Structure and development of CalCAST – Nitrogen and Phosphorus

Isabella Bertani, Gopal Bhatt, Gary Shenk, Lewis Linker

Modeling Workgroup Quarterly Review
10/04/2022

JULY QUARTERLY RECAP

What is CalCAST?

- Relatively parsimonious, spatially explicit, largely data-driven watershed modeling tool calibrated in a statistical framework

- Currently represents > 80,000 National Hydrography Dataset Plus (NHDPlus) catchments within the Bay watershed and leverages data from > 400 USGS monitoring stations for calibration

- Currently time-averaged (but may be extended to predict at the annual time step in the future)

- Currently predicts long-term average streamflow and sediment at NHDPlus catchments

JULY QUARTERLY RECAP

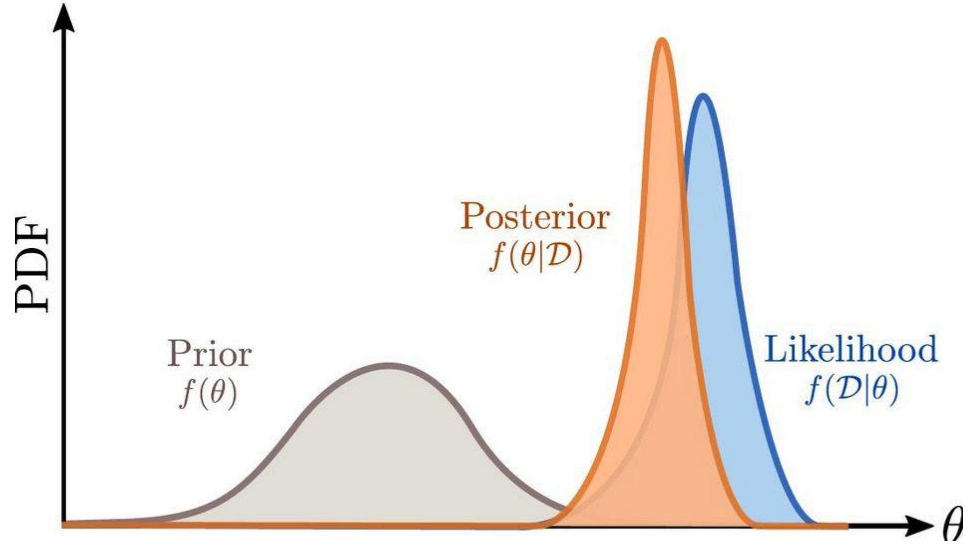
Why CalCAST?

- Primarily used as spatial calibration tool
- Main purpose: probabilistically test hypotheses on factors related to spatial variation in contaminant loads and quantify parameters that describe such relationships
- Spatial parameters estimated by CalCAST will inform CAST and the dynamic model
- Incorporate data-driven line of evidence into modeling approach

JULY QUARTERLY RECAP

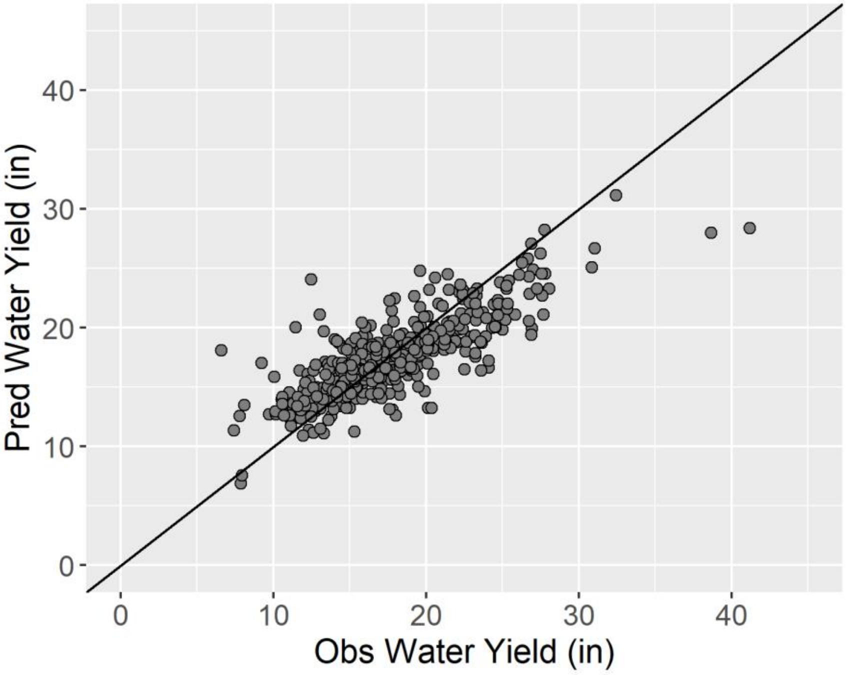
Plan for this year

- Implement Bayesian calibration framework
- Get the code infrastructure up and running
- Get "*on the graph*" results for hydrology, sediment, and nutrients

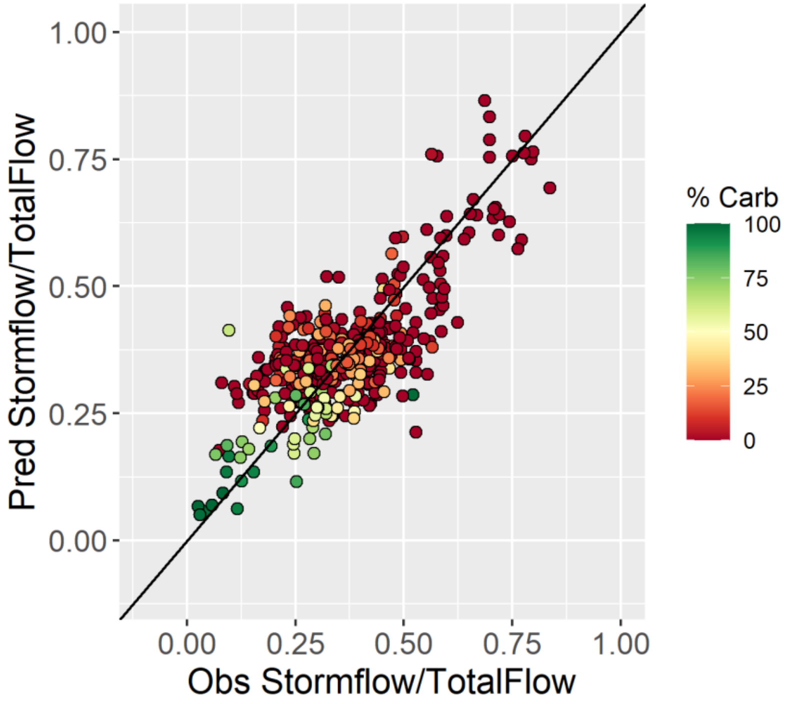


Hydrology – Observed vs. Predicted

Total Flow



Stormflow/Total Flow

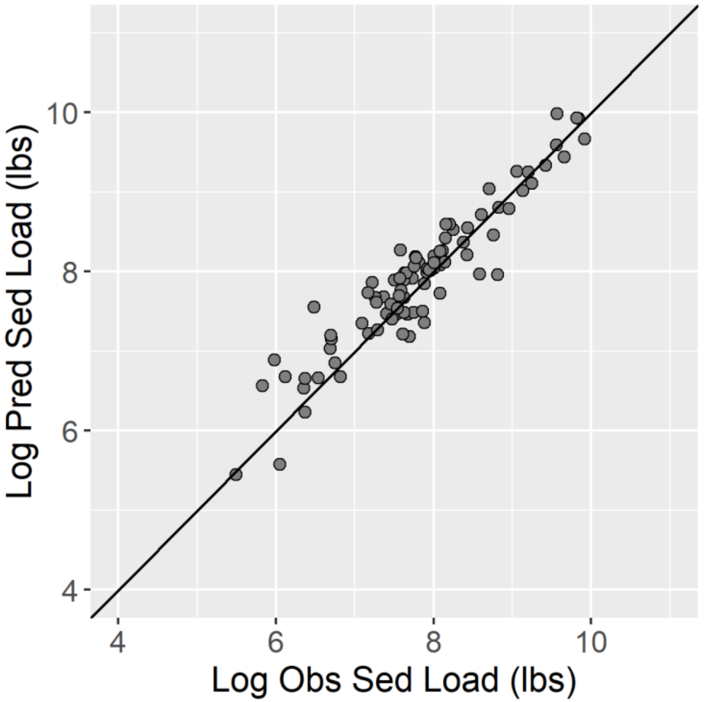


«On the graph»

