Nutrient improvements in Chesapeake Bay: Direct effect of load reductions and implications for coastal management

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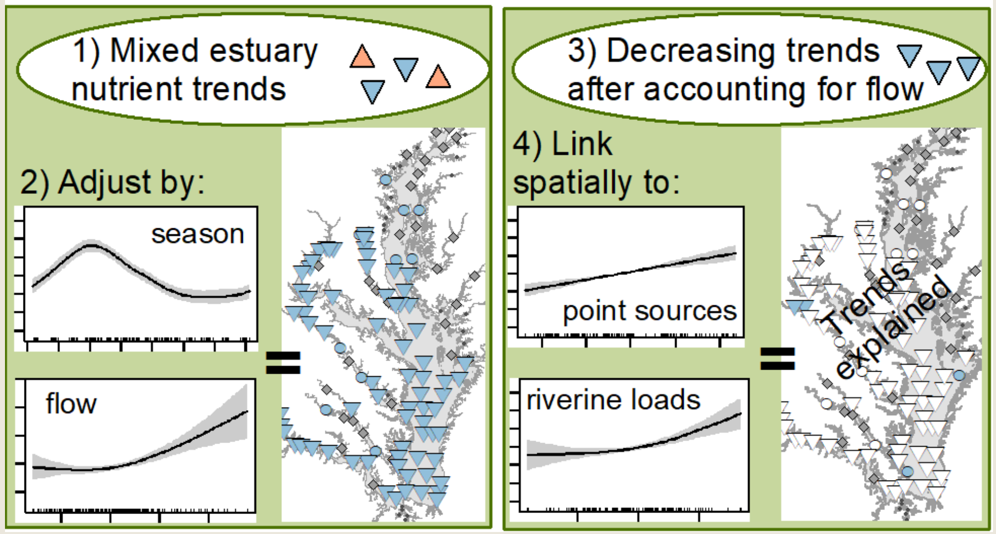

Presentation to ITAT

Feb. 23, 2022

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https://doi.org/10.1021/acs.est.1c05388

Goals of this study

- **Part 1:** Summarize the observed tidal nutrient changes over time for surface total nitrogen (TN) and total phosphorus (TP)

- **Part 2:** Evaluate and document the extent to which we can explain these estuary nutrient patterns with monitored nutrient loads
  - *RIM and some NTN loads of TN and TP ("river loads")*
  - *Below-gage point loads*

Methods: Part 1

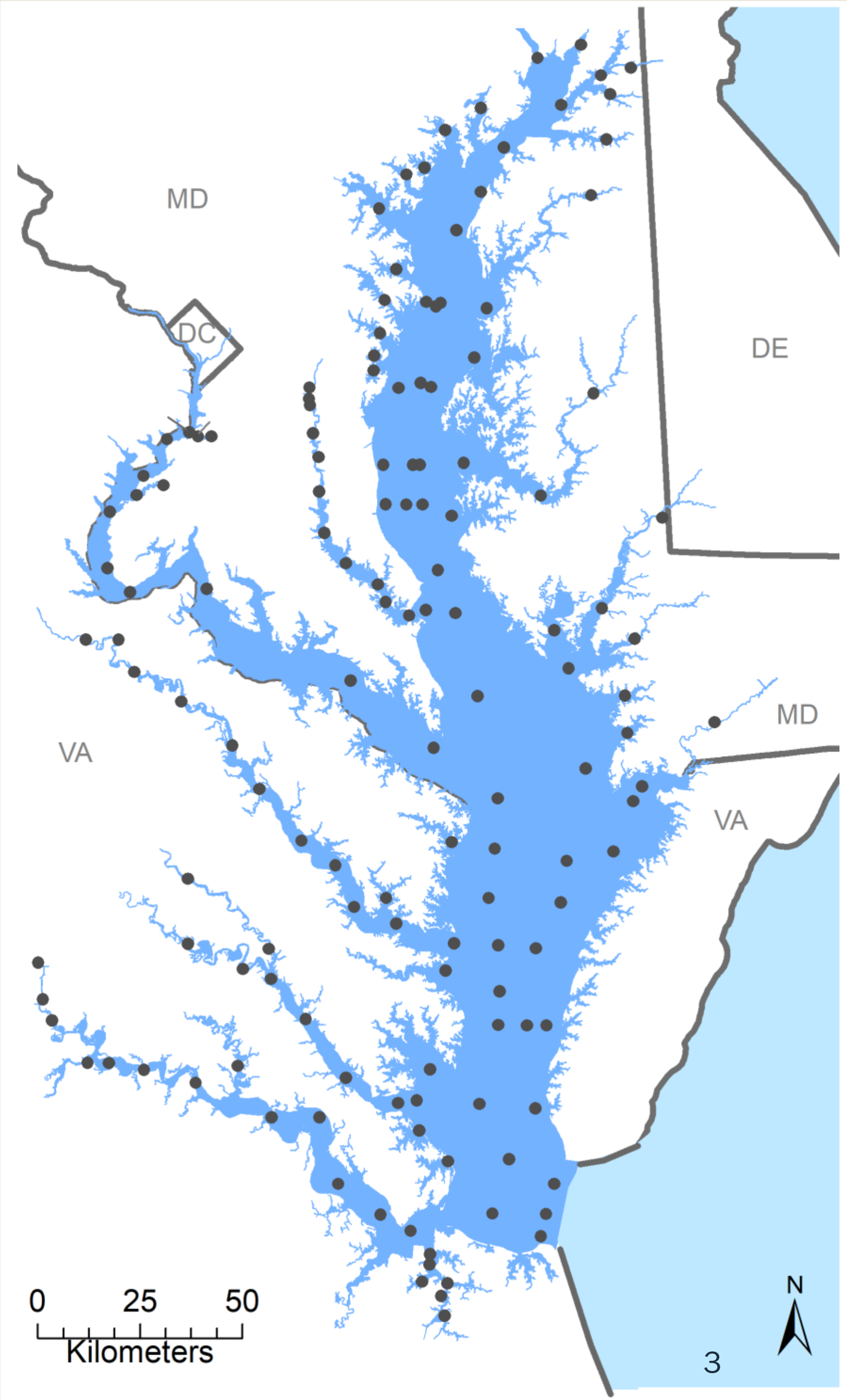
- Stations evaluated = 136 tidal monitoring stations with data from the mid-1980s to present
- Generalized Additive Model (GAM) structures set up to capture change over time and season

GAM equations:

y ~ date + s(date) + s(doy)+ ti(date,doy)

y ~ intervention + date + s(date) + s(doy)+ ti(date,doy)

date = decimal date (1985.6, etc)
doy = day of year (1, … 365)
s() smooth spline fit
ti() tensor product interaction
intervention = factor variable indicating when change occurred (applies to some TN data sets)



