Statistical Modeling and Trends in Freshwater Derived Nutrient Loads, Lavaca Bay, Texas

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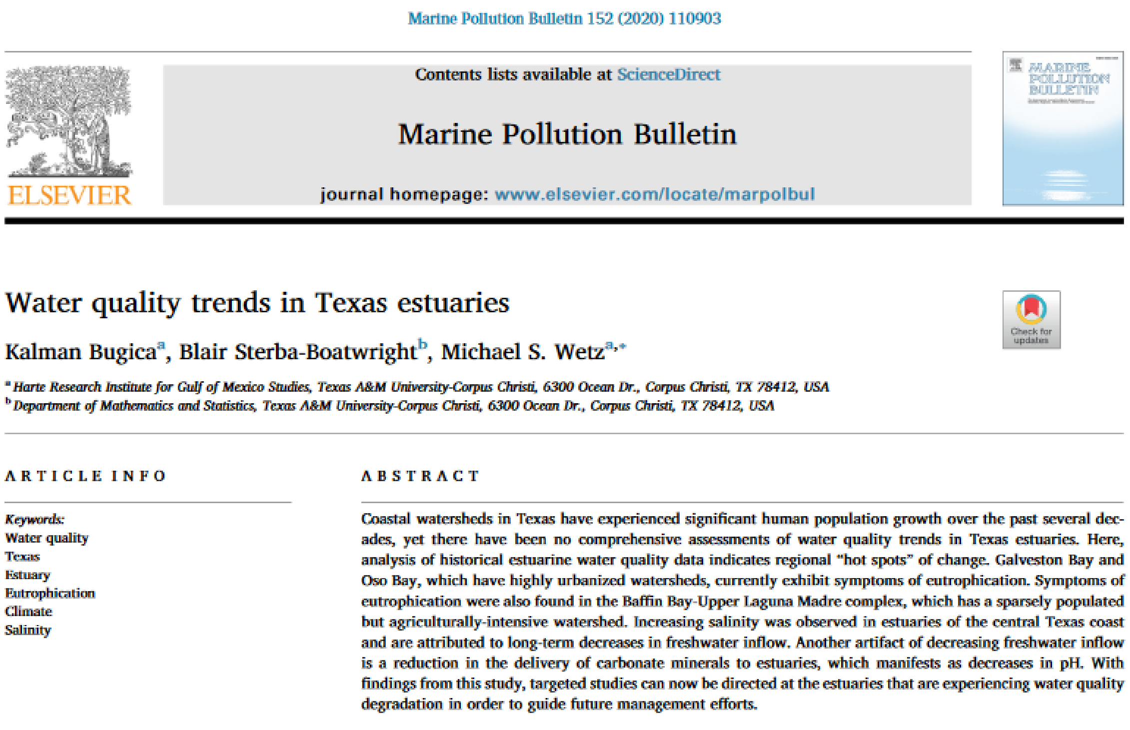
Background

Lavaca Bay Watershed

- 3,146 miles^2
- 50% Pasture and rangeland
- 20% Cultivated cropland (cotton, soy, corn, sorghum)
- 17% Forested
- 5% Suburban, urban

Background



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Water quality trends in Texas estuaries

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ABSTRACT

Coastal watersheds in Texas have experienced significant human population growth over the past several decades, yet there have been no comprehensive assessments of water quality trends in Texas estuaries. Here, analysis of historical estuarine water quality data indicates regional "hot spots" of change. Galveston Bay and Oso Bay, which have highly urbanized watersheds, currently exhibit symptoms of eutrophication. Symptoms of eutrophication were also found in the Baffin Bay-Upper Laguna Madre complex, which has a sparsely populated but agriculturally-intensive watershed. Increasing salinity was observed in estuaries of the central Texas coast and are attributed to long-term decreases in freshwater inflow. Another artifact of decreasing freshwater inflow is a reduction in the delivery of carbonate minerals to estuaries, which manifests as decreases in pH. With findings from this study, targeted studies can now be directed at the estuaries that are experiencing water quality degradation in order to guide future management efforts.

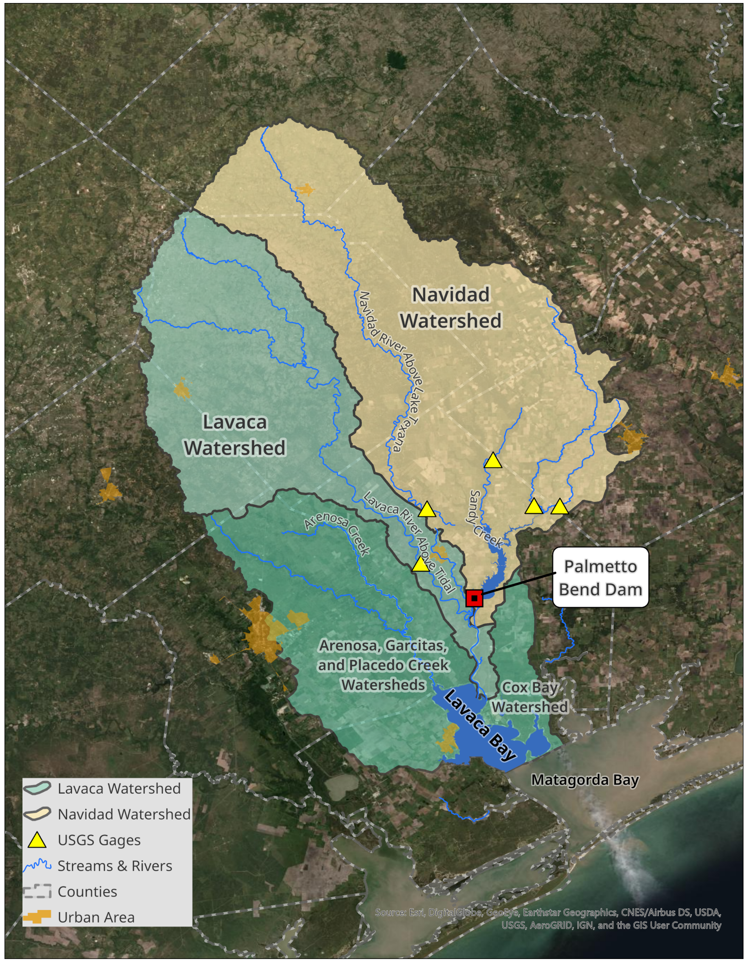
- Bugica, Sterba-Boatwright, and Wetz (2020) identify eutrophication risk in Lavaca Bay due to ⬆ TP and ⬆ Chlorophyll-a concentrations.

