

# Comparison of WRTDS and GAMs for evaluating long-term trends in chlorophyll

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## Since the last call...

- Application of GAMs and WRTDS to 30 year time series of monthly chlorophyll at LE1.2 and TF1.6
- Implementation of similar methods for model fitting
- Model comparisons
- Development of simulated datasets to evaluate flow-normalization
- Simulation comparisons
- Conclusions

# Spatial and temporal observations

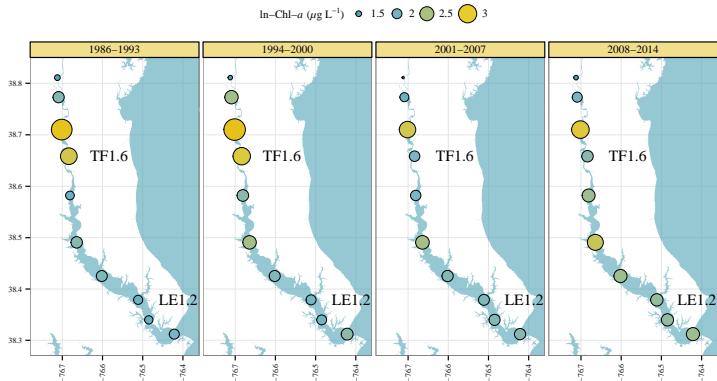


Figure : Vertically integrated bi-monthly chlorophyll observations in the Patuxent, grouped by annual, seasonal, and flow periods.

# Spatial and temporal observations

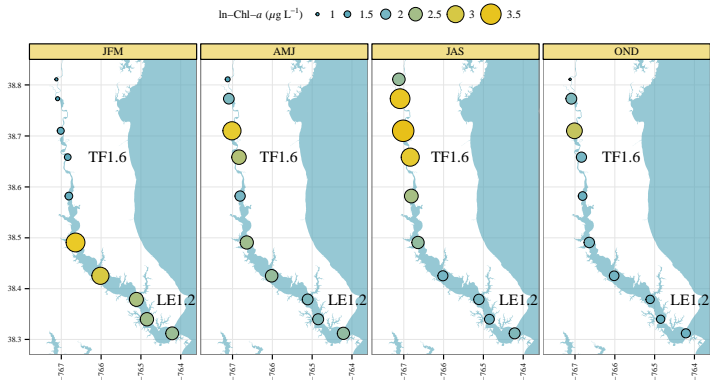


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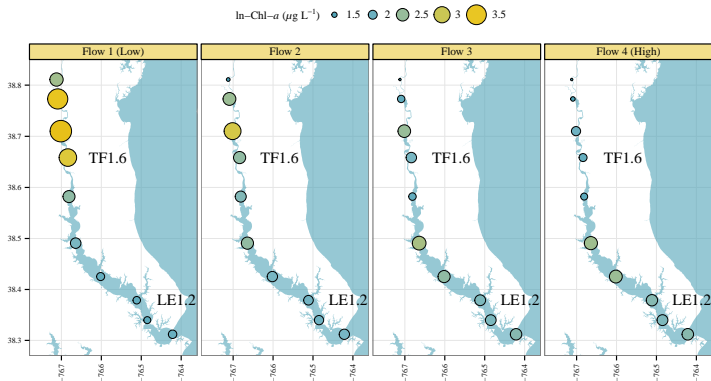


Figure : Vertically integrated bi-monthly chlorophyll observations in the Patuxent, grouped by annual, seasonal, and flow periods.

