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VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

James River Modeling Results Used to Inform Revisions to Virginia’s Water Quality Management Plan Regulation

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Modeling Workgroup Quarterly Review

January 7, 2021

What's the Water Quality Management Plan Regulation?

- This regulation (9 VAC 25- 720) lists all Virginia TMDL waste load allocations by major river basin, stream segment, and discharger.
- The waste load allocations for the Bay basins need to be amended to reflect both Virginia's WIP III and nutrient trading agreements.
- The allocations for the James River need to be amended to reflect chlorophyll criteria-based TN and TP WLAs for significant dischargers.

New James River chlorophyll criteria (effective Jan 2020)

Seasonal Mean Criteria

Designated Use	Chlorophyll a μ/l	Chesapeake Bay Program Segment	Temporal Application
Open water	8	JMSTF2	March 1 - May 31 (spring)
	10	JMSTF1	
	13	JMSOH	
	7	JMSMH	
	8	JMSPH	
	21	JMSTF2	July 1 - September 30 (summer)
	24	JMSTF1	
	11	JMSOH	
	7	JMSMH	
	7	JMSPH	

Not to be exceeded more than twice in a six-year period

Short Duration Criteria (summer only)

Chlorophyll a μg/l	Chesapeake Bay Program Segment	Spatial Application	Duration
--	JMSTF2	Upstream boundary of JMSTF2 to river mile 95	--
52	JMSTF2	River mile 95 to downstream boundary of JMSTF2	1-month median
52	JMSTF1	Upstream boundary of JMSTF1 to river mile 67	1-month median
34	JMSTF1	River mile 67 to downstream boundary of JMSTF1	1-month median
--	JMSOH	Entire segment	--
59	JMSMH	Entire segment	1-day median
20	JMSPH	Entire segment	1-day median

Not to be exceeded more than 10% of the time in a six-year period

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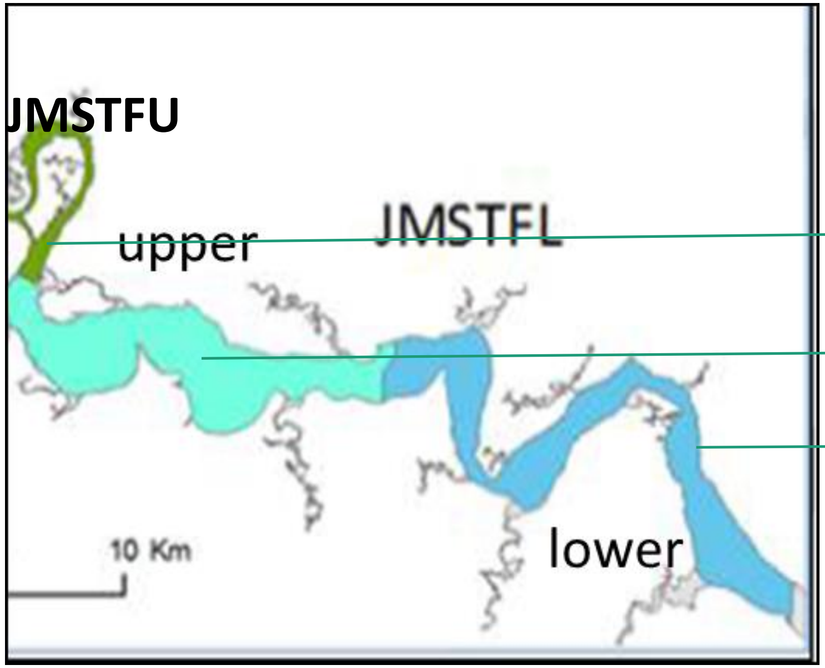
New James River chlorophyll criteria



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Not to be exceeded more than 10% of the time in a six-year period

DEQ is using the VIMS water quality model to inform the decision-making process to set WLAs for the James River significant dischargers.

Incorporating climate change factors into the water quality modeling is an important component of this work.