- Possible concerns for Total Phosphorus at some FW sites.
- Texas does not currently have nutrient standards for streams.
- Long-term quarterly monitoring, no historical storm or flow-biased data to this point.

Project Objectives

- 1. Develop estimates of NO_3-N and TP loading from Lavaca and Navidad Rivers
- 2. Link nutrient loads and river discharge to changes in nutrient concentration in Lavaca Bay

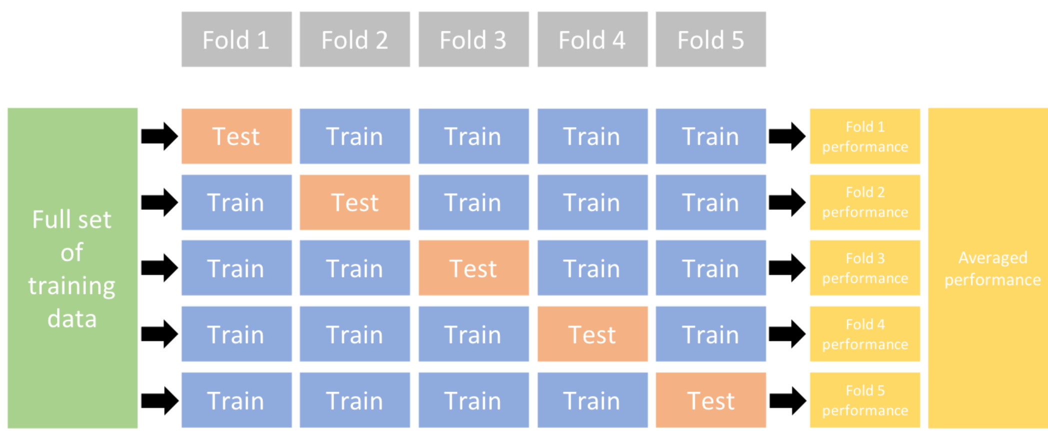
Lavaca Bay Watersheds



- 1.3 million acre-feet per year
- 65% from Lavaca/Navidad watershed
  - 61% from Navidad at Palmetto Bend Dam
  - 32% from Lavaca near City of Edna
  - 7% ungaged downstream runoff

Methods

- Loading estimates:
  - **Specify Concentration Regression Model** - Generalized Additive Models (Kuhnert et al. 2012; Robson and Dourdet 2015; McDowell et al. 2021)
    - model error structure and specify link function
    - predictor variables can be smooth functions allowing non-linear responses.
  - **Model performance** - Repeated 5-fold cross-validation
  - **Predict daily loads** - Point estimates with uncertainty

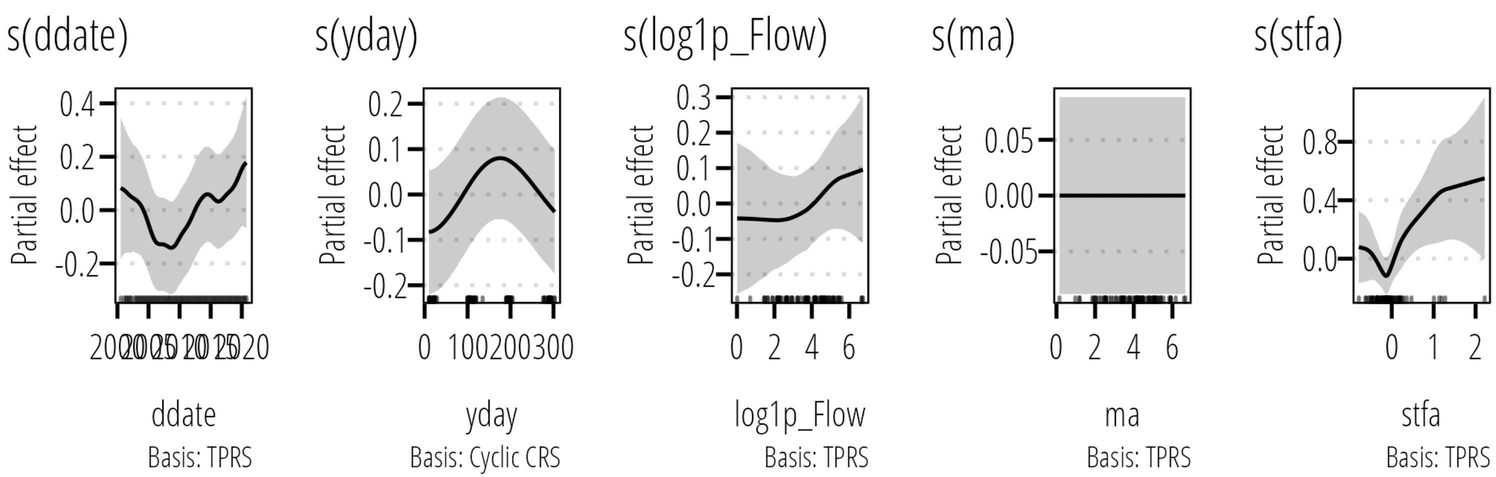


5-fold CV procedure. Image from Boehmke & Greenwell 2020 (https://bradleyboehmke.github.io/HOML/)

