Chesapeake Bay Program Phase 6 Watershed Model Webinar

Gary Shenk – USGS - Chesapeake Bay Program

Dave Montali – WV DEP – Modeling WG Co-Chair

3/10/16

Partnership Feedback on Modeling

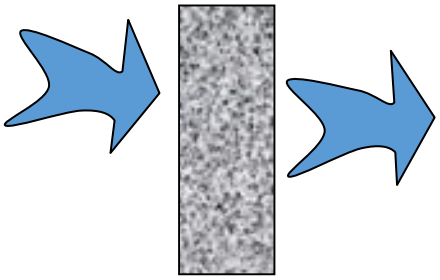
- **Water Quality Goal Implementation Team**
  - Need more transparent and easier to understand decision-support tools to enable successful engagement of local partners

- **Scientific and Technical Advisory Committee**
  - Multiple Models
  - Phosphorus
  - Conowingo
  - WSM and WQSTM reviews coming

Goals for Phase 6

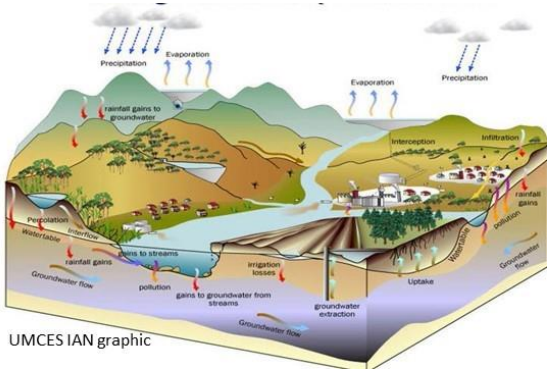
Understandability

Simple explanation
but not content



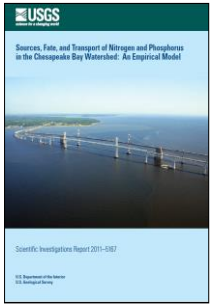
Build upon Current Knowledge

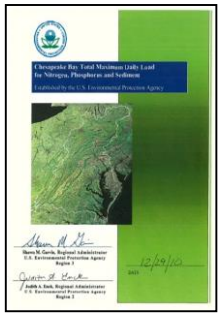
Refined Geographic Scale

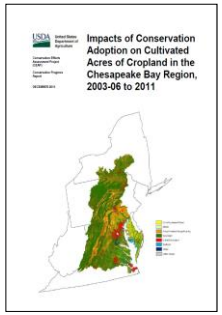


UMCES IAN graphic

Multiple Models





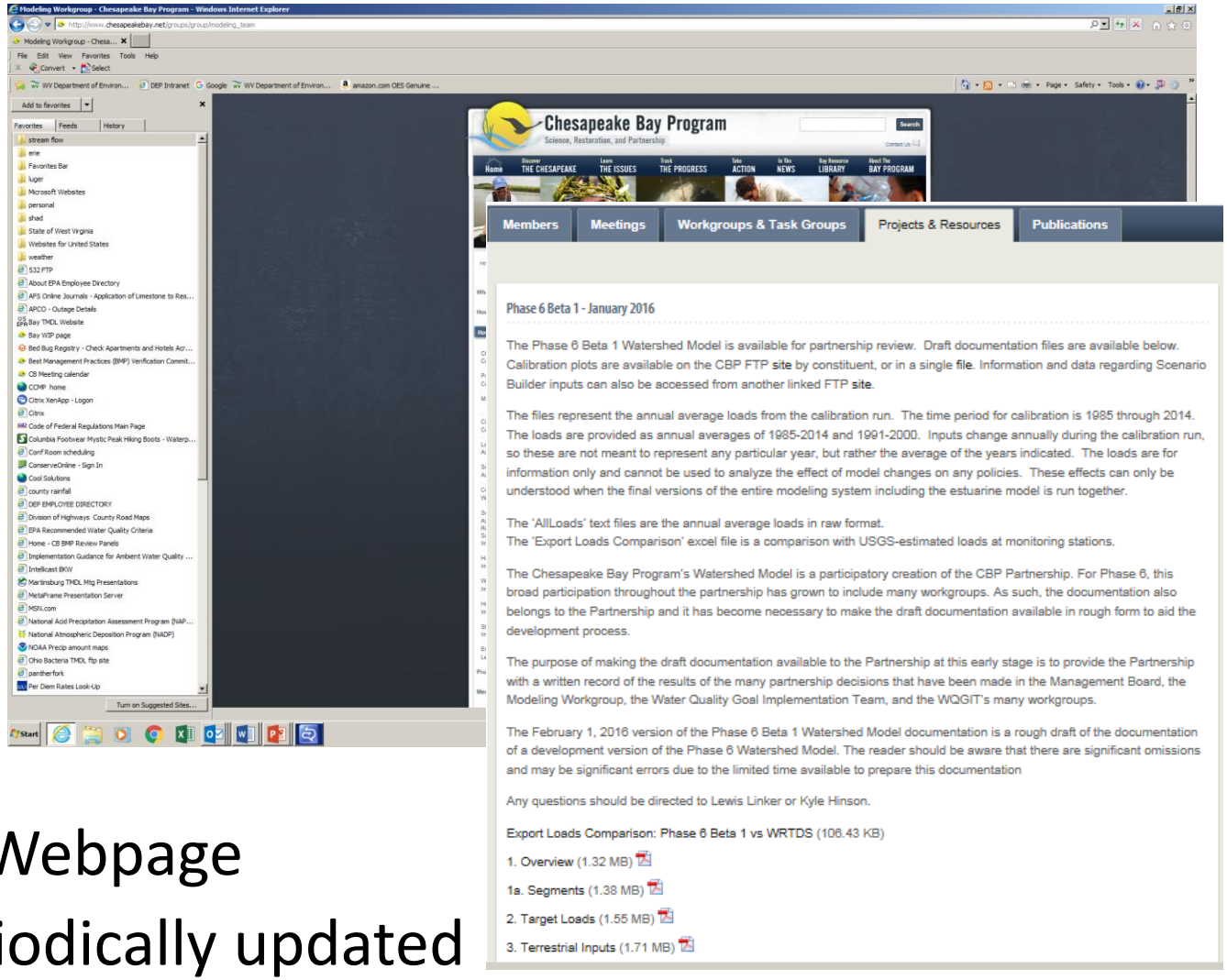


Accessibility

WSM Improvements

- Extended simulation time period
- More stations and many more observations
- New land uses and relative loading rates from WQGIT WGs
- Improved inputs and more to come
- Inclusion of loading lag times
- More transparent N simulation
- New TP simulation approach
- Conowingo simulation - more to come
- Reduced dependence upon Regional Factors

Documentation



- See MWG Webpage
- Will be periodically updated





Phase 6 Model Structure

Average Load + Δ Inputs * Sensitivity

*

Land Use Acres

*

BMPs

*

Land to Water

*

Stream Delivery

*

River Delivery

Direct Loads

Phase 6

Multiple models

Multiple Lines of Evidence And multiple models

Average Load = Δ Inputs * Sensitivity

*

Land Use Acres

*

BMPs

Scenario Builder

*

Estimated with Sparrow
Estimated by Land Data team

Land to Water

Estimated with Sparrow
Estimated by USGS / WVU / land data team

*

Stream Delivery

*

River Delivery

Simulated in HSPF
Calibrated with data, WRTDS, and Sparrow

Setting

Calculation

Science Quality

Delivered Load from a land use =

Avg No BMP Nutrient Load

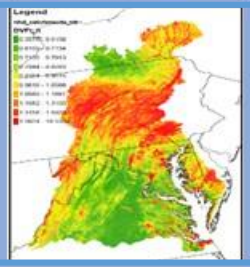
+

Sensitivity * Change in Inputs

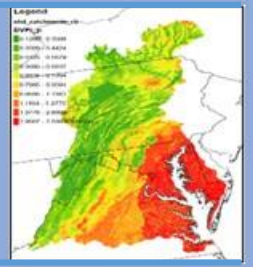
*****

Land to water

SPARROW
For nitrogen:
Soil, vegetation,
and climate variables



SPARROW
For Phosphorus
Soil, slope,
and climate
variables



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BMPs

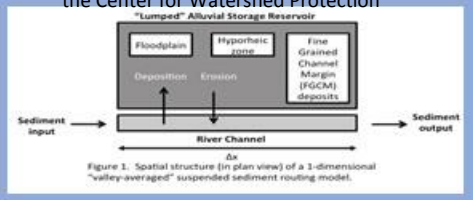
Effect of BMPs

*****

Stream Delivery

Sparrow

Potential models from USGS and
the Center for Watershed Protection



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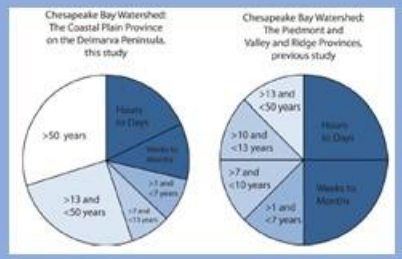
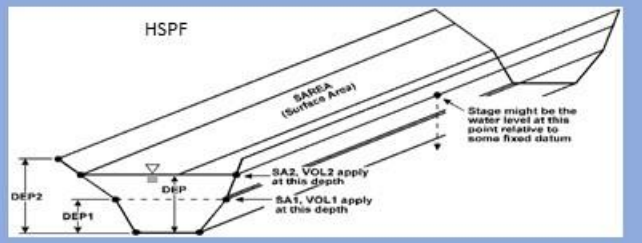
River Delivery









Phase 6 Model Structure

Average Load + ΔInputs * Sensitivity

*

Land Use Acres

*

BMPs

*

Land to Water

*

Stream Delivery

*

River Delivery

Direct Loads

Phase 6





Phase 6 Model Documentation

Section 1: Overview

Section 2: Targets + Section 3: Inputs * Section 4: Sensitivity

*

Section 5: Land Use

*

Section 6: BMPs

*

Section 8: Direct Loads

Section 7: Land to Water

*

Section 9: Stream Delivery

*

Section 10: River Delivery

Section 11: Applications





Webinar Structure

"Scenario Builder"

"Watershed Model"

Average Load + ΔInputs * Sensitivity

*

Land Use Acres

*

BMPs

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Land to Water

Direct Loads

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Stream Delivery

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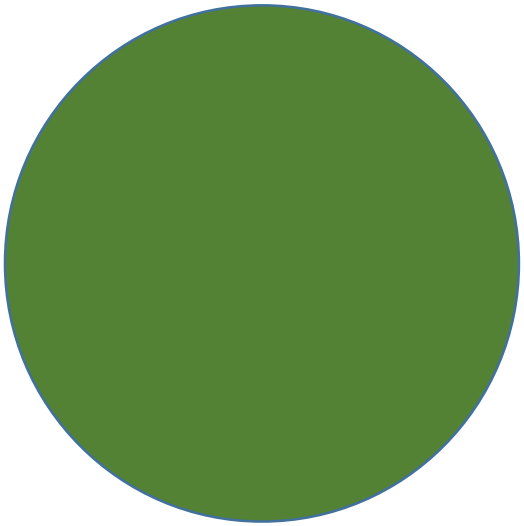
River Delivery

Phase 6

Average Loads

Average Loads – Average edge-of-small-stream loading rate for a given land use for the entire CB watershed



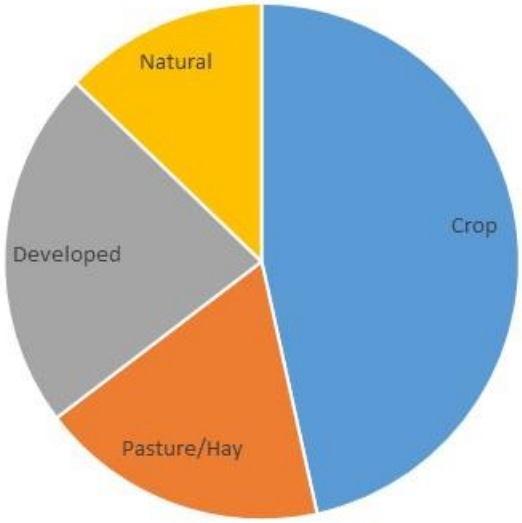
Estimate Total Non-point Source Load

Modeling Workgroup

Monitoring Data

Average Loads

Average Loads – Average edge-of-small-stream loading rate for a given land use for the entire CB watershed



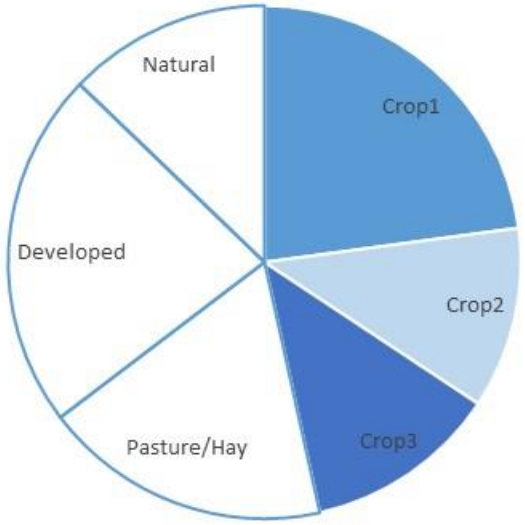
Divide into Broad Classes

Modeling Workgroup

Multiple models

Average Loads

Average Loads – Average edge-of-small-stream loading rate for a given land use for the entire CB watershed



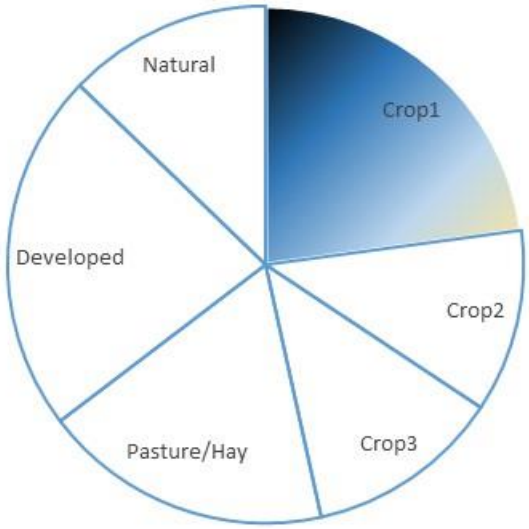
Split Classes into individual land uses

WQGIT Workgroups

Multiple lines of evidence

Target Loads

Target Loads – Edge-of-small-stream loading rate for a given land use in a segment



Assign targets to land uses within land segments

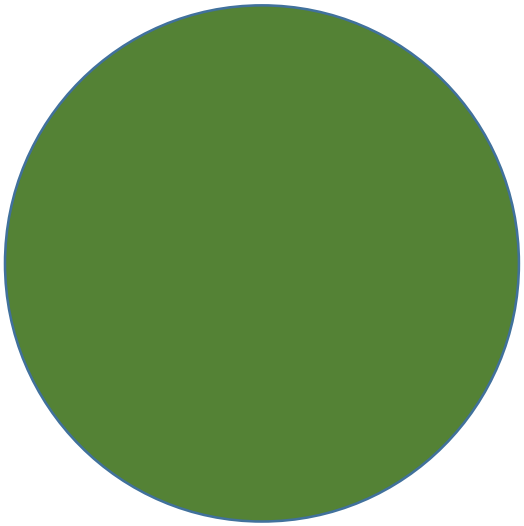
Modeling Workgroups

Multiple models

Average Load + Δ Inputs * Sensitivity

Average Loads

Average Loads – Average edge-of-small-stream loading rate for a given land use for the entire CB watershed



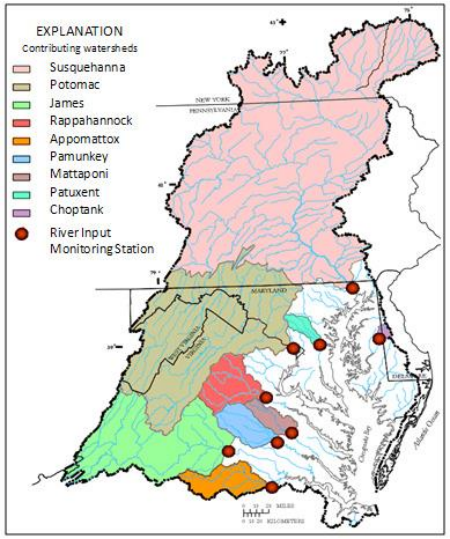
Estimate Total Non-point Source Load

Modeling Workgroup

Monitoring Data

Watershed Land Loads

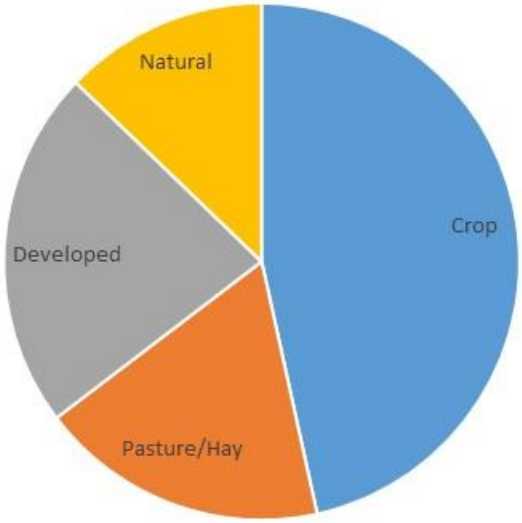
- Monitored loads at RIM stations 1993-2014, averaged
- Subtract out:
  - Point sources
  - Atmospheric deposition to water
  - Septic
  - AFO/CFO
  - River attenuation effects
  - Small stream attenuation effects
  - BMP effects



- Leaves edge-of-small stream loads to distribute to land
- Apply same rates to land downstream of RIM stations

Average Loads

Average Loads – Average edge-of-small-stream loading rate for a given land use for the entire CB watershed



Divide into Broad Classes

Modeling Workgroup

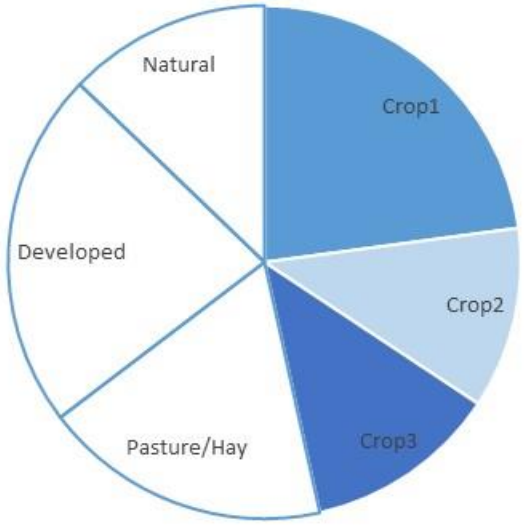
Multiple models

Divide into broad classes -- Nitrogen

Sector	Crop	Pasture/ Hay	Developed	Natural
Acres*	4,361,964	5,156,450	5,289,606	24,788,695
P532 Export Rate (pounds per acre)	47.5	19.9	19.4	4.2
CEAP Export Rate (pounds per acre)	42.5	10.2	Not used	1.6
SPARROW Export Rate with BMP effects removed (pounds per acre)	22.9	10.2	8.9	0.4
Average Ratio to Crop Rate	1.00	0.37	0.40	0.05
Average Sector Export Rate (pounds per acre)	46.65	15.36†	18.62	2.26

** Note that no target is calculated for 1,148,100 acres in the land uses: permitted feeding space, non-permitted feeding space, and combined sanitary sewer and water.*
† The afo/cfo load of 9,063,059 pounds is removed from pasture.