Phytoplankton Bloom

Climate Change

Sea-level rise

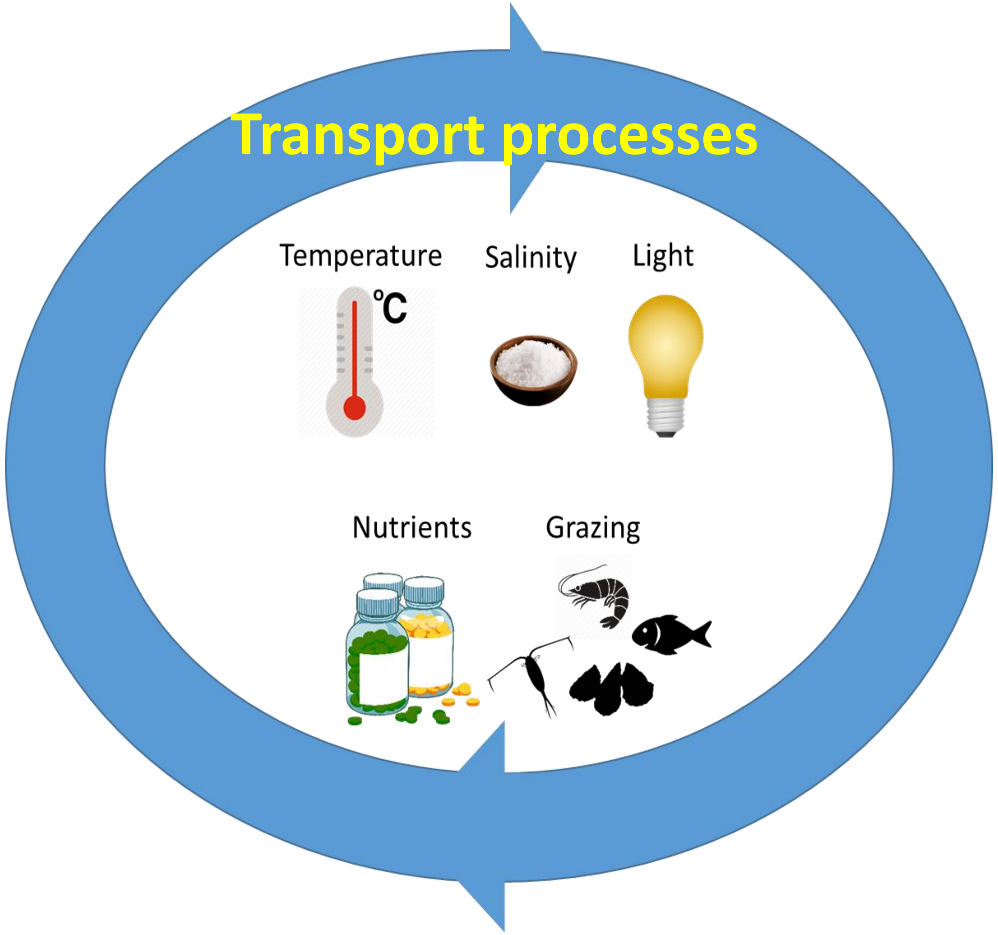
- Increase of salinity intrusion
- Change in estuarine circulation

Changes in discharge

- Change in residence time

Increase temperature

- Increase growth rate
- Increase respiration rate
- Change in grazing



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Temperature Function

(Brush et a;., 2002)

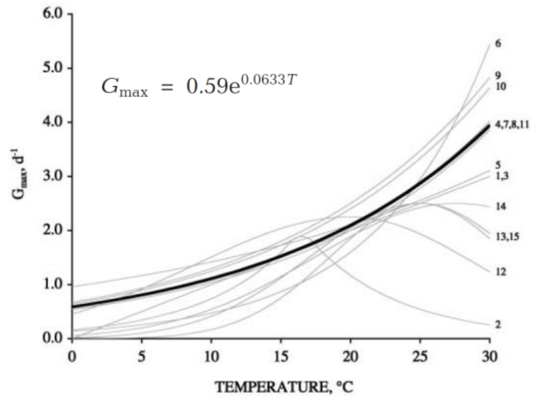
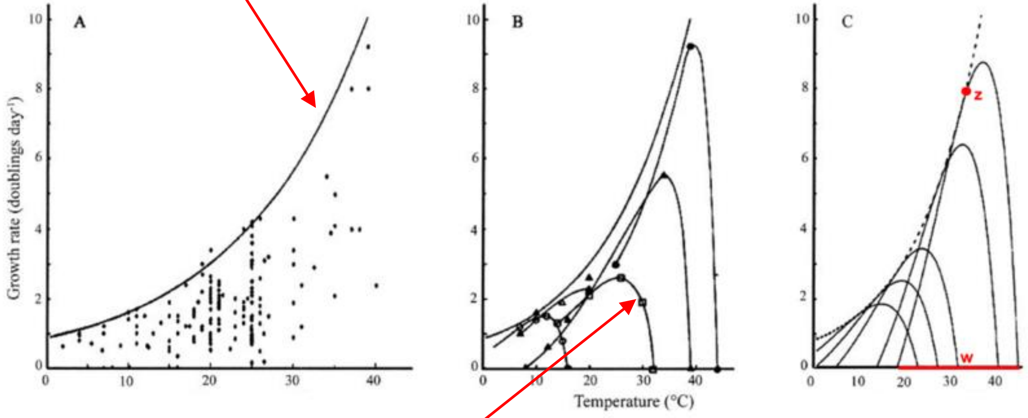