Methods

$$Y = s(ddate) + s(yday) + s(log1p(Flow)) + s(ma) + s(fa)$$

- Y = NO_3 or TP concentration;
- s = smoothing function;
- $ddate$ = decimal date;
- $yday$ = numeric day of year;
- $Flow$ = mean daily discharge;
- ma = exponential moving average (Kuhnert et al. 2012; Zhang and Ball 2017).
- fa = short- or long-term flow anomaly (stfa, ltfa) (Vecchia et al. 2009; Zhang and Ball 2017);
- Gamma family with log-link



Methods

Loading estimates:

- Prediction of **daily loads** from GAM models at each site
  - predicted concentrations $\times$ mean daily streamflow
  - aggregated to monthly and annual totals
- Report **model uncertainty**
  - **95% credible intervals** developed from 1000 draws of parameter estimates from the multivariate normal posterior distribution of model parameters provided by `mgcv::gam` function in R.
- Account for variance in mean daily discharge
  - **Flow-normalized estimates** calculated similar to WRTDS, assume daily flow variables are random occurrence from all possible values on that day of year.

Methods

Do variations in Flow and Load explain Bay nutrient concentration?

Temporal Model

$$Y = s(Day) + s(Date) + ti(Day, Date)$$

Flow Model

$$Y = s(Day) + s(Date) + ti(Day, Date) + s(Flow)$$

Full Model

$$Y = s(Day) + s(Date) + ti(Day, Date) + s(Flow) + s(Load)$$

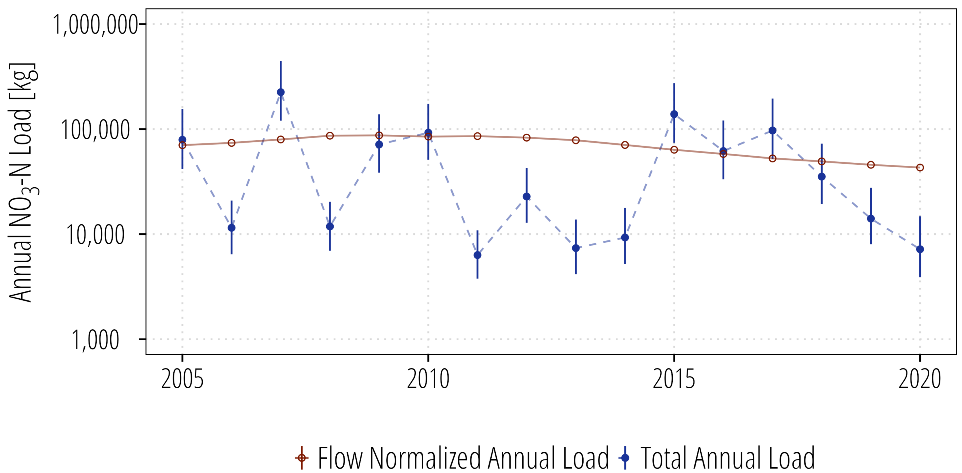
- $Flow$ is seasonally adjusted
- $Load$ is flow adjusted
- Simplified methodology following Murphy et al. (2019) and Murphy et al. (2022).
- Compare AIC and other model metrics

Results

Lavaca River

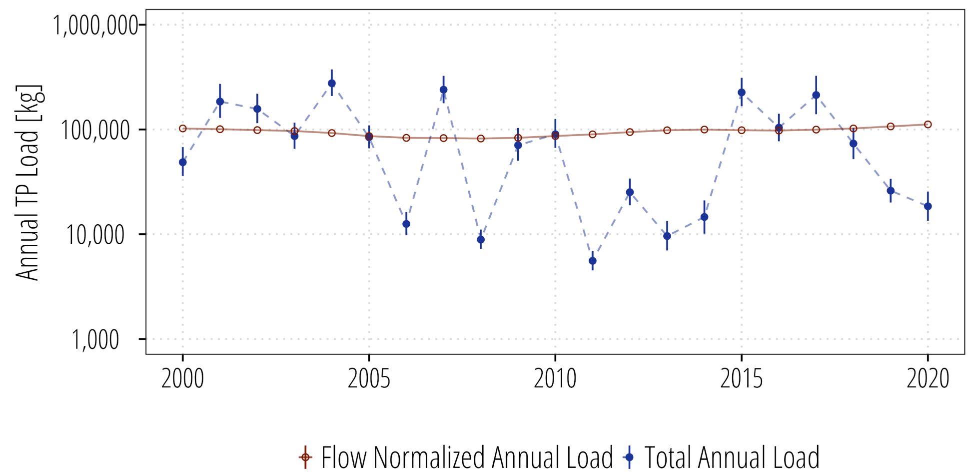
NO_3-N

Metric	Median (IQR)
NSE	0.758 (0.714, 0.765)
R^2	0.761 (0.728, 0.771)
Percent Bias	-7.80 (-9.02, -4.15)



TP

Metric	Median (IQR)
NSE	0.77 (0.71, 0.81)
R^2	0.77 (0.72, 0.82)
Percent Bias	-7.45 (-9.10, -6.35)

