# Structure and development of CalCAST Annual time step

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Modeling Workgroup Quarterly Review

01/10/2023

OCTOBER QUARTERLY RECAP

# What is CalCAST?

- Relatively parsimonious, spatially explicit, largely data-driven watershed modeling tool calibrated in a statistical framework
- Represents > 80,000 National Hydrography Dataset Plus (NHDPlus) catchments within the Bay watershed and leverages data from > 400 USGS monitoring stations for calibration
- Predicts long-term average streamflow, %stormflow, sediment, and nutrients at NHDPlus catchments
- Preliminary results of annual flow and loads predictions at Jan 2023 Quarterly (today)

# Why CalCAST?

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- 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

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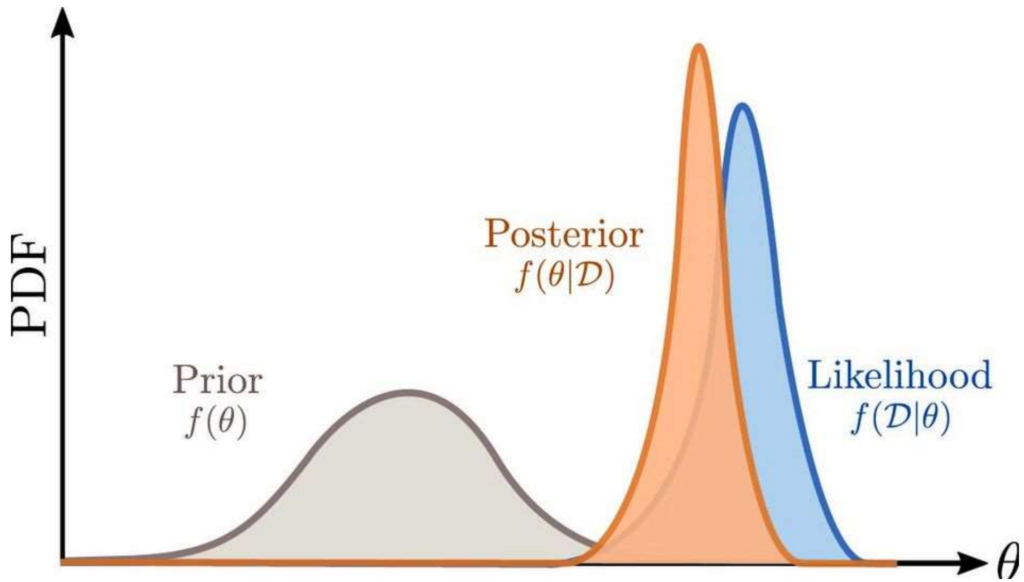
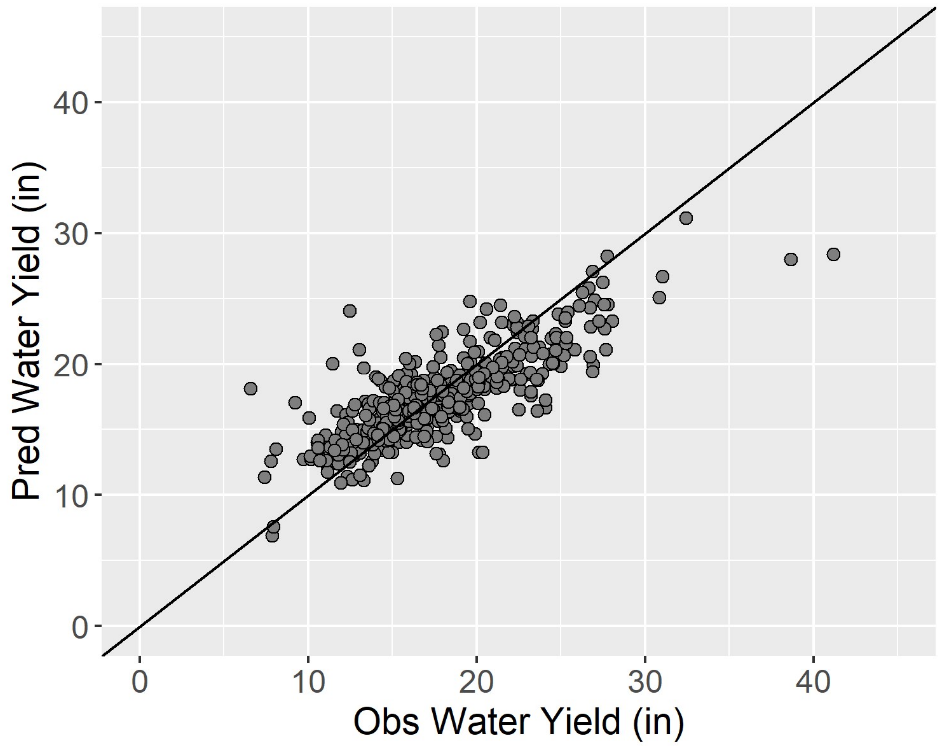
# Plan for this year

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

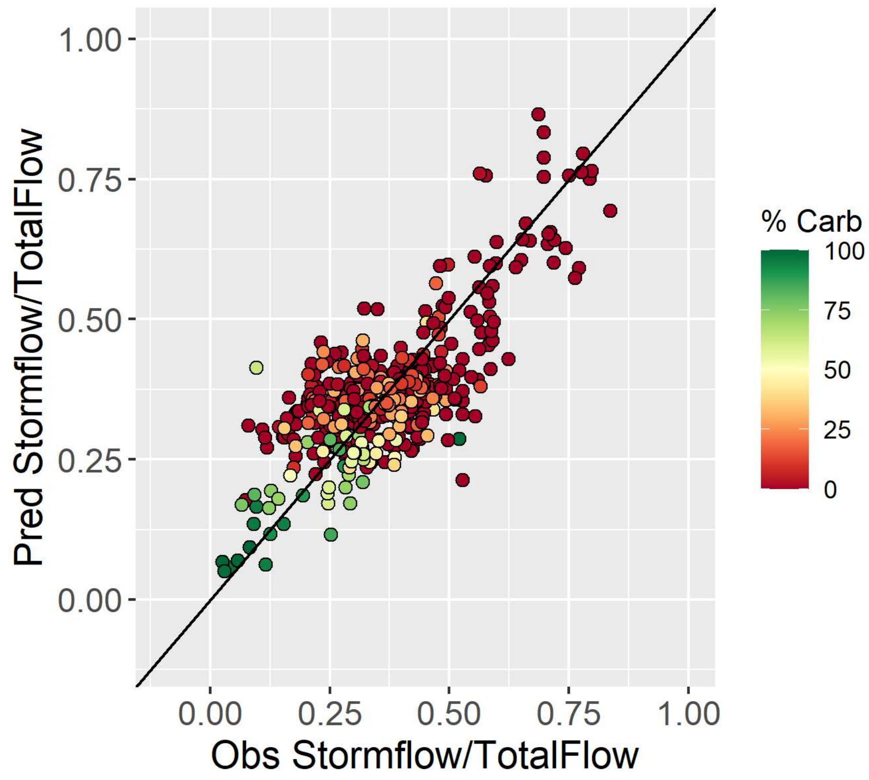


# Average Annual Hydrology – Observed vs. Predicted

## Water Yield




## Stormflow/Total Flow




«On the graph»