Methods: Part 1

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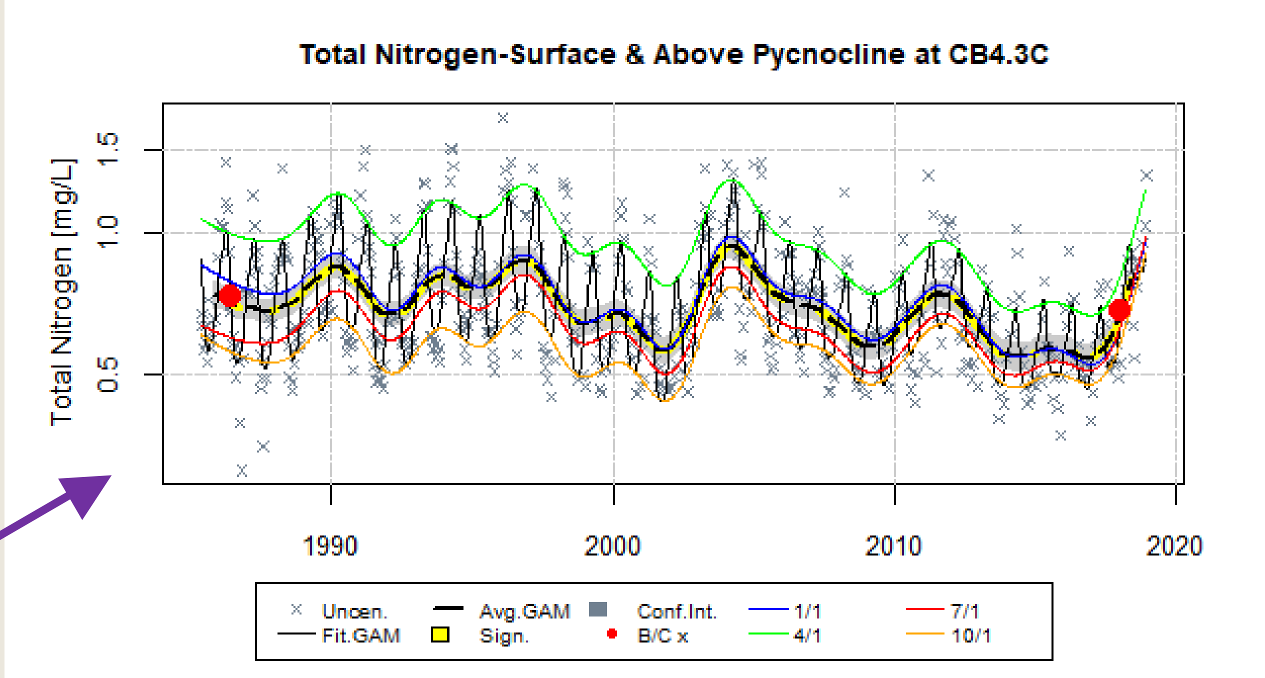
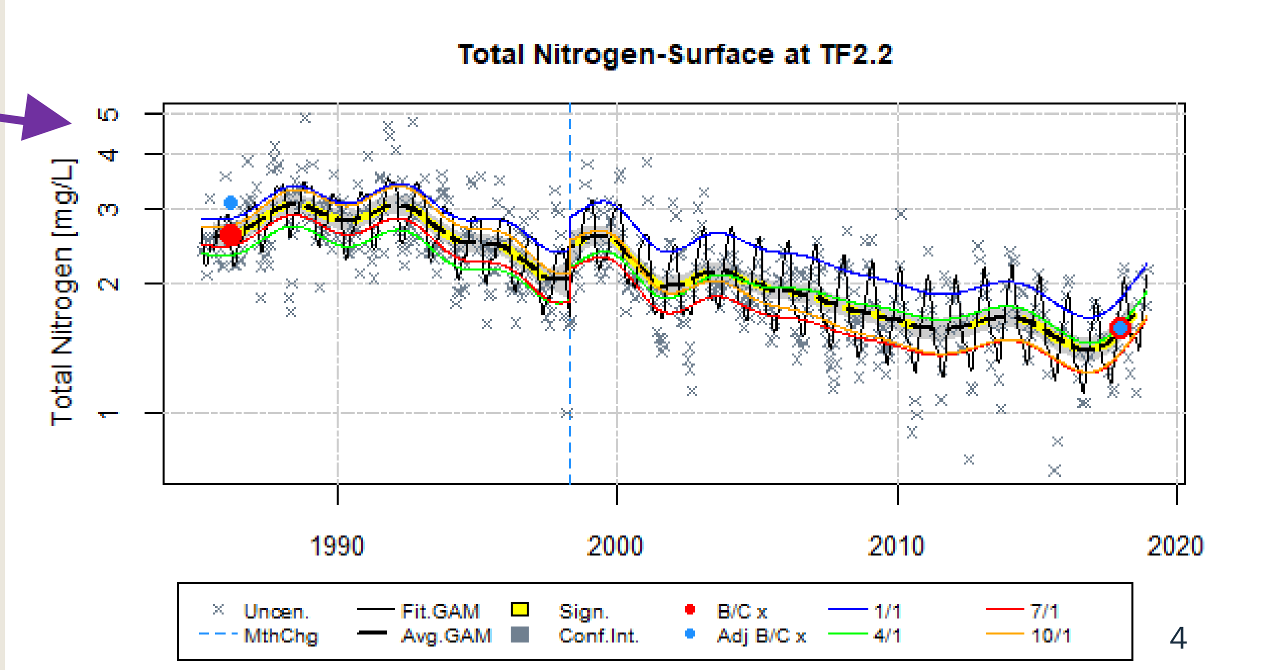
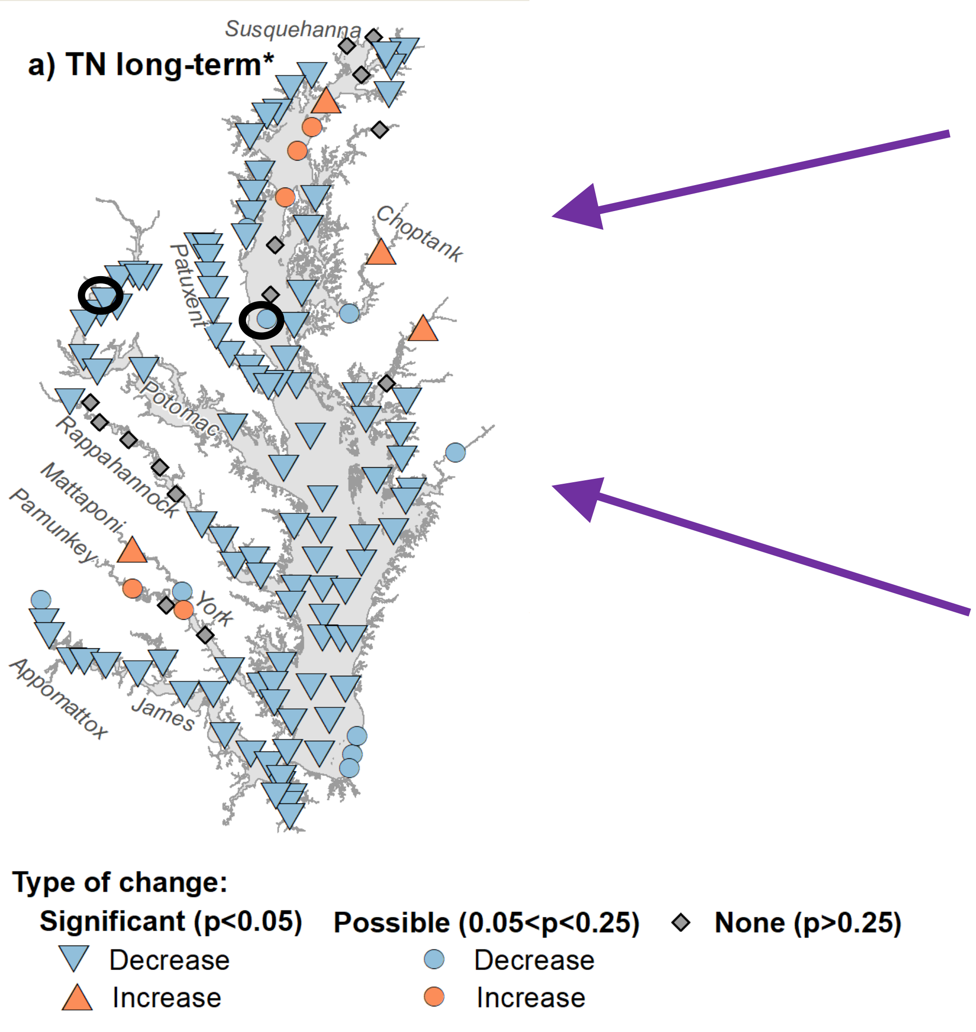
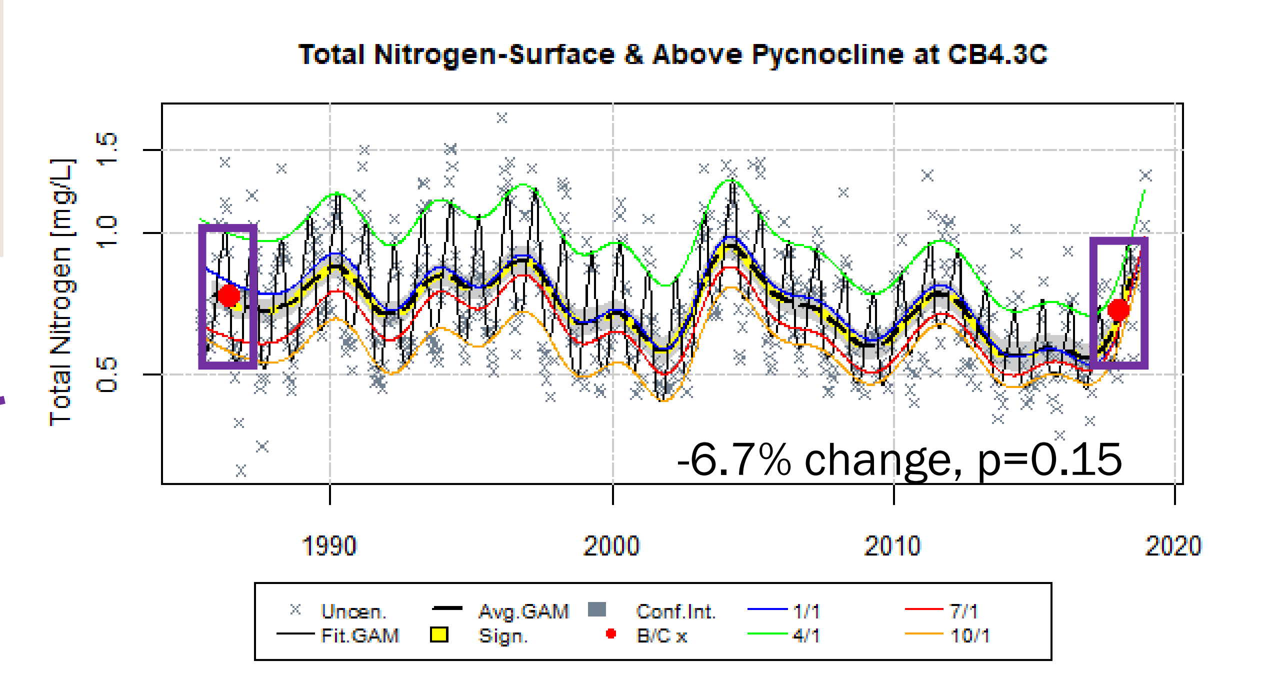
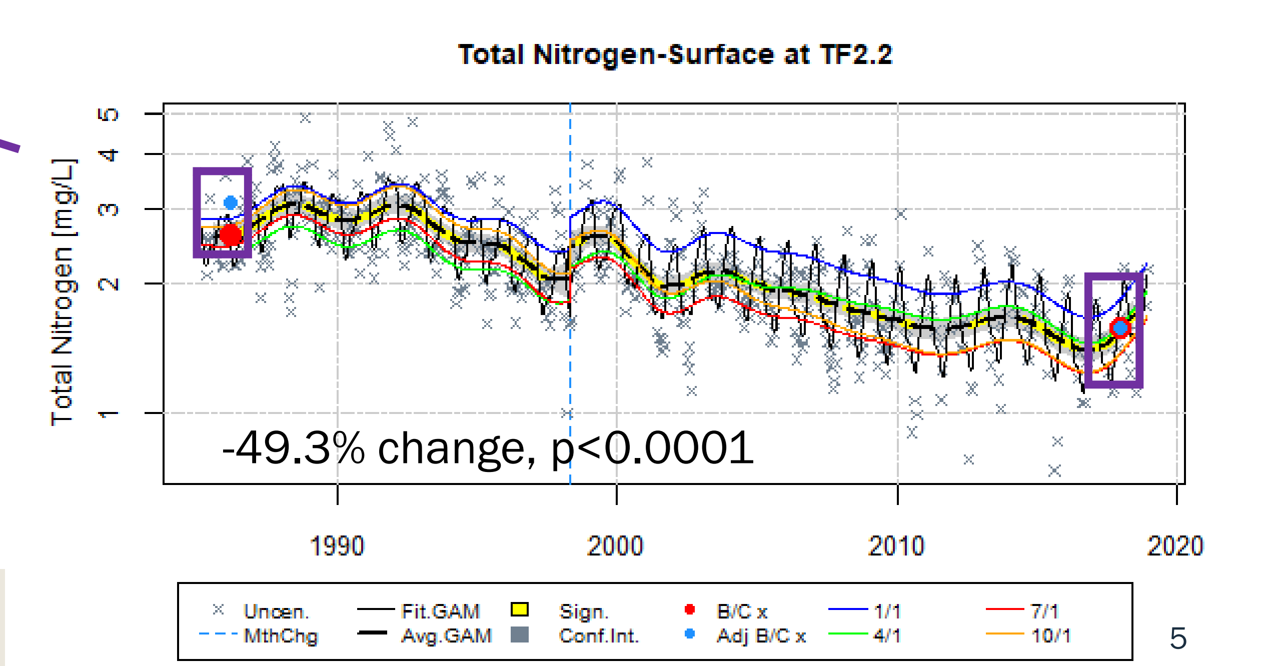




