Anticipating and Adapting to Phenologic Changes in the Chesapeake Water System

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CBP Modeling Workgroup Quarterly Review

4/8/20

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Now with!
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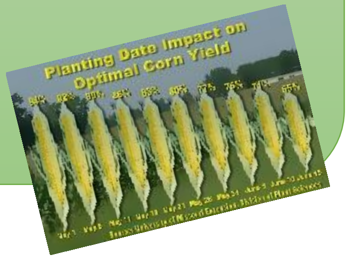
Water Sustainability & Climate

Modeling System to Evaluate Climate & Socio-Ecological System Change

Climate Change
- Model: Downscaled GCMs
- Output: Temperature, precipitation, and storms

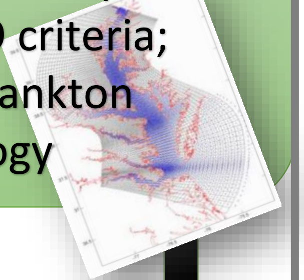
Farmer Decisions
- Models: Empirical
- Output: Planting date, & Cropping systems



Watershed Processes
- Models: rSAS, SWAT & CBP

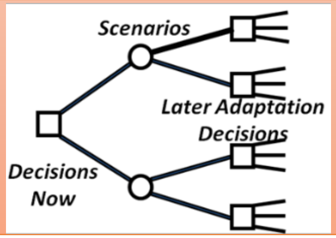
  Output: N&P Loading

Estuarine Processes
- Model: ROMS-RCA, Empirical
- Output: Compliance with DO criteria; phytoplankton phenology



Education Outreach
- Model: Farm Simulation Game
- Output: Net Revenues & N loads

State-Contingent Policy
- Weather Triggers



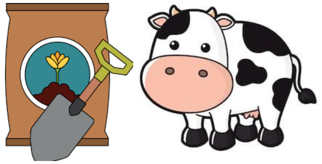
Policy Scenarios
- Model: Empirical
- Output: Policy Adopters by Location

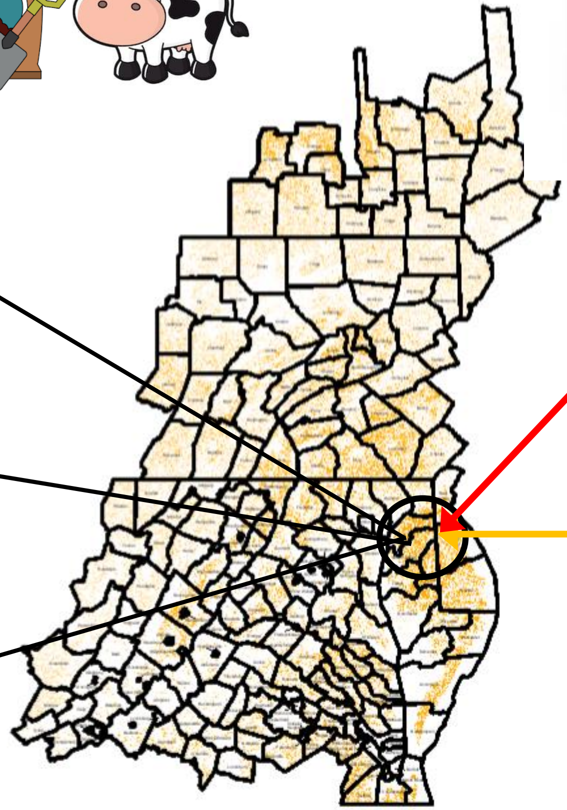
Major Questions Being Addressed

- How do farmers change their behavior in response to climate change?
- How does watershed nutrient runoff-response change under climate and farmer behavior change?
- What is the net effect of “upstream” changes and direct climate effects on the estuary?
- Would “state-contingent” BMPs be more cost-effective than permanent BMPs at managing extreme weather conditions that harm Chesapeake Bay habitat?

Effects of seasonal and long-term climate variability on hydrology and nitrate export in the Chesterville Branch catchment of the Eastern Shore, MD

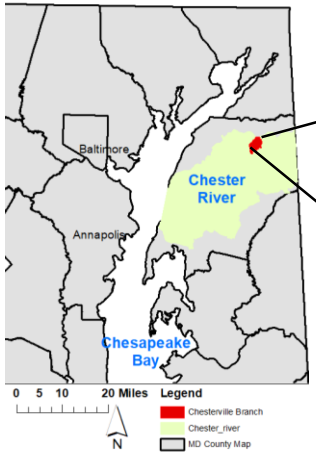
Major N Sources to CB

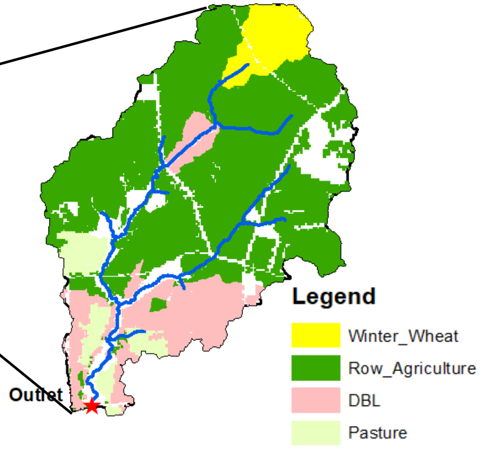




How might climate change affect seasonal signals of nitrate loads and hydrology through physical way and effects on farmers?

