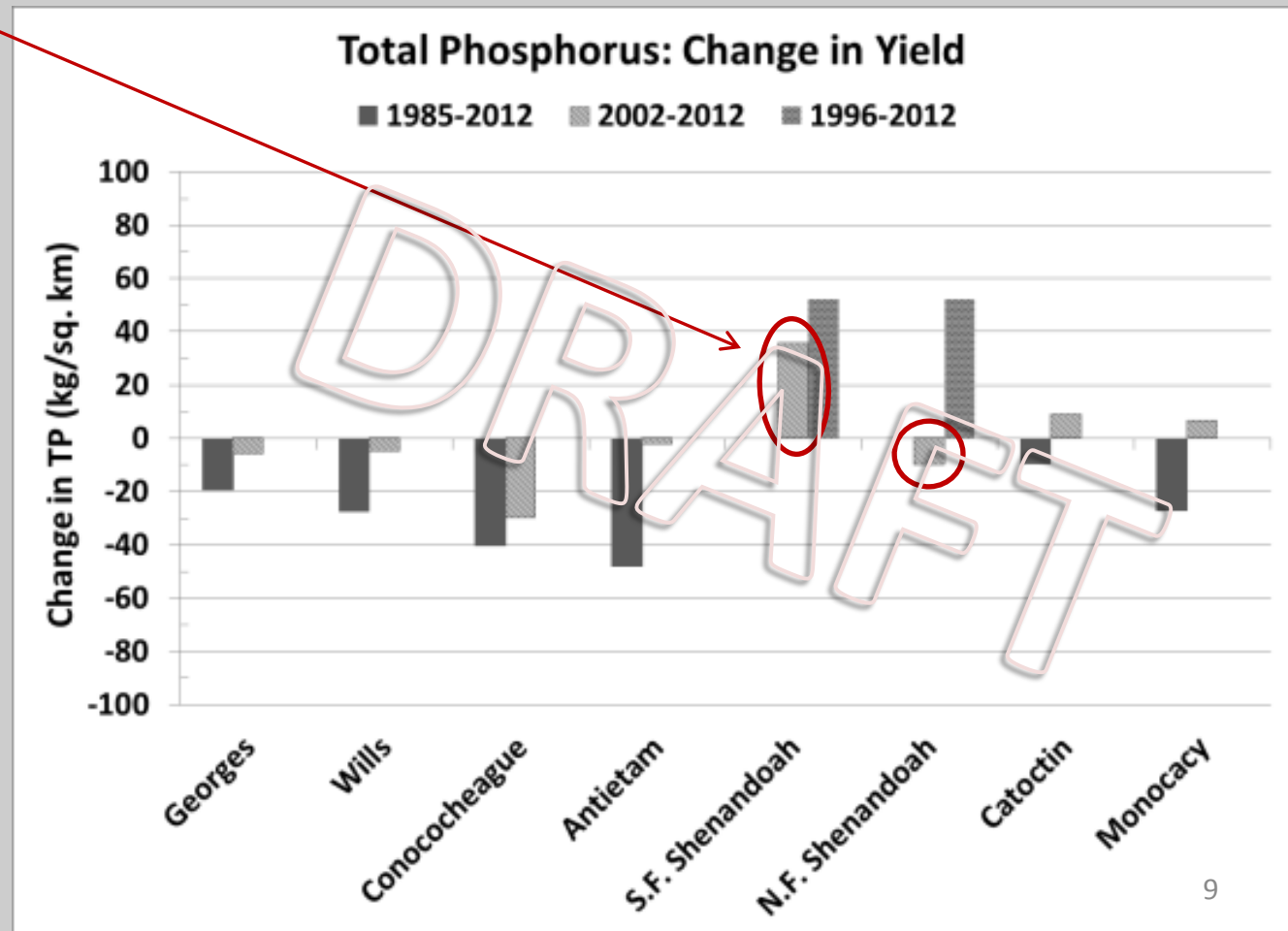
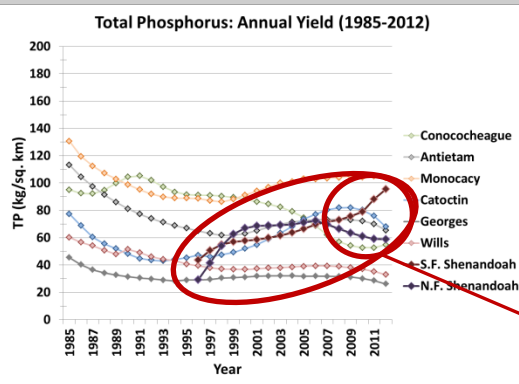
Total Nitrogen: Change in Yield