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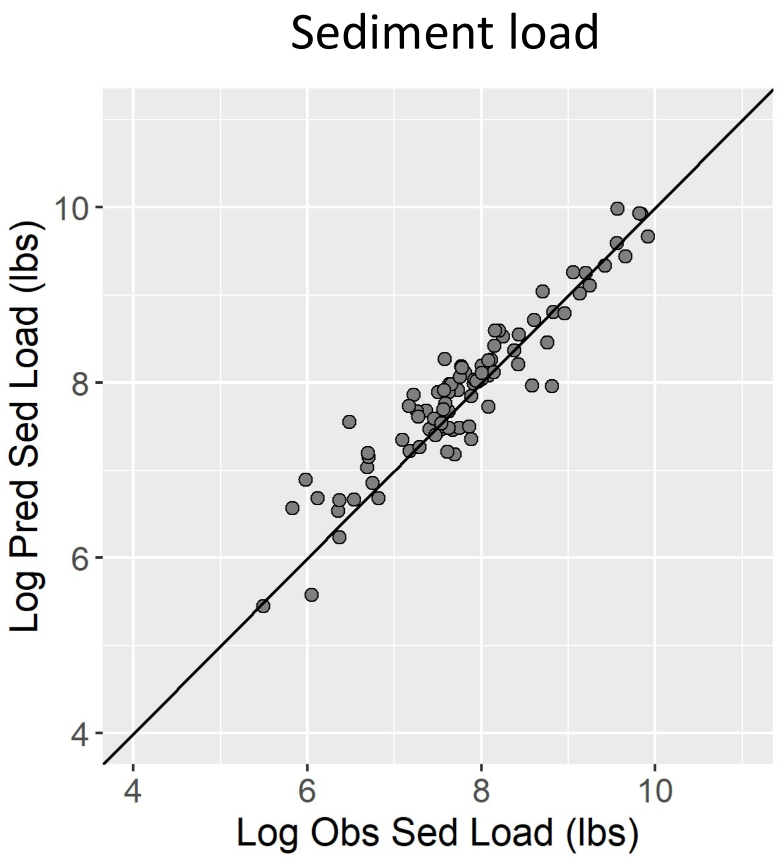
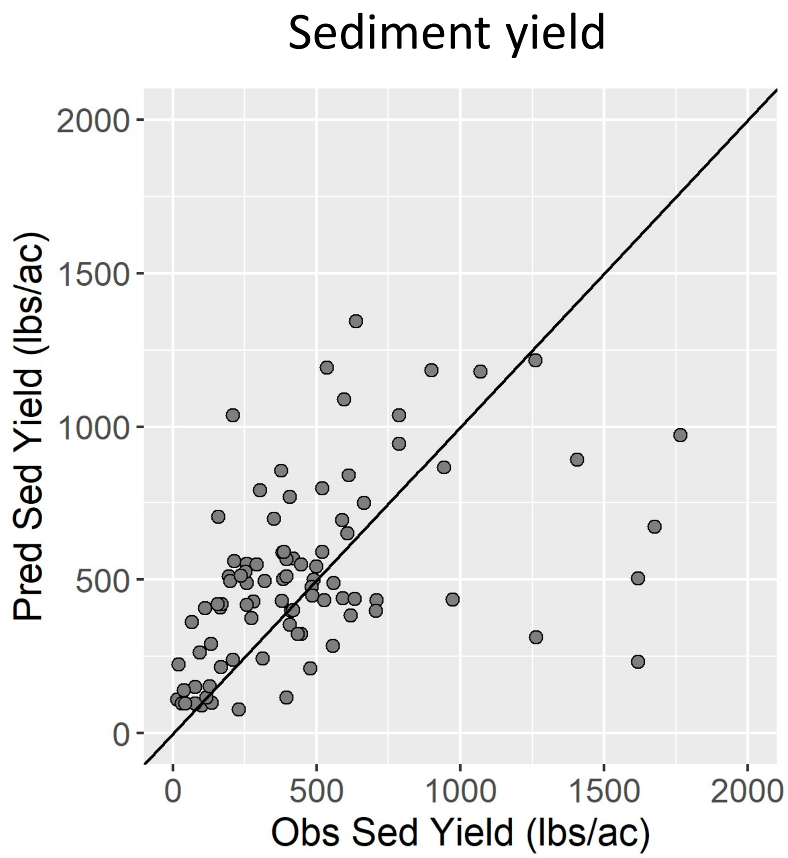
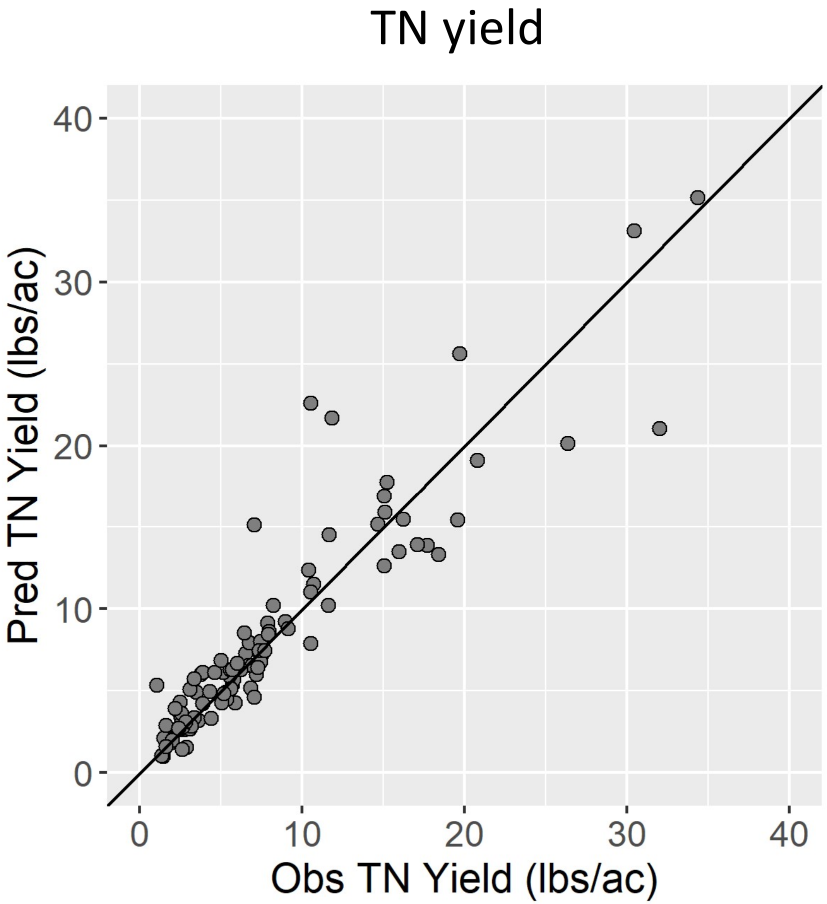
# Average Annual Sediment – Observed vs. Predicted

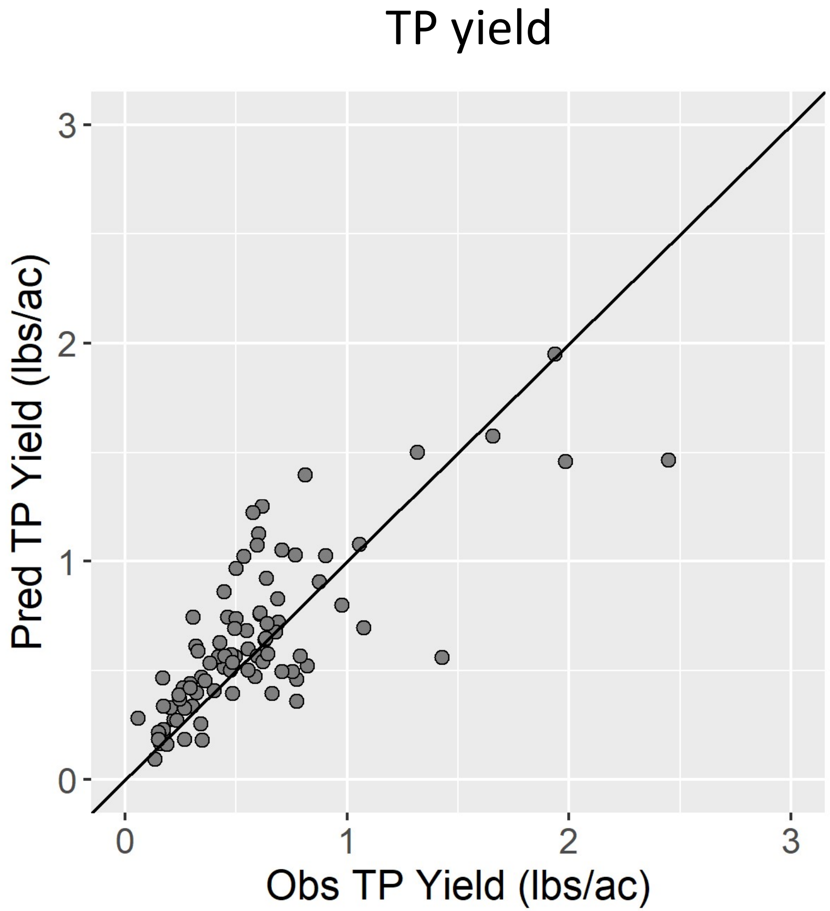



Definitely not great, but «On the graph»

# Average Annual TP and TN – Observed vs. Predicted




«On the graph»

