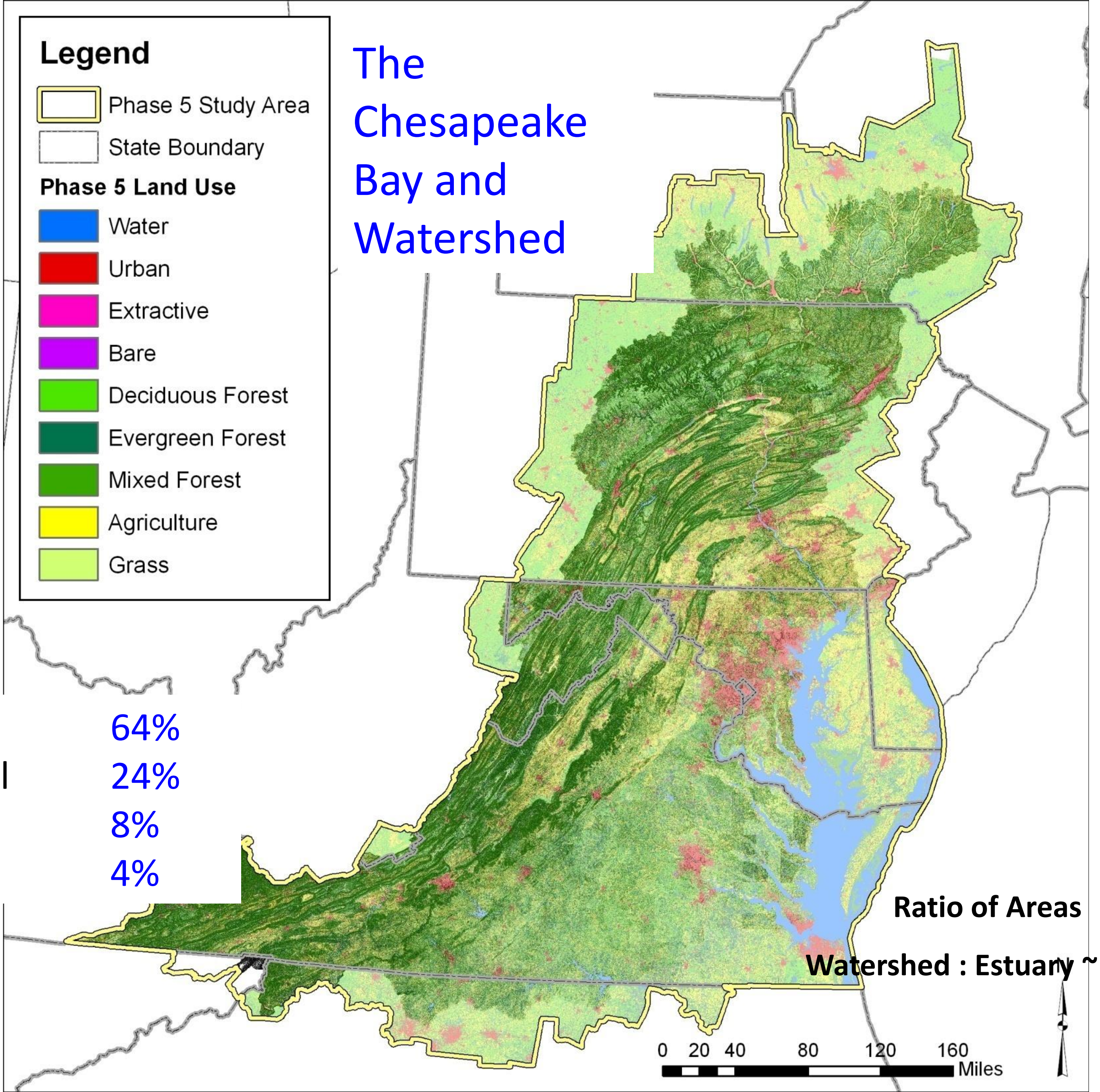
CBP Watershed Model
STAC Panel on P simulation

Gary Shenk

2/6/2012

The Chesapeake Bay and Watershed



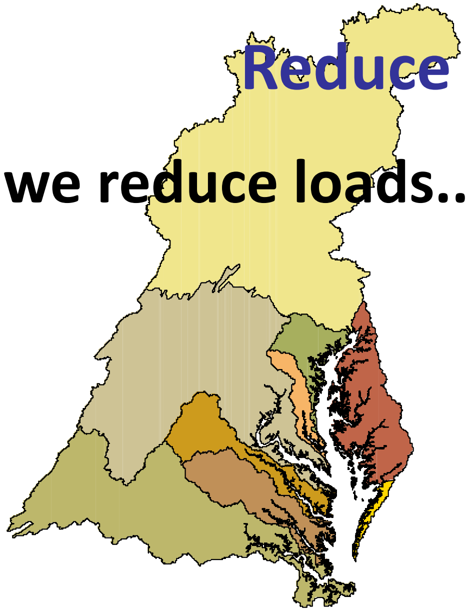
Forest	64%
Agricultural	24%
Urban	8%
Other	4%

Ratio of Areas

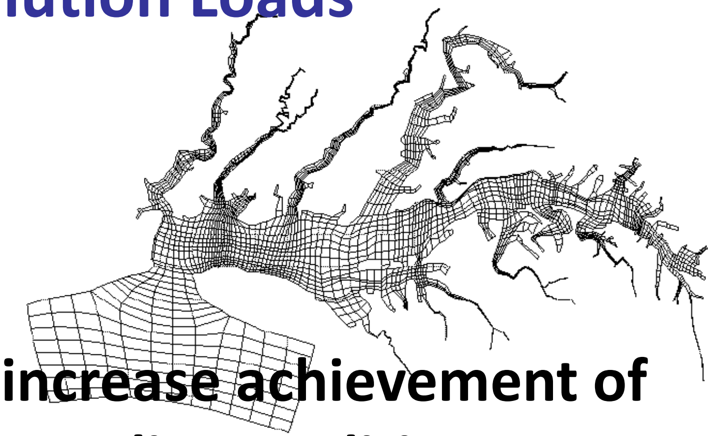
Watershed : Estuary ~ 15:1

2

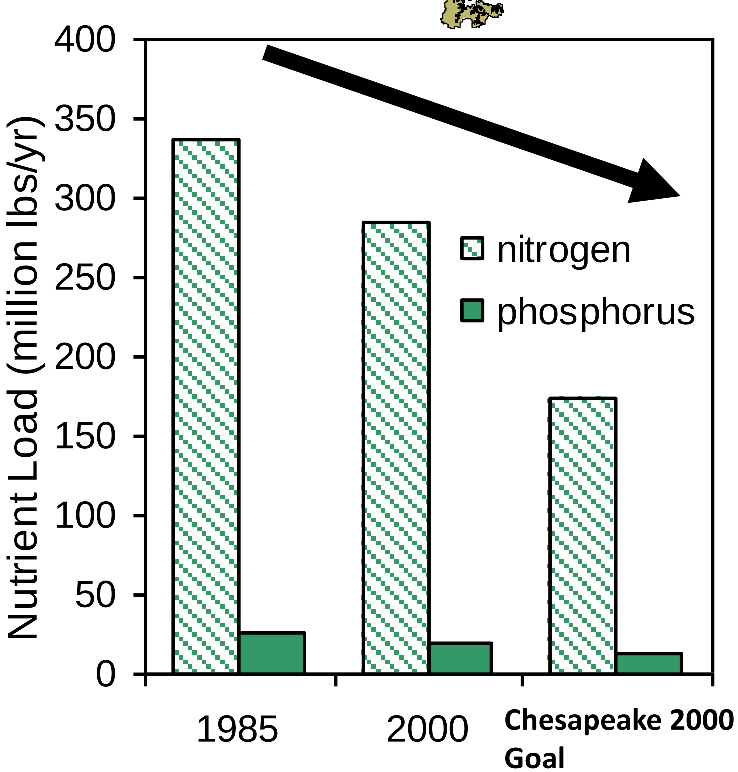
Reduce Nutrient Pollution Loads

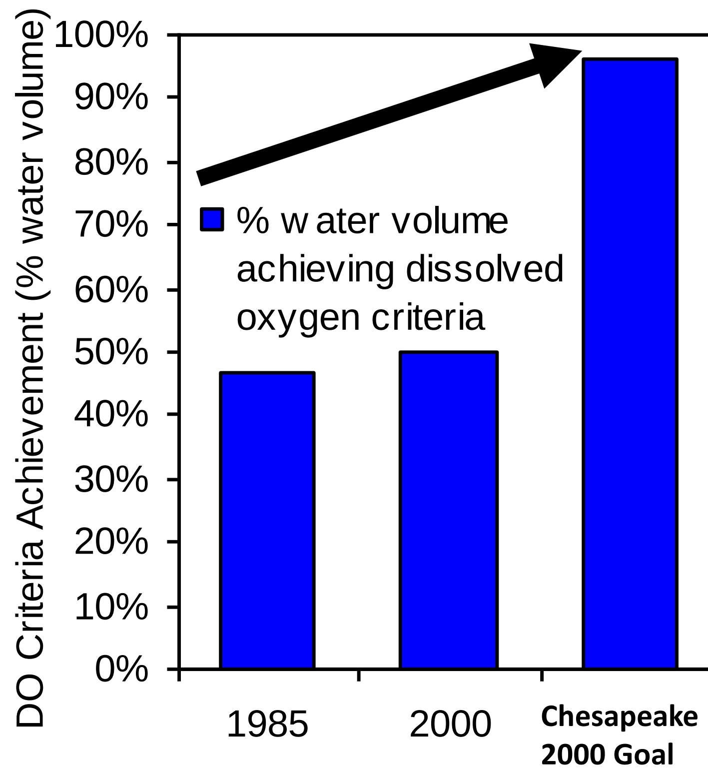


As we reduce loads...



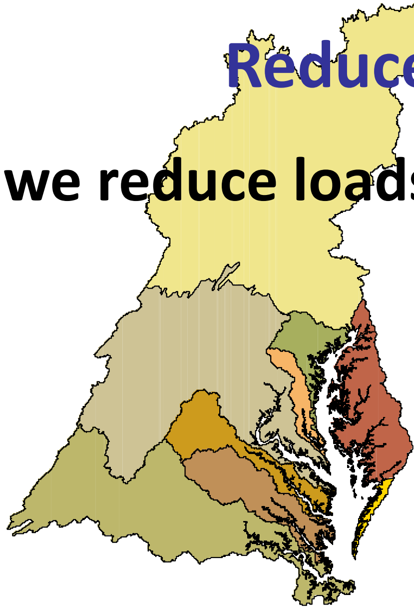
...we increase achievement of water quality conditions.

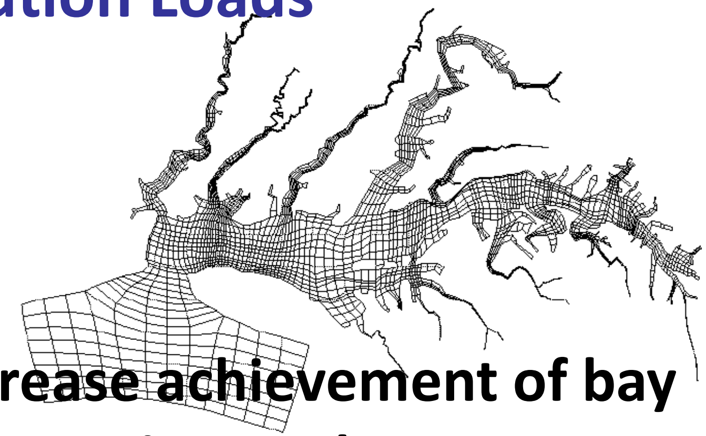




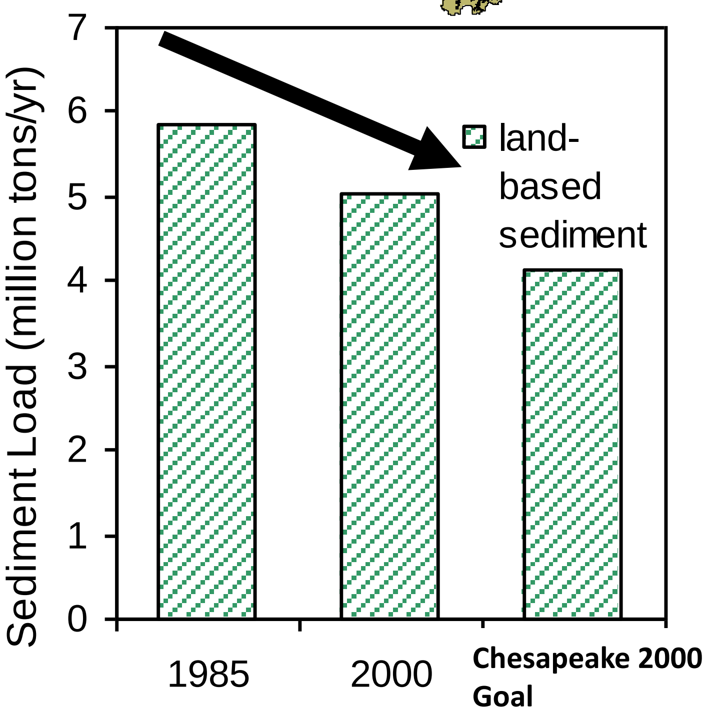
Reduce Sediment Pollution Loads

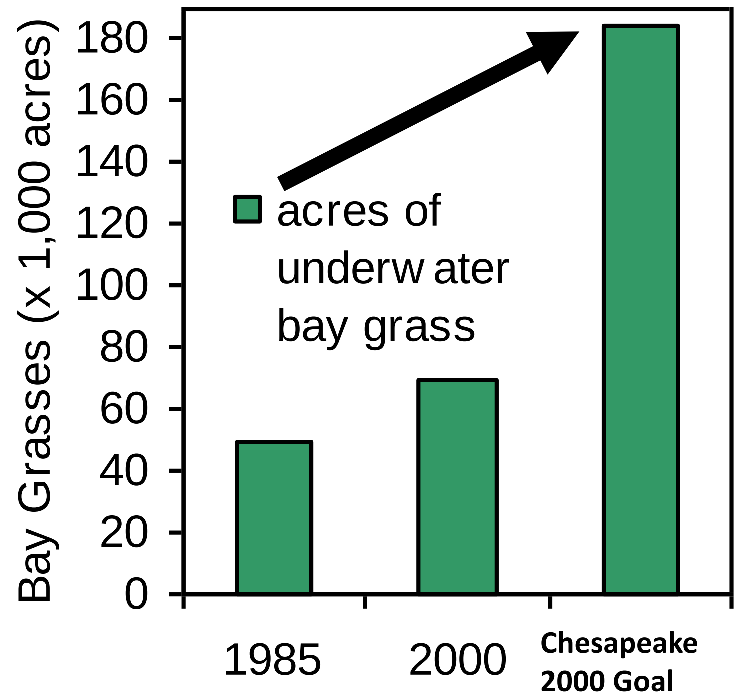
As we reduce loads...



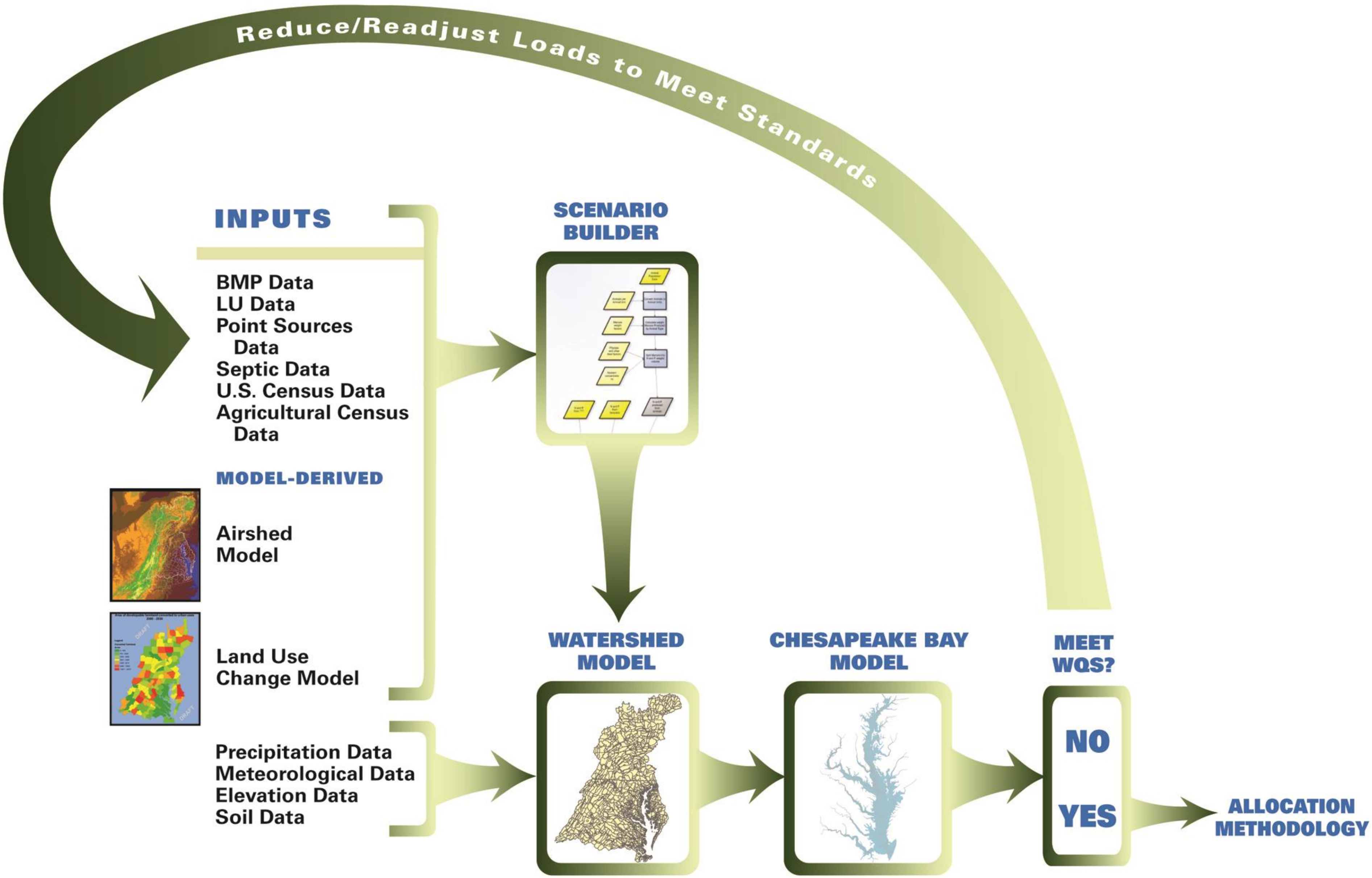


...we increase achievement of bay grass restoration goals.





Chesapeake Bay Partnership Models



Bay Airshed Model

Inputs: Hourly

Outputs: Hourly

Meteorology from a Weather Model

Emissions from the EPA National Inventory

Air Quality Model: CMAQ

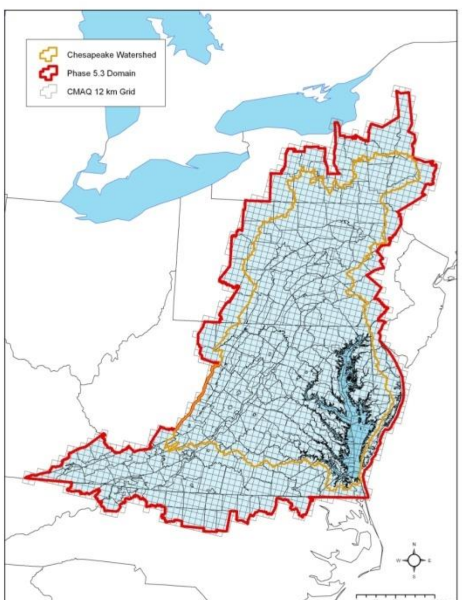
- Transport
- Transformation:
  - Gas Chemistry
  - Aqueous Chemistry
- Loss Processes

Air Concentrations

O_3
$PM_{2.5}$

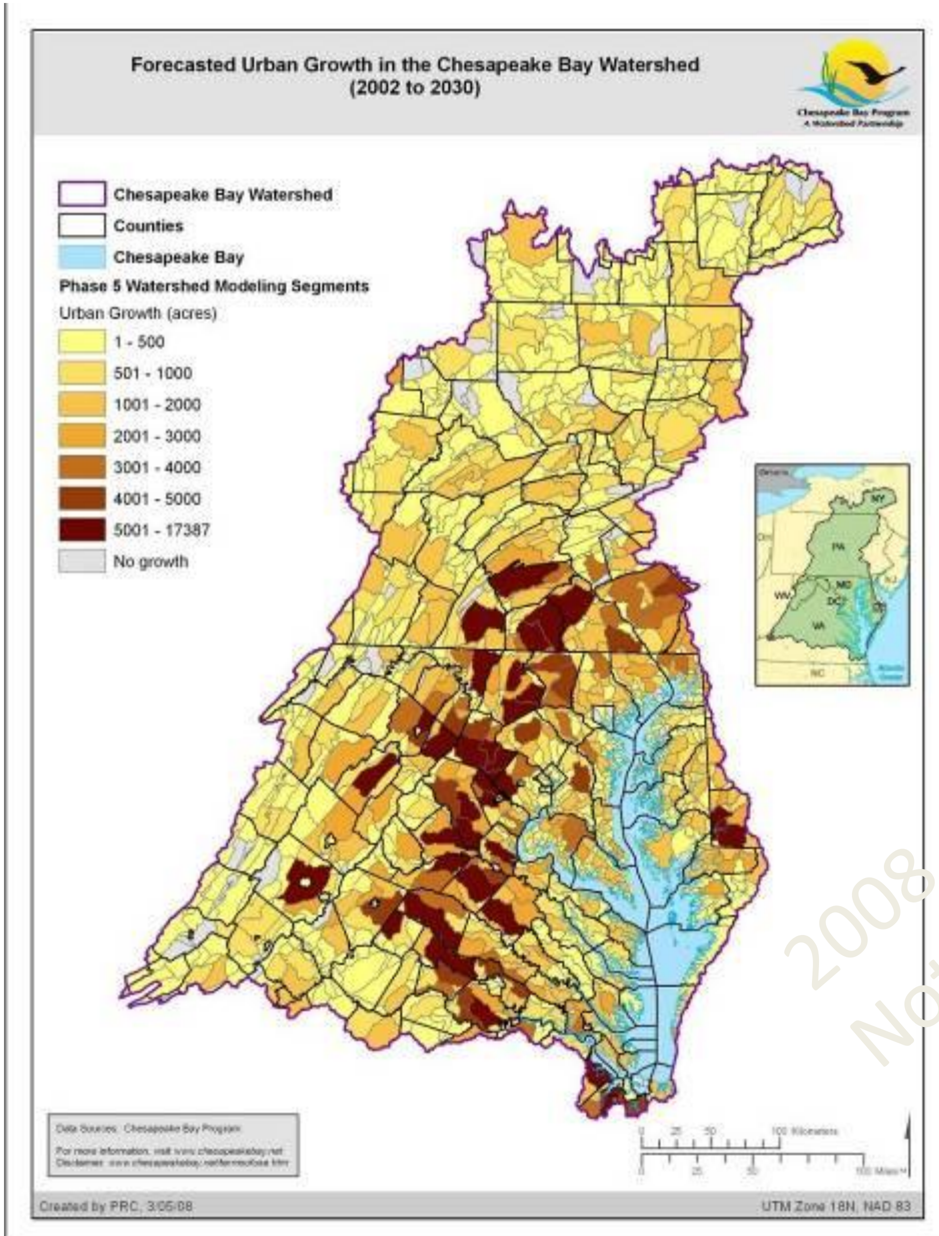
Wet and Dry Deposition

SO_2 gas	NO
SO_4 aerosol	NO_2
SO_4 **wet**	N_2O_5
Hg^0	HNO_3 gas
RGM	NO_3 aerosol
Hg(part.)	Organic NO_3
Hg **wet**	NO_3 **wet**
	PAN's
	NH_3 gas
	NH_4 aerosol
	NH_4 **wet**



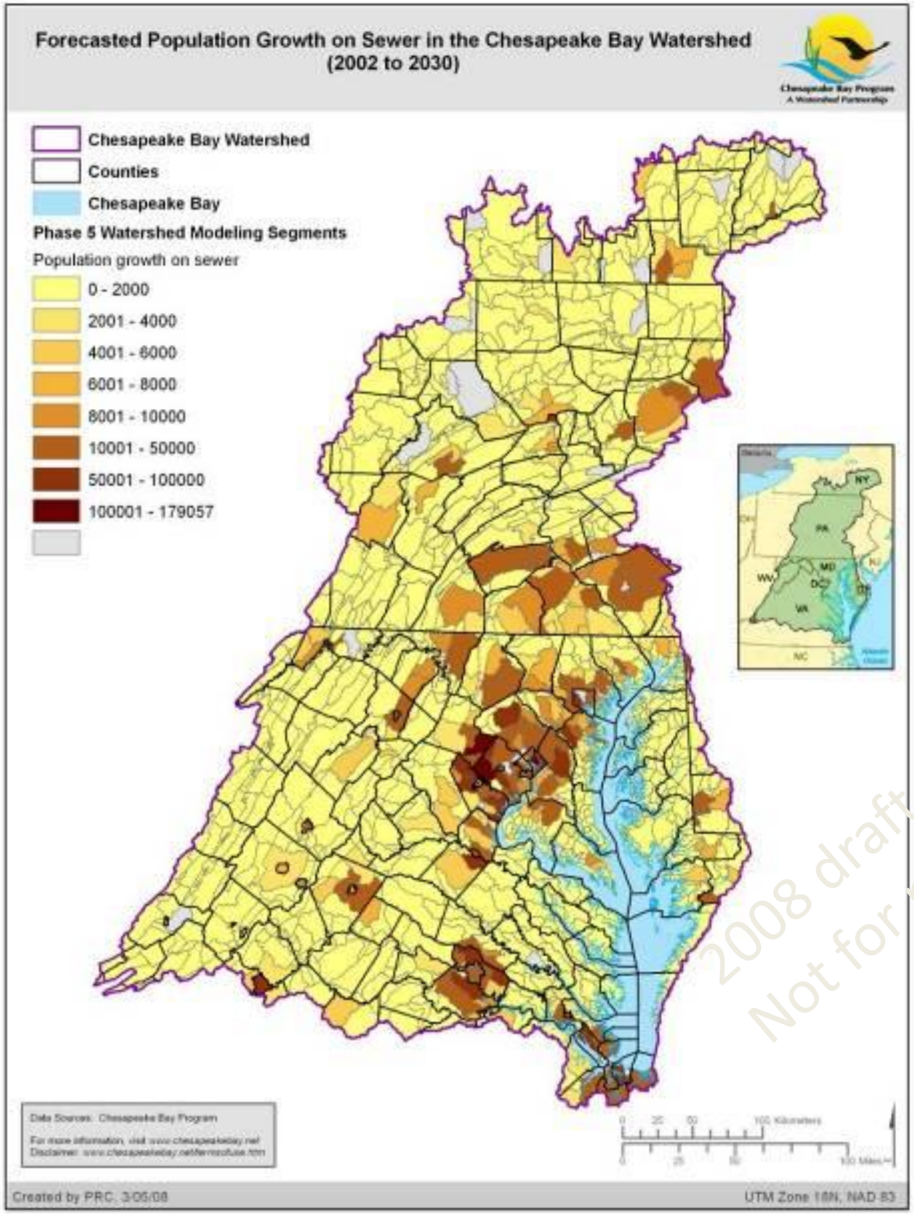
CMAQ: Community Multi-scale Air Quality Model

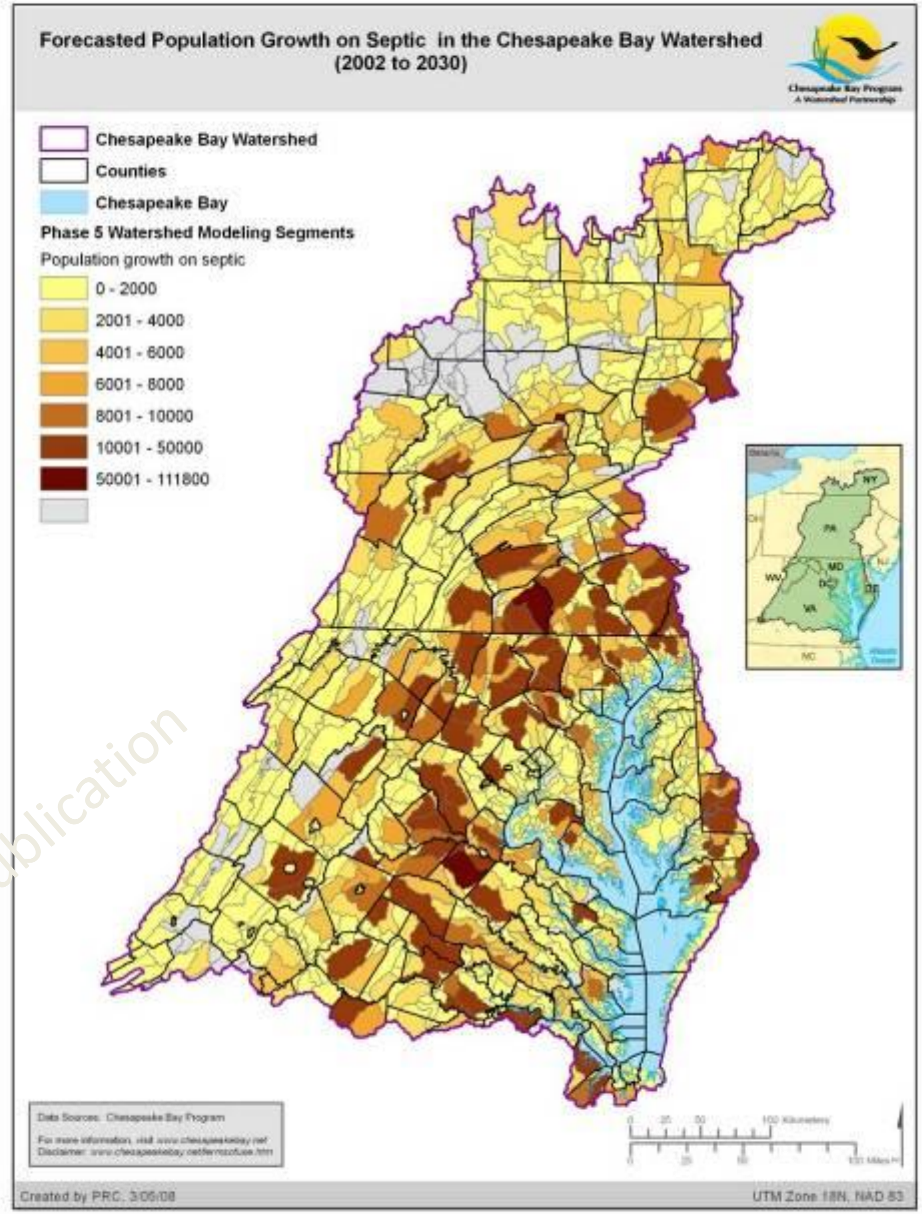
Forecasted Urban Growth (2000 to 2030)



Source: Chesapeake Bay Land Change Model Version 3

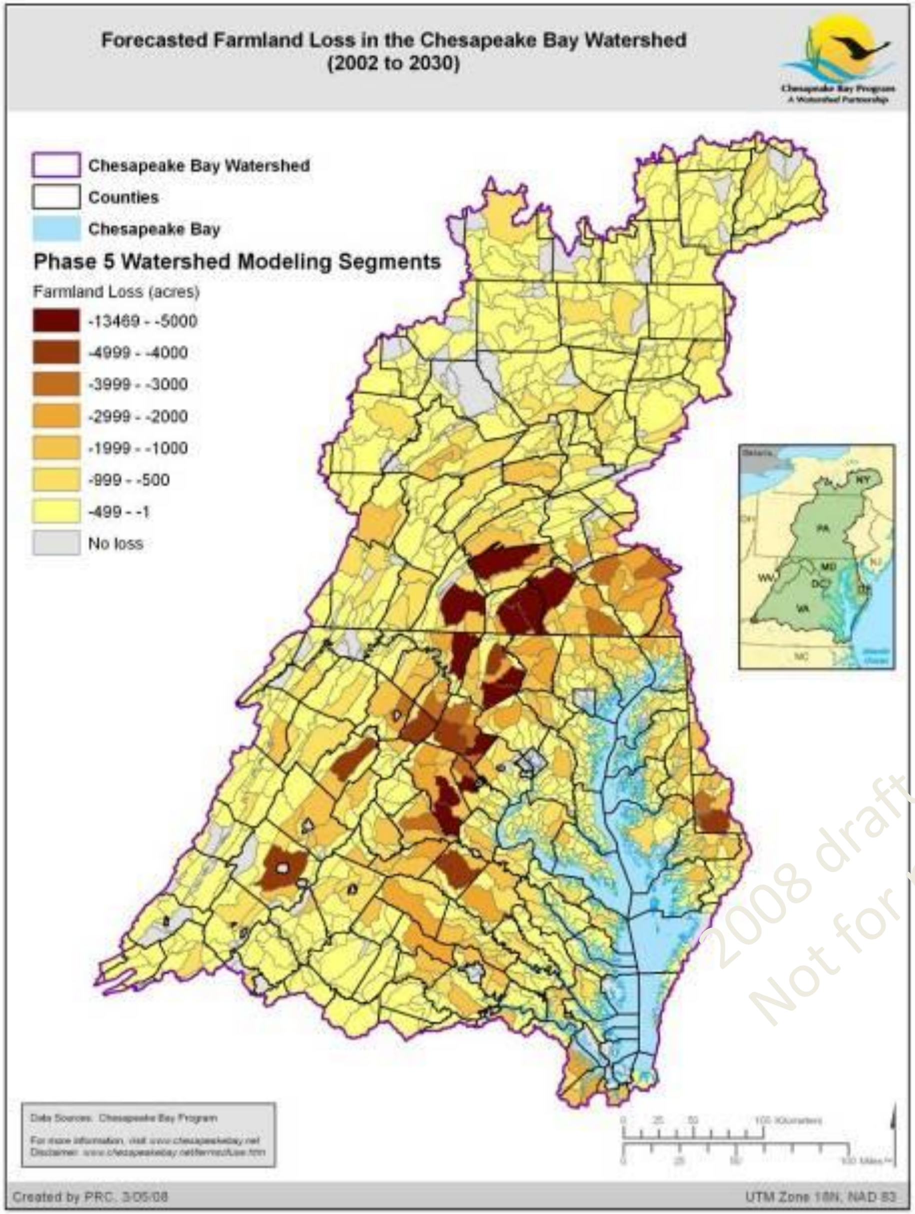
Forecasted Population Growth on Sewer vs. Septic (2000 to 2030)

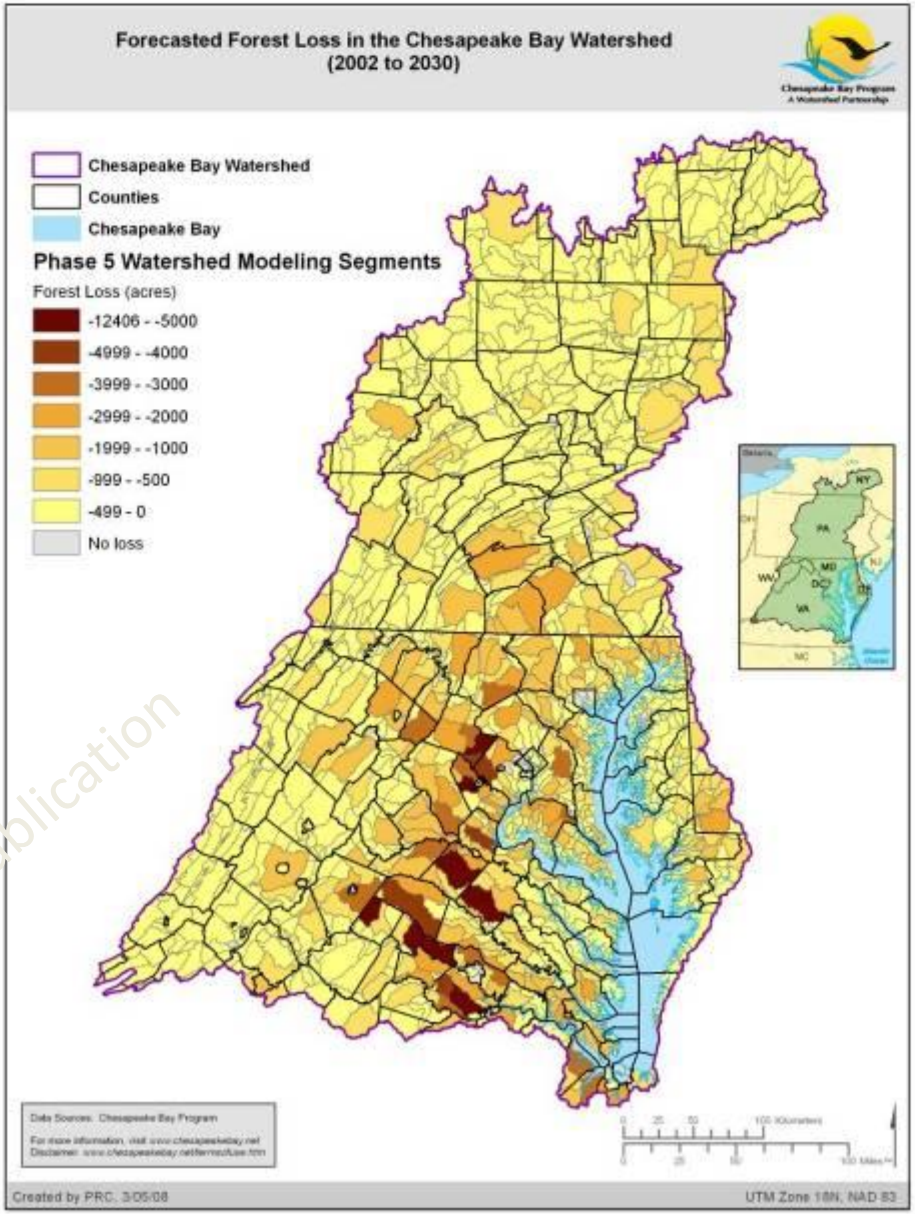




Source: Chesapeake Bay Land Change Model Version 3

Farmland and Forest Land Loss (2000 to 2030)