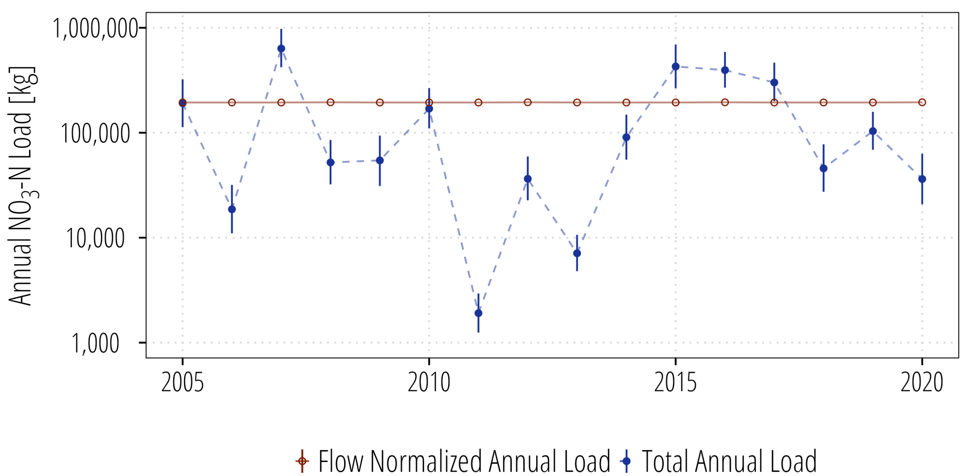


Results

Navidad River/Palmetto Bend Dam

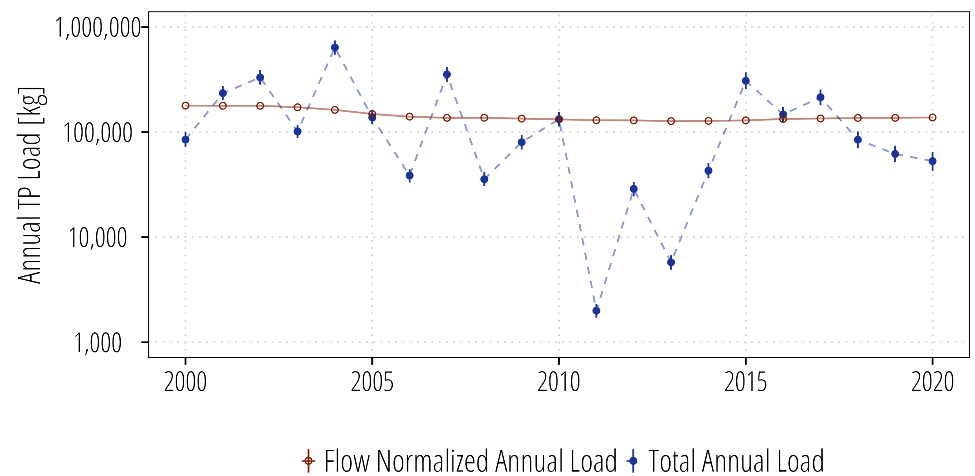
NO_3-N

Metric	Median (IQR)
NSE	0.42 (0.34, 0.46)
R^2	0.60 (0.52, 0.66)
Percent Bias	-43 (-47, -38)

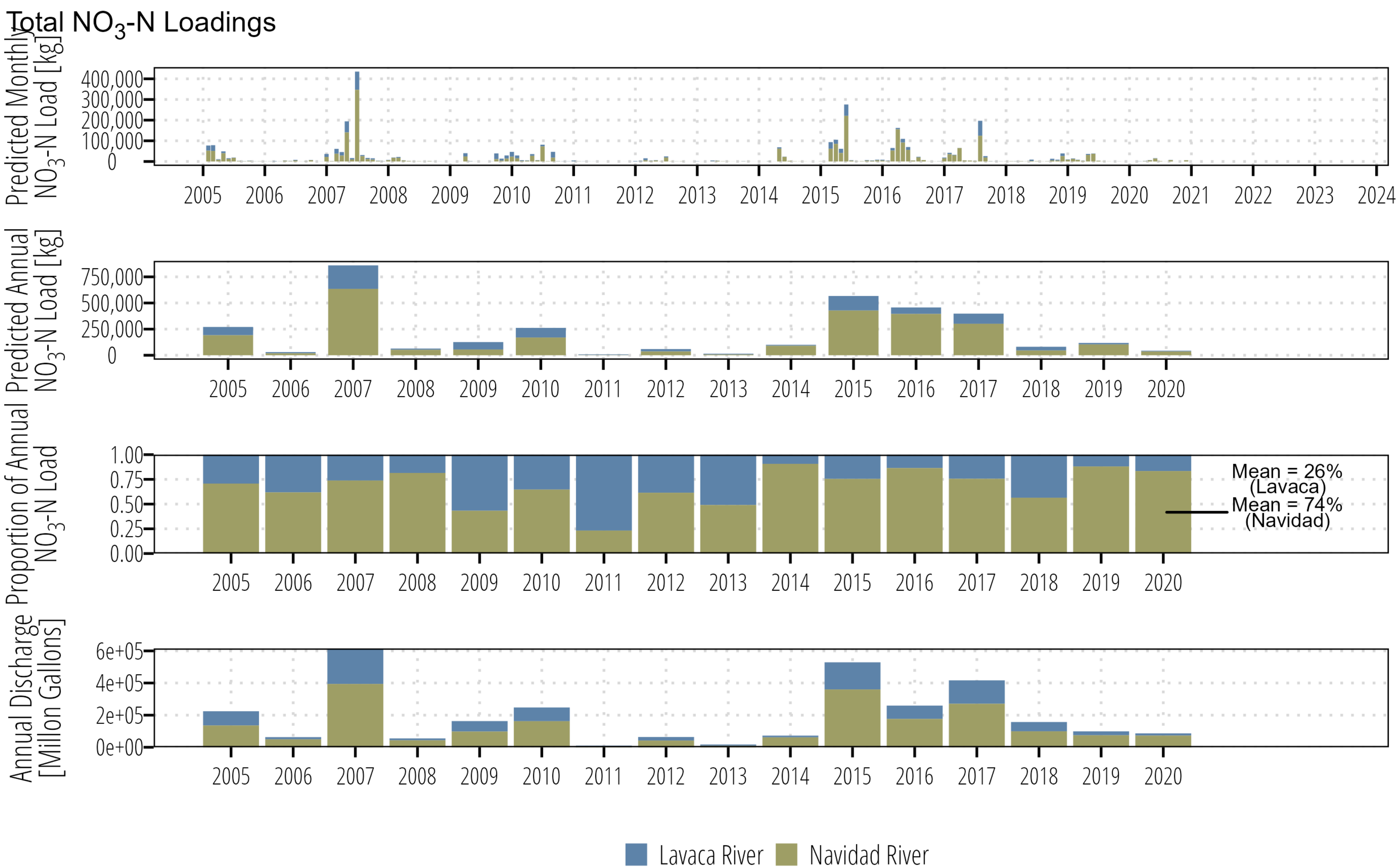


TP

Metric	Median (IQR)
NSE	0.877 (0.862, 0.911)
R^2	0.961 (0.956, 0.975)
Percent Bias	-17.6 (-21.1, -12.7)