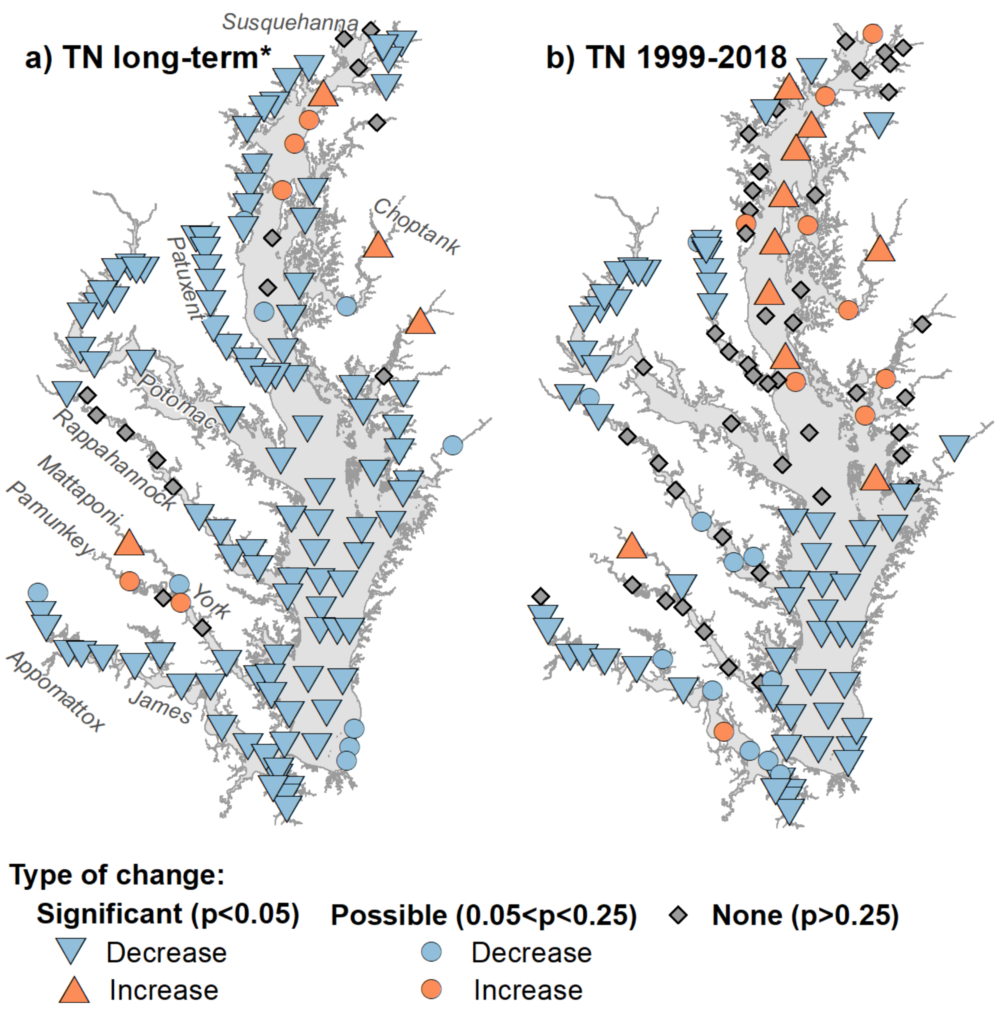
Methods: Part 1

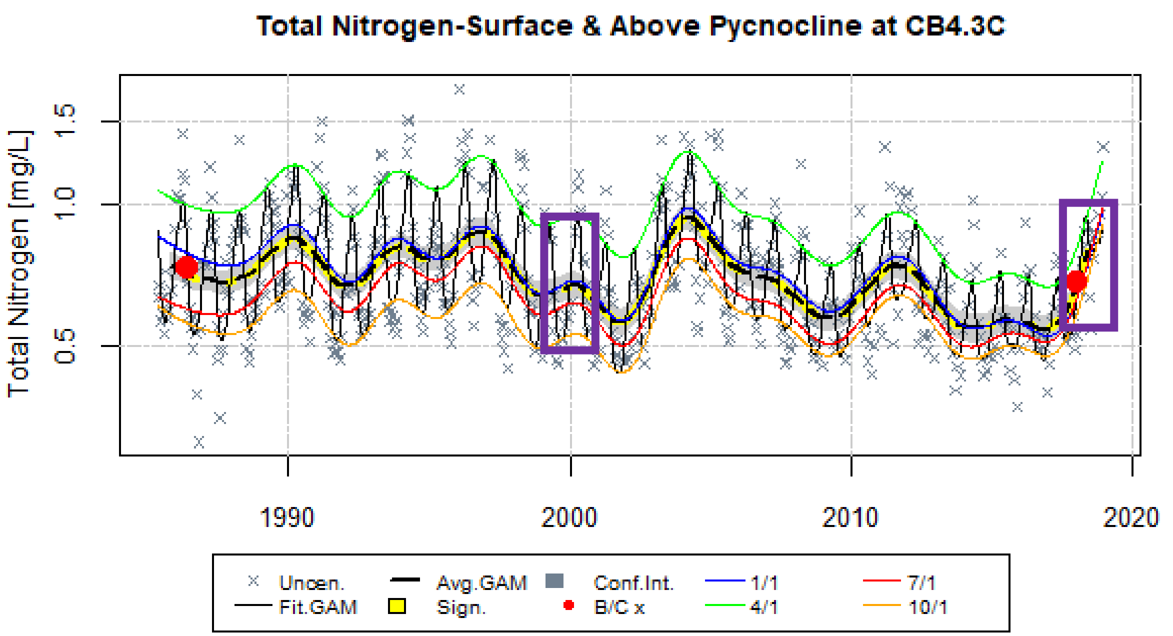


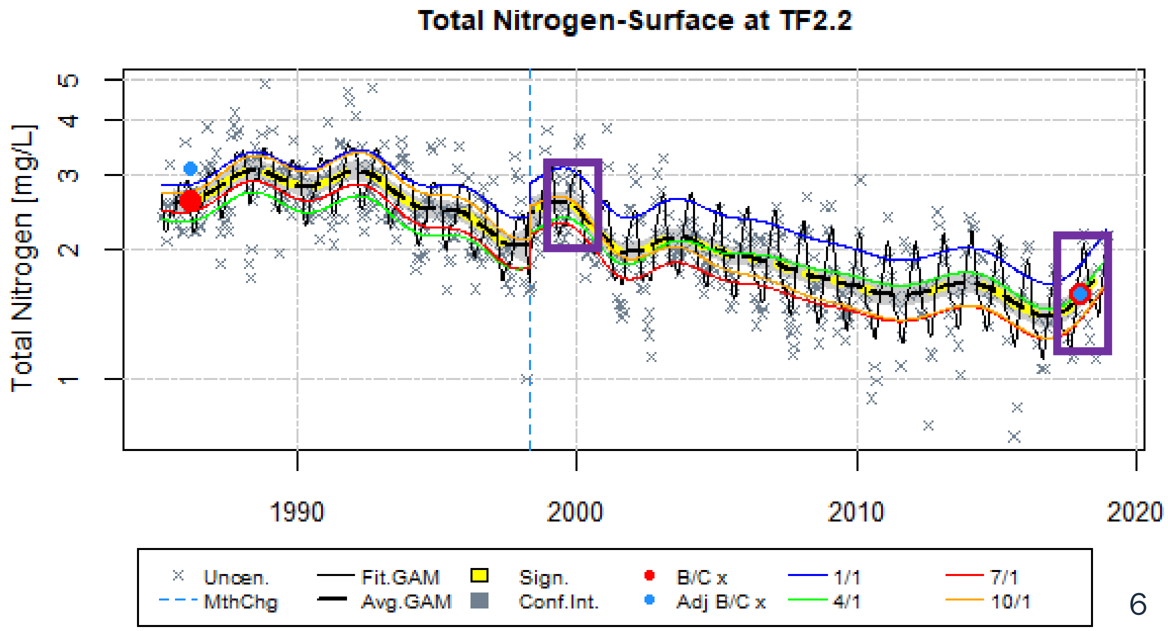




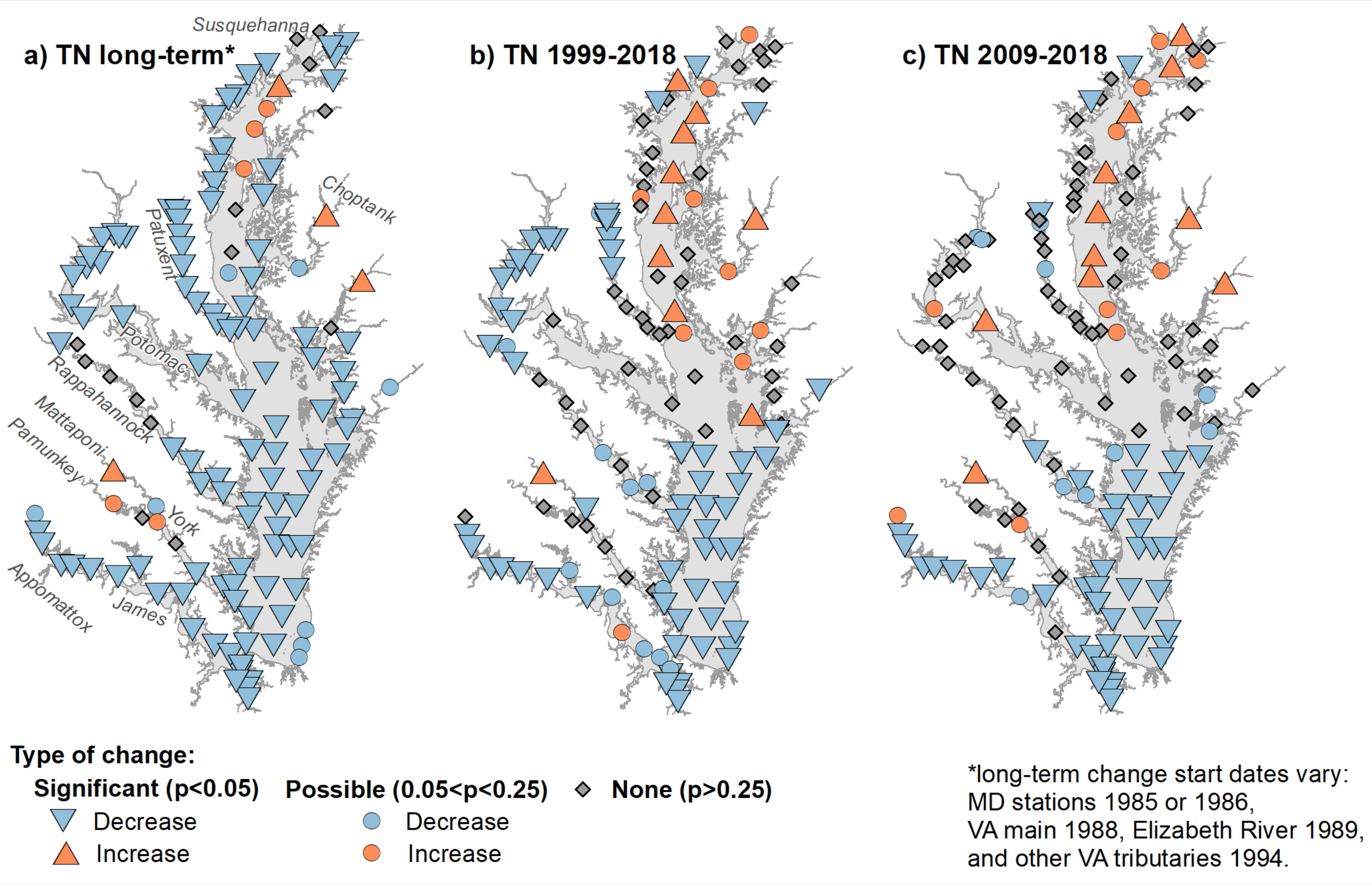
Methods: Part 1



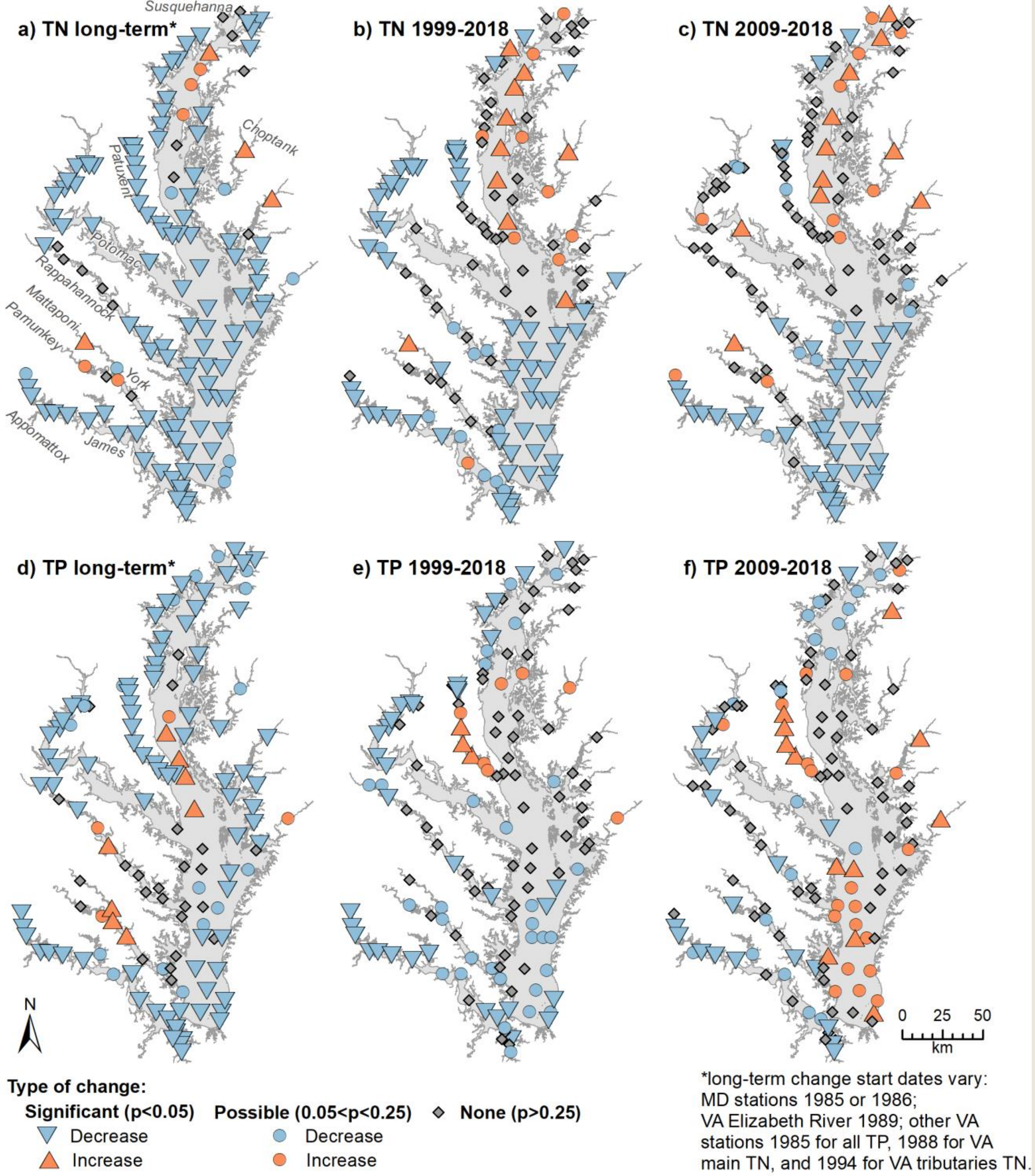


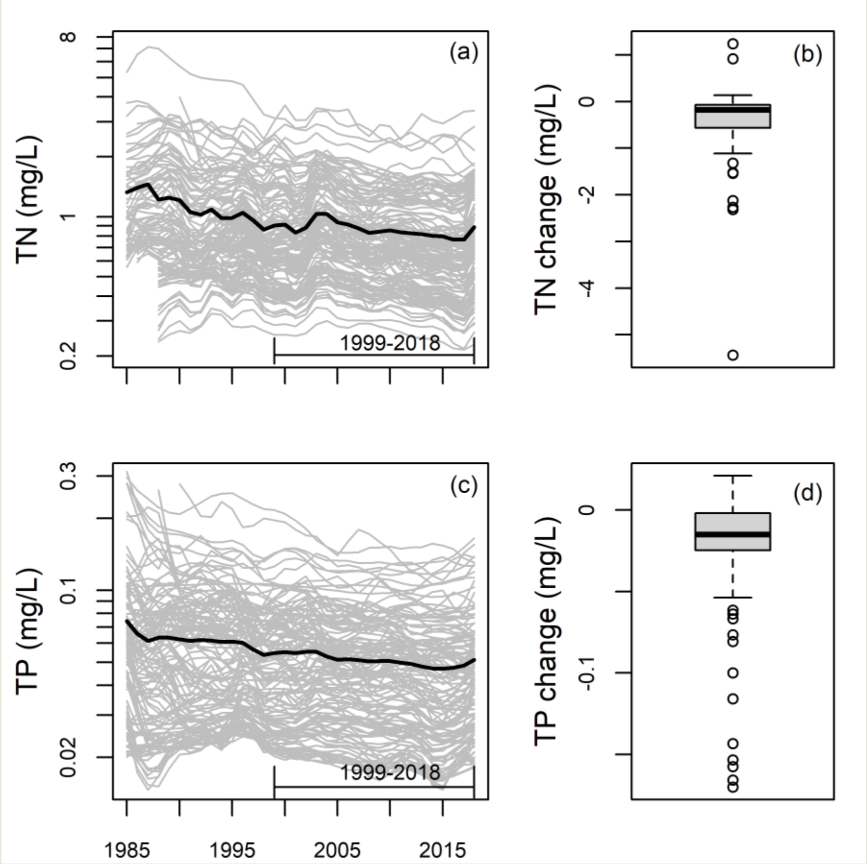


Results Part 1: Observed surface TN change



Results Part 1: Surface TN and TP changes





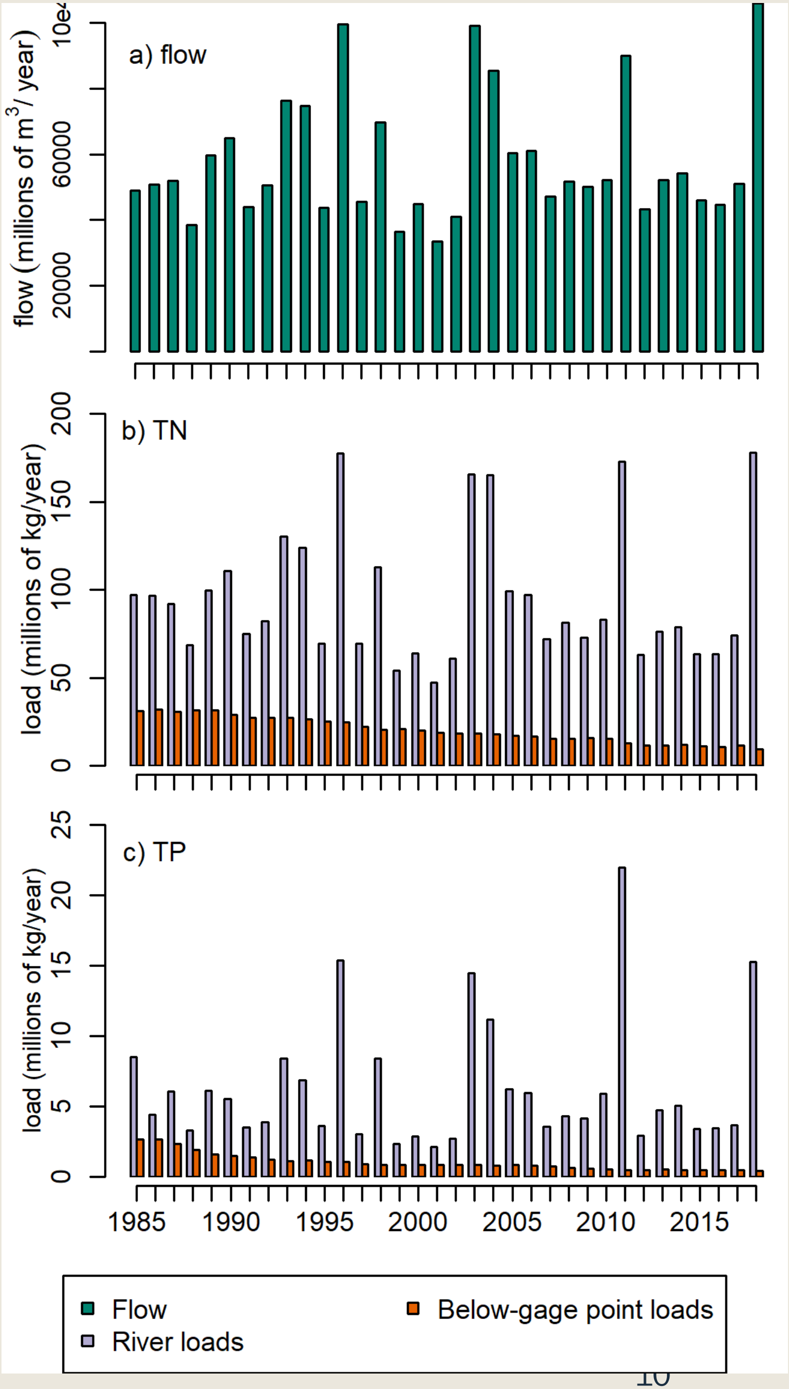
All annual average GAM fits (grey lines) and average bay-wide pattern (black lines)

Summary Part 1

- Long-term TN and TP concentrations have decreased at 83% and 73% of the stations.
- Shorter-term changes include more constant or increasing patterns.
- Bottom patterns are very similar.
- Long-term patterns generally consistent with other findings showing some possible increases in oligohaline region for mainstem, strong decreases in the larger tributaries.