- Quantify seasonality
- Effects of climate change, shifting agricultural management practices and the combination of the two factors

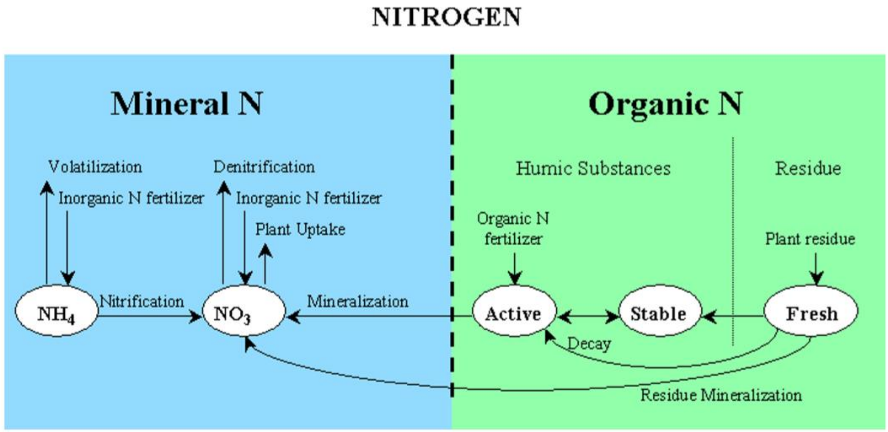




*Shuyu Chang, **Ciaran Harman**, Ariel Ortiz Bobea, Dano Wilusz, Gopal Bhatt,William P. Ball*

Methodology

Soil and Water Assessment Tool (SWAT)



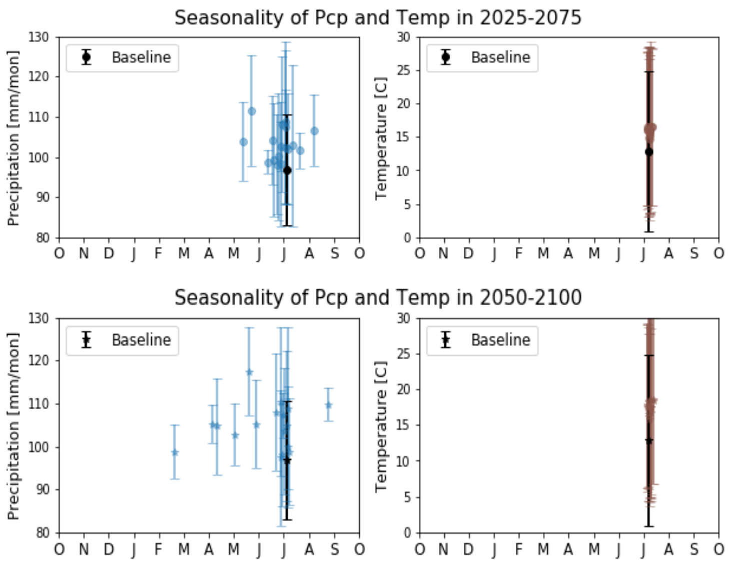
- Long-term, continuous, basin-scale, process-based model

- Inputs

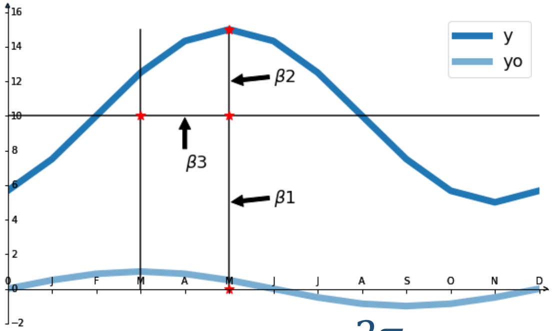
Land use: 2016 NLCD Land Use, CBP Phase 6 Crop data
Agriculture: CBP Phase 6 deposition, fertilizer and manure data, USDA Plant and harvest timing
Climate: PRISM daily pcp and temp

(Arnold et al., 1998; Neitsch et al., 2011)

Climate Scenarios (CMIP5 GCM)



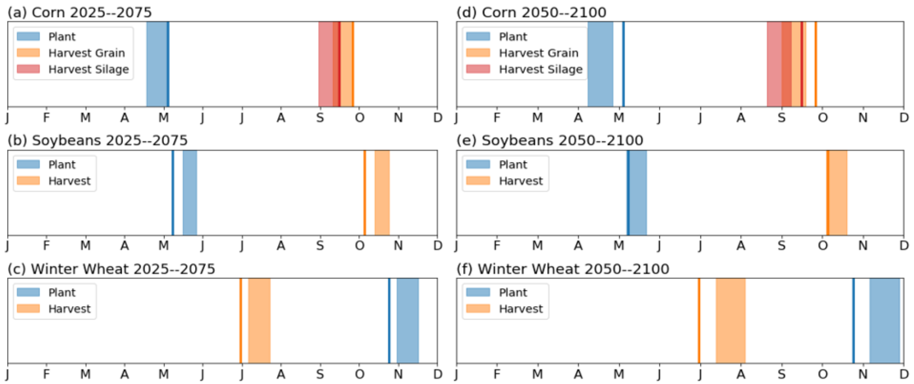
Seasonality Model



$$y = \beta_1 + \beta_2 \times sin(\frac{2\pi}{12}(t + \beta_3))$$

β_1: Mean β_2: Variation
β_3: Phase

Agricultural Scenarios (Crop Yield Stats Model)



- Based on historical data under RCP 4.5 CMIP5 GCM scenarios

(Ortiz-Bobea et al.,2019)