# Model applications

LE1.2:  $\ln\text{chla} \sim \text{time} + \textit{salinity}$

TF1.6:  $\ln\text{chla} \sim \text{time} + \textit{flow}$

Fits evaluated for whole time series and annual/seasonal/flow aggregations:

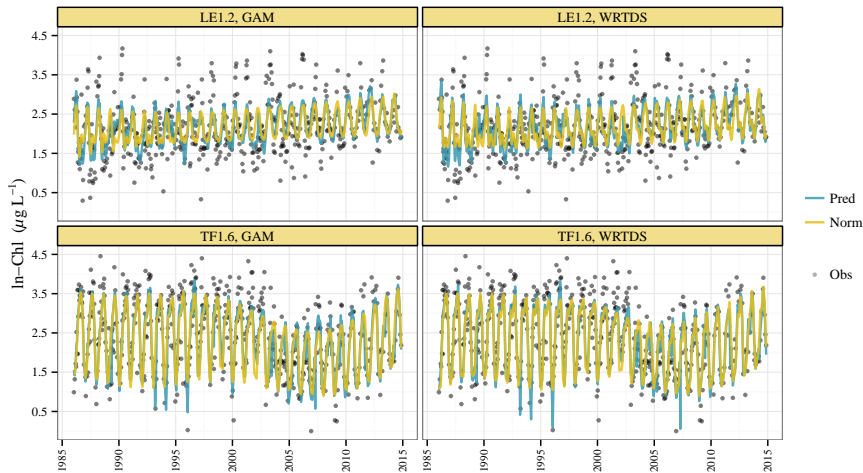
- predicted to observed, GAM predicted to WRTDS predicted
- Trends in flow-normalized results (average and % change overall, by time period)

Model comparisons of flow-normalized results with simulated datasets

# Parameter fitting methods

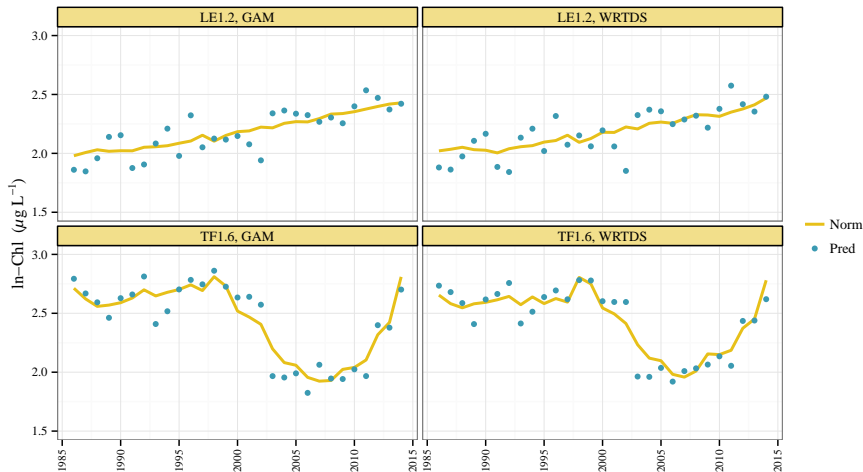
- GAMs: identify optimal smoothing parameter to balance fit and ‘wiggleness’
  - ▶ Iterative generalized cross-validation with penalized likelihood maximization
- WRTDS: identify optimal window widths for time, discharge (salinity or flow), and season
  - ▶ k-fold cross-validation with search algorithm (‘limited memory BFGS quasi-Newton method’) that chooses window widths

# Model comparisons





# Model comparisons



# Model comparisons

Table : RMSE of observed to predicted ln-chlorophyll.

Period	LE1.2		TF1.6	
	GAM	WRTDS	GAM	WRTDS
<b>All</b>				
	0.54	0.51	0.54	0.52
<b>Annual</b>				
1986-1993	0.54	0.50	0.53	0.49
1994-2000	0.52	0.50	0.58	0.58
2001-2007	0.63	0.60	0.54	0.53
2008-2014	0.39	0.36	0.49	0.44
<b>Seasonal</b>				
JFM	0.61	0.58	0.53	0.49
AMJ	0.69	0.64	0.60	0.58
JAS	0.38	0.35	0.48	0.46
OND	0.41	0.38	0.55	0.54
<b>Flow</b>				
1 (Low)	0.40	0.36	0.48	0.46
2	0.47	0.42	0.56	0.54
3	0.61	0.57	0.56	0.52
4 (High)	0.64	0.63	0.56	0.54

# Model comparisons

Table : Comparison of predicted results between models.