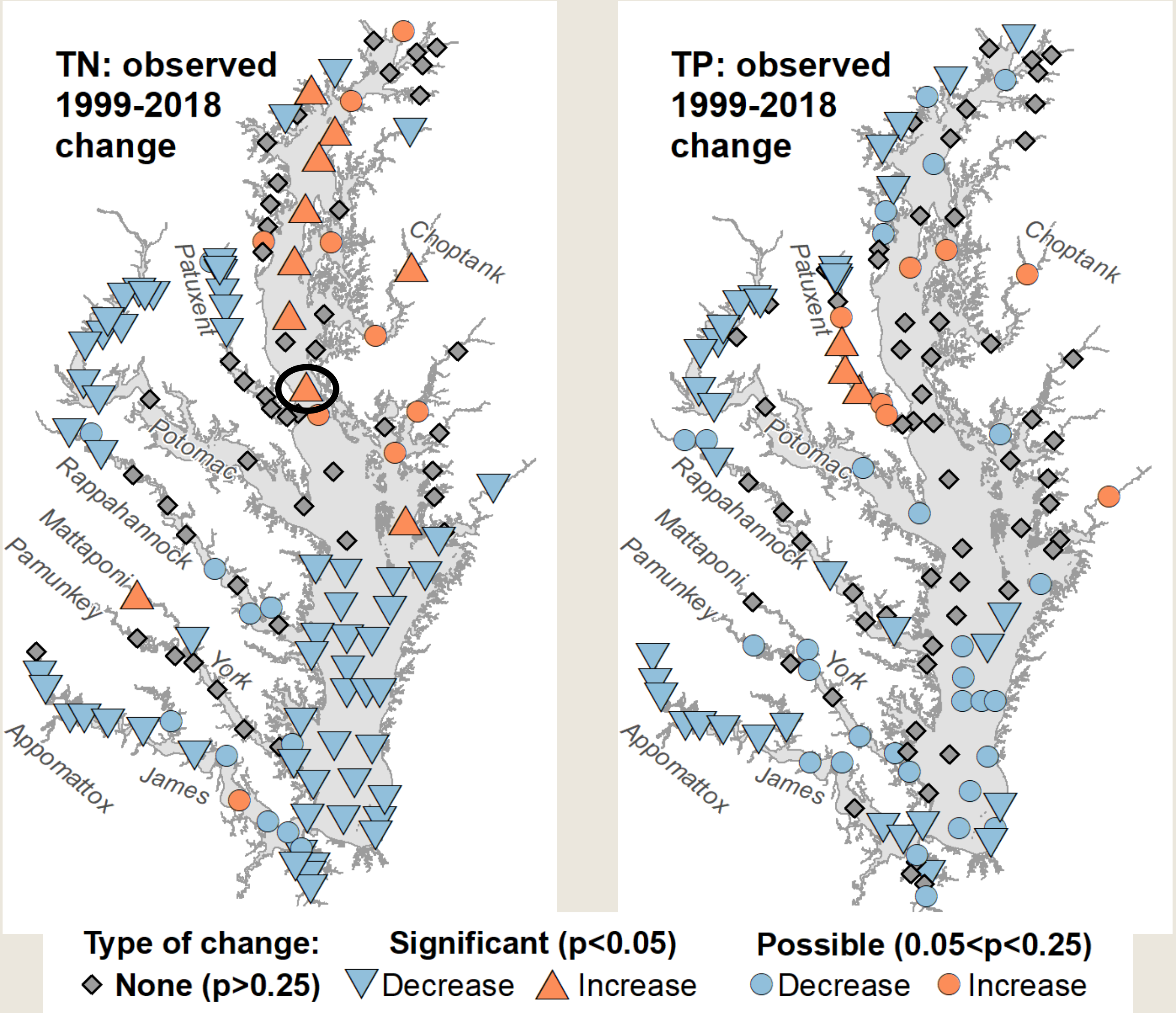
Part 2. Using GAMs to test factors influencing trends

Are variations in freshwater flow and nutrient loads causing the trends over time?



Step 1

Test flow or salinity for explaining trends



Fit temporal change:

TN = s(day of year) + ~~s(date)~~ + interaction(~~date~~,doy)

Factor-testing equation:

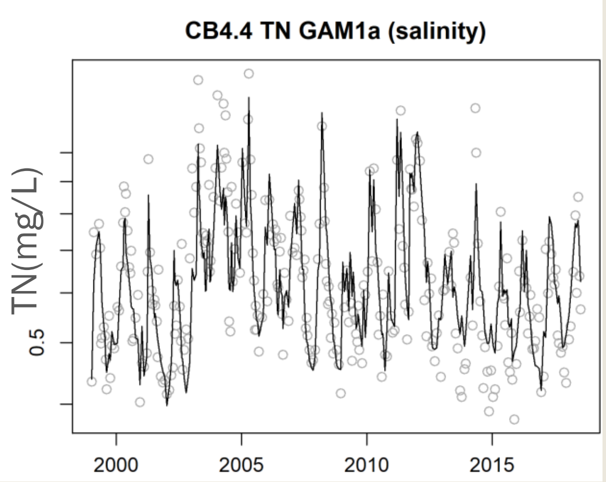
TN = s(day of year) + s(flw_sal) + interaction(flw_sal,doy)

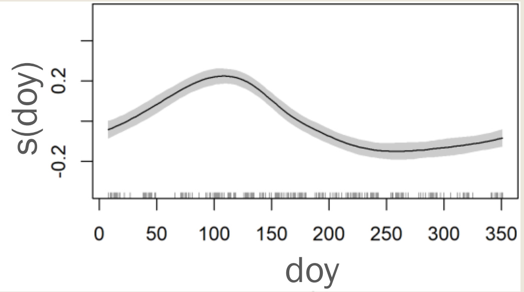
Identify either a freshwater flow time series OR salinity as the best measure of freshwater influence at each station.

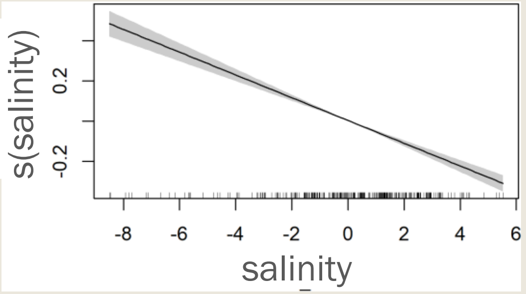
Step 1

Test flow or salinity for explaining trends

a) TN = s(doy) + **s(flw_sal)** + interaction(**flw_sal**,doy)



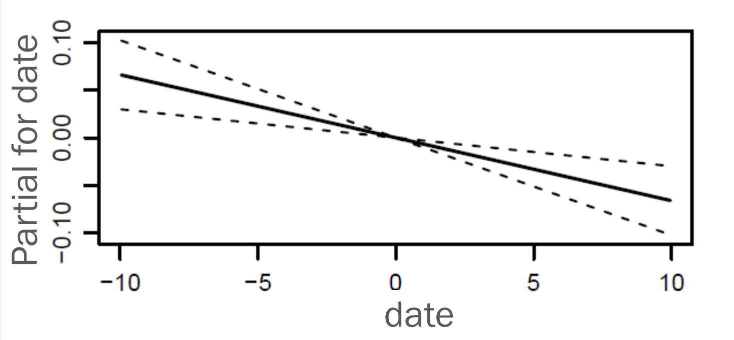




AIC = -349
R^2 = 0.76

TN goes down as salinity increases, but does that explain the trend?

b) TN = s(doy) + **s(flw_sal)** + interaction(**flw_sal**,doy) **+ date**



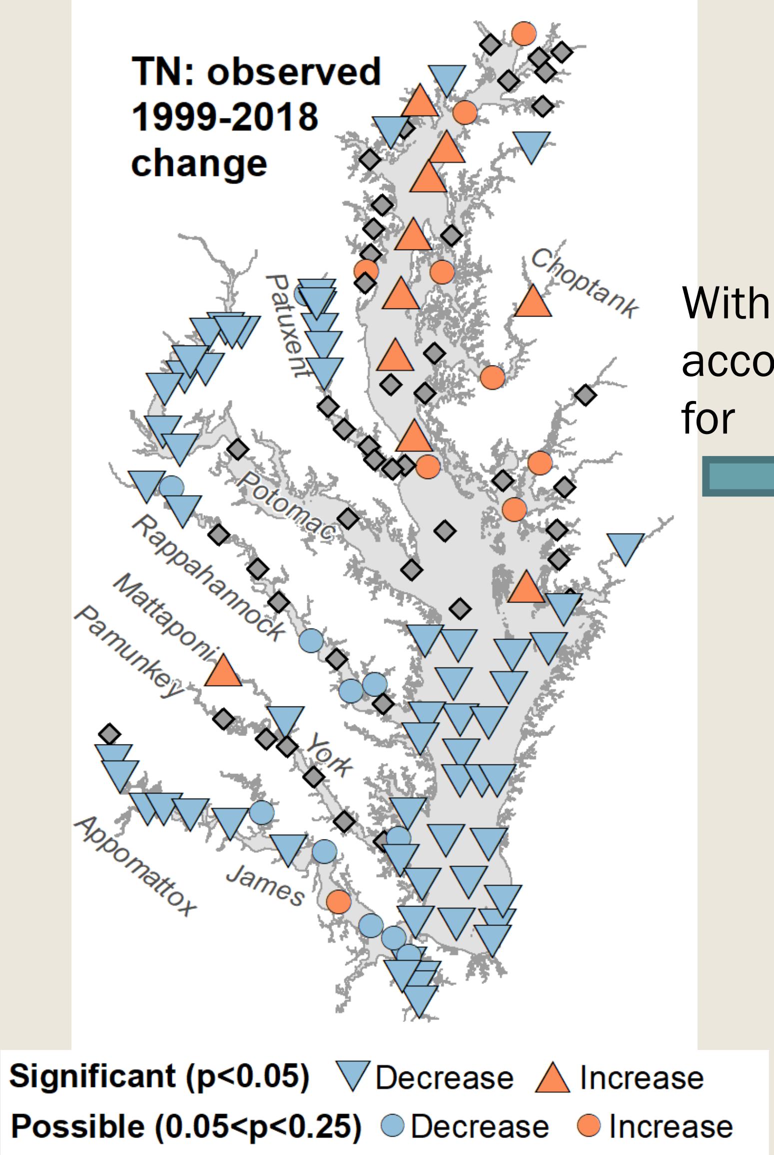
AIC = -359
AIC difference = 10
Slope on date = negative

Conclusion: *After accounting for the influence of flow, TN is* *<u>strongly decreasing</u>* *at this station*

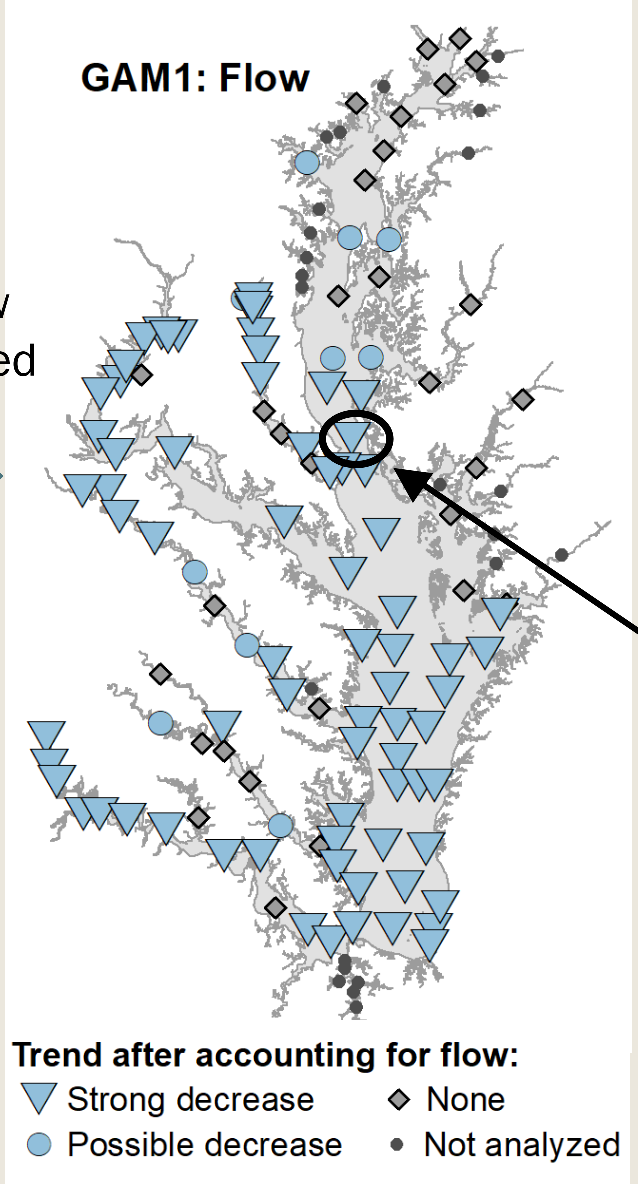
Note: all models used include autocorrelation (AR1) term