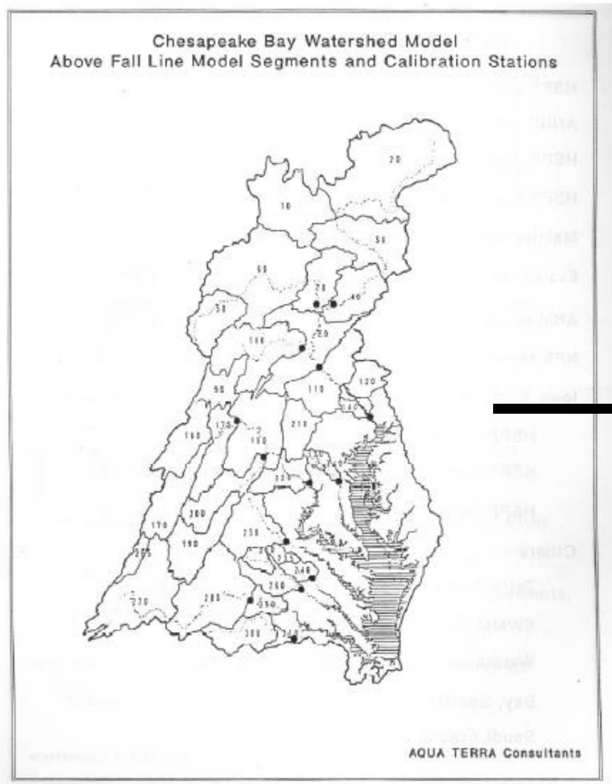




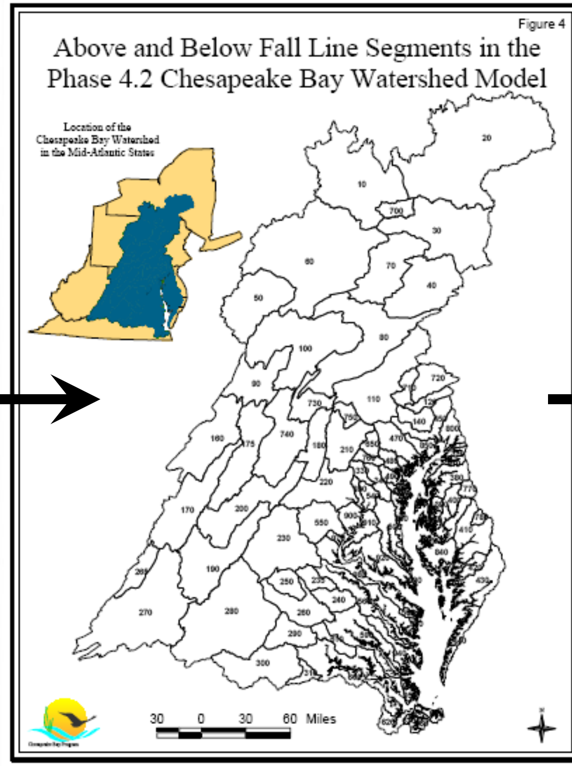
Source: Chesapeake Bay Land Change Model Version 3

A Quarter Century of Watershed Model Development

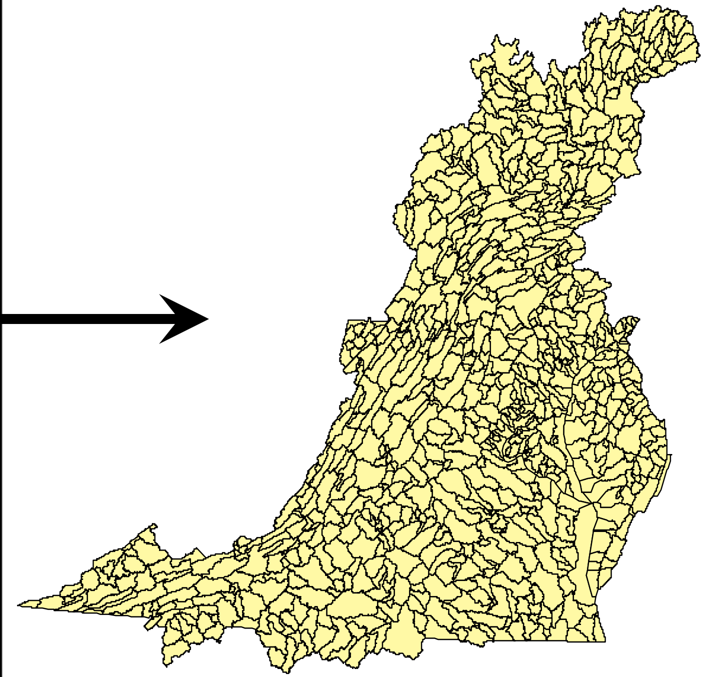
Phase 1



Phase 4



Phase 5

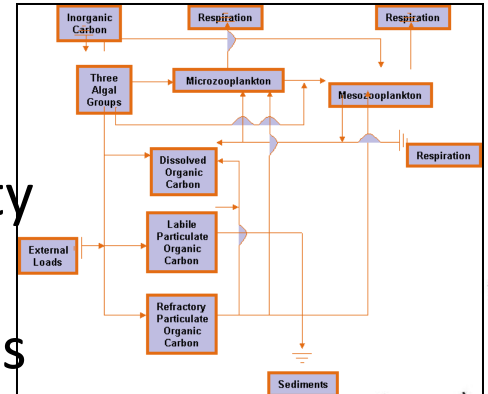


- **Completed in 1982**
- **63 model segments**
- **5 land uses**
- **2 year calibration period (Mar.- Oct.)**

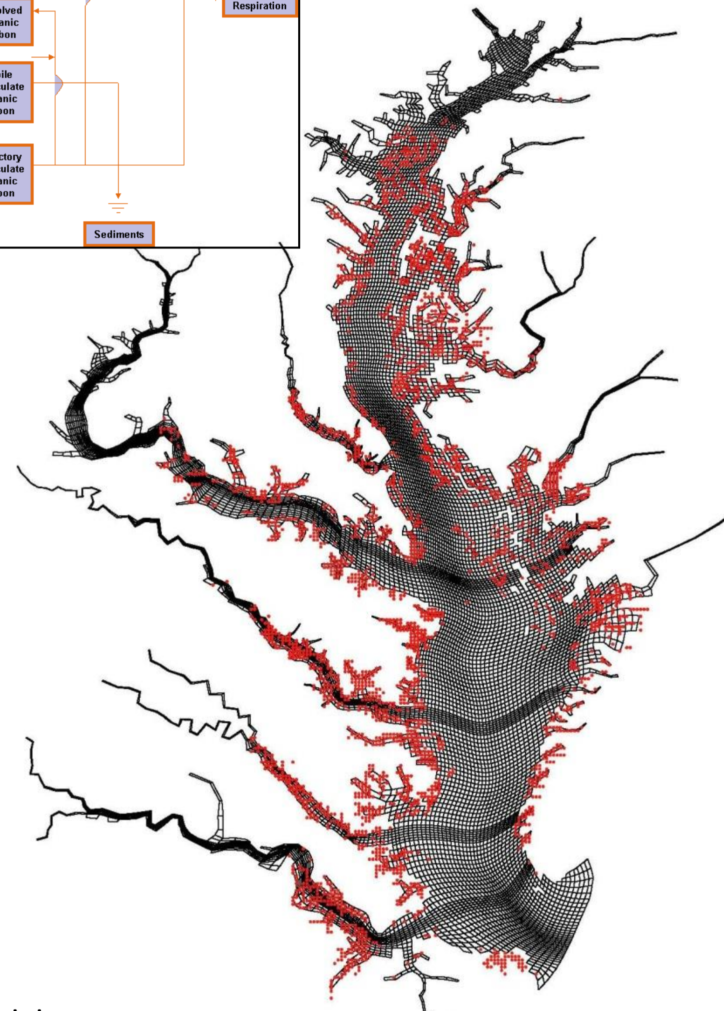
- **Completed in 1998**
- **94 model segments**
- **9 land uses**
- **14 year calibration period (1984-97)**

- **Completed in 2009**
- **1,000+ model segments.**
- **25 land uses using time-varying land use & BMPs**
- **21 year calibration period (1985-2005)**

Bay Water Quality Model

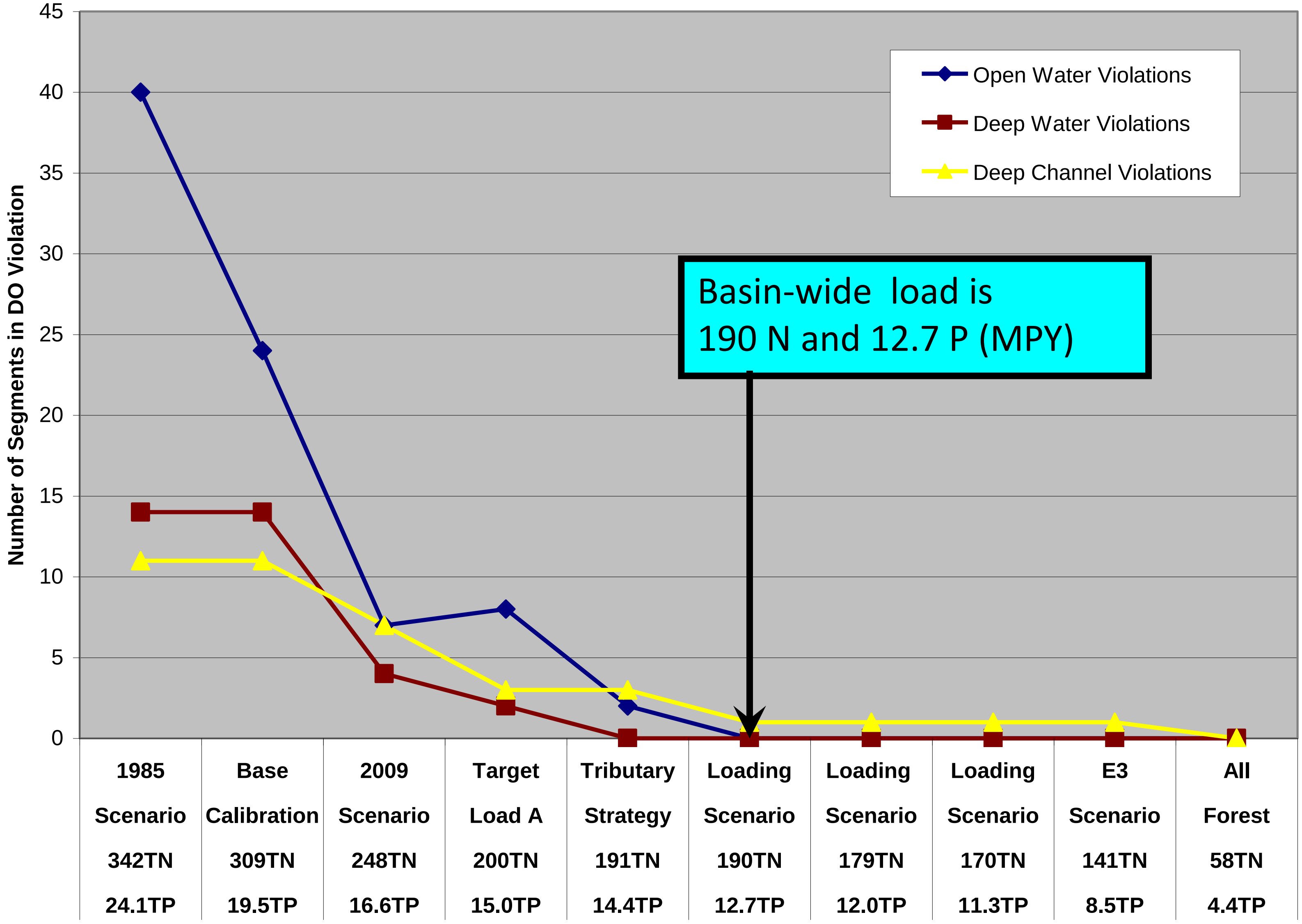


- 57,000 cells
- Predicts changes in water quality due to changes in nitrogen, phosphorus, and sediment loads
  - Dissolved Oxygen
  - Water clarity
  - Chlorophyll *a*
- Also simulates algae, underwater Bay grasses, bottom dwelling worms and clams, oysters, and menhaden

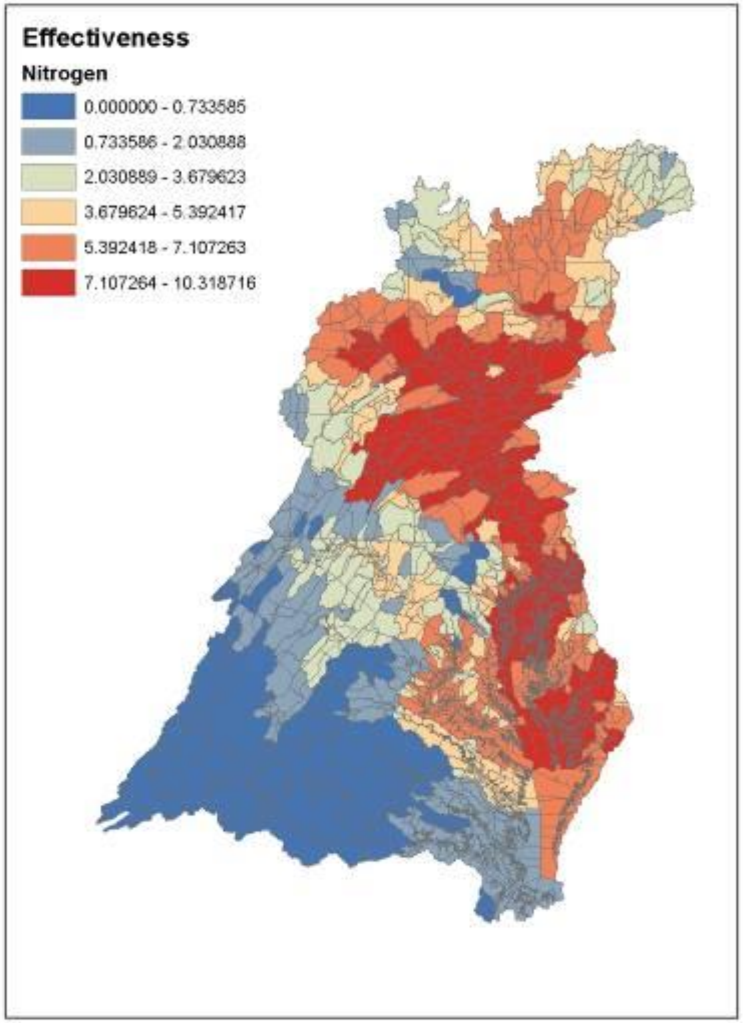


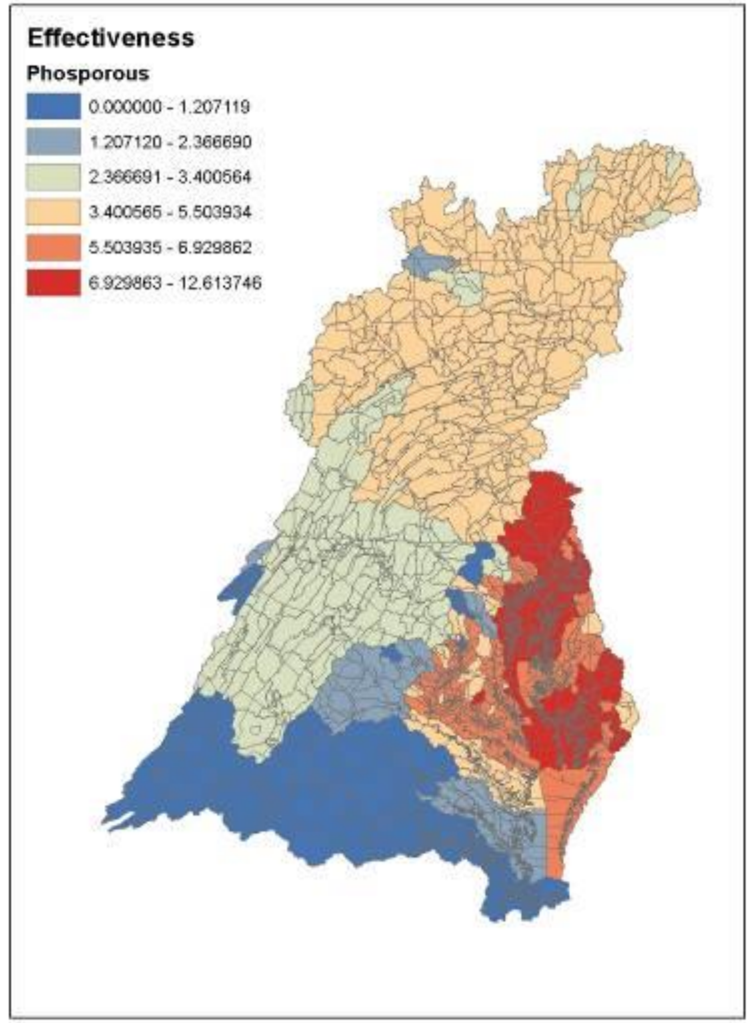
Developed by scientists at the US Army Corps of Engineers, University of Maryland, Virginia Institute of Marine Science, HydroQual, Versar, and Rutgers University

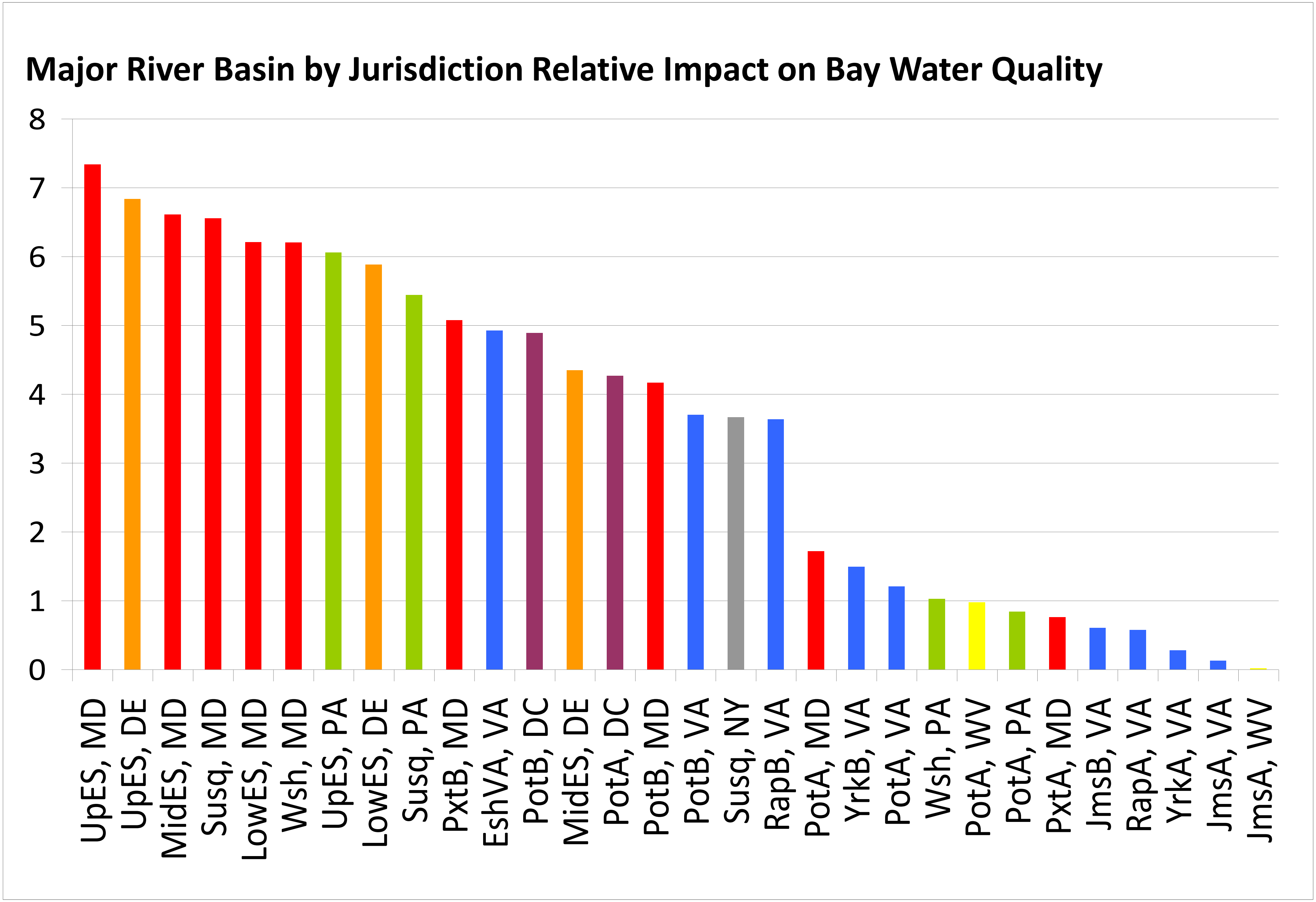
Use of modeling suite in the Chesapeake TMDL

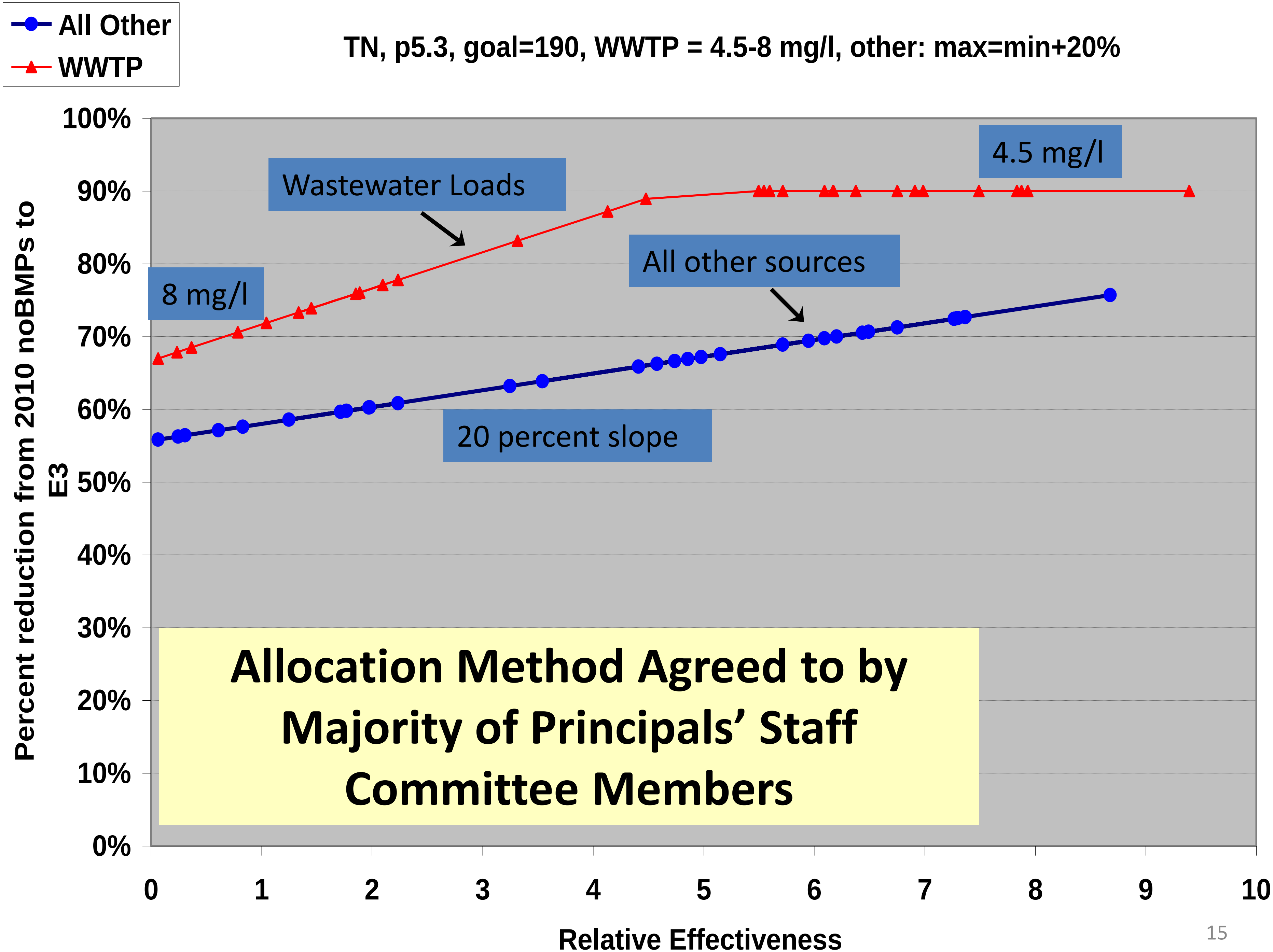


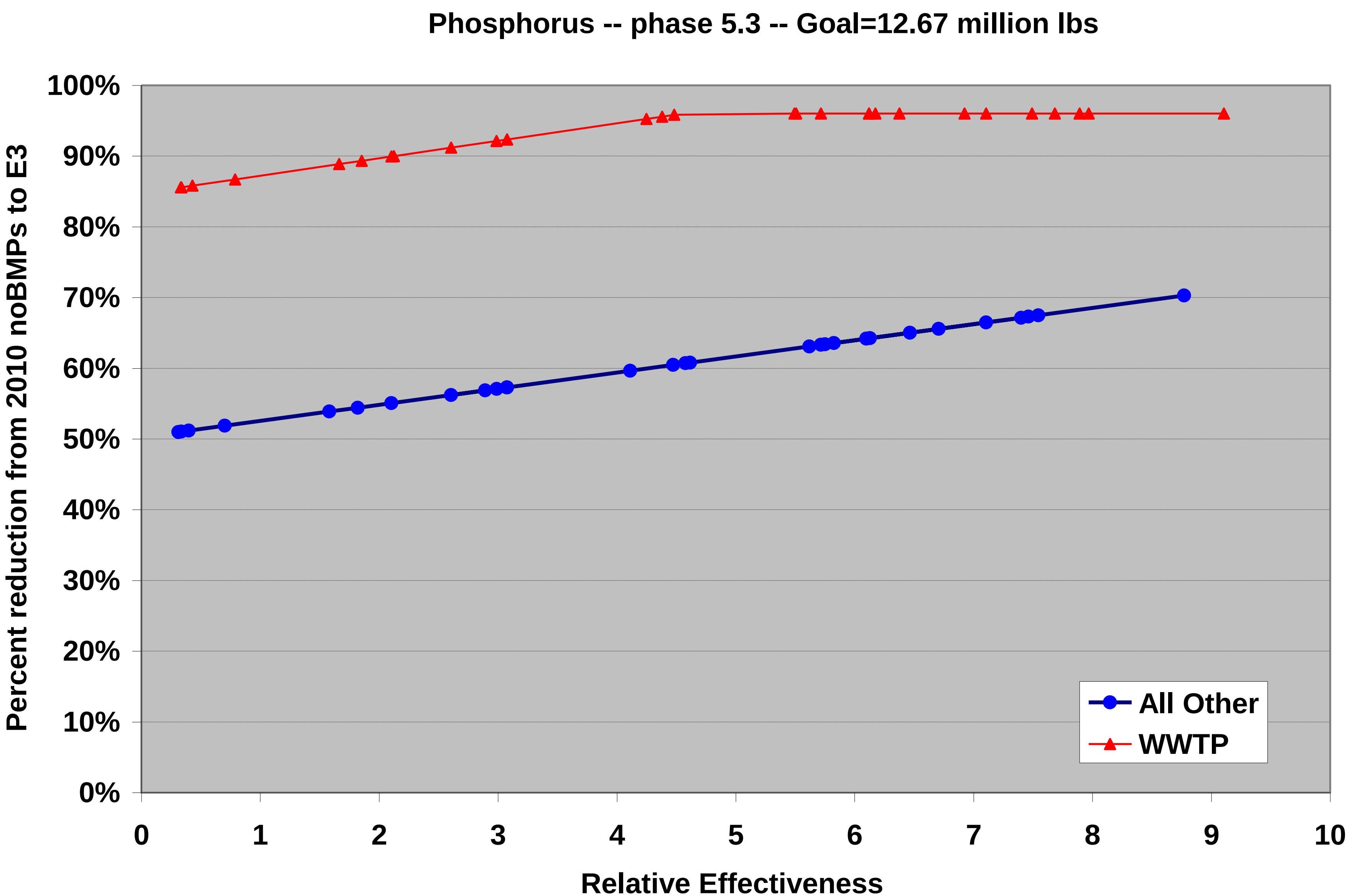
Nutrient Impacts on Bay WQ





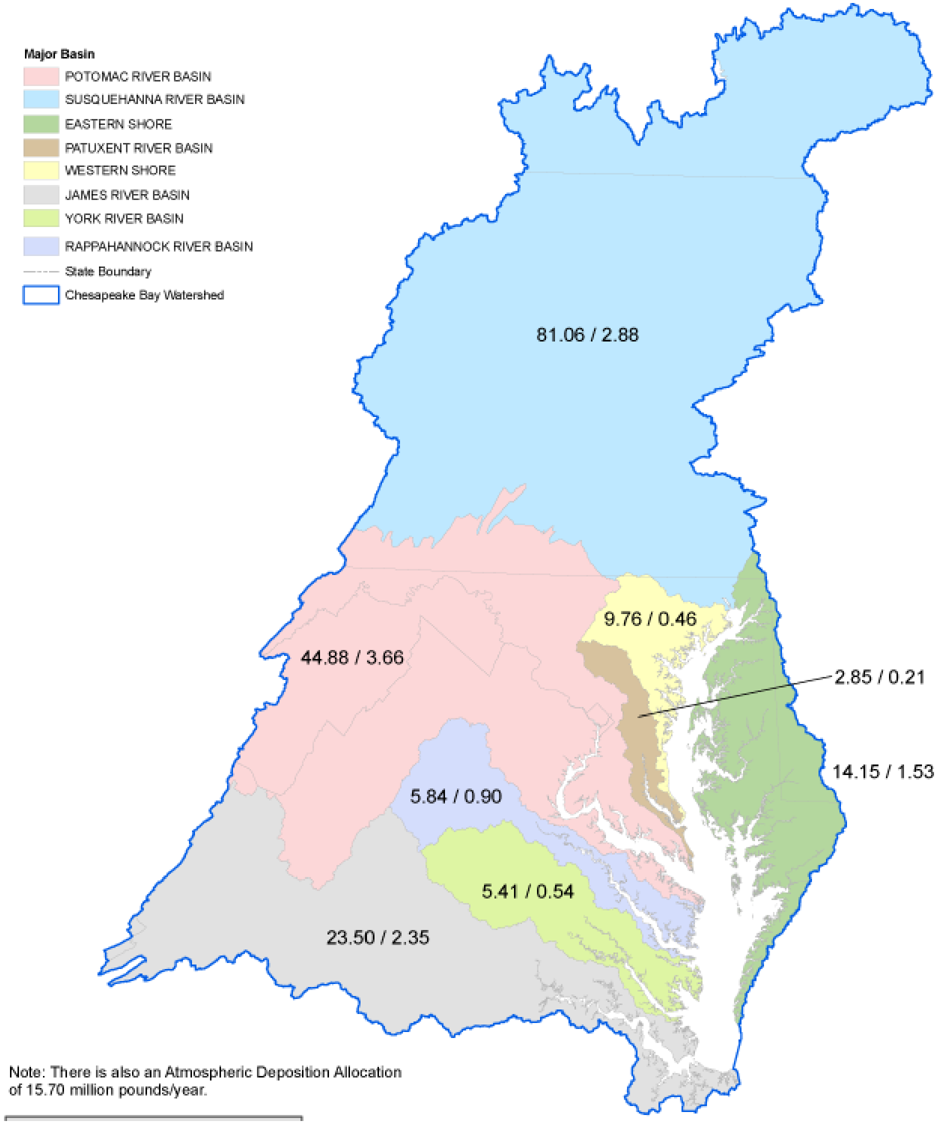

Major River Basin by Jurisdiction Relative Impact on Bay Water Quality
8
7
6
5
4
3
2
1
0
UpES, MD
UpES, DE
MidES, MD
Susq, MD
LowES, MD
Wsh, MD
UpES, PA
LowES, DE
Susq, PA
PxtB, MD
EshVA, VA
PotB, DC
MidES, DE
PotA, DC
PotB, MD
PotB, VA
Susq, NY
RapB, VA
PotA, MD
YrkB, VA
PotA, VA
Wsh, PA
PotA, WV
PotA, PA
PxtA, MD
JmsB, VA
RapA, VA
YrkA, VA
JmsA, VA
JmsA, WV


All Other
WWTP
TN, p5.3, goal=190, WWTP = 4.5-8 mg/l, other: max=min+20%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent reduction from 2010 noBMPs to E3
Wastewater Loads
4.5 mg/l
8 mg/l
All other sources
20 percent slope
Allocation Method Agreed to by Majority of Principals' Staff Committee Members
0
1
2
3
4
5
6
7
8
9
10
Relative Effectiveness



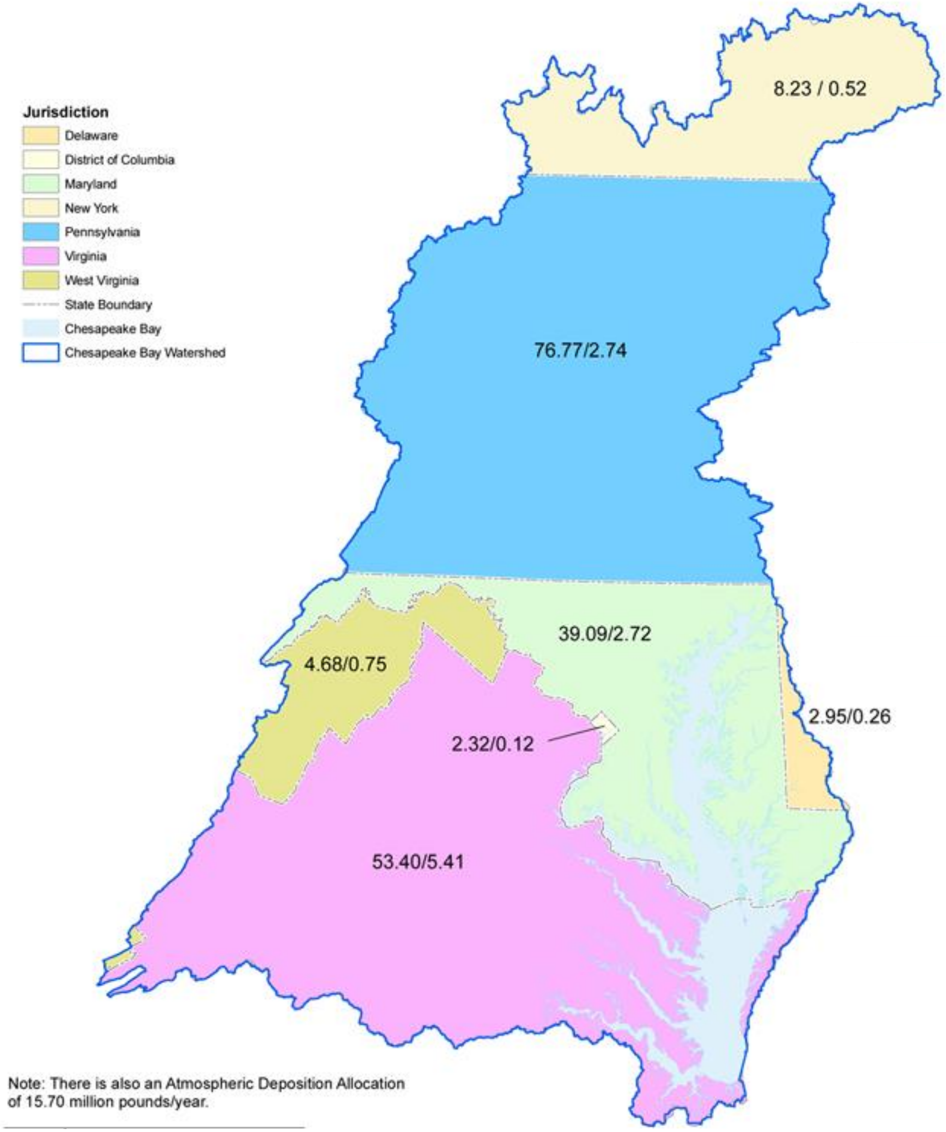
Phosphorus -- phase 5.3 -- Goal=12.67 million lbs
Percent reduction from 2010 noBMPs to E3
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
7
8
9
10
Relative Effectiveness
All Other
WWTP

Pollution Diet by River



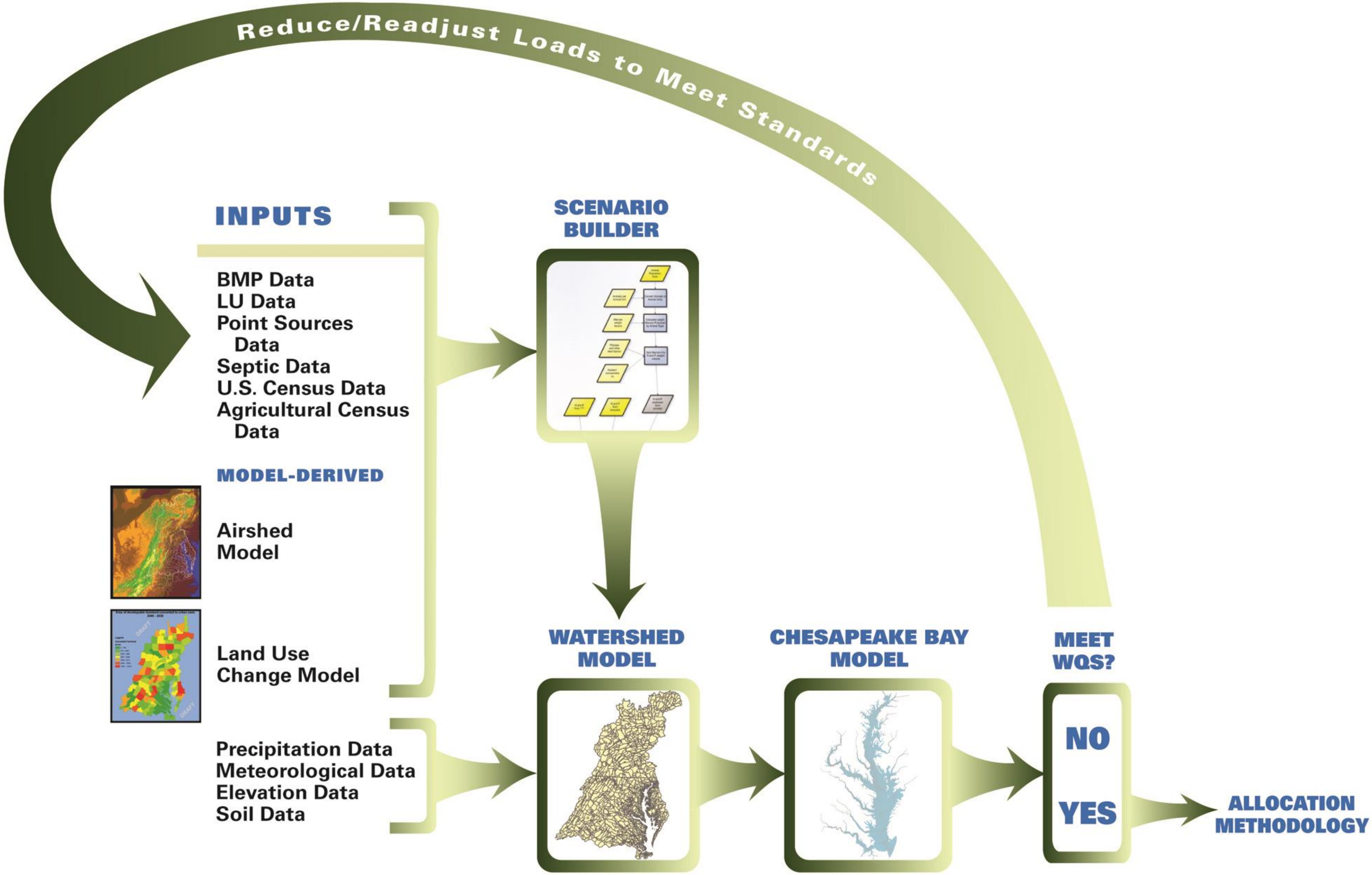
Note: There is also an Atmospheric Deposition Allocation of 15.70 million pounds/year.