Period	LE1.2		TF1.6	
	Ave. diff.	RMSE	Ave. diff.	RMSE
<b>All</b>				
	-0.11	0.15	0.01	0.17
<b>Annual</b>				
1986-1993	0.18	0.16	-0.78	0.17
1994-2000	0.53	0.15	-1.09	0.19
2001-2007	-0.95	0.14	0.48	0.14
2008-2014	-0.18	0.14	3.12	0.18
<b>Seasonal</b>				
JFM	2.91	0.14	-5.02	0.22
AMJ	-3.42	0.17	0.93	0.14
JAS	5.03	0.14	-0.10	0.17
OND	-5.25	0.14	2.08	0.17
<b>Flow</b>				
Flow 1 (Low)	0.19	0.16	-0.09	0.12
Flow 2	-0.83	0.16	0.73	0.15
Flow 3	0.19	0.15	0.84	0.20
Flow 4 (High)	0.03	0.13	-1.62	0.20

# Model comparisons

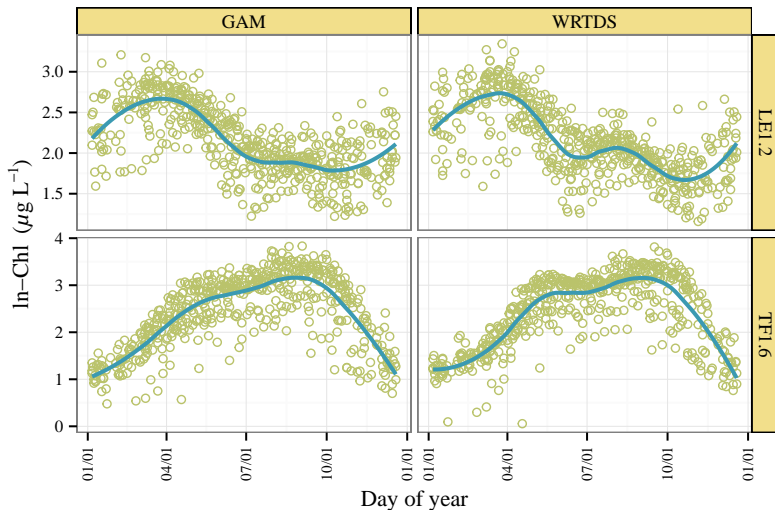
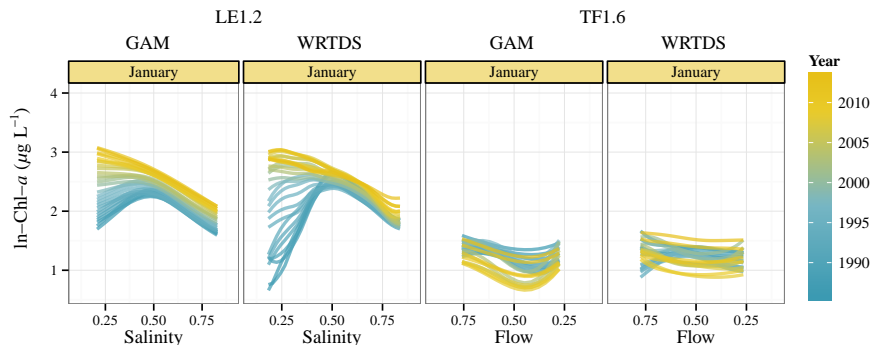