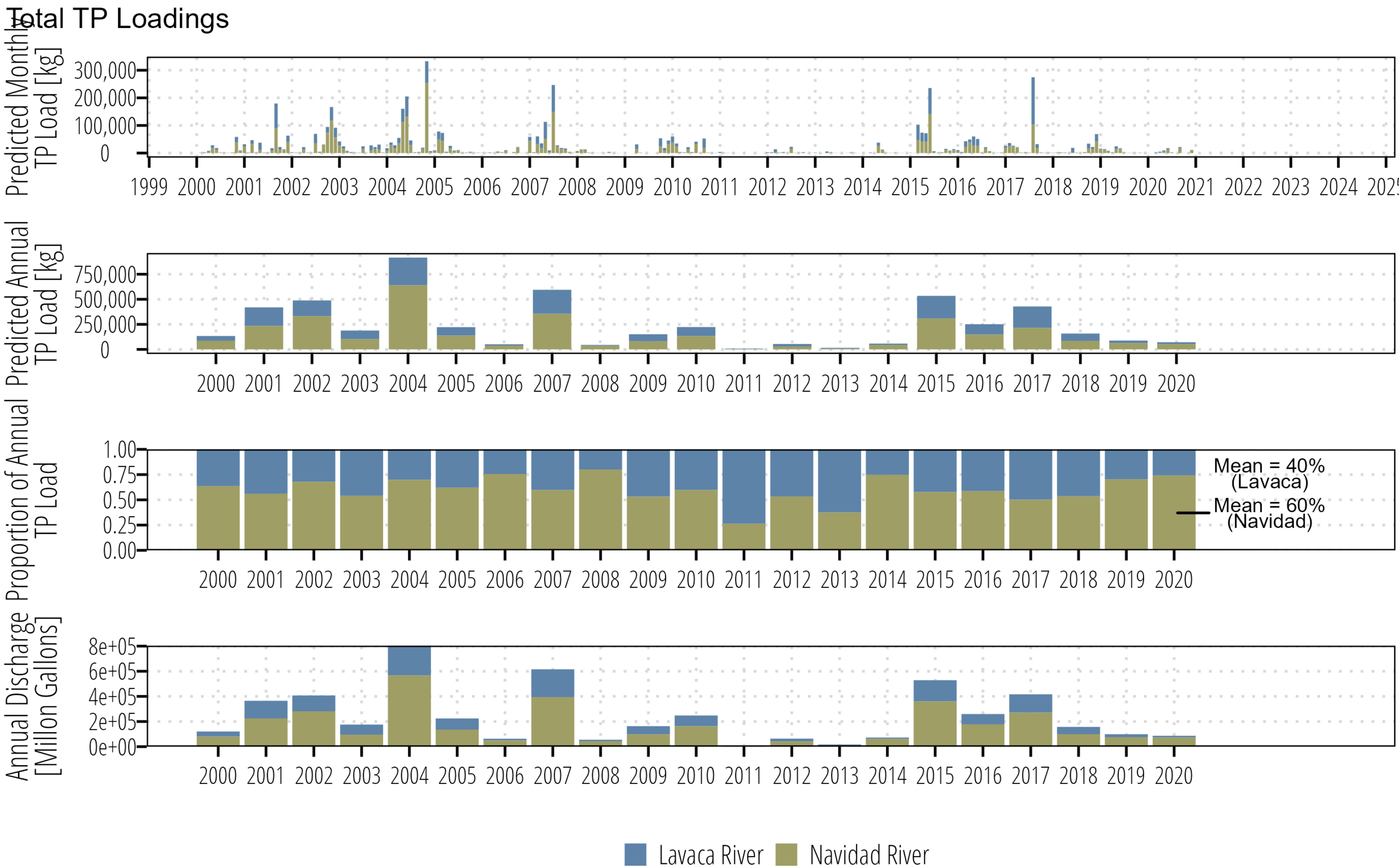


Results



Total NO_3-N Loadings
Predicted Monthly NO_3-N Load [kg]
400,000
300,000
200,000
100,000
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
Predicted Annual NO_3-N Load [kg]
750,000
500,000
250,000
0
Proportion of Annual NO_3-N Load
1.00
0.75
0.50
0.25
0.00
Mean = 26% (Lavaca)
Mean = 74% (Navidad)
Annual Discharge [Millon Gallons]
6e+05
4e+05
2e+05
0e+00
Lavaca River
Navidad River

Results


Total TP Loadings
Predicted Monthly TP Load [kg]
300,000
200,000
100,000
0
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025
Predicted Annual TP Load [kg]
750,000
500,000
250,000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Proportion of Annual TP Load
1.00
0.75
0.50
0.25
0.00
Mean = 40% (Lavaca)
Mean = 60% (Navidad)
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Annual Discharge [Millon Gallons]
8e+05
6e+05
4e+05
2e+05
0e+00
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Lavaca River
Navidad River