Pollution Diet by State

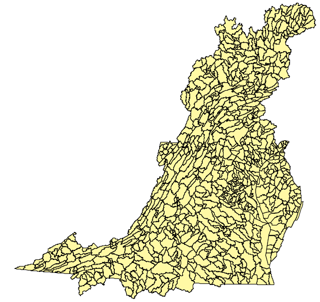


Note: There is also an Atmospheric Deposition Allocation of 15.70 million pounds/year.

Chesapeake Bay Partnership Models



Chesapeake Bay Watershed Model

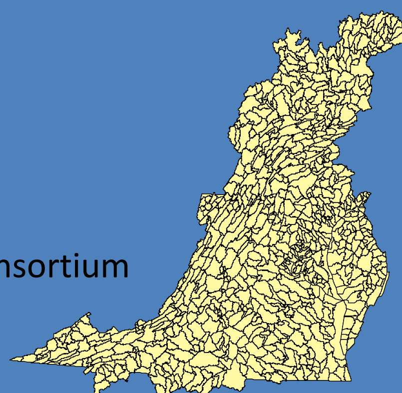


- **Open model development process**:
  - Open participation in modeling workgroup, the water quality goal implementation team and its workgroups
  - Anyone can work with the CBPO to provide credible data or to get new restoration practices incorporated
  - Complete watershed model available for download
- **Peer Review Status**:
  - CBP STAC independent scientific peer reviews of Phase 5 model conducted in 2005 and 2008 (200th presentation)
- **More Information**:
  - http://ches.communitymodeling.org/models/CBPhase5/index.php
  - http://www.chesapeakebay.net/phase5.htm

Integrated model built by integrated community of decision makers and modelers

Chesapeake Bay Program

Developers
EPA
U of Maryland
USGS
NRCS
Chesapeake Research Consortium
Virginia Tech



Advisors and data suppliers
State Governments of
NY, PA, MD, DE, VA, WV, DC
Scientific and Technical Advisory Committee

Maryland Department of the Environment
Virginia Department of Conservation and Recreation

$

Interstate Commission on the Potomac River Basin

$

$

USGS

How the Watershed Model Works

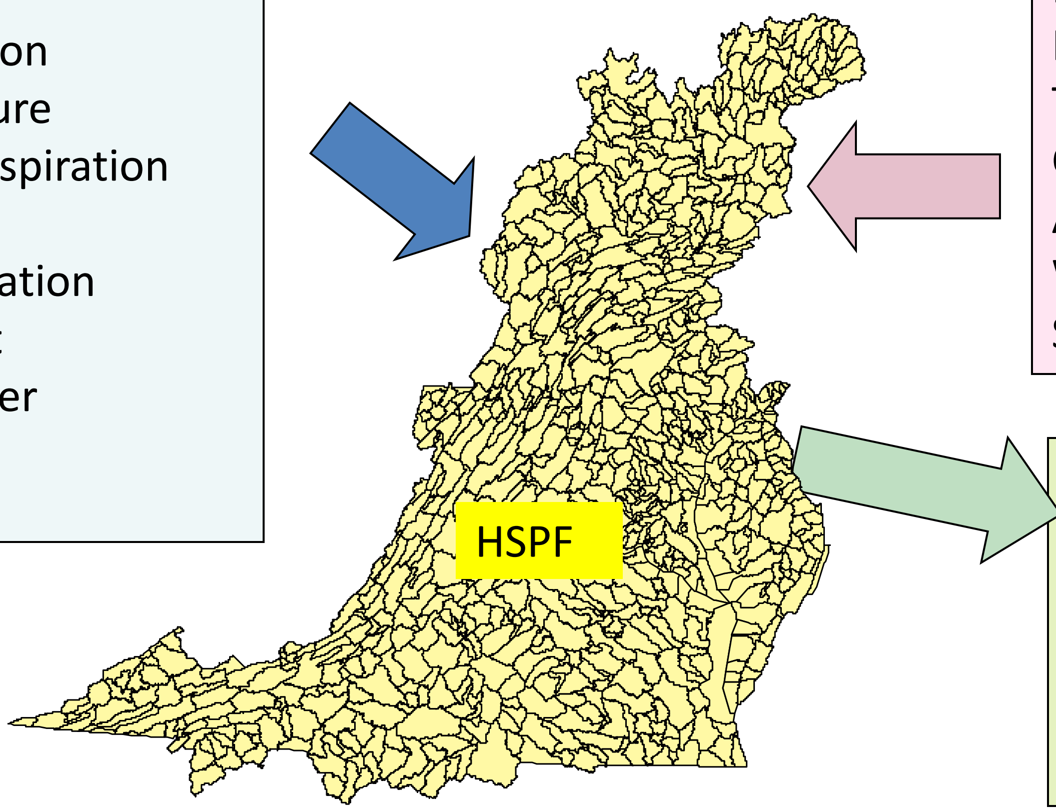
Calibration Mode

Hourly or daily values of Meteorological factors:

Precipitation
Temperature
Evapotranspiration
Wind
Solar Radiation
Dew point
Cloud Cover

Annual, monthly, or daily values of anthropogenic factors:

Land Use Acreage
BMPs
Fertilizer
Manure
Tillage
Crop types
Atmospheric deposition
Waste water treatment
Septic loads



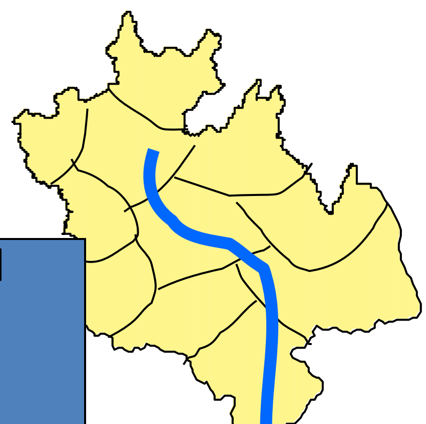
Daily flow, nitrogen, phosphorus, and sediment compared to observations over 21 years

How the Watershed Model Works

Each segment consists of 30 separately-modeled land uses:

- Regulated Pervious Urban
- Regulated Impervious Urban
- Unregulated Pervious Urban
- Unregulated Impervious Urban
- Construction
- Extractive
- Combined Sewer System
- Wooded / Open
- Disturbed Forest

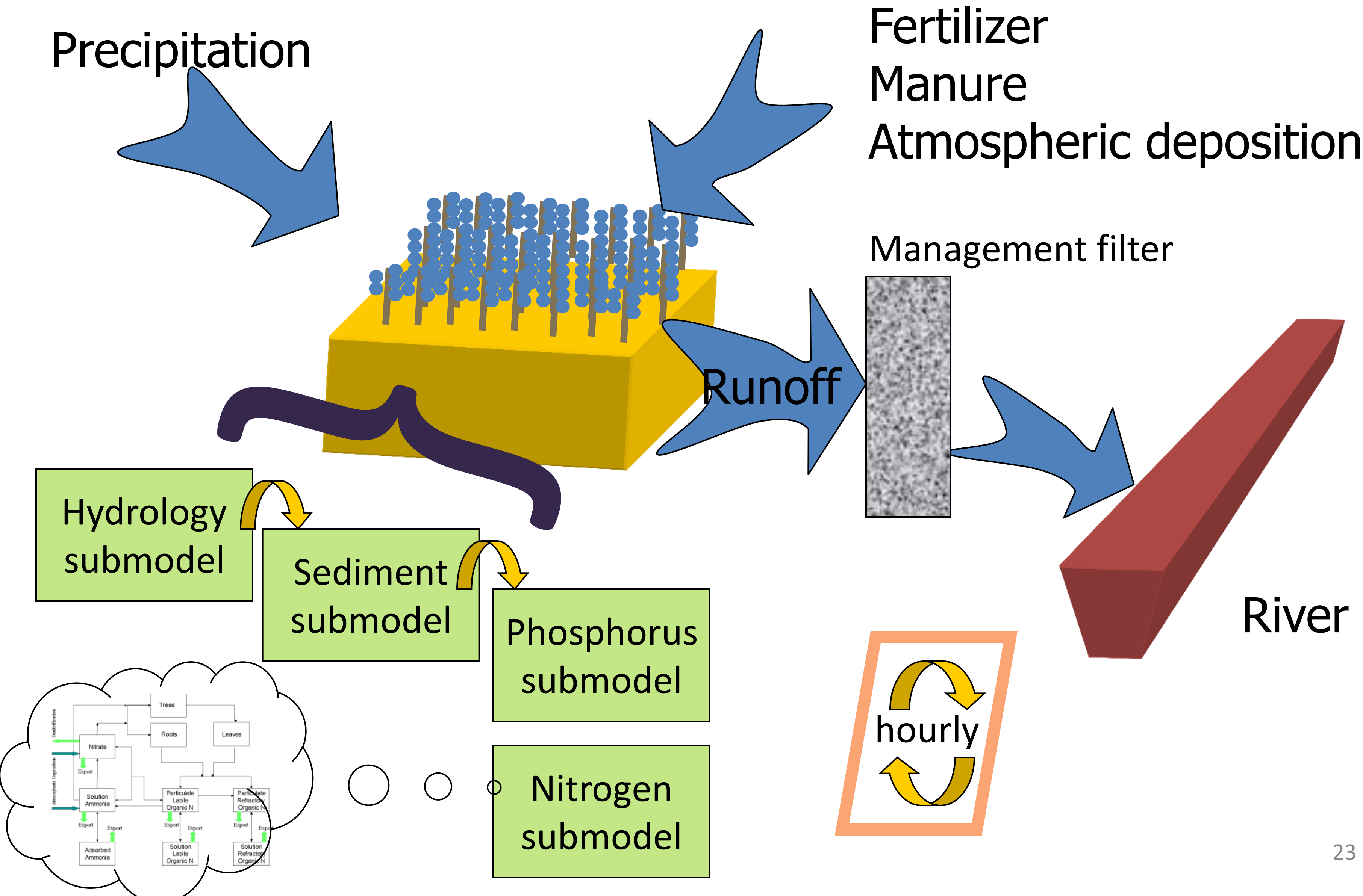
- Corn/Soy/Wheat rotation (high till)
- Corn/Soy/Wheat rotation (low till)
- Other Row Crops
- Alfalfa
- Nursery
- Pasture
- Degraded Riparian Pasture
- Afo / Cafo
- Fertilized Hay
- Unfertilized Hay
  - Nutrient management versions of the above



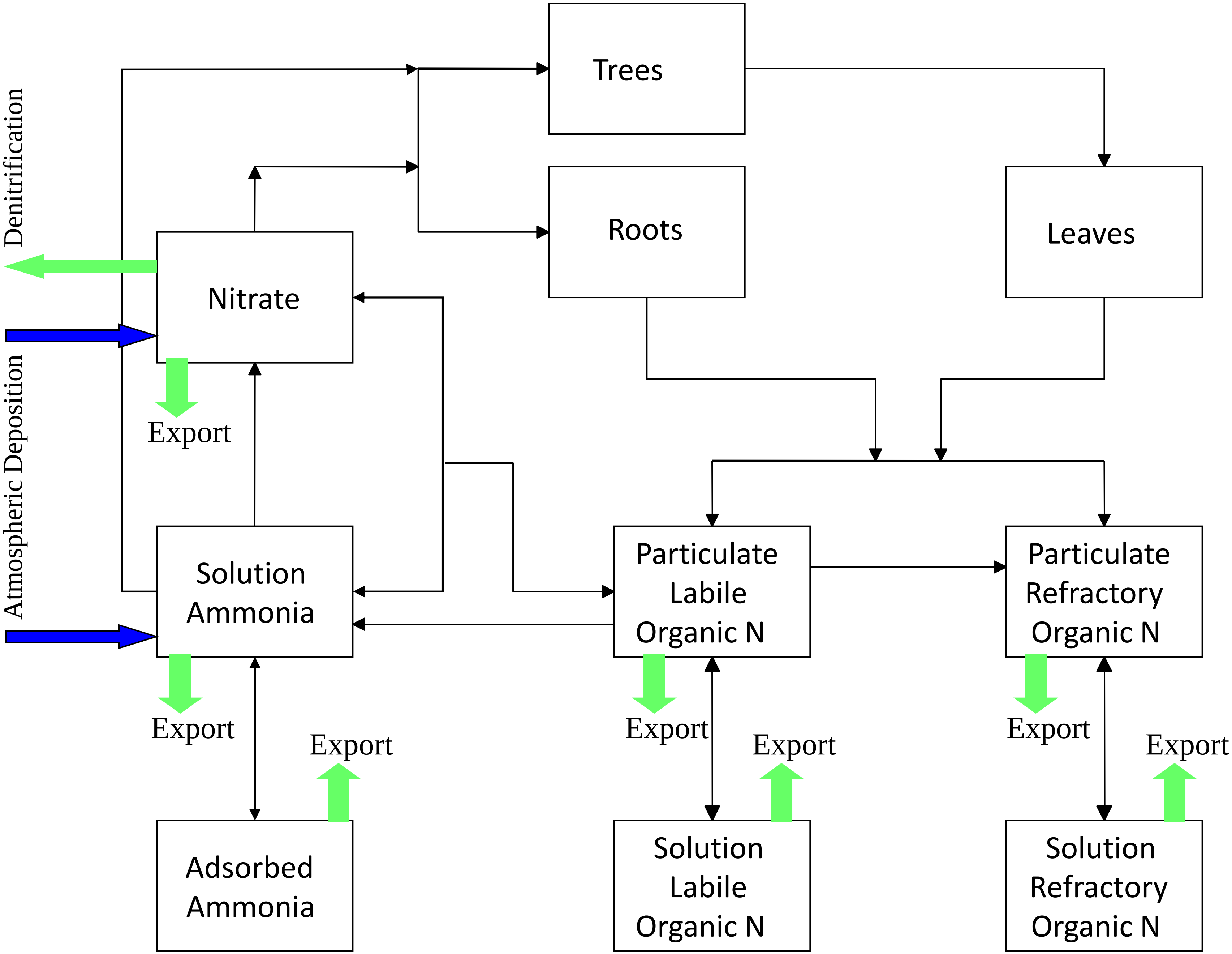
Plus: Point Source and Septic Loads, and Atmospheric Deposition Loads

Each calibrated to nutrient and Sediment targets

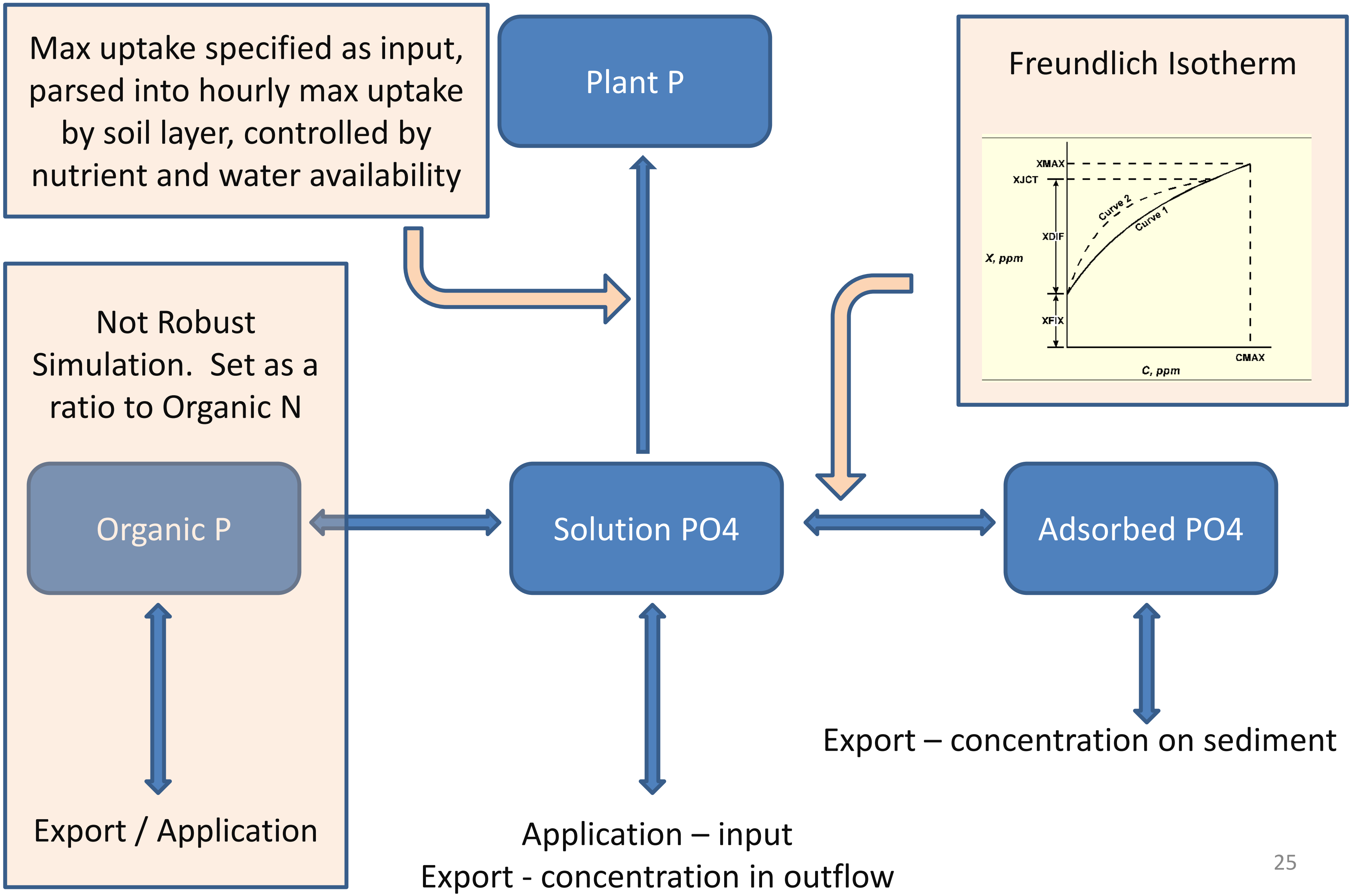
How the Watershed Model Works



Each submodel has a complex hydrologic or nutrient cycling structure



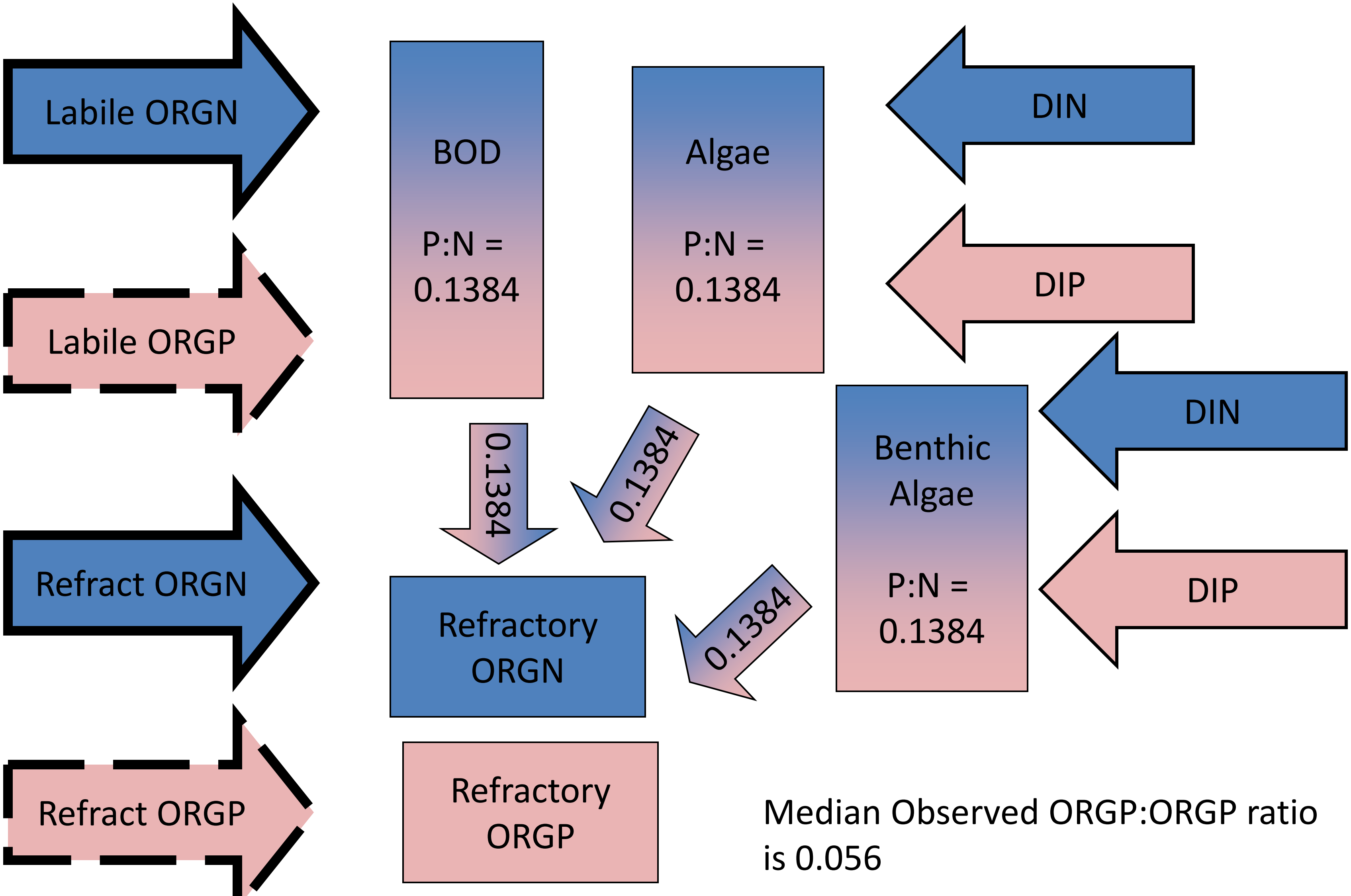
Cropland Phosphorus Simulation



Interesting Point

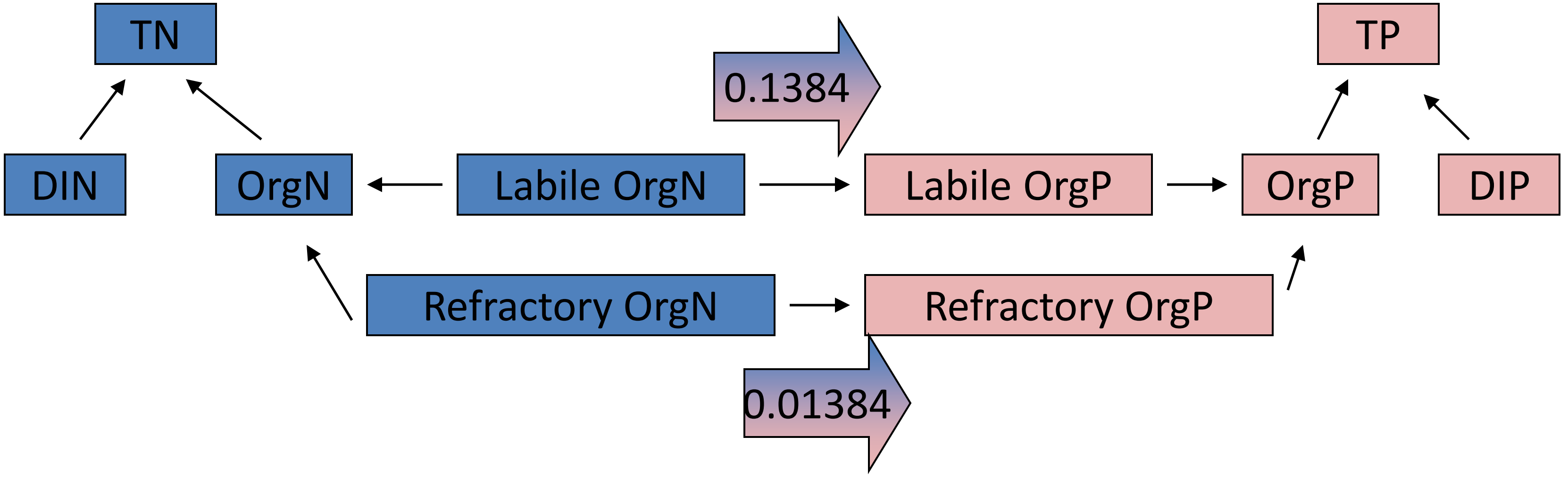
- In late 90s, the WSM simulated phosphorus saturation and breakthrough on the Eastern Shore
- Nutrient Subcommittee did not think that that was an accurate simulation so it was removed by calibration

Organic Simulation



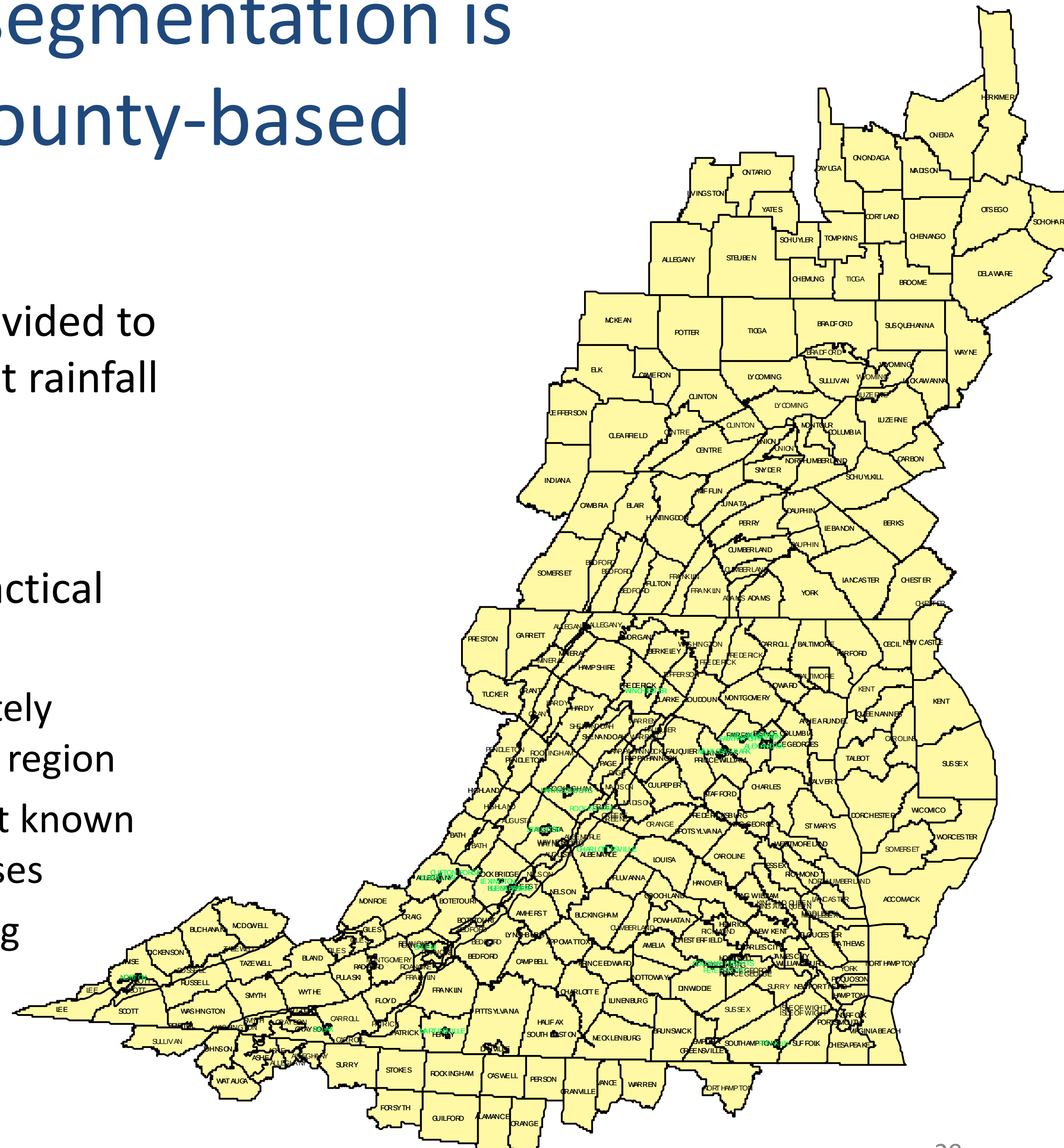
Median Observed ORGP:ORGP ratio is 0.056

P and N simulation in AGCHEM



Phase 5 land segmentation is primarily county-based

- Some counties were divided to accommodate different rainfall patterns.



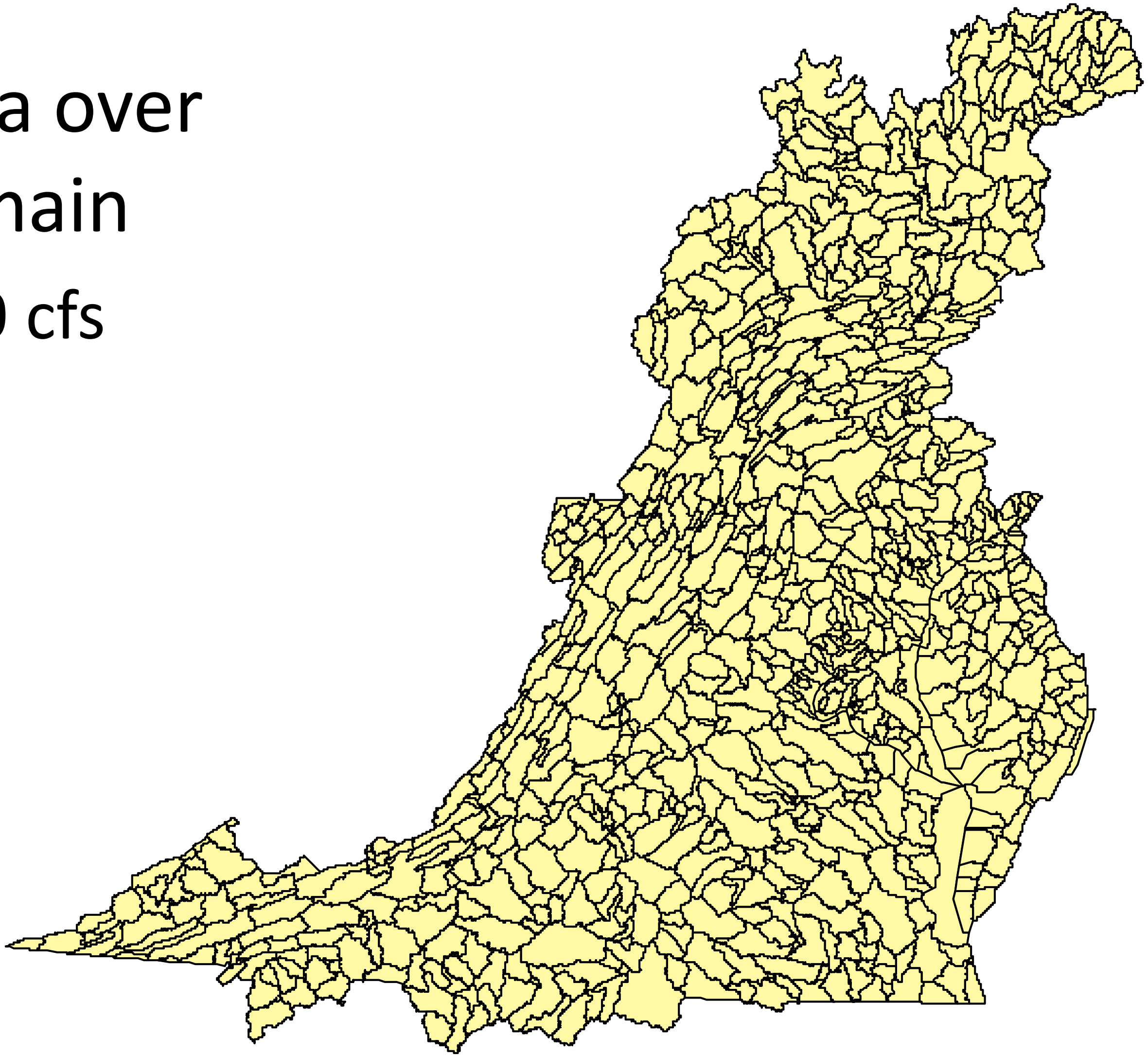
Reasons why counties are a practical choice for segmentation:

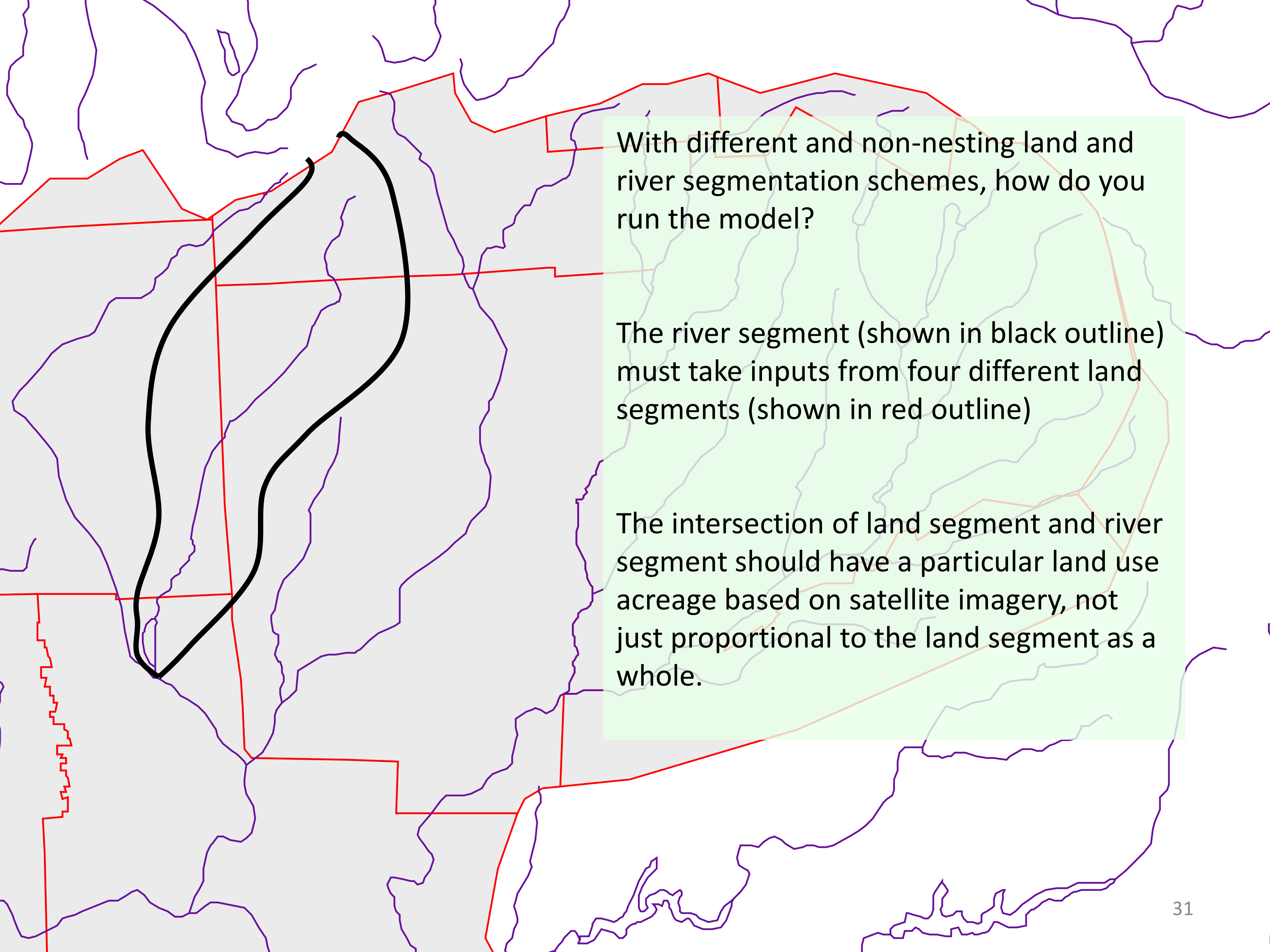
- Most counties are completely within a hydrogeomorphic region
- BMP and Crop data are not known on a finer scale in most cases
- Near the limit of computing capacity

Phase 5 river segmentation

- Consistent criteria over entire model domain
  - Greater than 100 cfs

    or
  - Has a flow gage
- Near the limit of meaningful data



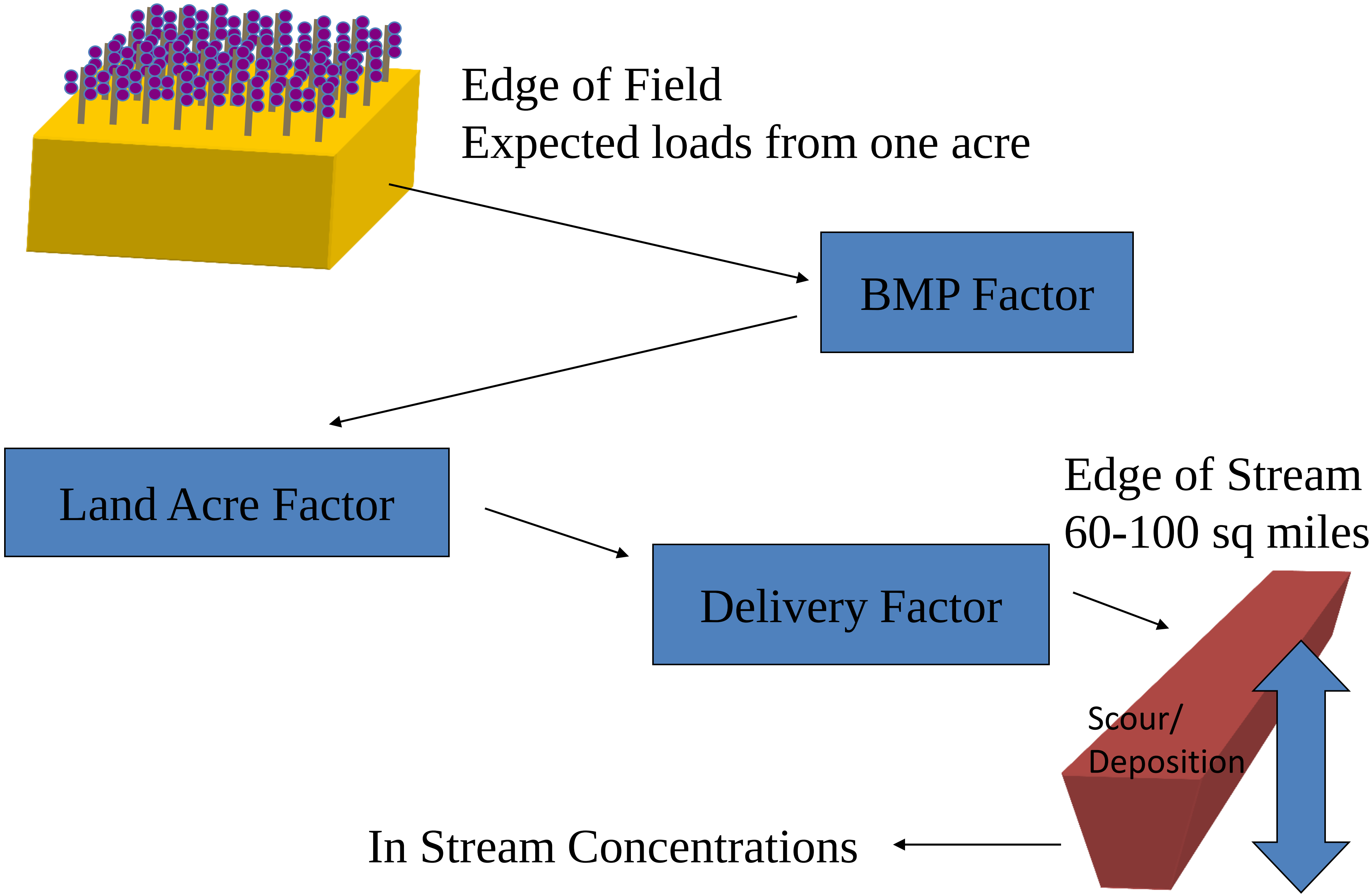


With different and non-nesting land and river segmentation schemes, how do you run the model?