Step 2

TN: Examine salinity- or flow-adjusted trends



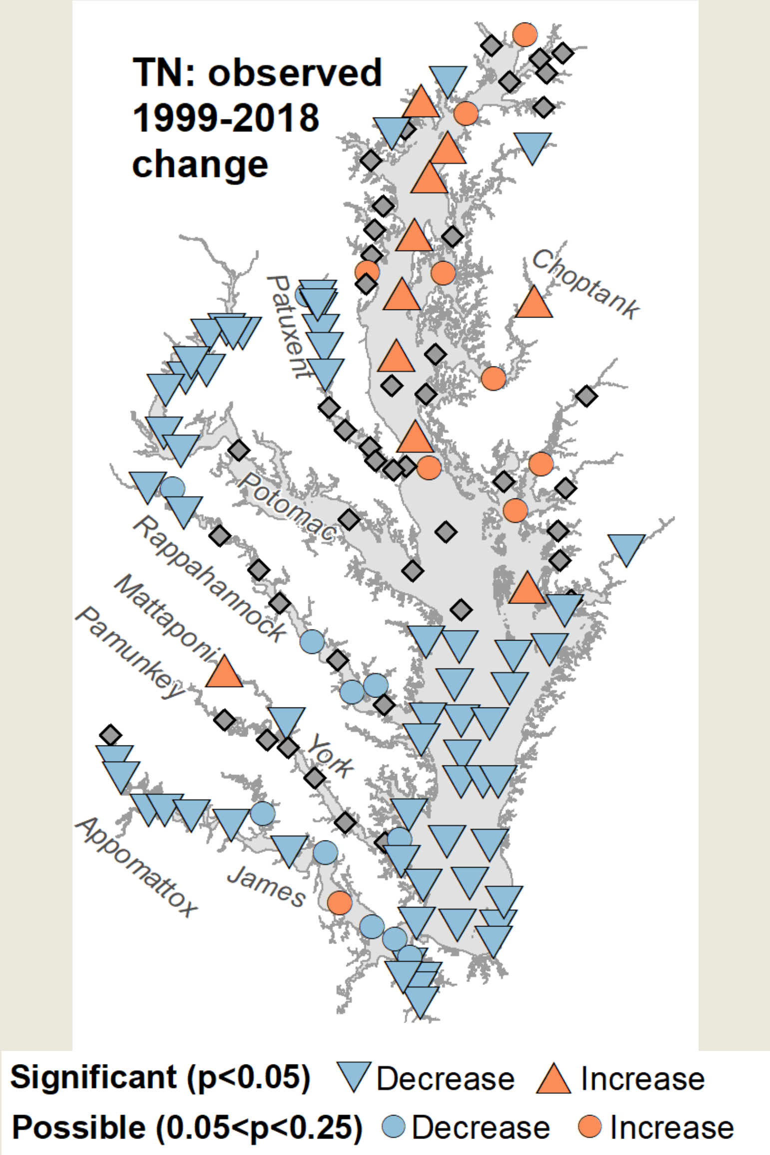
With flow accounted for

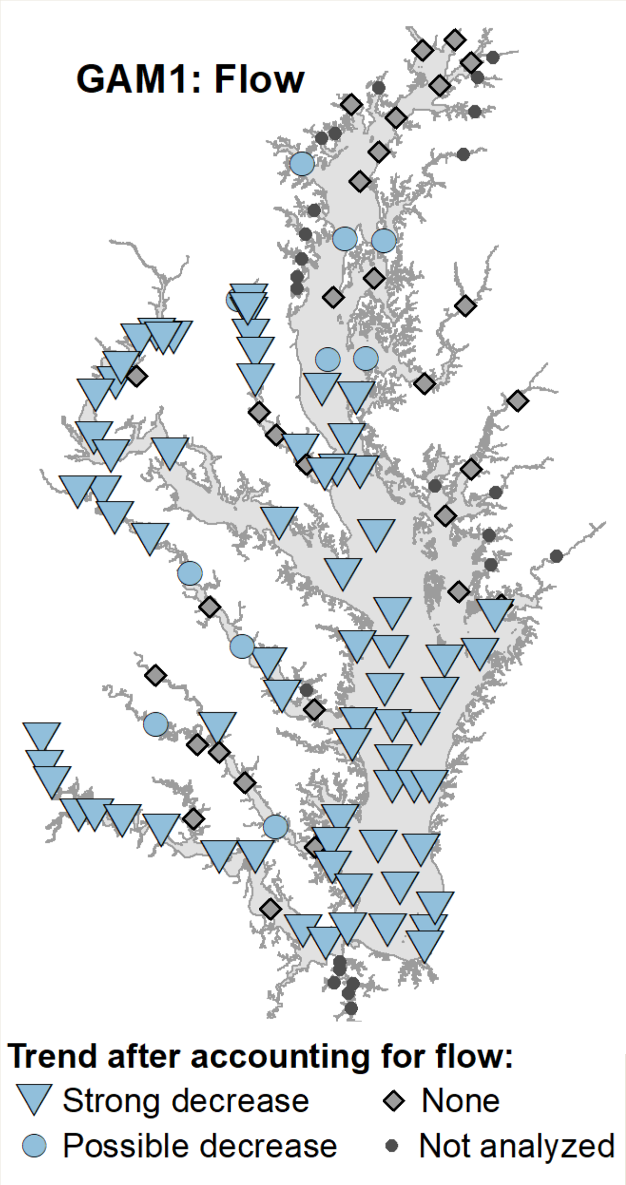


Conclusion: *After accounting for the influence of flow, TN is* ***strongly decreasing*** *at this station*

Step 2

TN: Examine salinity or flow-adjusted trends



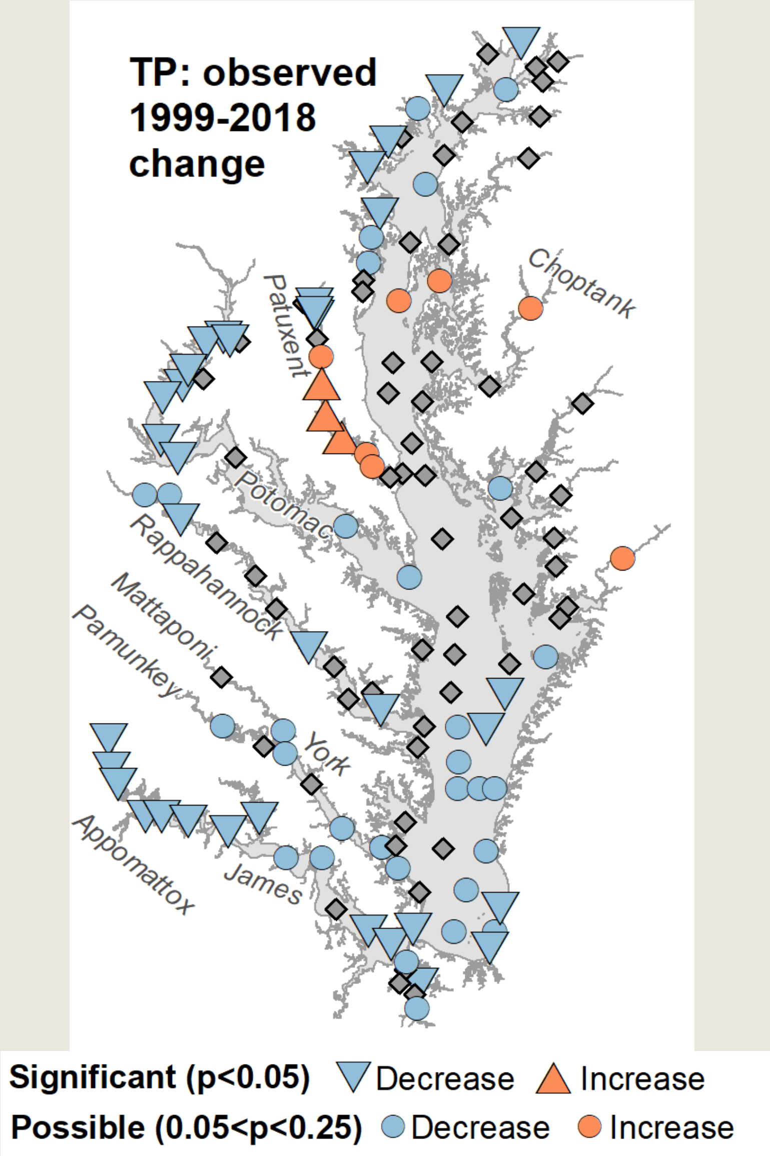


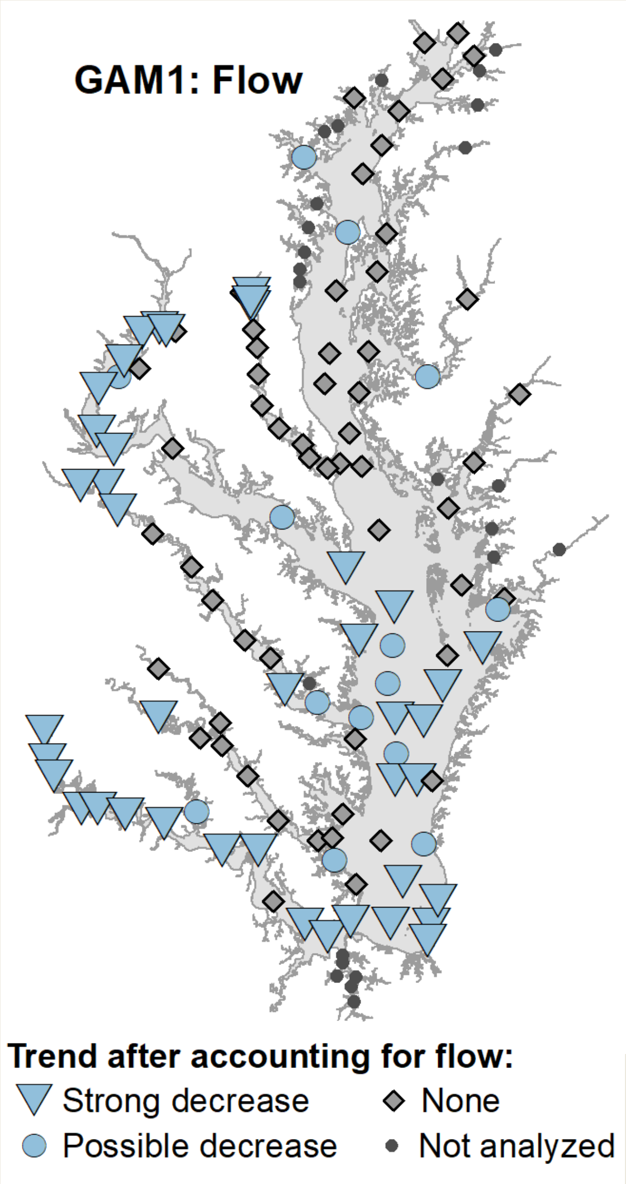
Summary:

- For TN, the increasing observed trends appear to be mostly explained by freshwater flow fluctuations
- After flow or salinity adjustment:
  - *27% of stations have no trend*
  - *73% of stations have improving flow-adjusted TN*