JULY QUARTERLY RECAP

Sediment – Observed vs. Predicted

Sediment load

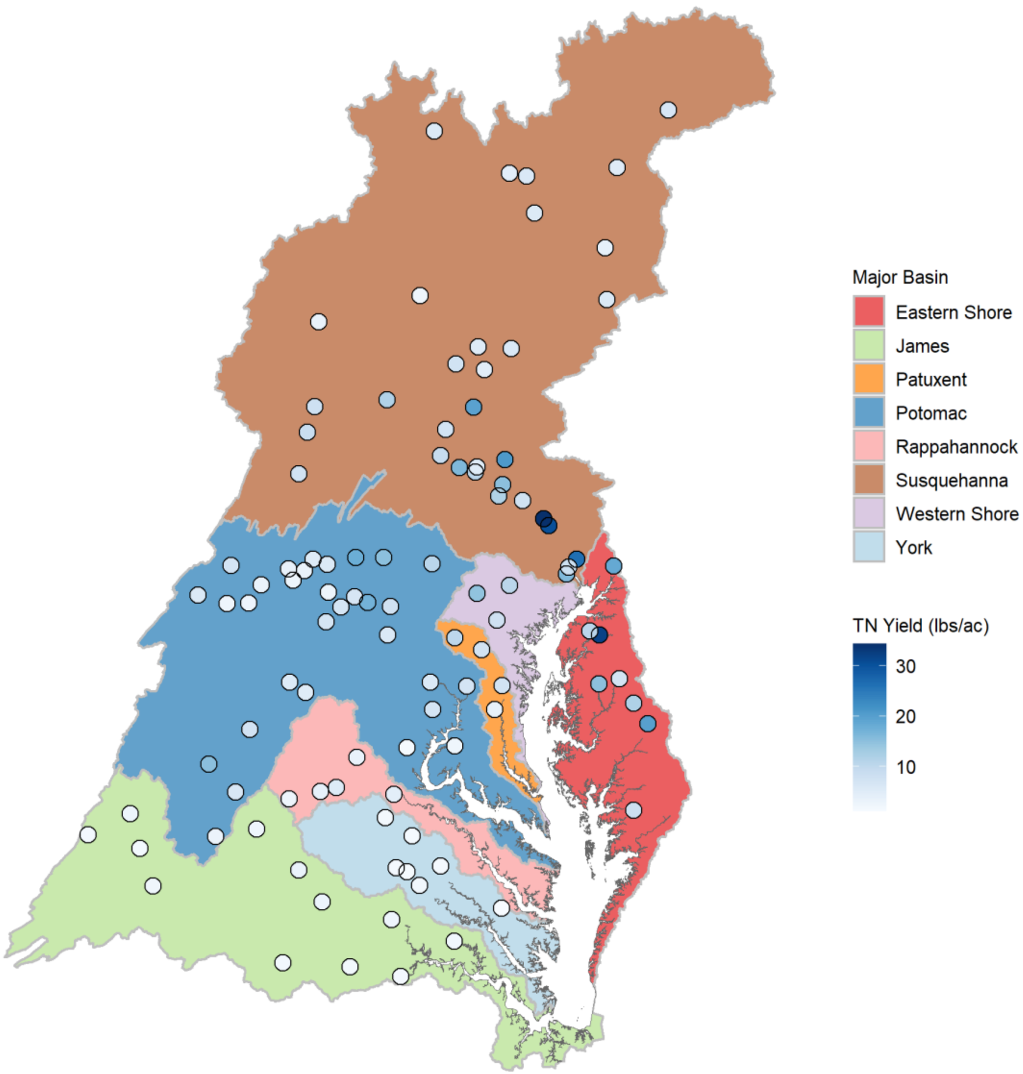


Sediment yield

Definitely not great, but «On the graph»

Nitrogen

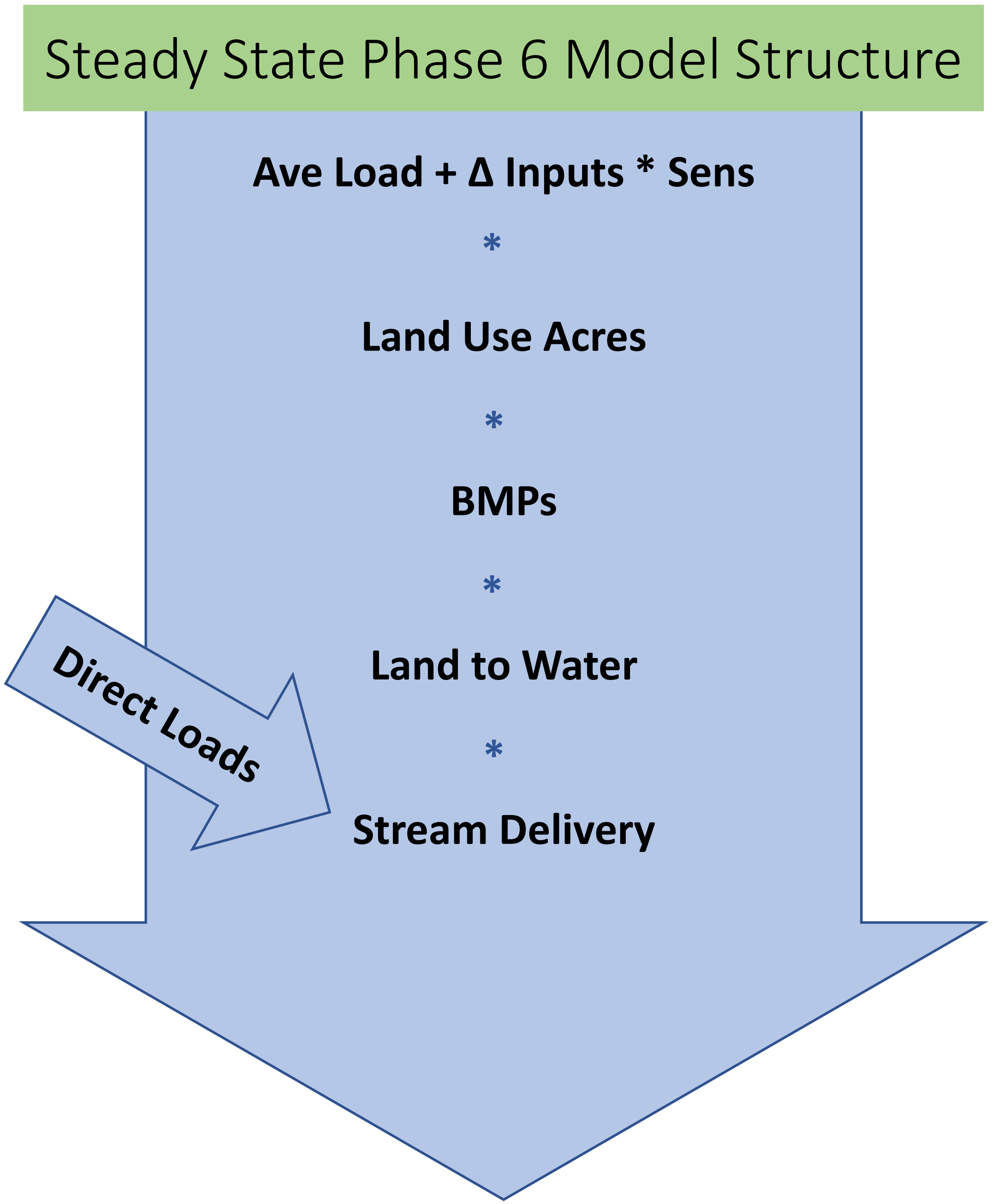
Calibration stations - TN



- Calibration target:

  WRTDS flow-normalized total nitrogen load estimated at non-tidal network stations