Fig. 1. Temperature-dependent functions for the maximum daily phytoplankton growth rate (base e) in a variety of dynamic simulation models. The bold line is the Eppley curve. Sources which use the Eppley curve directly include models of Lake Ontario (Thomann et al. 1975), Narragansett Bay (Kremer & Nixon 1978), the Baltic Sea (Stigebrandt & Wulff 1987), the outer southeastern US continental shelf (Hofmann & Ambler 1988), the subarctic Pacific (Matear 1995), and nearshore regions of Chesapeake Bay (Madden & Kemp 1996). Sources which use a variation of the Eppley Curve include models of the following systems and species groups: 1, Sacramento-San Joaquin Delta (DiToro et al. 1971); 2, Lake Glumsø (Jørgensen 1976); 3, Potomac River (DiToro et al. 1977); 4, Lake Huron and Saginaw Bay (DiToro & Matystik 1980); 5, Lake Erie diatoms (DiToro & Connolly 1980); 6, other Lake Erie phytoplankton (DiToro & Connolly 1980); 7, Potomac River (Thomann & Fitzpatrick 1982); 8, Chesapeake Bay main stem (HydroQual 1987); 9, James, York, and Rappahannock Rivers (HydroQual 1987); 10, Patuxent River (HydroQual 1987); 11, the WASP (Water Quality Analysis Simulation Program) model (Ambrose et al. 1993); 12, Chesapeake Bay diatoms (Cerco & Cole 1994); 13, Chesapeake Bay green algae (Cerco & Cole 1994); 14, Chesapeake Bay cyanobacteria (Cerco & Cole 1994); 15, Indian River Lagoon and Rehoboth Bay (Cerco et al. 1994)

Eppley Curve (Eppley, 1966, 1972)