Step 2

TP: Examine salinity or flow-adjusted trends

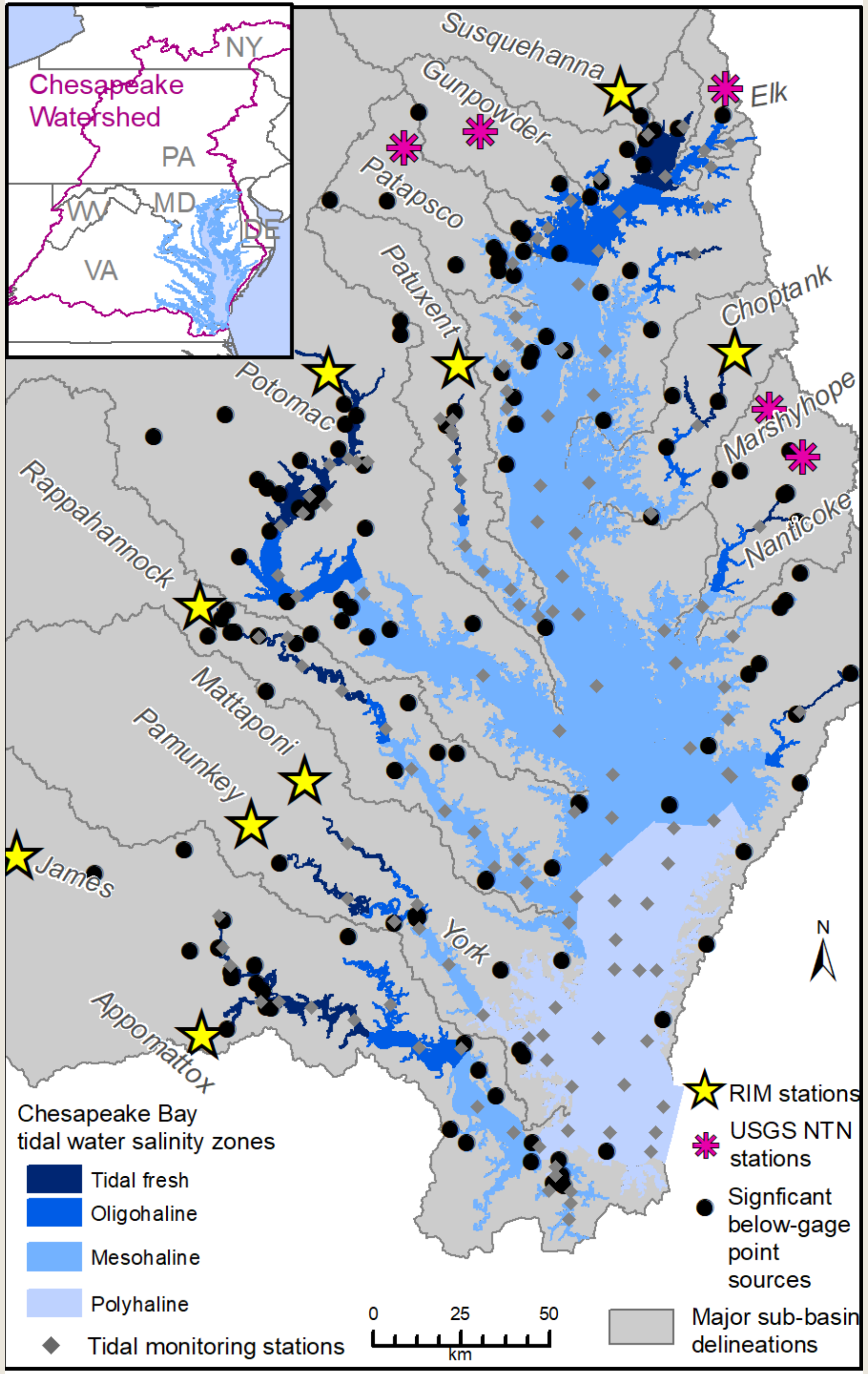




Summary:

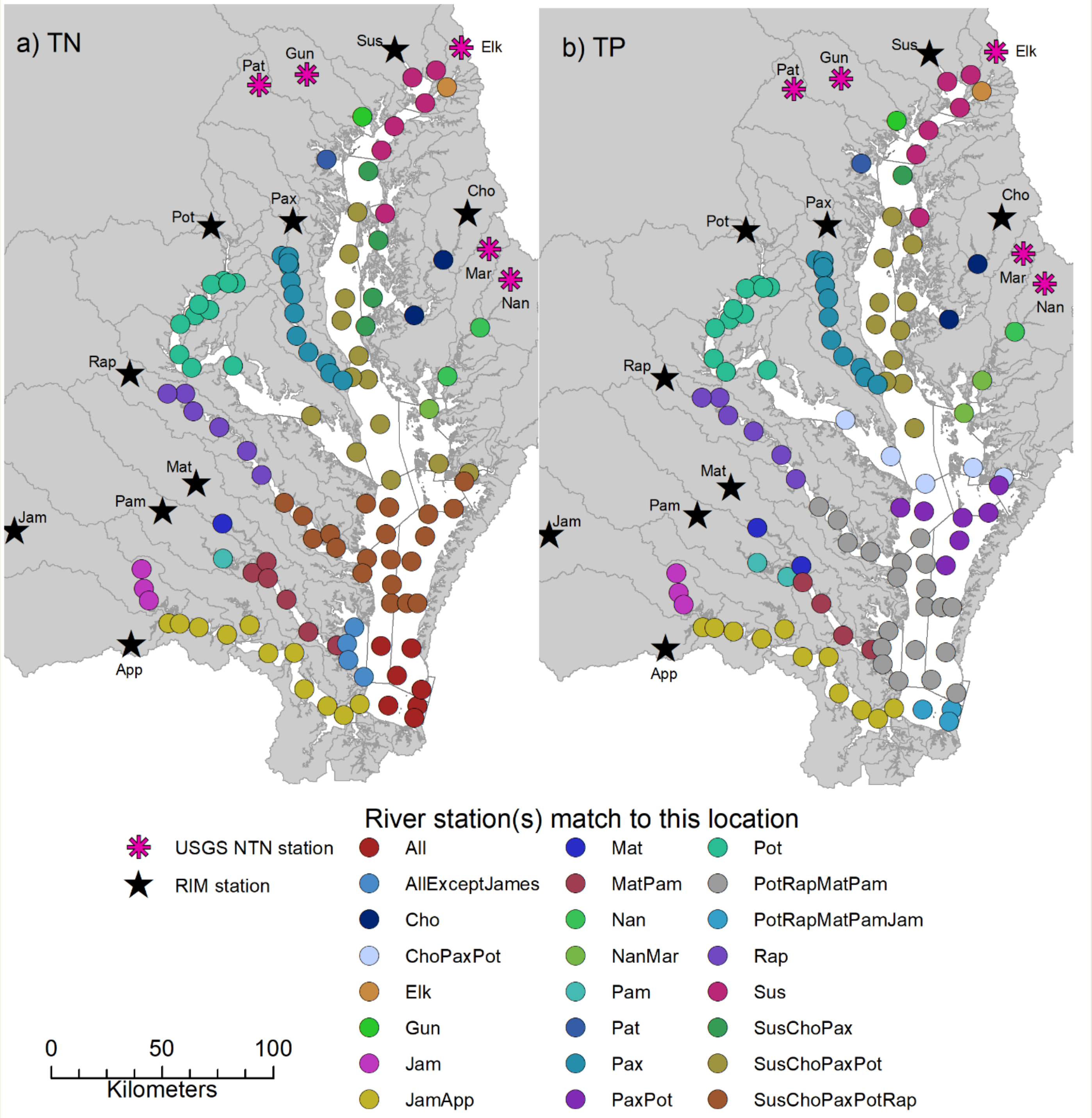
- For TP, similarly the increasing trends are explained by flow
- After flow or salinity adjustment:
  - *51% of stations have no trend*
  - *49% of stations have improving flow-adjusted TP*

Step 3 – Test if nutrient loads from the watershed explain change



Step 3.
Spatial influence

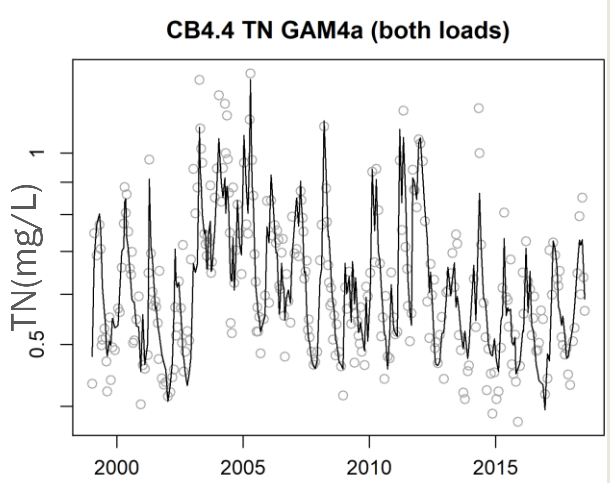
- Key step: Identify which nutrient loads are most explanatory at each estuarine station.

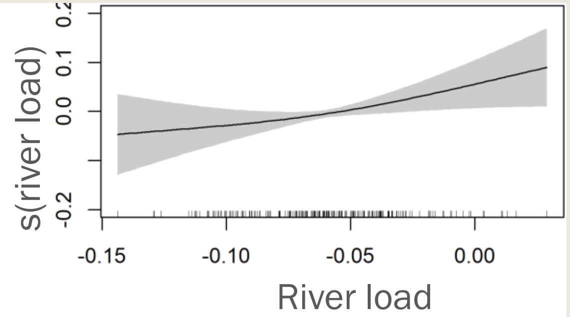


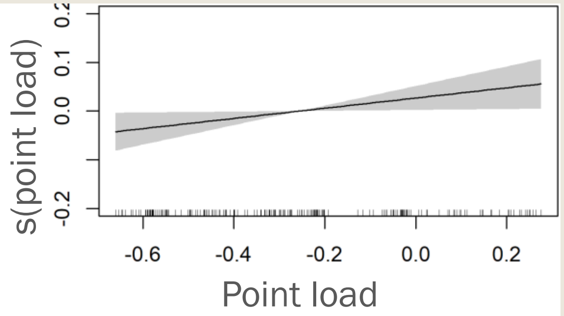
Step 3

Test if loads explain change

a) TN = s(doy) + s(flw_sal) + interaction(flw_sal,doy) + **s(river loads) + s(point loads)**



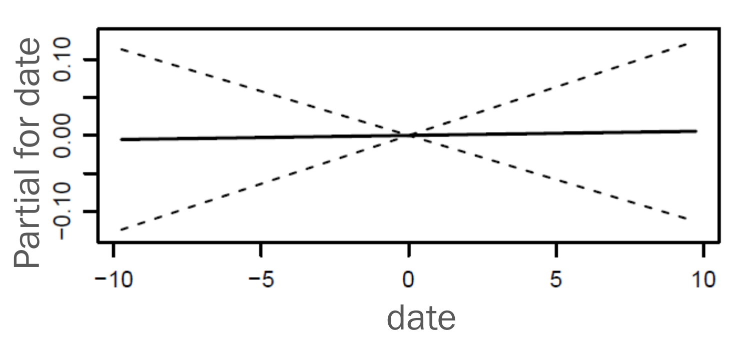




AIC = -352
R^2 = 0.78

Relationships follow our expectation, but do they explain the trend?

b) TN = s(doy) + s(flw_sal) + interaction(flw_sal,doy) + **s(river loads) + s(point loads) + date**

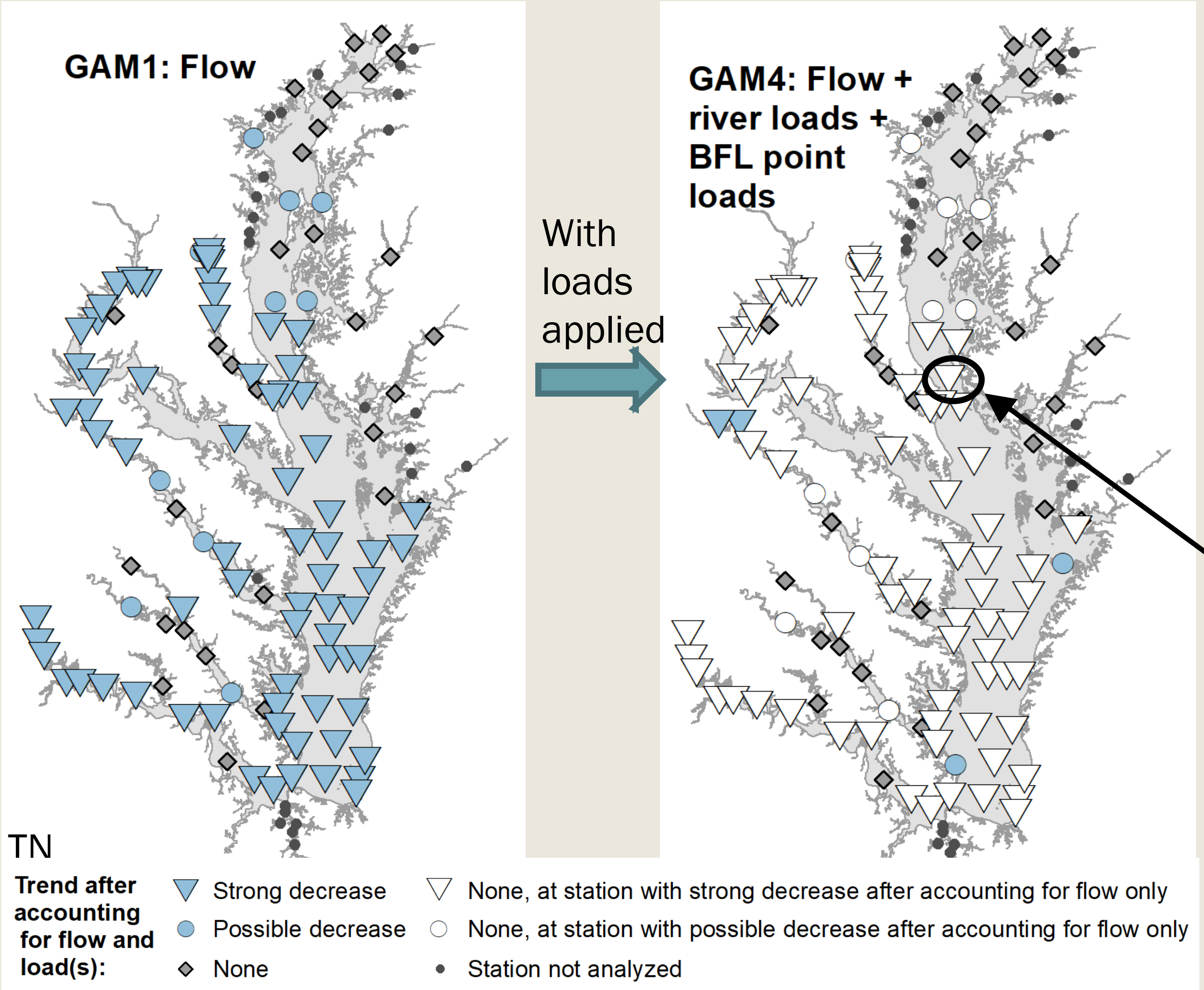


AIC = -350
AIC difference = -2 (minimal)
Slope on date = negligible

Conclusion: *After accounting for flow + watershed loads, there is* ***no unexplained trend*** *at this station*