Implementing P6 at NHDPlus scale in CalCAST

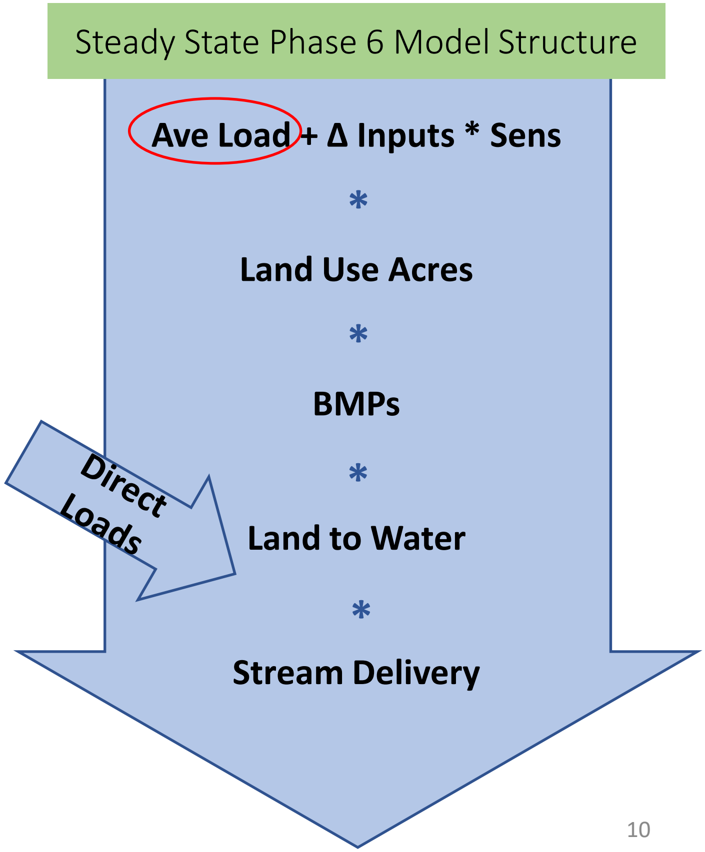


Watershed-wide average land use loading rates

- 11 CalCAST land uses grouped into 4 broad classes. Each class has an «anchor land use» (in bold):

Land Class	Land uses in Class
Cropland	**CRP**
Pasture	**PAS**
Developed	**IR**, INR, TCI, TCT, TG
Natural	**FOR**, MO, WLF, WLO

INR: Impervious Non-Roads
IR = Impervious Roads
TCI = Tree Canopy over Impervious
TCT = Tree Canopy over Turfgrass
TG = Turfgrass
FOR = Forest
MO = Mixed Open
WLF = Floodplain Wetlands
WLO = Other Wetlands



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- Each land use's watershed-wide average loading rate (lbs/ac) estimated as:

$$\mathbf{Ave}_l = \mathbf{CLR} \times \mathbf{RC}_{\mathbf{cl}_l} \times \mathbf{RL}_l$$

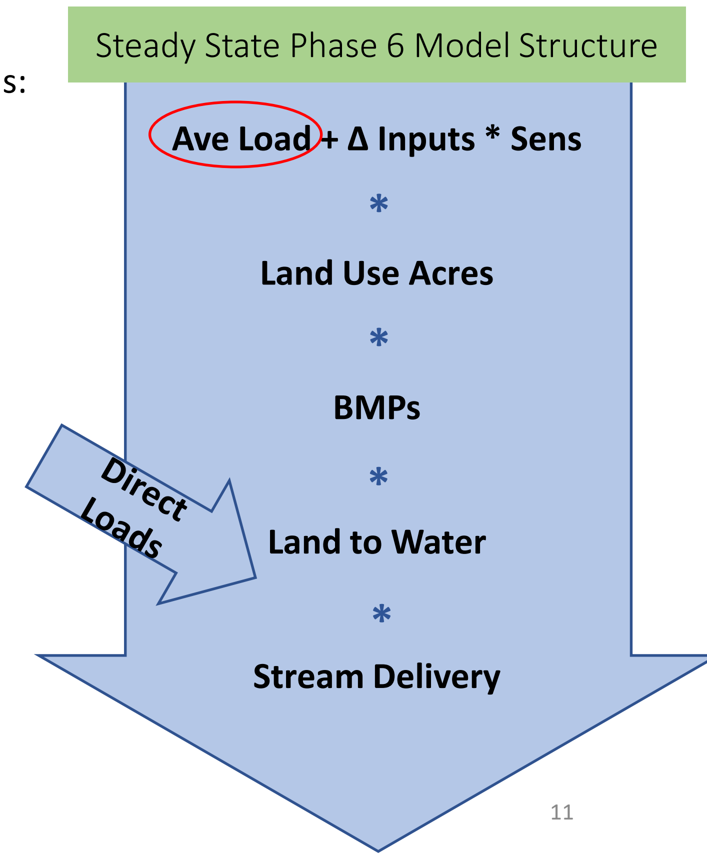
CLR = Loading rate of Cropland class. Set to **38 lbs/ac** for now for TN and **1.87 lbs/ac** for TP (P6 estimates), can be estimated by CalCAST if desired.

RC_{cl} = Ratio of average loading rate of land class *cl* to Cropland loading rate. Estimated by CalCAST, with priors centered around P6 values, e.g.:

RCpas ~ Normal(0.29,1)

RL_l = Ratio of average loading rate of land use *l* in class *cl* to loading rate of anchor land use in class *cl*. Estimated by CalCAST, with priors centered around P6 values, e.g.:

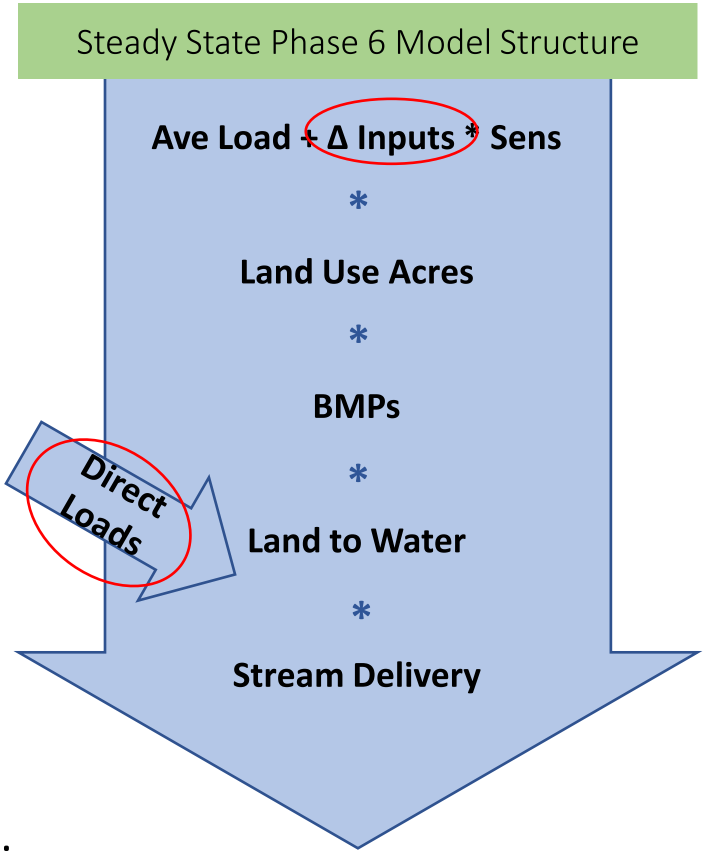
RLtg ~ Normal(0.5,1)



Inputs - TN

The following P6 inputs were downscaled from CAST county scale and land uses to NHDPlus catchment scale and CalCAST land uses (thank you **Jess Rigelman** and **Olivia Devereux**!):

Atmospheric Deposition (on land and water bodies*)
Biosolids
Crop Cover
Fertilizer
Manure
Riparian Pasture Deposition*
Nitrogen fixation
Rapid Infiltration Basins*
Septic*
Plant Uptake
Feeding Space*
Wastewater*
CSO*



* Treated as direct loads

For details on downscaling methods, ask questions or see:
https://www.sciencebase.gov/catalog/item/60be31b3d34e86b938910b2f