$$\mu = a \cdot \exp(b \cdot T)$$

$$*a = 0.81,\ b = 0.0631$$



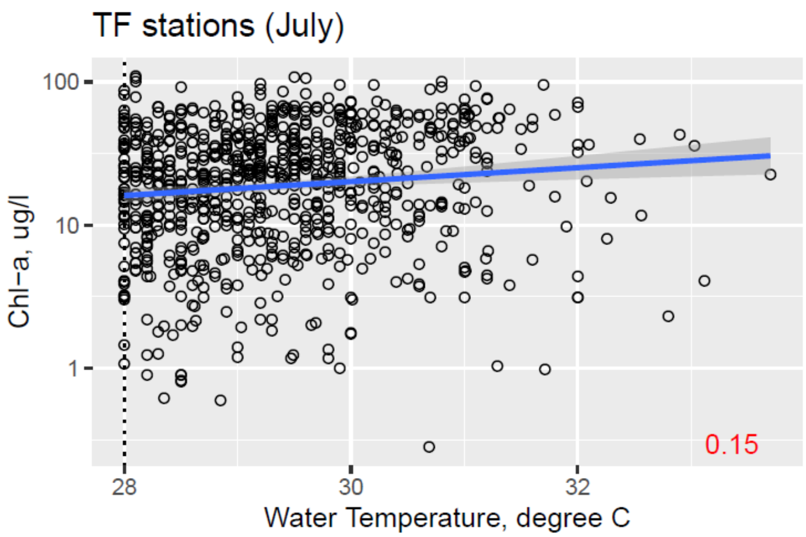
Growth for each species

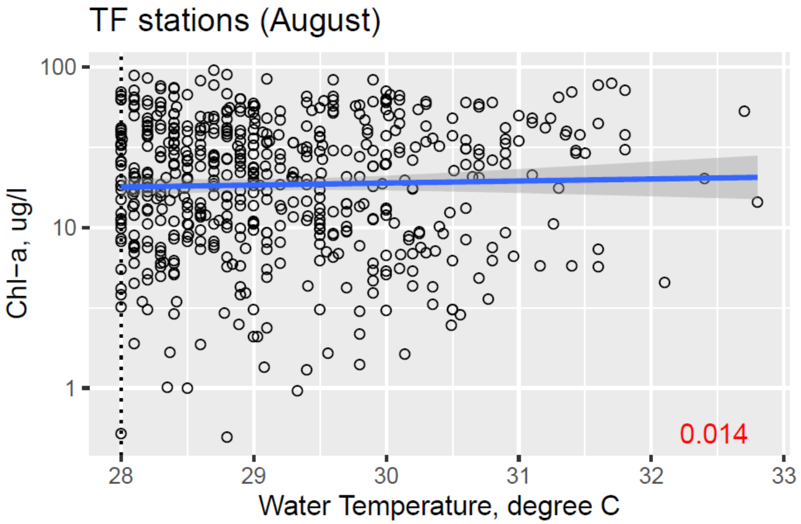
$G = g_{20} f(T)$

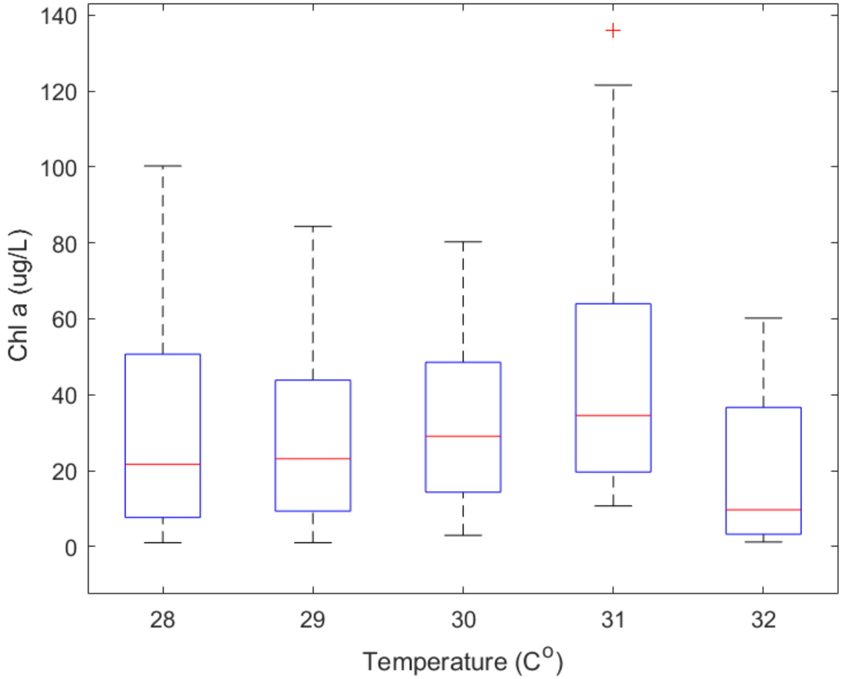
$$f(T) = \exp\left(-KTG1_x\,[T - TM_x]^2\right) \quad \text{when } T \le TM_x$$

$$= \exp\left(-KTG2_x\,[TM_x - T]^2\right) \quad \text{when } T > TM_x$$

Is there a signal of Climate Change?