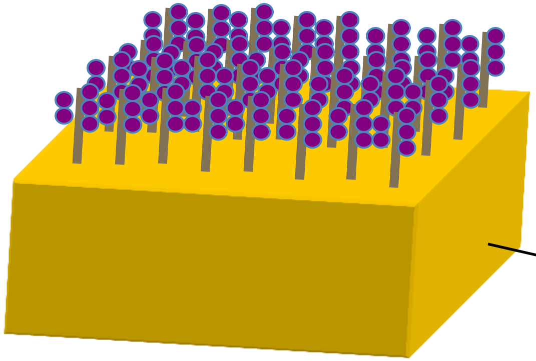
The river segment (shown in black outline) must take inputs from four different land segments (shown in red outline)

The intersection of land segment and river segment should have a particular land use acreage based on satellite imagery, not just proportional to the land segment as a whole.

Scale in Phase 5 - Sediment



Scale in Phase 5 - Nutrients



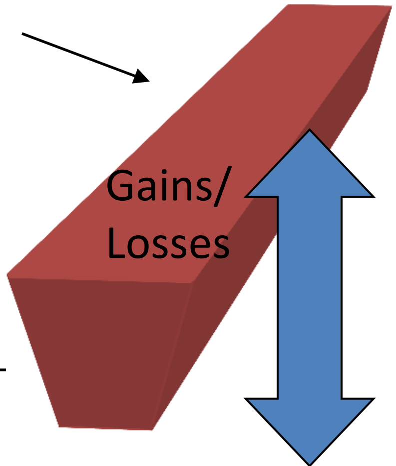
Edge of **Stream**
Expected loads from one acre that reach 100 cfs stream or tidal waters

BMP Factor

Land Acre Factor

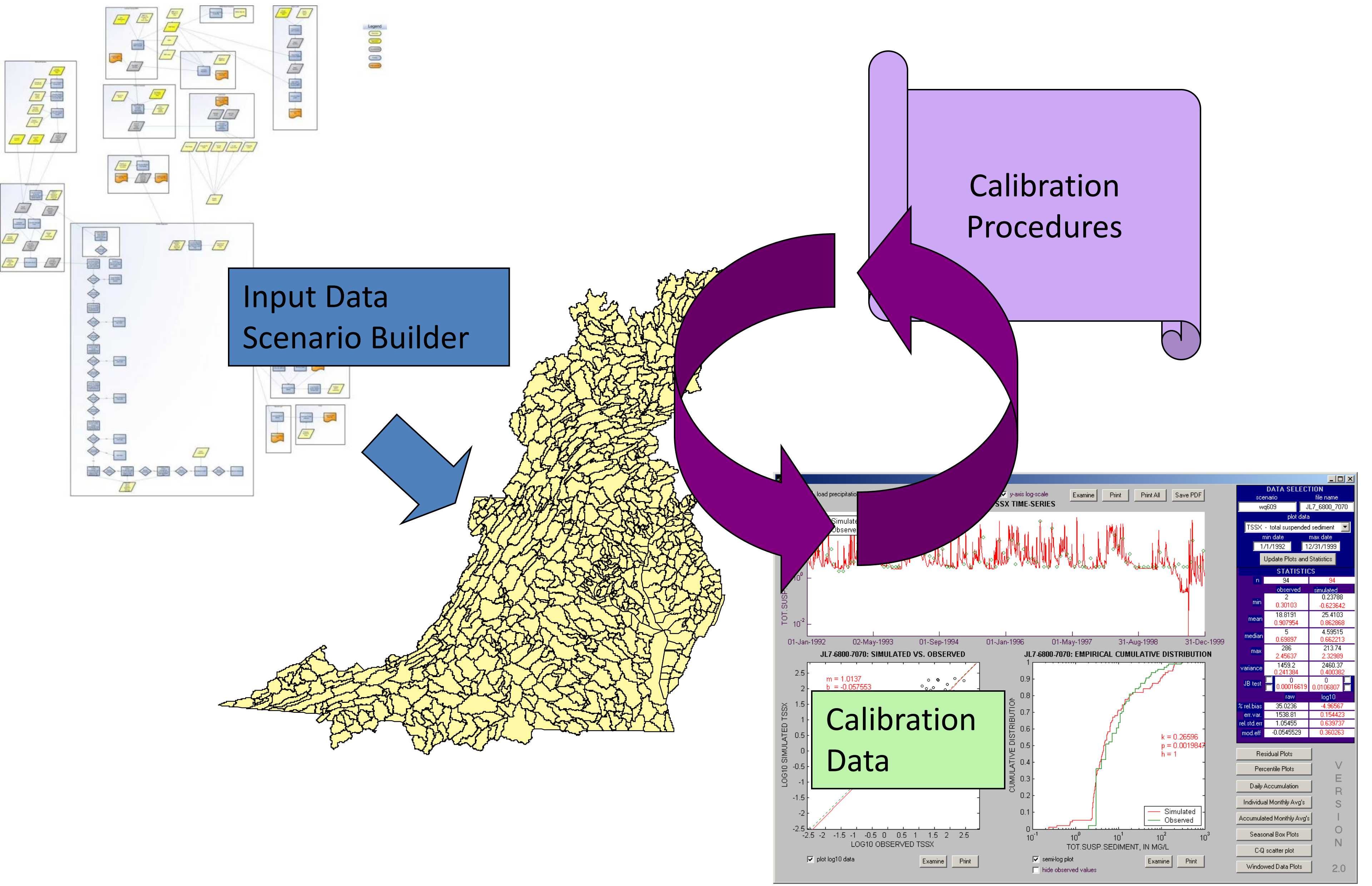
Regional Factor

Edge of Stream
60-100 sq miles

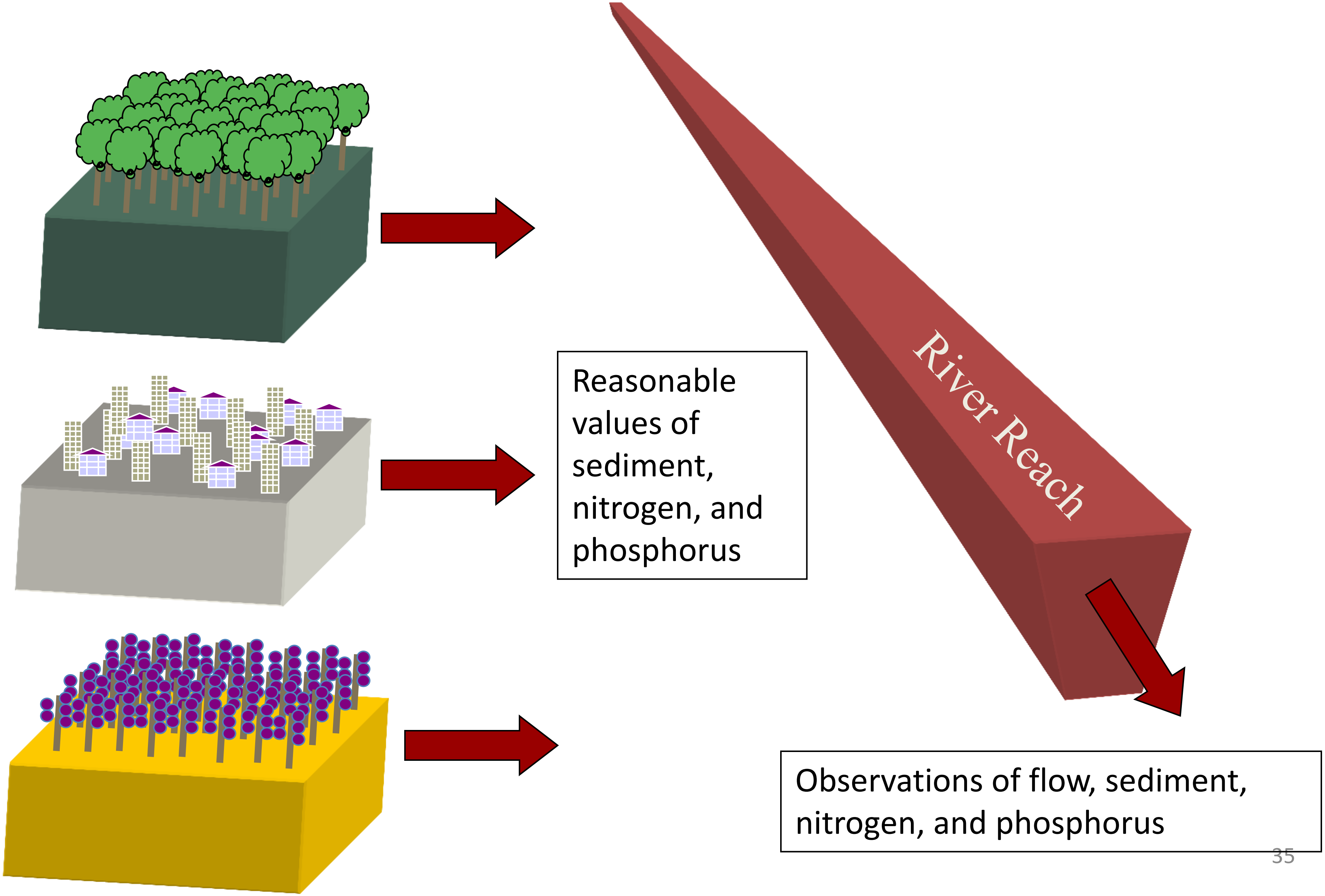


In Stream Concentrations

Automated Calibration



How do we calibrate?



Calibration Strategy

- Match observations in rivers
- Match properties and trends
  - Groundwater recession curve
  - Crop uptake
- Match literature and other models
  - Reasonable rates of nutrient export
  - USGS estimator and sparrow models

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Nutrient EOF Targets

- Purpose: Develop targets that:
  - Appropriately order the influence of different land uses in the same area
  - Appropriately account for differences in loading between the same land uses in different areas.

- Regional differences due to physiographic effects areresolved through load balancing in the river calibration.

Sources of Data

- Literature Reviews
  - Beaulac & Reckhow (1982)
  - Sweeney (2001)
  - Lin (2004)
  - Primary Sources (about 30)
- Previous Modeling Studies
  - Phase 4.3
  - Sparrow

Targets

- Chose average export load based on literature
- Created method of differentiating between the same land use in different segments based on the balance of inputs and uptake

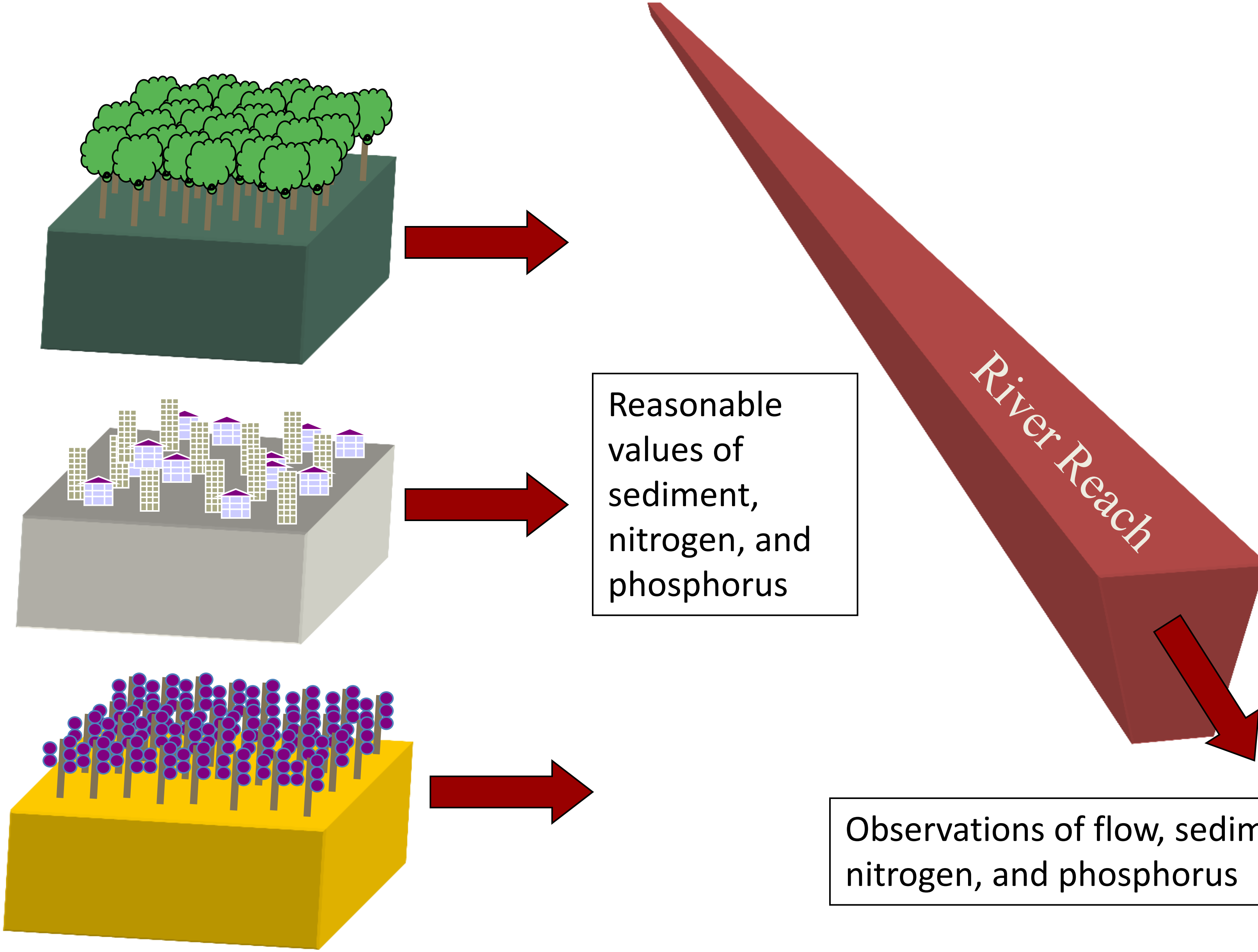
Average Targets

Land Use	TN	TP
Forest	2.0	0.15
Harvested Forest	20.0	0.80
Crop	23.0	2-2.5
Hay	6.0	0.4-0.8
Pasture	4.5	0.7
Urban	9.3	1.5
Extractive	12.5	3.5
Nursery	240	85

Differentiating between regions

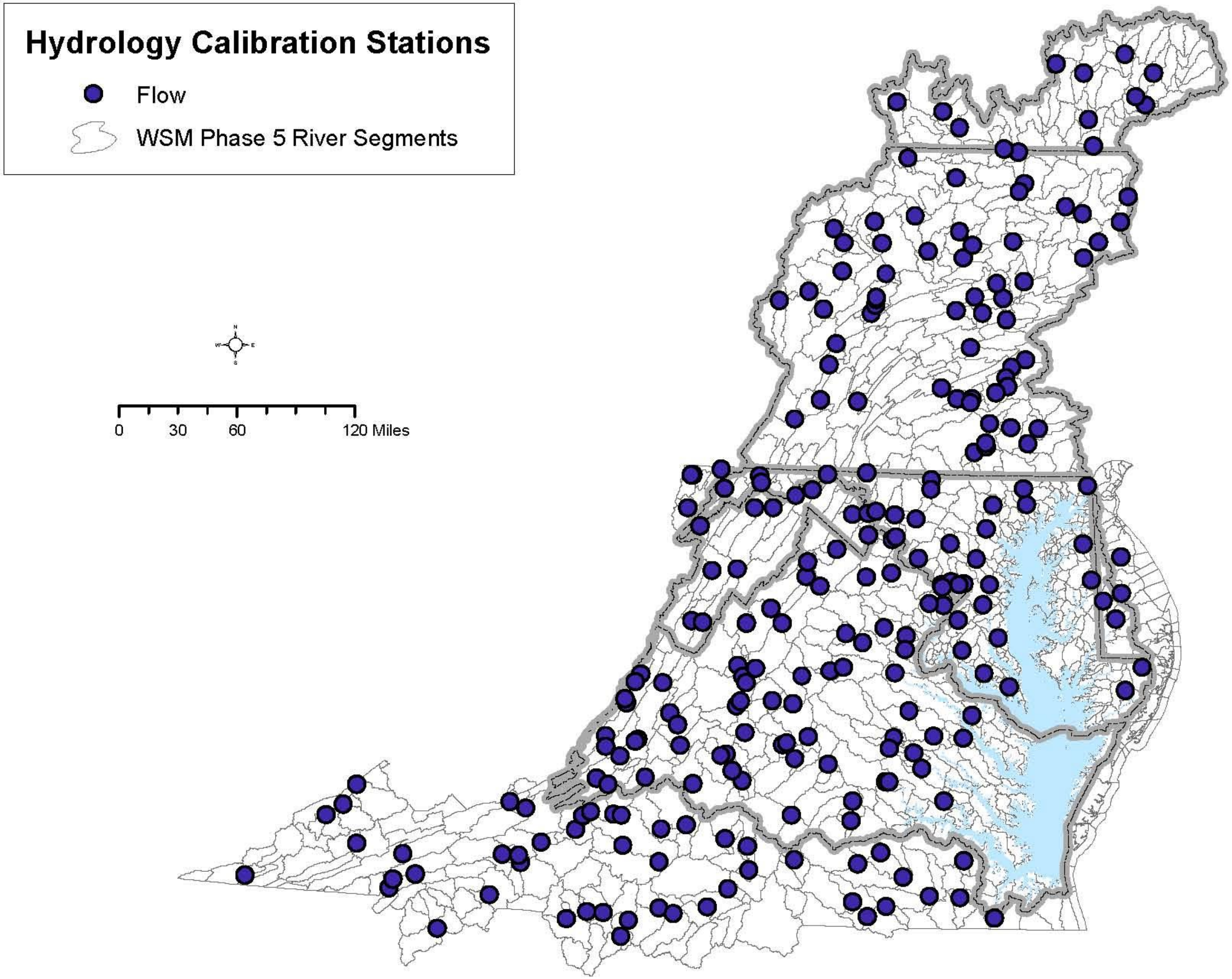
- Forest – Assume constant loss efficiency
- Crop –
  - median balance = median export
  - Zero balance = ½ median export
- Urban – Assume constant concentration
- No method of differentiation for
  - Alfalfa, construction, extractive, harvested forest, hay without nutrients, nurseries

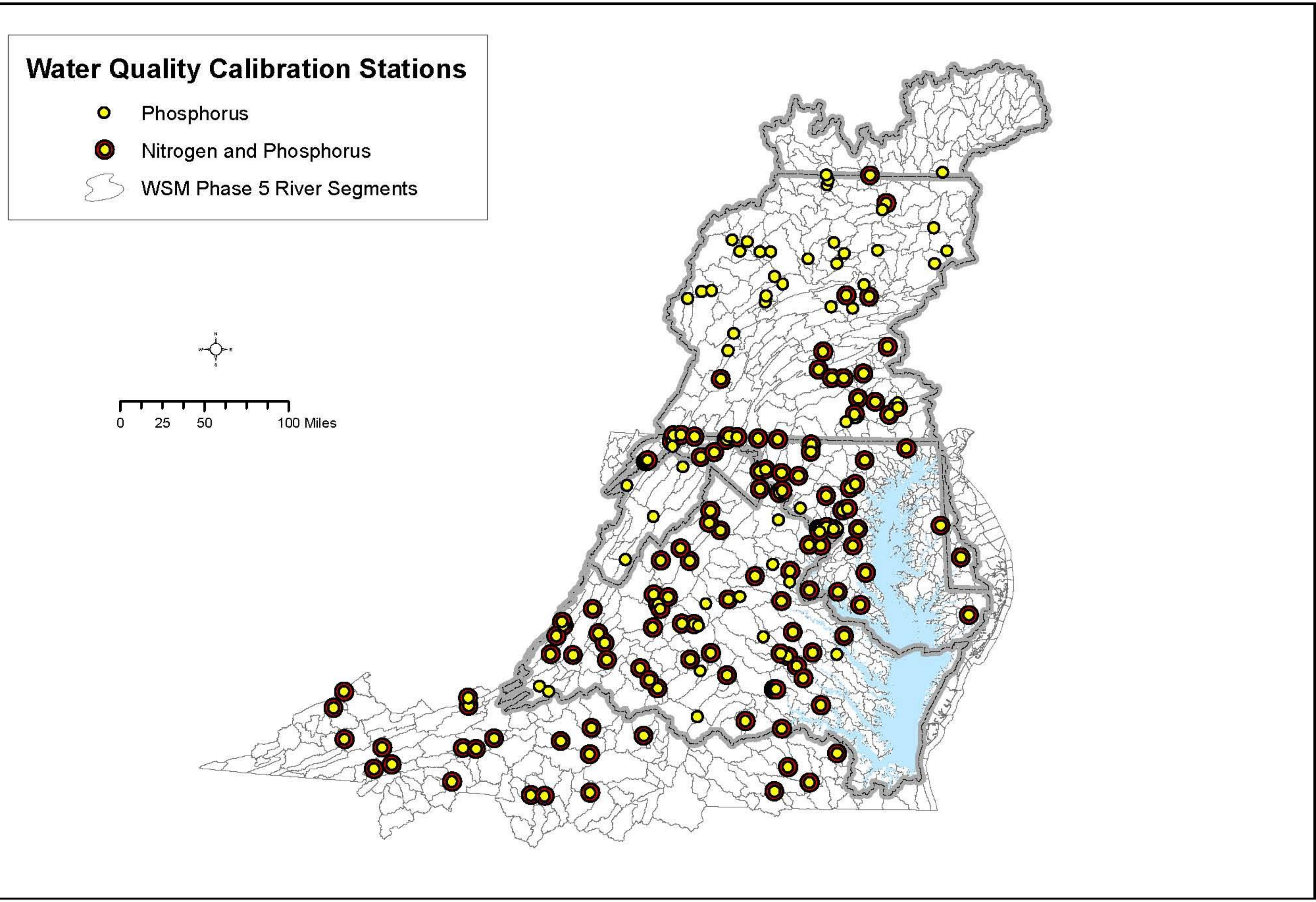
How do we calibrate?



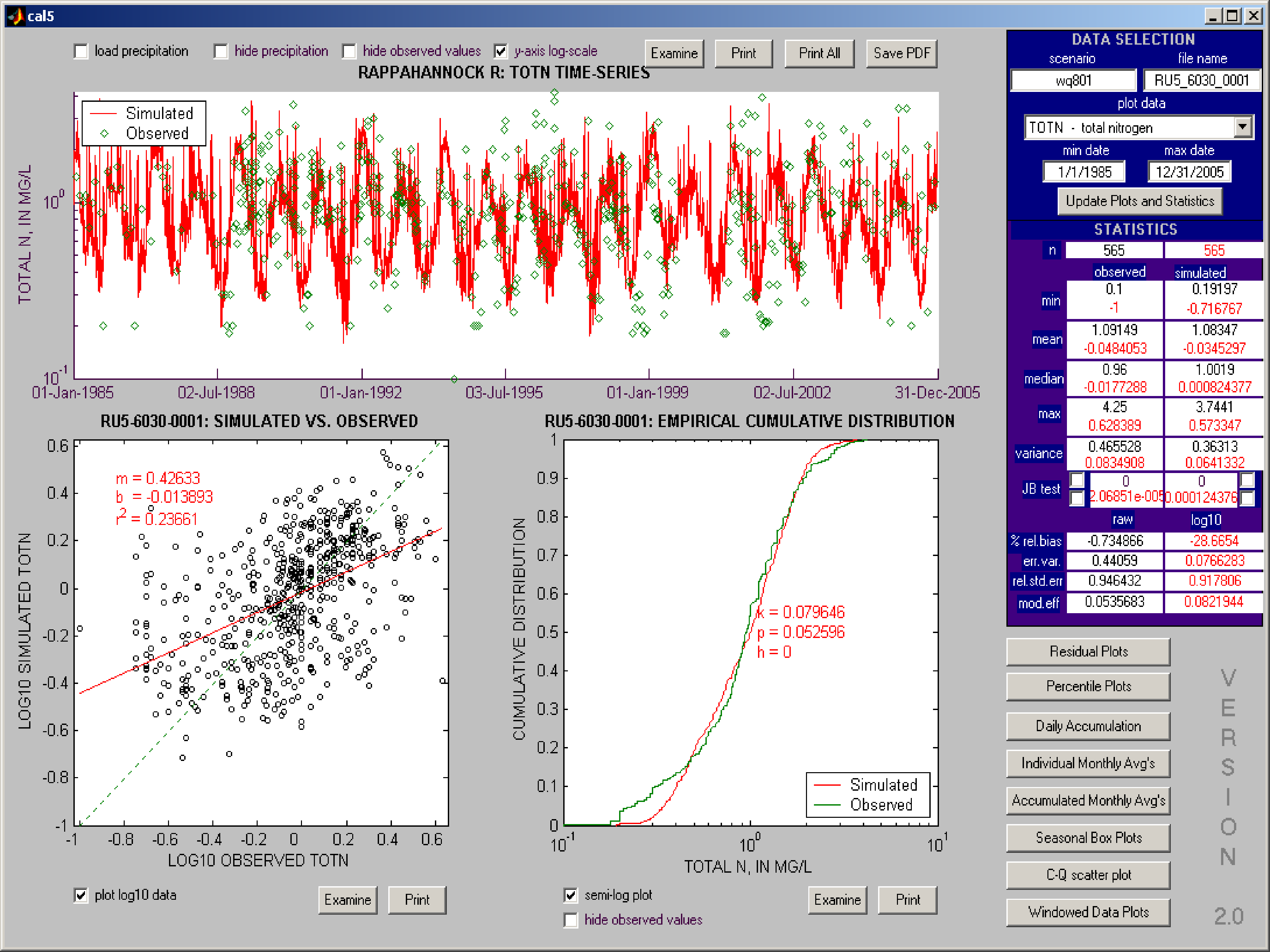
Reasonable values of sediment, nitrogen, and phosphorus

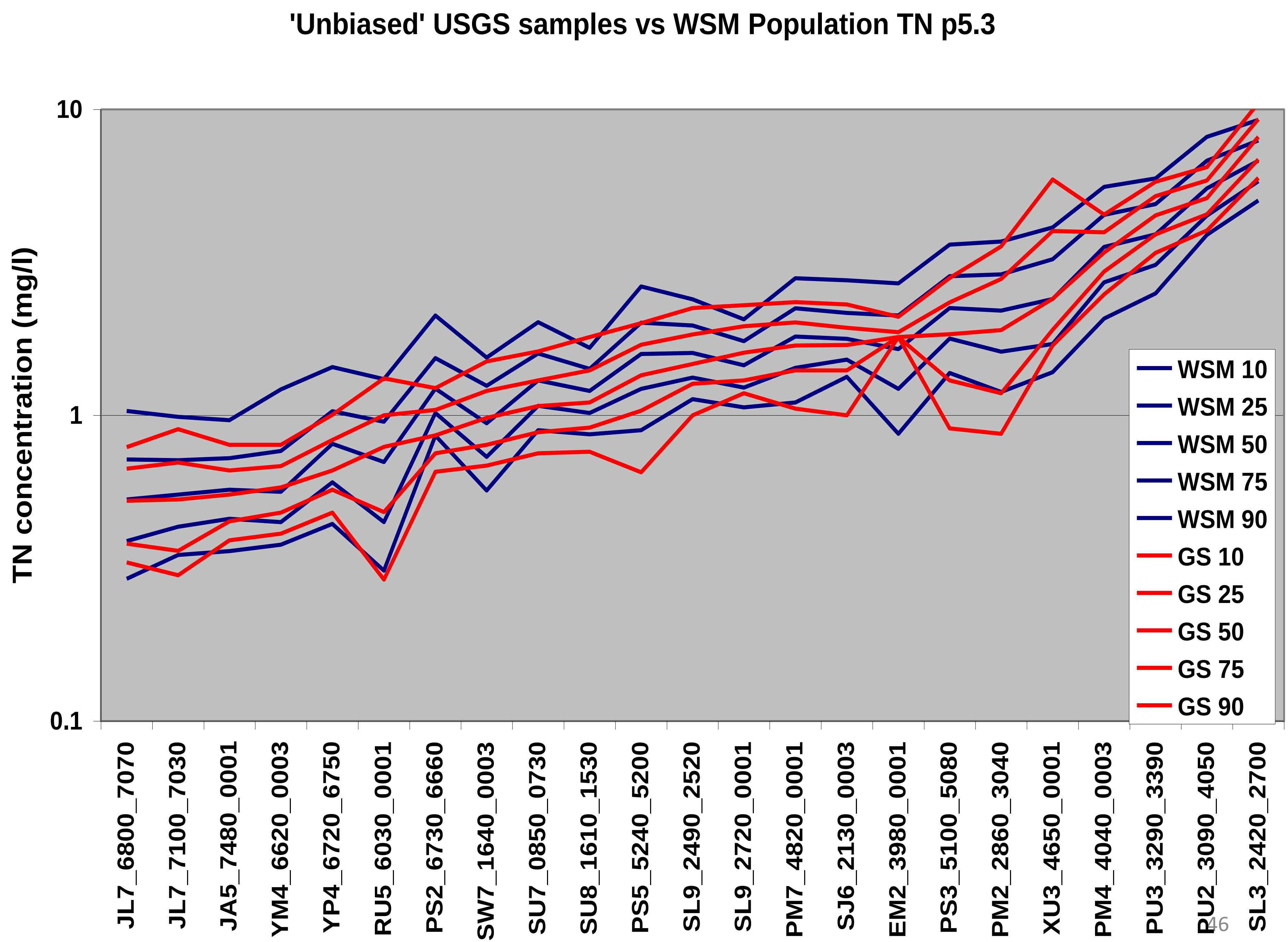
Observations of flow, sediment, nitrogen, and phosphorus

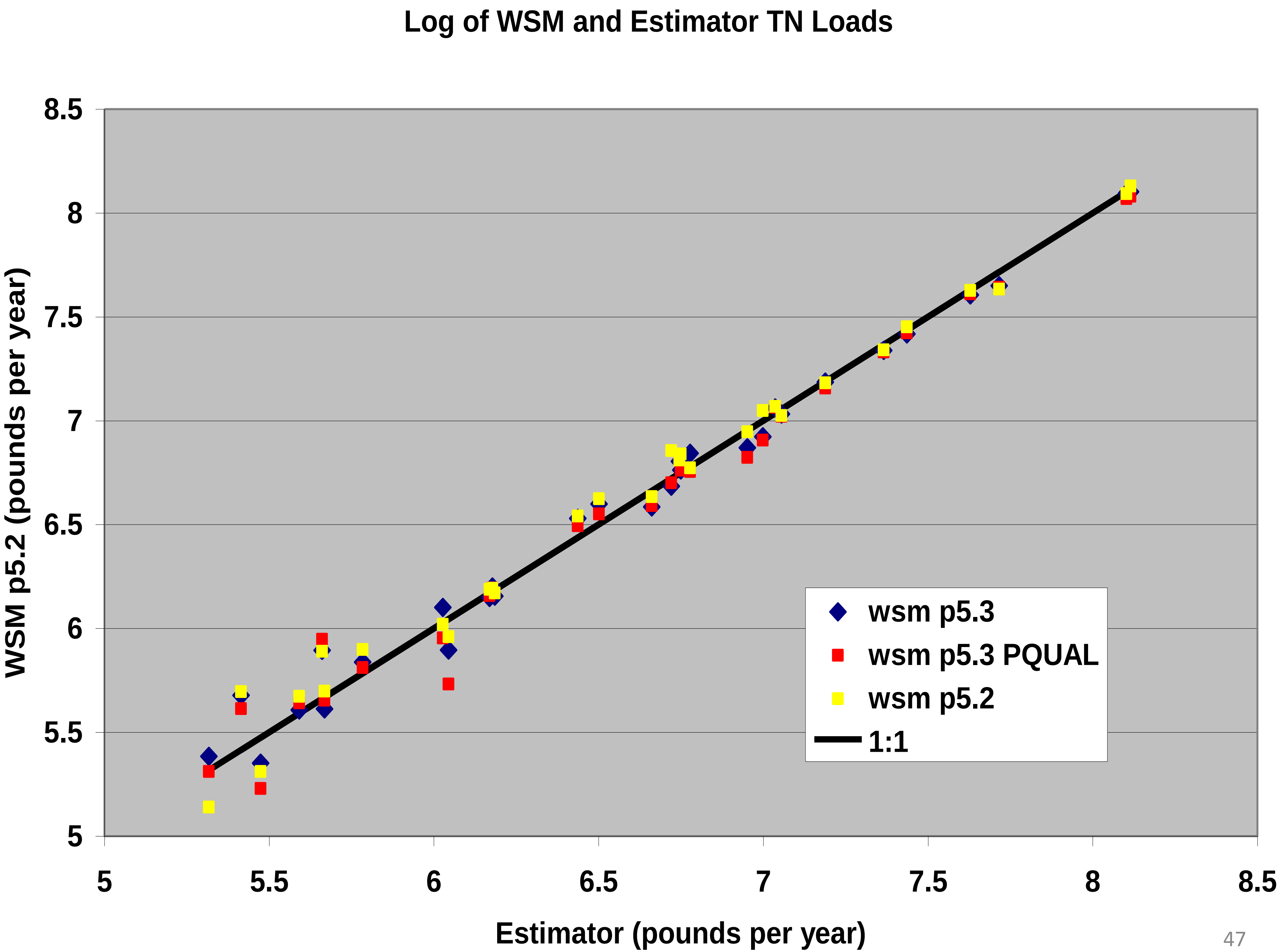

Hydrology Calibration Stations
Flow
WSM Phase 5 River Segments
0
30
60
120 Miles



Water Quality Calibration Stations
Phosphorus
Nitrogen and Phosphorus
WSM Phase 5 River Segments
0
25
50
100 Miles


cal5
load precipitation
hide precipitation
hide observed values
y-axis log-scale
Examine
Print
Print All
Save PDF
RAPPAHANNOCK R: TOTN TIME-SERIES
Simulated
Observed
TOTAL N, IN MG/L
01-Jan-1985
02-Jul-1988
01-Jan-1992
03-Jul-1995
01-Jan-1999
02-Jul-2002
31-Dec-2005
DATA SELECTION
scenario
file name
wq801
RU5_6030_0001
plot data
TOTN - total nitrogen
min date
max date
1/1/1985
12/31/2005
Update Plots and Statistics
STATISTICS
n
565
565
observed
simulated
min
0.1
-1
0.19197
-0.716767
mean
1.09149
-0.0484053
1.08347
-0.0345297
median
0.96
-0.0177288
1.0019
0.000824377
max
4.25
0.628389
3.7441
0.573347
variance
0.465528
0.0834908
0.36313
0.0641332
JB test
0
2.06851e-005
0
0.00012437
raw
log10
% rel.bias
-0.734866
-28.6654
err.var.
0.44059
0.0766283
rel.std.err
0.946432
0.917806
mod.eff
0.0535683
0.0821944
RU5-6030-0001: SIMULATED VS. OBSERVED
m = 0.42633
b = -0.013893
r2 = 0.23661
LOG10 SIMULATED TOTN
LOG10 OBSERVED TOTN
plot log10 data
Examine
Print
RU5-6030-0001: EMPIRICAL CUMULATIVE DISTRIBUTION
k = 0.079646
p = 0.052596
h = 0
CUMULATIVE DISTRIBUTION
TOTAL N, IN MG/L
Simulated
Observed
semi-log plot
hide observed values
Examine
Print
Residual Plots
Percentile Plots
Daily Accumulation
Individual Monthly Avg's
Accumulated Monthly Avg's
Seasonal Box Plots
C-Q scatter plot
Windowed Data Plots
VERSION
2.0


'Unbiased' USGS samples vs WSM Population TN p5.3
TN concentration (mg/l)
10
1
0.1
JL7_6800_7070
JL7_7100_7030
JA5_7480_0001
YM4_6620_0003
YP4_6720_6750
RU5_6030_0001
PS2_6730_6660
SW7_1640_0003
SU7_0850_0730
SU8_1610_1530
PS5_5240_5200
SL9_2490_2520
SL9_2720_0001
PM7_4820_0001
SJ6_2130_0003
EM2_3980_0001
PS3_5100_5080
PM2_2860_3040
XU3_4650_0001
PM4_4040_0003
PU3_3290_3390
RU2_3090_4050
SL3_2420_2700
WSM 10
WSM 25
WSM 50
WSM 75
WSM 90
GS 10
GS 25
GS 50
GS 75
GS 90



Log of WSM and Estimator TN Loads
WSM p5.2 (pounds per year)
8.5
8
7.5
7
6.5
6
5.5
5
5
5.5
6
6.5
7
7.5
8
8.5
Estimator (pounds per year)
wsm p5.3
wsm p5.3 PQUAL
wsm p5.2
1:1