Sensitivities

Sensitivity: change in edge-of-stream load per change in unit of input

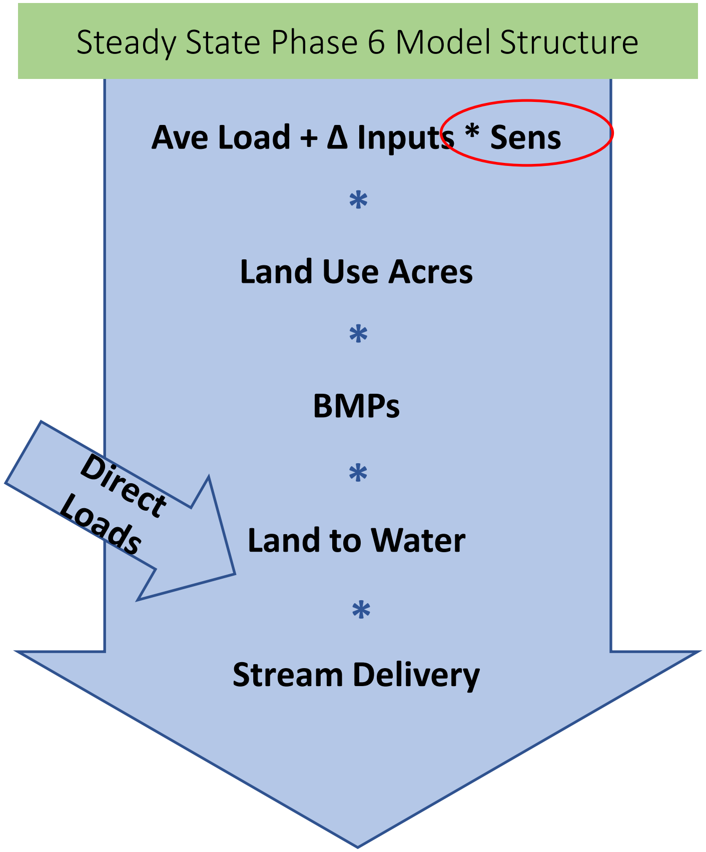
For now, sensitivities are set to P6 values rather than estimated in CalCAST. We can let CalCAST estimate sensitivities in the future, e.g., as follows:

$$\text{Sens}_{i,l} = \text{Sens}_{i,cl_l} \times RL_l$$

$\textbf{Sens}_{i,l}$ = Sensitivity to input *i* on land use *l*

$\textbf{Sens}_{i,cl}$ = Sensitivity to input *i* on anchor land use in class *cl*

$\textbf{RL}_l$ = Ratio of average loading rate of land use *l* in class *cl* relative to loading rate of anchor land use in class *cl*



Land to Water - TN

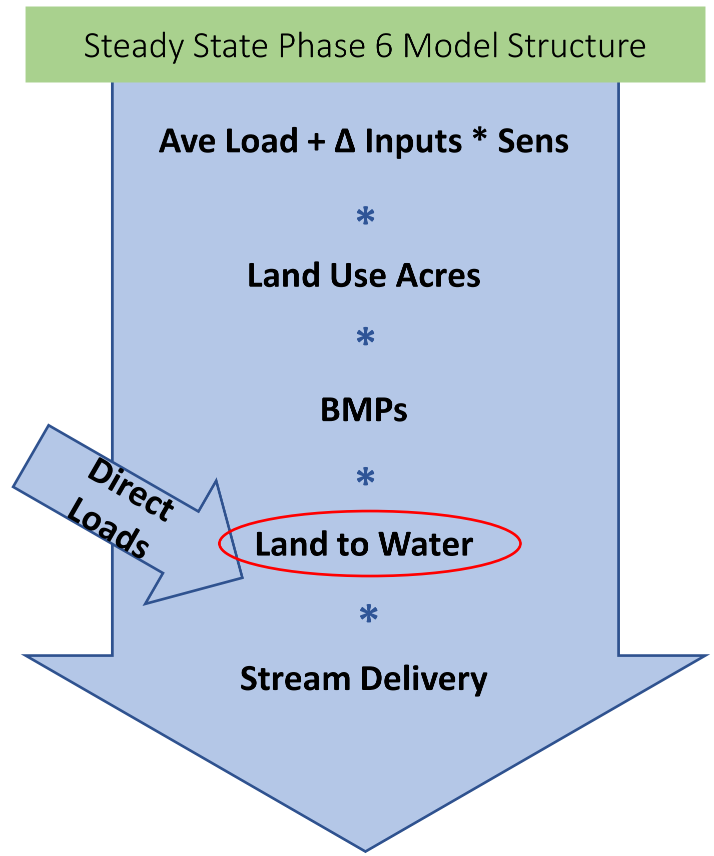
For now, same Land To Water structure as in P6, based on SPARROW variables and coefficients. Other variables/watershed properties will be tested in CalCAST next year.

Table 7-2: Estimated Coefficients and Statistics from SPARROW Nitrogen Model of the Chesapeake Bay Watershed, Version 4

Variable	Estimate	90% Confidence Interval	Standard Error	P-value
Sources				
Point sources (kg yr^{-1})	0.774	0.375 – 1.17	0.242	0.0008
Crop fertilizer and fixation (kg yr^{-1})	0.237	0.177 – 0.297	0.0363	< 0.0001
Manure (kg yr^{-1})	0.0582	0.0138 – 0.103	0.0269	0.0157
Atmospheric deposition (kg yr^{-1})	0.267	0.179 – 0.355	0.0533	< 0.0001
Urban2 (km^2)	1090	707 – 1480	234	< 0.0001
Land-to-Water Delivery				
ln[Mean EVI for WY02 (dimensionless)]	-1.7	-2.65 – -0.737	0.58	0.0039
ln[Mean soil AWC (fraction)]	-0.829	-1.26 – -0.401	0.26	0.0016
ln[Groundwater recharge (mm)]	0.707	0.499 – 0.916	0.126	< 0.0001
ln[Piedmont carbonate (percent of area)]	0.158	0.0755 – 0.241	0.05	0.0018

$$DVF_c = e^{(0.707 * gwrech_c - 0.829 * awc_c + 0.158 * pca_c)}$$

DVF_c = Delivery Variance Factor for catchment c
$gwrech_c$ = groundwater recharge for catchment c
awc_c = soil available water capacity for catchment c
pca_c = % of catchment c in Piedmont carbonate



Stream Delivery - TN

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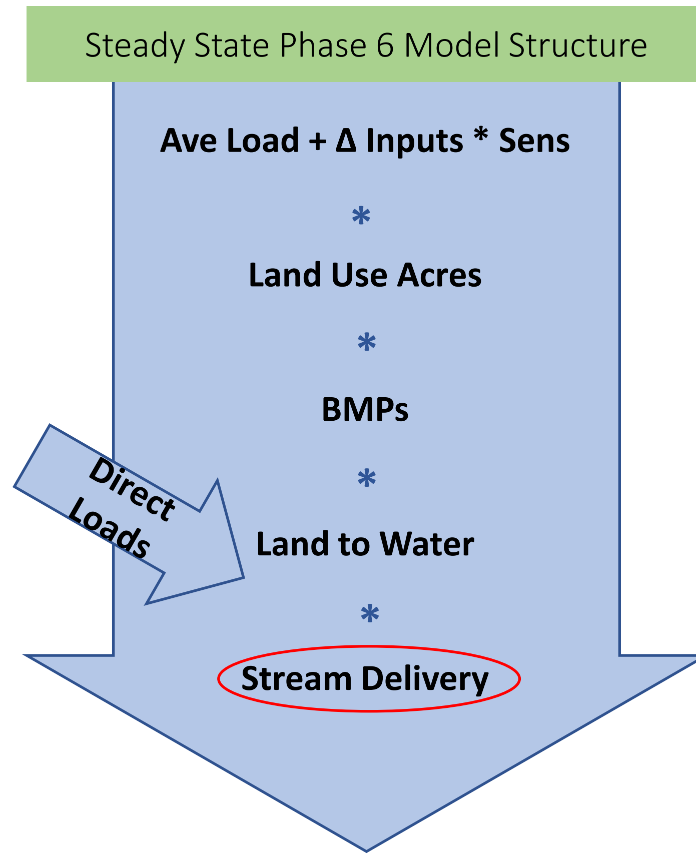
Aquatic Decay				
Impoundments				
Inverse hydraulic load (yr m^{-1})	5.93	0.271 – 11.6	3.42	0.0424
Streams, time of travel (d) MAQ =mean annual flow; T30 = 30 year mean maximum temperature				
Small (MAQ ≤ 3.45 m^3 s^{-1})	0.339	0.0936 – 0.585	0.148	0.0118
Large (MAQ > 3.45 m^3 s^{-1}) T30 > 18.5°C	0.153	0.0622 – 0.245	0.0551	0.003
Large (MAQ > 3.45 m^3 s^{-1}) T30 ≤ 15°C	0.0131	-0.111 – 0.137	0.0751	0.431