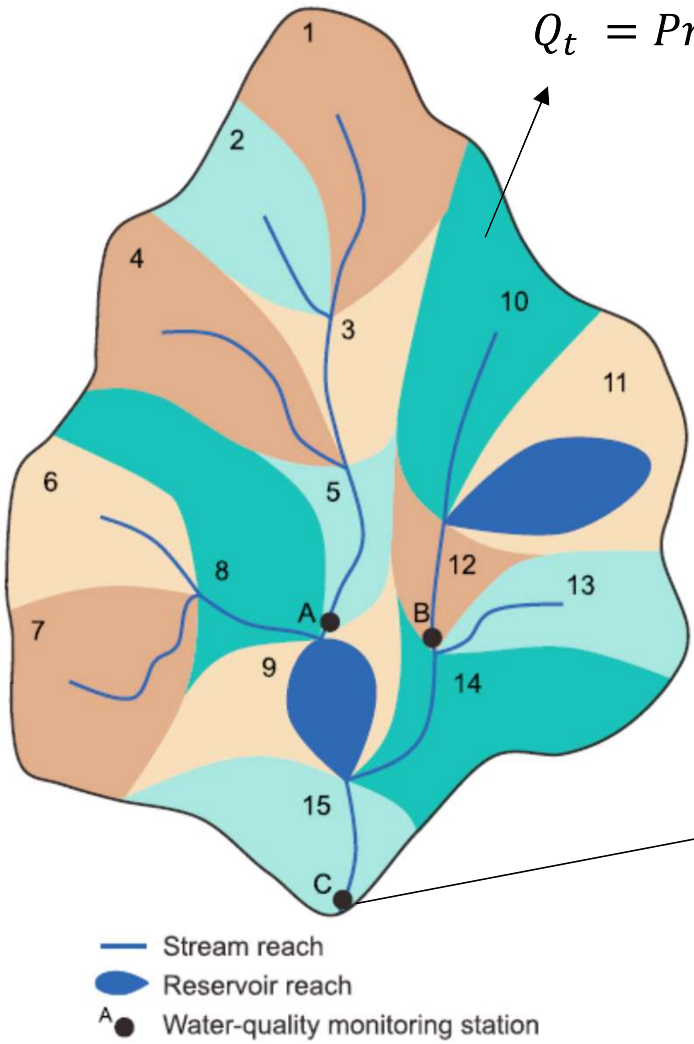
# Annual Total Flow

# Model formulation*

Total flow in year *t* at catchment *c*:

$$Q_t = Precip_t - \sum_{LU} (PET_t \times \beta_{LU}) - Withdrawals_t + Point\ Sources_t$$

Land use-specific PET parameters. Estimated through calibration.



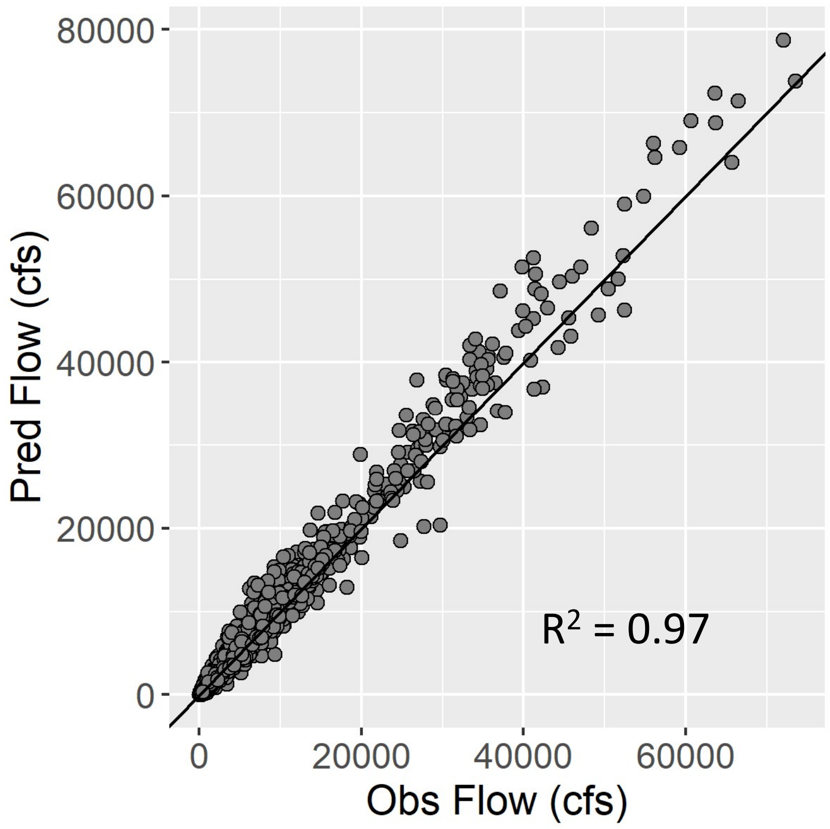

Streamflow predicted in each year at a monitoring station is the sum of all upstream streamflow

Figure: Chanat & Yang, 2018 WRR

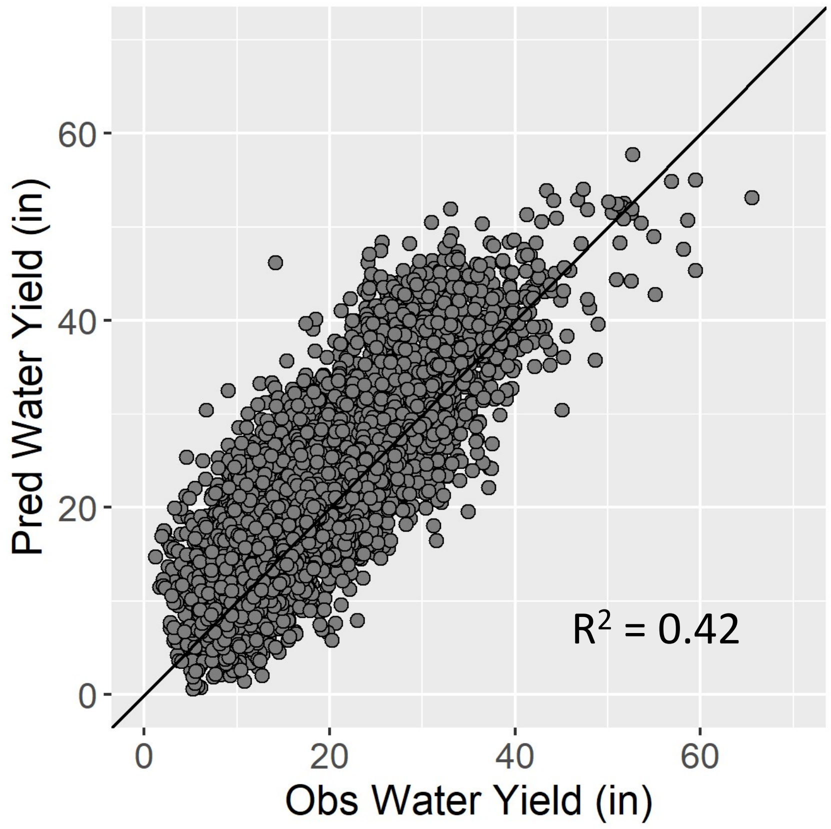
*See Extra Slides for detailed equations