How the Watershed Model Works

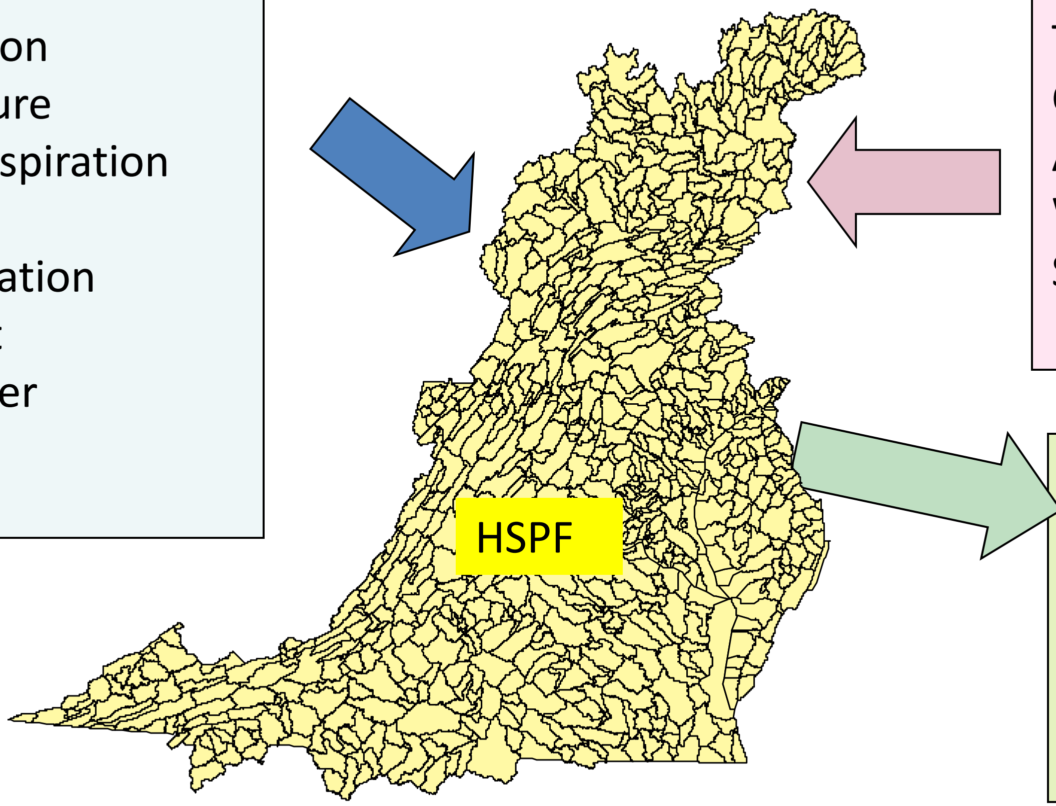
Scenario Mode

Hourly or daily values of Meteorological factors:

Precipitation
Temperature
Evapotranspiration
Wind
Solar Radiation
Dew point
Cloud Cover

Constant values of anthropogenic factors:

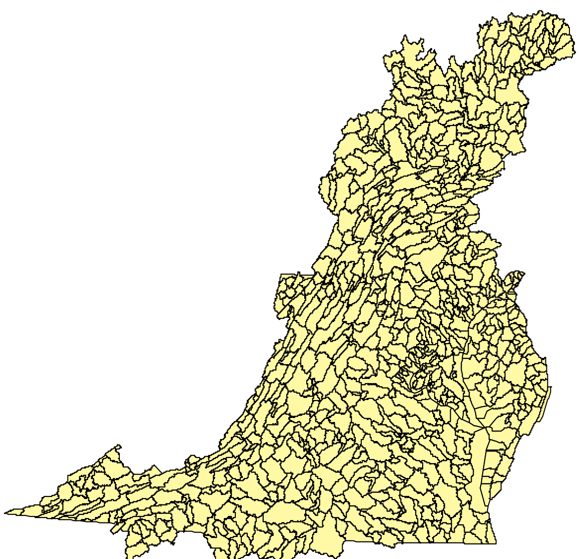
Land Use Acreage
BMPs
Fertilizer
Manure
Tillage
Crop types
Atmospheric deposition
Waste water treatment
Septic loads



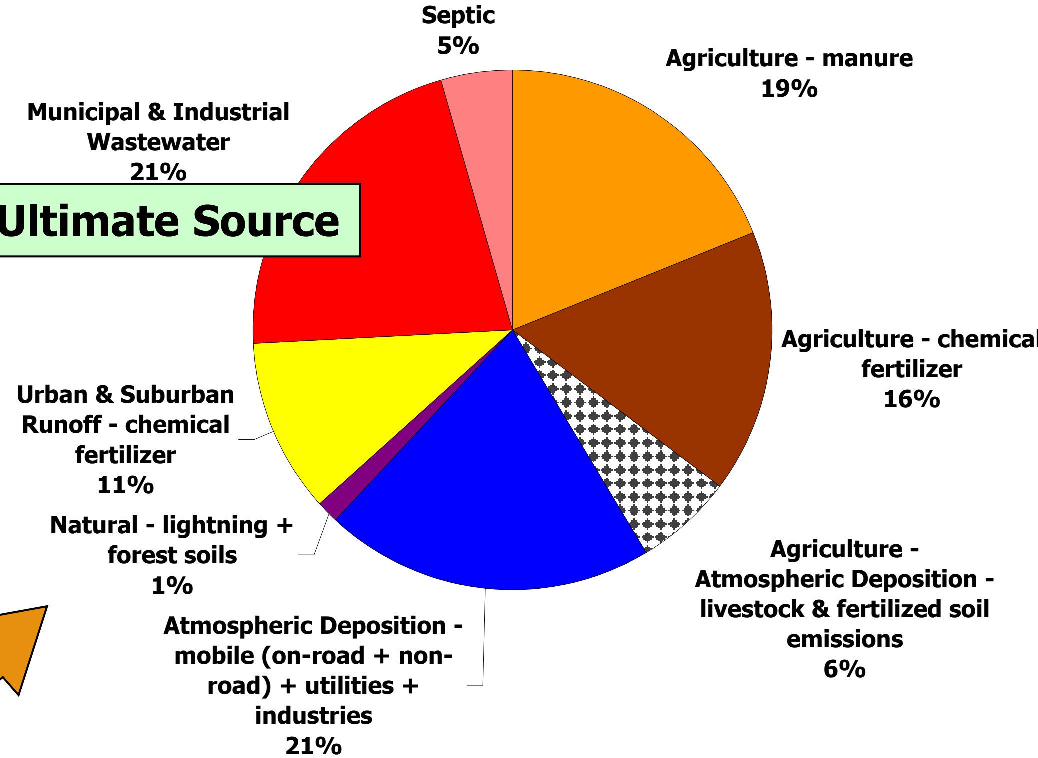
Run for 1984-2000
Average 1991-2000
For ‘flow-normalized average annual loads’

WSM Uses:

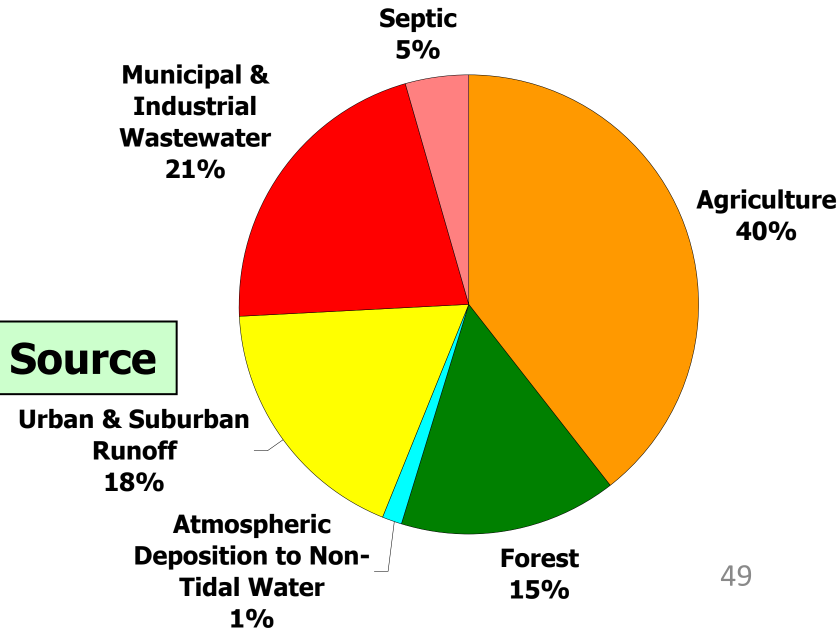
Divide Load into contributing areas and sources



Ultimate Source

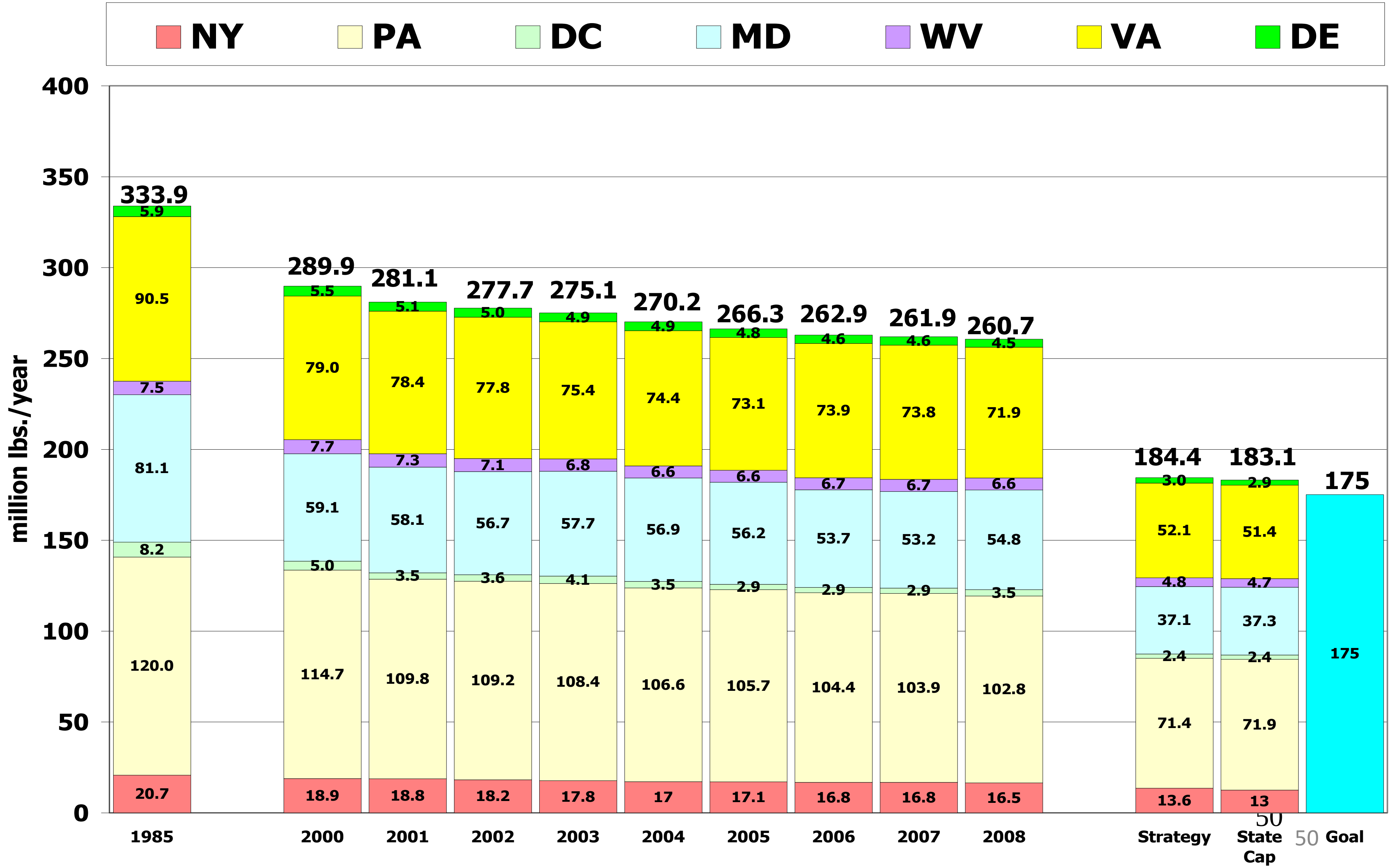


Land Use Source

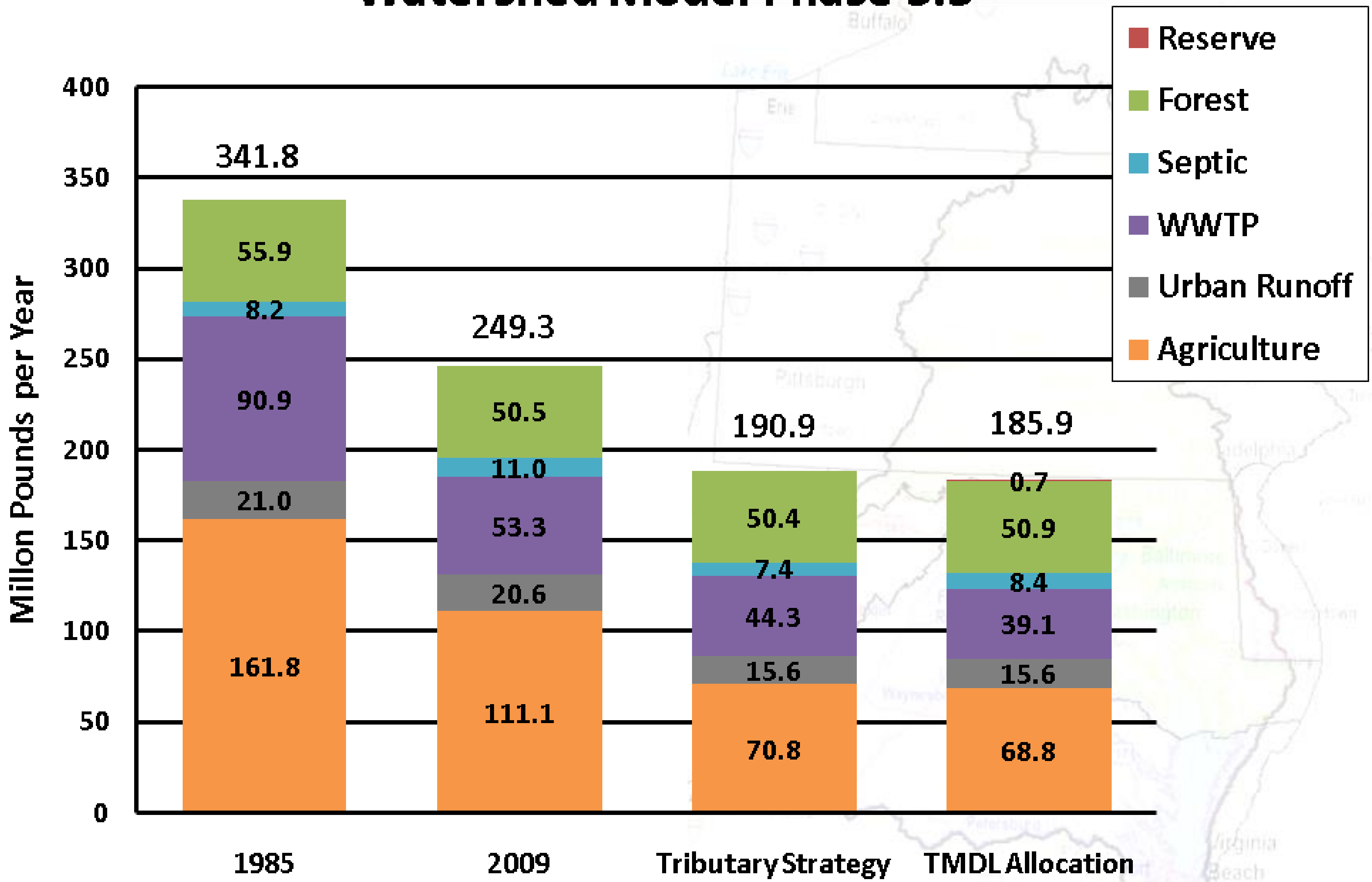


Nitrogen Loads Delivered to the Chesapeake Bay By Jurisdiction

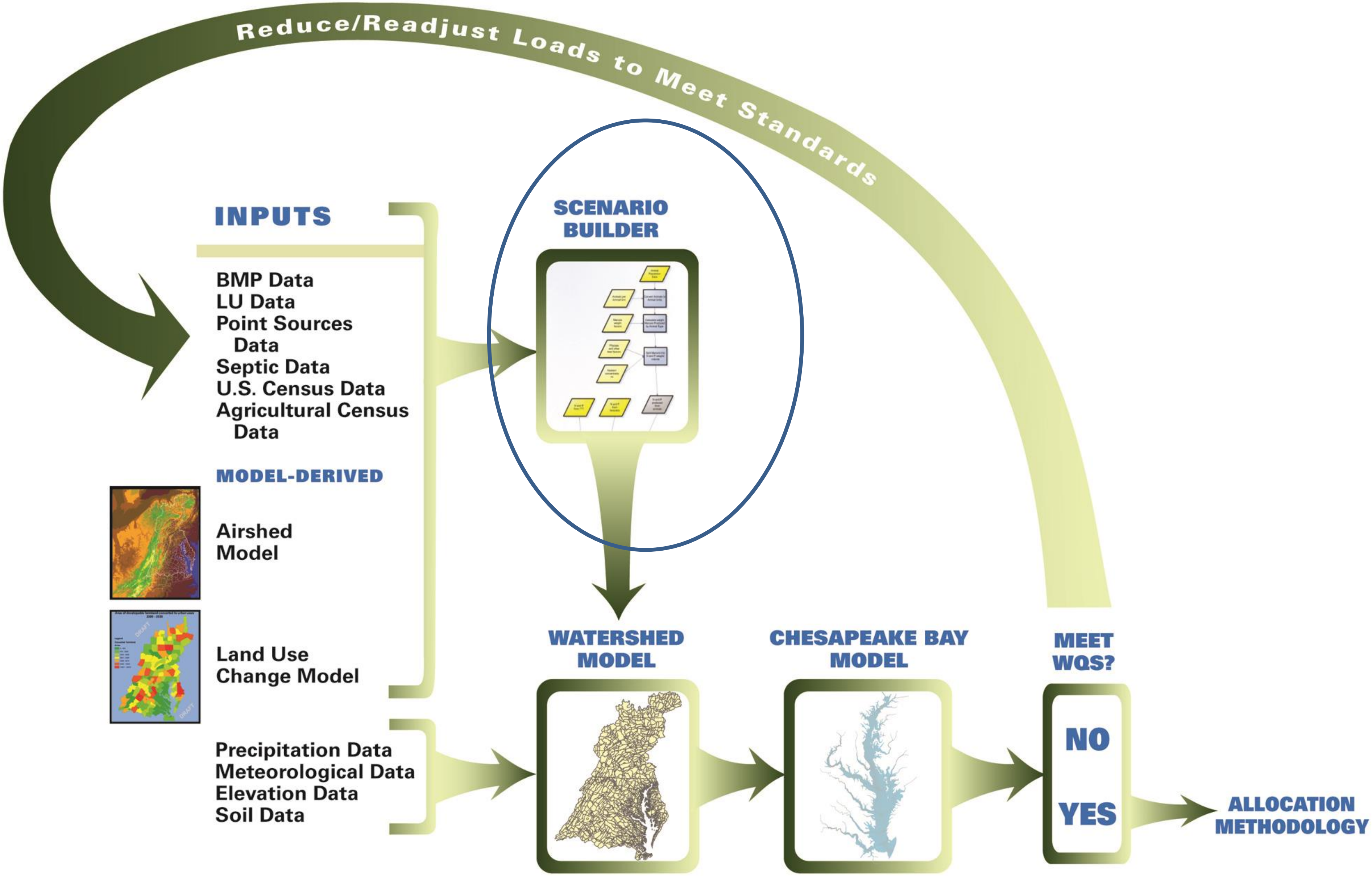
Point source loads reflect measured discharges while
nonpoint source loads are based on an average-hydrology year



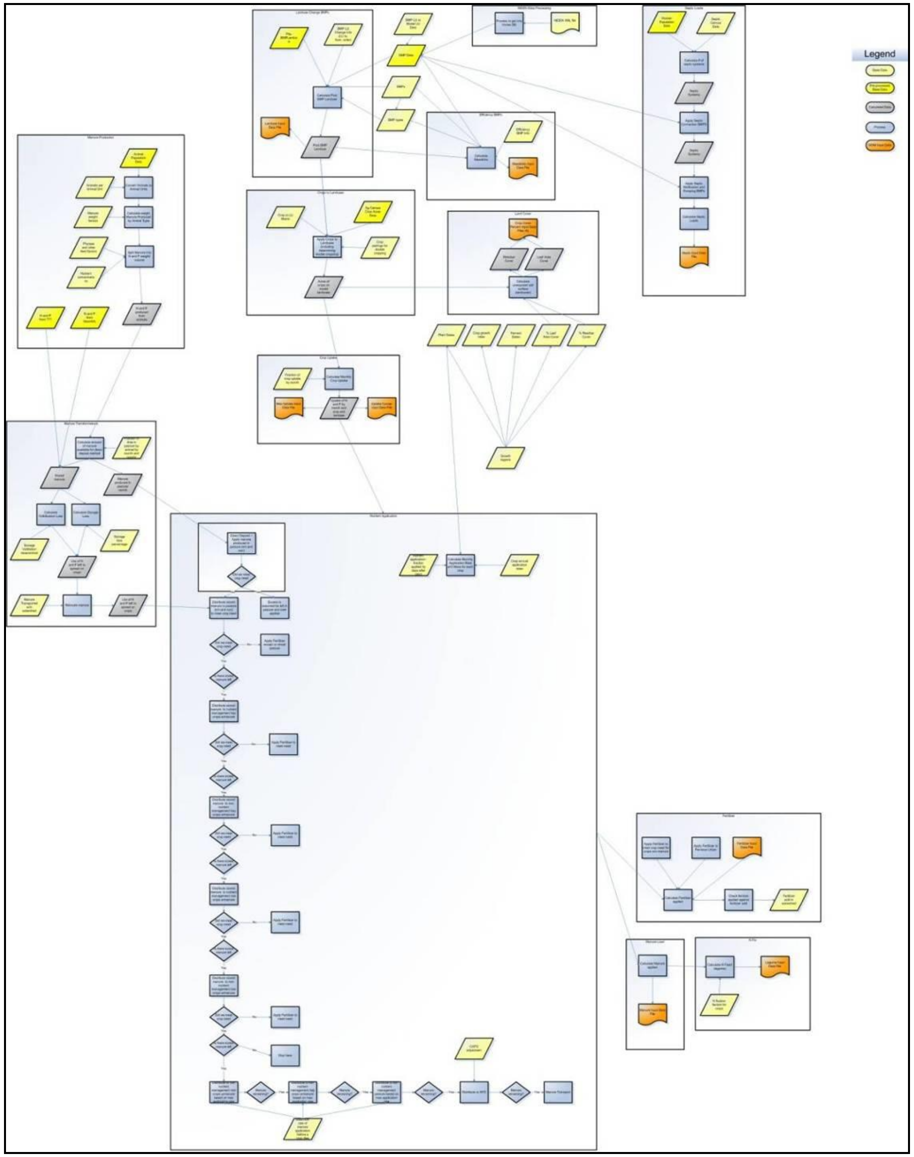
Nitrogen Loads by Source Sector and Scenario - Watershed Model Phase 5.3



Chesapeake Bay Partnership Models



Scenario Builder



- Input processor for the Watershed Model
- Generates past, present or future state of watershed conditions
- Specific WSM Inputs from Scenario Builder:
  - Management practices
  - Land use acres
  - Manure and chemical fertilizer application rates
  - Crop growth
  - Septic loads

Scenario Builder

Inputs

- BMP Type and location (NEIEN/State supplied)
- Land acres
- Remote Sensing, NASS Crop land Data layer
- Crop acres
- Yield
- Animal Numbers (Ag Census or state supplied)
- Land applied biolsolids
- Septic system (#s)

Parameters

(Changeable by user)

- BMP types and efficiencies
- Land use change (BMPs, others)
- RUSLE2 Data: % Leaf area and residue cover
- Plant and Harvest dates
- Best potential yield
- Animal factors (weight, phytase feed, manure amount and composition)
- Crop application rates and timing
- Plant nutrient uptake
- Time in pasture
- Storage loss
- Volatilization
- Animal manure to crops
- N fixation
- Septic delivery factors

Outputs

- BMPs, # and location
- Land use
- % Bare soil, available to erode
- Nutrient uptake
- Manure and chemical fertilizer (lb/segment)
- N fixation (lb/segment)
- Septic loads

Scenario Builder Direction

- Water Quality Goal Implementation Team
  - Watershed Technical Workgroup
  - Agriculture Workgroup
  - Urban Stormwater Workgroup
  - Forestry Workgroup
  - Sediment Workgroup
- Modeling Workgroup
- Scientific and Technical Advisory Committee
- Principals' Staff Committee (state secretary)

Agricultural Workgroup

- **Federal**
  - USDA, EPA
- **State**
  - Chesapeake Bay Commission, Delaware Department of Agriculture, Maryland Department of Agriculture, NY DEC, PA Department of Environmental Protection, Pennsylvania Department of Environmental Protection, Pennsylvania State Conservation Commission, VA DCR, VA DEQ, West Virginia Department of Agriculture, WV DEP
- **University**
  - Chesapeake Research Consortium, Cornell University, Penn State University, University of Delaware, University of Maryland, West Virginia University
- **Industry Groups**
  - Delaware Maryland Agribusiness Association, Delaware Pork Producers Association, Delmarva Poultry Industry, Inc., MD Farm Bureau, VA Farm Bureau, VA Grain Producers Producers Association, Virginia Agribusiness Council, Virginia Poultry Association, U.S. Poultry & Egg Association,
- **Local organizations**
  - Cortland County Soil and Water Conservation District, Lancaster County Conservation District, Madison Co. SWCD, Upper Susquehanna Coalition
- **NGOs**
  - American Farmland Trust, Environmental Defense Fund, Keith Campbell Foundation for the Environment, MidAtlantic Farm Credit, PA NoTill Alliance

The Collaborators are Many…

These are the federal, state, and regional agency, academic institution, non-governmental organization and agricultural industry contributors to just the two-year effort to evaluate and revised the best management practice efficiencies:

Mid-Atlantic Water Program, U.S. Department of Agriculture-Natural Resources Conservation Service, Virginia Department of Conservation and Recreation, Virginia Department of Forestry, Pennsylvania State Conservation Commission, Pennsylvania Department of Conservation and Natural Resources, Pennsylvania Department of Environmental Protection, Maryland Department of Agriculture, Maryland Department of Natural Resources, Maryland Department of the Environment, University of Maryland Cooperative Extension, University of Maryland-College Park, Delaware Department of Agriculture, Delaware Department of Natural Resources and Environmental Control, Delaware Maryland Agribusiness Association, West Virginia Department of Agriculture, West Virginia Department of Environmental Protection, Cacapon Institute - West Virginia, New York Department of Environmental Conservation, Upper Susquehanna Coalition, American Farmland Trust, Chesapeake Bay Commission, U.S. Forest Service, U.S. Fish and Wildlife Service, U.S. Geological Survey, U.S. Environmental Protection Agency, Keith Campbell Foundation for the Environment, Pinchot Institute, Piedmont Environmental Council

Agricultural Processes in Scenario Builder

Christopher F. Brosch
University of Maryland, College Park
Chesapeake Bay Program

Chesapeake Bay Program
A Watershed Partnership

Scenario Builder Ag Data Output

- BMPs
  - Acres
  - Pounds nitrogen, phosphorus and sediment reduced
- Manure application (nutrient species/month)
- Fertilizer application (month)
- Legumes (pounds ammonium)
- Crop uptake (monthly nutrients)
- Bare soil
- Detached Sediment
- Landuses

Crop and Plant Types

Most of those in the Agricultural Census are used

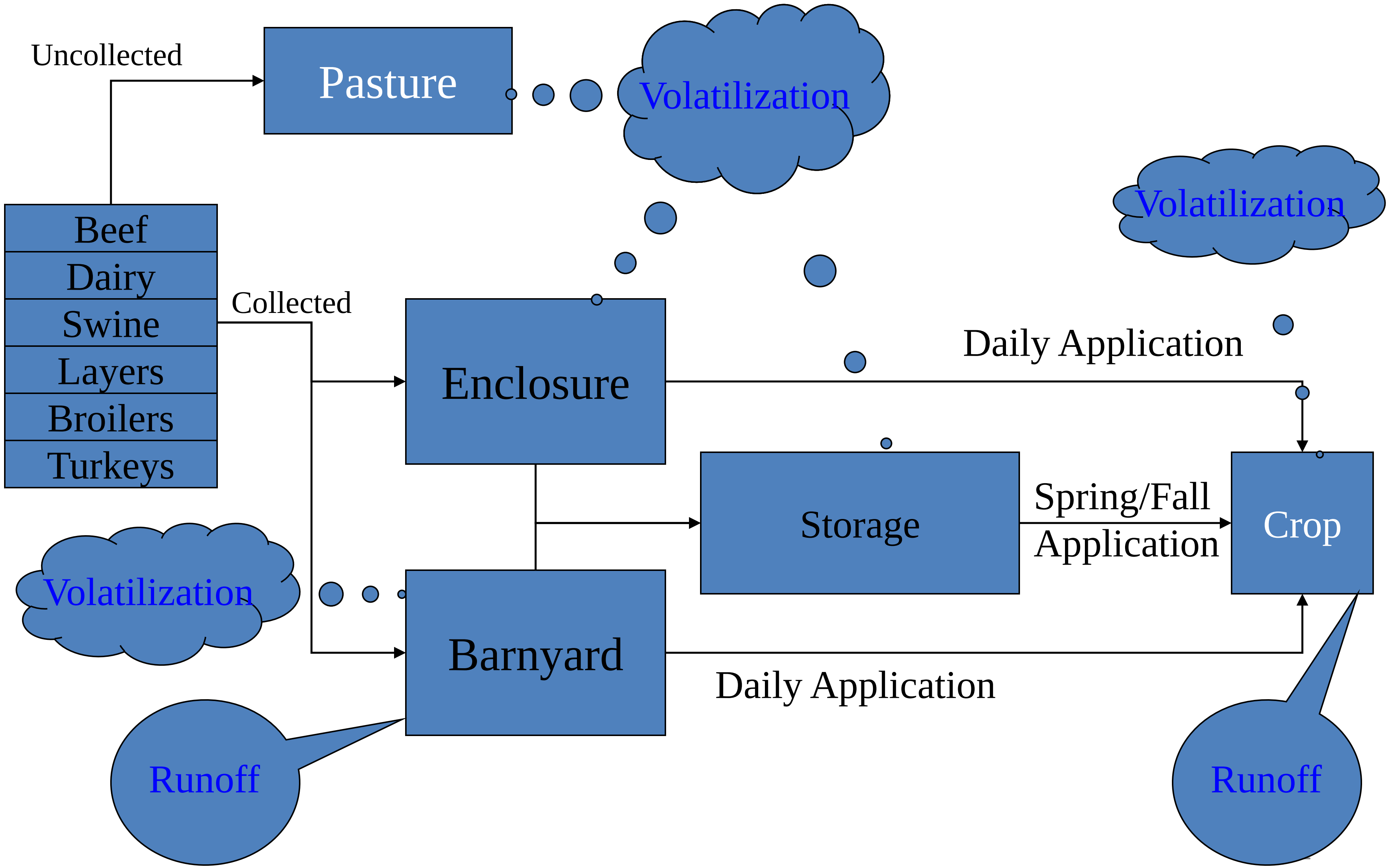
120 total

– 54 are fruits and vegetables

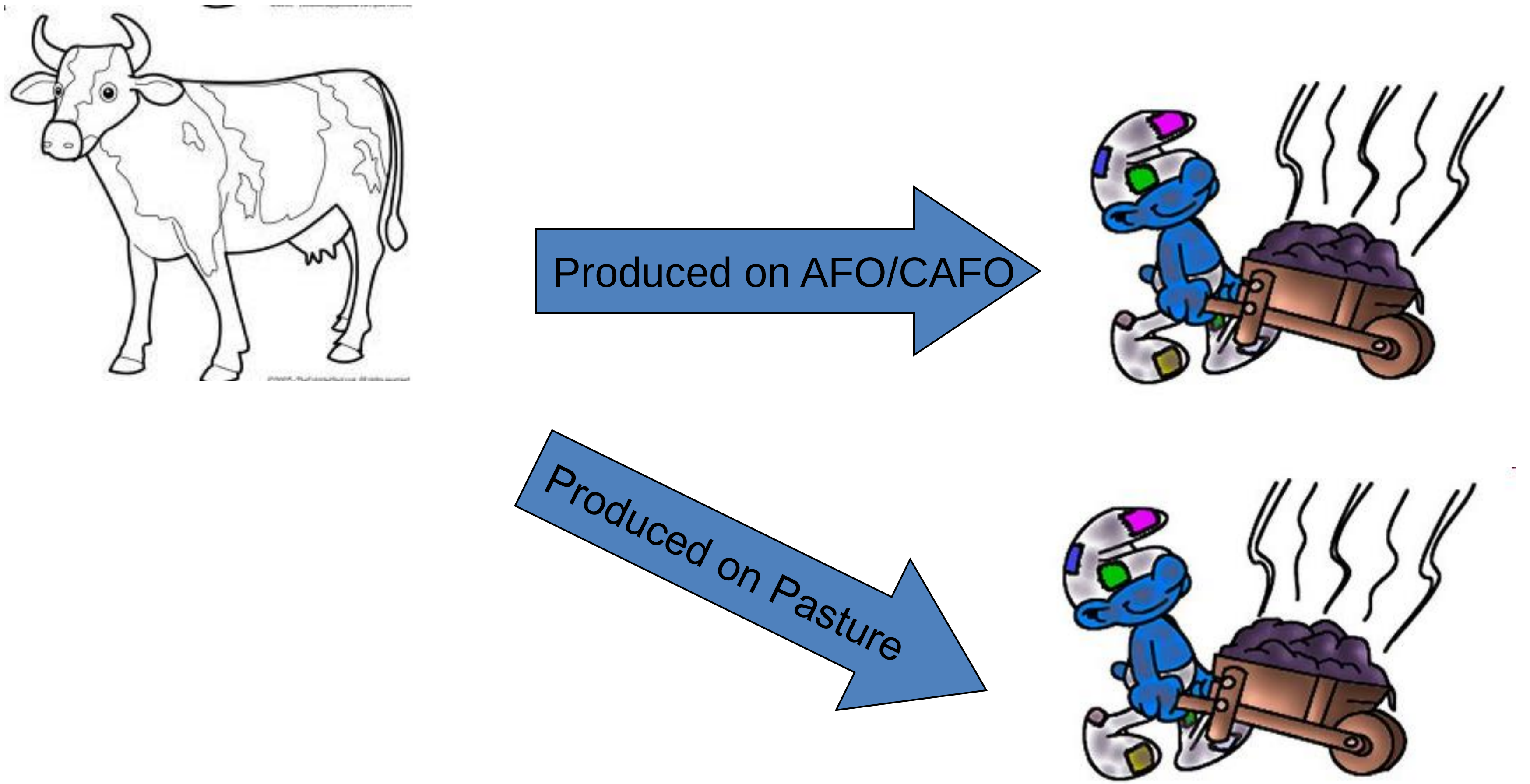
– 21 are greenhouse crops

NUTRIENT SOURCES

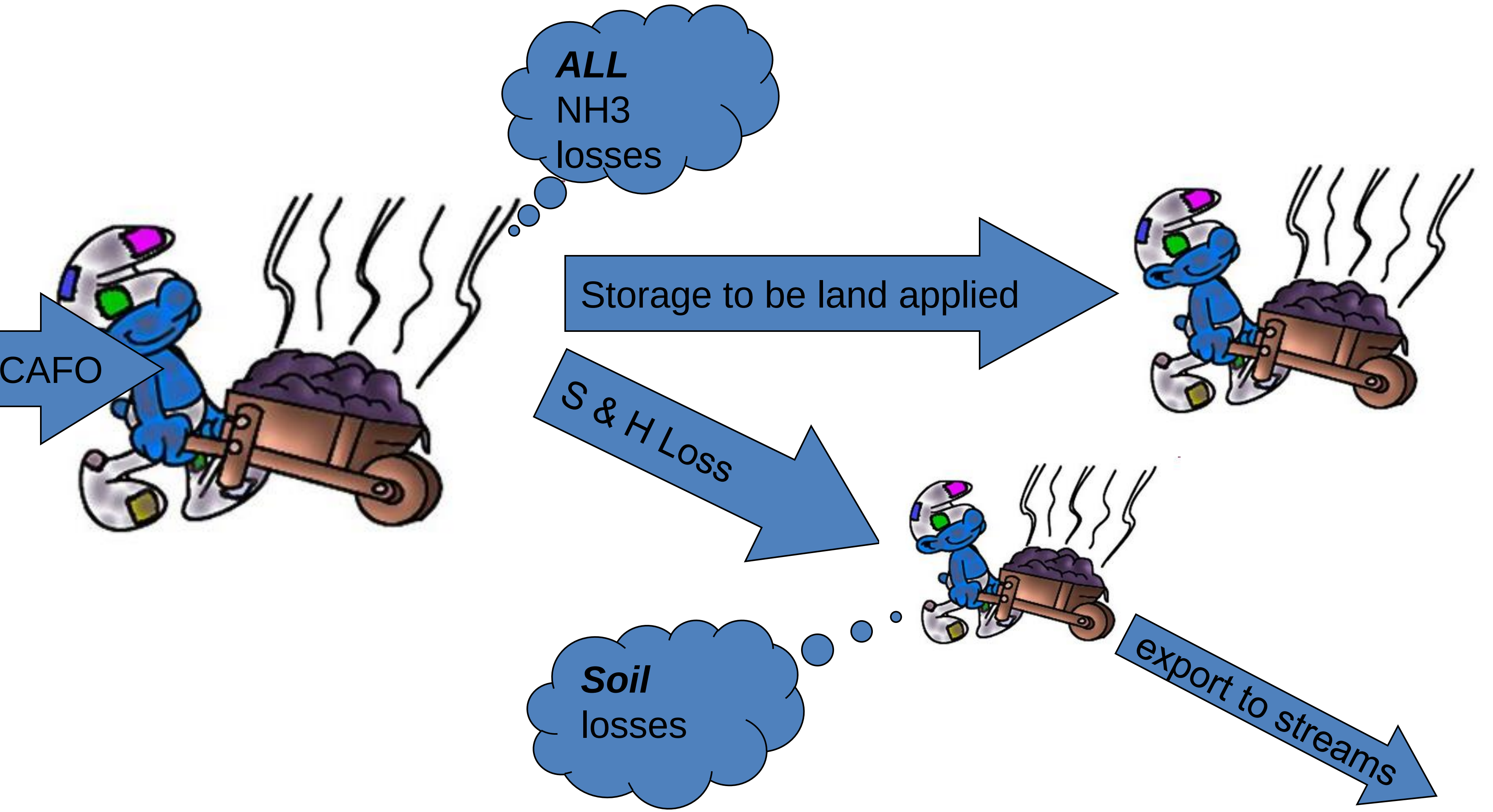
Manure Data Model



Manure generation: calculated monthly



Manure produced in confinement



Animal Counts → Animal Units (AUs)

- 1 Animal Unit = 1000 lbs avg. weight of animal
- Sources available in [documentation]()

Animal type	*Live animal weight (lbs)*	*No. of animals per animal unit (animal unit=1000 lbs)*	*Manure (lbs) per day per animal unit*
beef	877.19	1.14	58
dairy	1351.35	0.74	86
other cattle	480.77	2.08	64.39
broilers	2.20	455	85
layers	4.00	250	64
pullets	2.84	352.5	45.56
turkeys	14.93	67	47
hogs and pigs for breeding	374.53	2.67	33.46
hogs for slaughter	110.01	9.09	84
horses	1000.00	1	51
angora goats	65.02	15.38	41
milk goats	65.02	15.38	41
sheep and lambs	100.00	10	40

Manure Nutrient Concentration

Source types	***TN lb/lb manure***	***TP lb/lb manure***
angora goats	0.011	0.0027
Beef	0.0059	0.0016
Biosolids	0.039	0.025
Broilers	0.0129	0.0035
Dairy	0.0052	0.0011
hogs and pigs for breeding	0.0066	0.0021
hogs for slaughter	0.0062	0.0021
Horses	0.0059	0.0014
Layers	0.0131	0.0047
milk goats	0.011	0.0027
other cattle	0.0037	0.001
Pullets	0.0136	0.0053
sheep and lambs	0.0105	0.0022
turkeys	0.0132	0.0049

Source: ASAE. 2003. Manure Production and Characteristics. In ASAE Standards. D384.1. St. Joseph, MI, pp. 683-685.