Reservoirs: $$Del_c = \frac{1}{1+bres*IHL_c}$$

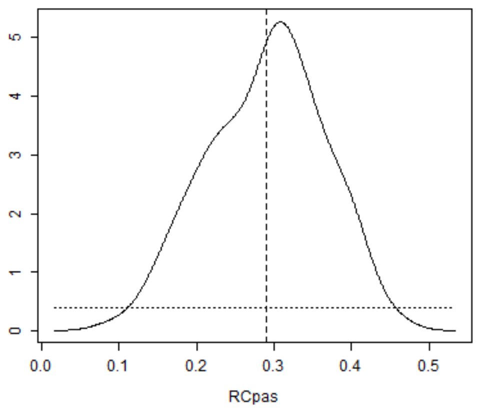
Streams: $$Del_c = e^{-bstr * TT_c}$$

Del_c = Stream/Reservoir delivery factor for catchment c
IHL_c = Inverse Areal Hydraulic Load for reservoir in catchment c
TT_c = Time of Travel for stream reach in catchment c
bres= estimated through CalCAST
bstr = P6 values

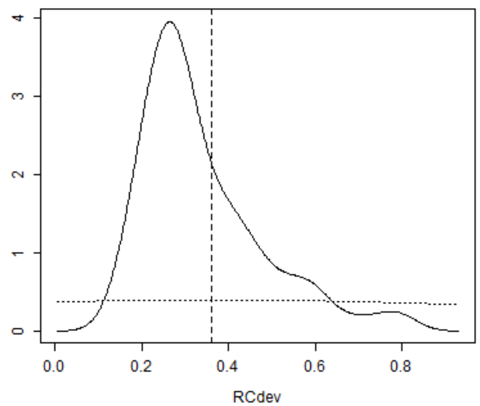
Total Nitrogen – RC estimates

$$\mathbf{Ave}_{l} = \mathbf{CLR} \times \mathbf{RC}_{\mathbf{cl}_{\mathbf{l}}} \times \mathbf{RL}_{\mathbf{l}}$$

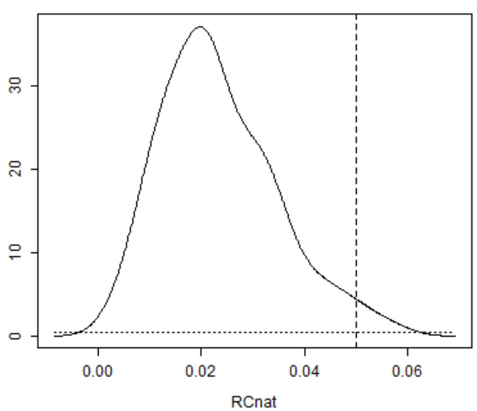
Pasture



Developed



Natural



Solid lines: posterior probability distributions estimating RC_{cl}

Dotted lines: prior probability distributions

Dashed vertical lines: P6 value

Total Nitrogen – RL estimates

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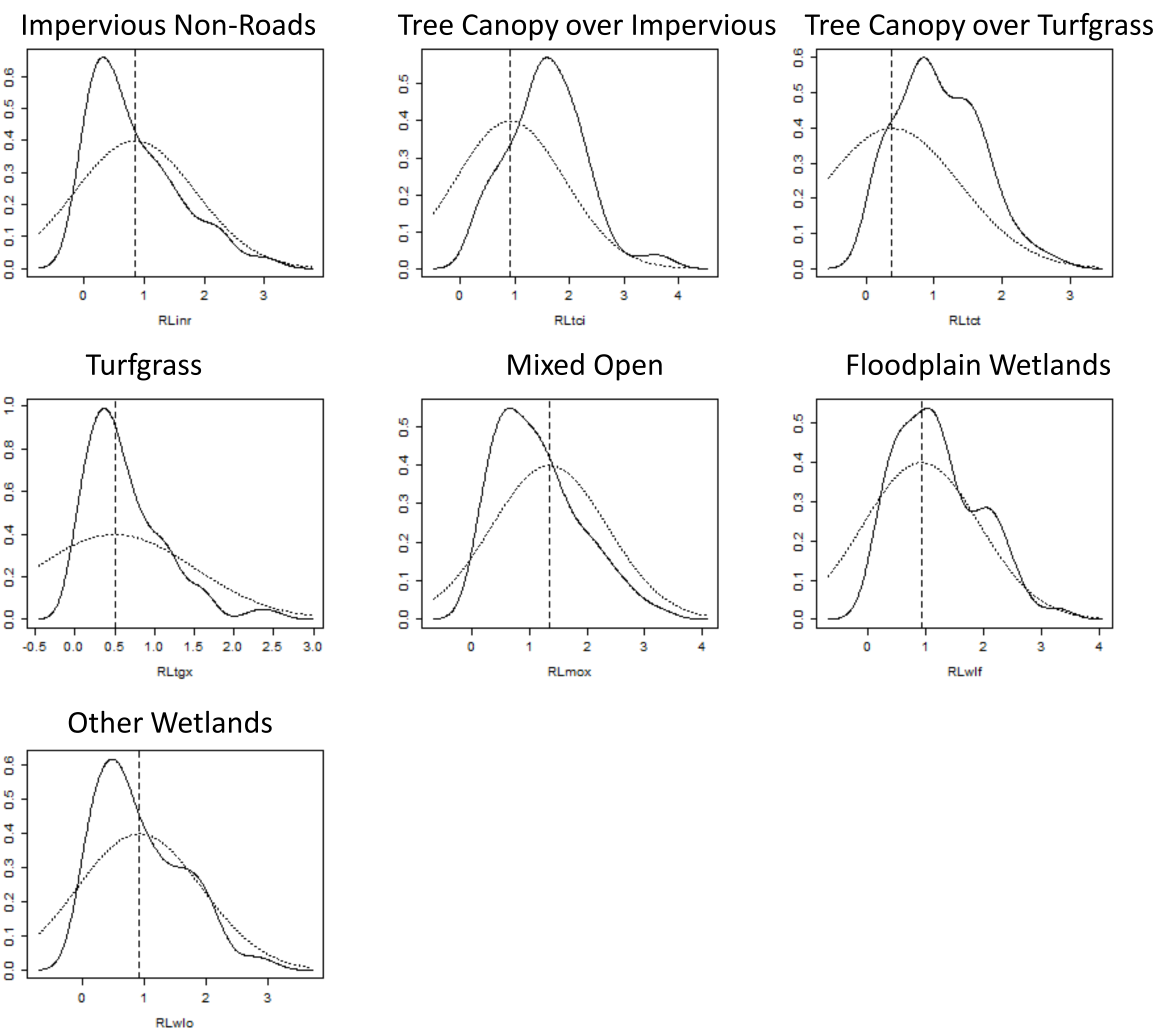


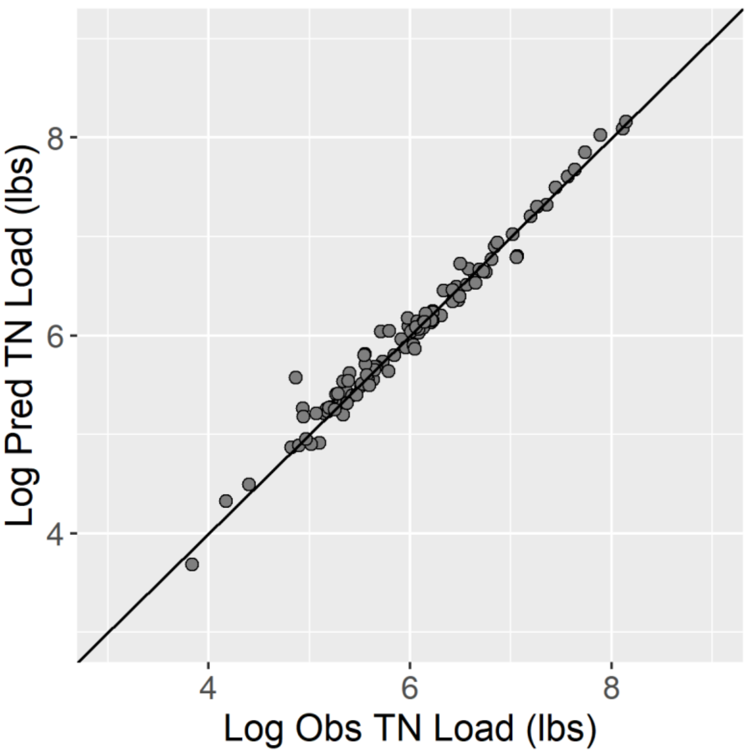
Solid lines: posterior probability distributions estimating RL_l