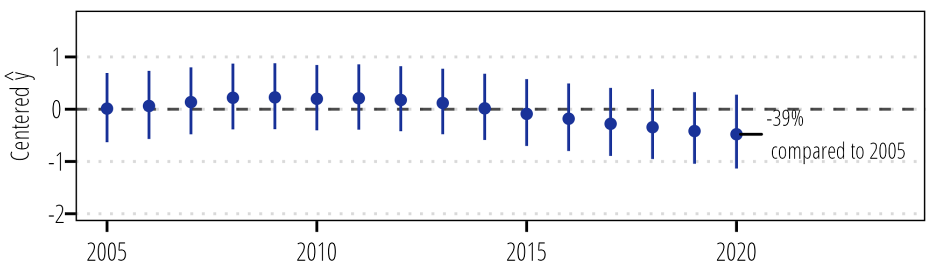
Regional Study Comparison

Parameter	Reported Yield ($kg/km^2/yr$)	Approach	Time Period	Reference
TP	42.9 (34.4, 54.0)	GAM	2000-2020	-
TP	45.2	SPARROW	2012	Wise, Anning, and Miller (2019)
TP	42	SWAT	1977-2005	Omani, Srinivasan, and Lee (2014)
TP	20.81-91.58	SPARROW	2002	Rebich et al. (2011)
TP	28.9	LOADEST	1972-1993	Dunn (1996)

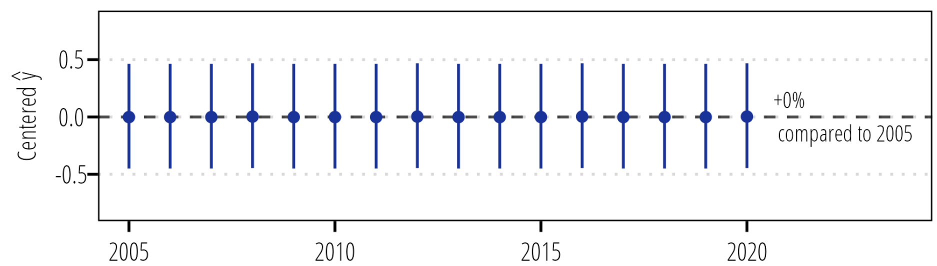
What About Trends?

- High variability in actual loads that reflect total discharge
- Flow-normalized loads:

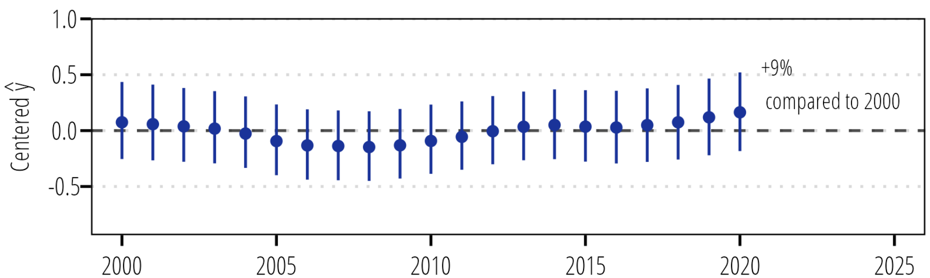
Flow-Normalized NO_3-N Load, Lavaca River



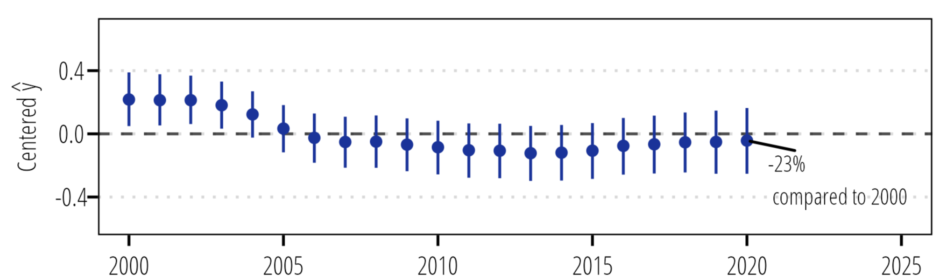
Flow-Normalized NO_3-N Load, Navidad River