Results-Calibrations

Model Calibrations

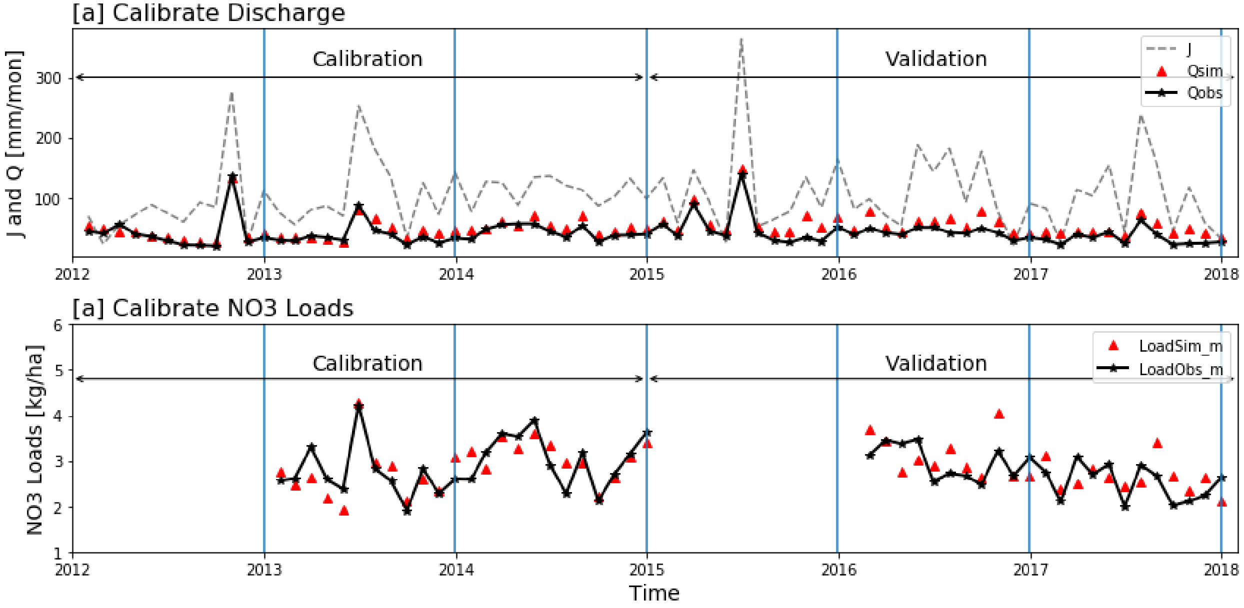
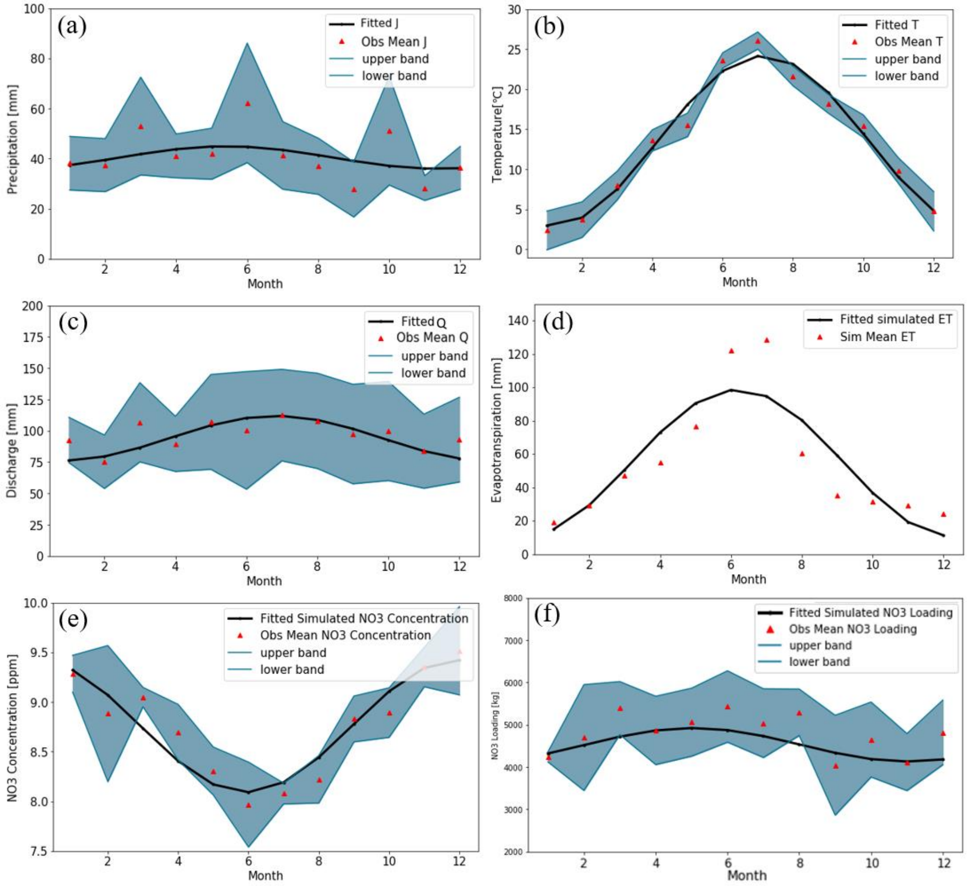


Table 1. Objective functions of model performances

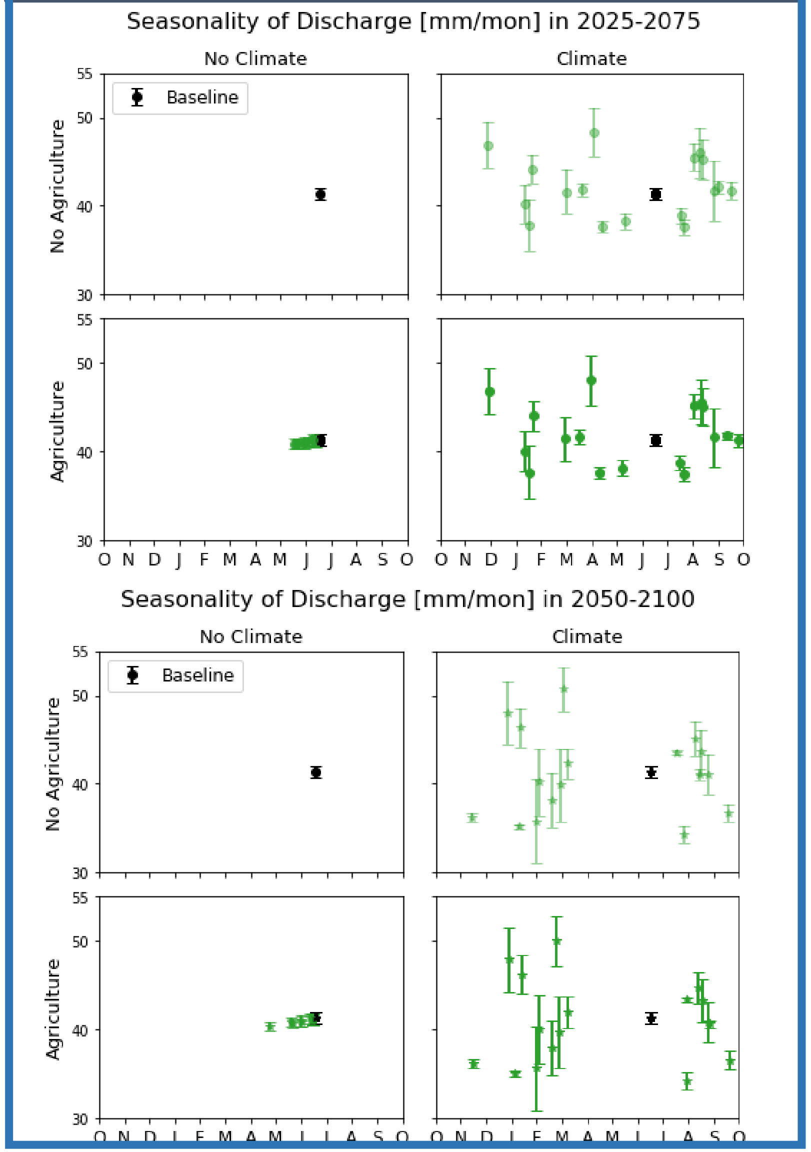
	Period	R2	NSE	RSR
	Calibration	0.87	0.86	0.14
Stream Flow	Validation	0.88	0.65	0.24
	Calibration	0.59	0.52	0.59
Nitrate Loads	Validation	0.4	0.35	0.4