Dotted lines: prior probability distributions

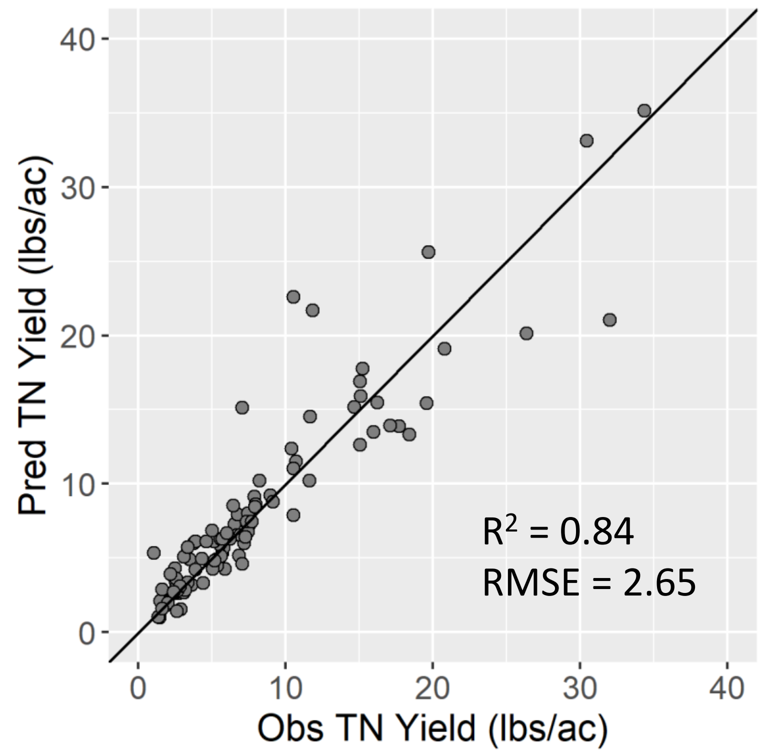
Dashed vertical lines: P6 value

Total Nitrogen – Observed vs. Predicted

TN load



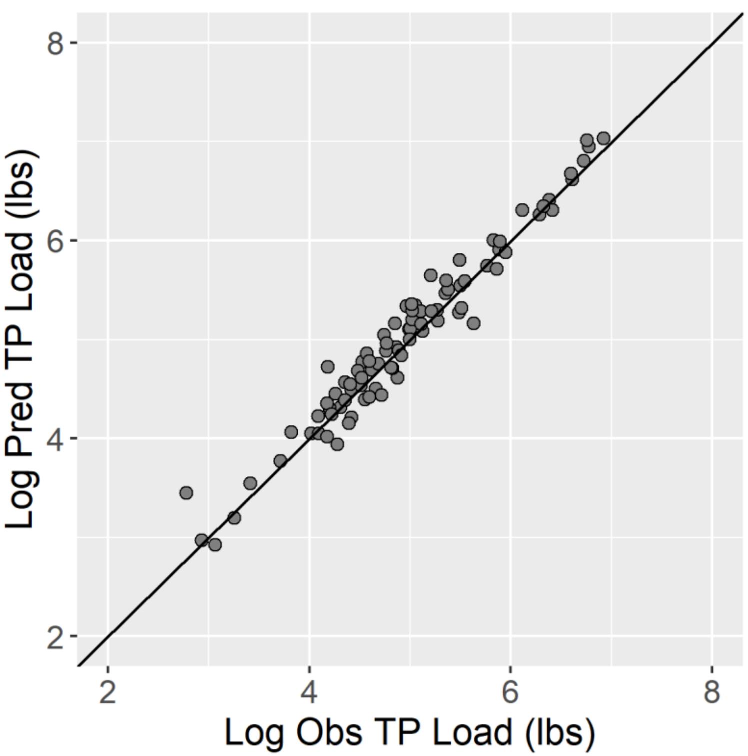
TN yield



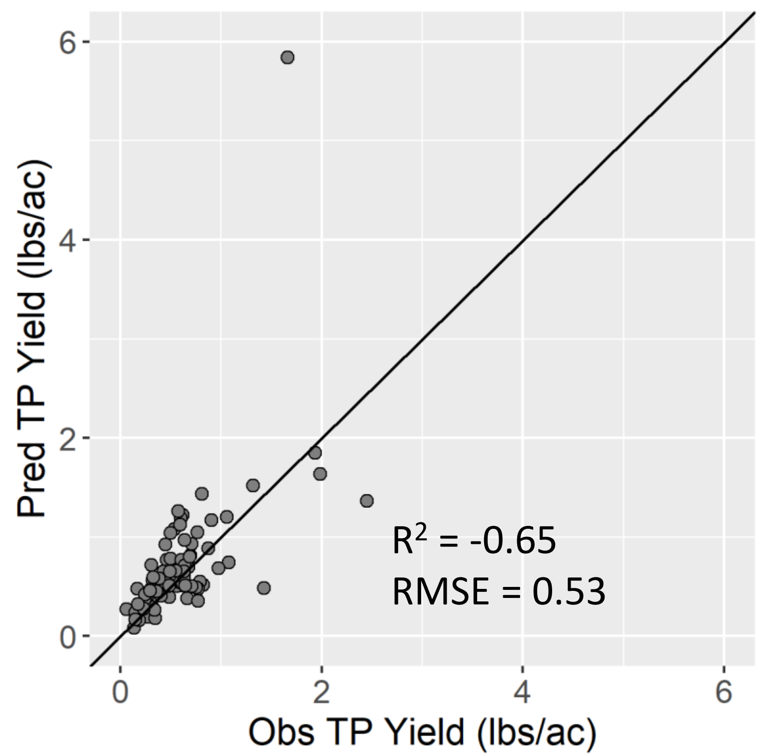
«On the graph»