## 2. Water quality monitoring

Were there identifiable differences in practices, independent of natural factors, that might explain why P yields from the S.F. Shenandoah increased in the past 10 years while yields from the N.F. Shenandoah remained relatively stable (or decreased slightly)?



### 3. Models: 2002 SPARROW

#### INPUTS

water quality  
monitoring data

land cover

fertilizer inputs

Manure inputs

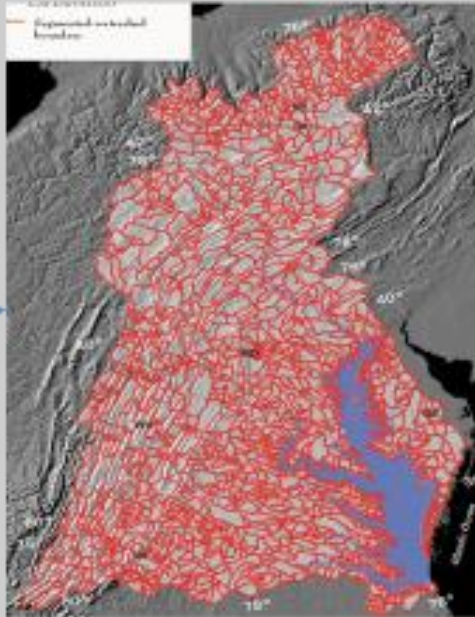
Crop fixation

point source inputs

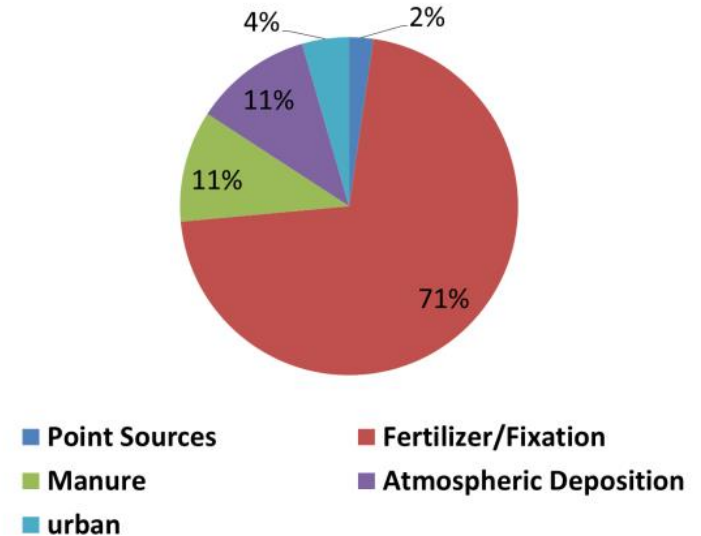
soil conditions