Average Loads



Average Loads – Average edge-of-small-stream loading rate for a given land use for the entire CB watershed

Split Classes into individual land uses

WQGIT Workgroups

Multiple lines of evidence

Split classes into individual land uses – Crop Nitrogen

Target Sector	Land Use	Acres	TN Export Rate Ratio	TN Export Rate (pounds per acre per year)
Cropland	Full Season Soybeans	926,048	0.71	36.98
	Grain with Manure	362,887	1.40	72.93
	Grain without Manure	989,101	1.00	52.09
	Other Agronomic Crops	527,481	0.45	23.44
	Silage with Manure	188,744	1.62	84.39
	Silage without Manure	403,534	1.16	60.42
	Small Grains and Grains	420,426	0.84	43.76
	Small Grains and Soybeans	313,019	0.79	41.15
	Specialty Crop High	66,706	1.34	69.8
	Specialty Crop Low	164,013	0.31	16.15

Split classes into individual land uses – Pasture/Hay Nitrogen

Target Sector	Land Use	Acres	TN Export Rate Ratio	TN Export Rate (pounds per acre per year)
Pasture	Ag Open Space	158,000	0.43	6.92
	Legume Hay	790,391	0.74	11.91
	Other Hay	1,528,606	1.04	16.74
	Pasture	2,679,452	1.00	16.09

Target Sector	Land Use	Acres	TP Export Rate Ratio	TP Export Rate (pounds per acre per year)
Cropland	Full Season Soybeans	926,048	N/A	TBD
	Grain with Manure	362,887	N/A	TBD
	Grain without Manure	989,101	N/A	TBD
	Other Agronomic Crops	527,481	N/A	TBD
	Silage with Manure	188,744	N/A	TBD
	Silage without Manure	403,534	N/A	TBD
	Small Grains and Grains	420,426	N/A	TBD
	Small Grains and Soybeans	313,019	N/A	TBD
	Specialty Crop High	66,706	N/A	TBD
	Specialty Crop Low	164,013	N/A	TBD

Ag Land Use Loading Rate Subgroup recommendation:

Let sensitivities to inputs determine relative loading rate





Webinar Structure

"Scenario Builder"

"Watershed Model"

Average Load + Δ Inputs * Sensitivity

*

Land Use

*

BMPs

*

Land to Water

*

Stream Delivery

*

River Delivery

Direct Loads

Phase 6

Atmospheric Deposition

- Expecting Data set from Penn State pending funding
- Data set will be modified by scenarios in CMAQ





Webinar Structure

"Scenario Builder"

"Watershed Model"

Average Load + Δ Inputs * Sensitivity

*

Land Use Acres

*

BMPs

*

Land to Water

*

Stream Delivery

*

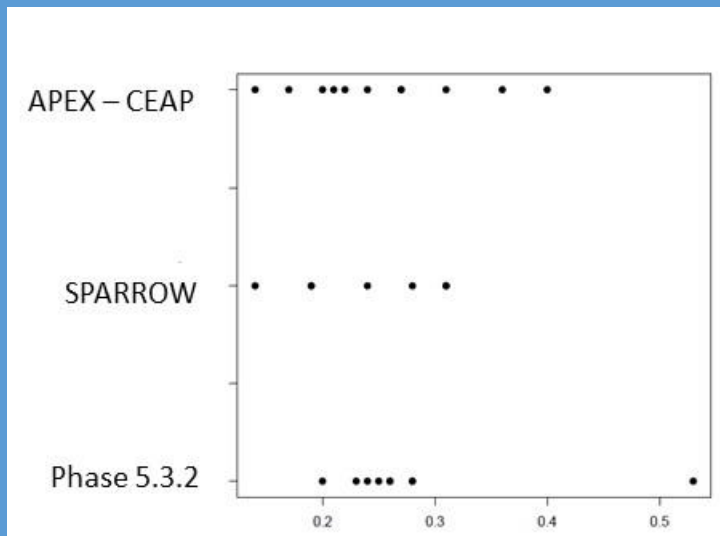
River Delivery

Direct Loads

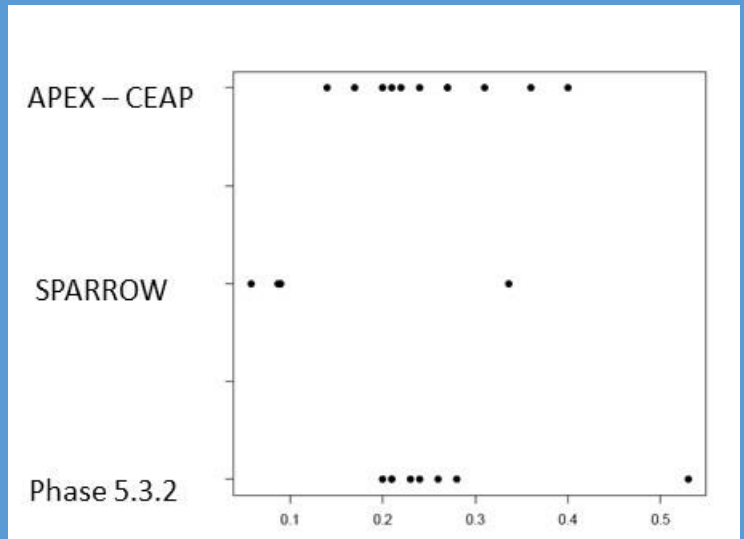
Phase 6

Nitrogen Sensitivity

Definition – Average Change in export per change in input



Commercial Fertilizer

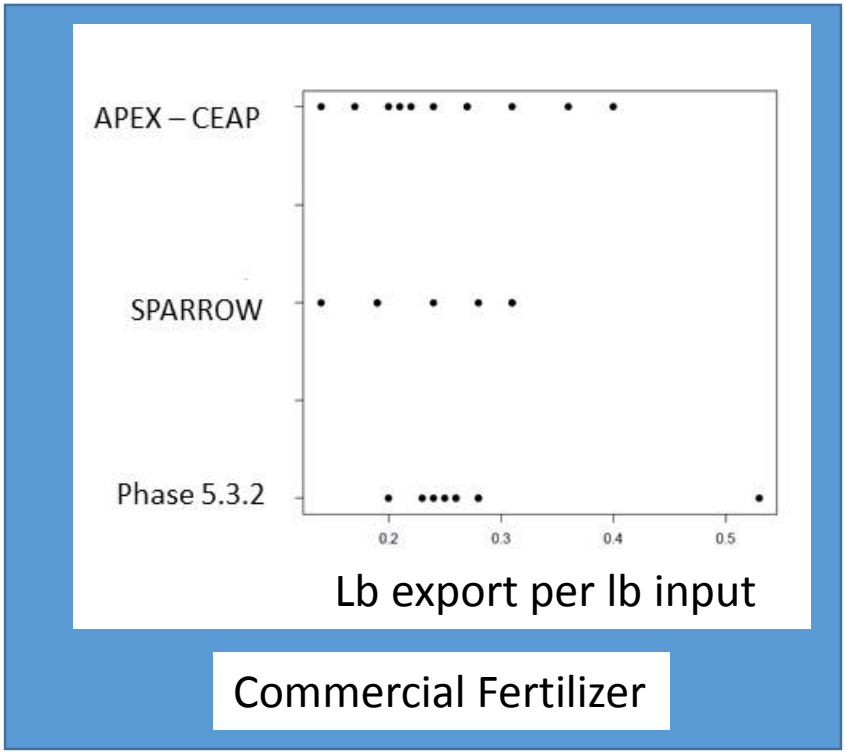


Manure

Multiple Model comparison – All in general agreement on the average effect

Nitrogen Sensitivity

Definition – Average Change in export per change in input



Modeling Workgroup Decision:

Use Phase 5.3.2 for global sensitivities

- Supported by CEAP and SPARROW results
- Answers the right question
  - ***Change*** in export per ***change*** in input
- No direct access to APEX-CEAP
- Sparrow had different land use classifications

Sensitivity of Phase 5 Hightill with Manure land use

gwm	NH3	NO3	OrgN
AtmDep	0.01	0.226	0.083
Fert	0.018	0.19	NA
Legume	0.01	NA	NA
Manure	0.005	0.067	0.104
CropCov	-0.012	0.012	-0.404
Uptake	0	-0.057	0

Sensitivities are modified according to relative loading rates

P5.3.2 hwm = p6 gwm (grain with manure)

What about Small Grains and Grains?
Adjusted sgg sensitivity = (sgg load / gwm load) * original gwm sensitivity

STAC Guidance on Phosphorus

A Review of Agricultural P-dynamics in the Chesapeake Bay Watershed Model

"…output from CBWM [indicated] major reductions in P losses from cropland on the Maryland Eastern Shore that seemed to be inconsistent with research findings and monitoring data in the region."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Agenda
Presenters
Location
Hosts
The State of the Science of Phosphorus
This symposium drew 350 attendees seeking to better understand the current state of science surrounding phosphorus transport, soil dynamics, legacies, modeling, and its impact on water quality. Experts on the science of phosphorus from across the country were featured on the program.
Visit the Phosphorus Symposium playlist to watch presentations by selecting individual sessions or play all for continuous play of the program. Proceedings are also available in PDF format to download.
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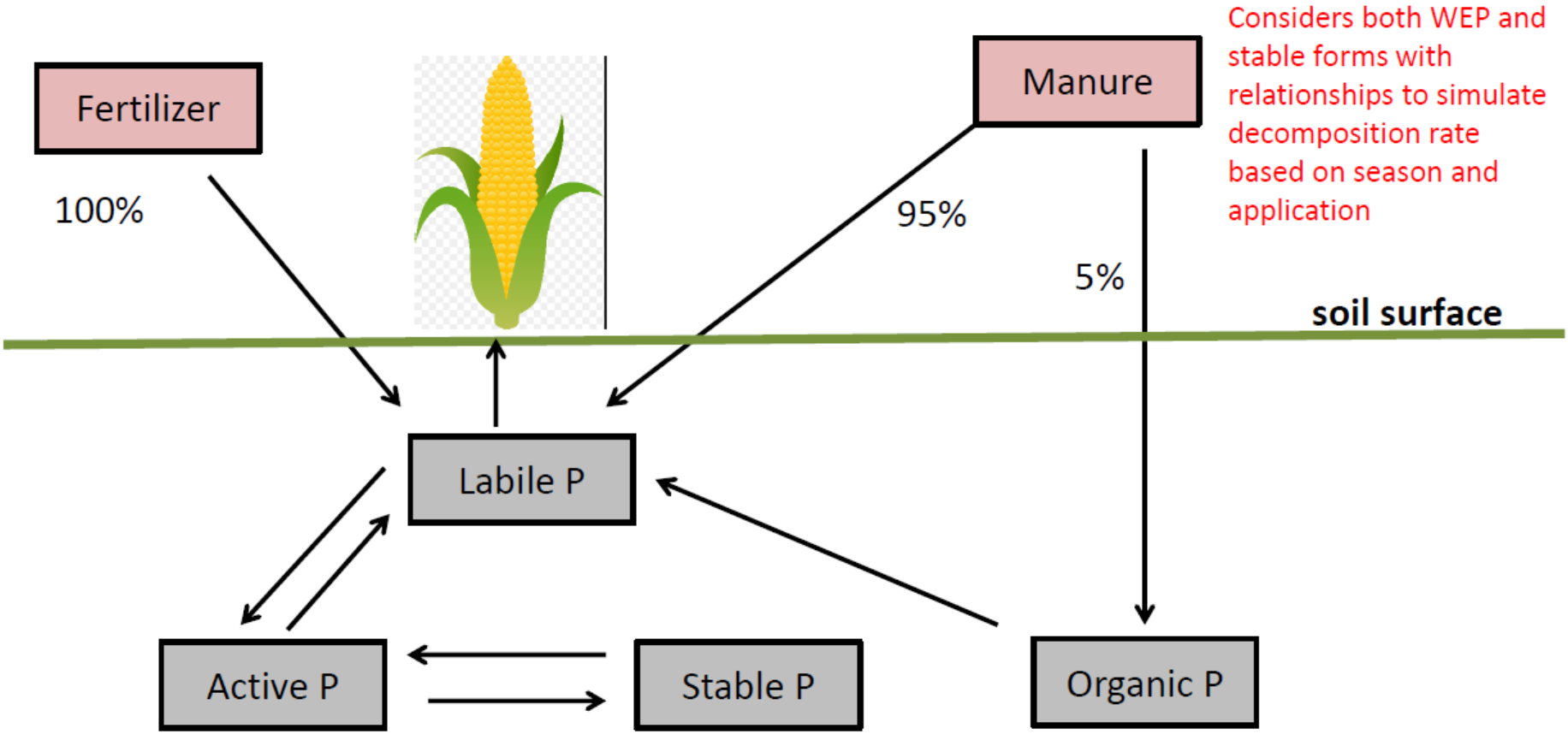
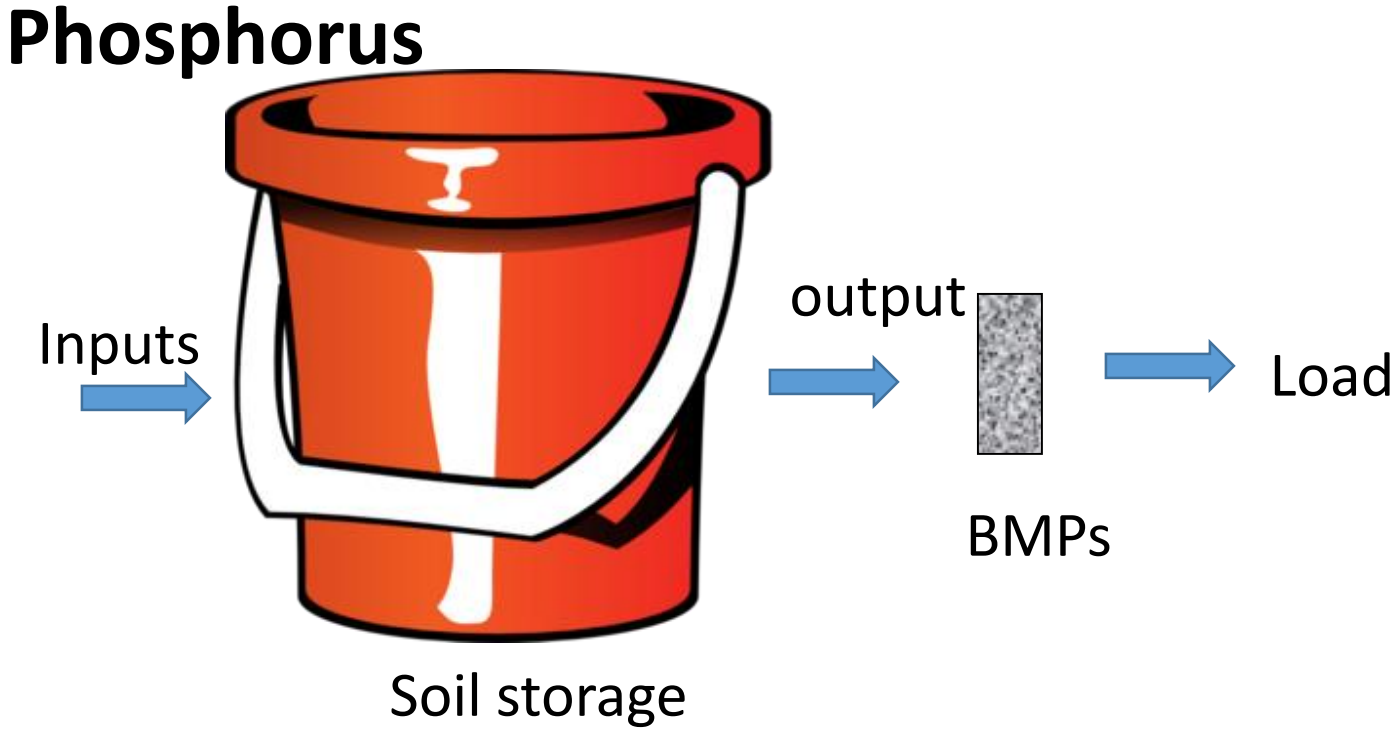
Diagram of APLE Nutrient Sources and Soil Pools



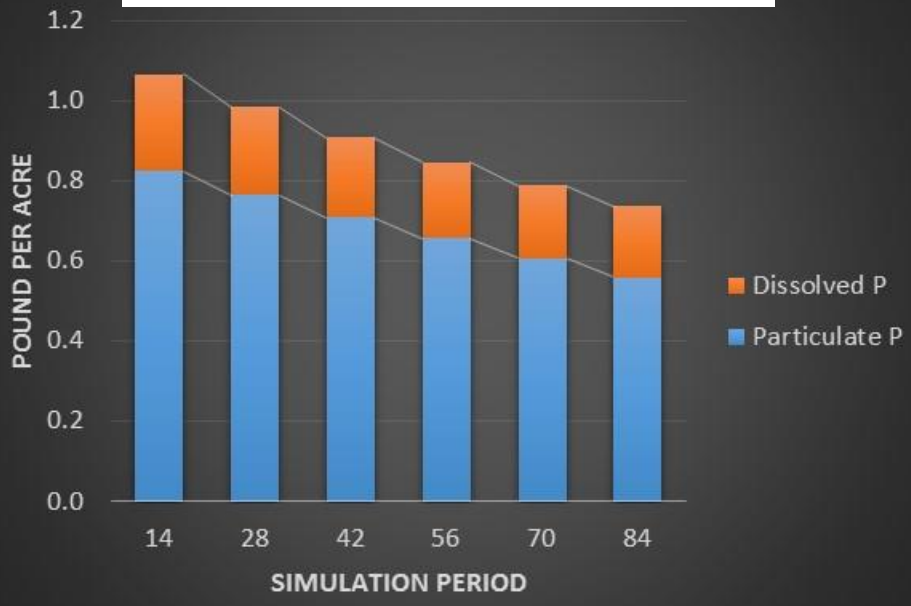
Equations to estimate Manure runoff P, Fertilizer runoff P, Sediment P loss, and Dissolved Soil P runoff

(Adapted from Vadas, et al. 2007)