Seasonality Quantifications

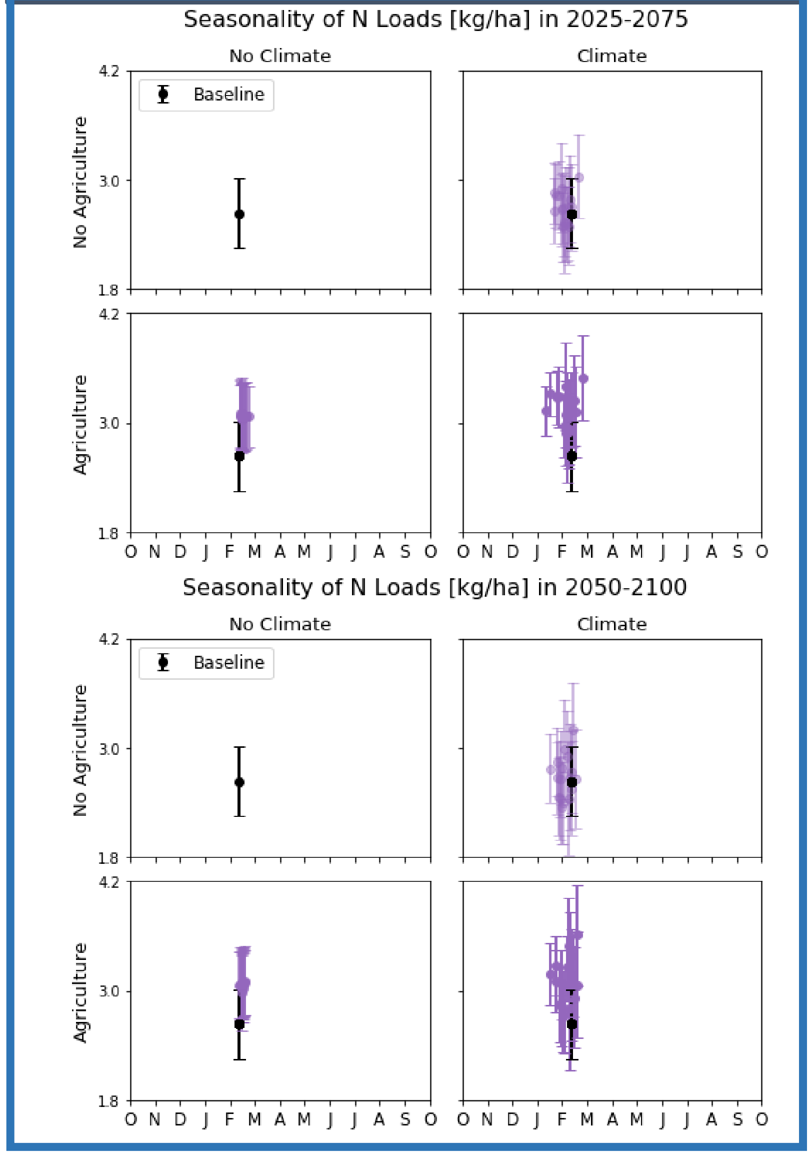


Results-Simulations

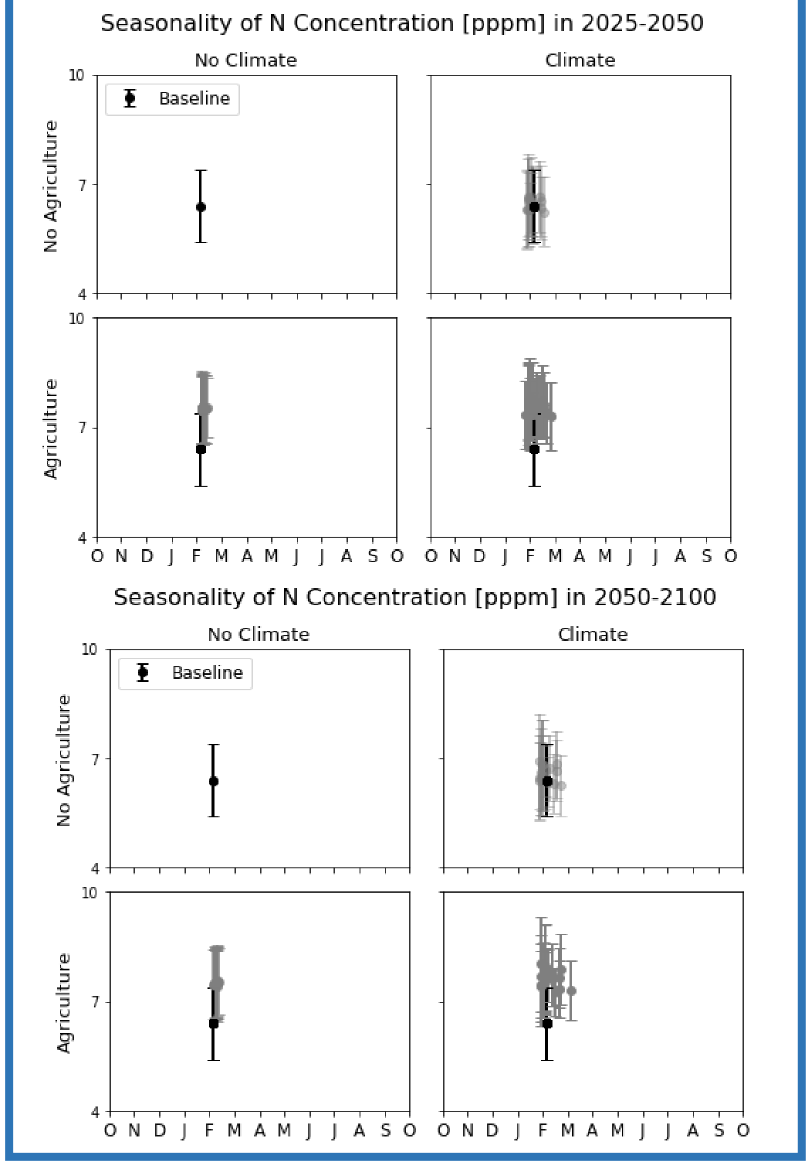
Discharge [mm/mon]