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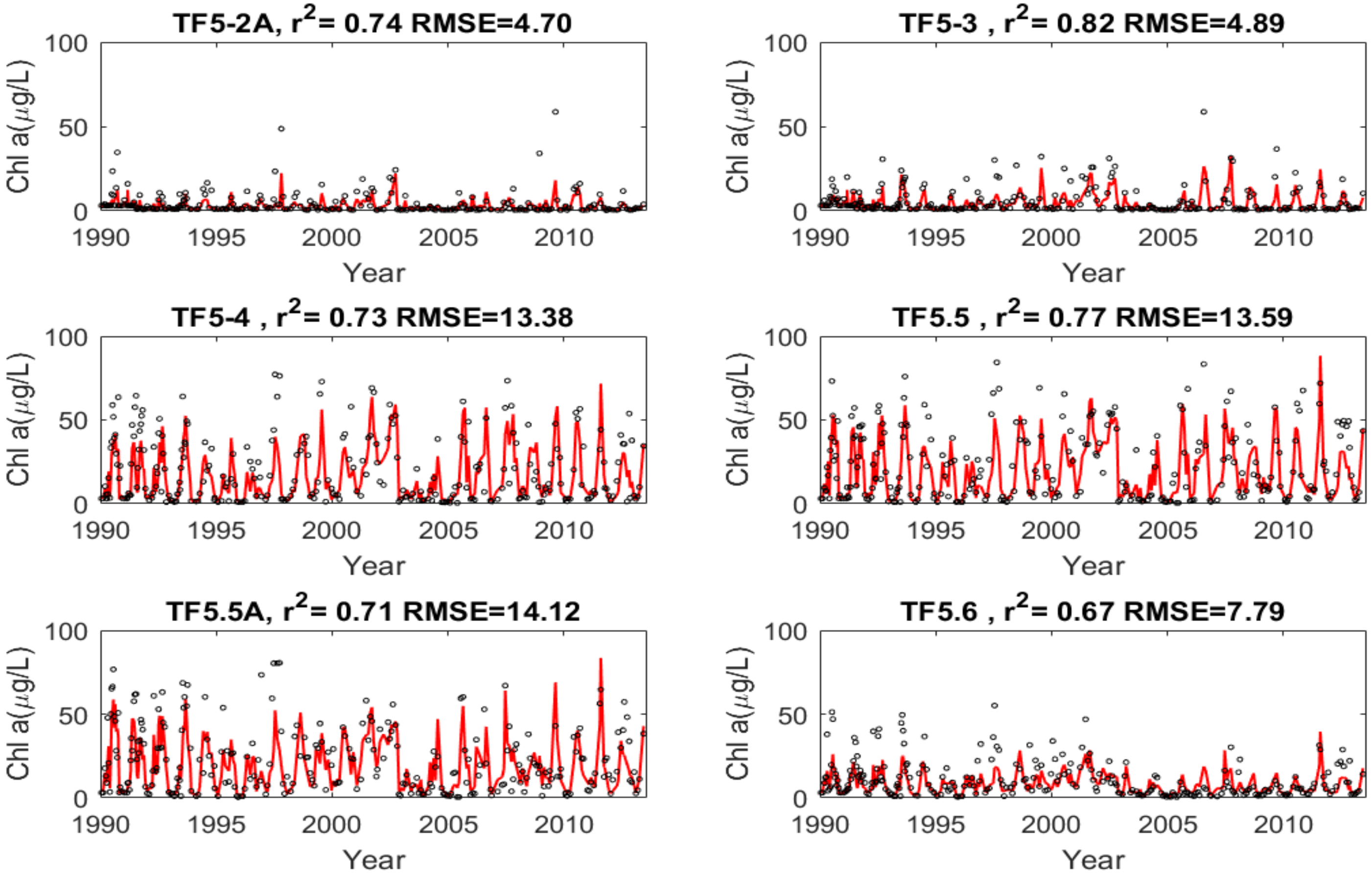
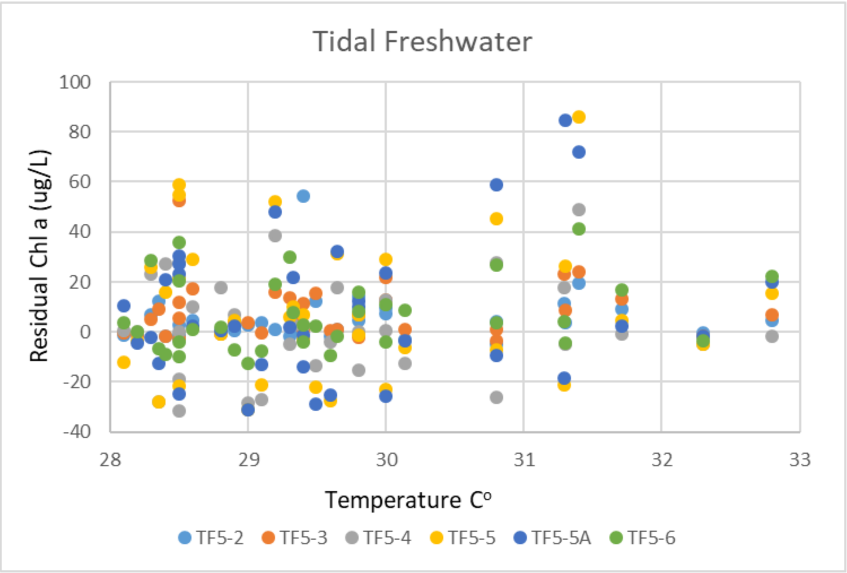
Is there a signal of Climate Change?