Nutrient speciation lb/lb

Nutrient	N fertilizer	P Fertilizer	Broiler manure (lb-nutrient/lb-manure)
Phosphate	0	1	0.001082
Min P	0	0	0.002447
NH3	0.25	0	0.003235
NO3	0.75	0	0
Min N	0	0	0.005824
Org N – not Plant Available	0	0	0.003882

Mineralization by manure type

Manure type	*Phosphorus Mineralization factor*	*Organic Nitrogen Mineralization factor*
All bovine	1	0.35
All swine	1	0.50
All poultry	1	0.60
horses	1	0.50
Biosolids	1	0.30
sheep, lambs, and goats	1	0.35

Example: Broilers - 60% = MinN/(MinN+OrgN)

Animal Un-confinement

- Time spent on pasture is based on estimates from states
  - Is growth-region specific, Full version available in [documentation]
- Defines portion of manure produced in month to be direct deposited on pasture land

Growing Area ID	Animal Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PA_1	angora goats	0	0	0	0	1	1	1	1	1	1	0	0
PA_1	beef	0	0	1	1	1	1	1	1	1	1	1	0.6
PA_1	broilers	0	0	0	0	0	0	0	0	0	0	0	0
PA_1	dairy	0	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.65
PA_1	hogs and pigs for breeding	0	0	0	0	0	0	0	0	0	0	0	0
PA_1	hogs for slaughter	0	0	0	0	0	0	0	0	0	0	0	0
PA_1	horses	0.6	0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6
PA_1	layers	0	0	0	0	0	0	0	0	0	0	0	0
PA_1	milk goats	0	0	0	1	1	1	1	1	1	1	0	0
PA_1	other cattle	0.75	0.75	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.75
PA_1	pullets	0	0	0	0	0	0	0	0	0	0	0	0
PA_1	sheep and lambs	0	0	0	1	1	1	1	1	1	1	1	0
PA_1	turkeys	0	0	0	0	0	0	0	0	0	0	0	0

Storage and Handling loss

- Assuming Pre-BMP condition:
  - All poultry and swine, 15% of manure is lost during storage.
  - Beef, dairy, sheep and lambs, goats, and horses, 20% is lost
- Amount lost is AFO or CFO load
- Amounts flagged as issue and scheduled for thorough review in Agriculture and Sediment Reduction Workgroup

Stored Manure Apportionment

- Manure stored from AFO/CAFO is retained until monthly crop need calls on nutrients to be supplied from manure
- Manure applied to crops is removed from the amount stored
- N:P Ratio of the original manure is preserved through process after volatilization
  - Generally results in over-application of P when applied for N

BMPs

CBP Agricultural BMPs

Nutrient Management
- Nutrient Management
- Precision Agriculture
- Enhanced Nutrient Management

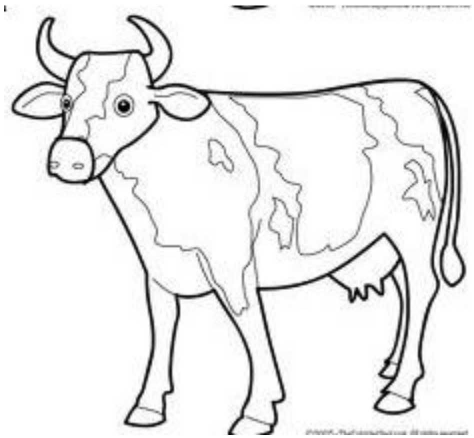
Conservation Tillage
- Continuous No-Till
- Other Conservation Tillage

Cover Crops
- Cover Crops – Late Planting
- Cover Crops – Early Planting
- Small Grain Enhancement – Late Planting
- Small Grain Enhancement – Early Planting

Pasture Grazing BMPs
- Pasture Fencing
- Precision or Intensive Rotational Grazing
- Horse Pasture Management
- Water Control Structures

Other Agricultural BMPS
- Forest Buffers
- Wetland Restoration
- Land Retirement
- Grass Buffers
- Tree Planting
- Carbon Sequestration/Alternative Crops
- Conservation Plans/SCWQP
- Non-Urban Stream Restoration
- Manure transport
- Animal Waste Management Systems
- Mortality Composters
- Poultry Phytase
- Dairy Precision Feed and/or Forage Management
- Swine Phytase
- Ammonia Emissions Reductions

Feed Mgmt: Load Reduction BMP



To AFO/CAFO

To Pasture

- Dairy Precision Feeding: PA: 24% TN; 25% TP

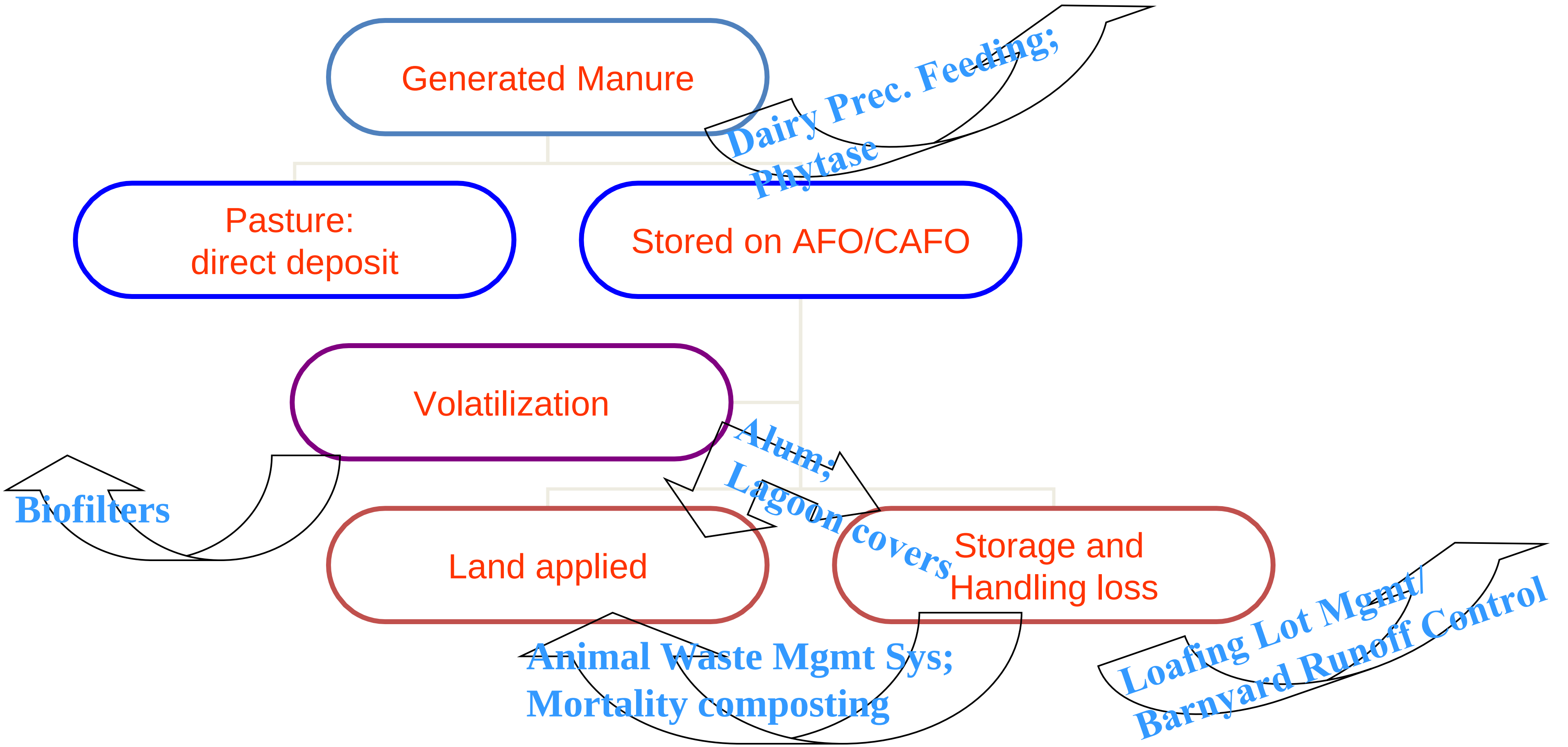
- Phytase Default: Broilers 16%; Layers 21%; Pullets 21%; Turkeys 16%; Sows and hogs 0%

Loafing Lot Mgmt/Barnyard Runoff Control

- Efficiency reduction with nutrients being removed from system

Effectiveness estimate:	TN: 20%, TP:20%, TSS:40%

Manure BMP Processes



Land Application of Nutrients

Nutrients Applied To Land

- Calculated by
  - County
  - Year
  - Crops, post-BMP landuse changes
- Elements include
  - Manure
  - Fertilizer
  - Biosolids
  - Nitrogen Fixation (total fixed includes uptake)
  - Uptake (includes whole plant uptake, not just removal)
  - BMPs (reductions)

Rates and Timing

- Rates are important for applying the proper amount of nutrient
- Timing of nutrients is parsed out and fulfilled monthly – based on HSPF time step
- Starter fertilizer is applied based on state supplied data

Growing area code	Crop id	Crop name	Major nutrient	Double crop (1=true)	Days after planting	Fraction applied	Starter fertilizer (1=true)
PA_1	35	Corn for Grain	Nitrogen	0	-15	0.3	0
PA_1	35	Corn for Grain	Phosphorus	0	-15	1	0
PA_1	35	Corn for Grain	Nitrogen	0	45	0.7	1

Nutrient Application

- Nutrient Type
  - Biosolids
    - Treated same rules as manure for crop types and rates
    - applied according to plant-available N: 30% Organic N
  - Manure (applied according to plant-available N 35-65% Org N)
  - Fertilizer (inorganic; N assumed 100% Plant available)
- Order by Nutrient Source

1. Starter fertilizer
2. Direct Deposition
3. Biosolids (to NM land first if available)
4. CAFO Manure (to NM land first if available)
5. AFO manure
6. Fertilizer (to supplement remaining need)
7. Disposal sequence

Very High P Applications on nutrient management land

- All Biosolid and CAFO manure goes to satisfy nitrogen need on nutrient management land first
- Crop need is satisfied in application by inorganic + mineralizable organic.
- ‘Unmineralizable’ N is still available for runoff
- Biosolids and manure have a high P:N ratio relative to crop need

Disposal Sequence

- Excess manure after all crop need is satisfied and manure transport has been credited is applied at disposal rate

Scenario Builder
Documentation

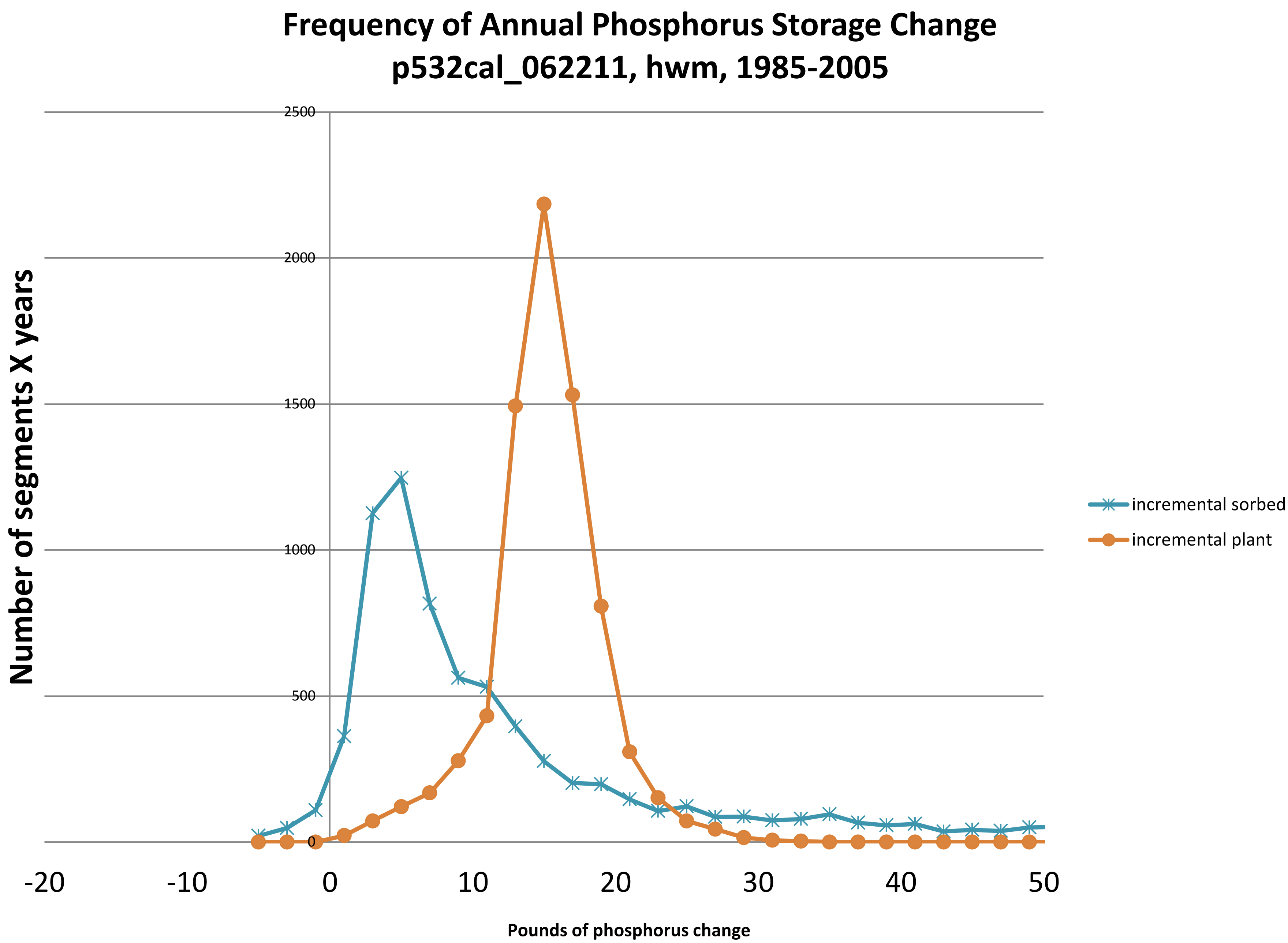
- Estimates of County-Level Nitrogen and Phosphorus Data for Use in Modeling Pollutant Reduction
    - http://archive.chesapeakebay.net/pubs/SB_V22_Final_12_31_2010.pdf
- Chesapeake Bay TMDL – Section 5. Chesapeake Bay Monitoring and Modeling Frameworks
    - http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/CBayFinalTMDLSection5_final.pdf
- Chesapeake Community Modeling Program – Models & Data, HSPF Phase 5 (Chesapeake Bay Program), Chesapeake Bay Watershed Phase 5.3 Model
    - http://ches.communitymodeling.org/models/CBPhase5/documentation.php#scenario

Some direction going forward

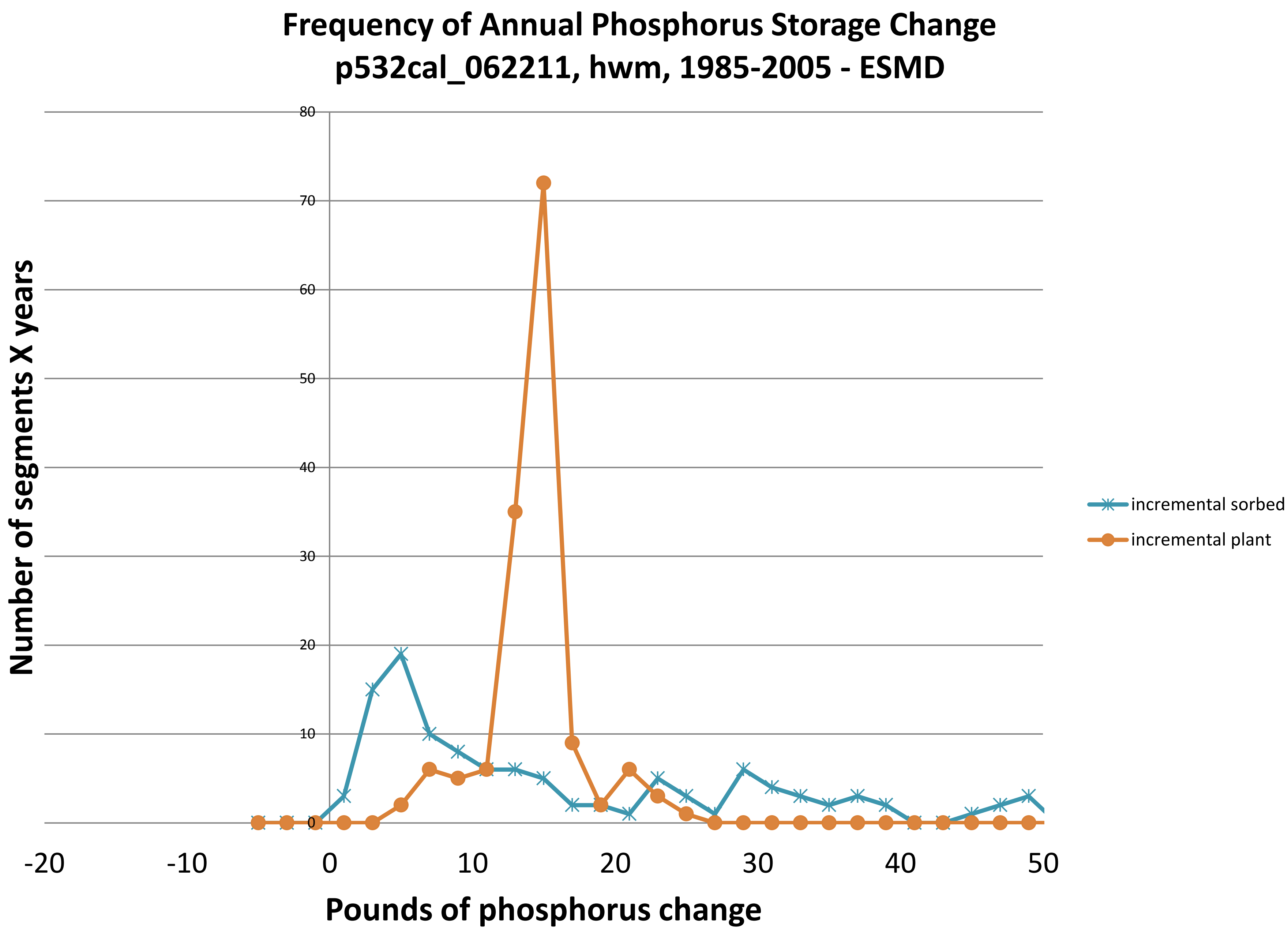
- The Golden Rule of Modeling
  - Always improve
  - Never Change
- The Absolute Axiom of Modeling
  - Include everything
  - Keep it simple
- Increase transparency - Stakeholders
- Use multiple models – Scientific Community
- Be done on time – CBP management

Watershed Model Results

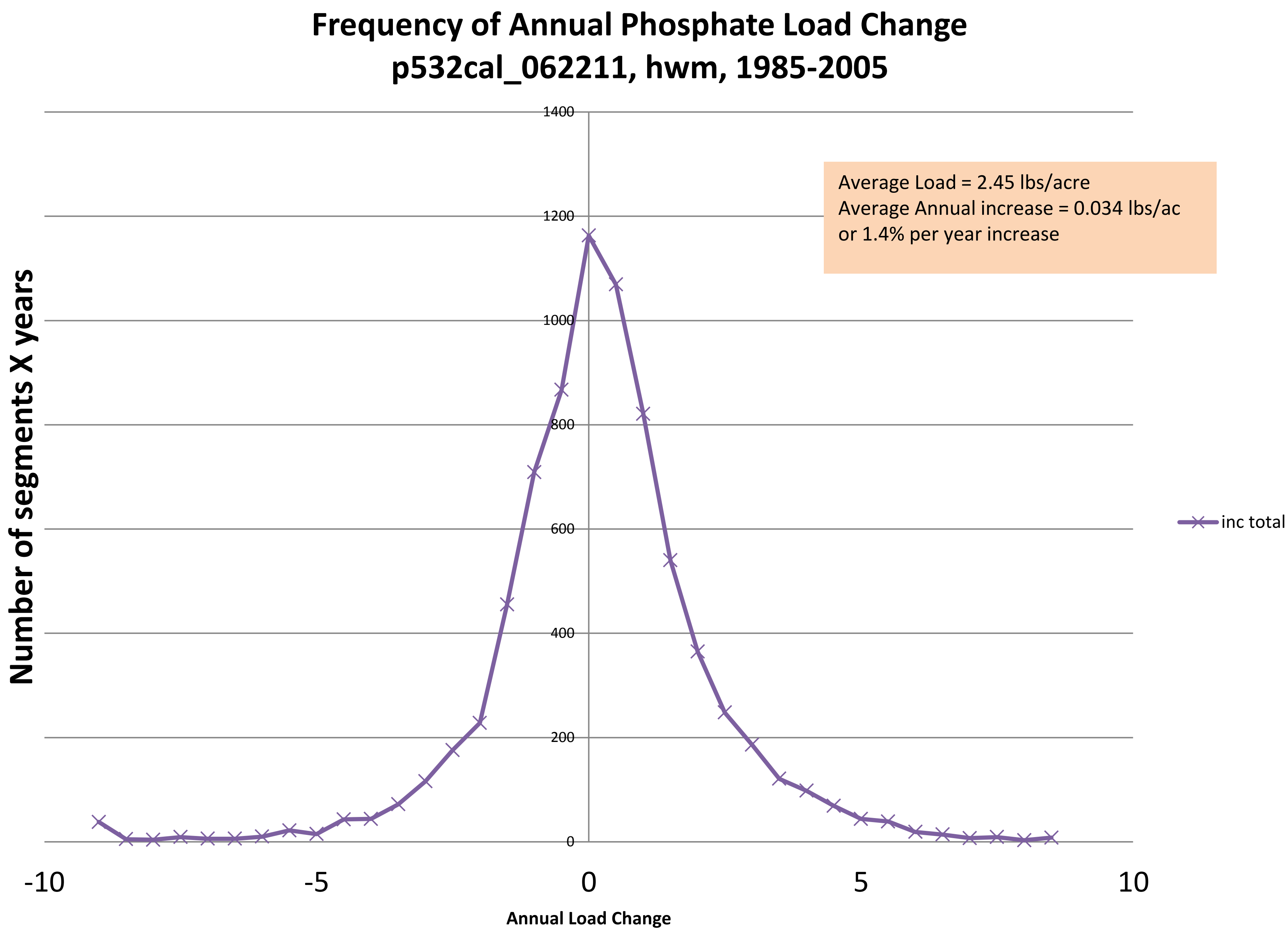
- Calibration run – entire watershed and ESMD
  - Annual storage increase
  - Increasing export load trend
- Load change across 100 scenarios – ESMD counties
  - Export follows application
- Removing poultry manure creates significant load reduction on ESMD
- Load change across ‘progress’ scenarios ESMD
  - Base load increasing – controlled by BMPs

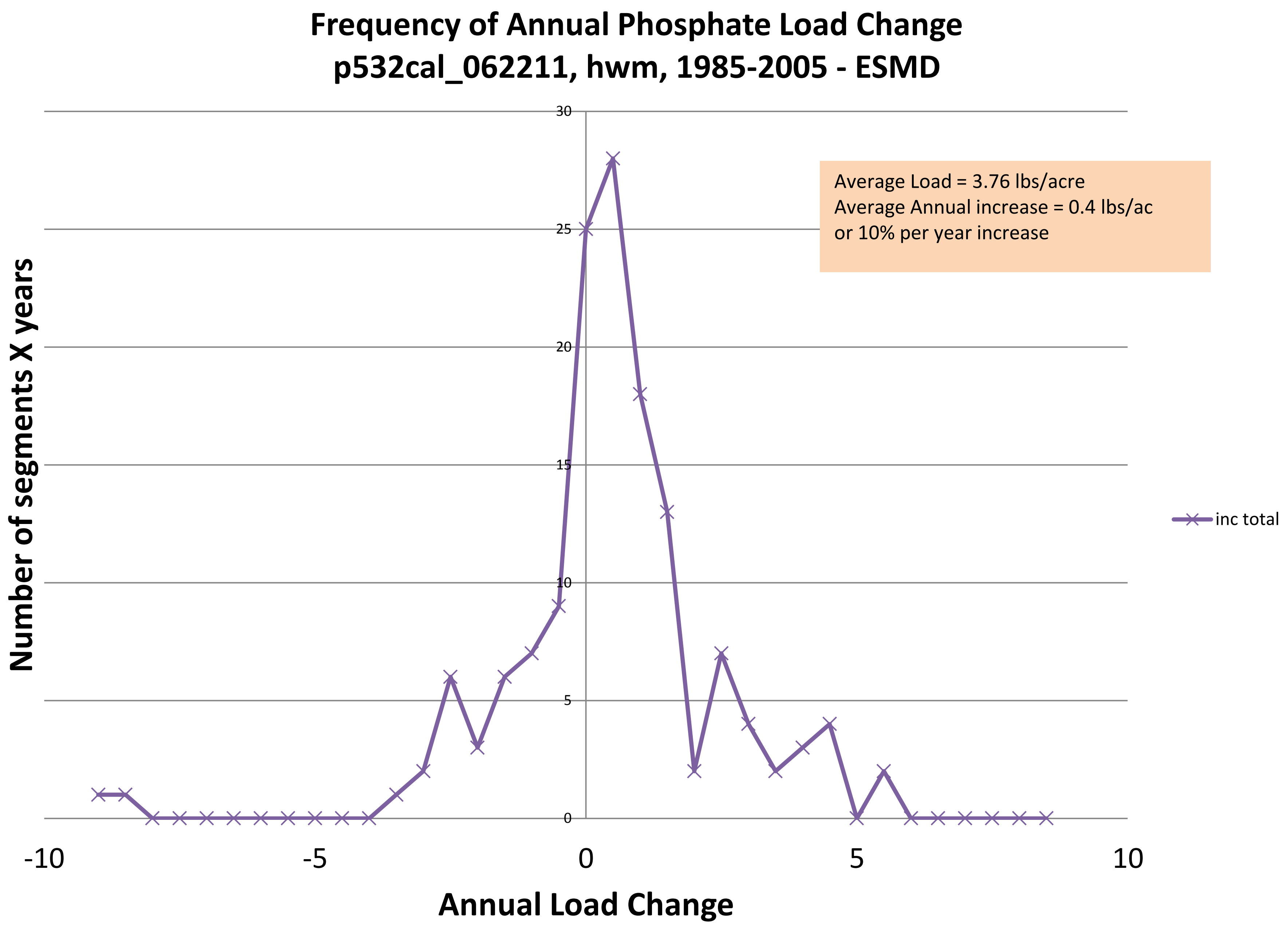


Frequency of Annual Phosphorus Storage Change
p532cal_062211, hwm, 1985-2005
Number of segments X years
Pounds of phosphorus change
2500
2000
1500
1000
500
0
-20
-10
0
10
20
30
40
50
incremental sorbed
incremental plant

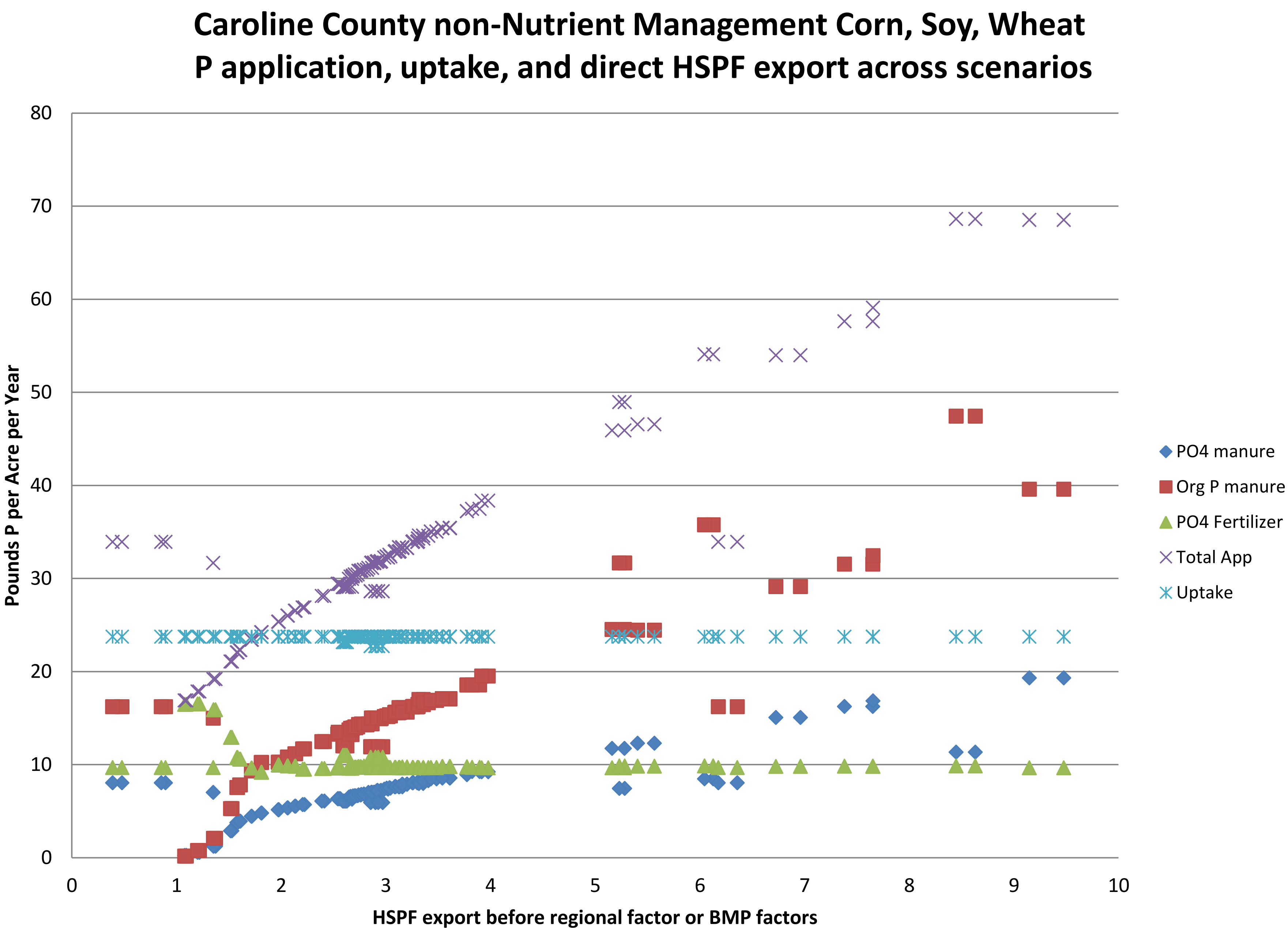


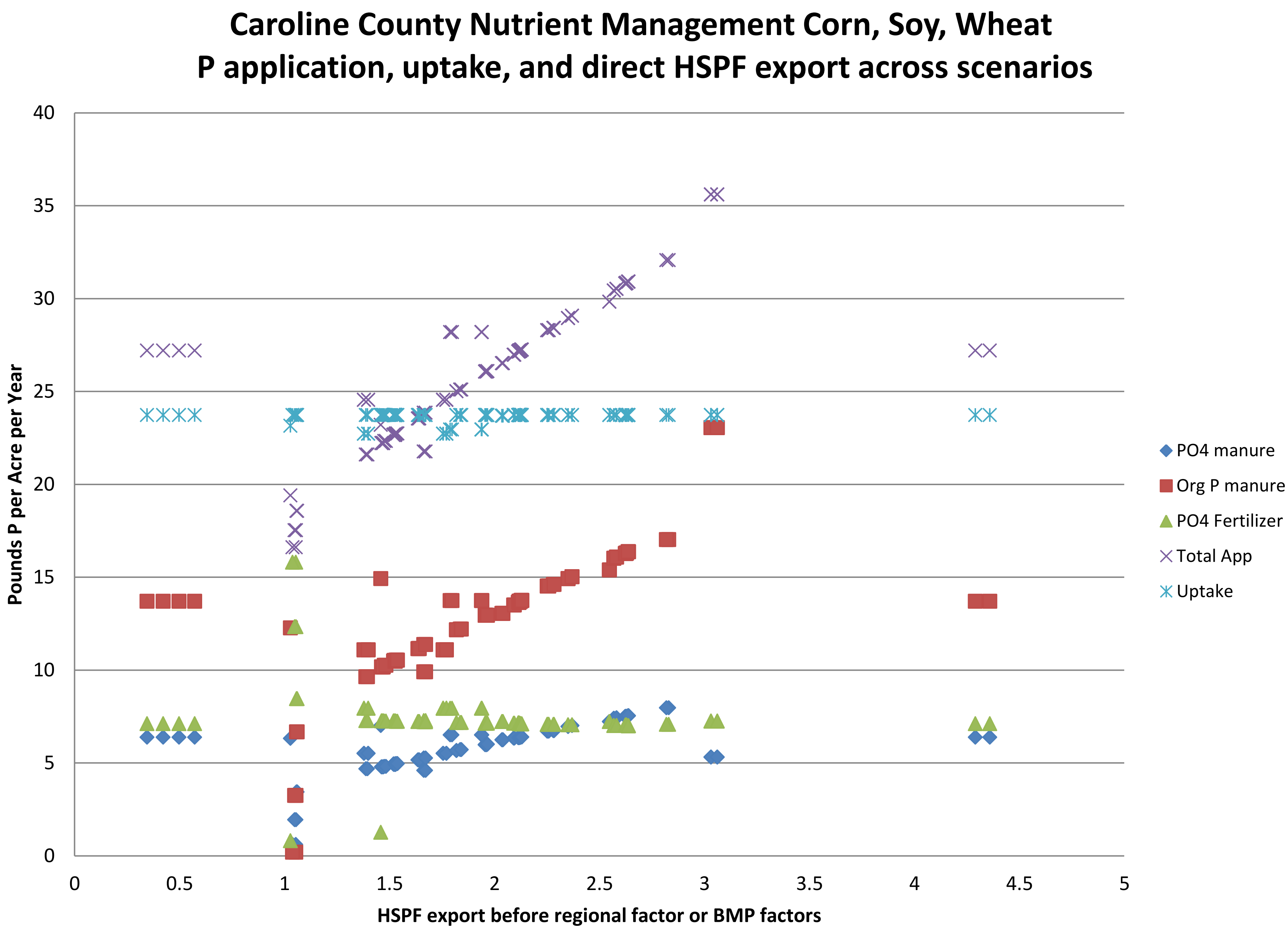
Frequency of Annual Phosphorus Storage Change
p532cal_062211, hwm, 1985-2005 - ESMD
Number of segments X years
Pounds of phosphorus change
80
70
60
50
40
30
20
10
0
-20
-10
0
10
20
30
40
50
incremental sorbed
incremental plant


Frequency of Annual Phosphate Load Change
p532cal_062211, hwm, 1985-2005
Average Load = 2.45 lbs/acre
Average Annual increase = 0.034 lbs/ac
or 1.4% per year increase
Number of segments X years
Annual Load Change
inc total
1400
1200
1000
800
600
400
200
0
-10
-5
0
5
10