vegetation conditions

meteorological data

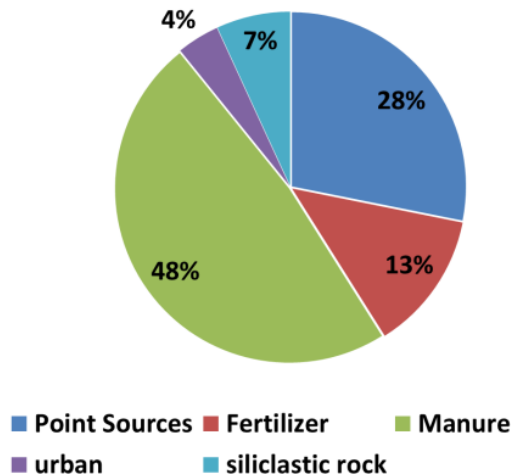


#### Monocacy TN



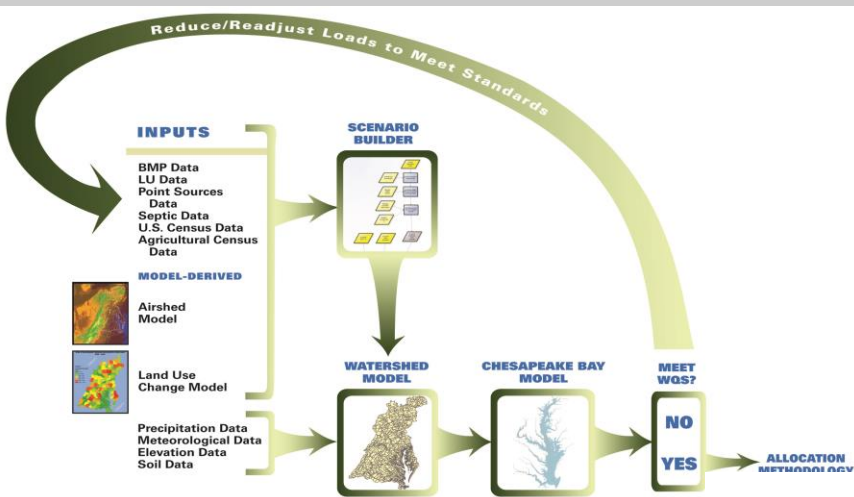
Fertilizer accounts for about 70% of nitrogen yields from the Monocacy watershed.

#### N.F. Shenandoah



Manure is the dominant component of phosphorus loads from the N.F. Shenandoah

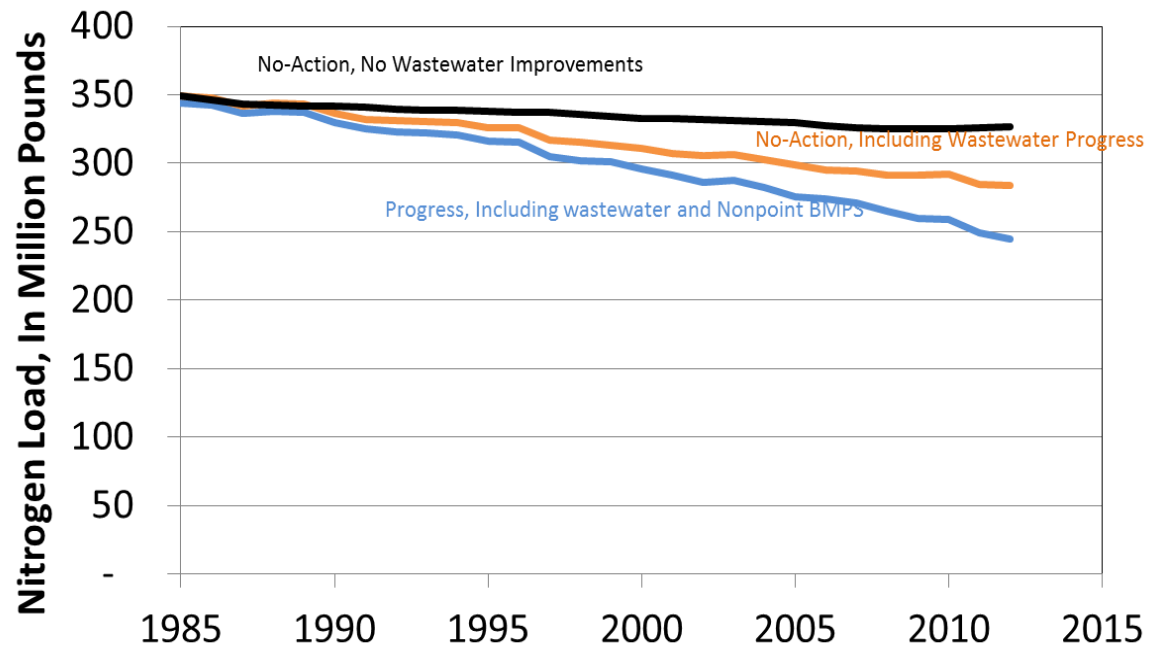
### 3. Models: CBP Modeling Suite



- “No Action” scenarios = No BMPs implemented
- “Progress” scenarios = BMPs “on the ground” as of each year were simulated.