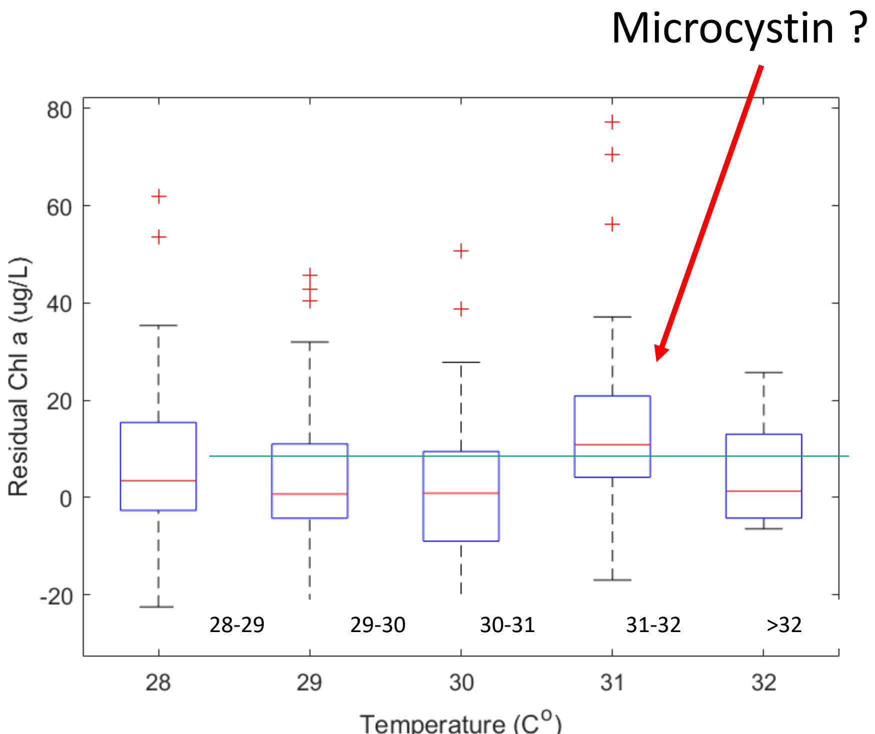
- Create a data model for Chl a with respect to flow, TN, TP, TSS.
- Compute the residuals to remove the impacts of flow and nutrients.