Total Phosphorus – Observed vs. Predicted

TP load

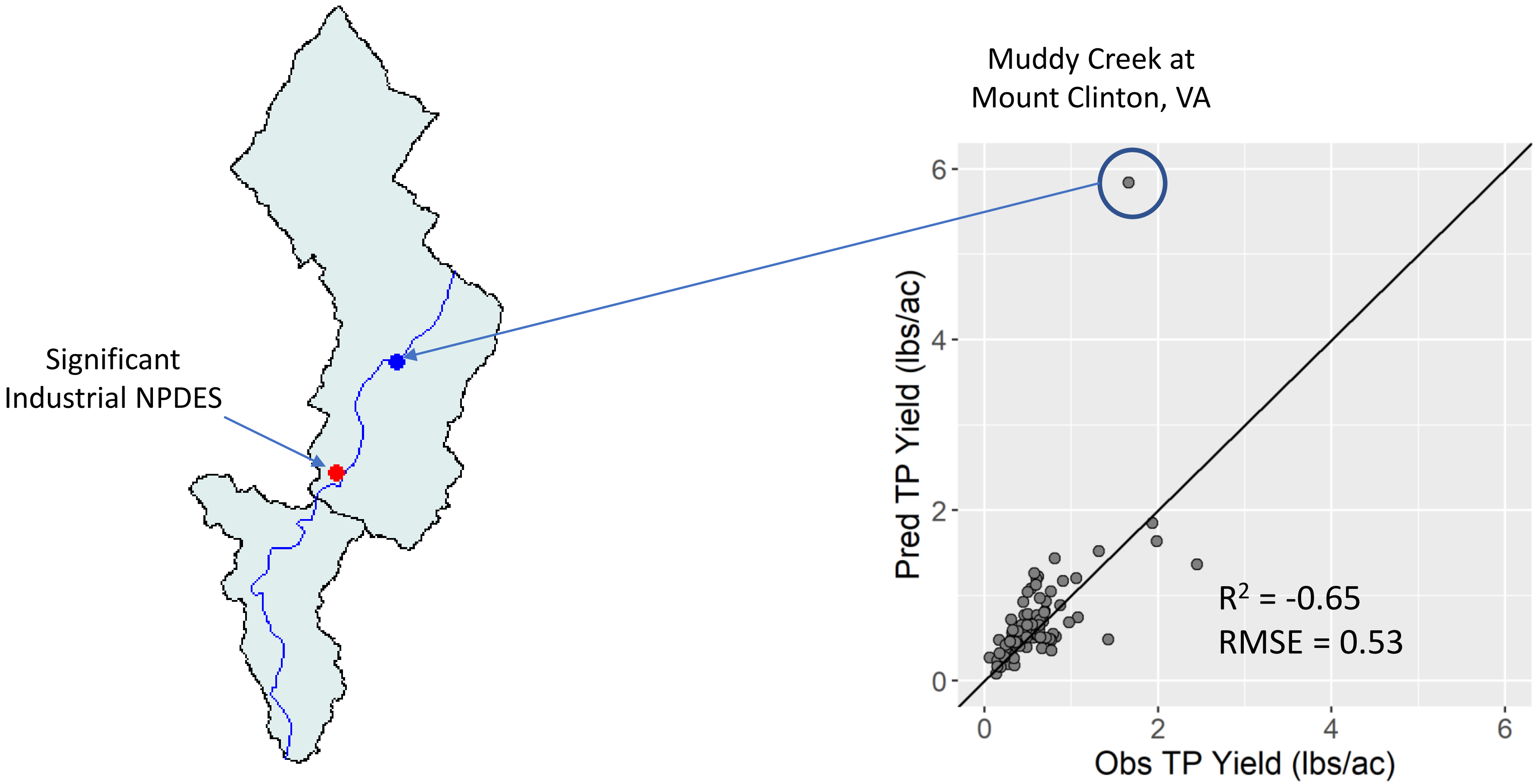


TP yield



*For details on model formulation, ask questions or see Extra Slides

Total Phosphorus – Observed vs. Predicted



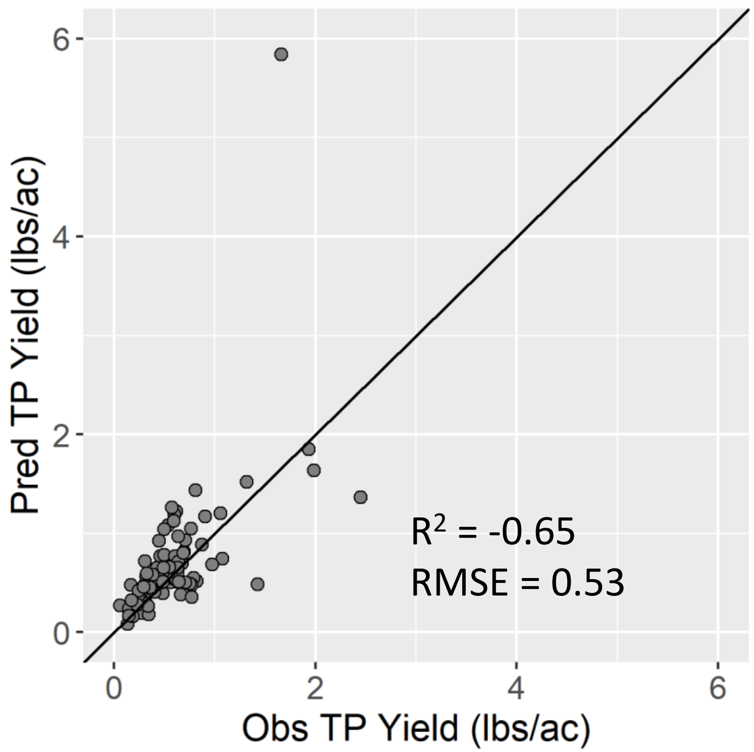
In this case, the calibration station is upstream of a point source that falls within that station's catchment

➡

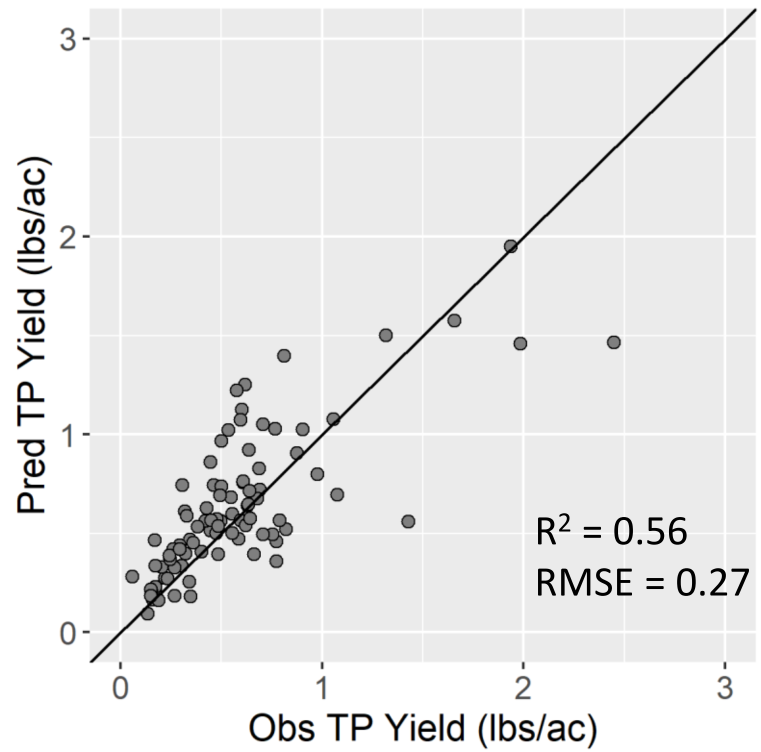
Moved NPDES to immediately downstream catchment in the model

Total Phosphorus – Observed vs. Predicted

TP yield – Before moving point source



TP yield – After moving point source



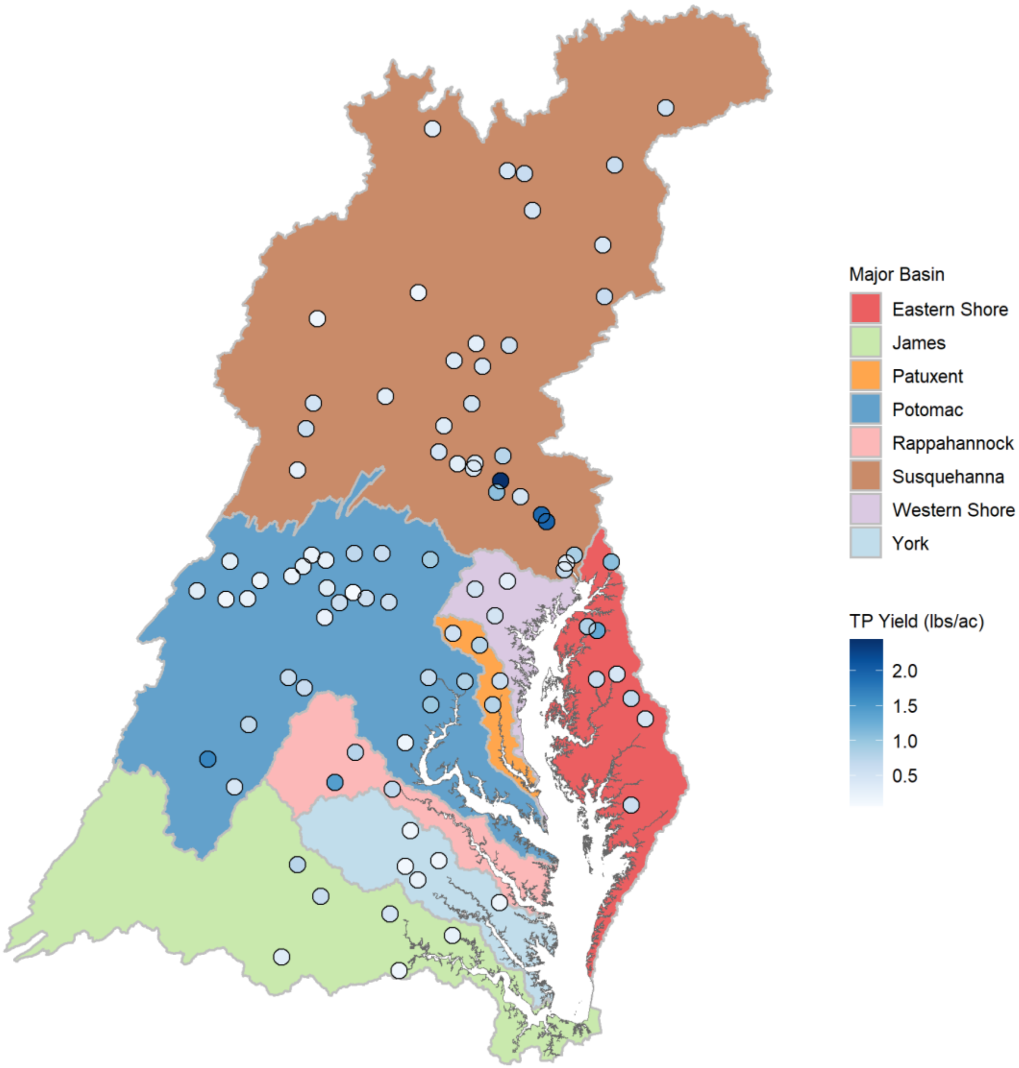
Next steps

- Code checking/de-bugging
- Annual CalCAST
- Refine/improve hydrology, sediment, and nutrient CalCAST