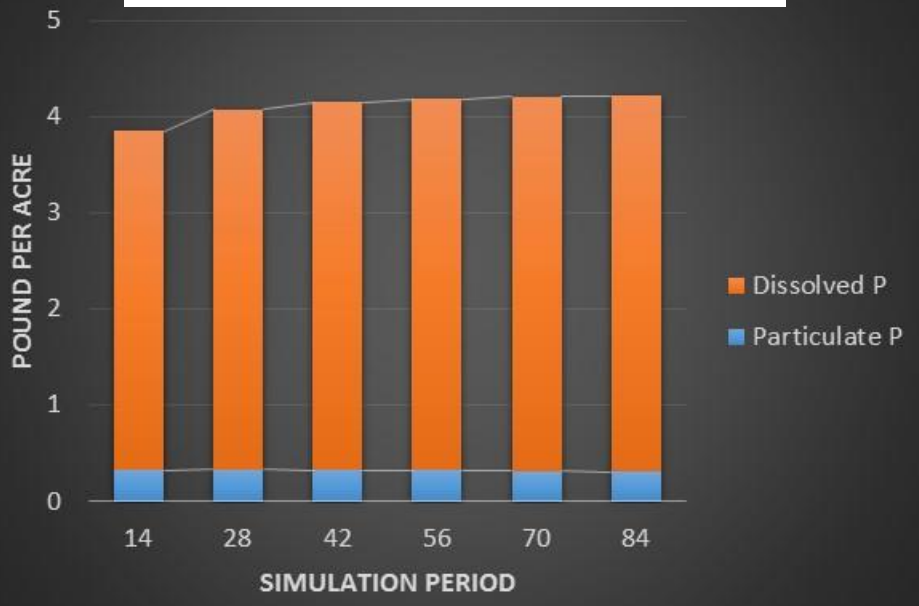
Phosphorus Conceptual Model



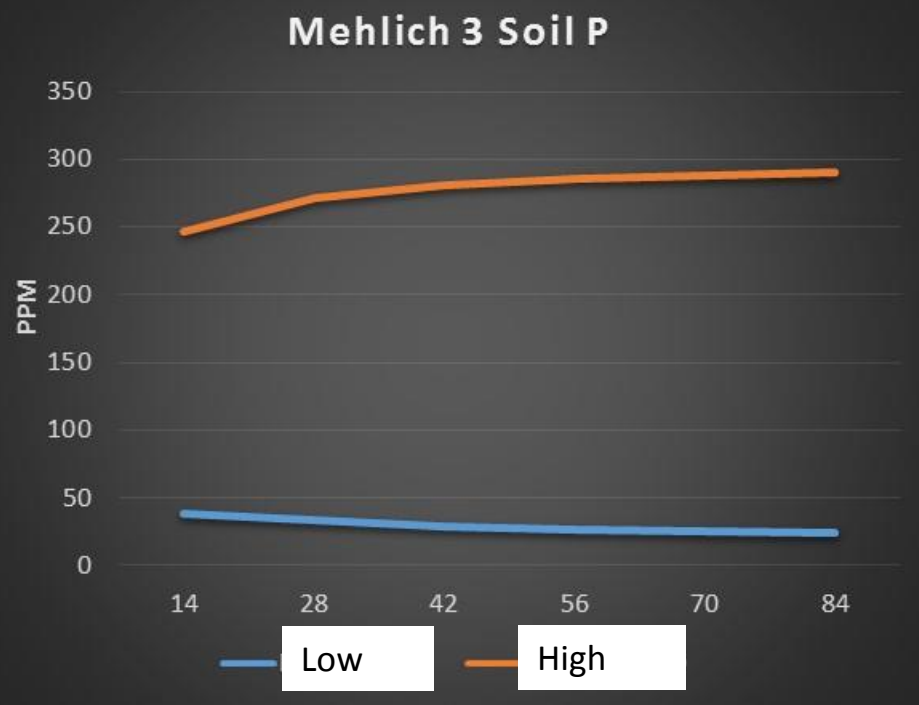
Low input County



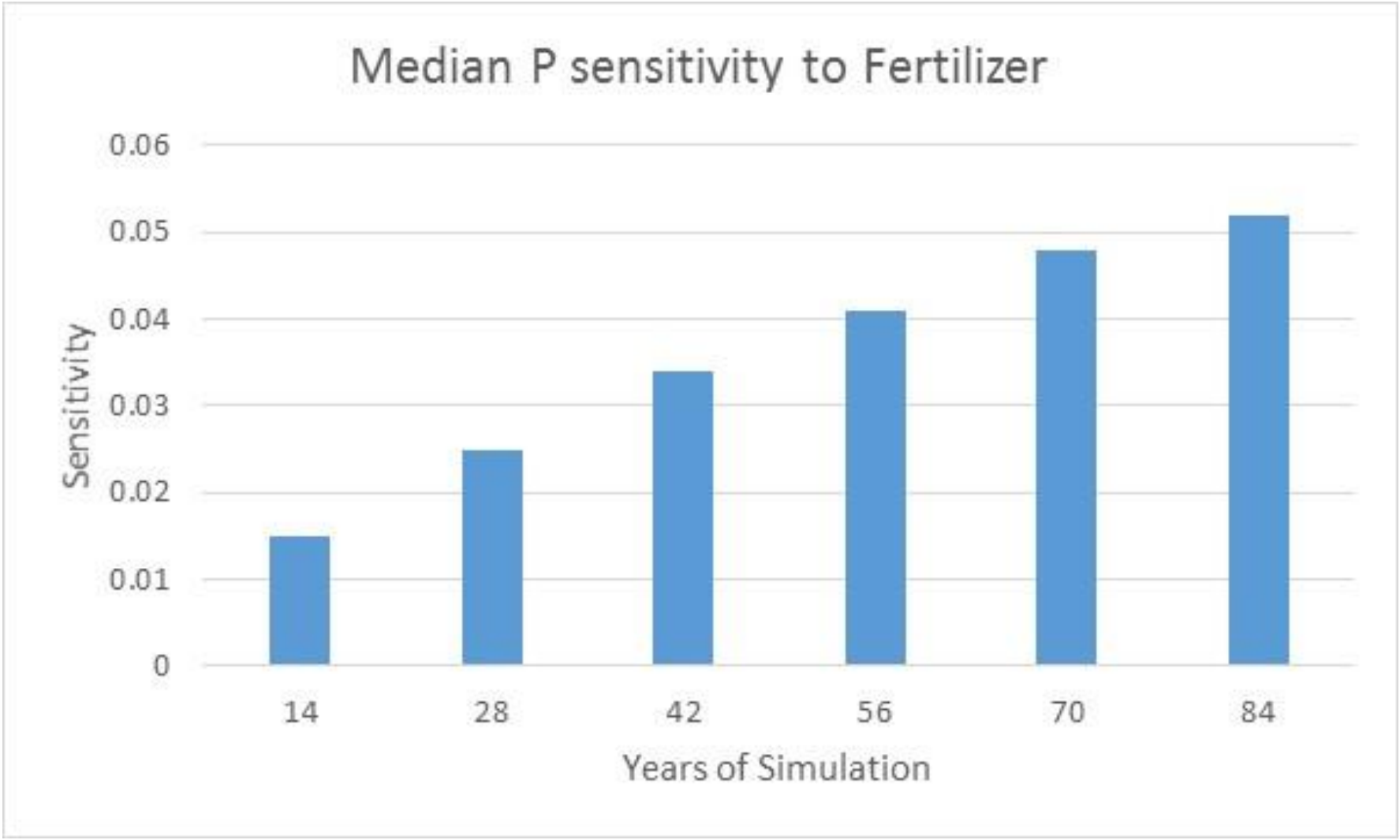
High input County



The concept of a sensitivity to inputs is problematic because the long term simulations do not level off



Different Simulation Periods to Evaluate Sensitivities



APLE Hightill Landuse Sensitivities using Constant Mehlich 3 Soil P

Table 1. Phosphorus Loss APLE Model Sensitivity to change in inputs				
Inputs	**Units**	**MEDIAN SLOPE**	**MEDIAN SR**	**Relative Sensitivity**
Mehlich	ppm	0.015	0.696	Sensitive
Sediment	ton/ac	0.168	0.633	Sensitive
Runoff	inches	0.057	0.403	Moderately sensitive
Manure	lbs/acre	0.007	0.111	Slightly sensitive
Fertilizer	lbs/acre	0.004	0.068	Slightly sensitive
Uptake	lbs/acre	0	0	Insensitive

APLE Hightill Landuse Sensitivities using Constant Mehlich 3 Soil P

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Uptake	lbs/acre	0	0	Insensitive

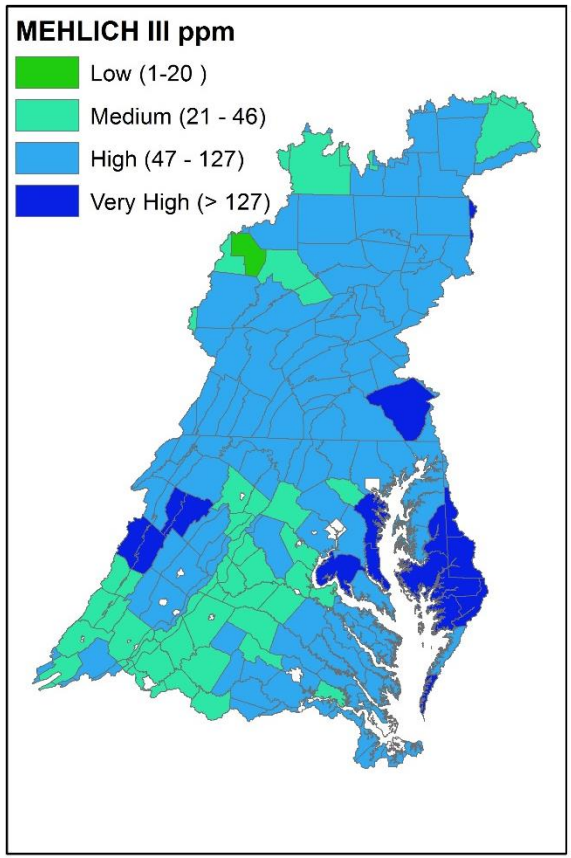
Requires estimate of soil P

Summary of Soil P data sources

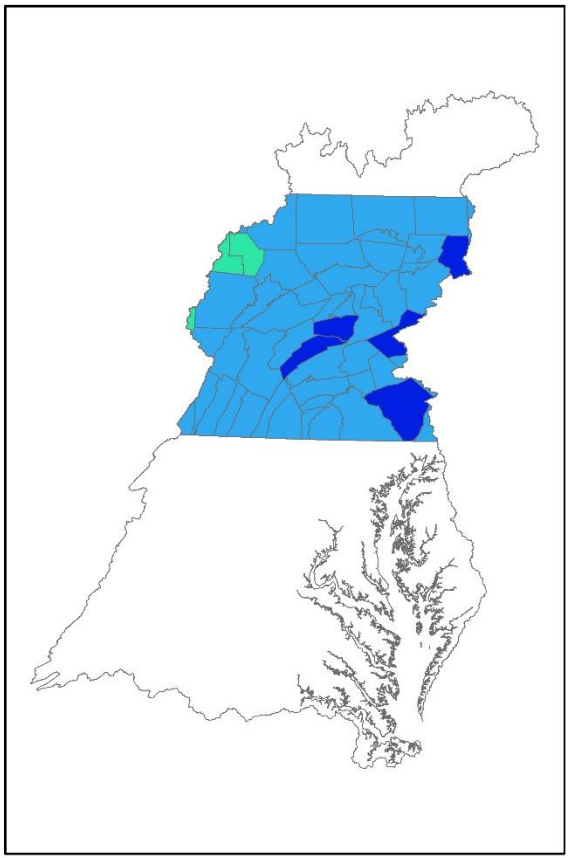
SOURCE	YEARS	LOCATION	UNITS	SAMPLE TYPE
AgriAnalysis	2003 - 2014	DE,MD,NY,PA,VA,WV	Phos lbs/ac	by county & zip code
Penn State University	2001 - 2014	PA	Mehlich III soil P (ppm)	by county and by crop
Virginia Tech Soil Testing Lab	Average of 2012-2014	VA	Mehlich III soil P (ppm)	by county and by crop
University of Maryland	1954 - 2002	MD	number of samples	by county
University of Maryland	1992	DE,MD,NY,PA,VA,WV	Mehlich III soil P (ppm)	by county

CBW Soil P Observed Data

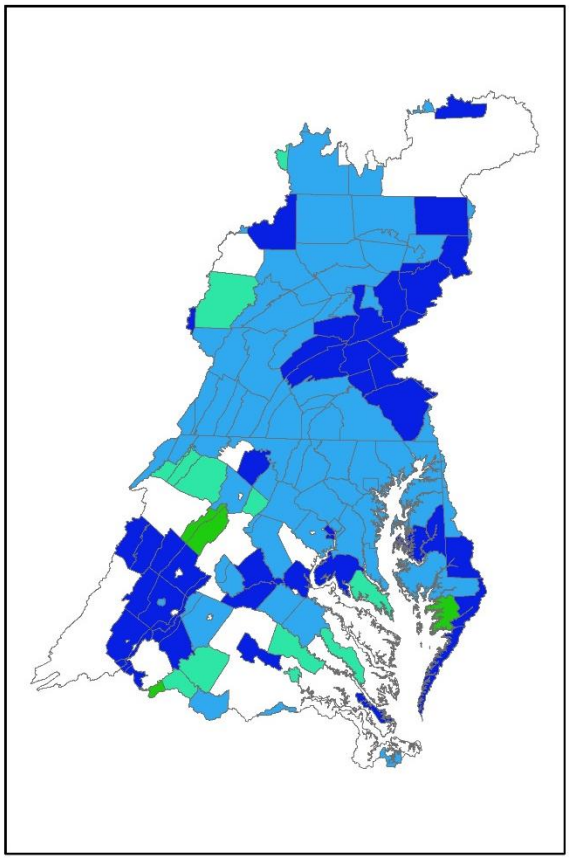
U. MD ***1992***



Penn State 2001-2014



Agri Analysis 2003-2014

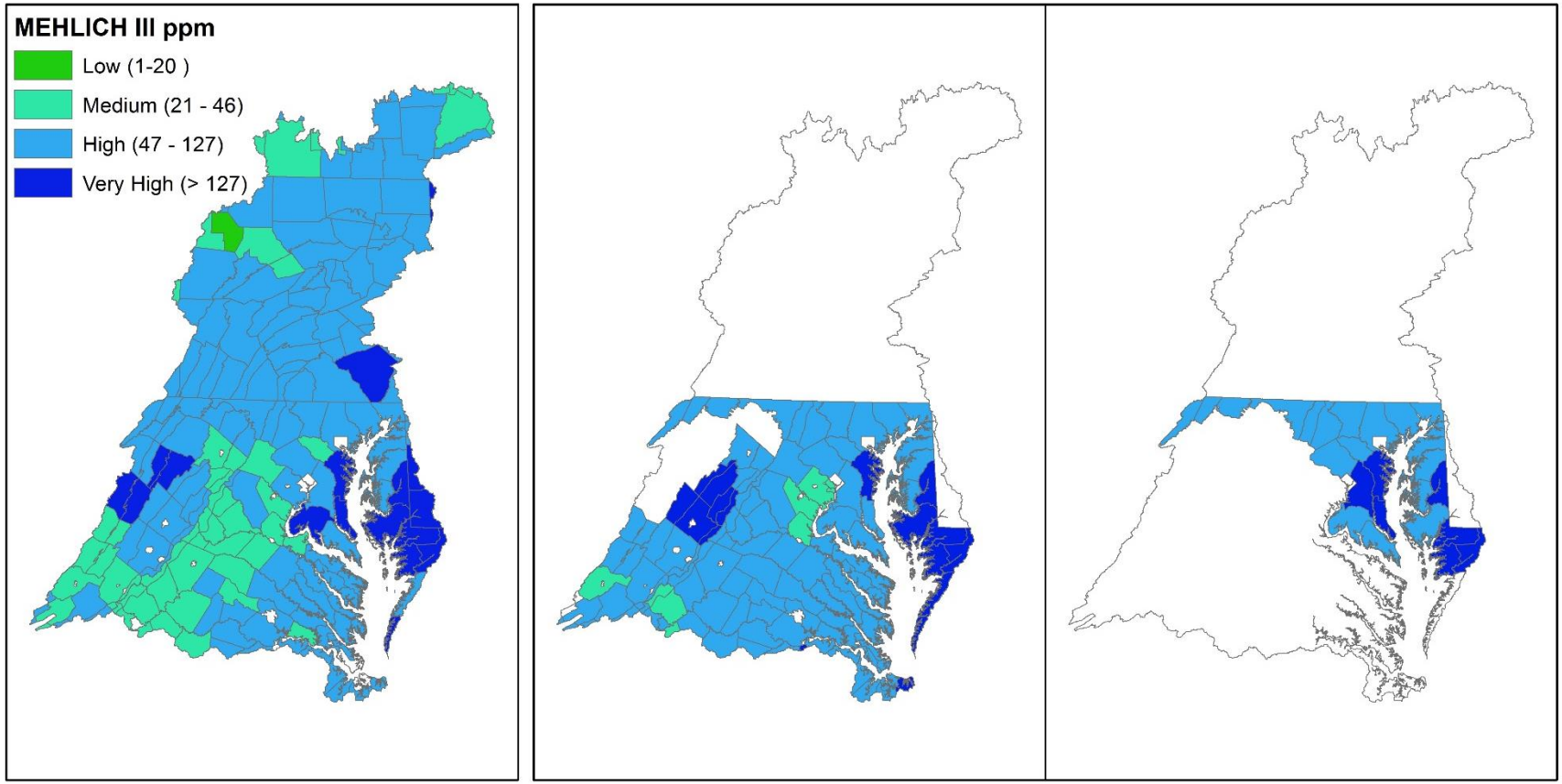


CBW Soil P Observed Data

U. MD ***1992***

Virginia 2012-2014 & Maryland 1984-1996

Maryland 1997-2002

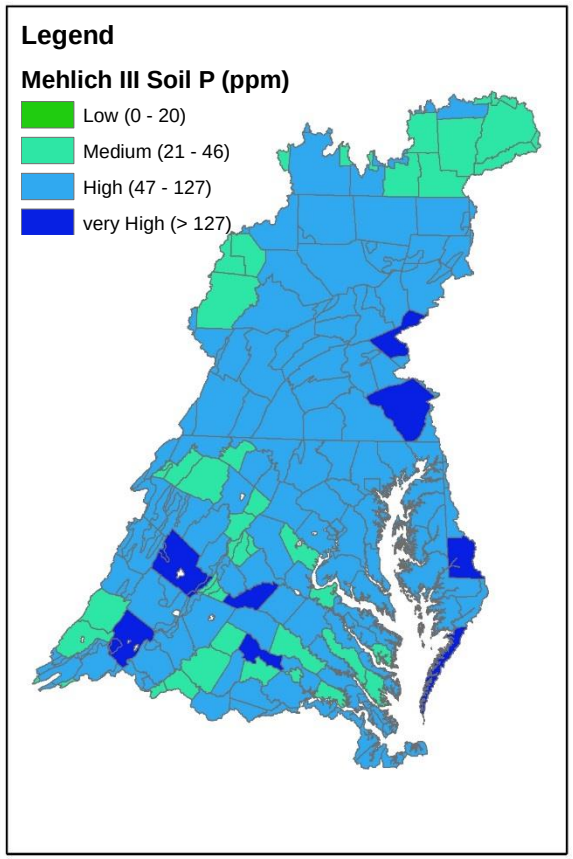


Soil P Landuse Ratios

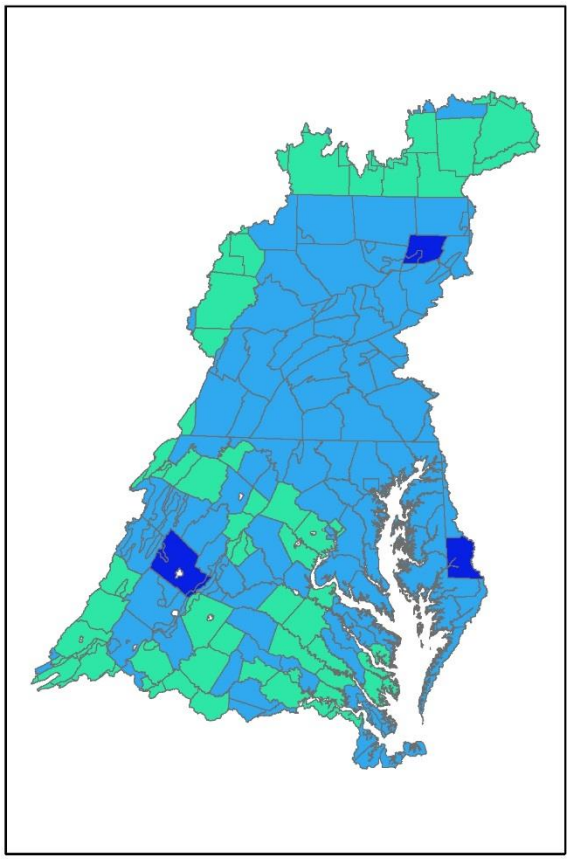
Landuse	Landuse name	PA		VA	
		Average Mehlich III	Ratio	Average Mehlich III	Ratio
ALL	ALL	102		85	
sch	Specialty Crop High	190	1.9	146	1.7
scl	Specialty Crop Low	151	1.5	120	1.4
oac	Other Agronomic Crops	132	1.3	106	1.3
swm	Silage with Manure	90	0.9	88	1.0
gwm	Grain with Manure	89	0.9	76	0.9
soy	Full Season Soybeans	83	0.8	64	0.8
sgg	Small Grains and Grains	76	0.7	72	0.8
ohy	Other Hay	73	0.7	58	0.7
lhy	Legume Hay	73	0.7	58	0.7
pas	Pasture	66	0.6	56	0.7

- PA and VA provided soil P data by crop.
- The average soil P ratios were applied to other states' soil P datasets.