Flow-Normalized TP Load, Lavaca River



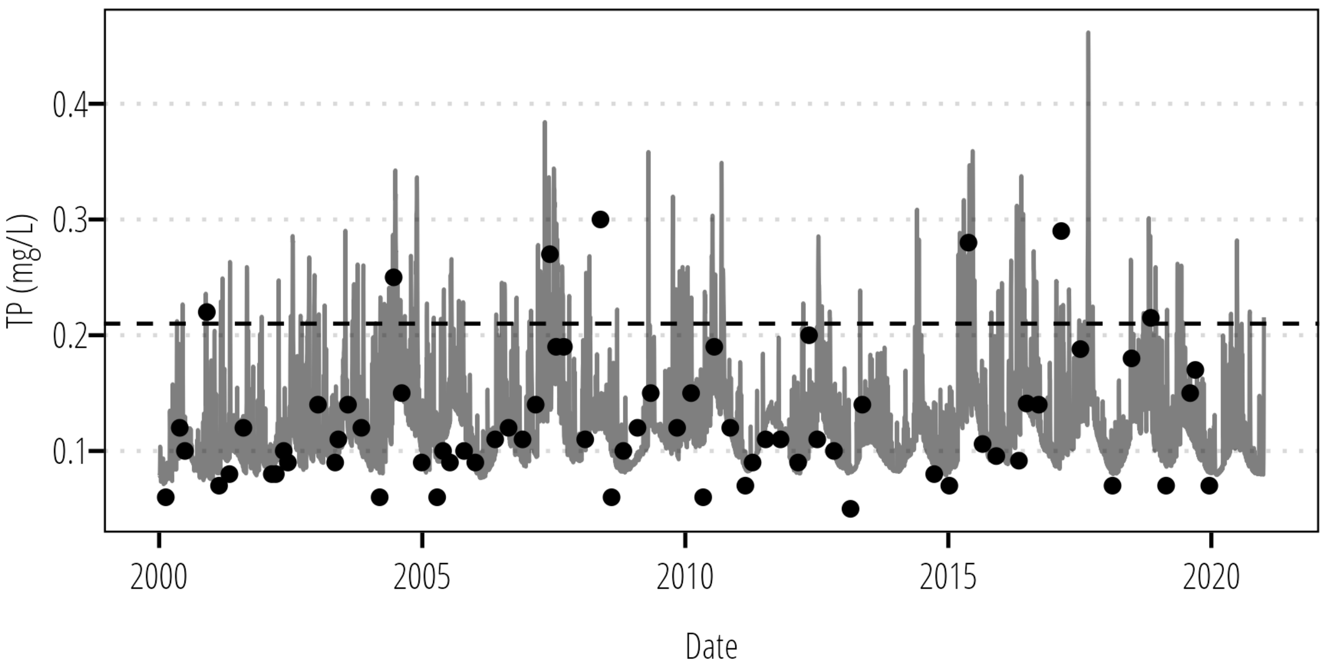
Flow-Normalized TP Load, Navidad River



Estuary Models

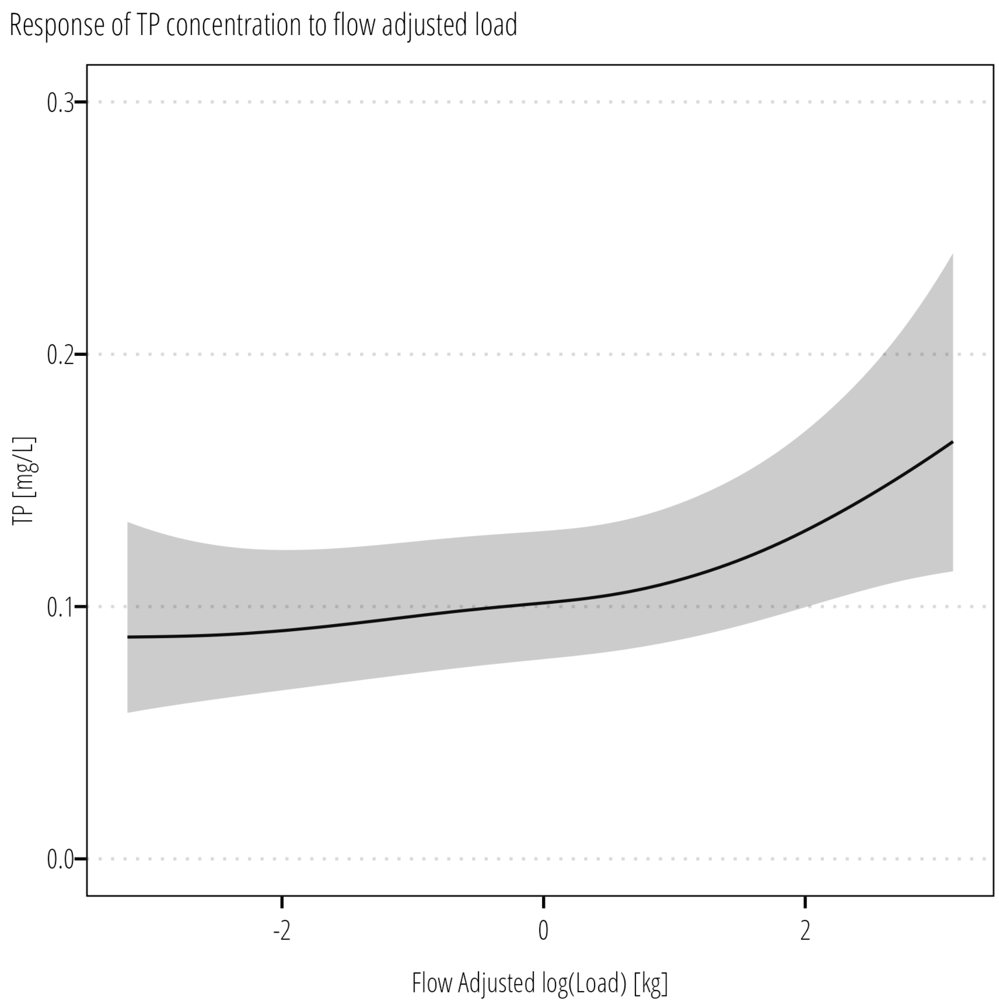
Example: Site 13563 TP

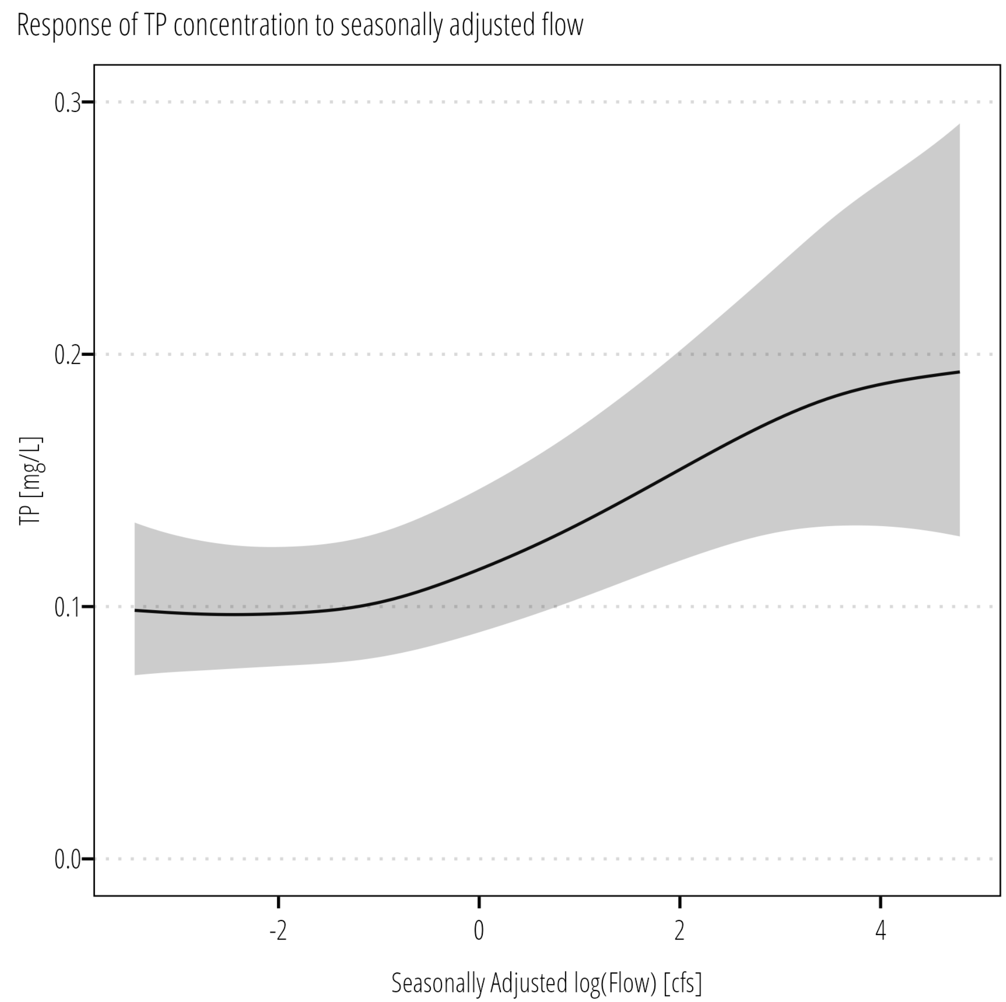
	df	AIC	adj.r.sq	dev.expl
Temporal Model	9.735954	-222.5104	0.1492214	0.2597455
Flow Model	8.479287	-241.3721	0.3383421	0.4107901
Flow and Load Model	14.272933	-252.4411	0.4755137	0.5754284