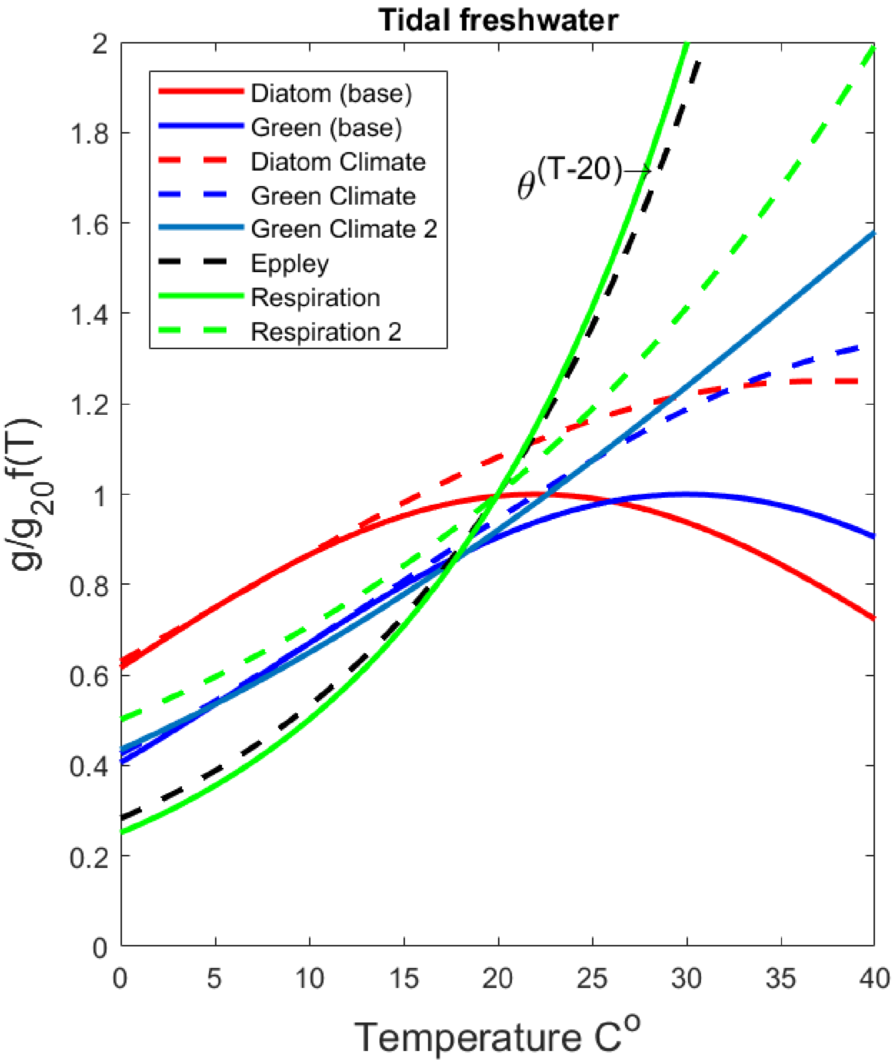
Questions Regarding Climate Change

- Create a data model for Chl a with respect to flow, TN, TP, TSS.
- Compute the residuals.
- Plot residuals corresponding to temperatures of 28,29,30,31,32





Temperature Effect on Growth and Respiration Rates



Testing cases

- Reduced respiration
- Revised curve for diatom
- Use 2 curves for summer green
- Use Eppley curve
- Change grazing

Respiration rate changes faster than growth rate when temperature increase.

The temperature increases in summer due to climate change ranges from 1-2 C°, and the growth rate does not increase fast enough and Chl-a could decrease.

If a high growth rate is used, the model calibration is not satisfactory in the James River

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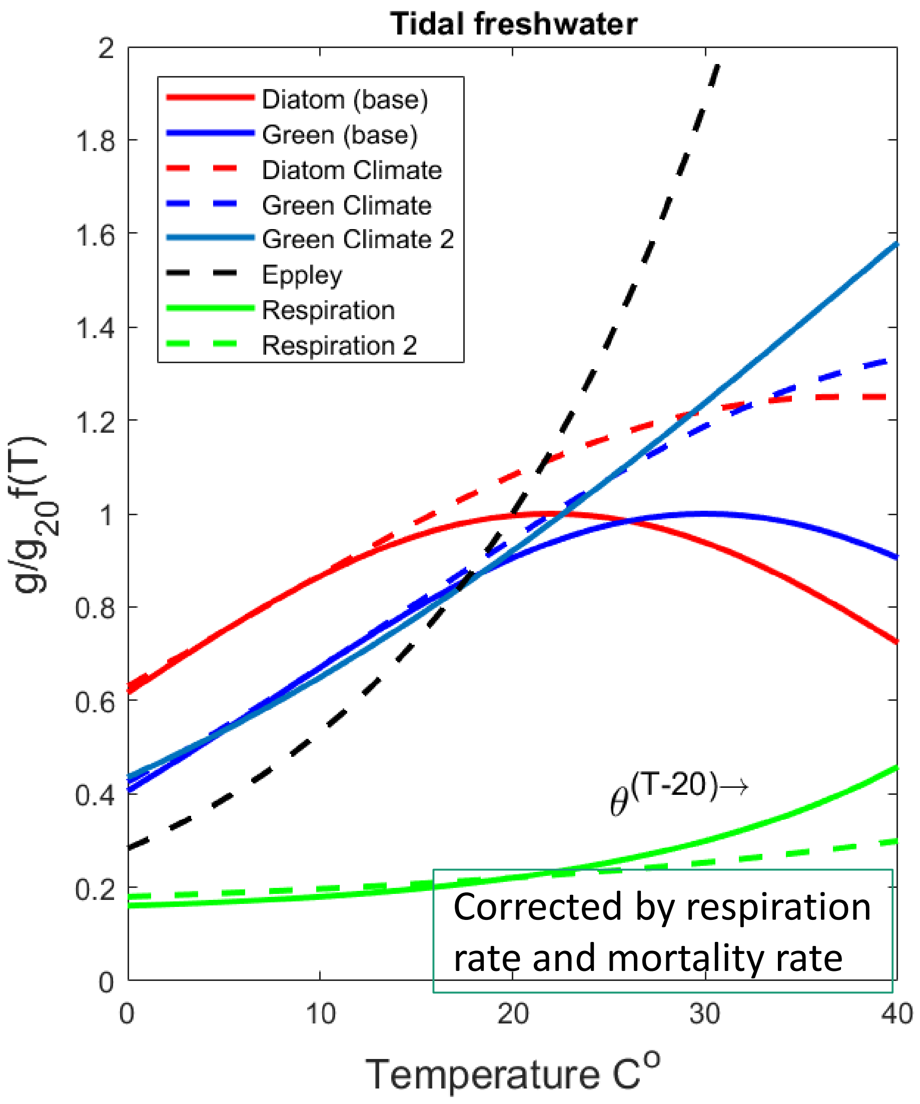
Temperature Effect on Growth and Respiration Rates