Estimates of expected nutrient load reductions due to reported implementation of non-point source BMPs.

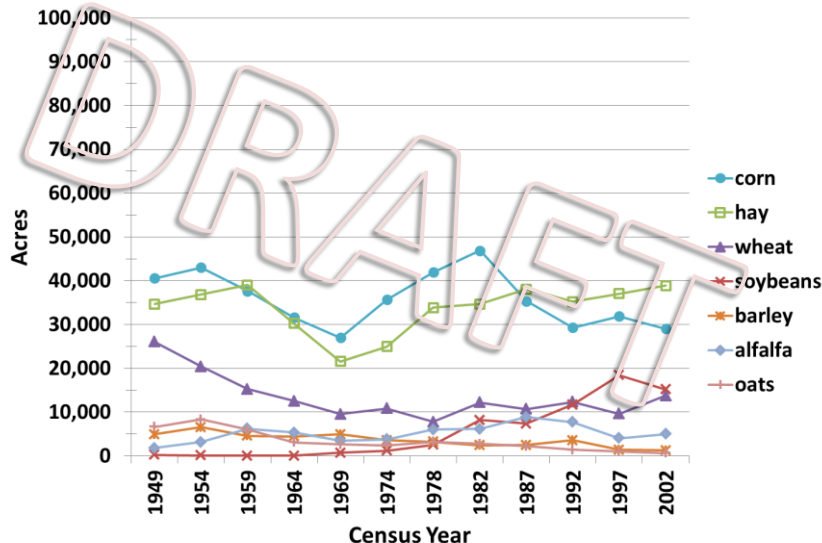
Chesapeake Bay Watershed Model (5.3.2)  
Expected Nitrogen Loads (reductions)



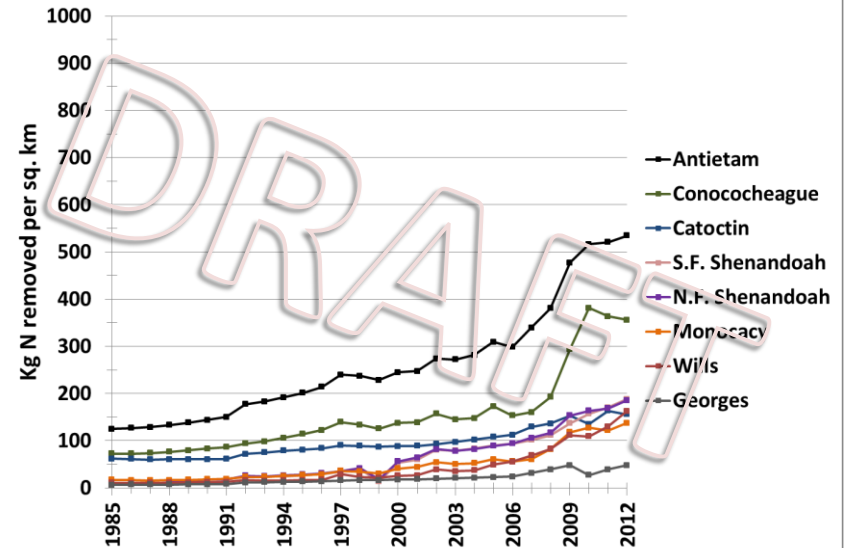
# 4. N inputs and interacting factors

- Manure inputs appeared to decrease between 1985 and 1993, while fertilizer inputs increased slightly.
- Corn acres decreased between 1982 and 2002
- BMP implementation inconclusive