Estuary Models

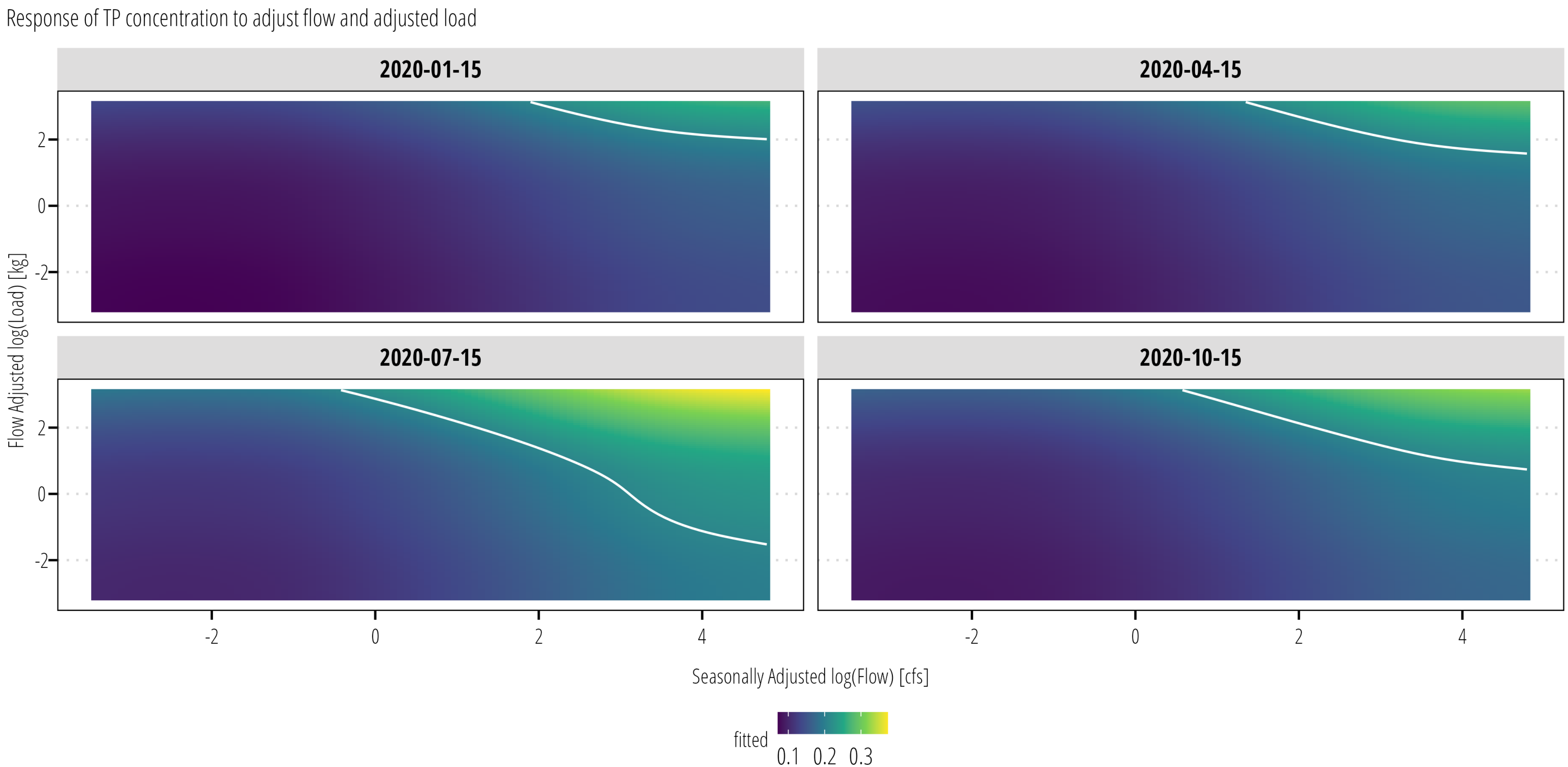
Example: Site 13563 TP





Estuary Models

Example: Site 13563 TP



Conclusions

- GAMs
  - Useful framework for statistical load estimation and exploratory analysis of estuarine water quality.
- Nutrient Loading
  - High variance in actual loads.
  - Shifts in riverine sources during drought conditions.
  - Changes in watershed loads explains some variation in estuary nutrient concentration.

Further work

- Comparison of above lake and below lake loads;
- Develop/fund supplemental flow-biased monitoring to identify significant changes and trends;
- Continue work on estuary water quality responses…

Thank You!

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