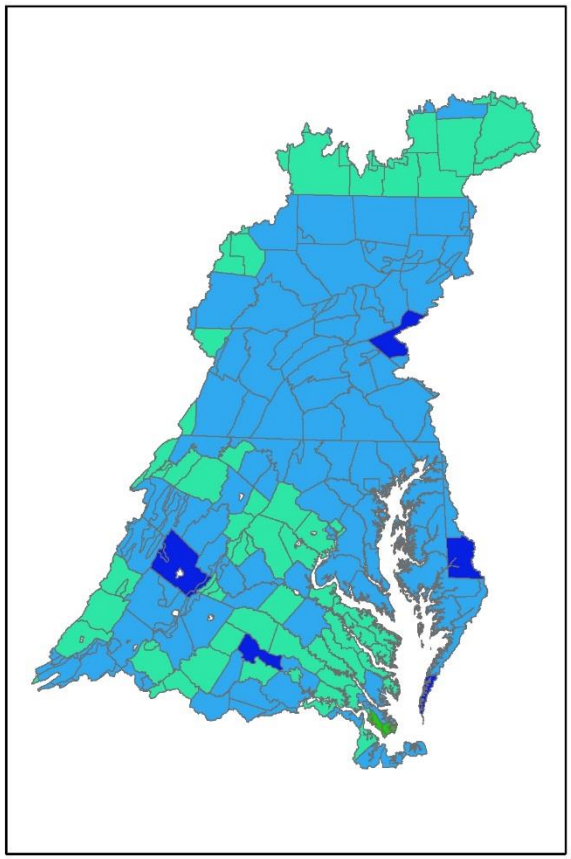
Small Grains and Grains (sgg)



Other Hay (ohy)



Legume Hay (lhy)

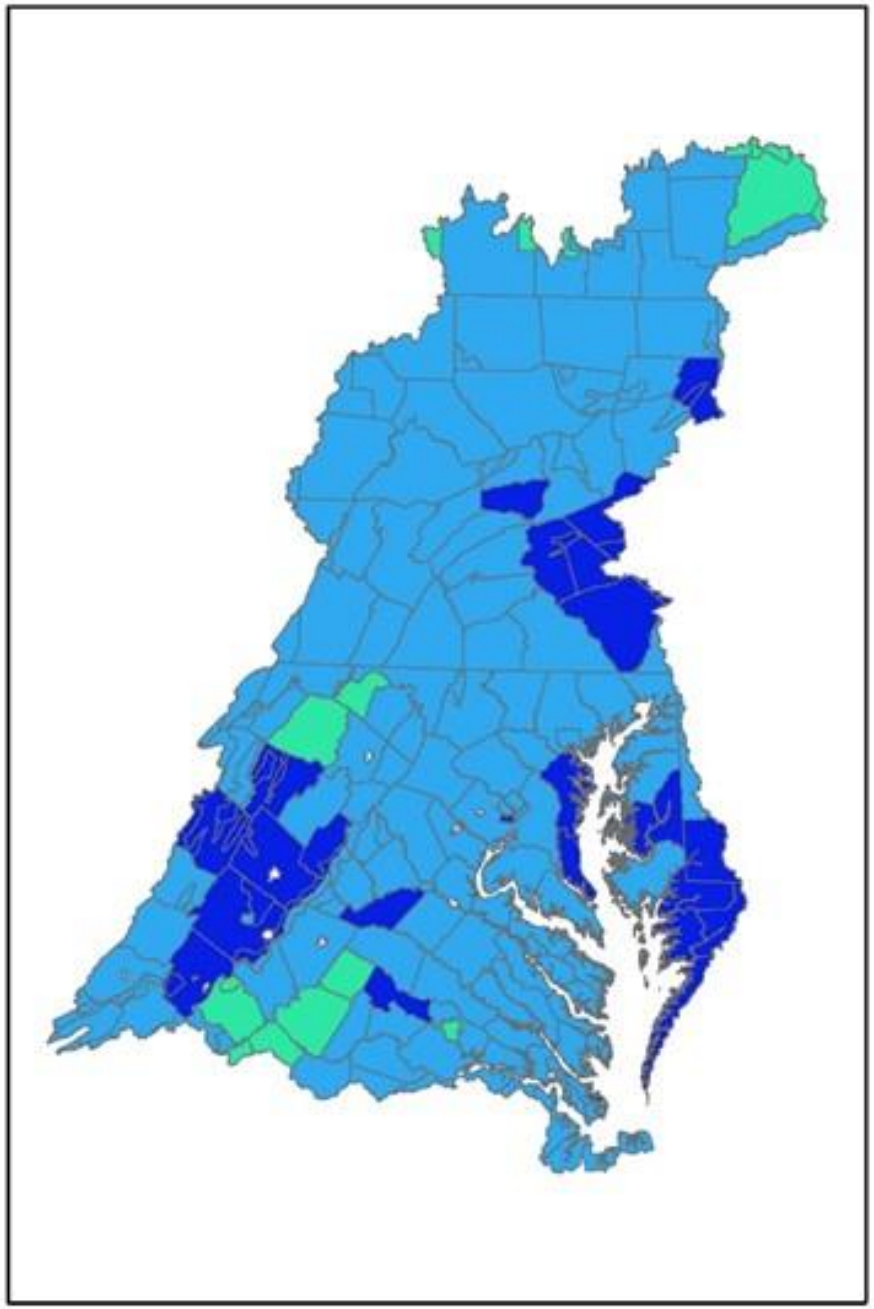


CBW Average

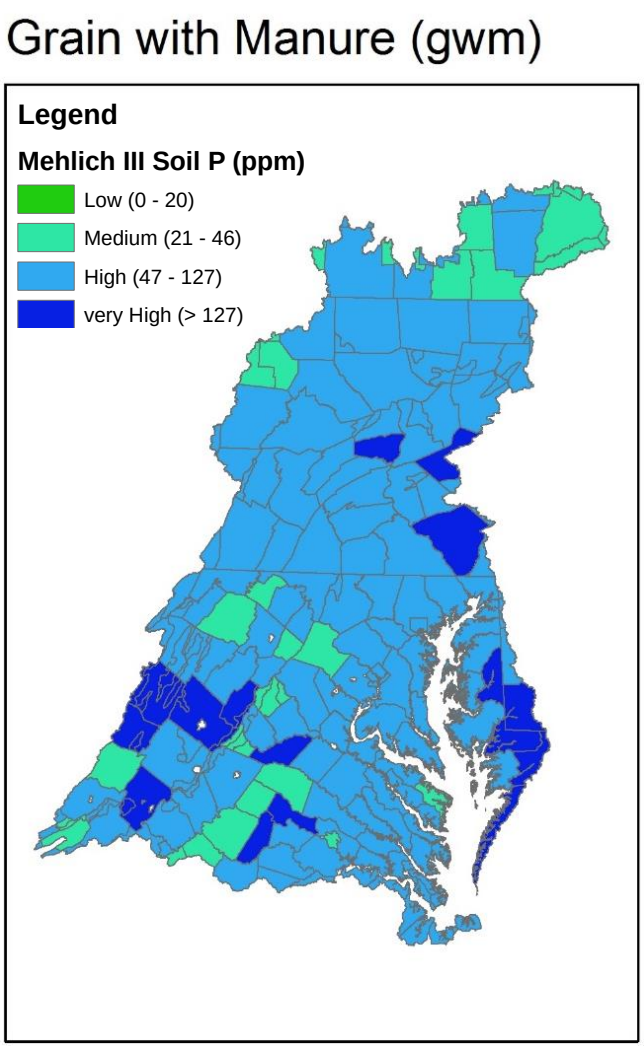
Legend

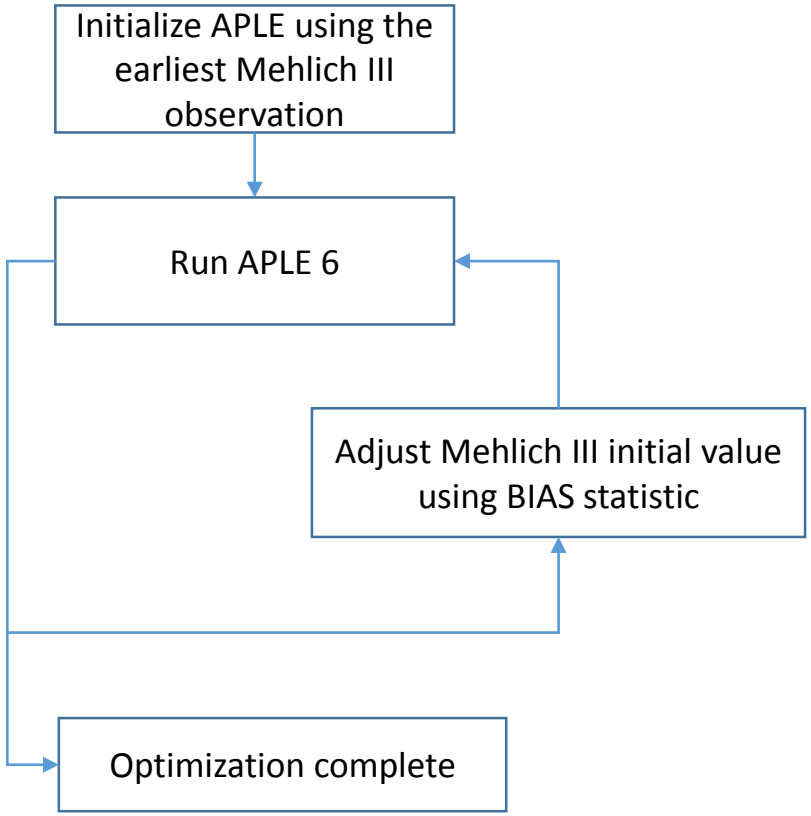
Mehlich III Soil P (ppm)

- Low (0 - 20)
- Medium (21 - 46)
- High (47 - 127)
- very High (> 127)



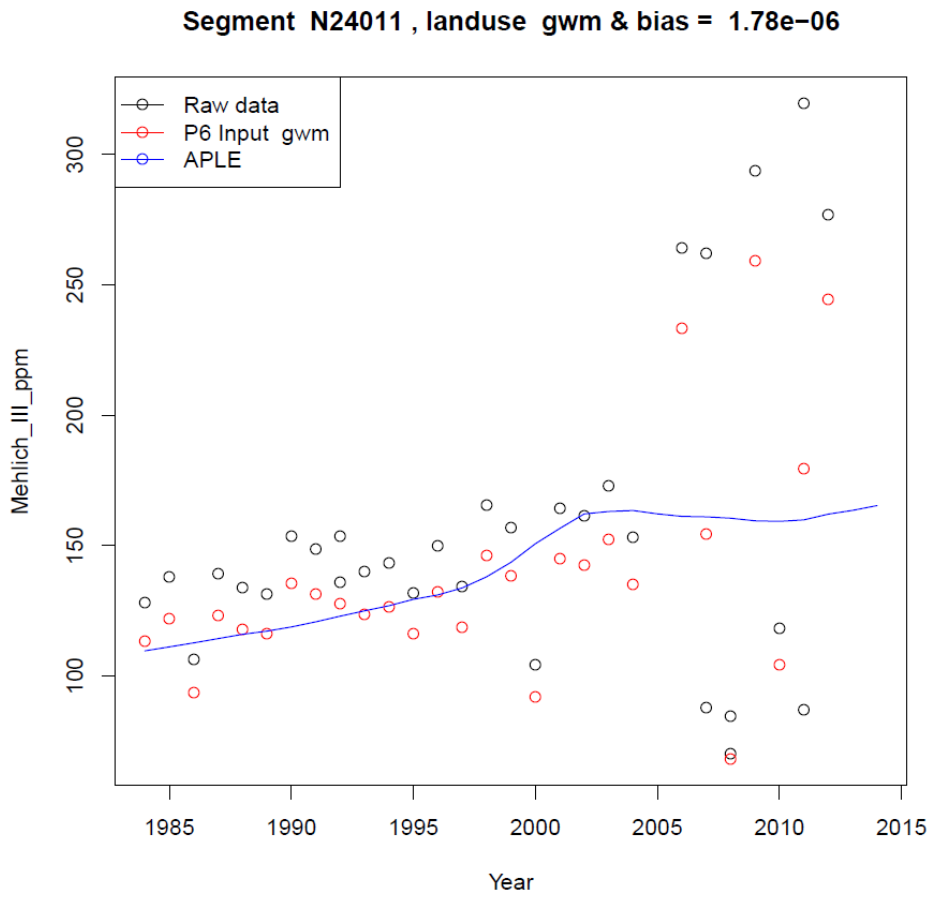
Soil P History

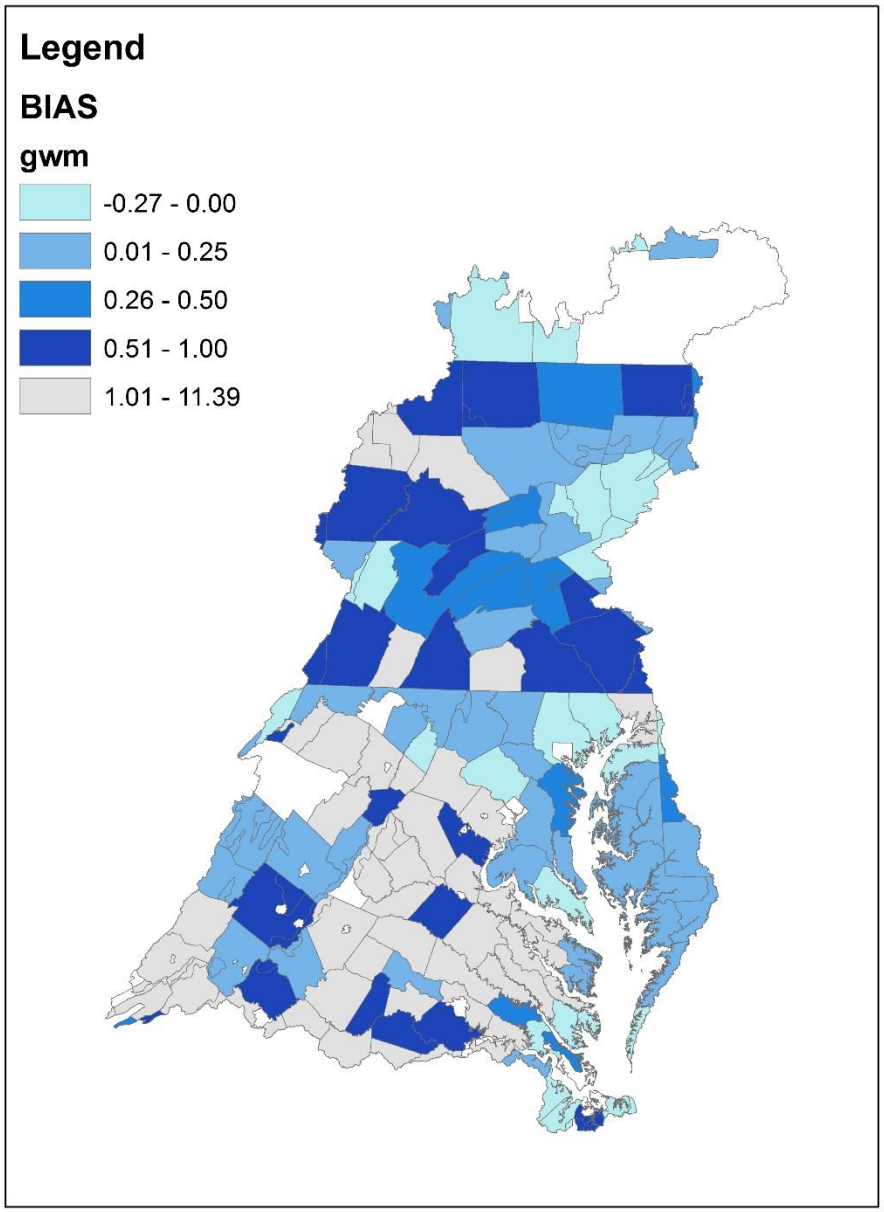




$$Adjusted\ Mehlich\ III = Mehlich\ III\ - \frac{\Sigma(Simulated_i - Observedi)}{n}$$

Well-performing segment





- Segments in blue performed well and were used to calculate targets.