# Total Flow – Observed vs. Predicted

Total flow



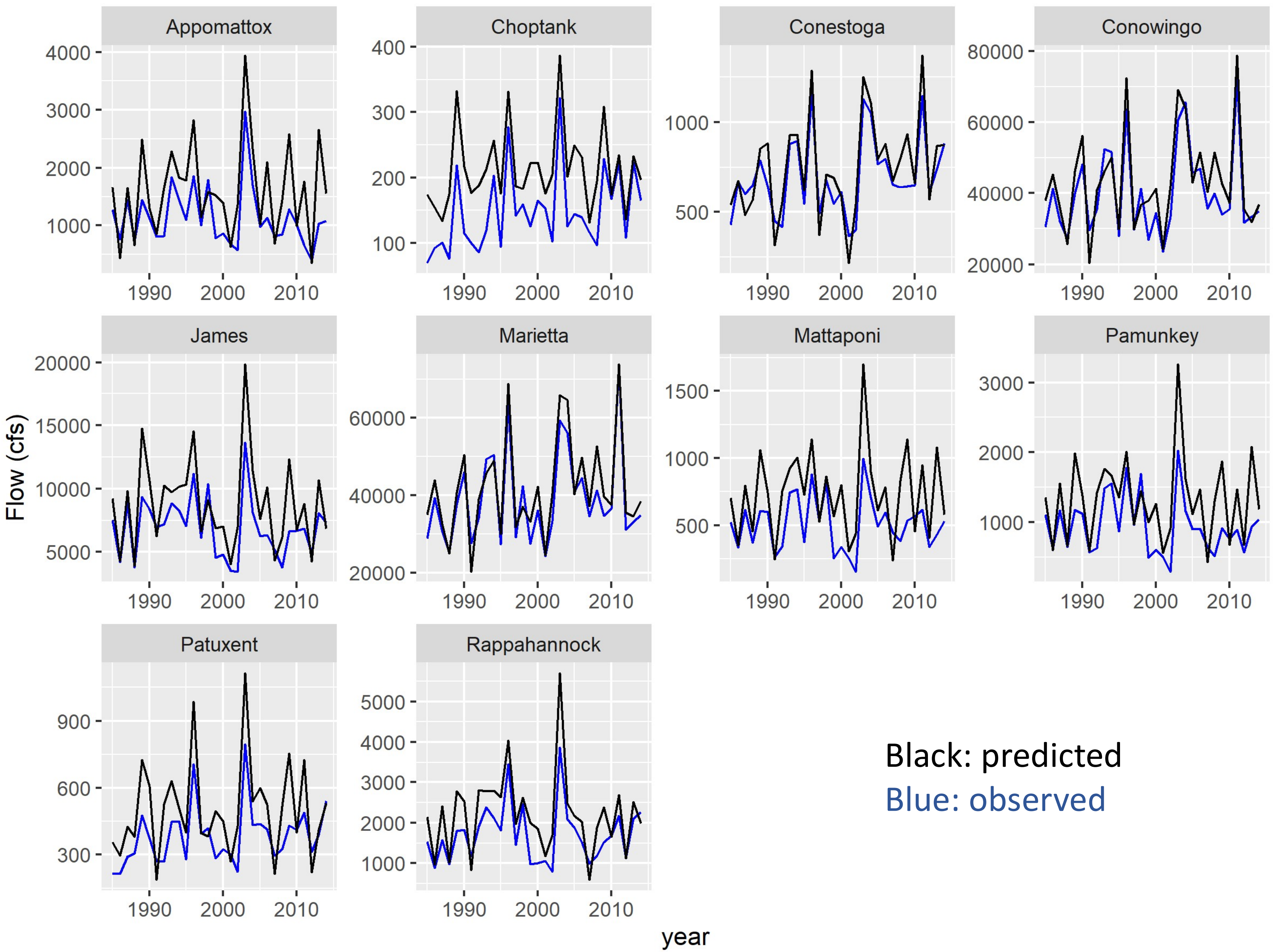

Water yield




«On the graph»

* Data points are individual years at different calibration stations

# Total Flow – Observed vs. Predicted time series




Black: predicted
Blue: observed

# Annual Stormflow/Total Flow

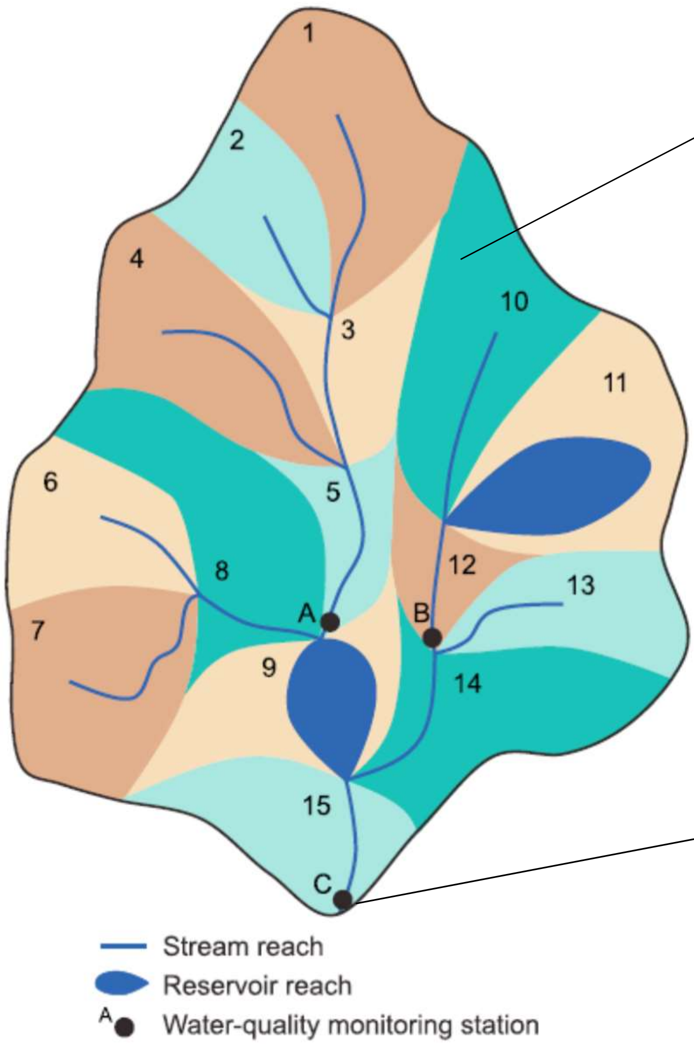
# Model formulation*

%Stormflow in year *t* at catchment *c*:

$$\%Stormflow_t = \sum_{LU}\left(Runoff_{t,LU} \times \gamma_{LU}\right)$$

$$Runoff_{t,LU} = Precip_t - PET_t \times \beta_{LU}$$

Stormflow fraction coefficient for land use *LU*. Estimated through calibration.



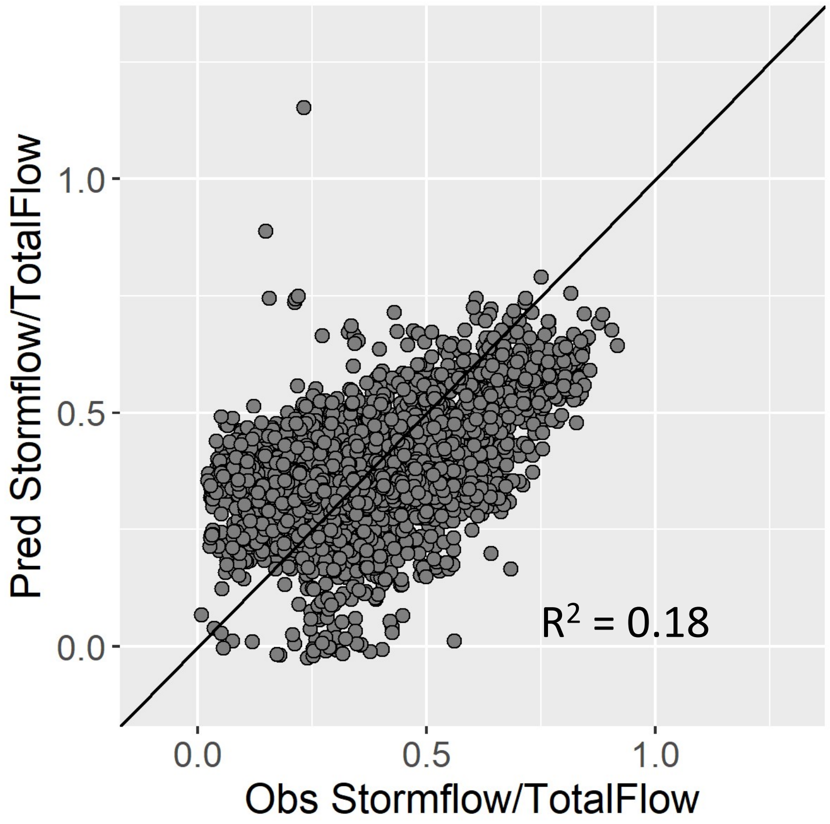

%Stormflow predicted in each year at a monitoring station is the weighted average of all upstream %Stormflow

Figure: Chanat & Yang, 2018 WRR

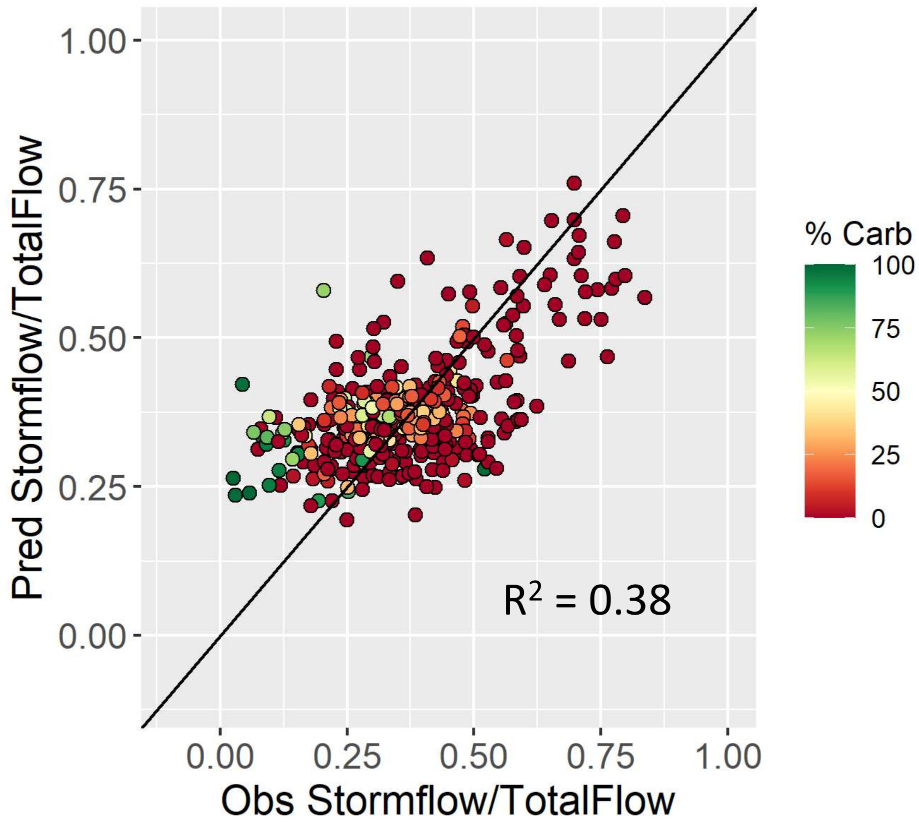
*See Extra Slides for detailed equations