Step 3

TN: Test if loads explain change

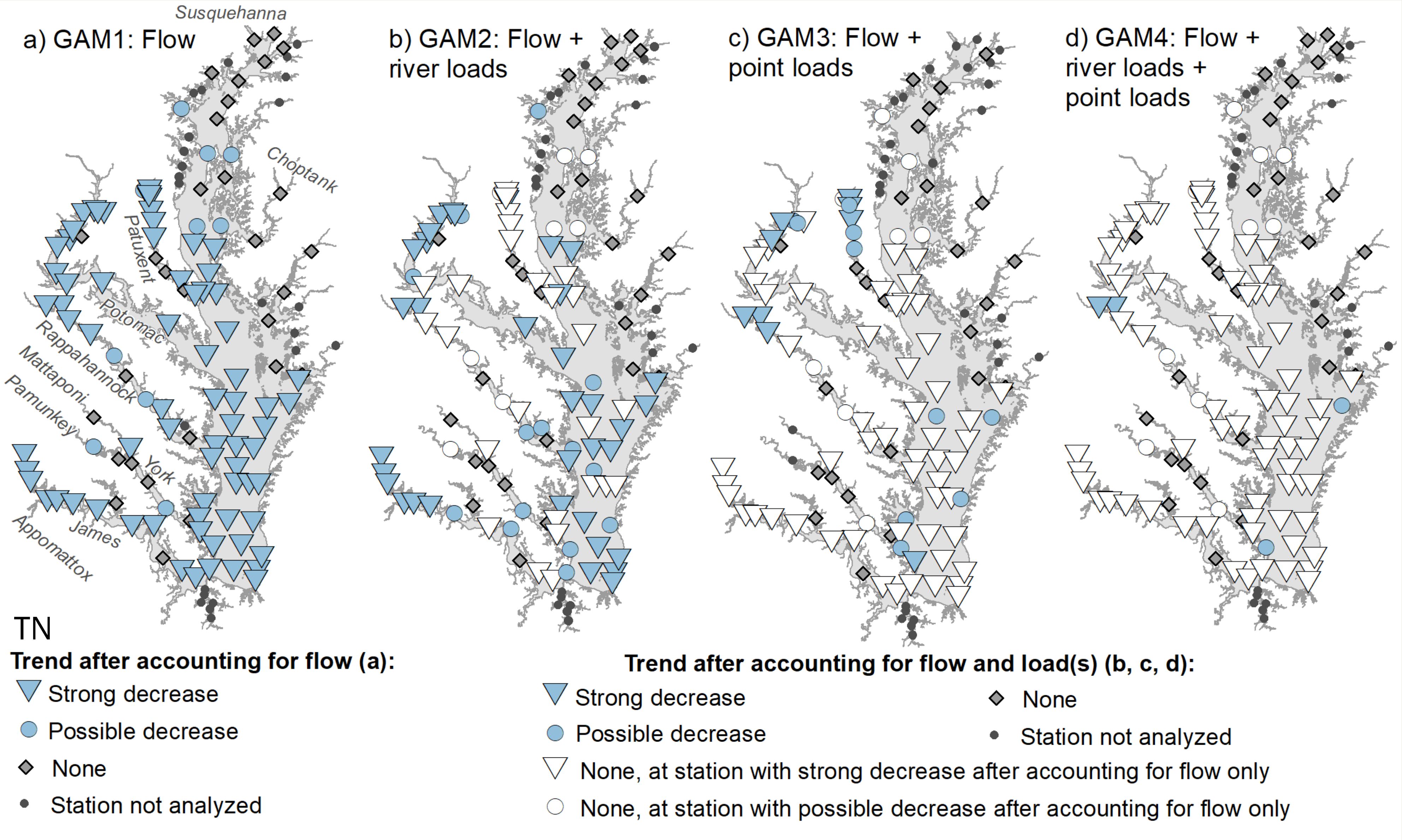


Summary:

- TN loads are highly explanatory at most stations.
- 95% of the flow-adjusted trends are explained by both TN loads together.

Conclusion: *After accounting for flow + watershed loads, there is* ***no unexplained trend*** *at this station*

TN: Are Point or River loads more influential?