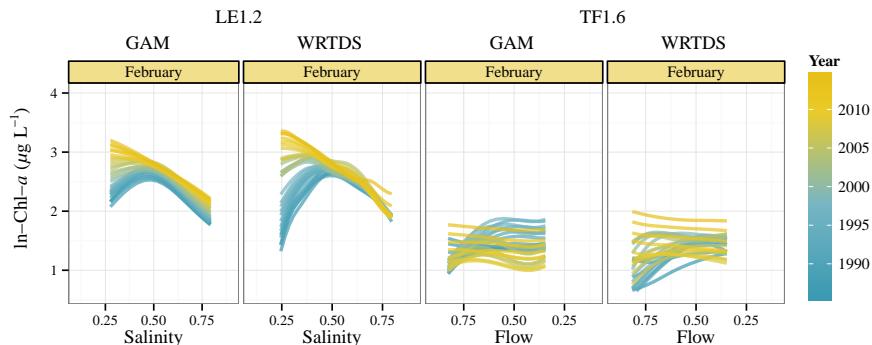
Figure : Seasonal variation from model predictions.

# Model comparisons



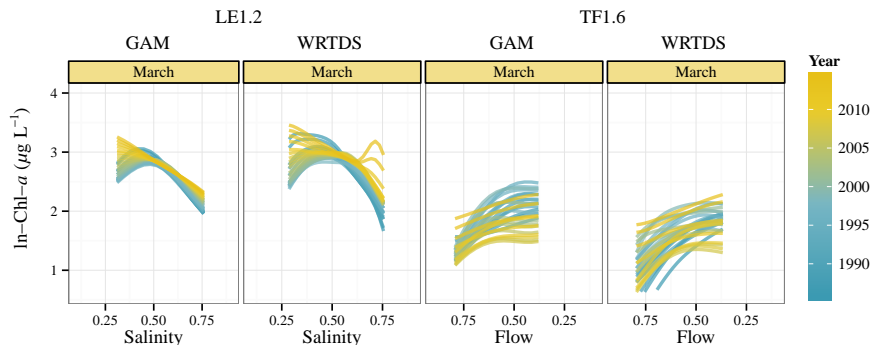
**Figure :** Changes in the relationship between chlorophyll and flow across the time series with separate plots by month, model, and station. The scales of salinity and flow are reversed for trend comparison with units in proportion of the total range for each month.

# Model comparisons



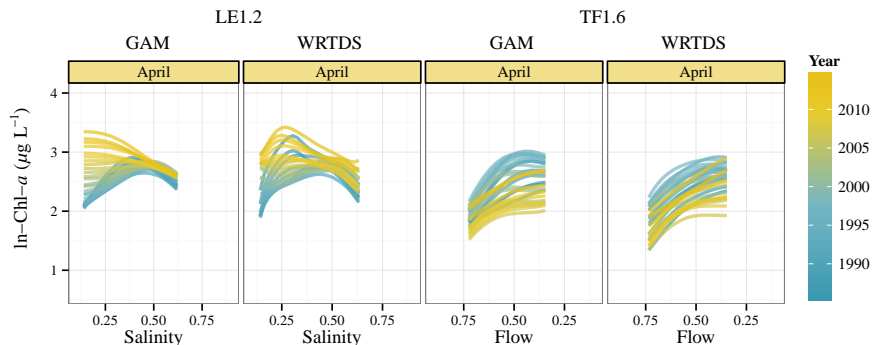
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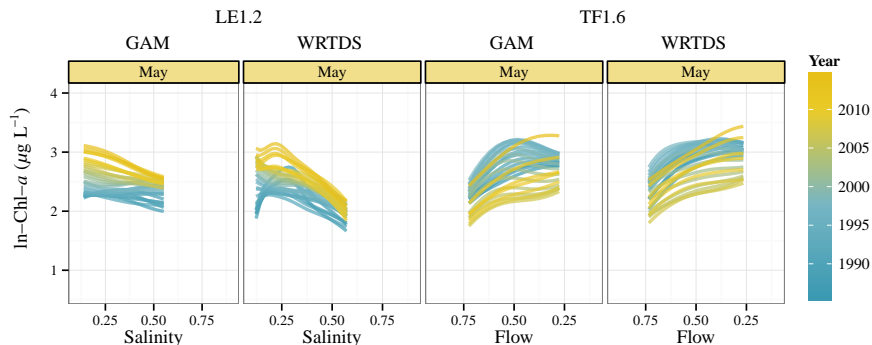
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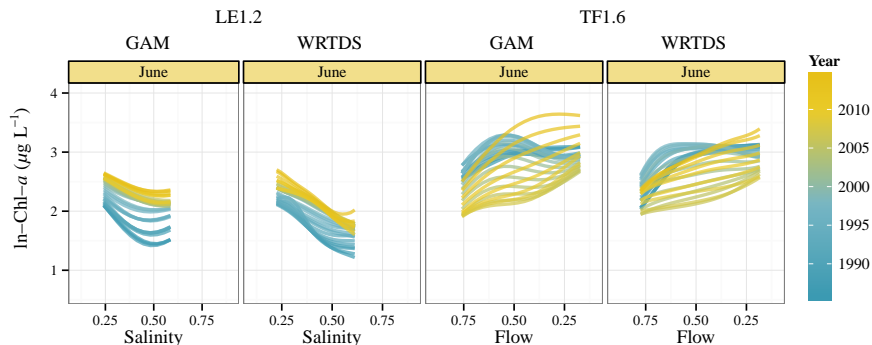