# Stormflow/Total Flow – Observed vs. Predicted

Annual




Average annual

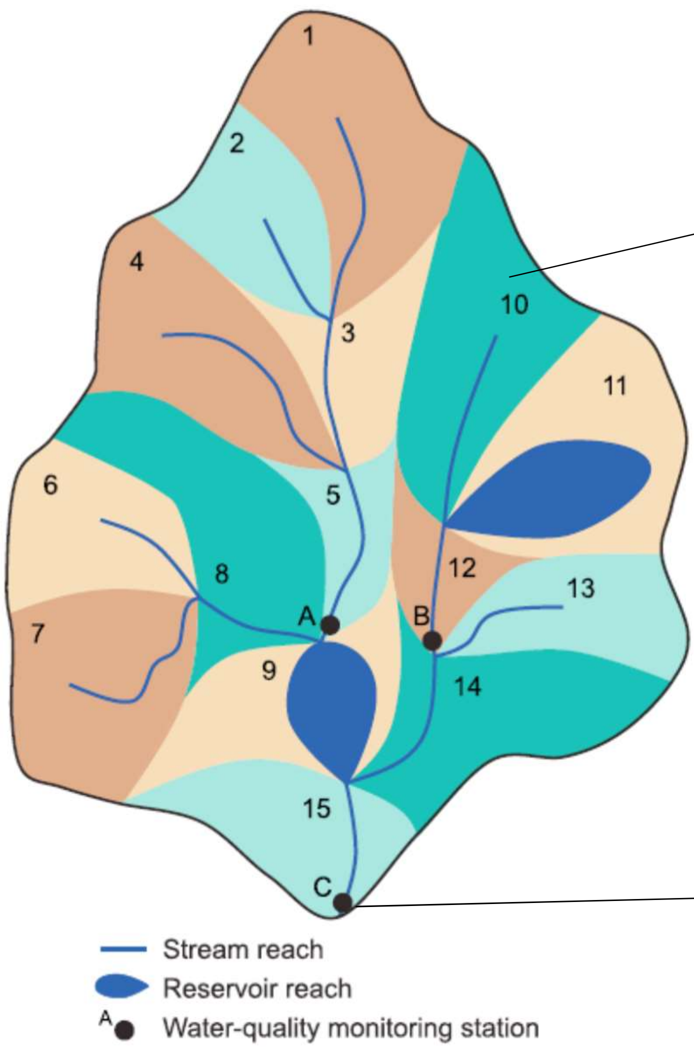


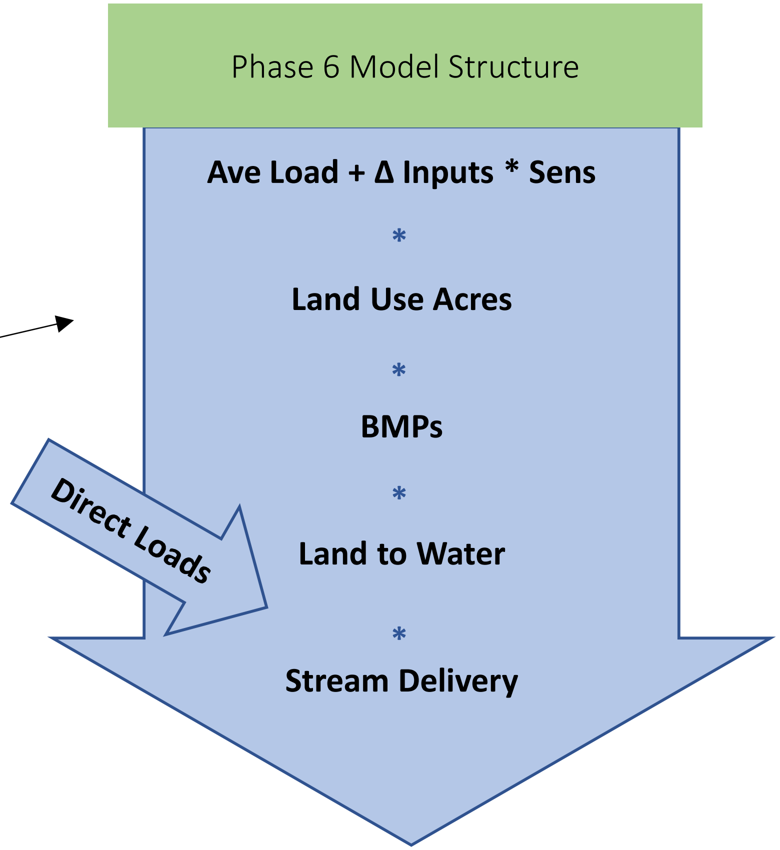

Note that before inclusion of watershed predictors (such as carbonate lithology), average annual stormflow prediction performance was also relatively poor

# Annual TN – Flow Normalized

# Implementing P6 at NHDPlus scale in CalCAST*

TN load generated in catchment c and year t is estimated using same (downscaled) inputs and equations as in P6, with some parameters estimated through calibration




TN Load predicted in each year at a monitoring station is the sum of all upstream loads, with appropriate attenuations/transport processes



Figure: Chanat & Yang, 2018 WRR

*See Extra Slides for more details

# Accounting for lags in nutrient transport

Only a fraction of the non-point source (NPS) load introduced to a catchment in year t is delivered in the same year due to lags in nutrient transport through different flow paths (e.g., surface flow vs. groundwater).

As a result, the NPS load delivered in year t is the sum of fractions of NPS loads introduced in previous years as well.

Example of calculation of the NPS load delivered in a catchment in year 2014, assuming that the load delivered in a certain year is influenced by loads introduced in the previous 3 years:

$$NPS\_DEL_{c,2014} = NPS_{c,2012} * lag_{c,2} + NPS_{c,2013} * lag_{c,1} + NPS_{c,2014} * lag_{c,0}$$

Load delivered in catchment c in year 2014

Load introduced in catchment c in year 2012

Fraction of load introduced in year t that is delivered 2 years later. P6 lag parameters used for now (vary by P6 land-segment)

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Load delivered in catchment c in year 2014

Load introduced in catchment c in year 2012

Fraction of load introduced in year t that is delivered 2 years later. P6 lag parameters used for now (vary by P6 land-segment)

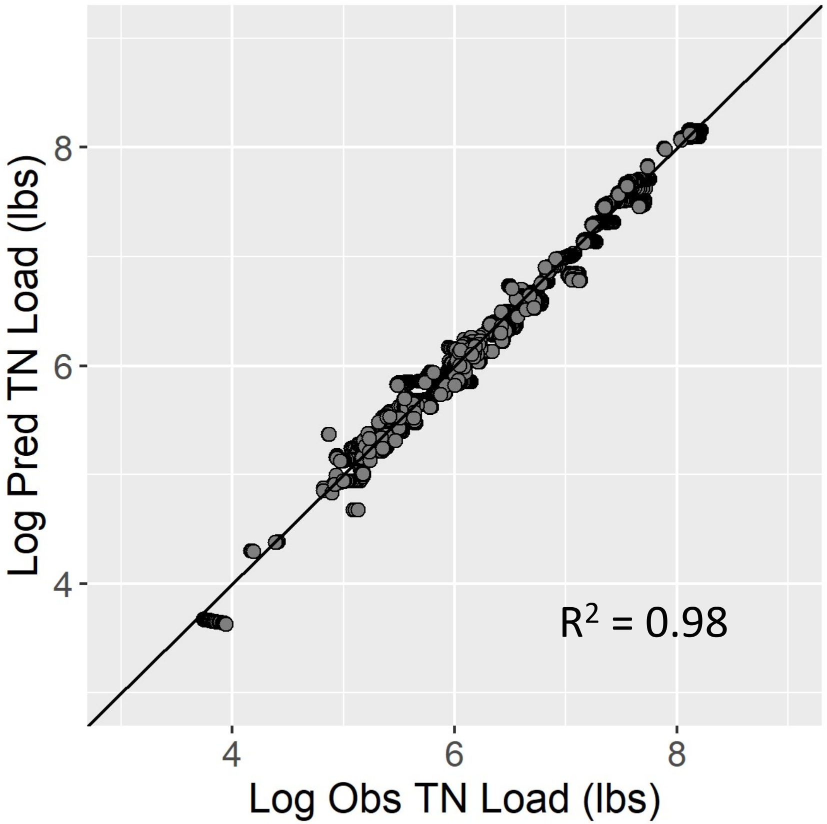
The load in each year is split between two flow paths (surface and groundwater), each with a different lag:

$$NPS_{c,2012} * lag_{c,2} = NPS_{c,2012} * \left(SUR_c * lag\_sur_{c,2} + GW_c * lag\_gw_{c,2}\right)$$