- Segments in grey or white did not have reasonable APLE model runs. Soil history was assumed to be constant at the average county value





Webinar Structure

"Scenario Builder"

"Watershed Model"

Average Load + ΔInputs * Sensitivity

*

Land Use Acres

*

BMPs

*

Land to Water

*

Stream Delivery

*

River Delivery

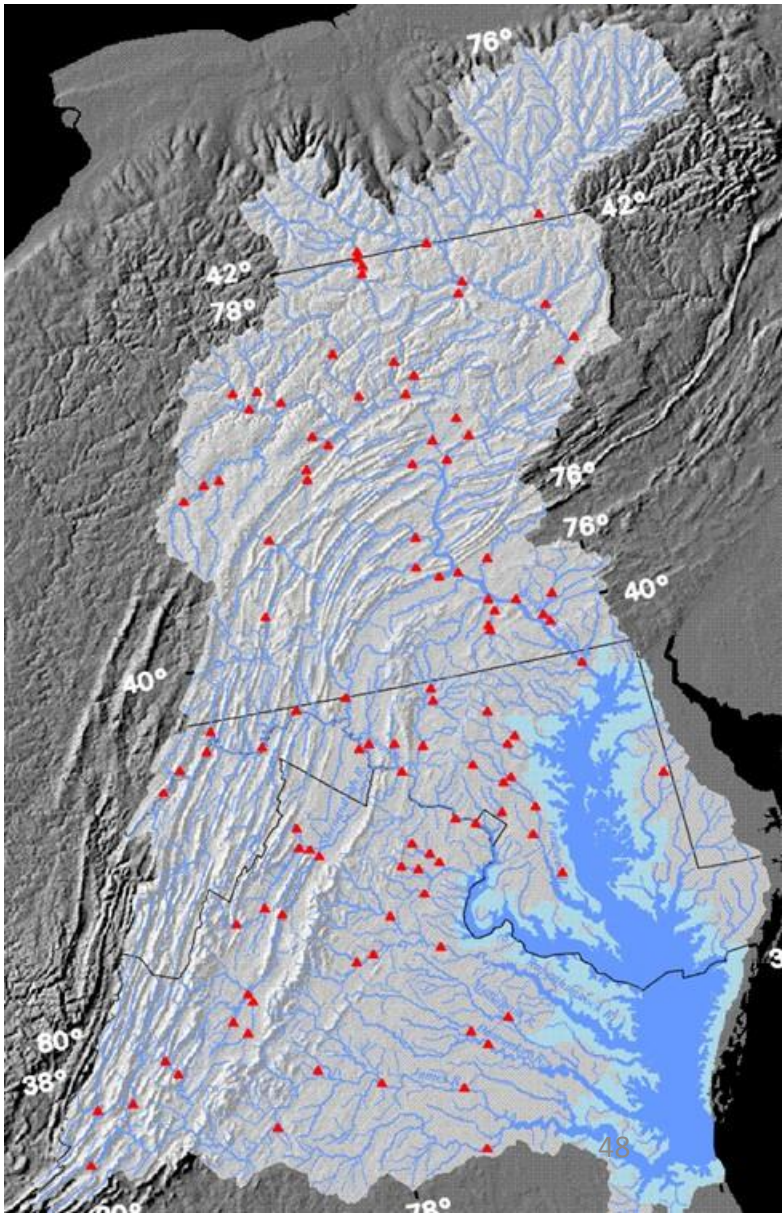
Direct Loads

Phase 6

$$LOAD_i = \left\{ \sum_{j \in J(i)} \left[\sum_{n=1}^{N} S_{n,j} \beta_n \exp(-\alpha' Z_j) \right] \prod_m \exp(-\delta_m^s T_{i,j,m}) \prod_l 1/(1+\lambda^r q_{i,j,l}^{-1}) \right\} \exp(\varepsilon_i)$$

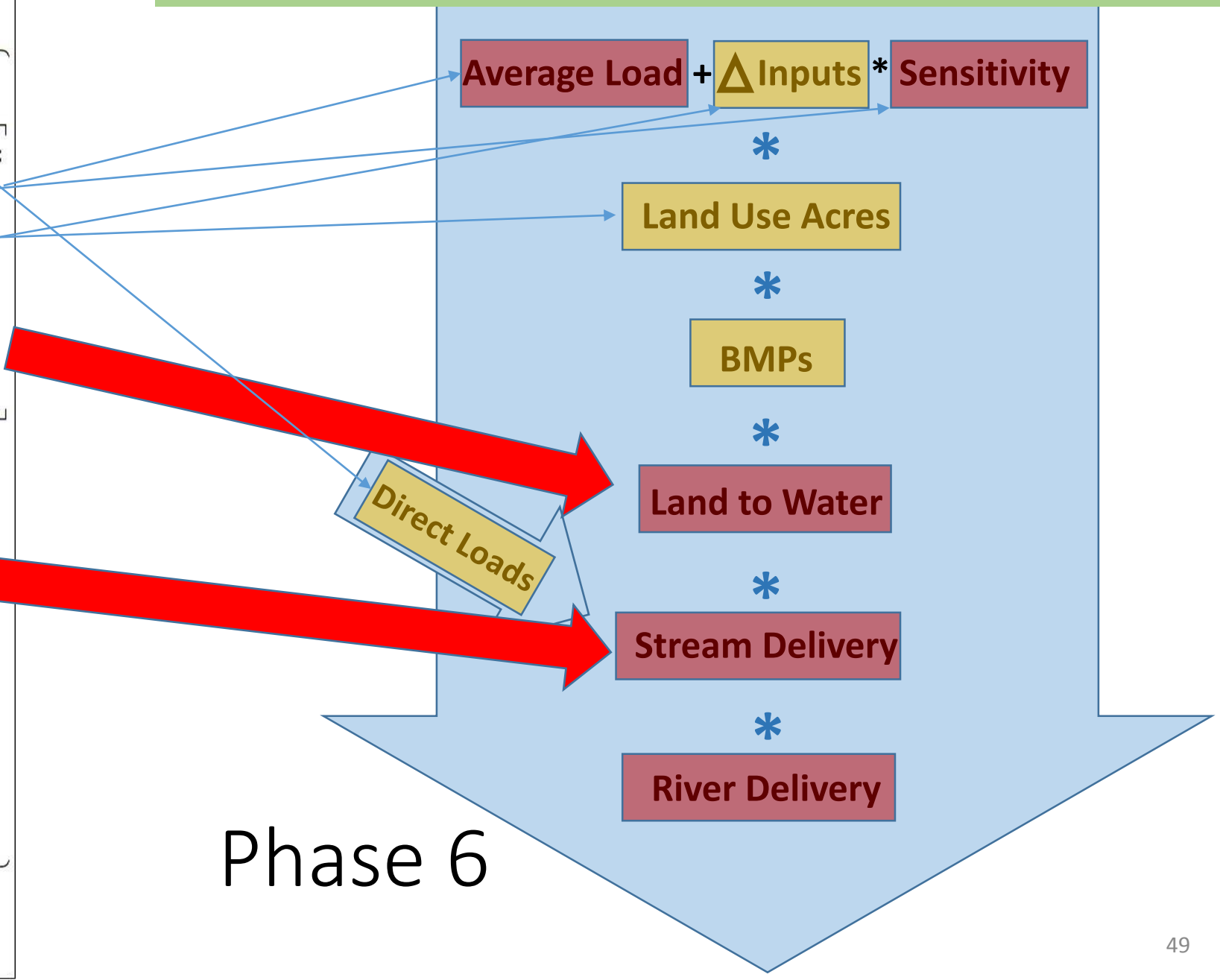
USGS Sparrow Model

- Regression Model
- Gain knowledge about the watershed based on observations



Phase 6 Model Structure

$$LOAD_i = \left\{ \sum_{j \in J(i)} \left[\sum_{n=1}^{N} S_{n,j} \beta_n \exp(-\alpha' Z_j) \right] \prod_m \exp(-\delta^s_{m_1,j,m} T_{i,j,m}) \prod_l 1/(1 + \lambda^r q^{-1}_{i,j,l}) \right\} \exp(\varepsilon_i)$$



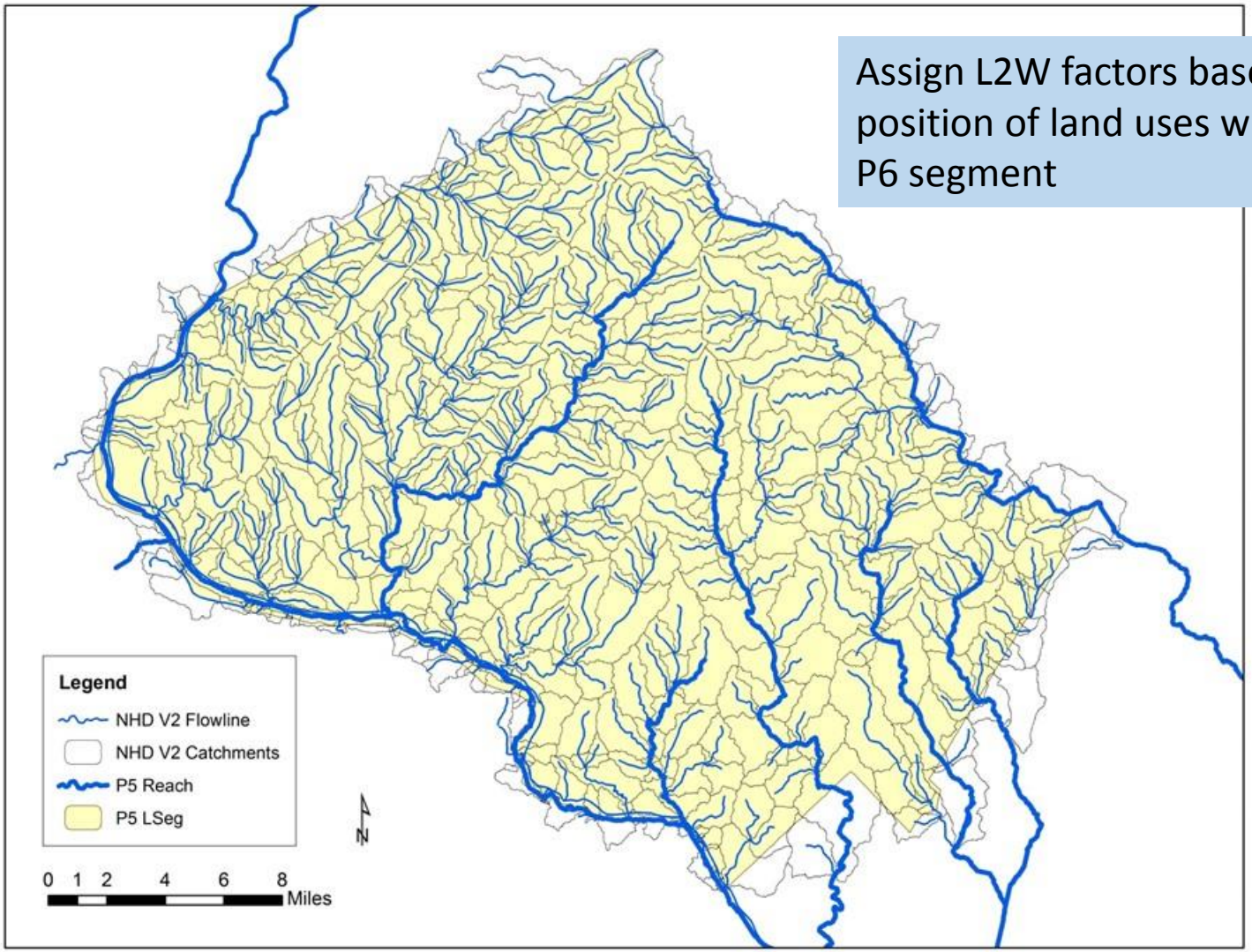
Phase 6

Catchment and Reach Attributes Used in SPARROW Models

Explanatory Variable	Nitrogen	Phosphorus
Land-to-Water Delivery	1. % catchment in Piedmont carbonate 2. Groundwater recharge 3. Available soil water capacity 4. Enhanced vegetative index	1. % catchment in Coastal Plain 2. well-drained soils ~~3. Precipitation~~ * ~~4. Soil erodibility~~ *

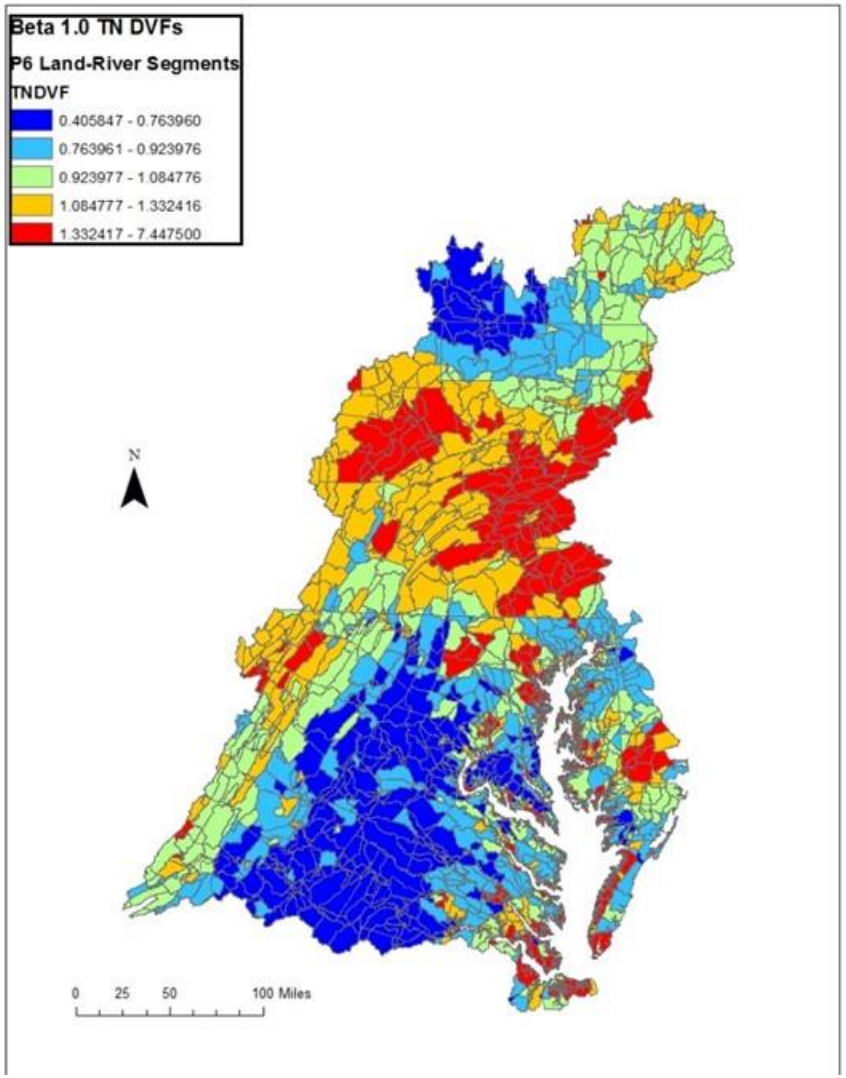
* Not used in P6 calculations because redundant with APLE sensitivities to runoff and erosion

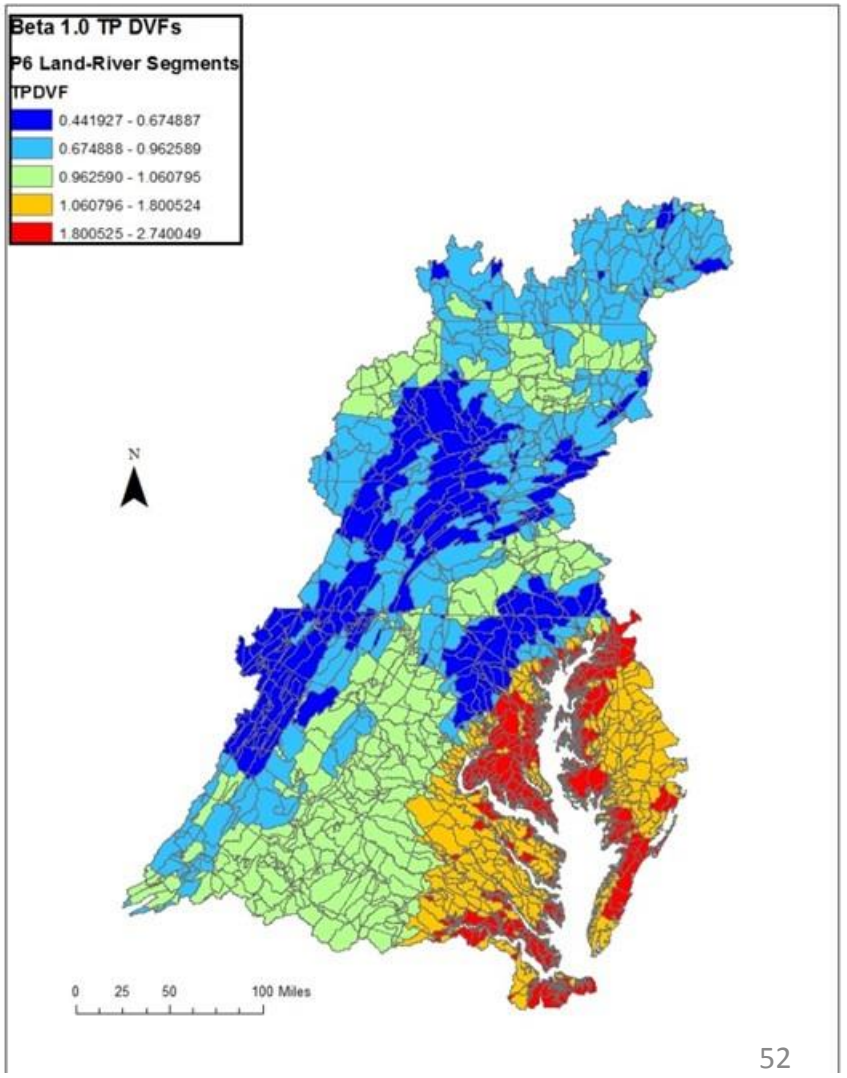
Comparison of NHD+ and P6 Scales



Assign L2W factors based on position of land uses within P6 segment

Overall L2W Factors









Webinar Structure

"Scenario Builder"

"Watershed Model"