Extra Slides

Phosphorus

Calibration stations - TP



- Calibration target:

  WRTDS flow-normalized total phosphorus load estimated at non-tidal network stations

Inputs - TP

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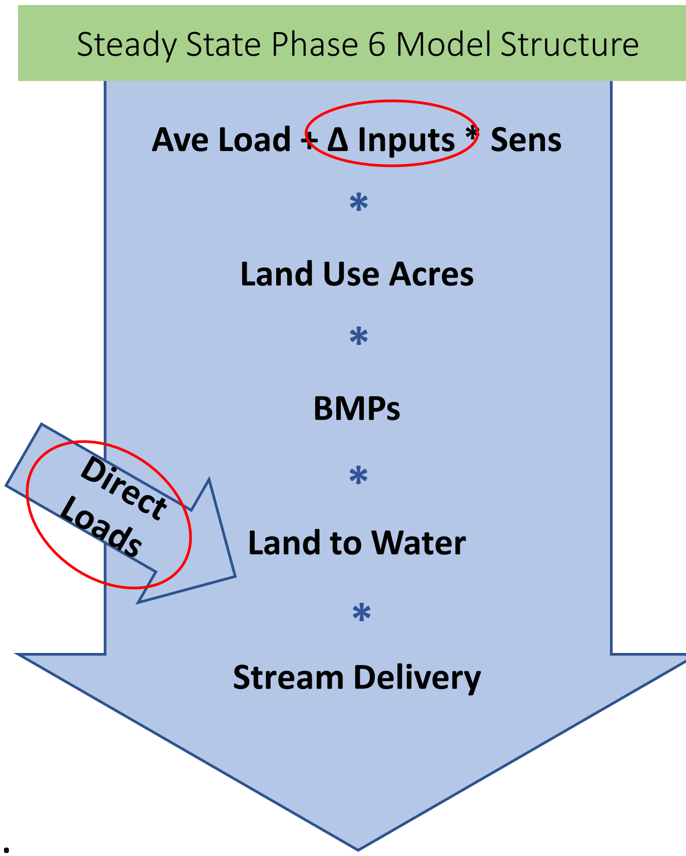
Soil P (not included yet)
Water Extractable P
Sediment loss (EOF from Sediment-CalCAST)
Stormflow (from Stormflow-CalCAST)
Riparian Pasture Deposition*
Rapid Infiltration Basins*
Feeding Space*
Wastewater*
CSO*

* Treated as direct loads



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Land to Water - TP

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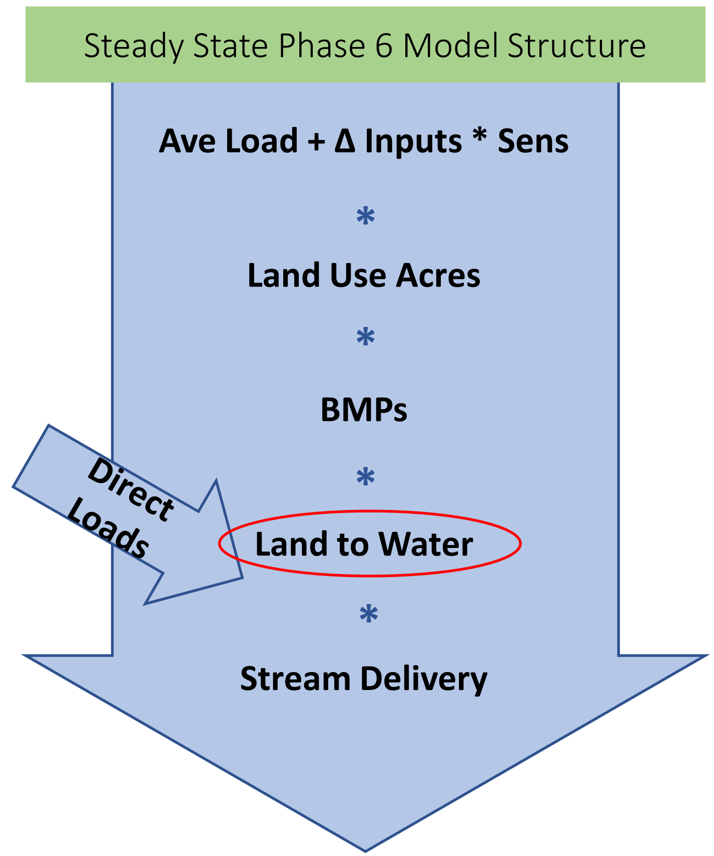
Point sources (kg yr^{-1})	0.877	0.573 – 1.18	0.183	< 0.0001
Crop fertilizer (kg yr^{-1})	0.0377	0.0171 – 0.0583	0.0125	0.0014
Manure (kg yr^{-1})	0.0253	0.0144 – 0.0362	0.00658	0.0002
Siliciclastic rocks (km^2)	8.52	6.10 – 10.9	1.46	< 0.0001
Crystalline rocks (km^2)	6.75	3.25 – 10.2	2.12	0.0009
Urban2 (km^2)	49	30.4 – 67.7	11.3	< 0.0001
Land-to-Water Delivery				
Soil erodibility (K factor)	6.25	3.55 – 8.95	1.63	0.0002
ln[Well-drained soils (percent)]	-0.1	-0.153 – -0.0478	0.0317	0.0019
Coastal Plain (percent of area)	1.02	0.681 – 1.35	0.204	< 0.0001
ln[Precipitation3 (mm)]	2.06	0.567 – 3.55	0.903	0.0237
Aquatic Decay				
Impoundments- inverse hydraulic load (yr m^{-1})	54.3	12.1 – 96.5	25.5	0.0174

$$DVF_c = e^{(-0.1 * hga_c)}$$

DVF_c = Delivery Variance Factor for catchment c
hga_c = % of catchment in hydrologic soil group A



Stream Delivery - TP

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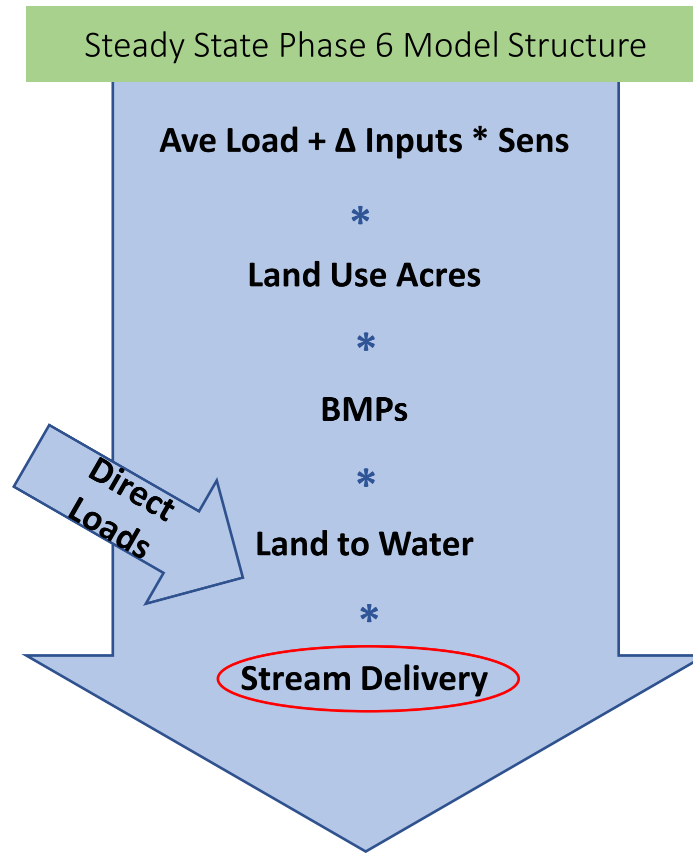

Reservoirs:

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Del_c = Stream/Reservoir delivery factor for catchment c
IHL_c = Inverse Areal Hydraulic Load for reservoir in catchment c
bres= estimated through CalCAST