NO3 loads [kg/ha]

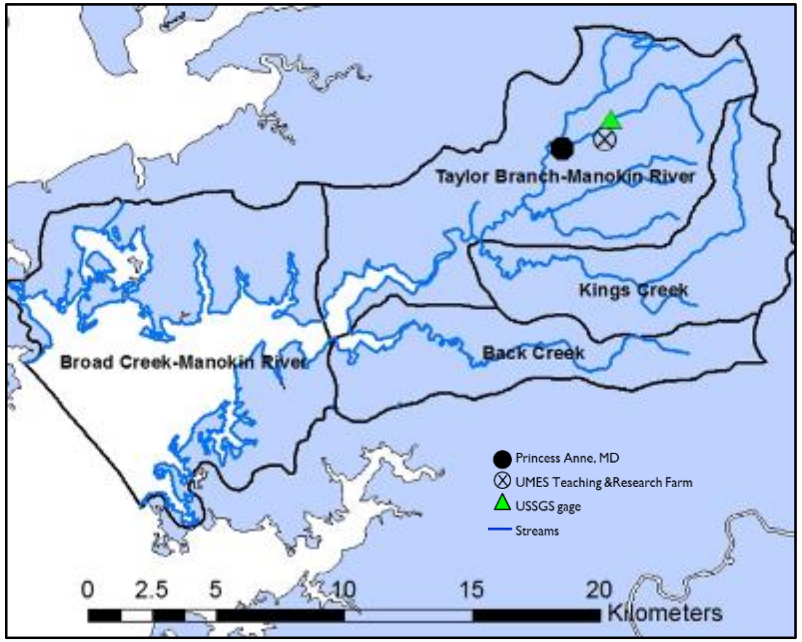


NO3 Concentration [ppm]



SWAT-VSA modeling for phosphorus results: Manokin Watershed, Princess Anne, MD

- Nutrient Management Challenges
  - Intensive poultry production and high soil nutrients from poultry litter applications above crop requirements
  - N and P losses from ditches consistently high
  - Subsurface transport processes drivers of nutrient loss
- Artificial surface drainage by field and public drainage association ditches
- Ongoing geophysical research on the subsurface hydrology driving the transport of nutrients off the field
- Subsurface processes poorly represented in many models



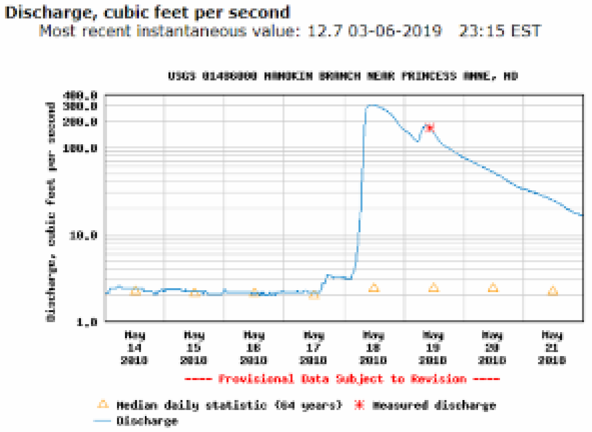
Modeled Watershed – Manokin Branch:

- Gauged headwater watershed on tributary of Manokin River
- Land cover composed of dry and wet forests (66%), cropland (22%), residential (6.1%), farm structures (2.6%), and other (3.3%)
- Manokin River drains directly to Chesapeake Bay

SWAT-VSA modeling for phosphorus results:
Methodology

- SWAT-VSA (Easton et al., 2008): topographic index (TI) (from TauDEM) integrated with soils layer
- Land use derived from USDA-NASS cropland data layer (CDL).
    - Cropland rotations from multiple year CDL images
    - Crop management based on regional ag guidelines
- Cropland WIP 2012 integrated into management (subset of LR segment: EL0_6001_0000)
- Weather data from UMES farm station (2001 – 2018)
- Scenario Development from multiple climate models for SWAT-VSA runs:
    - Temperature and precipitation deltas applied to weather scenarios
    - Planting dates modified from baseline for corn, soybean, and winter wheat
    - Weather and planting scenarios integrated

USGS 01486000 MANOKIN BRANCH NEAR PRINCESS ANNE, MD



Easton ZM, Fuka DR, Walter MT, Cowan DM, Schneiderman EM, Steenhuis TS. 2008. Re-Conceptualizing the Soil and Water Assessment Tool (SWAT) model to predict runoff from variable source areas. Journal of Hydrology 348: 279–291.