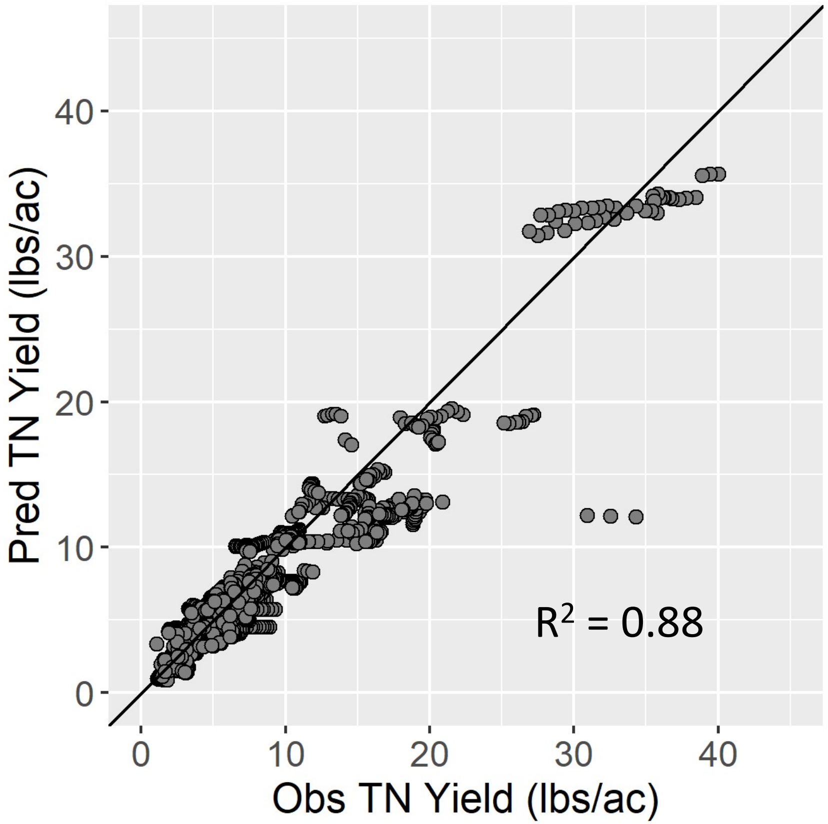
Fraction of load traveling through surface(SUR) and groundwater (GW) flow paths (currently estimated by CalCAST % stormflow as a place-holder)

# Total Nitrogen – Observed vs. Predicted

TN load

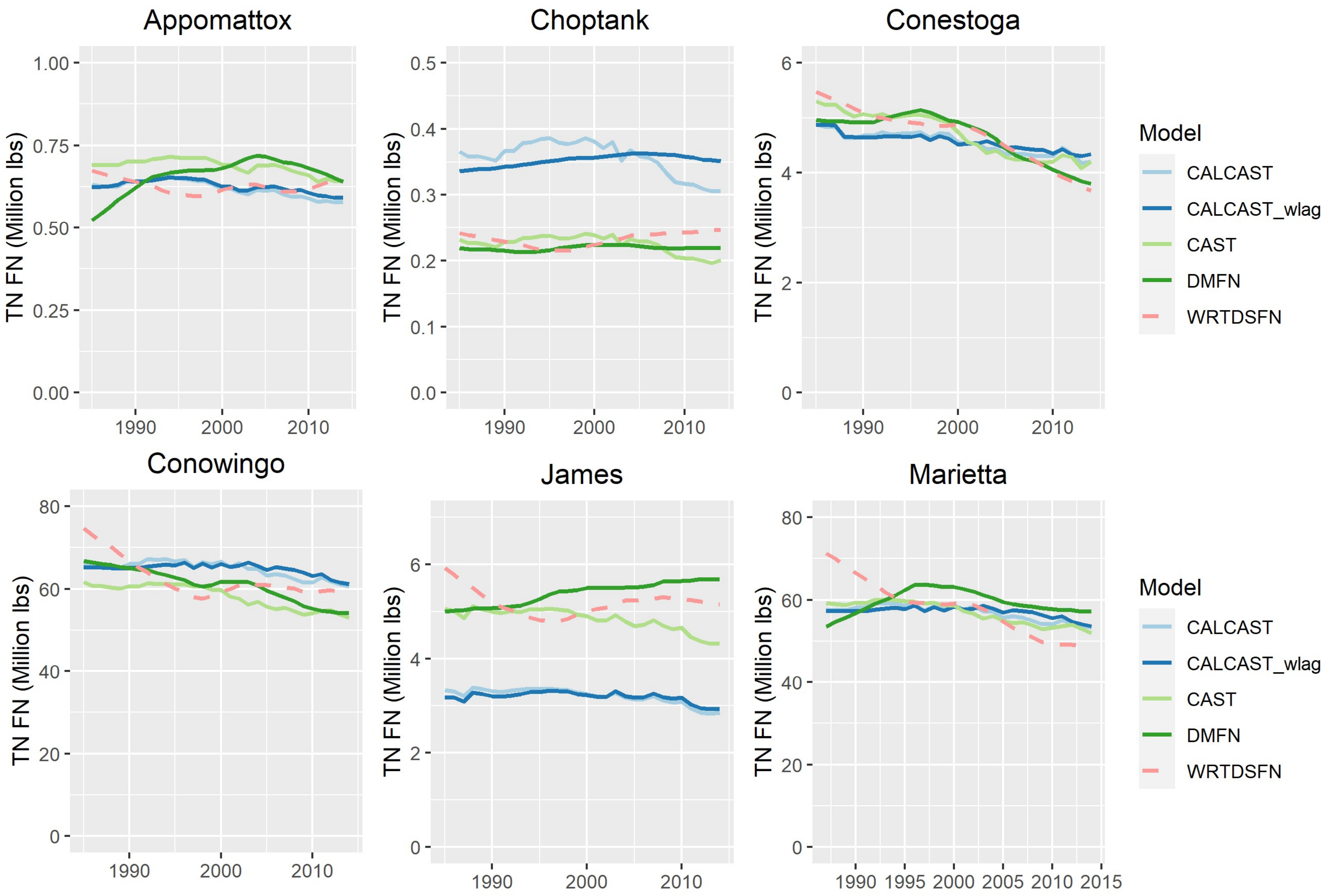



TN yield




«On the graph»