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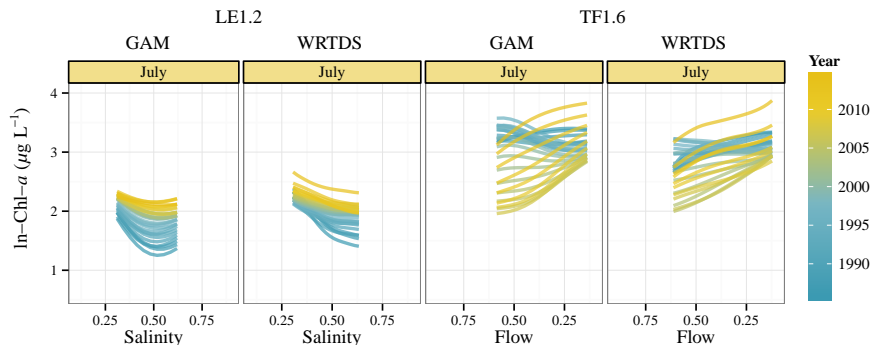
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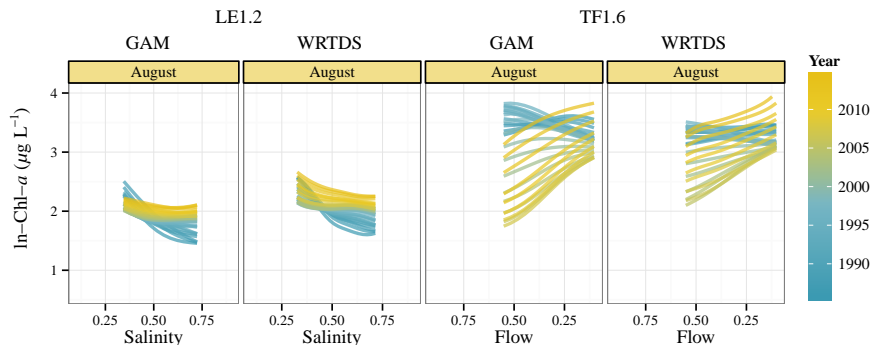
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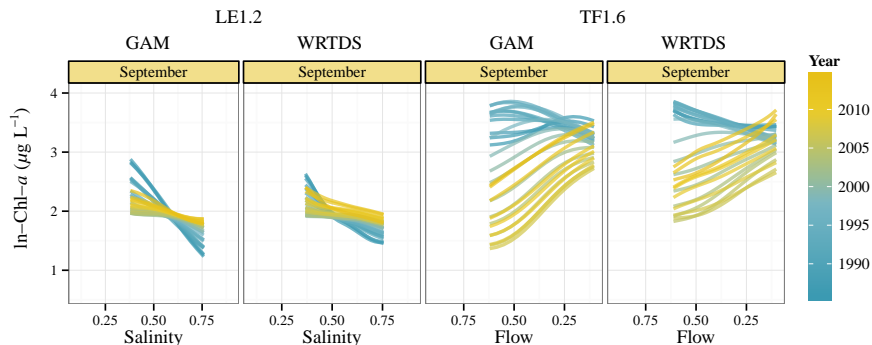