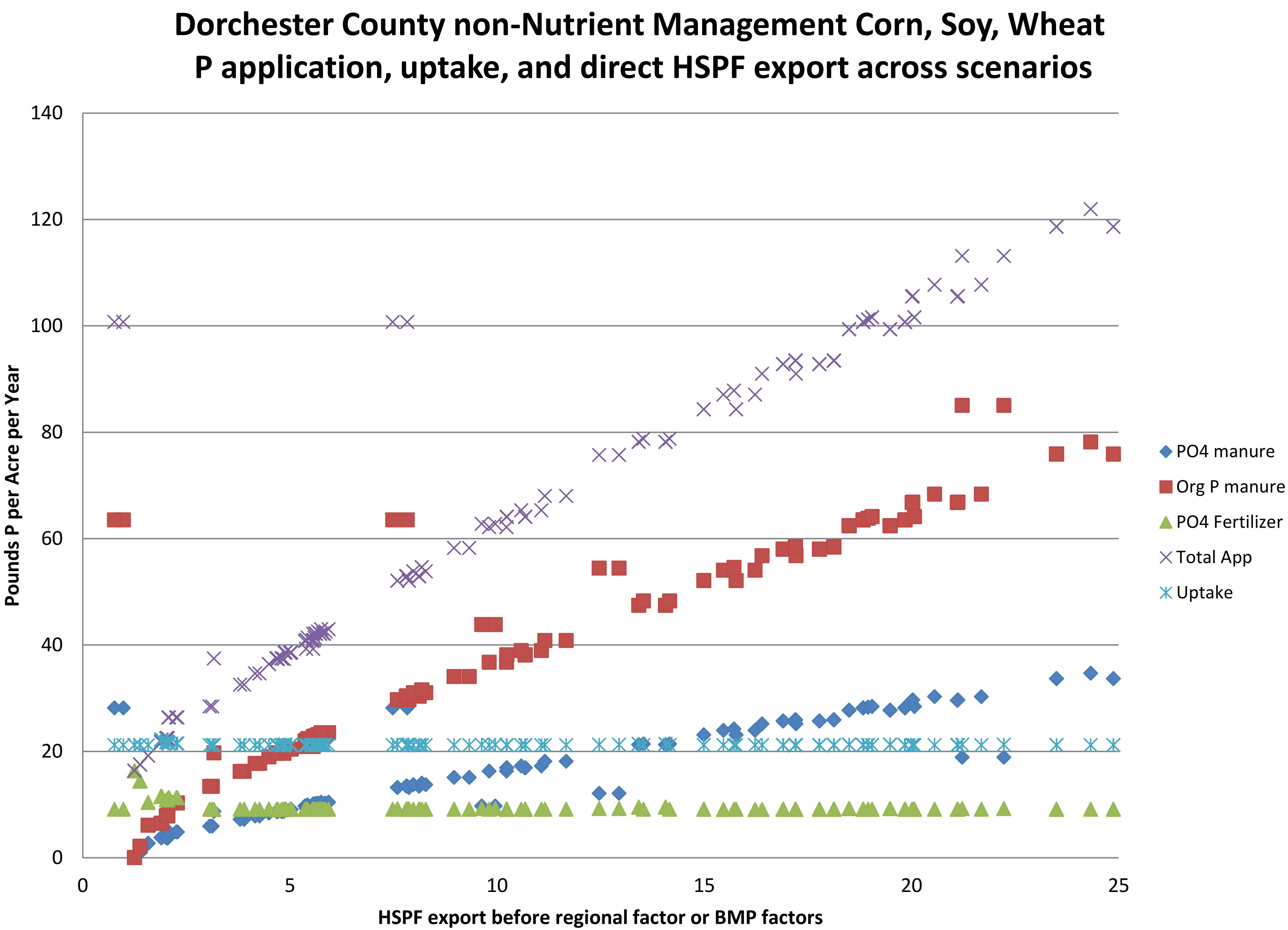


Frequency of Annual Phosphate Load Change
p532cal_062211, hwm, 1985-2005 - ESMD
Average Load = 3.76 lbs/acre
Average Annual increase = 0.4 lbs/ac
or 10% per year increase
inc total
Number of segments X years
Annual Load Change
30
25
20
15
10
5
0
-10
-5
0
5
10

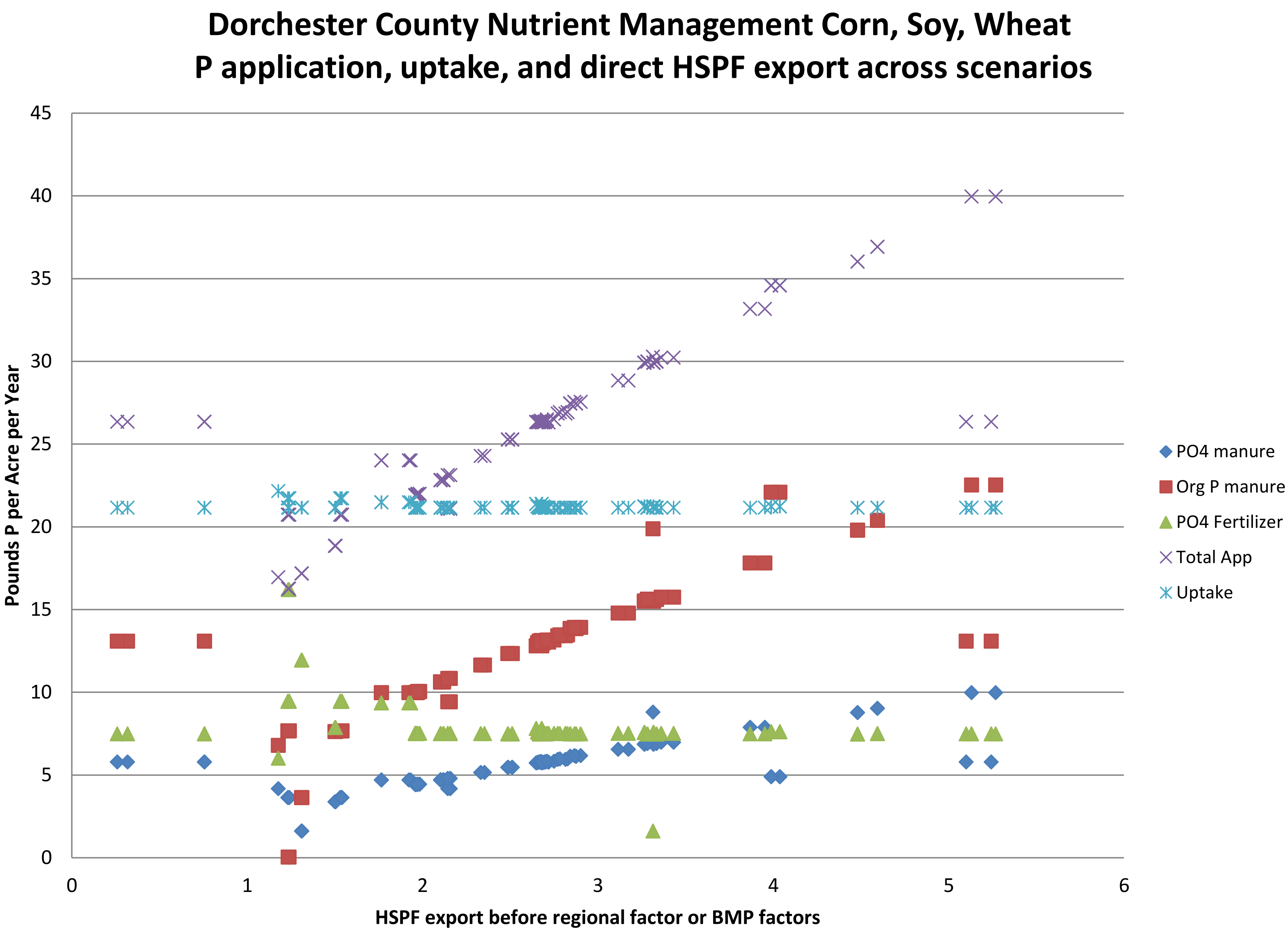

Caroline County non-Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
7
8
9
10
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

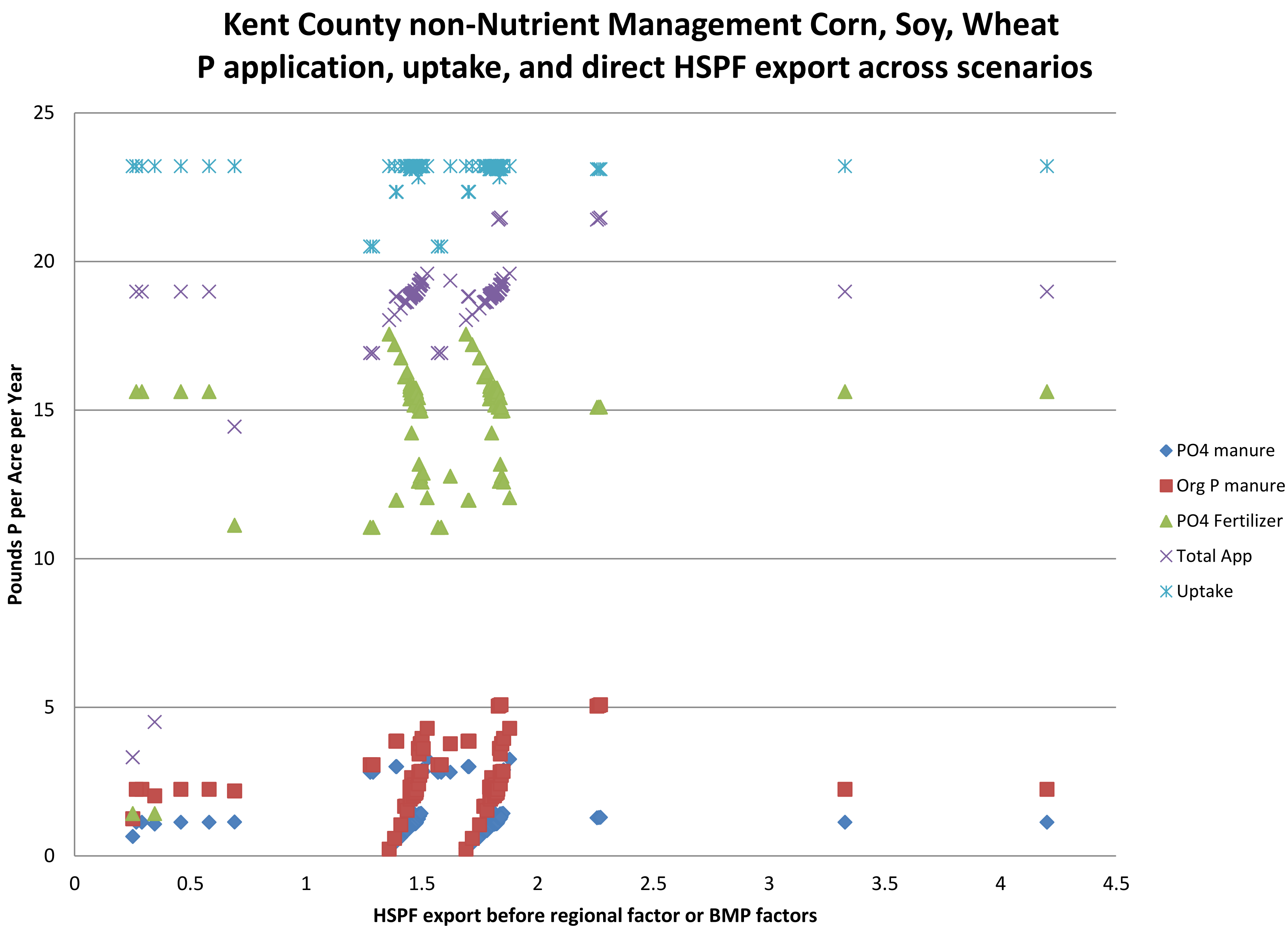


Caroline County Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
5
10
15
20
25
30
35
40
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

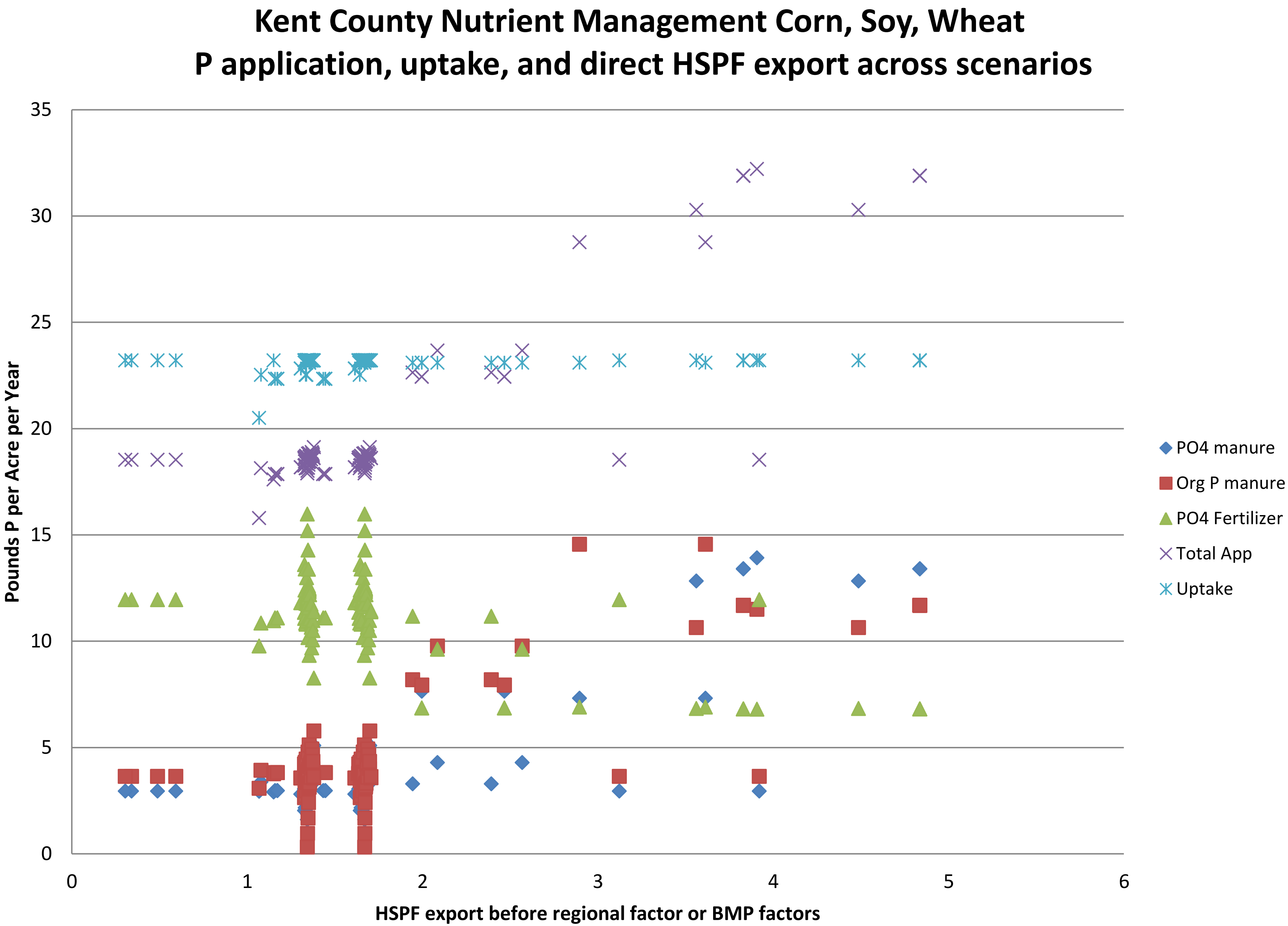


Dorchester County non-Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
20
40
60
80
100
120
140
0
5
10
15
20
25
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

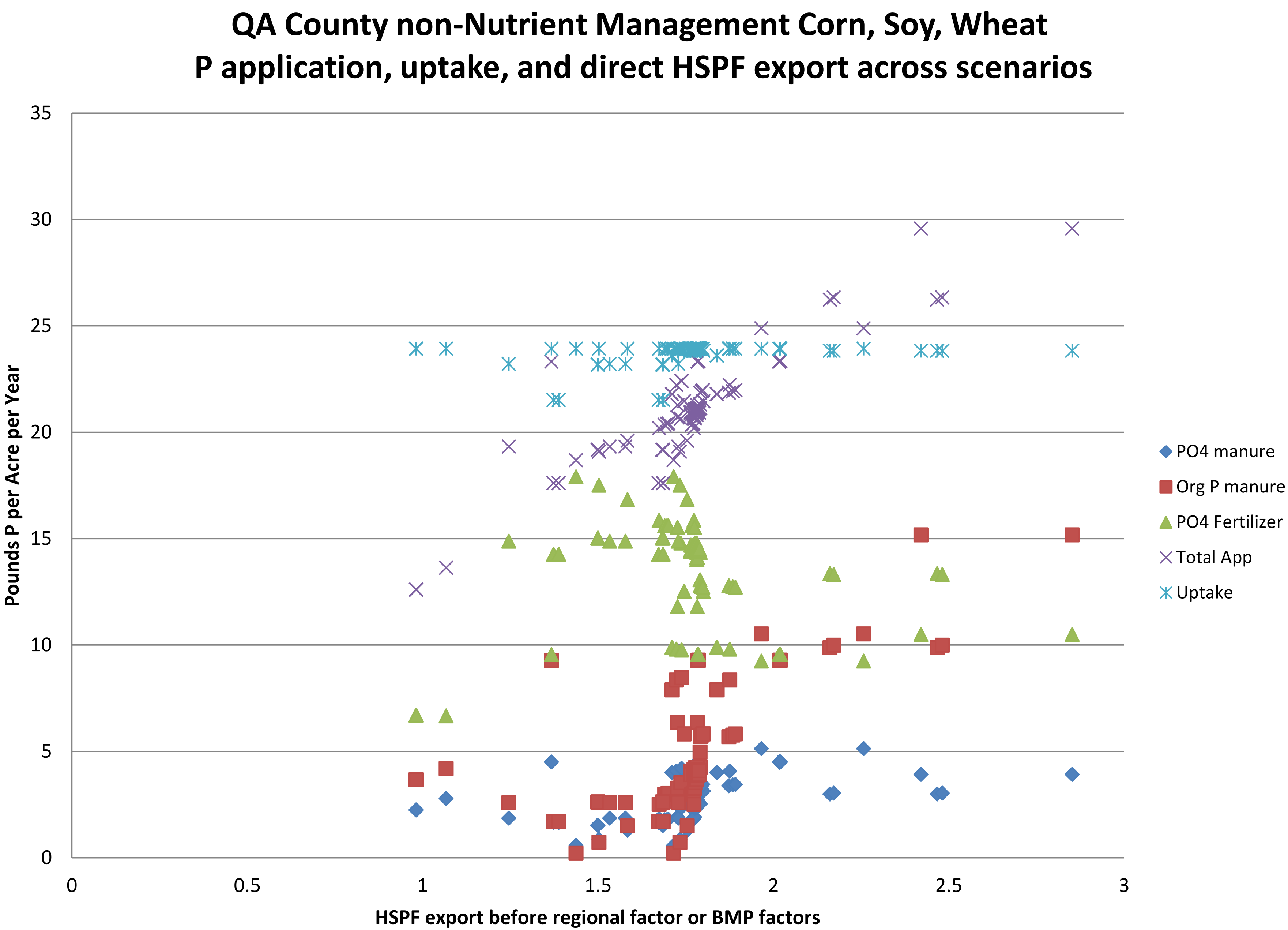

Dorchester County Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
HSPF export before regional factor or BMP factors
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

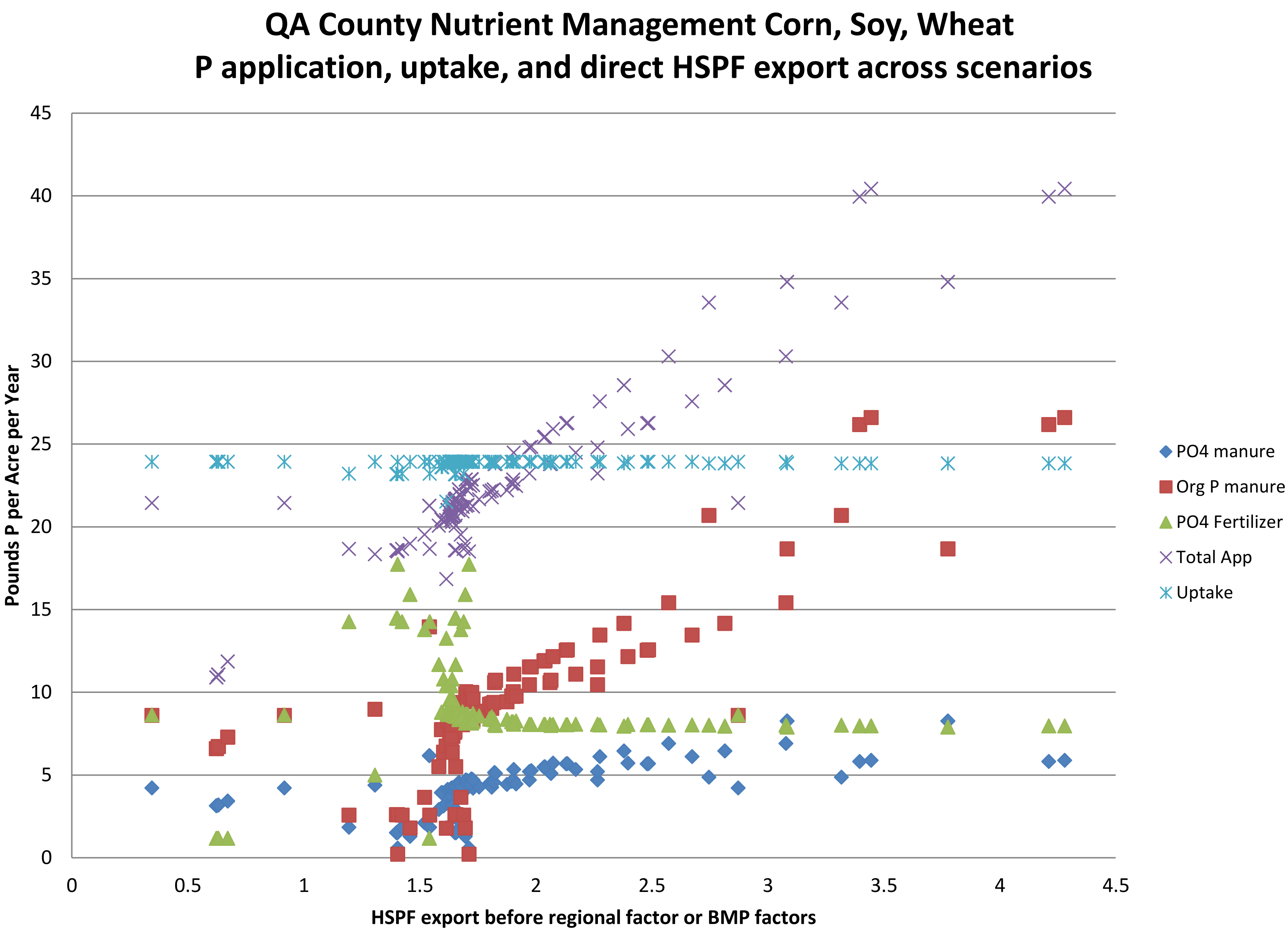


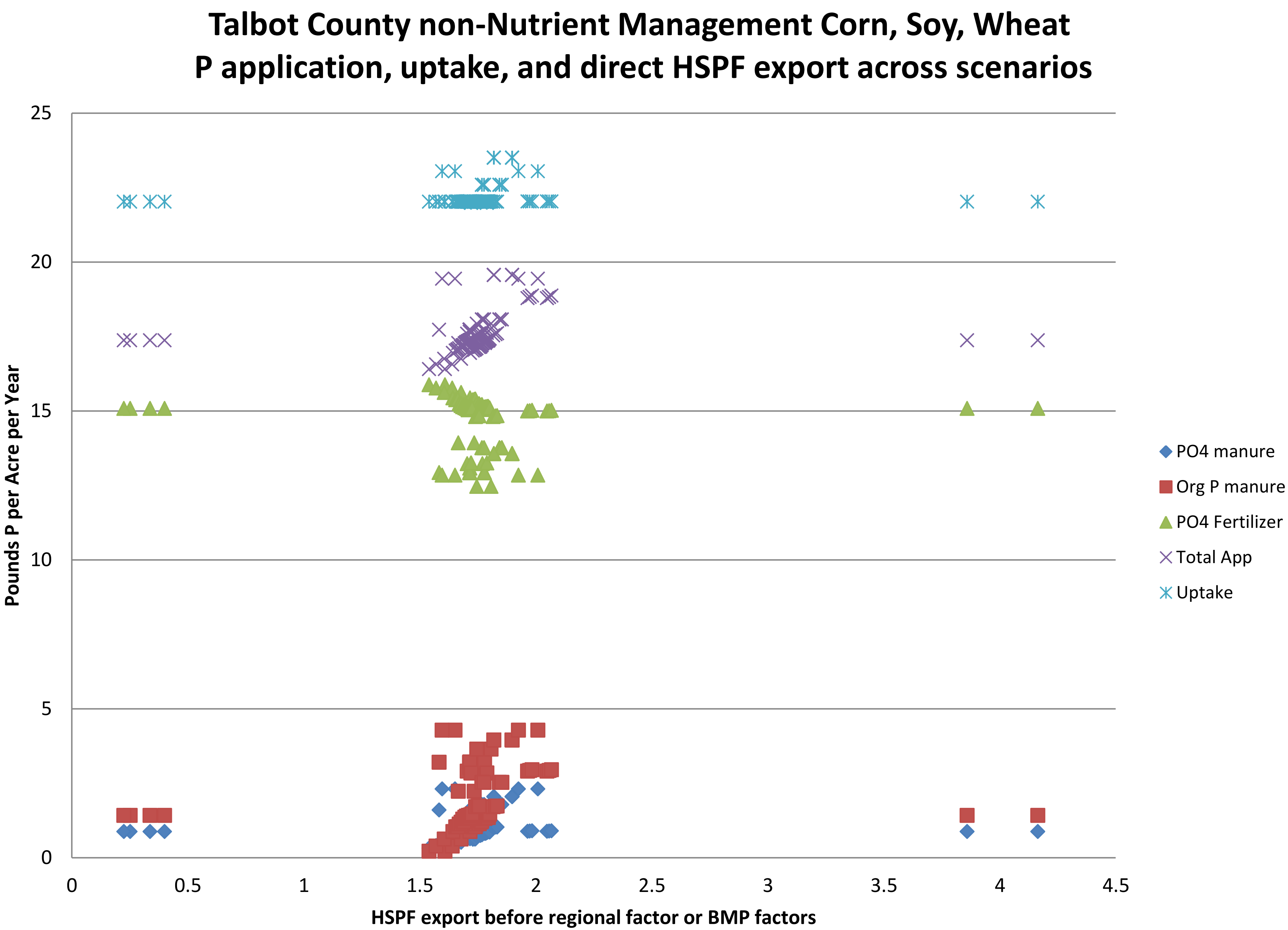
Kent County non-Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

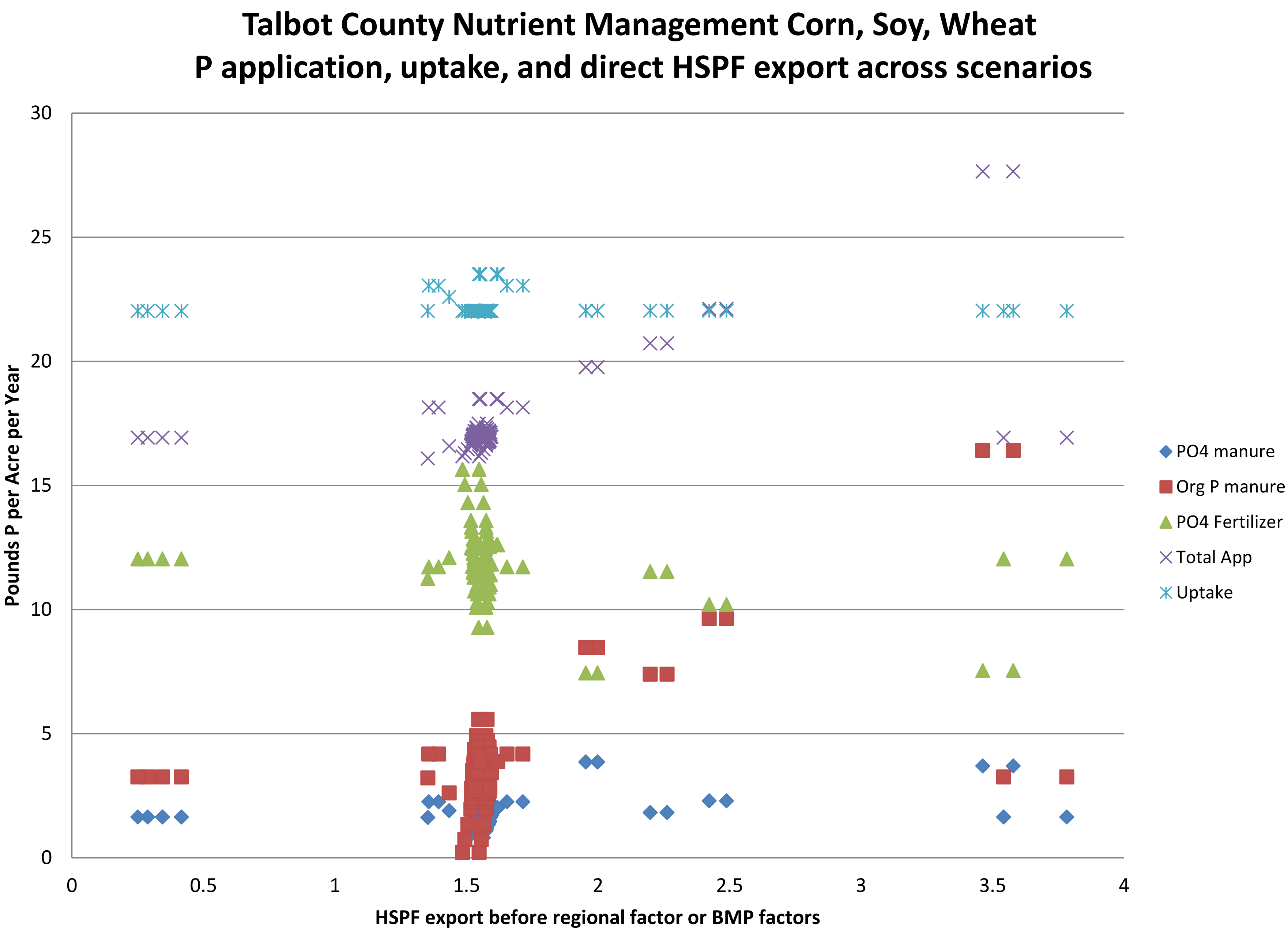


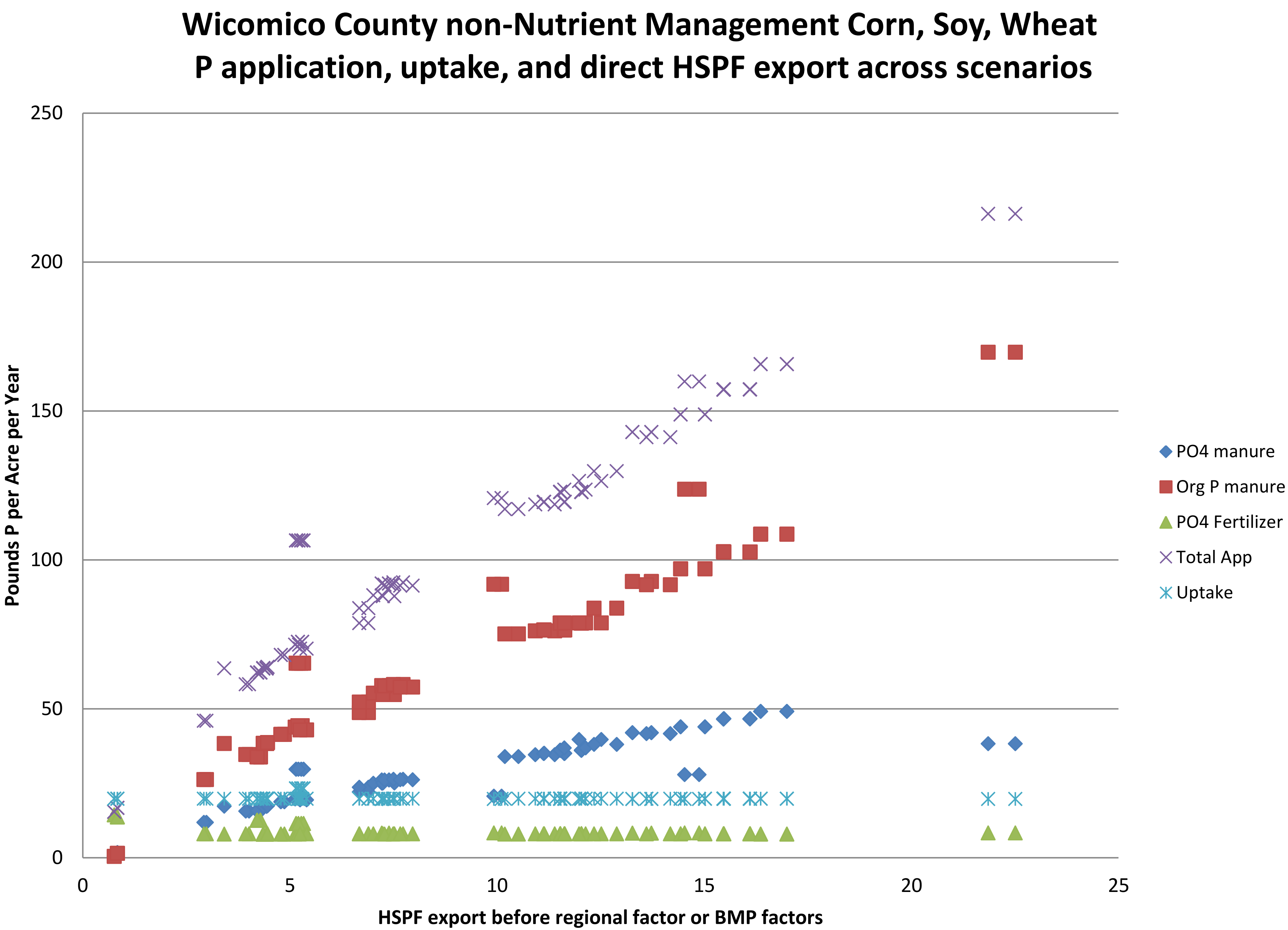
Kent County Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
5
10
15
20
25
30
35
0
1
2
3
4
5
6
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake


QA County non-Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
5
10
15
20
25
30
35
0
0.5
1
1.5
2
2.5
3
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

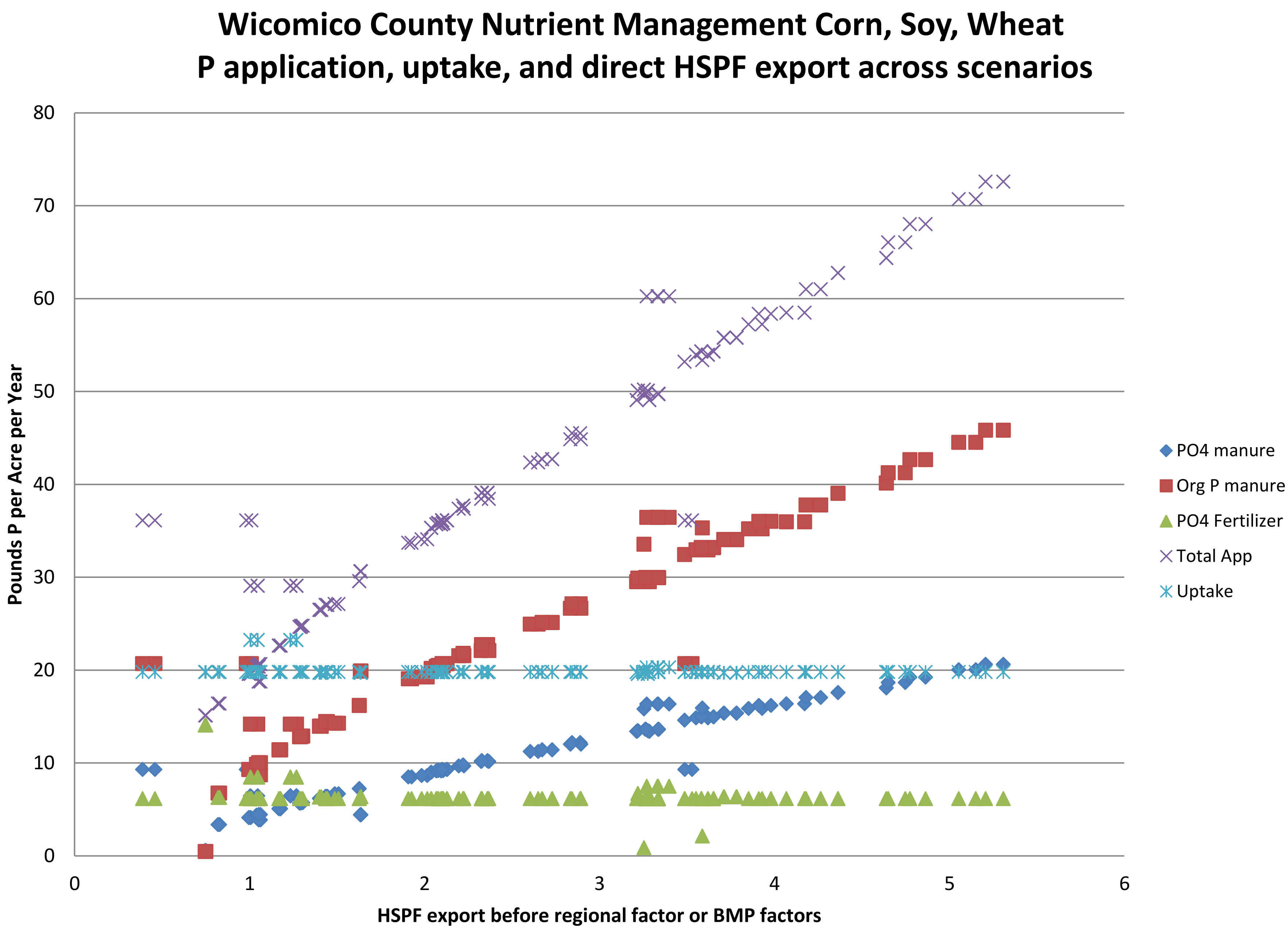

QA County Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
5
10
15
20
25
30
35
40
45
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake


Talbot County non-Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

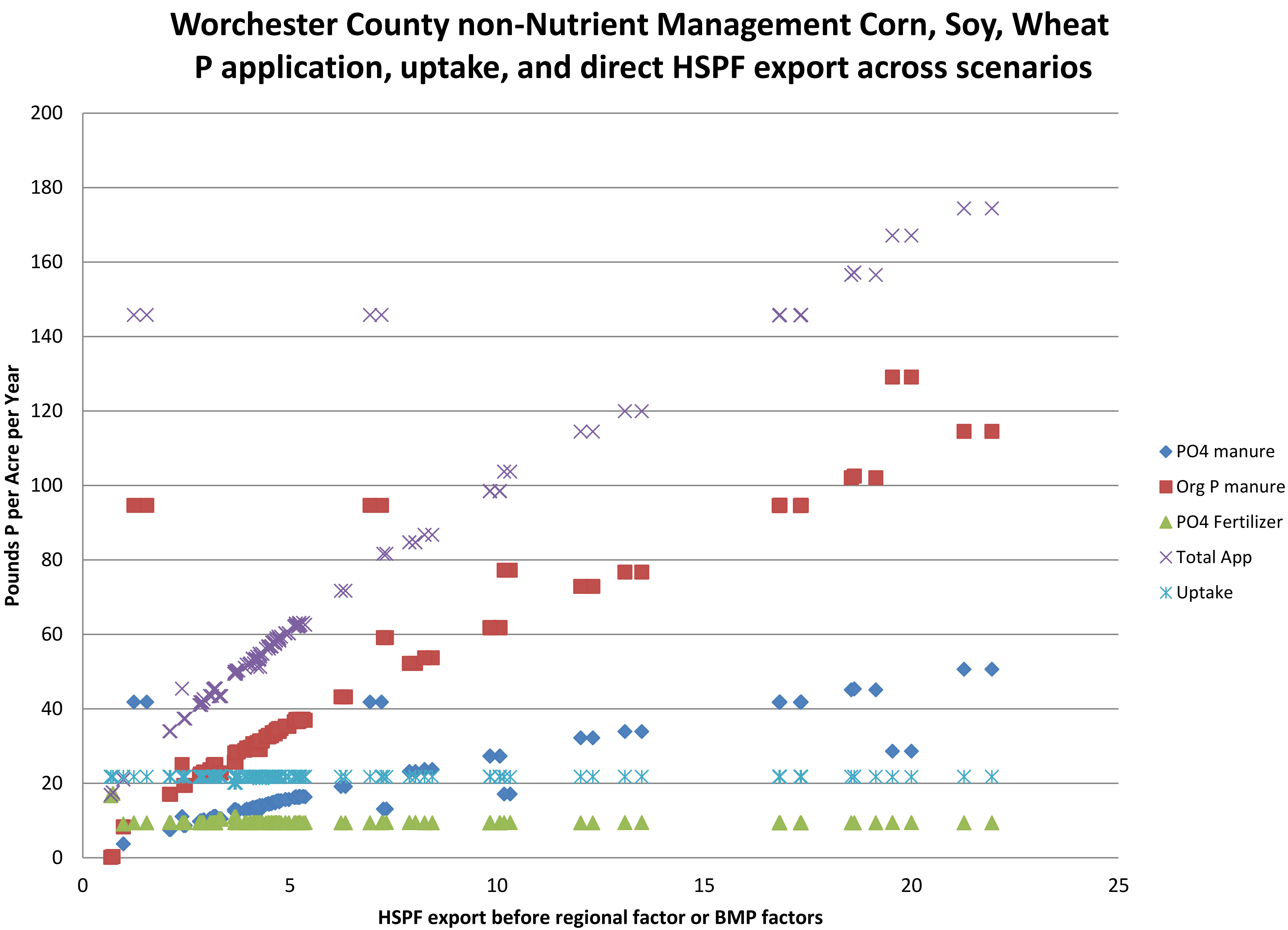

Talbot County Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
5
10
15
20
25
30
0
0.5
1
1.5
2
2.5
3
3.5
4
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