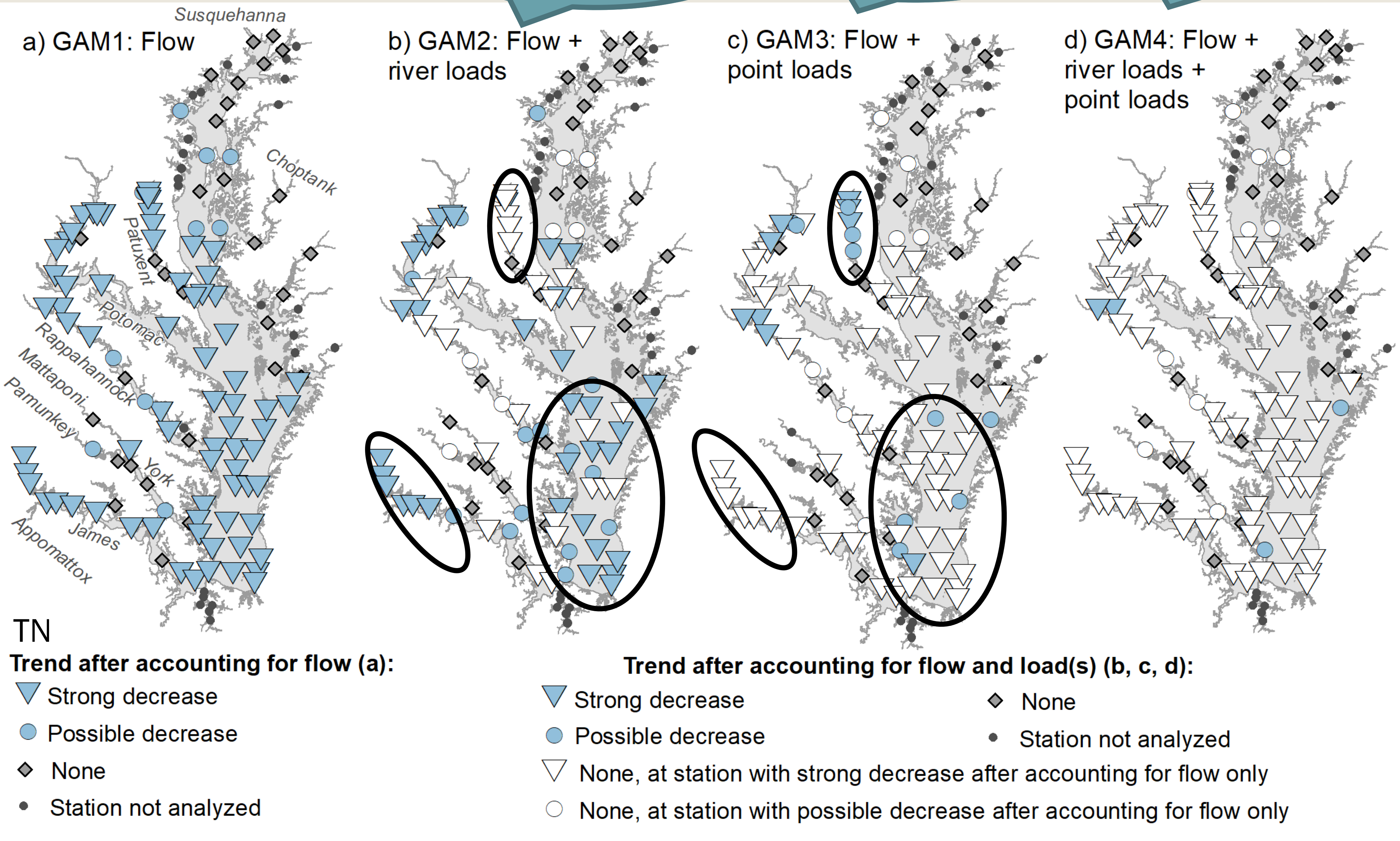


TN

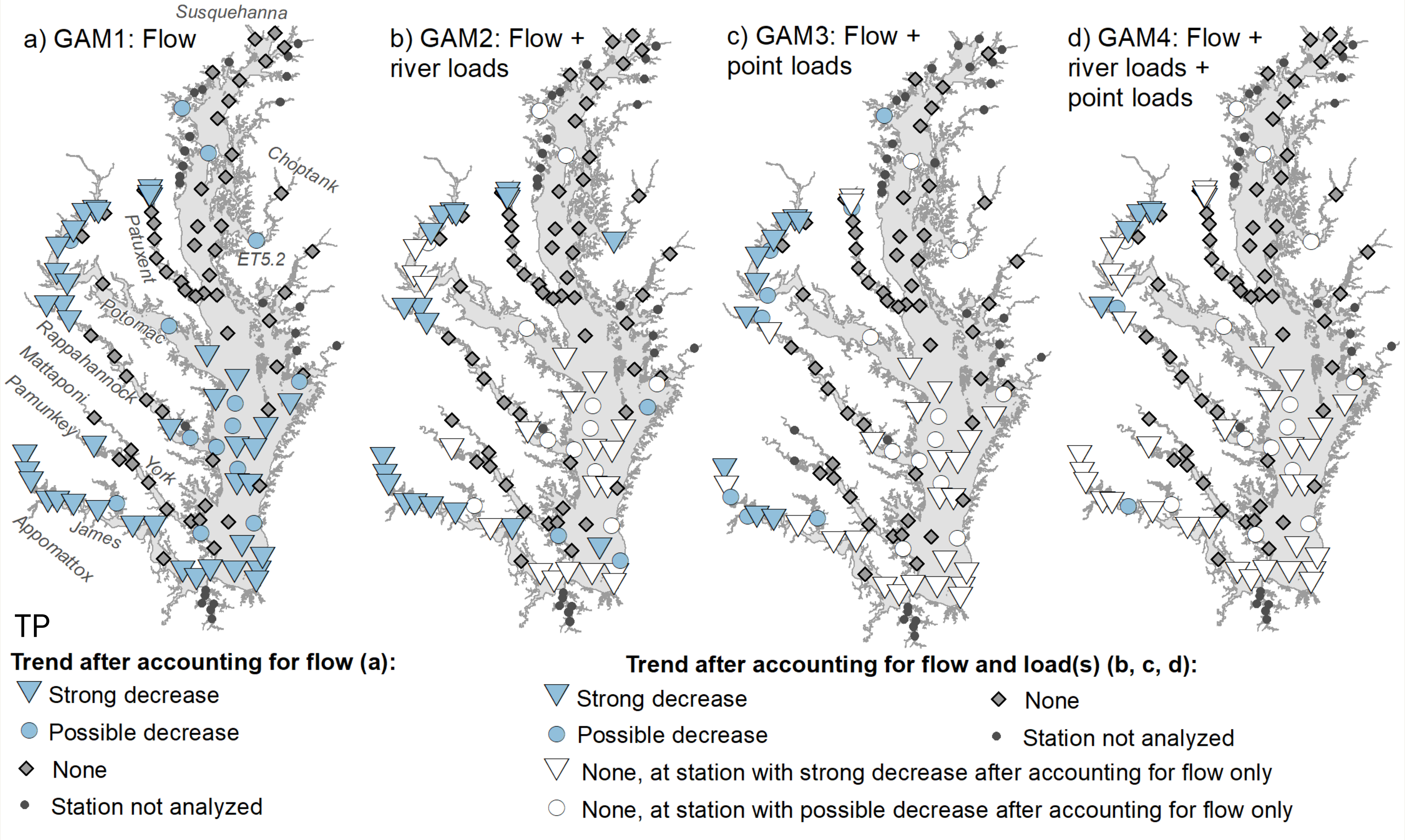
41% of flow-adjusted trends explained

77% explained

95% explained



Same analysis for TP

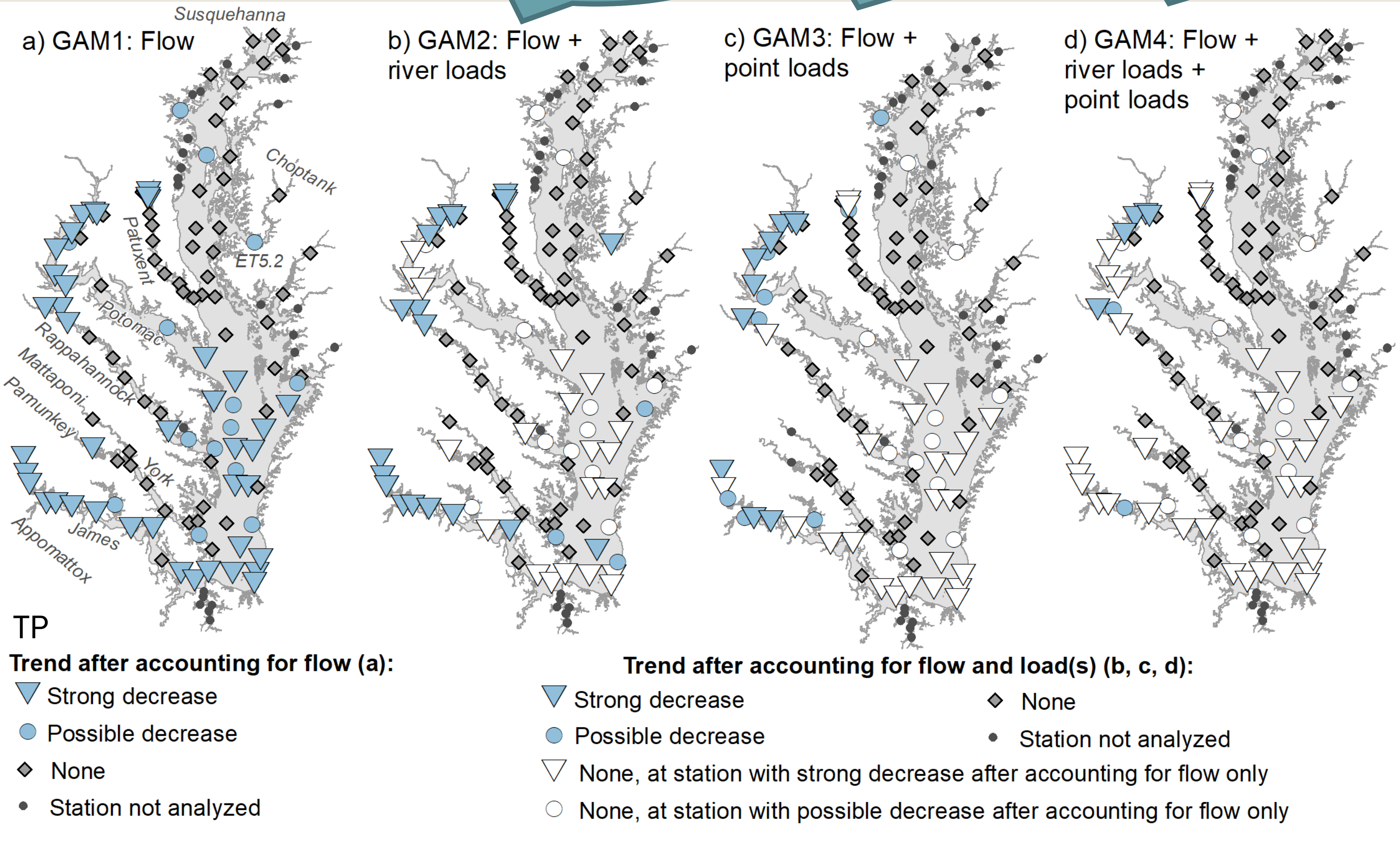


TP

60% of flow-adjusted trends explained

67% explained

87% explained

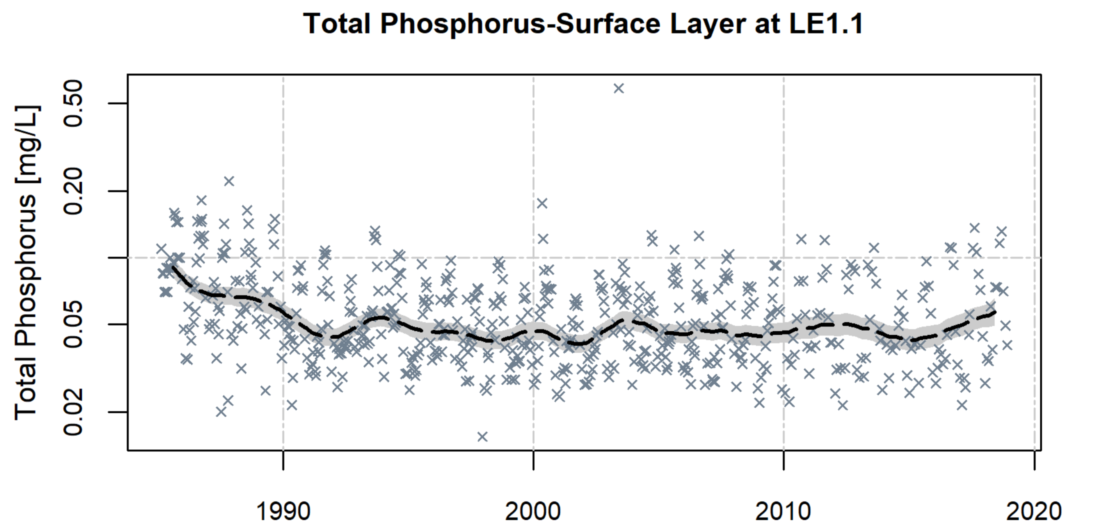


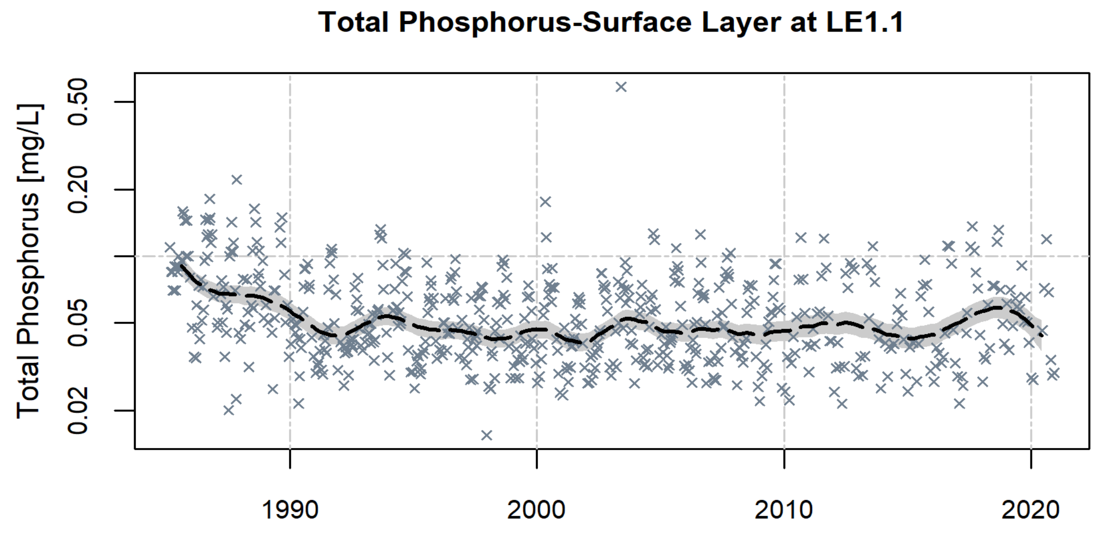
Conclusions

- Both riverine and point sources together are responsible for nutrient trends in the estuary.
- There is large spatial influence of loads from many parts of the watershed, indicating that reductions from only one source type or subbasin will not be sufficient to reduce nutrient concentrations bay-wide.
- Flow impacts on trends are substantial
  - The good news: After accounting for flow, TN and TP are improving at most stations.
  - However, reductions from nutrient sources may be masked in the estuary by impacts of large flows if flow variability increases in the future due to climate change.

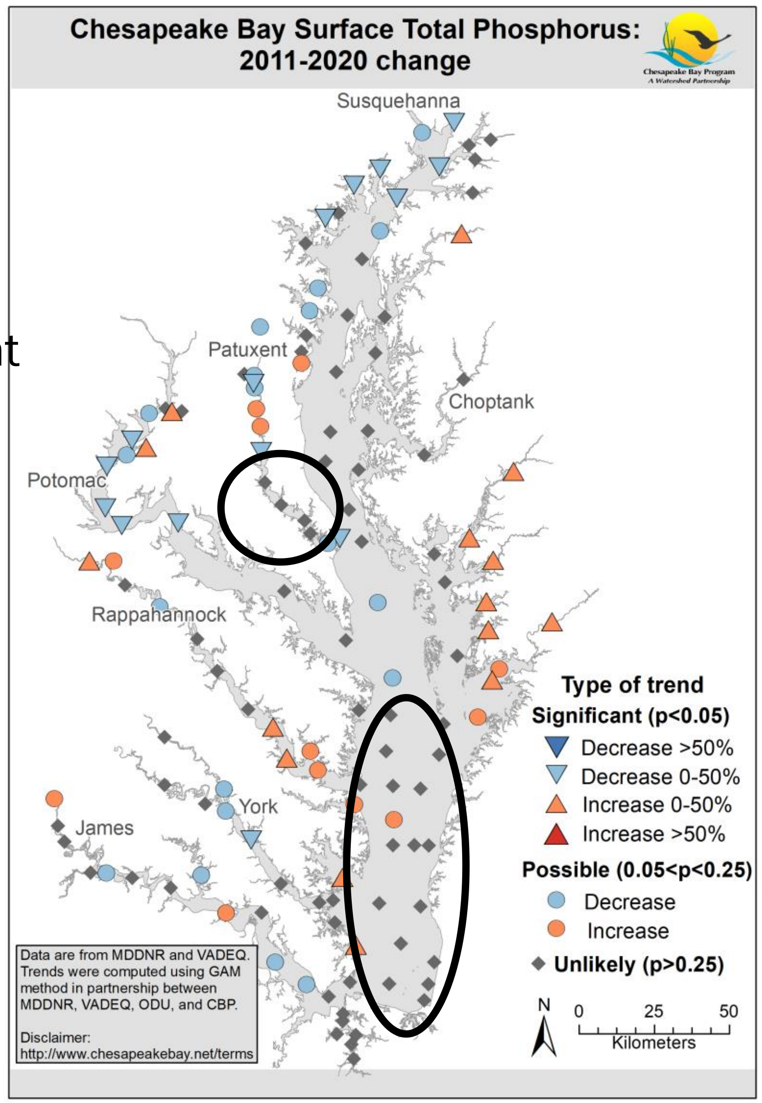
extras

Observed short-term TP increases

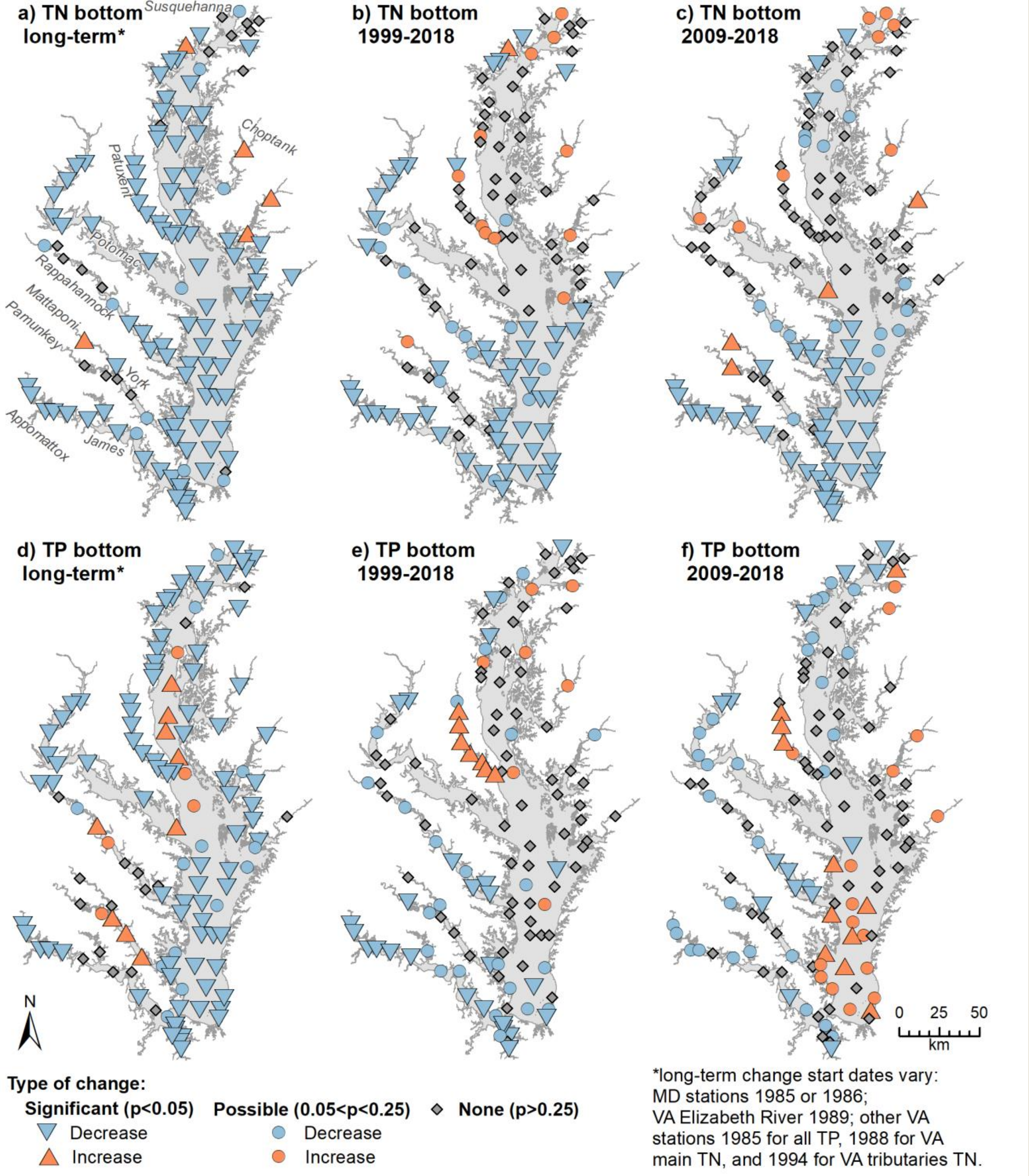




Appear to mostly be slight increases in wet years, during otherwise plateaued recent period



Bottom Results



Places with unexplained trends

- TN in tidal fresh Rappahannock
- TP in tidal fresh Rappahannock and Potomac

Some thoughts:

- The nutrient loads are highly explanatory at these stations (low p-values in the GAMs), there is just still residual trend even after they are included.
- SAV resurgence in the tidal fresh could play a role, if it causes a decrease in nutrients.
- This could be method-related – that the monthly aggregated loads are not fine enough resolution in this region for capturing the load-to-estuary relationships.