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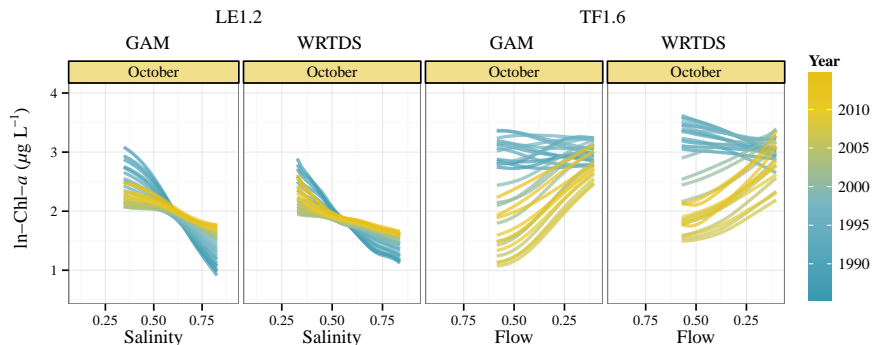
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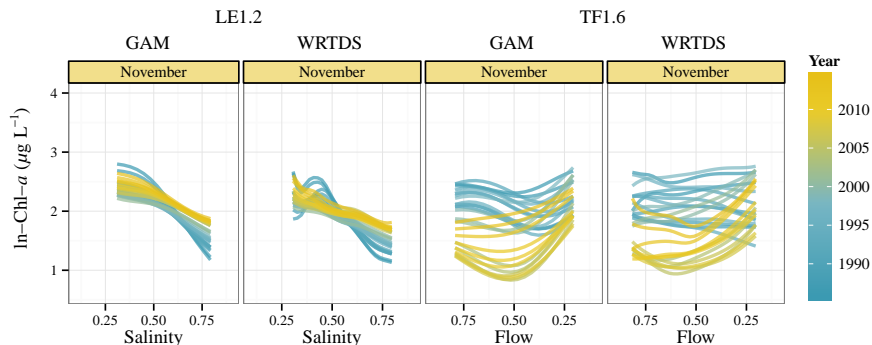
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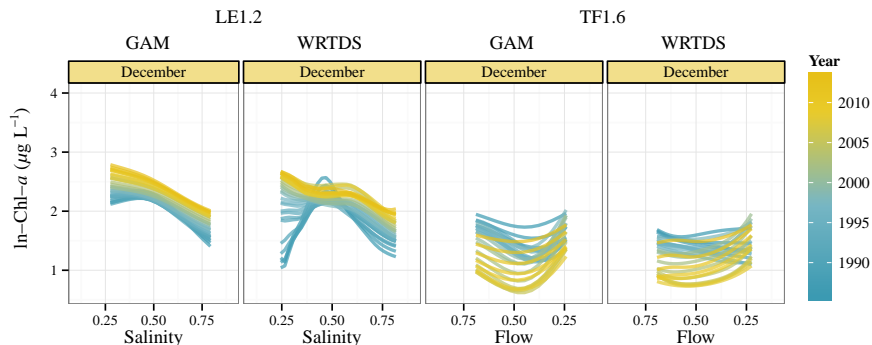
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# Development of simulated datasets