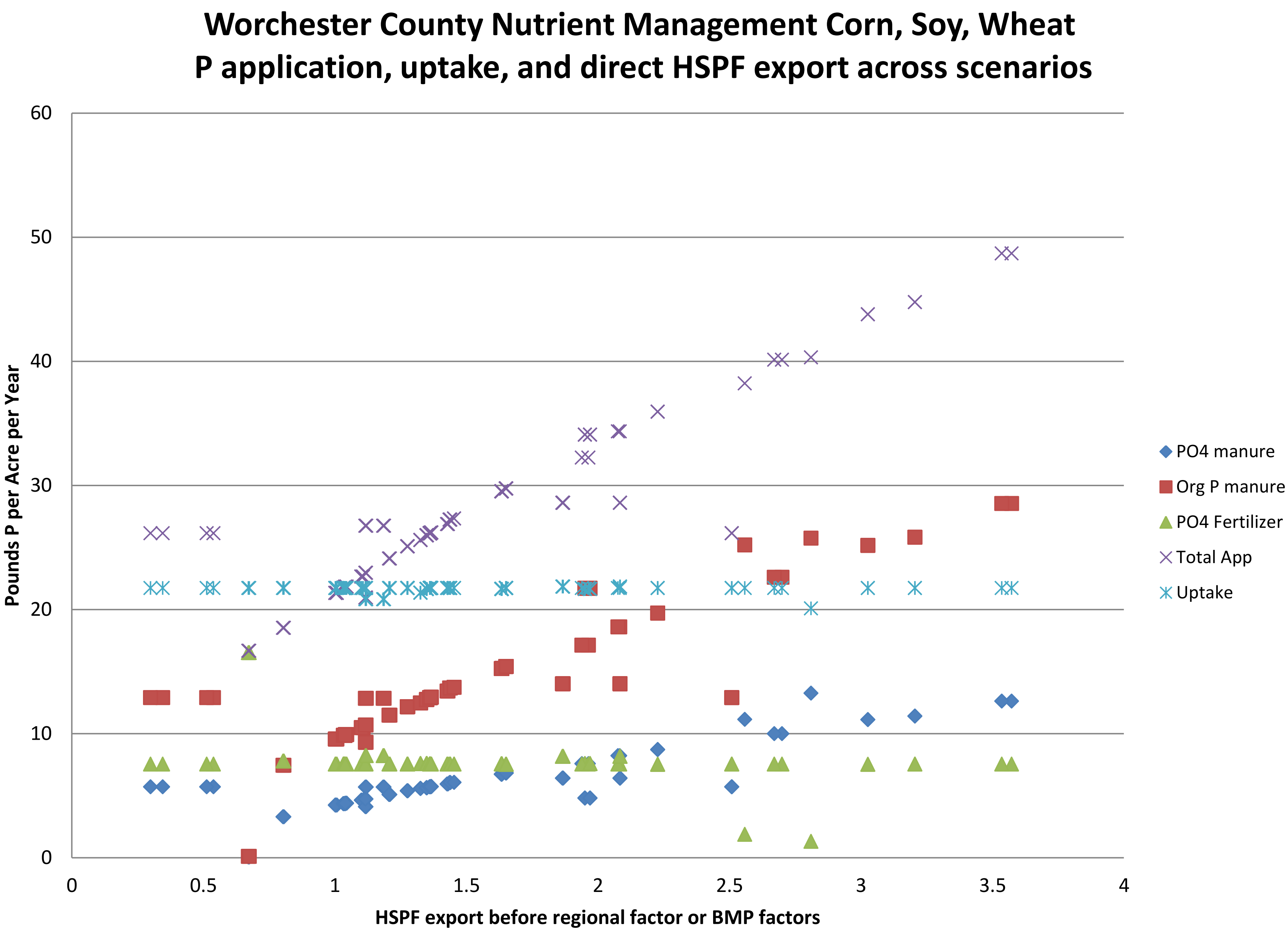


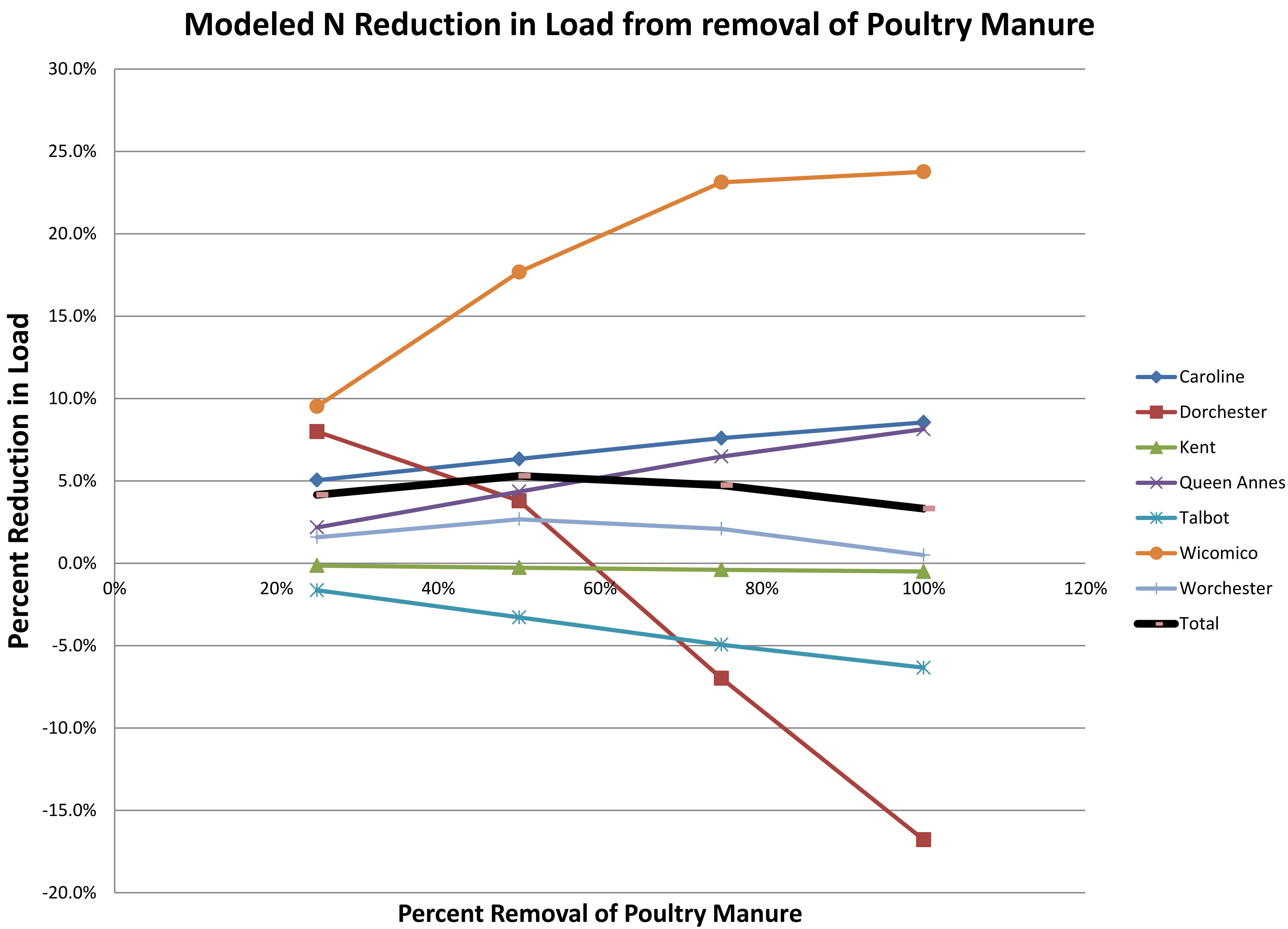
Wicomico County non-Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
250
200
150
100
50
0
0
5
10
15
20
25
HSPF export before regional factor or BMP factors
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake



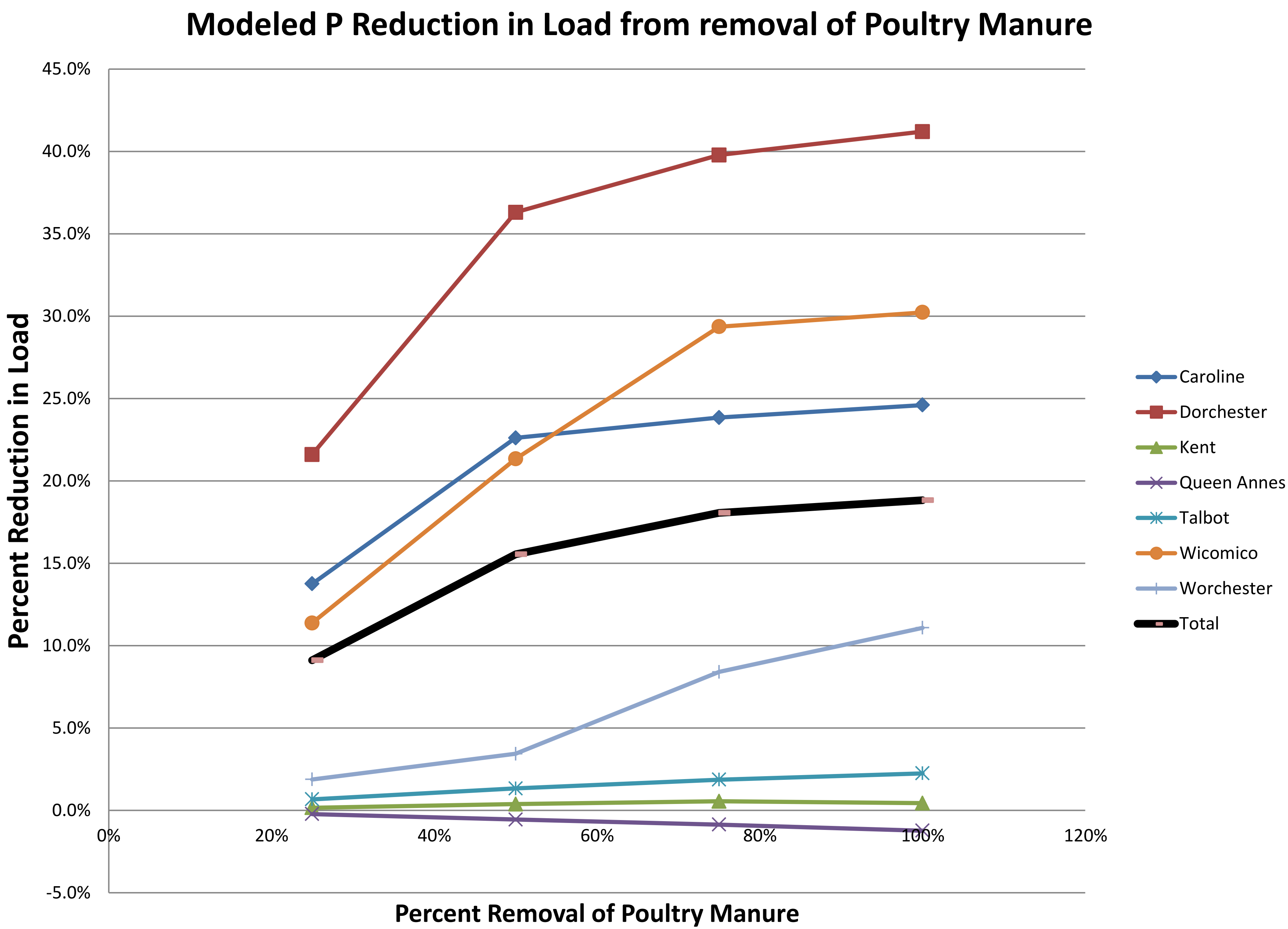
Wicomico County Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

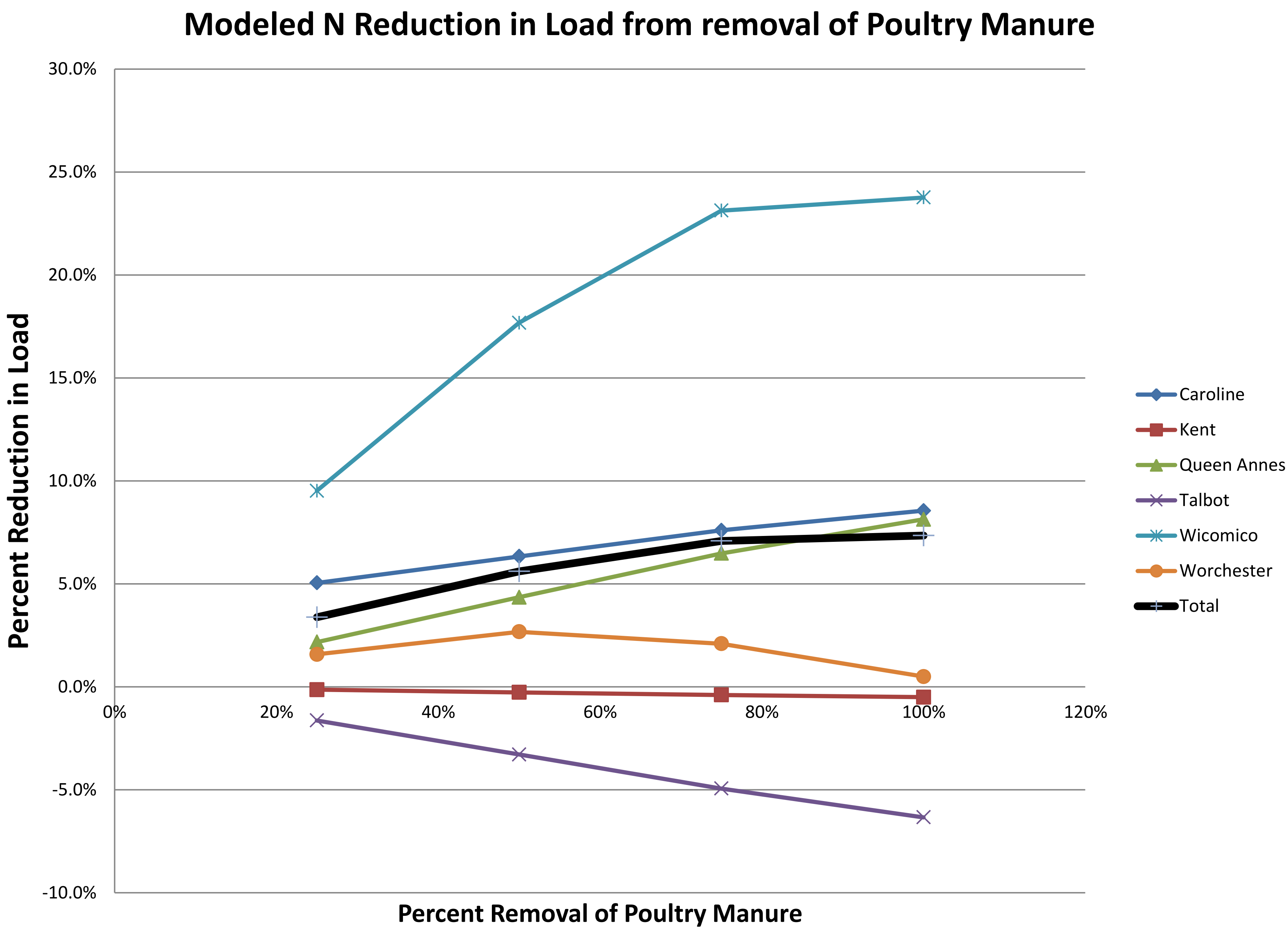

Worchester County non-Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
20
40
60
80
100
120
140
160
180
200
0
5
10
15
20
25
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

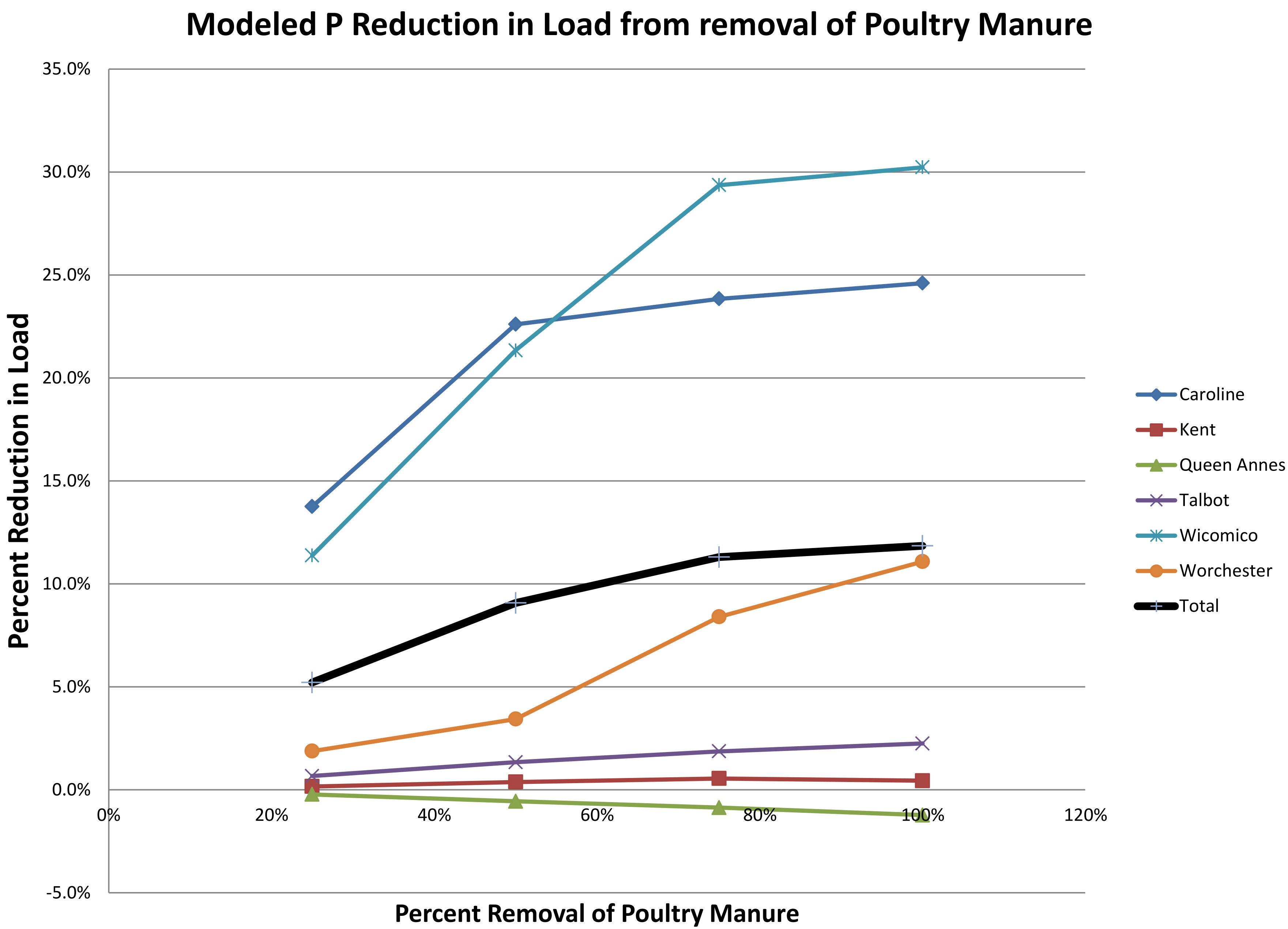

Worchester County Nutrient Management Corn, Soy, Wheat
P application, uptake, and direct HSPF export across scenarios
Pounds P per Acre per Year
HSPF export before regional factor or BMP factors
0
10
20
30
40
50
60
0
0.5
1
1.5
2
2.5
3
3.5
4
PO4 manure
Org P manure
PO4 Fertilizer
Total App
Uptake

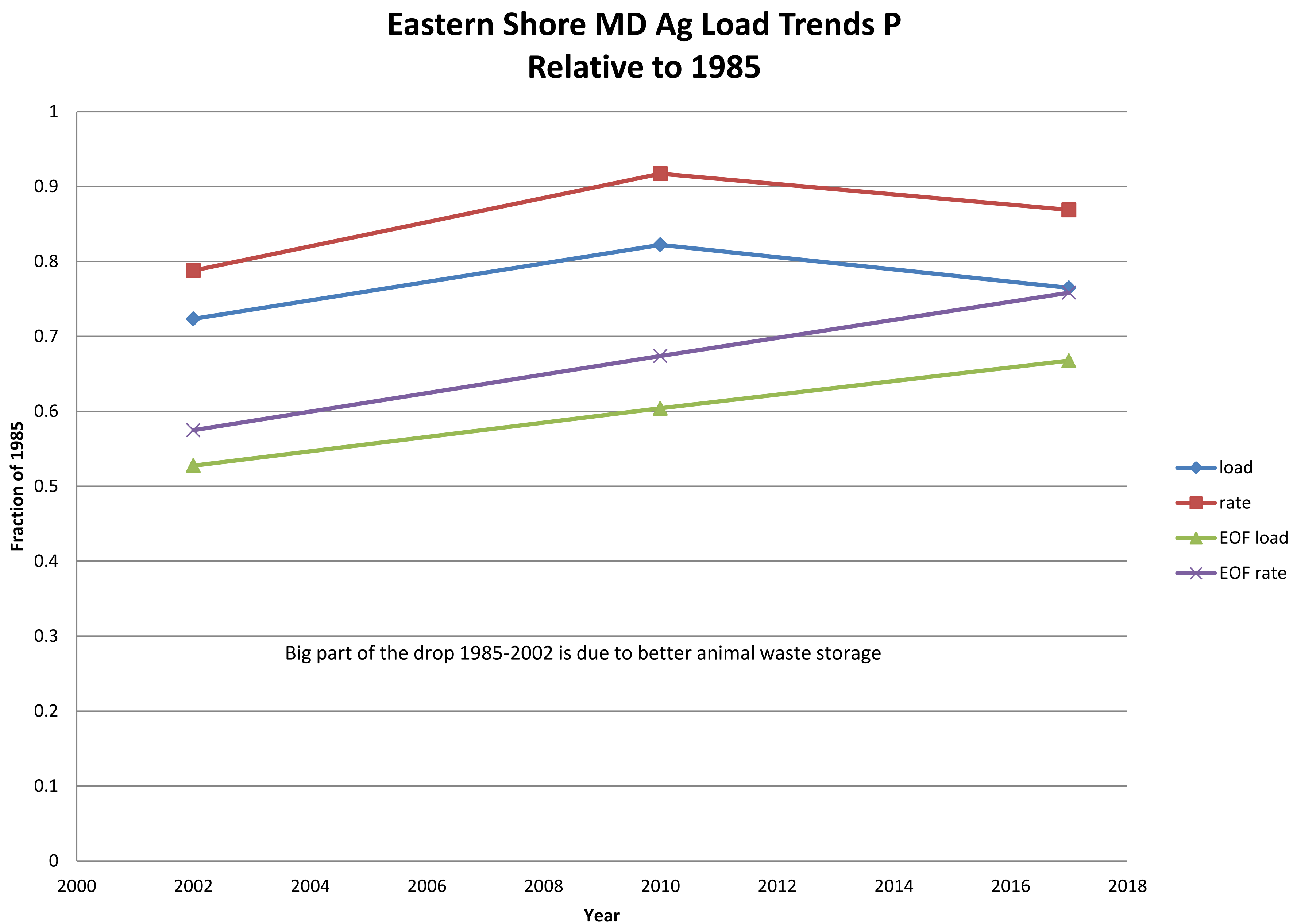


Modeled N Reduction in Load from removal of Poultry Manure
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
-5.0%
-10.0%
-15.0%
-20.0%
0%
20%
40%
60%
80%
100%
120%
Percent Reduction in Load
Percent Removal of Poultry Manure
Caroline
Dorchester
Kent
Queen Annes
Talbot
Wicomico
Worchester
Total


Modeled P Reduction in Load from removal of Poultry Manure
Percent Reduction in Load
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
-5.0%
0%
20%
40%
60%
80%
100%
120%
Percent Removal of Poultry Manure
Caroline
Dorchester
Kent
Queen Annes
Talbot
Wicomico
Worchester
Total


Modeled N Reduction in Load from removal of Poultry Manure
Percent Reduction in Load
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
-5.0%
-10.0%
0%
20%
40%
60%
80%
100%
120%
Percent Removal of Poultry Manure
Caroline
Kent
Queen Annes
Talbot
Wicomico
Worchester
Total


Modeled P Reduction in Load from removal of Poultry Manure
Percent Reduction in Load
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
-5.0%
0%
20%
40%
60%
80%
100%
120%
Percent Removal of Poultry Manure
Caroline
Kent
Queen Annes
Talbot
Wicomico
Worchester
Total


Eastern Shore MD Ag Load Trends P
Relative to 1985
Fraction of 1985
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Year
load
rate
EOF load
EOF rate
Big part of the drop 1985-2002 is due to better animal waste storage

ADDITIONAL SB MATERIAL

Landuse and Crops

- Vegetable and fruit row crops (54 crops) map to high till without manure (hom & nho)
  - Not eligible for manure
  - Not eligible for conservation till (yet)
- Alfalfa (alf & nal) landuse includes 3 crops
  - Alfalfa Hay
  - Alfalfa Seed
  - Haylage or greenchop from alfalfa or alfalfa mixture
- Pasture land (pas & npa)
  - 2 crops: pasture and rangeland, pasture for grazing

Landuse and Crops

- Hay crops that are designated as harvested by Ag census (hyw, nhy)
  - i.e. fescue, orchard grass, red clover, etc.
  - Includes category “failed crops”
- Hay without nutrients (hyo)
  - Receives no nutrients except atmo. dep.
  - Maps to a few unharvested ag census “crops” & harvested wild hay
- Nursery (urs) covers 21 high input crops
  - grown under glass or
  - in-ground nursery stock
- Row crops with manure covering grain and silage crops (hwm, nhi)
  - Eligible for conservation tillage (lwm, nlo) and manure application
  - ~40 crops

Degraded Riparian Pasture (TRP)

- Acreage taken from pasture to simulate higher loading portion of pasture adjacent to streams
- Acreage based on state data from trib strategies
- Direct deposition rate 9 times regular pasture
- Receives no other nutrients

Geographic unit	Unit	Measure
NY_Chemung River	acres	4106.61
NY_North Sus	acres	8517.597
PA_Potomac River Basin	acres	1591.11536
PA_Sus River Basin	acres	15025.4766
MD_Choptank River	acres	14.7937641
MD_Lower Eastern Shore	acres	7.21745348
MD_Lower Potomac	acres	20.8967
MD_Lower Western Shore	acres	2.40716815
MD_Middle Potomac	acres	20.6656055
MD_Patapsco/Back	acres	54.63695
MD_Patuxent River	acres	40.6168861
MD_Upper Eastern Shore	acres	146.719666
MD_Upper Potomac	acres	405.9285
MD_Upper Western Shore	acres	91.59927
VA	fraction	0.05
WV_Eastern Panhandle Conservation District	acres	3425.6543
WV_Potomac Valley Conservation District	acres	20697.9336

Double Cropping

- Double cropping added to account for summed crop acres exceeding Ag census acres of crop land
- Dates of doubled crops were adjusted to provide sequential coverage of crops
  - Most common sequence for crops chosen
    - Corn, soybeans and sunflowers planted before oats, rye or wheat in a calendar year
  - Universal dates for each crop chosen by AgWG to avoid >100% leaf cover, not specific to region like other crops

Covered Soil % (1 – Bare Soil %)

- Output to P5.3.2 WSM for leaf and residue coverage by month
- Crop specific from nearly 100 crop types in RUSLE runs
- TRP = pasture*0.88
- Upper limit set to 95%

Sample of cover fractions from PA

month	HiTill Corn grain Cover	LoTill Corn grain Cover	HiTill Corn Silage Cover	LoTill Corn Silage Cover
1	0.78	0.85	0.19	0.23
2	0.78	0.85	0.19	0.23
3	0.7767742	0.8487097	0.19	0.23
4	0.6168666	0.8326667	0.1529667	0.2296667
5	0.03341936	0.7990323	0.01052258	0.216129
6	0.1396667	0.7363333	0.1396667	0.1876667
7	0.6896774	0.6777419	0.6896774	0.5041935
8	0.9487097	0.9164516	0.9487097	0.9164516
9	0.95	0.95	0.5416667	0.578
10	0.857742	0.9170968	0.18	0.2406452
11	0.7936667	0.8646666	0.1886667	0.24
12	0.7822581	0.8596774	0.19	0.2319355

Detached Sediment

- Estimates sediment loss from soil disturbance (i.e. plowing)
- Quantifies load from planting date in T/ac
- Supplies difference between high and low till landuses

Legumes: N Fixation

- Available for source data to be county specific, most are only state specific
- PA lbs NH3/Ac/yr:

Alfalfa Hay	240
Alfalfa seed	240
Birdsfoot trefoil seed	180
Dry edible beans, excluding limas	300
Green Lima Beans	300
Peanuts for nuts	90
Peas, Chinese (sugar and Snow)	300
Peas, Green (excluding southern)	300
Peas, Green Southern (cowpeas) – Black-eyed, Crowder, etc.	300
Red clover seed	360
Snap Beans	300
Soybeans for beans	130
Vetch seed	300

Fixed N

- Only produced between plant and harvest dates
- Not produced in month of planting
- Divided out equally by month
- Crops summed into landuses
- Reduced if manure

applied for disposal

=fix-(disposal*0.2021)

Adams Co Sample T/Ac

crop	hom	hwm	lwm
Barley for grain Harvested Area		1.7	0.7
Broccoli Harvested Area	8.6		
Buckwheat Harvested Area		3.2	0.9
Canola Harvested Area		1.8	0.69
Cantaloupe Harvested Area	12.6		
Corn for Grain Harvested Area		7.34	1.39
Corn for silage or greenchop Harvested Area		12.4	4.1
Cotton Harvested Area	8.6		
Cucumbers and Pickles Harvested Area	12.6		
Cut Christmas Trees Production Area	8.6		
Emmer and spelt Harvested Area		1.8	0.69
Escarole and Endive Harvested Area	12.6		
Garlic Harvested Area	12.6		
Green Lima Beans Harvested Area	6.1		
Green Onions Harvested Area	12.6		
Head Cabbage Harvested Area	8.6		
Herbs, Fresh Cut Harvested Area	8.6		
Honeydew Melons Harvested Area	12.6		
Kale Harvested Area	12.6		
Land in Orchards Area	8.6		
Lettuce, All Harvested Area	12.6		
Mushrooms Area		12.6	0.9

NM versions of the landuses will have same data

AFO/CAFO acreage

- USDA Ag Census farm counts per animal type are multiplied by these fractions to produce an acreage to support BMP implementation that is tracked by systems.

Farm's Animal Type	***Acreage/farm***
All bovine categories	0.5
Both hog and pig categories	0.2
All poultry categories	0.25
Sheep and Lambs	0.1
Both goat categories	0.05

Ammonia Volatilization

Source	***Fraction not volatilized***
pullets	0.43
turkeys	0.43
hogs and pigs for breeding	0.19
beef	0.35
broilers	0.43
Heifers (cows and heifers that have calved)	0.35
hogs for slaughter	0.5
horses	0.68
layers	0.43
other cattle	0.35
sheep and lambs	0.35
angora goats	0.35
milk goats	0.35
biosolids	0.4875

Volatilization effect on N Concentration

Nutrient	N fertilizer	P Fertilizer	Broiler manure (lb-nutrient/lb-manure)
Phosphate	0	1	0.001082
Min P	0	0	0.002447
NH3	0.25	0	0.003235*0.43=0.001391
NO3	0.75	0	0
Min N	0	0	0.005824
Org N – not Plant Available	0	0	0.003882

Nutrient Application Rates

- Max rate - Theoretical Rate
  - max yield from any Ag census * max uptake from literature values for all crops

Crop Name	*Nitrogen pounds per yield unit*	*Phosphorus pounds per yield unit*	*Yield unit*	*Source*
Alfalfa Hay Harvested Area	59.516	8.927	dry tons	Meisinger, 1991
Alfalfa seed Harvested Area	0.511	0.058	pounds	NRCS
Asparagus Harvested Area	11.647	1.747	tons	Meisinger, 1991
Barley for grain Harvested Area	1.059	0.212	bushels	NRCS
Beets Harvested Area	7.059	1.059	tons	Meisinger, 1991
Birdsfoot trefoil seed Harvested Area	0.251	0.038	pounds	Meisinger, 1991
Broccoli Harvested Area	16.471	2.471	tons	Meisinger, 1991
Bromegrass seed Harvested Area	0.387	0.066	pounds	NRCS
Buckwheat Harvested Area	1.012	0.188	bushels	NRCS
Canola Harvested Area	0.041	0.007	pounds	NRCS
Cantaloupe Harvested Area	4.000	0.600	tons	Meisinger, 1991
Corn for Grain Harvested Area	0.976	0.146	bushels	Meisinger, 1991

Nutrient Application Rates

- Nutrient Management
  - Max rate discounted for yield history
    - Average yield history is substituted for Max yield based on state specific NM guide.
      - *Delaware*: average of the highest four of seven yields from the agricultural census. If less than seven agricultural censuses are available, use as manure are available as long as there are greater than four.
      - *Maryland*: average the highest 60% of the available agricultural censuses.
      - *New York, Pennsylvania, District of Columbia, West Virginia, Tennessee, and North Carolina*: average the highest three of five yields from the agricultural censuses.
    - Calculated for each crop by county

Nutrient Application Rates, cont.

- Non-Nutrient Management
  - Calculated as incremental increase from NM rate
    - NM rate + [(max rate * max yield) – (NM rate)] * % contribution to limiting nutrient of Manure
    - Counties or crops receiving no manure contribution are given a lower limit of 5%
    - Calculated for each crop by county
- NM and Non-NM rates act as “Crop need,” so the rate of the limiting nutrient must be satisfied and the *secondary nutrient* will be met or exceeded

Watershed Model Ag Data Sources

Livestock Production and Manure:

- Census of Agriculture Reports (1982-2007):
  USDA National Agricultural Statistics Service (NASS)
- Federal and State Equine Survey Data: (USDA-NASS, Delaware, Maryland, New York, Pennsylvania, Virginia)
- USDA and State Nutrient Management Standards and Handbooks (USDA-NRCS, Maryland, Virginia)
- University Extension Agronomy Handbooks and Fact Sheets (Delaware, Maryland, New York, Pennsylvania, Virginia)
- Mid-Atlantic Nutrient Management Handbook:
  USDA-NIFA Mid-Atlantic Water Program (MAWP)
- Nutrient Budgets for the Mid-Atlantic States:
  USDA-NIFA Mid-Atlantic Water Program (MAWP)
- Professional Agronomy, Engineering, Environmental and Soil Science Peer-Reviewed Journal Articles and Publications
- Chesapeake Bay Program's Agricultural Nutrient and Sediment Reduction Workgroup (AgNSRWG)

Watershed Model Ag Data Sources

Cropland Production and Nutrient Management:

- Census of Agriculture Reports (1982-2007):
  USDA National Agricultural Statistics Service (NASS)
- Revised Universal Soil Loss Equation (RUSLE2):
  USDA Natural Resource Conservation Service (NRCS)
- USDA and State Nutrient Management Standards
  (USDA-NRCS, Maryland, Virginia)
- University Extension Agronomy Handbooks and Fact Sheets (Delaware, Maryland, New York, Pennsylvania, Virginia)
- Mid-Atlantic Nutrient Management Handbook:
  USDA-NIFA Mid-Atlantic Water Program (MAWP)
- Nutrient Budgets for the Mid-Atlantic States:
  USDA-NIFA Mid-Atlantic Water Program (MAWP)
- Professional Agronomy, Environmental and Soil Science Peer-Reviewed Journal Articles and Publications
- Chesapeake Bay Program's Agricultural Nutrient and Sediment Reduction Workgroup (AgNSRWG)

Watershed Model Ag Data Sources

Implementation of Best Management Practices (BMPs):

- Agricultural implementation data is provided to the Chesapeake Bay Program through the following representative state agencies or organizations:
  - Delaware: Department of Natural Resources and Environmental Control (DNREC)
  - Maryland: Department of the Environment (MDE)
  - New York: Upper Susquehanna Coalition (USC)
  - Pennsylvania: Department of Environmental Protection (PADEP)
  - Virginia: Department of Conservation and Recreation (VADCR)
  - West Virginia: Department of Environmental Protection (WVDEP)
- Implementation data is provided to the representative state agency or organization by a diverse partnership of federal, state and county agencies and Non-Governmental Organizations.
- Chesapeake Bay Program’s Agricultural Nutrient and Sediment Reduction Workgroup (AgNSRWG)

Scenario Builder Documentation

- Estimates of County-Level Nitrogen and Phosphorus Data for Use in Modeling Pollutant Reduction
  - http://archive.chesapeakebay.net/pubs/SB_V22_Final_12_31_2010.pdf
- Chesapeake Bay TMDL – Section 5. Chesapeake Bay Monitoring and Modeling Frameworks
  - http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/CBayFinalTMDLSection5_final.pdf
- Chesapeake Community Modeling Program – Models & Data, HSPF Phase 5 (Chesapeake Bay Program), Chesapeake Bay Watershed Phase 5.3 Model
  - http://ches.communitymodeling.org/models/CBPhase5/documentation.php#scenario