# Total Nitrogen – Observed vs. Predicte time series




DMFN: P6 dynamic watershed model flow normalized; WRTDSFN: WRTDS flow-normalized

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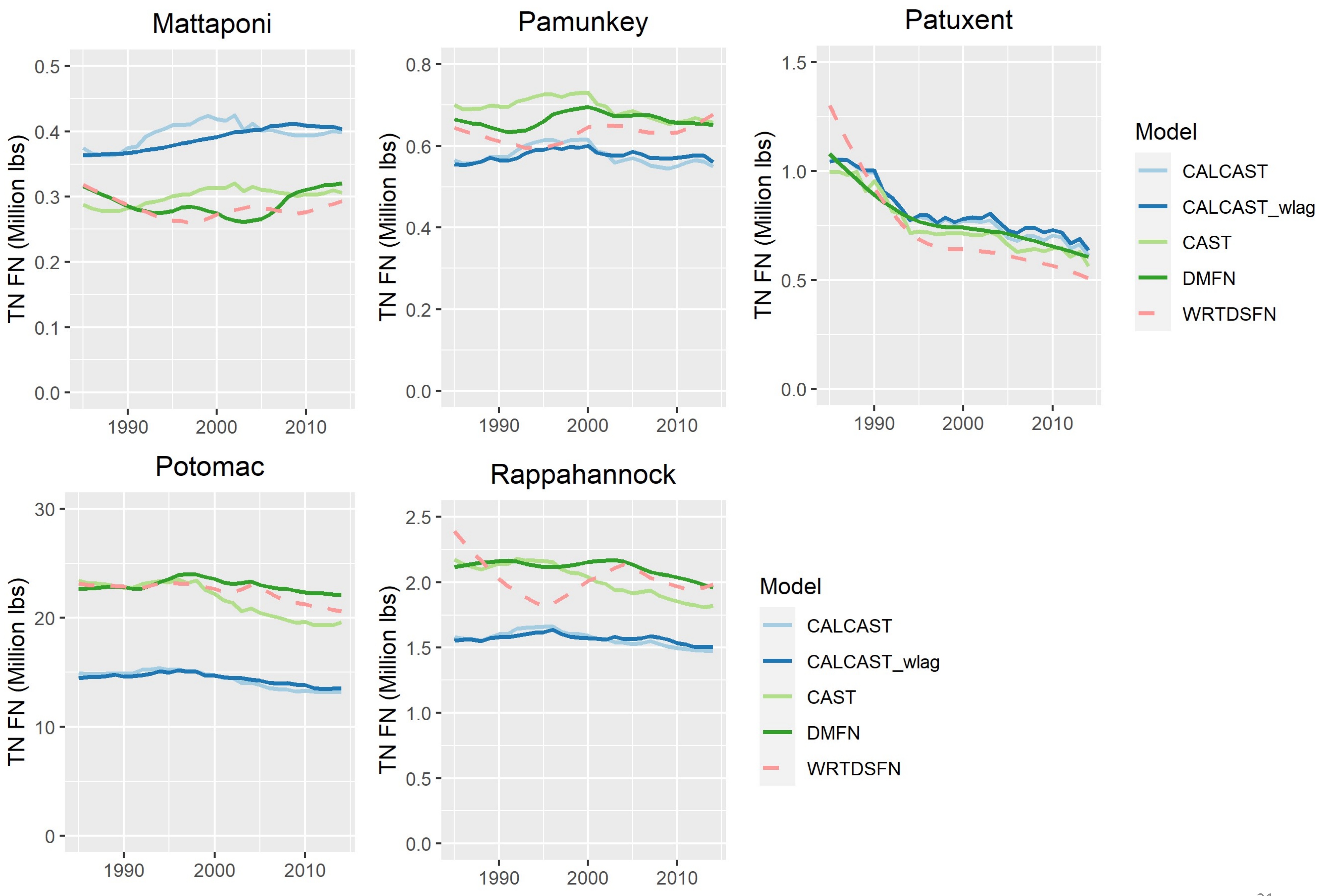


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# Conclusions

- We have developed “on the graph” versions of CalCAST that predict flow, stormflow, nutrients, and sediment
- We have both long-term average annual and annual model versions, and we have included the ability to account for lags in nutrient transport
- In 2023 we plan to work on improving and refine these models

# Extra Slides

# Model formulation

## Annual Total Flow:

$$Q_{g,t} = \sum_c \left( P_{c,t} - \sum_l \left( PET_{l,c,t} \times \beta_l \times \prod_f \left( \overset{*}{a_f} \times V_{c,f} \right) \right) - W_c + I_c \right)$$

- $Q_{g,t}$: Flow at gauge g in year t
- $P_{c,t}$: Precipitation in catchment c in year t
- $PET_{l,c,t}$: PET for land use l in catchment c in year t
- $\beta_l$: Land use-specific PET parameter
- $a_f$: Coefficient for factor f
- $V_{c,f}$: Value of factor f in catchment c
- $W_c$: Withdrawals in catchment c in year t
- $I_c$: Direct loads in catchment c in year t

* Watershed properties

# Model formulation

## Stormflow/Total Flow:

$$\mathrm{SG_g} = \frac{1}{A_g^{\alpha}} \times \frac{\sum_{l}\sum_{c}\sum_{t}\left(\mathrm{SL}_{l,c,t} \times R_{l,c,t}\right)}{\sum_{l}\sum_{c}\sum_{t} R_{l,c,t}}$$

Fraction of stormflow at gauge g

Drainage area of gauge g

Drainage area coefficient

Stormflow fraction for land use l, catchment c, year t

Runoff for land use l, catchment c, year t

$$R_{l,c,t} = P_{c,t} - PET_{l,c,t} \times \beta_l \times \prod_f \left(a_f \times V_{c,f}\right)$$

$$SL_{l,c,t} = \gamma_l \times \prod_f \left(b_f \times VS_{c,f}\right)$$

Stormflow fraction coefficient for land use l

Coefficient for factor f

Value of factor f in catchment c

# Implementing Nutrient P6 at NHDPlus scale in CalCAST

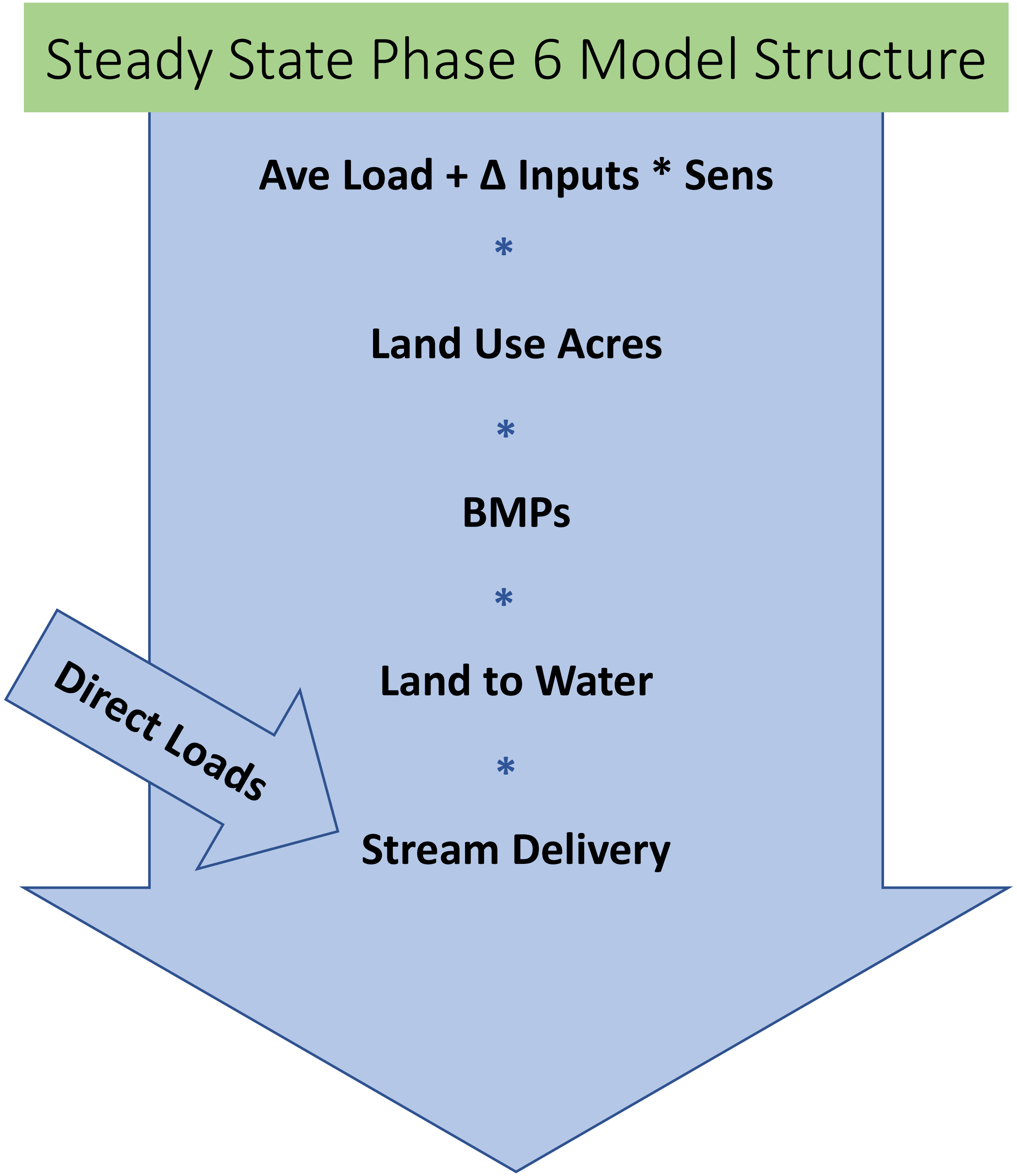
- 11 CalCAST land uses grouped into 4 broad classes

| 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

The following slides show example simplified nutrient equations for one CalCAST land use (FOR) in one NHDPlus catchment c.

FOR land use receives only one type of TN input: atmospheric deposition.