**Objective:** Evaluate ability of each model to reproduce flow-normalized trends

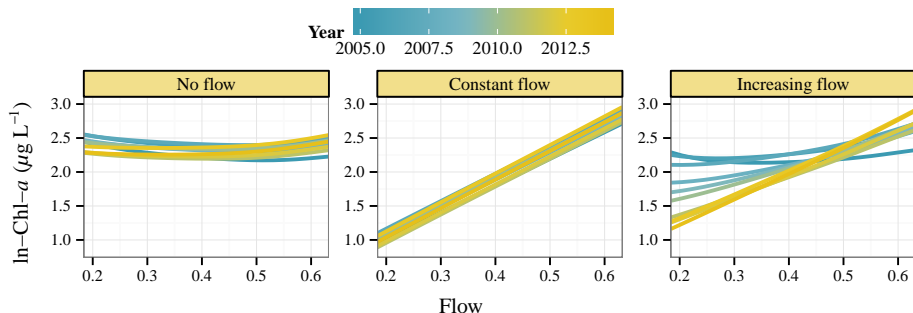
**Problem:** The true flow-normalized trends are not known and can only be empirically estimated

We simulated monthly datasets following techniques in Beck et al. 2015 and Hirsch et al. 2015

- Daily time series: Bowie gage discharge, Jug Bay fluorescence
- Overall:  $Chl_{obs} = Chl_{flo} + Chl_{bio}$
- Three monthly datasets with different flow components: none, constant, increasing

# Development of simulated datasets

Simulated data behaved as expected: three datasets with different flow contributions



**Figure :** WRTDS predictions from August for three simulated datasets with different flow contributions.

# Simulation comparisons

**Objective:** How well do flow-normalized predictions reproduce  $Chl_{flo}$

Simulated time series:  $Chl_{obs} = Chl_{flo} + Chl_{bio}$

**Table :** Performance summaries (RMSE) of model predictions for the three simulated time series.

Simulations	$Chl_{obs} \sim \widehat{Chl}_{obs}$	$Chl_{bio} \sim \widehat{Chl}_{bio}$
<b>No flow</b>		
GAM	0.51	0.53
WRTDS	0.50	0.52
<b>Constant flow</b>		
GAM	0.51	0.58
WRTDS	0.53	0.57
<b>Increasing flow</b>		
GAM	0.51	0.54
WRTDS	0.50	0.52

# Conclusions

- WRTDS prediction errors always less than GAMs
- Seasonal patterns were slightly different between models
- GAM estimates were more ‘stable’ during periods with little data
- No clear differences in flow-normalization abilities
- Interesting trends in Patuxent
  - ▶ Chlorophyll increasing lower estuary (LE1.2), mainstem influences
  - ▶ Multi-year signal of Isabel at TF1.6, flushing and low chlorophyll
  - ▶ Distinct changing relationships of chlorophyll with flow by station

# Conclusions

Journal venue? Modelling vs ecosystem dynamics? Two papers?

## Extra

For comparing each model's *predictions to observed*, at both sites:

$$RMSE_{fit} = \sqrt{\frac{\sum_{i=1}^n (Chl_i - \widehat{Chl}_i)^2}{n}}$$

For comparing *predictions between models*, at both sites:

$$RMSE_{btw} = \sqrt{\frac{\sum_{i=1}^n (\widehat{Chl}_{WRTDS,i} - \widehat{Chl}_{GAM,i})^2}{n}}$$

$$\text{Average difference} = \left( \frac{\sum_{i=1}^n \widehat{Chl}_{WRTDS,i} - \sum_{i=1}^n \widehat{Chl}_{GAM,i}}{\sum_{i=1}^n \widehat{Chl}_{GAM,i}} \right) * 100$$

Simulated datasets:

- Daily time series: Bowie gage discharge, Jug Bay fluorescence
- Overall:  $Chl_{obs} = Chl_{flo} + Chl_{bio}$
- From discharge:  $Chl_{flo} = I \left( \hat{Q}_{seas} + \sigma \cdot \varepsilon_{Q, sim} \right)$
- From fluorescence:  $Chl_{bio} = \widehat{Chl}_{seas} + \sigma \cdot \varepsilon_{Chl, sim}$
- Indicator  $I$  changes to simulate changing flow component