ROMS-RCA implementation in Chester River estuary

Grid 174 x 174 x 10 (cells ~ 70 m^2)

Loads from CBL Phase 6

Boundary from CBP data

Validation data:

-Sediment-water fluxes

-ConMon continuous data

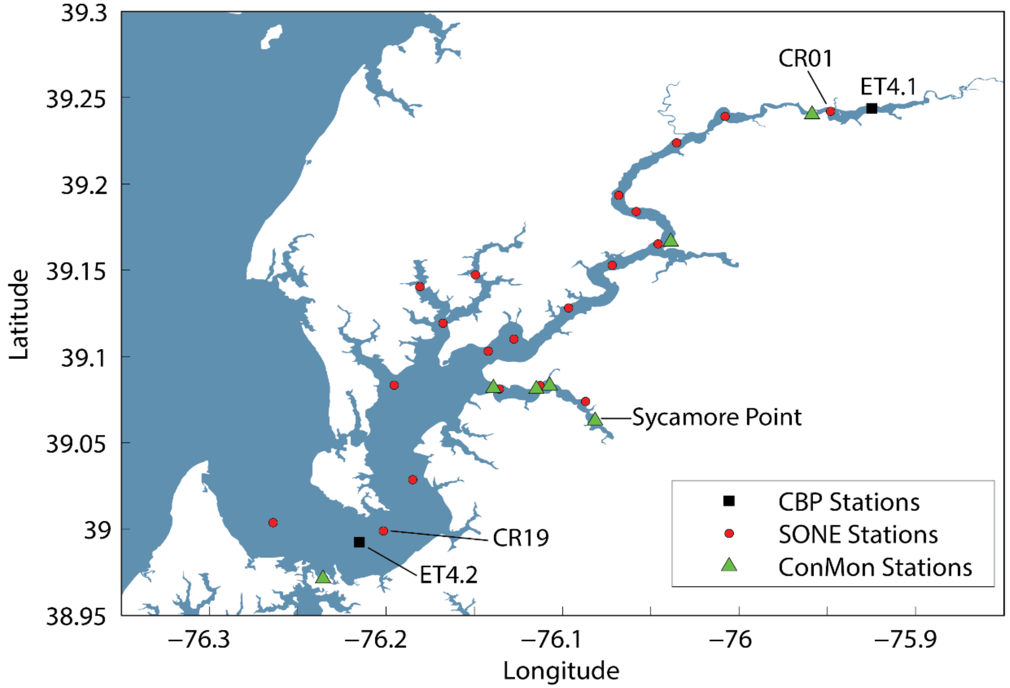
-Two long-term fixed stations

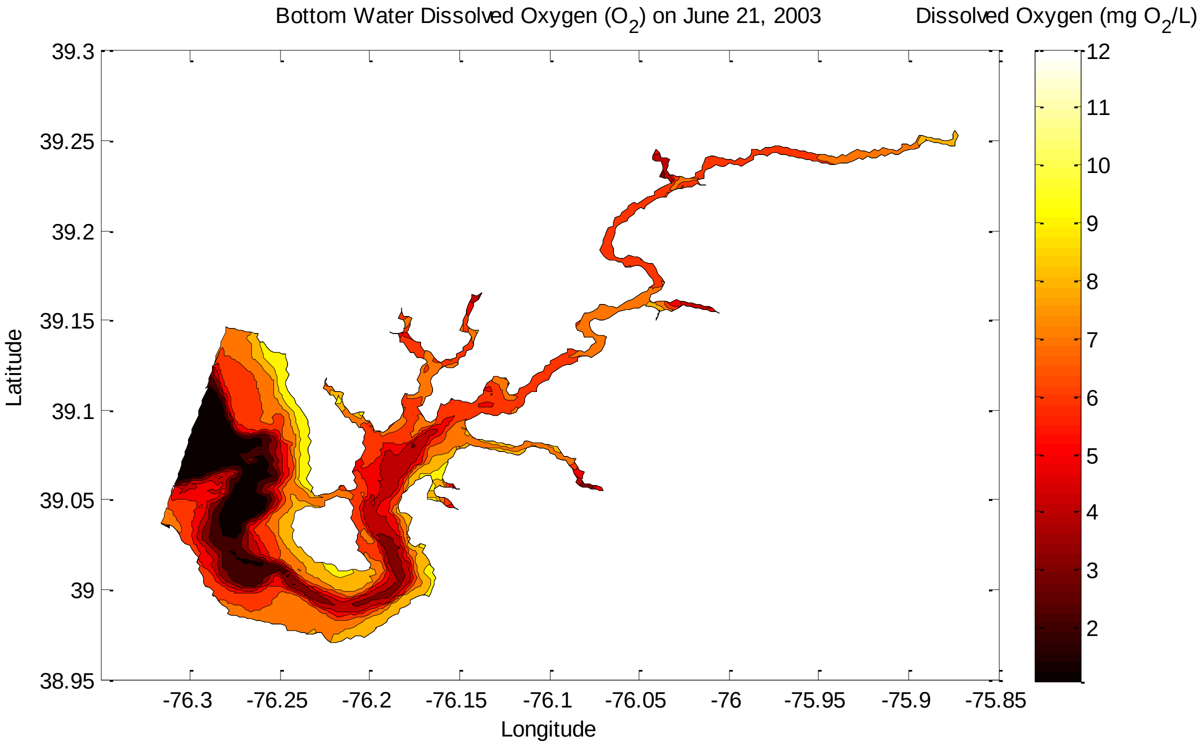
System Features:

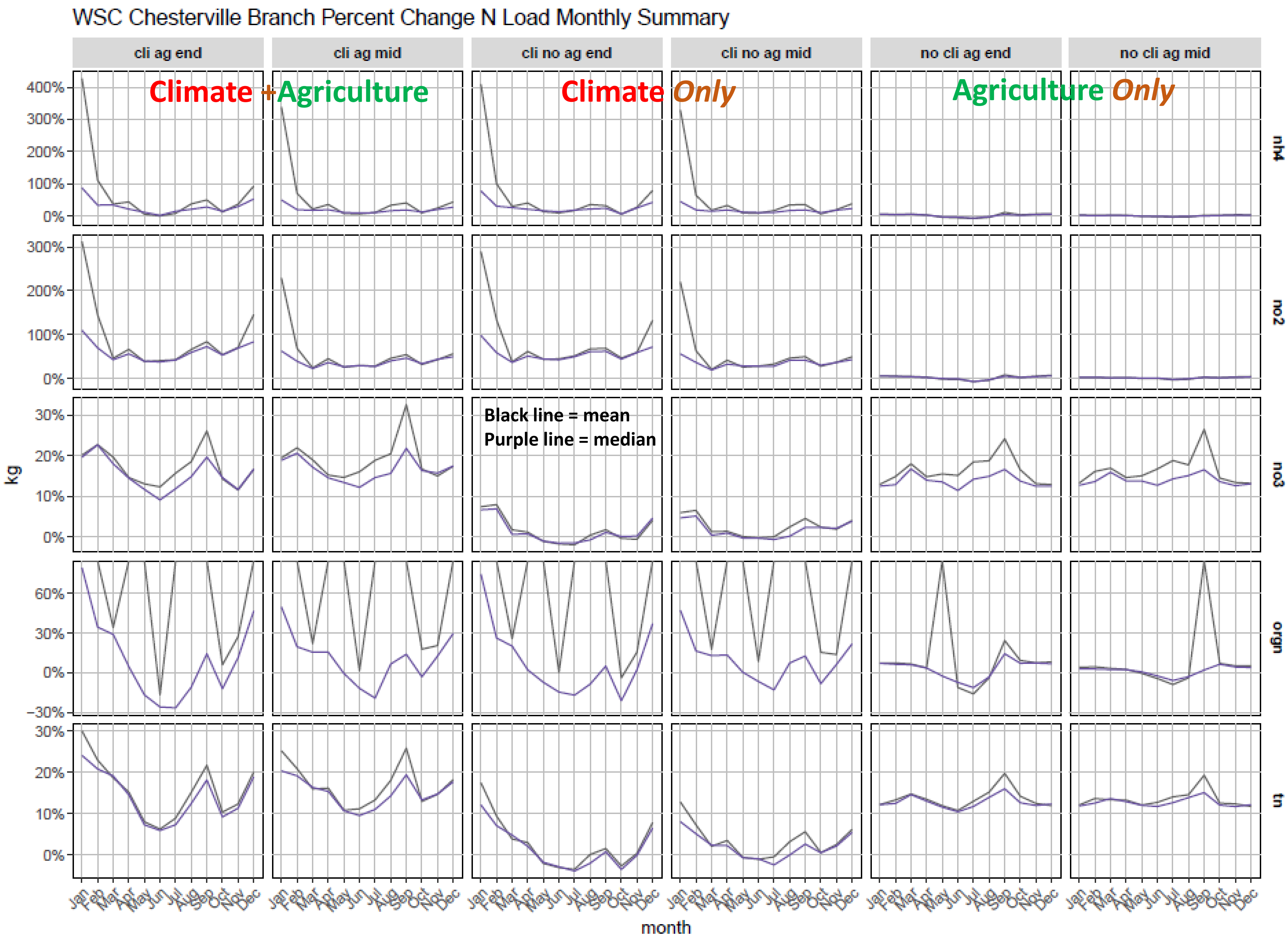
-Diel cycling + seasonal hypoxia

-high nutrients

-chl-a decline, SAV recovery in very upper estuary

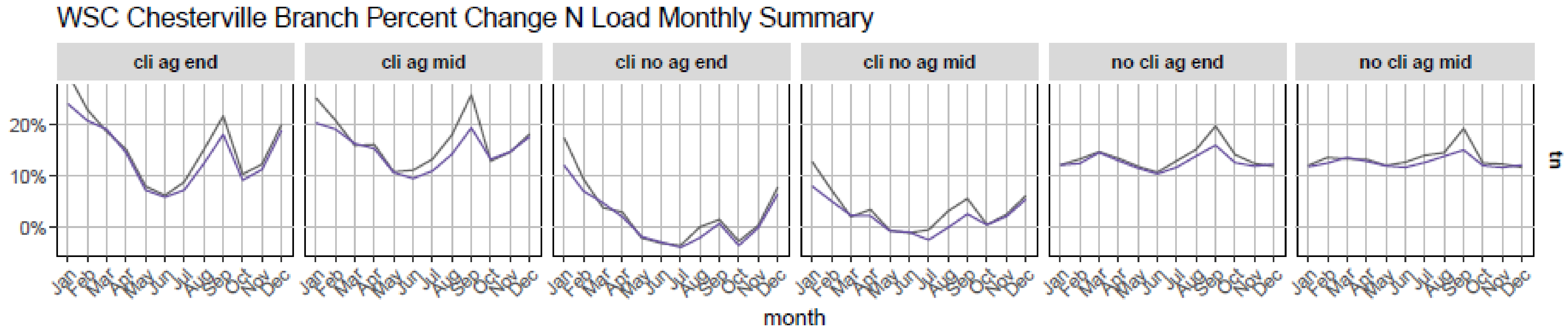






Mean and Median % load change for 17 projections, mid and end of century

Delta TN load by Scenario

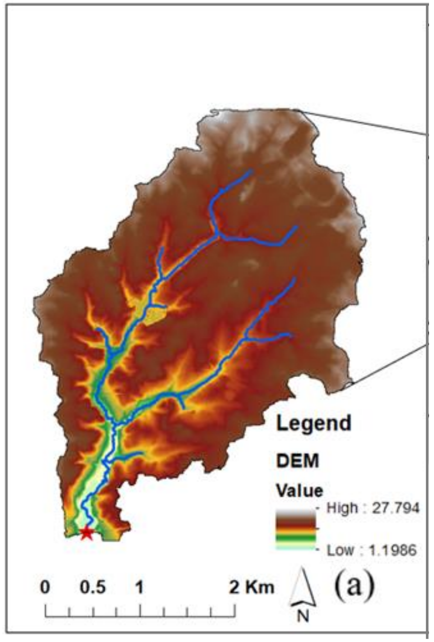


Climate-only scenarios leads to early and late year increase in TN load, mid summer decline