# Implementing Nutrient P6 at NHDPlus scale in CalCAST

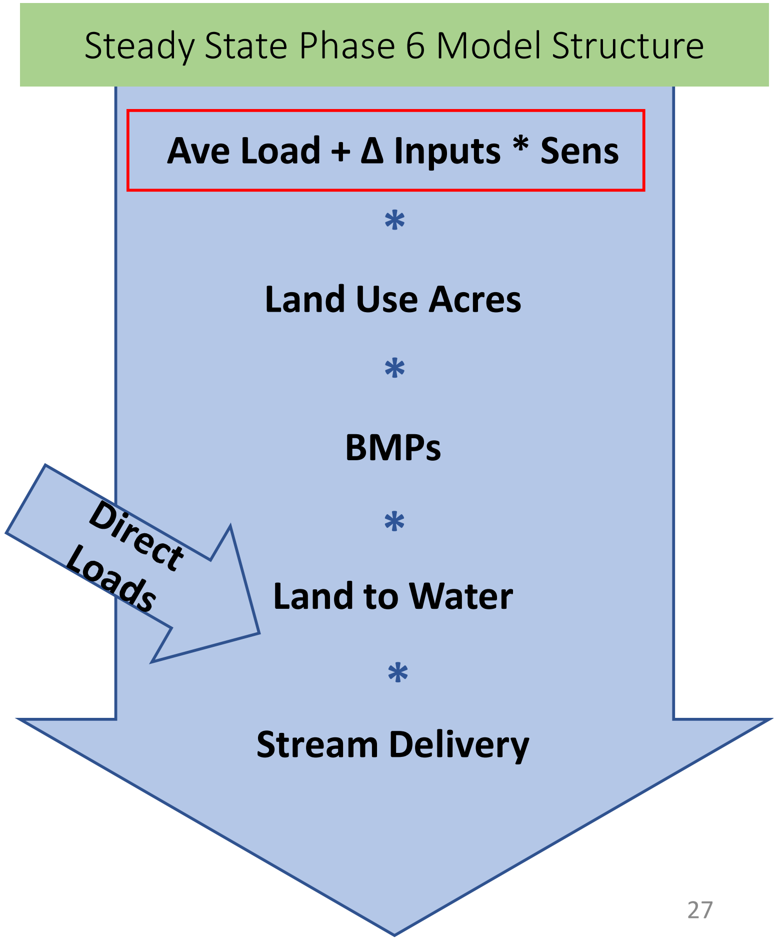
Example non-point source load generated by FOR land use in catchment c and year t:

Watershed-wide average FOR loading rate (lbs/ac). Estimated by CalCAST with prior information from P6

Difference between local TN input from atm dep in catchment c and year t and watershed-wide long-term average TN input from atm dep (lbs/ac). Downscaled to NHDPlus from P6 inputs

Change in atm dep load exported from FOR per change in unit of atm dep input on FOR. P6 values used for now

$$NPS_{FOR,c,t} = AVE_{FOR} + \left(TN_{ATM,c,t} - \widehat{TN_{ATM}}\right) * SENS_{FOR,ATM}$$



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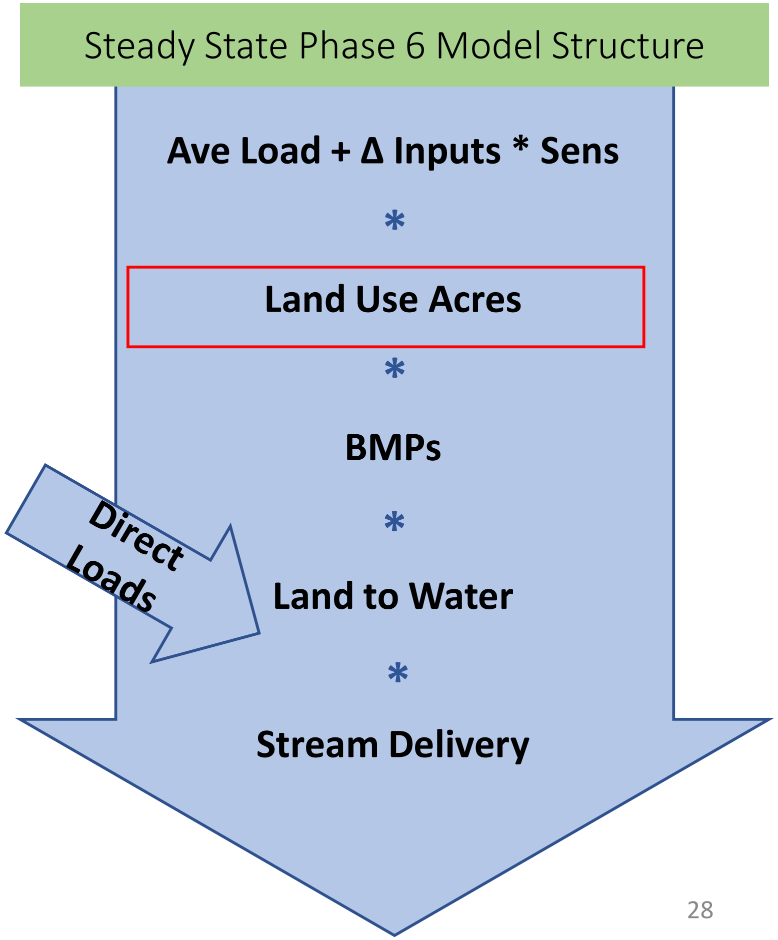
$$* \; ACRES_{FOR,c,t}$$

Acres of FOR in catchment c and year t. Same land use acres across years for now



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$$*$$

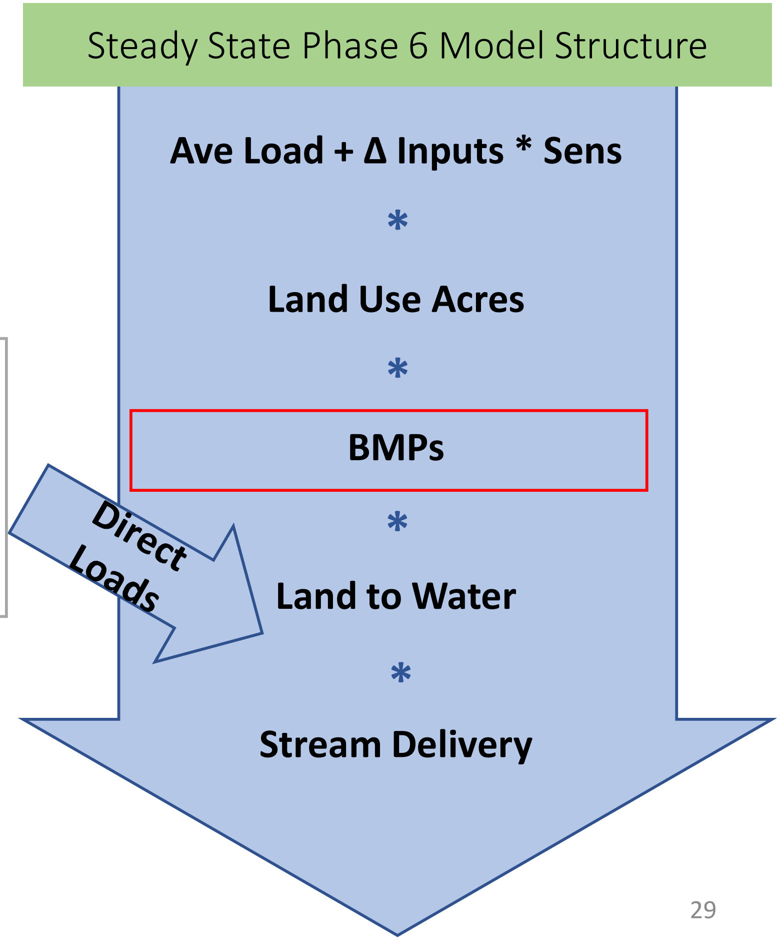
$$ACRES_{FOR,c,t}$$

$$*$$

$$BMP_{FOR,c,t}$$

Acres of FOR in catchment c and year t. Same land use acres across years for now

BMP pass-through fraction for FOR in catchment c and year t. Downscaled to NHDplus from P6 pass-throughs



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$$*$$

$$ACRES_{FOR,c,t}$$

$$*$$

$$BMP_{FOR,c,t}$$

$$*$$

$$L2W_c$$

$$*$$

$$DEL_c$$

Acres of FOR in catchment c and year t. Same land use acres across years for now

BMP pass-through fraction for FOR in catchment c and year t. Downscaled to NHDplus from P6 pass-throughs

Land-to-water delivery factor for catchment c. Estimated using same coefficients and predictors as in P6

Stream delivery factor for catchment c. Estimated using same coefficients and in-stream decay predictors as in P6.