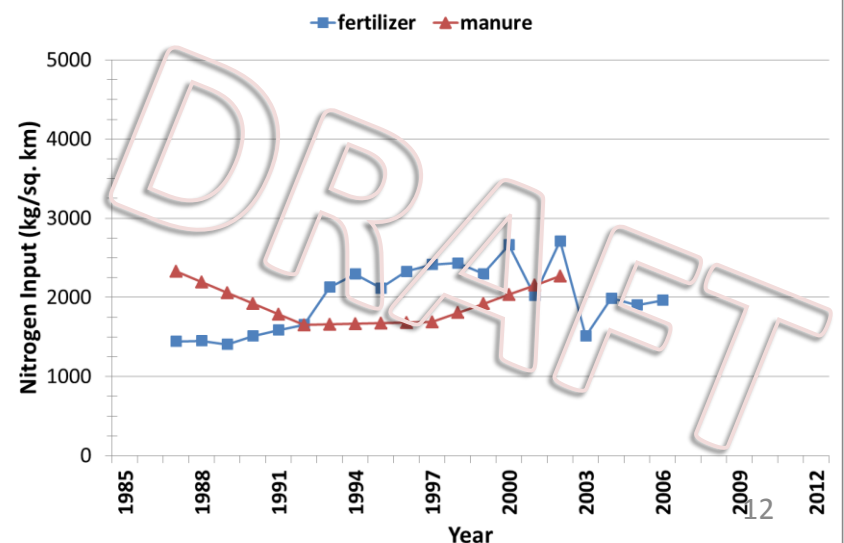
Adams County Crop Acreage, 1949-2002



Nitrogen Removed due to Agricultural BMPs



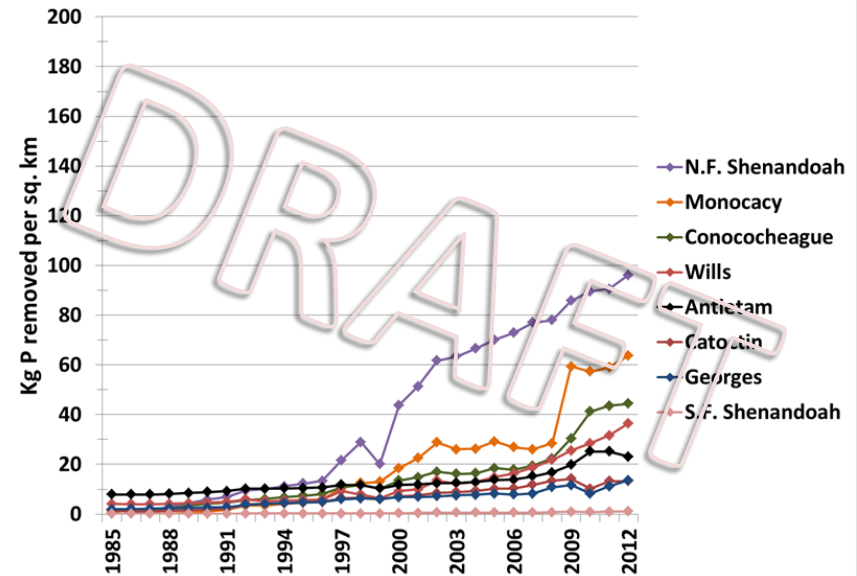
Monocacy Nitrogen inputs



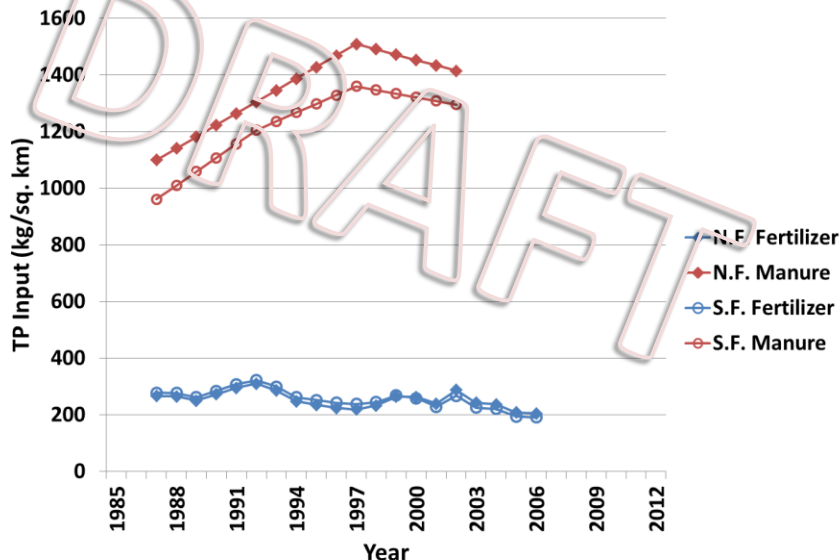
# 4. P inputs and interacting factors

- Manure inputs increased substantially from 1987 – 1997, and decreased thereafter, while fertilizer inputs decreased steadily
- Poultry populations increased dramatically between 1970 and 1997
- Large increase in BMP implementation from 2000 – 2012 in the N.F. Shenandoah, but not in the S.F.

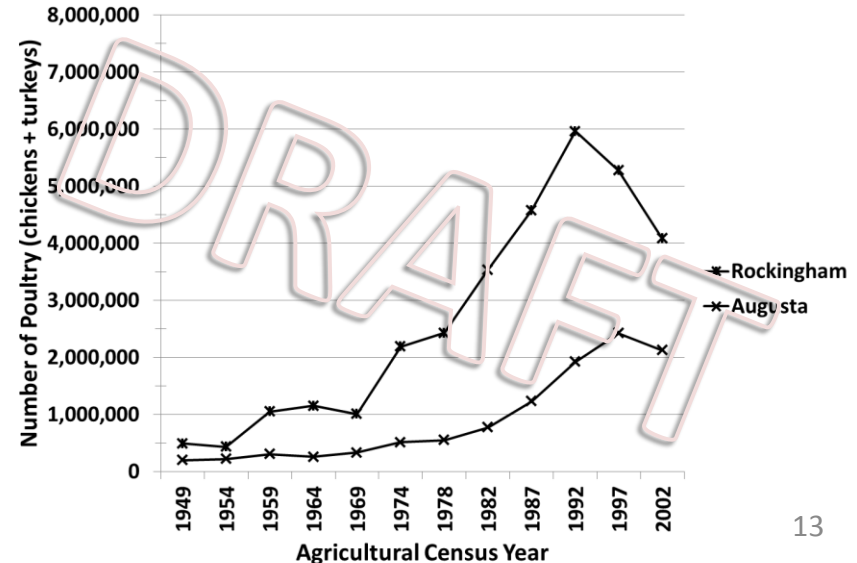
Phosphorus Removed due to Agricultural BMPs



Total Phosphorus Inputs: N.F. and S.F. Shenandoah



Augusta & Rockingham Poultry Populations, 1949-2002



# Using Monitoring Data To Measure Progress and Explain Change

## comparative analysis generates hypotheses

### Compare patterns in nutrient yields across watersheds

- The Monocacy watershed displayed a large decrease in N yield not observed in other Potomac sub-basins
- The North Fork and South Fork Shenandoah showed increases in P yield between 1985 – 2012, while P yields from other basins decreased.
- P yields from the N.F. decreased in recent years while P yield from the S.F. increased

### Where we see interesting patterns:

- SPARROW (2002) suggests that fertilizer inputs **MAY** be responsible for the majority of nitrogen fluxes from the Monocacy, while manure **MAY** be responsible for most of the phosphorus leaving the N.F. and S.F. Shenandoah watersheds.
- CBP models allow us to compare these patterns with estimates of the effects of BMP implementation

### Integrating information across data and models:

- Identifies areas for further study
- Generates **HYPOTHESES**

**Both traditional and novel statistical and modeling methods are required to distinguish the effects of non-point source management actions from other drivers of water quality change**

# Inform Management Strategies

## Midpoint Assessment Timeline