Average Load + ΔInputs * Sensitivity

*

Land Use Acres

*

BMPs

*

Land to Water

*

Stream Delivery

*

River Delivery

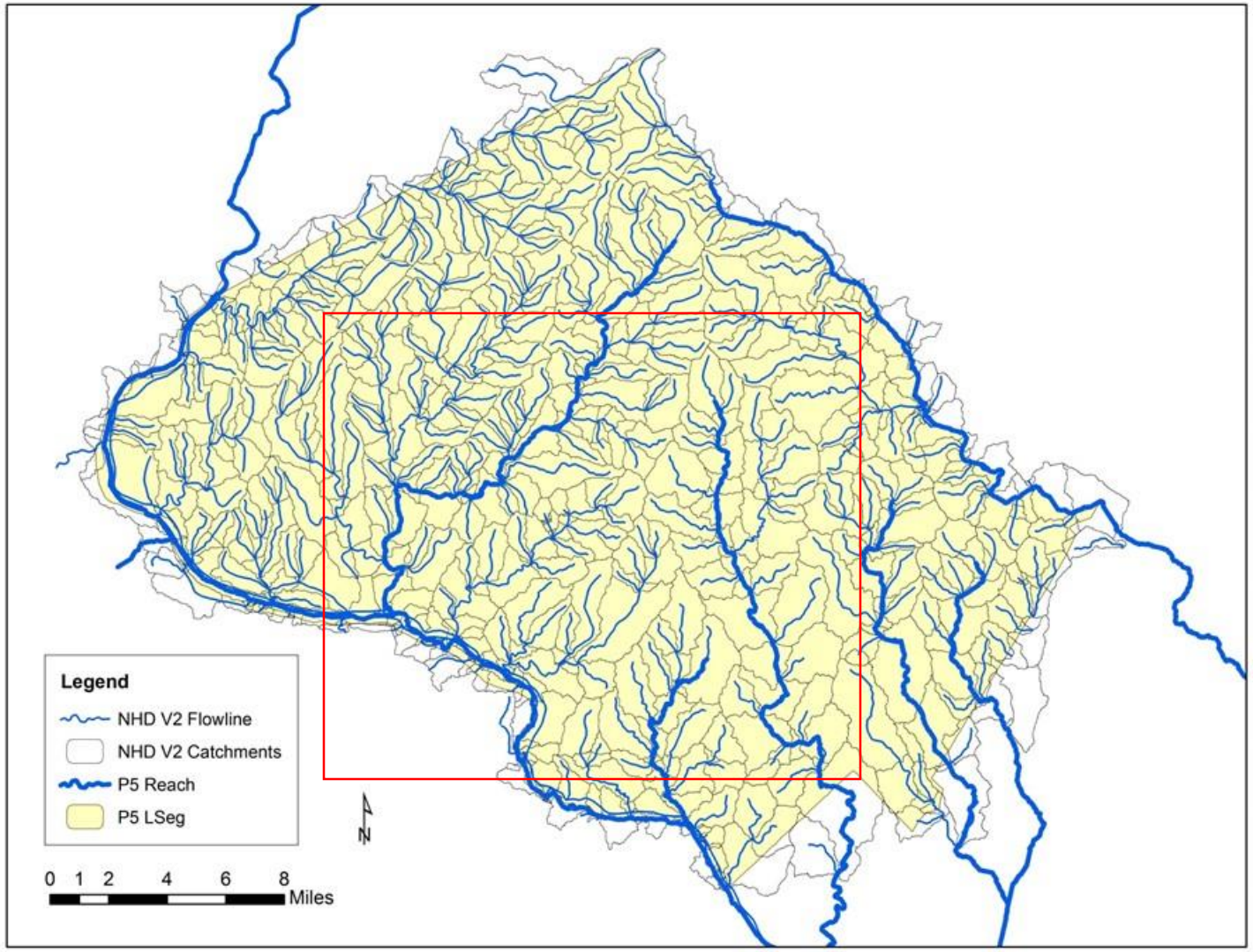
Direct Loads

Phase 6

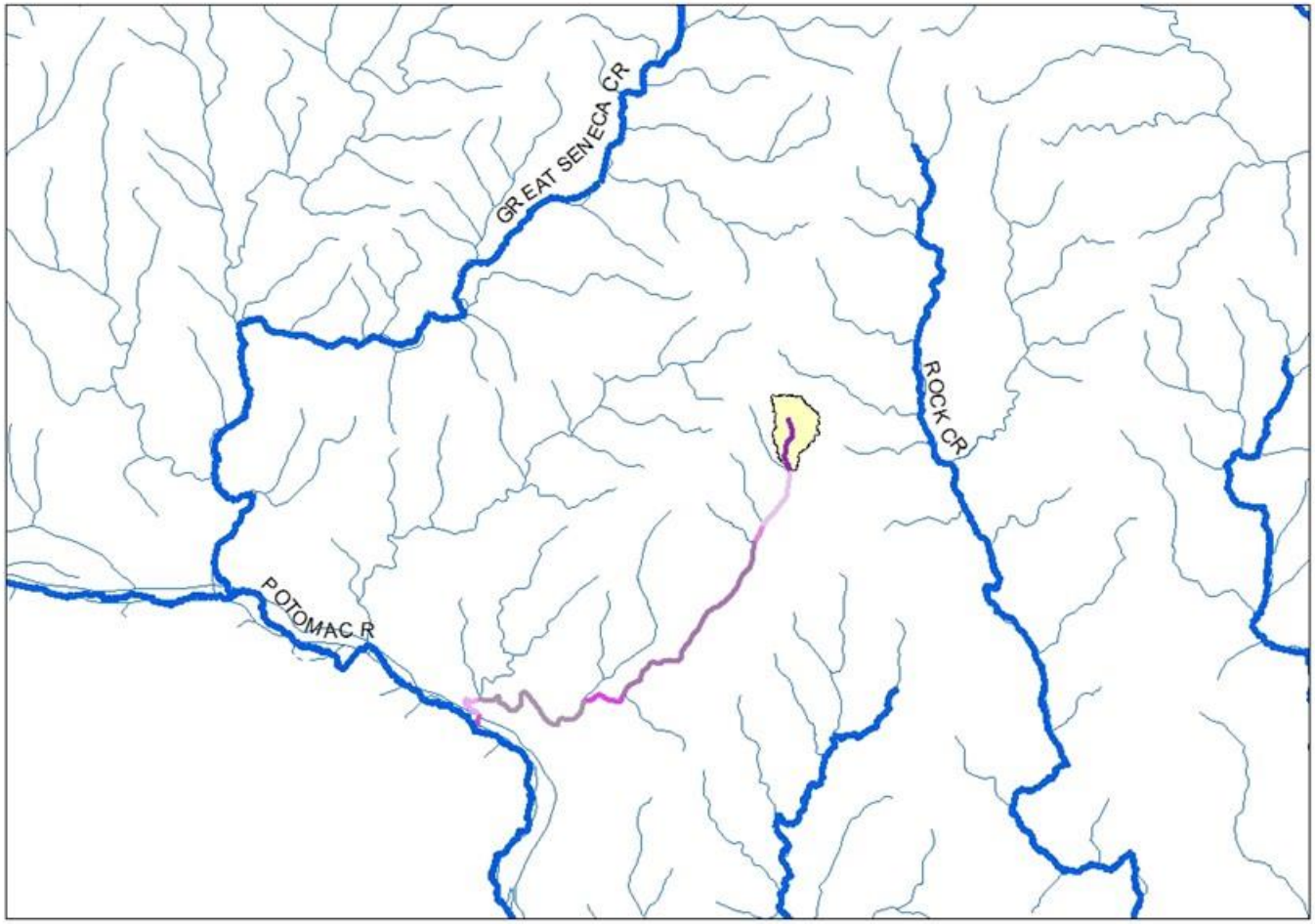
Catchment and Reach Attributes Used in SPARROW Models

Explanatory Variable	Nitrogen	Phosphorus
Stream-to-River Factors (Aquatic Decay)	Impoundments: Hydraulic loading rate Rivers and streams: Average annual temperature Travel time	Impoundments: Hydraulic loading rate Rivers and streams: No losses represented

Comparison of NHD+ and P6 Scales

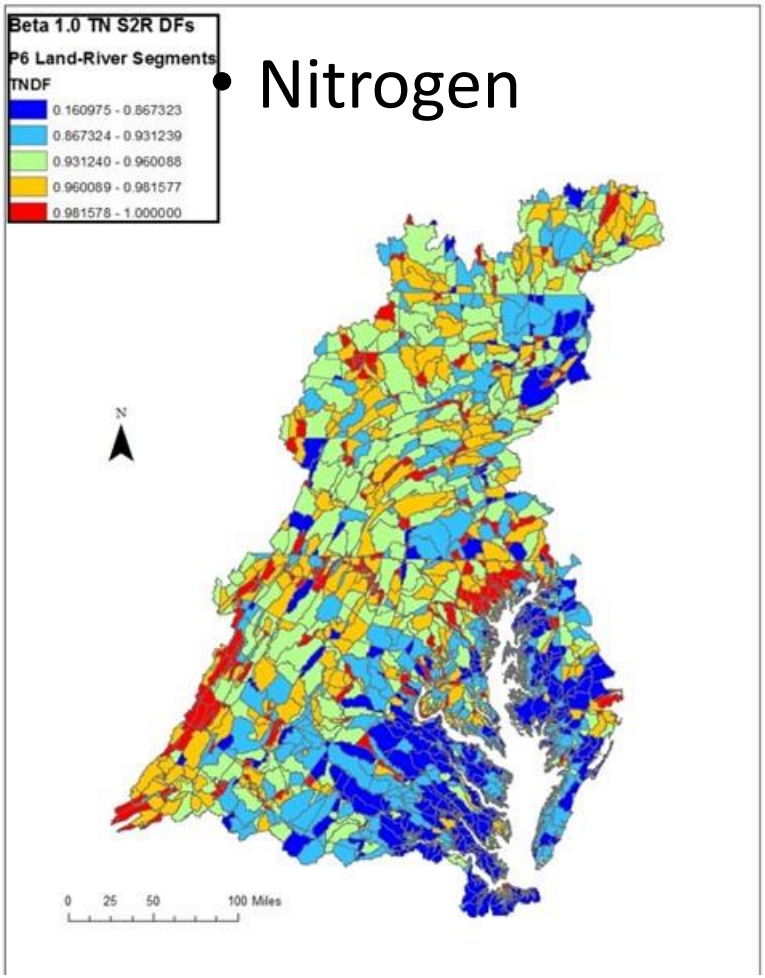


Transport Path from NHD+ Catchment to P6 River Reach

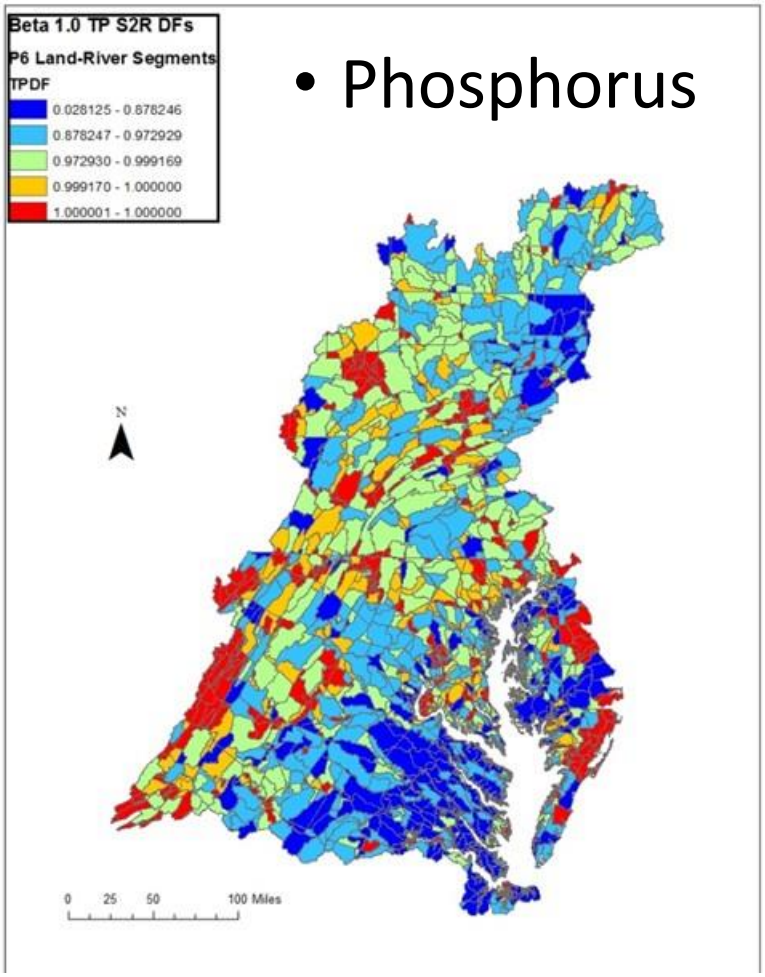


Stream-to-River Delivery Factors

- Nitrogen



- Phosphorus







Webinar Structure

"Scenario Builder"

"Watershed Model"

Average Load + ΔInputs * Sensitivity

*

Land Use Acres

*

BMPs

*

Land to Water

*

Stream Delivery

*

River Delivery

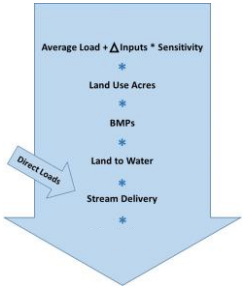
Direct Loads

Phase 6

Model to compare against Observations

Fertilizer
Manure
Atmospheric deposition
(…)