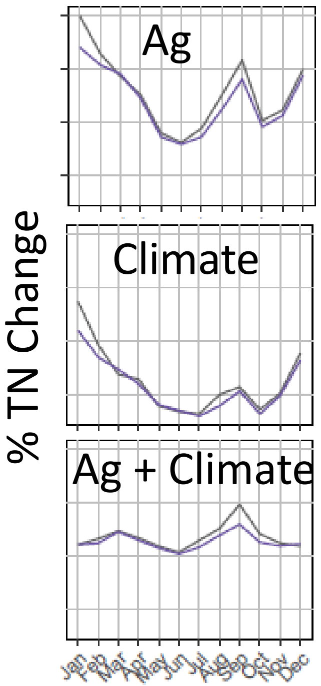
Agricultural simulation leads to higher TN (also higher NO_3) year round, especially in spring and late summer

Linking Chesterville SWAT Scenarios, Phase 6 Inputs, and Estuary

Chesterville Branch SWAT ‘deltas’

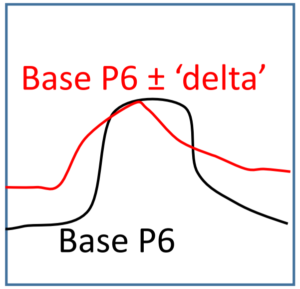


Chesterville Branch



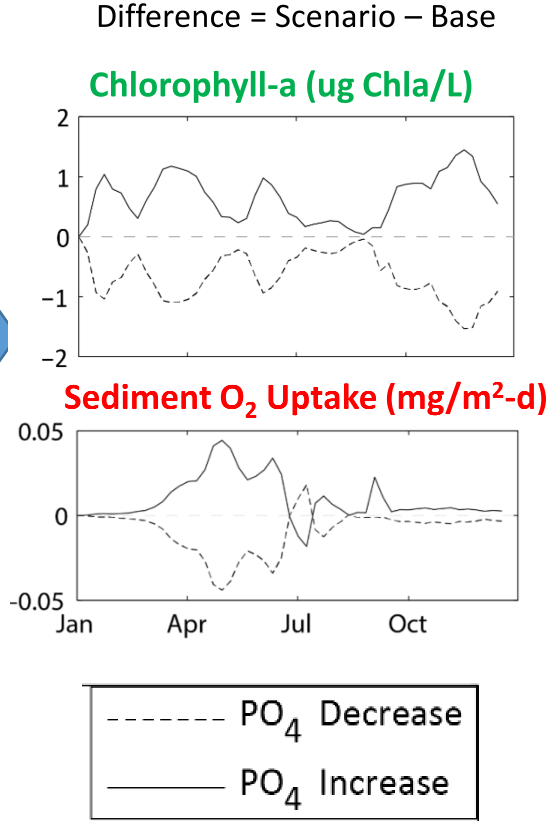
Apply to Phase 6

Phase 6 WSM



Extrapolate to Basin

Drive Estuary Model



Next steps

1. Finish SWAT modeling to generate seasonal changes in P loads
2. Finish farmer adoption modeling (Zipp, PSU)
3. Generate policy scenarios of farmer adoption of “extreme” drainage management
4. Run CBP watershed model (with post-processing) to estimate effects of permanent vs temporary BMPs on runoff and link to Testa estuary model to assess effects on bay water quality
5. Generate cost-effectiveness of adaptive policy scenarios under climate change

Most Relevant Papers - to date

- Testa, J.M., R.R. Murphy, D.C. Brady, and W.M. Kemp. 2018. Nutrient- and climate-induced shifts in the phenology of linked biogeochemical cycles in a temperate estuary. Frontiers in Marine Science: https://doi.org/10.3389/fmars.2018.00114.
- Testa, J.M., W.M. Kemp, and W.R. Boynton. 2018. Season-specific trends and linkages of nitrogen and oxygen cycles in Chesapeake Bay. Limnology and Oceanography: doi: 10.1002/lno.10823.
- Friedland, K.D., Mouw, C.B., Asch, R.G., Ferreira, A.S.A., Henson, S., Hyde, K.J., Morse, R.E., Thomas, A.C., & Brady, D.C. (2018) Phenology and time series trends of the dominant seasonal phytoplankton bloom across global scales. Global Ecology and Biogeography 27(5), 551-569 doi: 10.1111/geb.12717
- Fennel, K., and J.M. Testa. 2019. Biogeochemical controls on coastal hypoxia. Annual Review of Marine Science 11:105-130. https://doi.org/10.1146/annurev-marine-010318-095138
- Wilusz, D. C., C. J. Harman, W. P. Ball (2017). Sensitivity of catchment transit times to rainfall variability under present and future climates. *Water Resources Research*, 53, doi.org/10.1002/2017WR020894.
- Wilusz, D. C., C. J. Harman, W. P. Ball (2017). Data and code associated with the publication "Sensitivity of catchment transit times to rainfall variability under present and future climates", Johns Hopkins University Data Archive, doi:10.7281/T1/OM3OMQ.
- Wilusz, D. C., R. M. Maxwell, A. Buda, W. P. Ball, C. J. Harman. What can transit time distributions tell us about runoff mechanisms? Exploring age-equifinality with an integrated surface-groundwater model. (in review)
- Fang, Z., R. W. H. Carroll, R. Schumer, C. J. Harman, D. Wilusz, and K. H. Williams, Streamflow partitioning and transit time distribution in snow-dominated basins as a function of climate, Journal of Hydrology, vol. 570, pp. 726–738
- Ortiz-Bobea, A., "The Role of Nonfarm Influences in Ricardian Estimates of Climate Change Impacts on U.S. Agriculture," American Journal of Agricultural Economics (2019). Doi: 10.1093/ajae/aaz047.
- Ortiz-Bobea, A., H. Wang, C. Carrillo and T.R. Ault, "Unpacking the climatic drivers of U.S. agricultural yields", Environmental Research Letters 14:6 (2019)
- Wang, H. and A. Ortiz-Bobea, "Market-Driven Corn Monoculture in the US Midwest," Agricultural and Resource Economics Review(2019) 1–23.
- Ortiz-Bobea, A., E. Knippenberg and R.G. Chambers, "Growing Climatic Sensitivity of US Agriculture Linked to Technological Change and Regional Specialization,"Science Advances 4:12 (2018)