Precipitation



Nutrient Submodels

HSPF

Temporal Nutrient model

BMPs,
Land to Stream,
Stream to River

Hydrology submodel

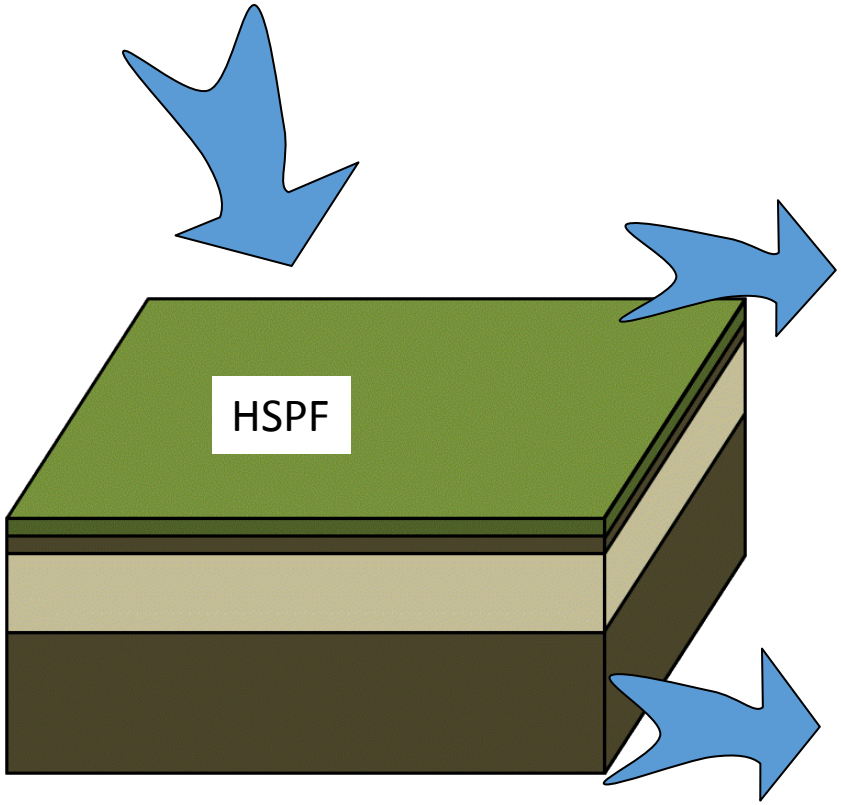
Sediment submodel

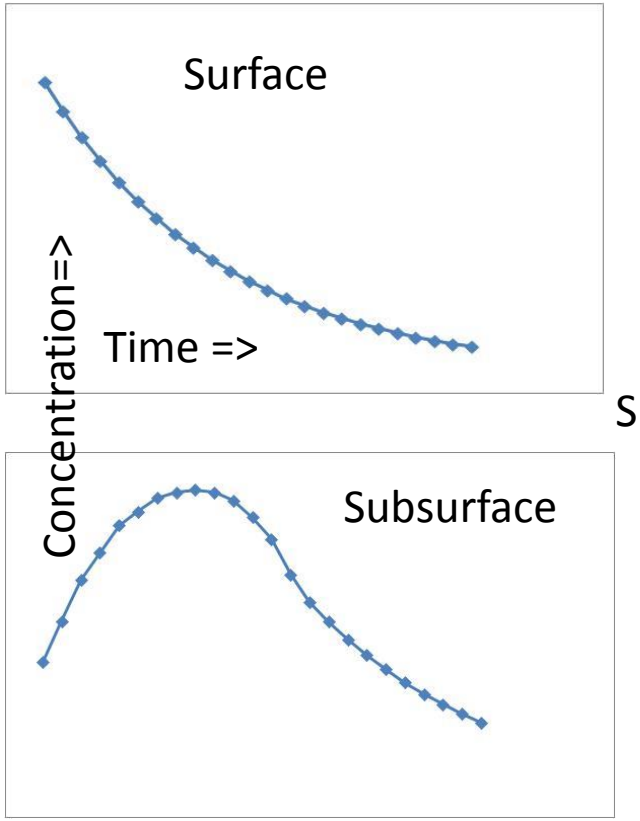
HSPF

River

Lag Models - Nitrogen

Each Loading Event



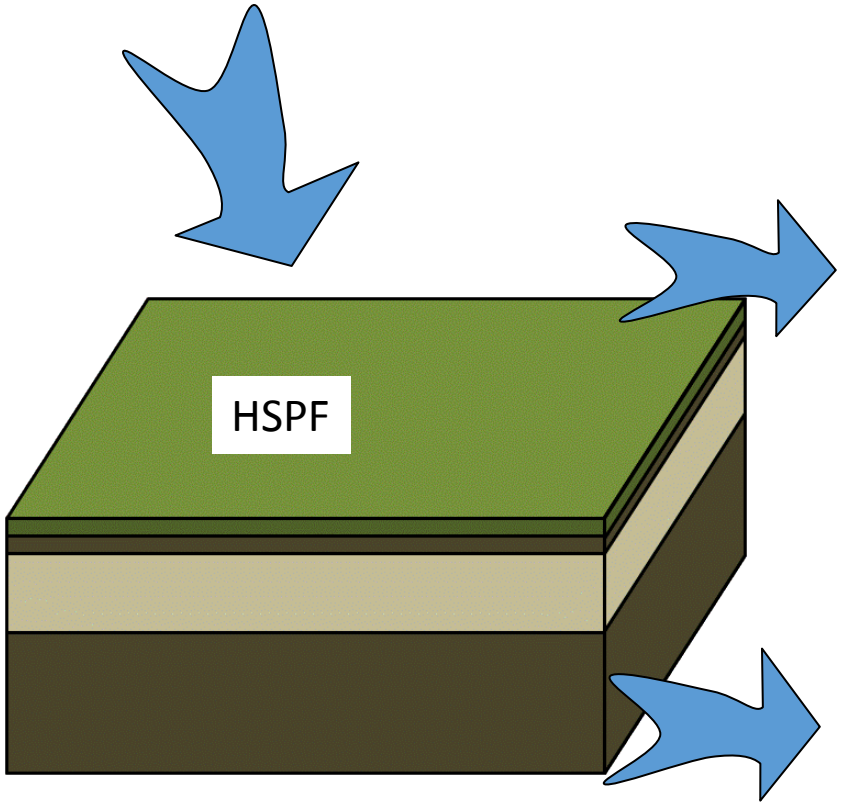


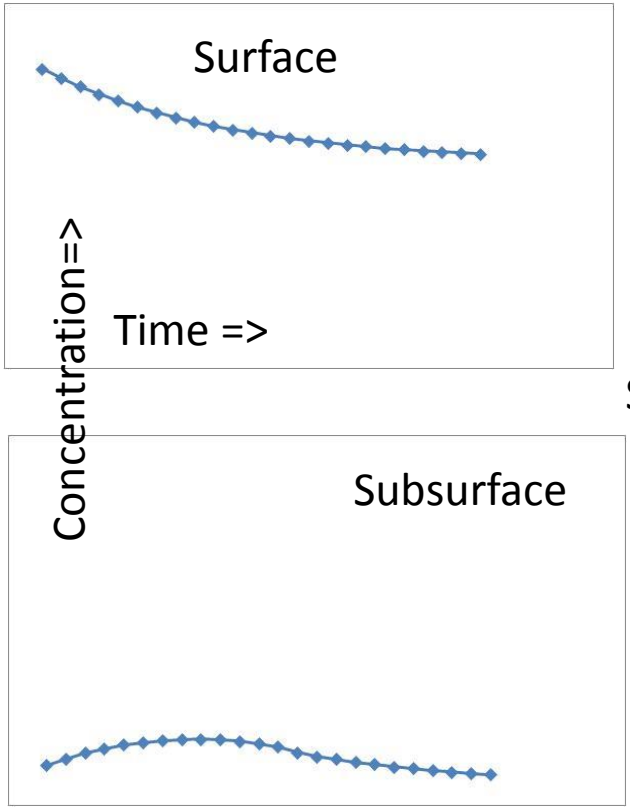
Sum=

Nutrient Submodels

Lag Models - Phosphorus

Each Loading Event

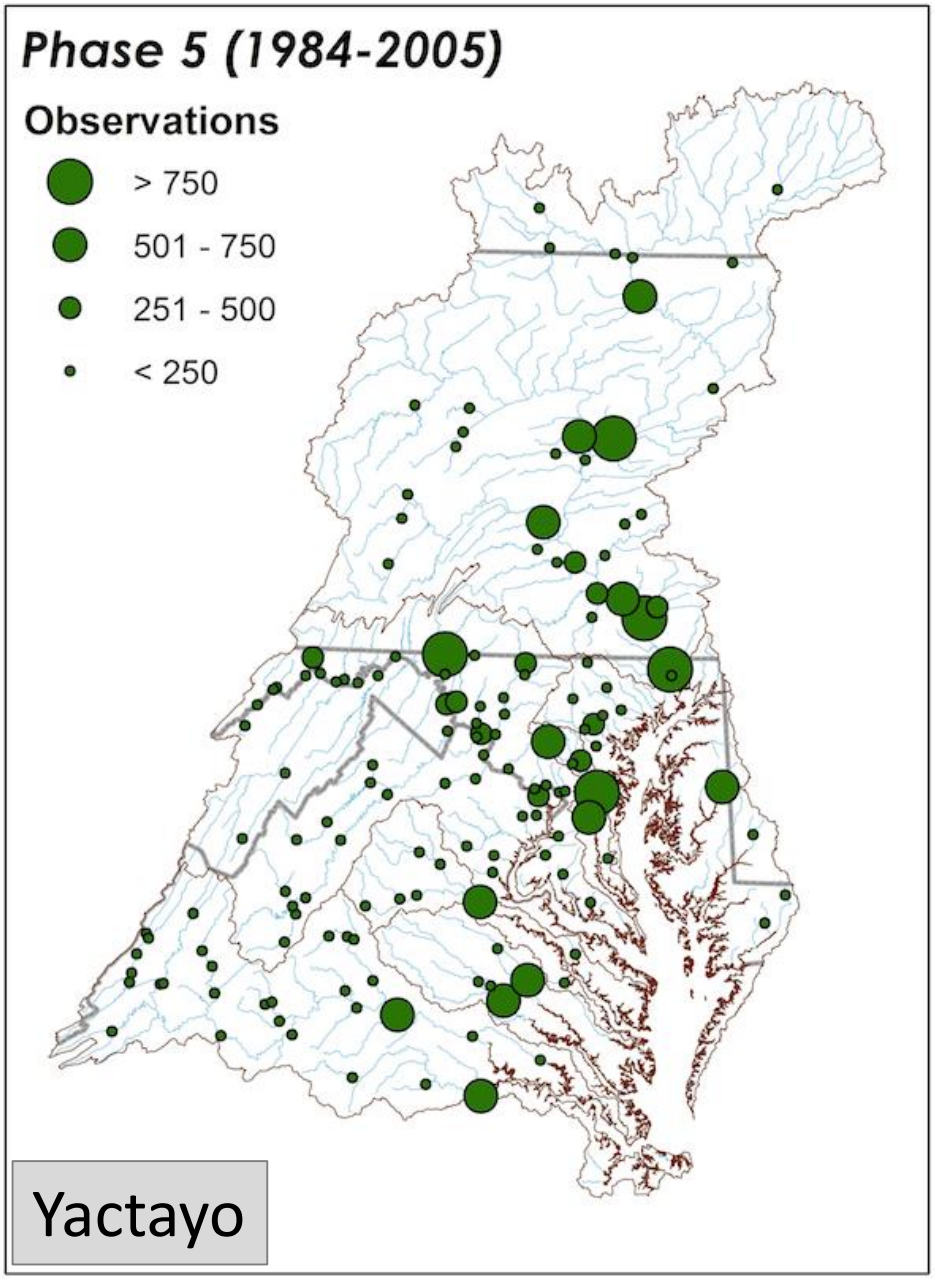


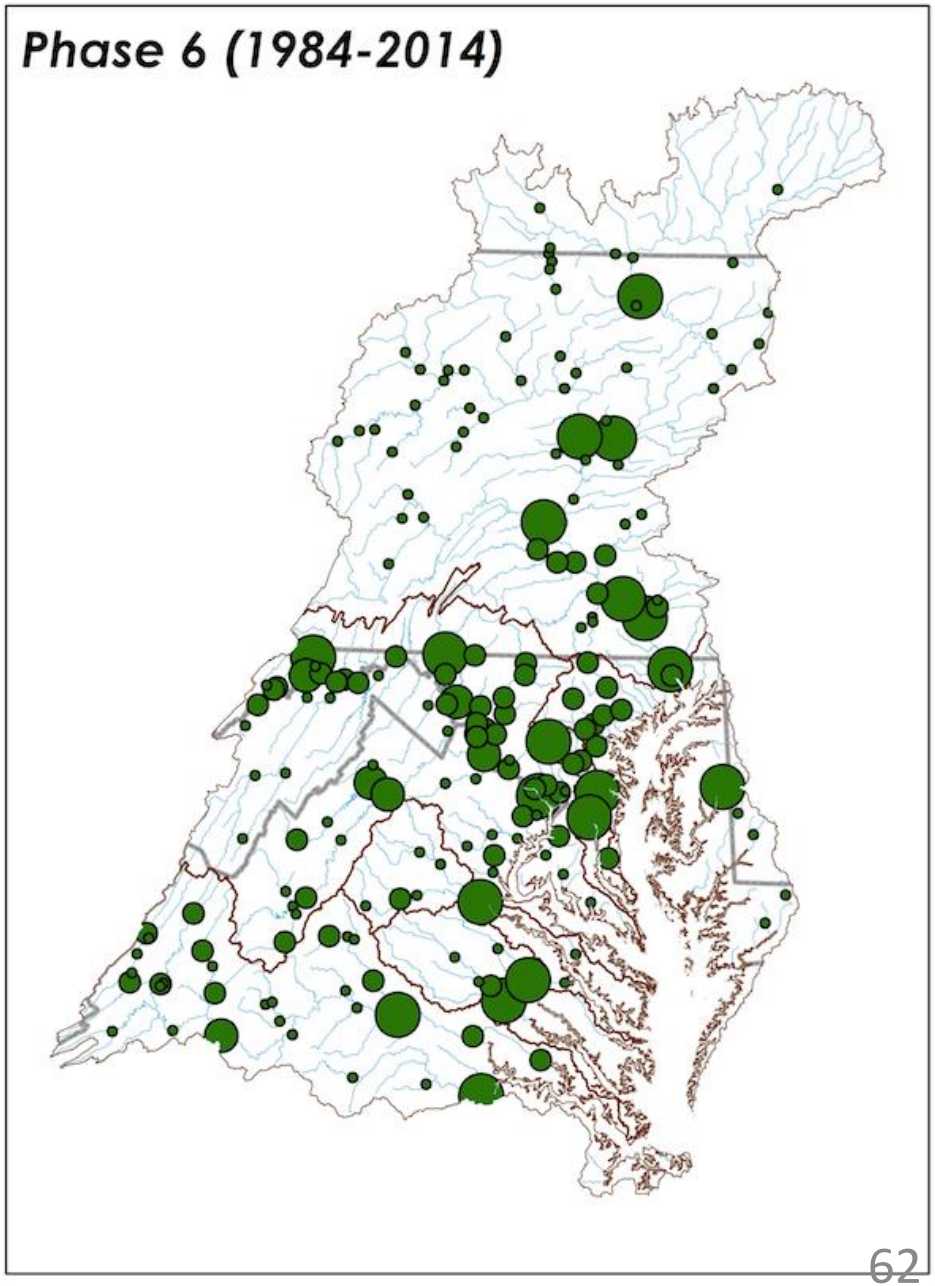


Sum=

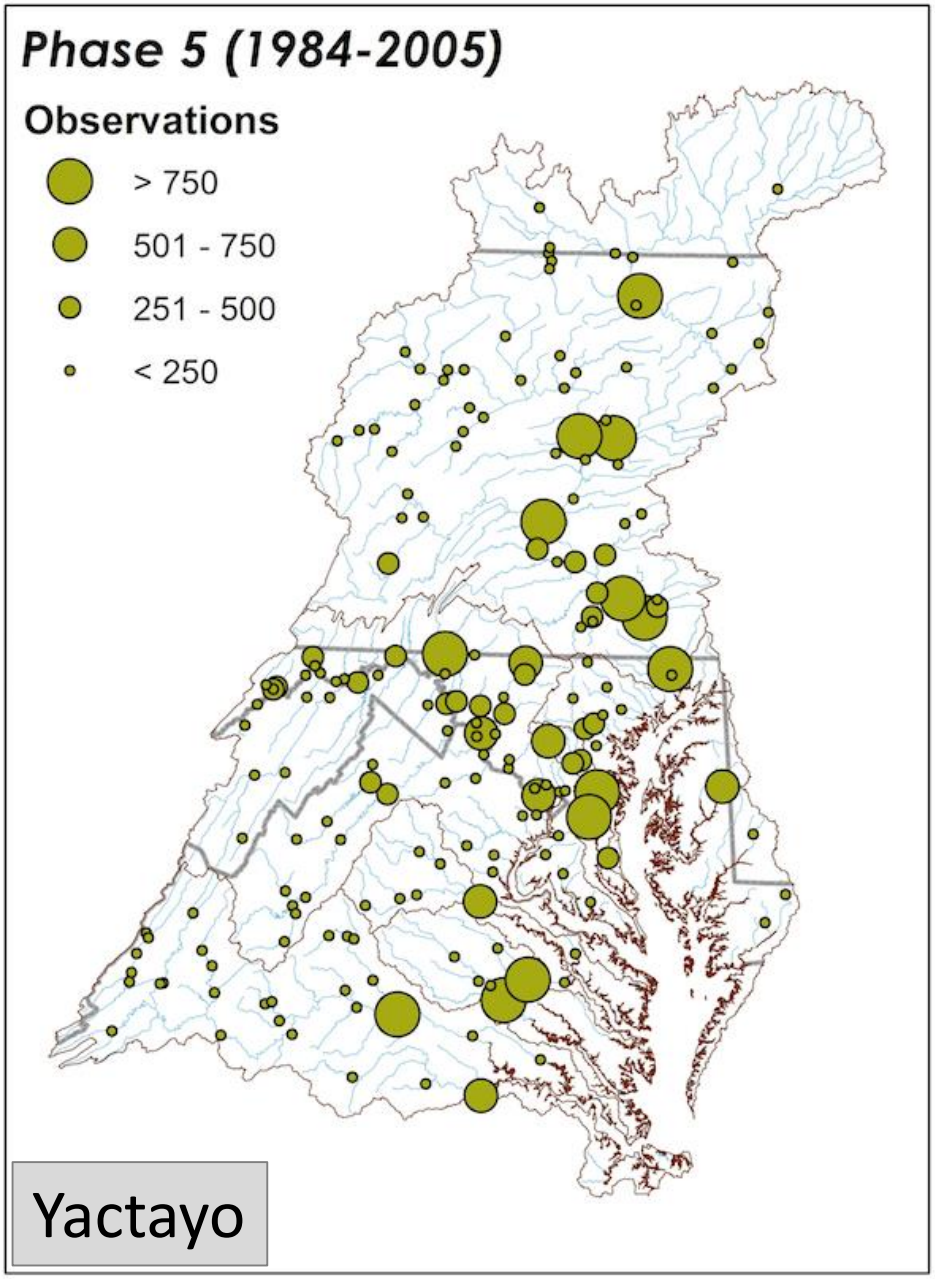
Nutrient Submodels

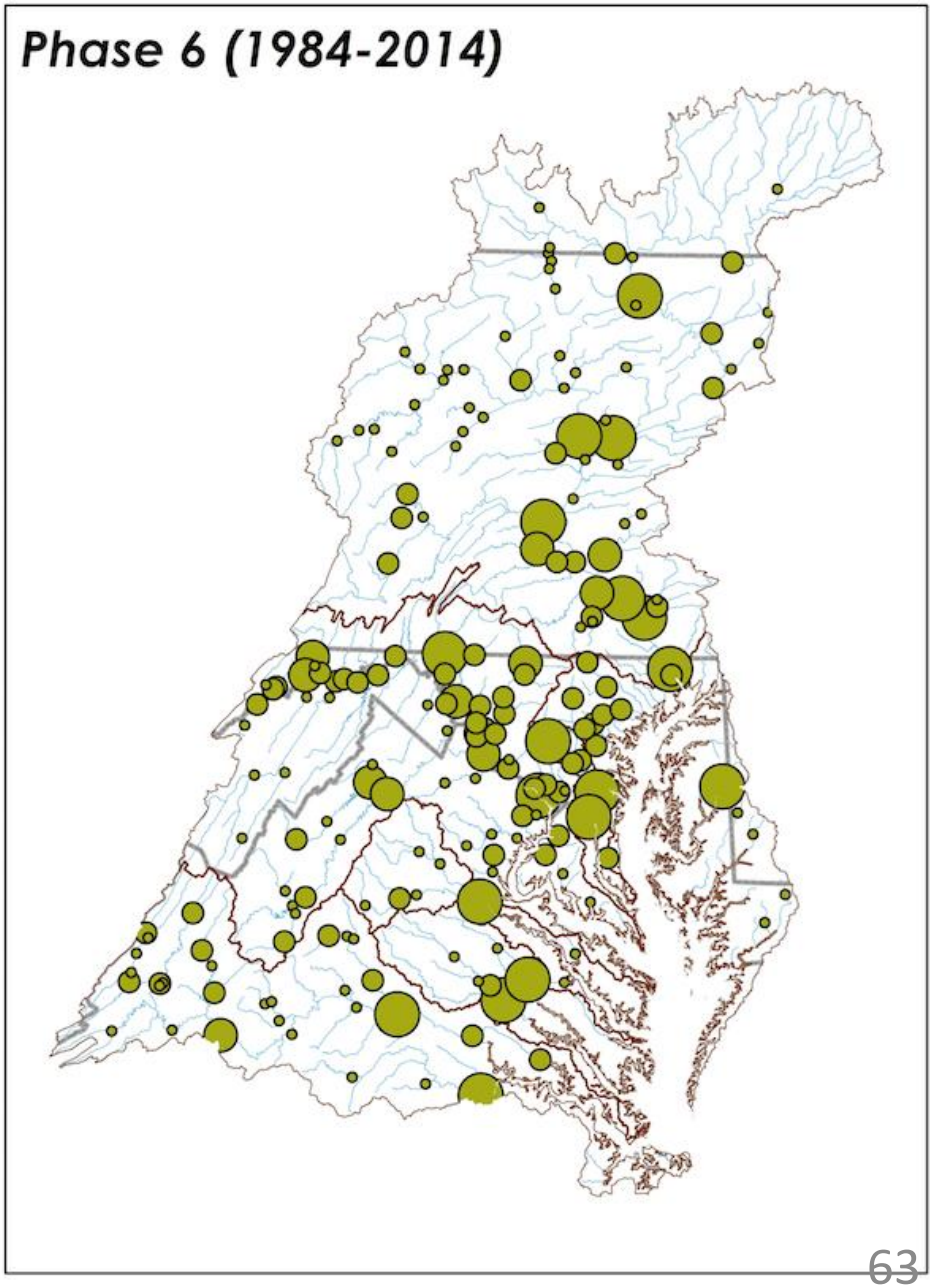
Observed Total Nitrogen - Number of Observations





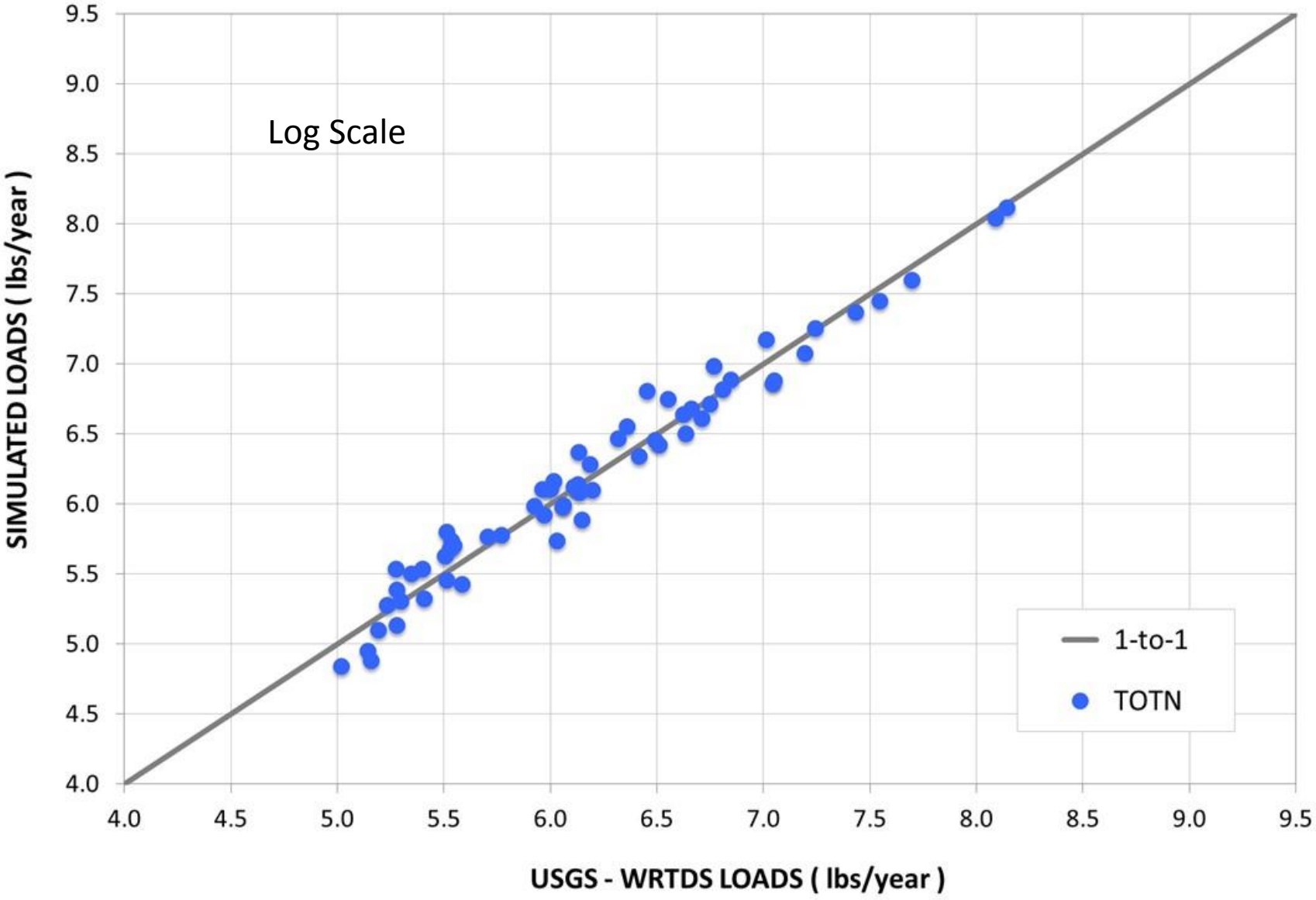
Observed Total Phosphorus - Number of Observations





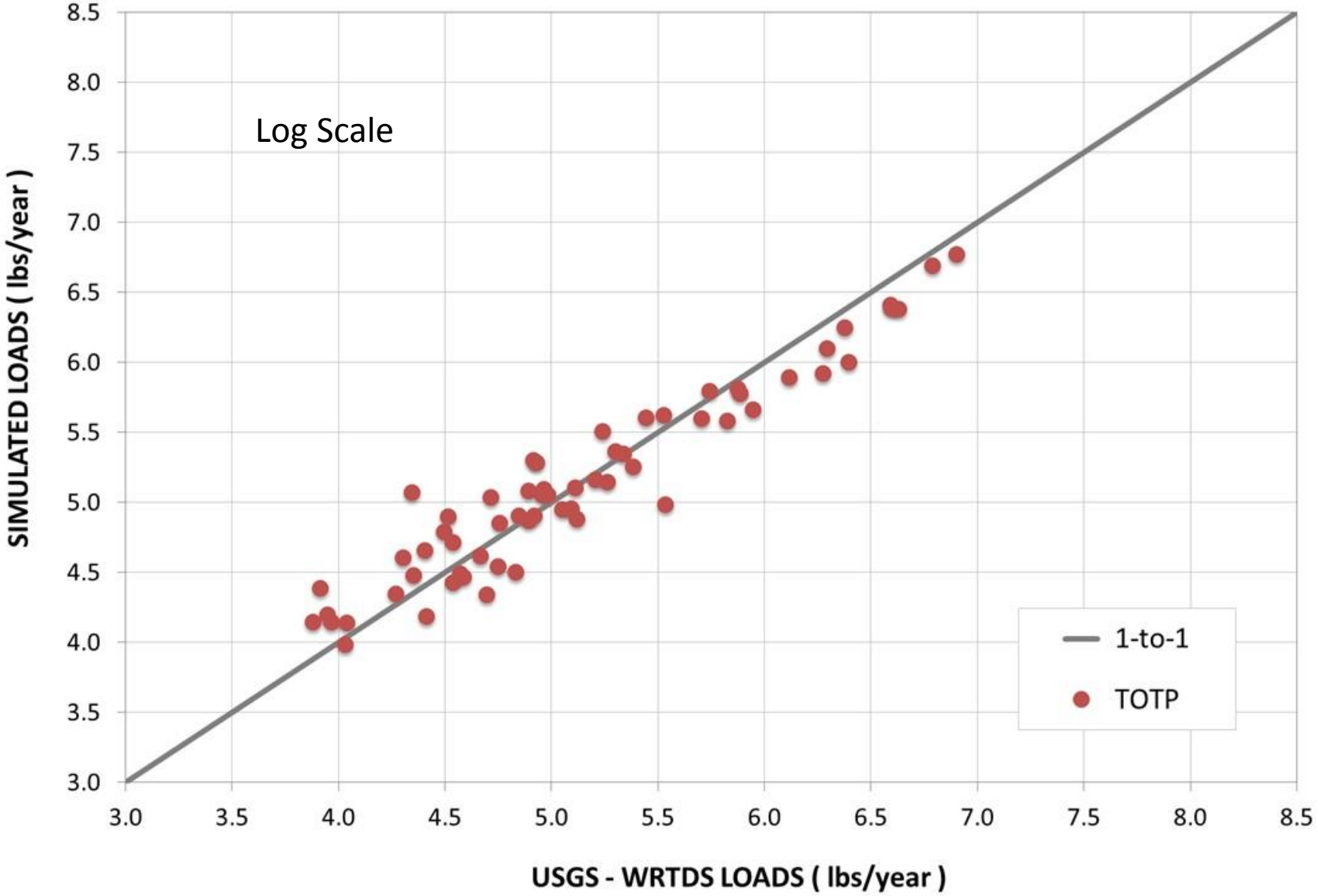
PHASE 6

NITROGEN



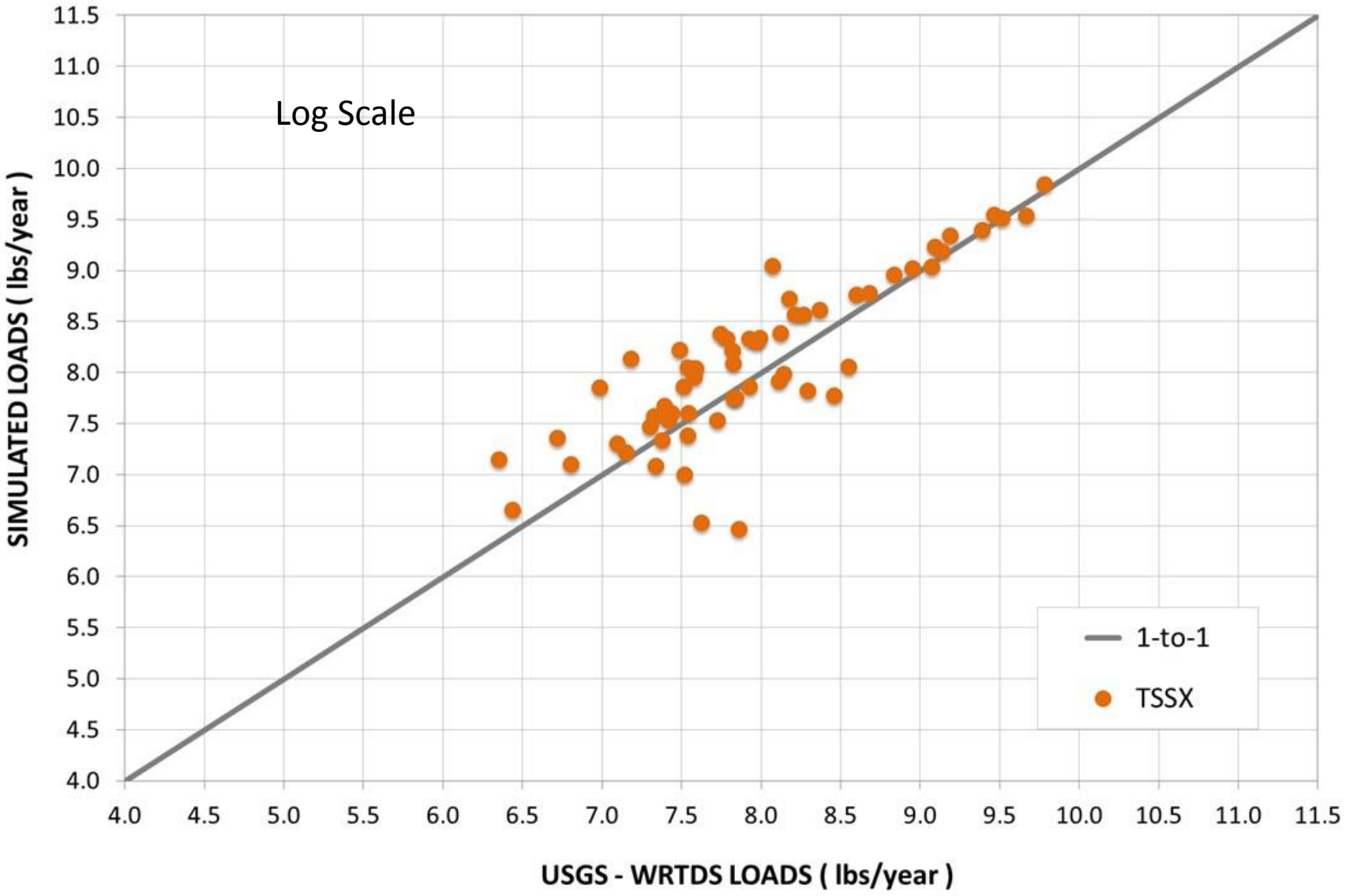
PHASE 6

PHOSPHORUS

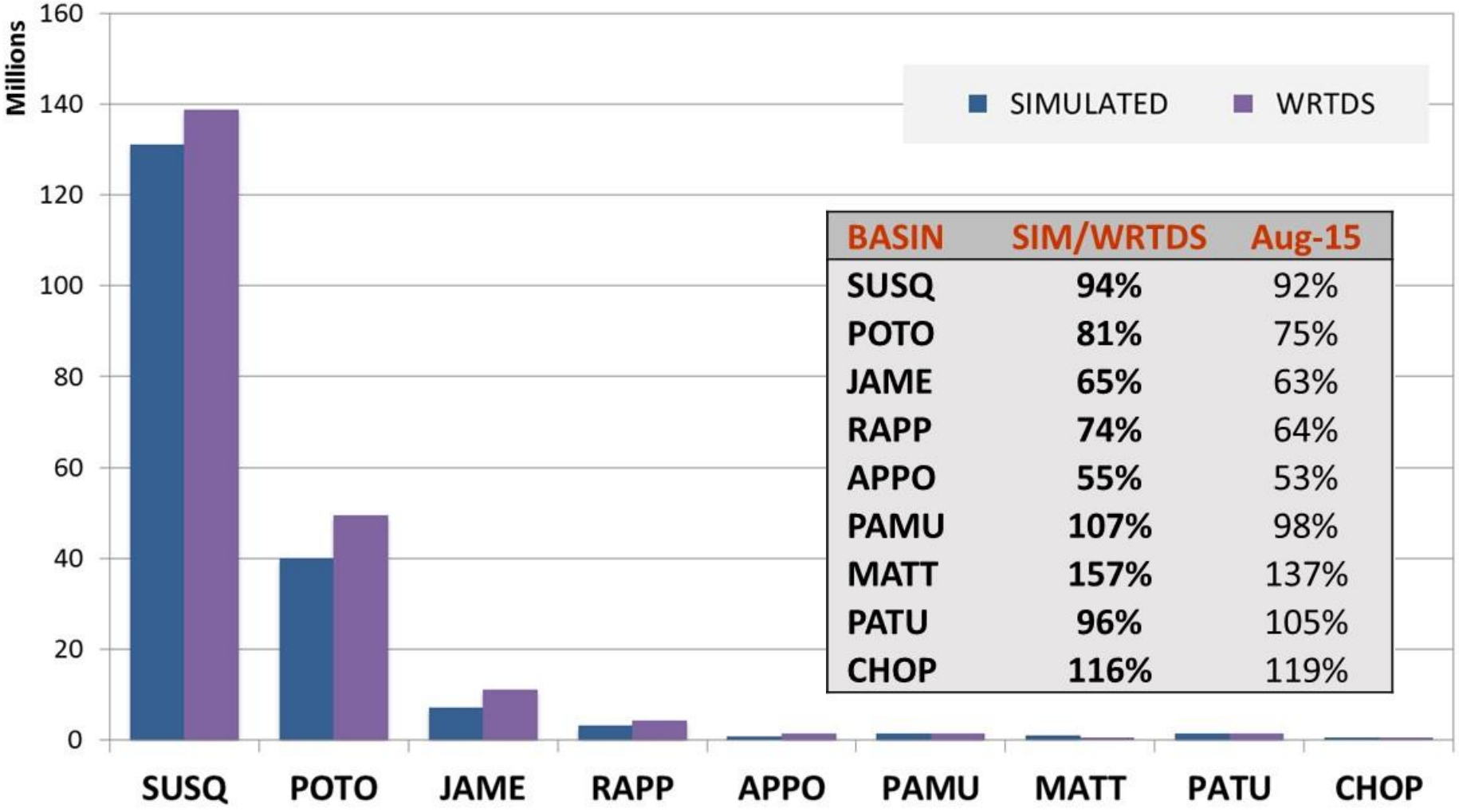


PHASE 6

SEDIMENT

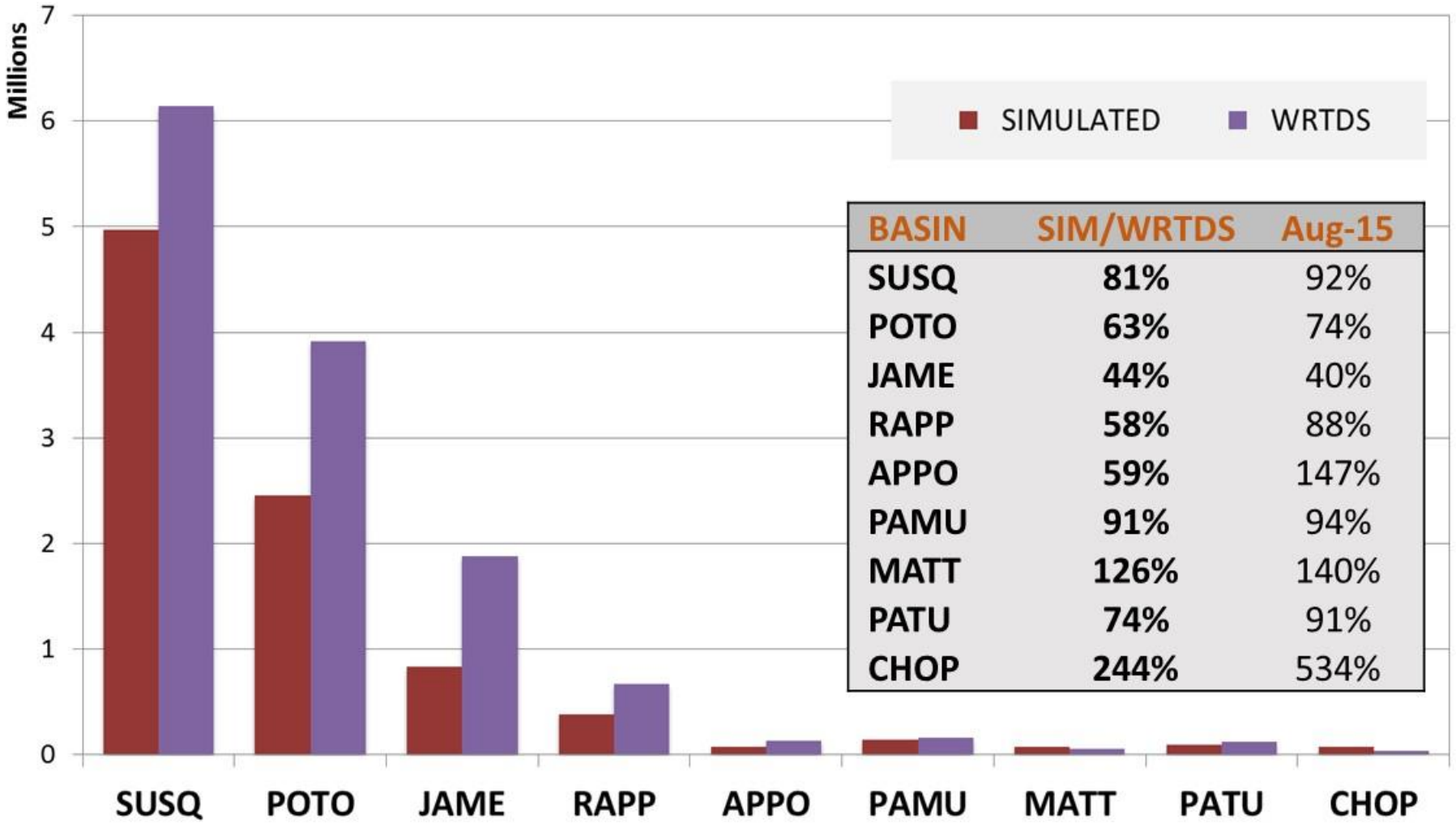


Total **Nitrogen** at RIM Stations



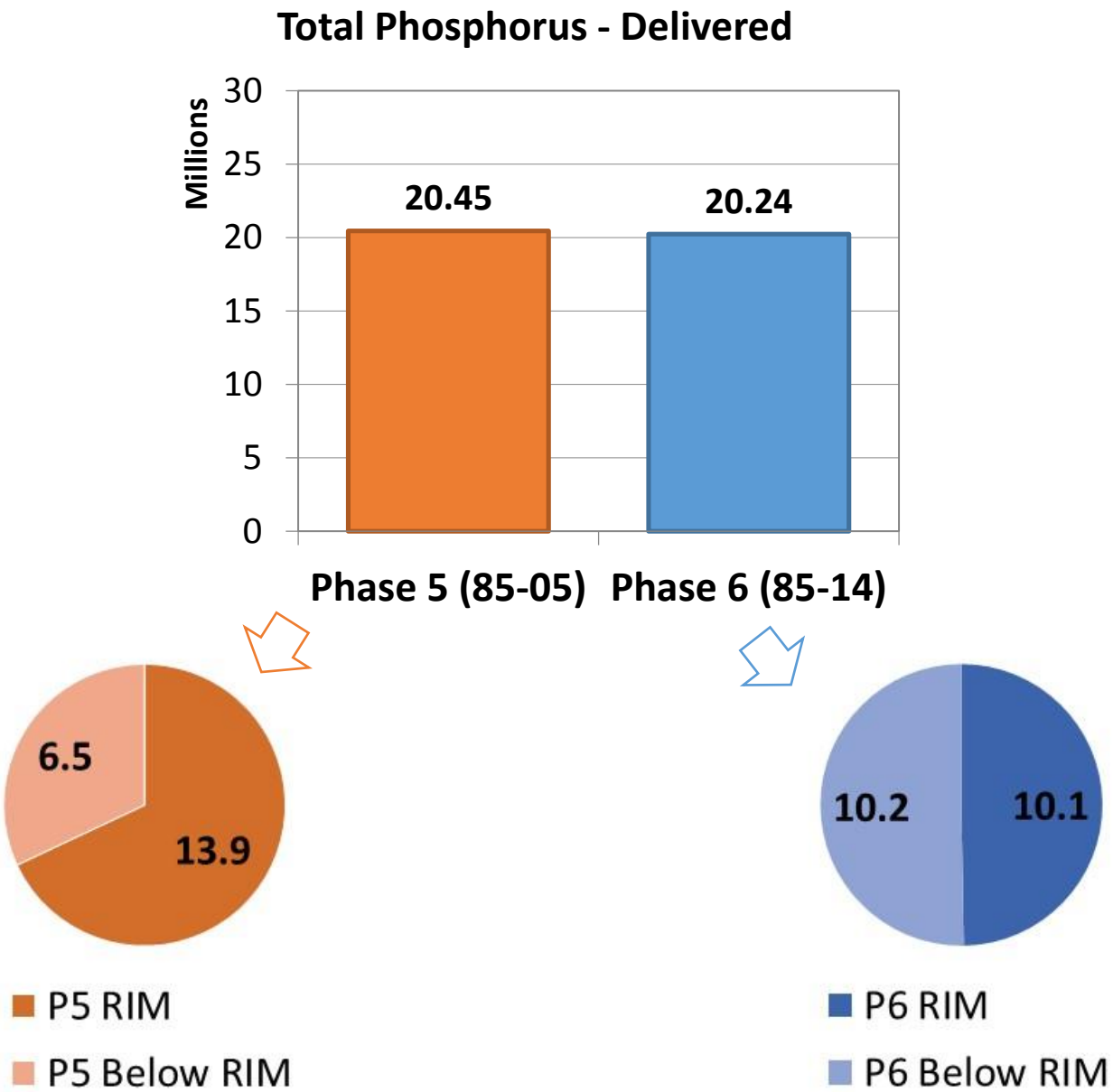
BASIN	SIM/WRTDS	Aug-15
SUSQ	94%	92%
POTO	81%	75%
JAME	65%	63%
RAPP	74%	64%
APPO	55%	53%
PAMU	107%	98%
MATT	157%	137%
PATU	96%	105%
CHOP	116%	119%

Total **Phosphorus** at RIM Stations



BASIN	SIM/WRTDS	Aug-15
SUSQ	81%	92%
POTO	63%	74%
JAME	44%	40%
RAPP	58%	88%
APPO	59%	147%
PAMU	91%	94%
MATT	126%	140%
PATU	74%	91%
CHOP	244%	534%

Phase 6 Beta 1



Beta 2 enhancements

- Average Loads
  - Tree canopy targets
  - Ag P: new APLE runs and distinction between land uses
  - Based on monitored load rather than total load
  - New RUSLE2 estimates
- Inputs – Updates for new coefficients
- Sensitivity – Limited change
- Land Use
  - removal of tree canopy over shrub scrub
- BMPs – Limited Change
- Land to Water
  - Sediment Interconnectivity Factors
- Direct Inputs – Limited Change
- Stream Delivery
  - Incorporation of sparrow reservoirs
  - Stream Mass Balances for sediment
- River Delivery
  - Better representation of high flow events
  - Improved representation of sediment and nutrient processes
  - Improved river calibration method

An approach to review the WSM……

- Read section 1 of the documentation to understand the overall structure
  - Determine the sections in the documentation that are most relevant to your work or interest in the Chesapeake Bay Program partnership.
- Review sections of interest to comment on
  - Quality of documentation
  - Overall concept used to calculate model values
  - Calculation methods used to determine model values
  - Data used
  - Long-term suggestions for future models.
- Review the calibration relative to concentrations and loads
  - Summary flow statistics
  - Summary of agreement between WRTDS and Phase 6 overall
  - Review particular stations of interest to your jurisdiction.
- Review scenarios
  - Broad Scale – Relative ranking of scenarios
  - The aggregate effect of BMPs
  - The effects of inputs, such as land use, animal numbers, etc.

Evaluation Focus – Model Performance

- Is the model simulating the processes correctly?
- Is the model performing reasonably with respect to observations?
  - RIM stations, large watersheds to smaller
  - Annual loads
  - Seasonal performance
  - B1 vs. P5, B2 vs. B1, B3 vs. B2…..
- Model trends vs observed trends
- How is the model performing in management scenarios?
  - Are BMPs reducing loads? sounds simple, but important
  - Do the ordinal ranking of scenarios make sense?
- Temperance, not perfect but reasonable

Review Structure/Schedule

- Modeling leadership has a plan, to be presented to MWG today and to WQGIT leadership tomorrow
- Multiple phases through this year, concurrent w/ beta releases
- At each phase:
  - Webinar w/focus on model performance improvement
  - Documentation update
  - Comment due date
- Comprehensive comment tracking
- More to come soon