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Temperature Changes in the James River

- Sea level rise is about 0.22 m at the mouth of James
- Salinity change increase by 0.86 on average
- Temperature adjustment is through heat flux (air temperature).

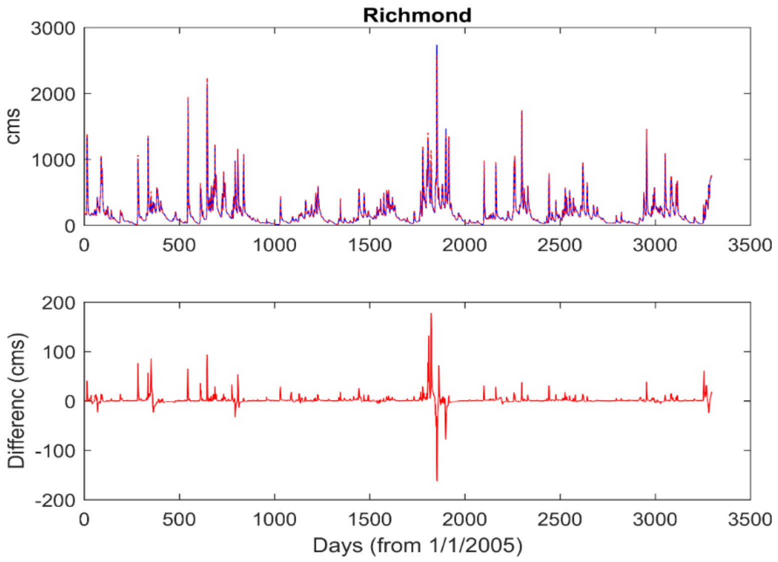
  fct(1) = 0.923938 , fct(2) = 0.917179 , fct(3) = 0.959050

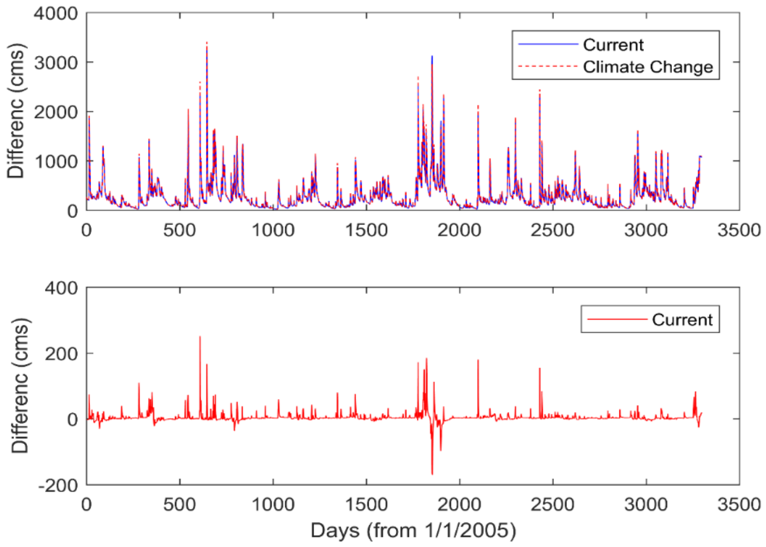
  fct(4) = 1.176651 , fct(5) = 0.967224 , fct(6) = 0.980705

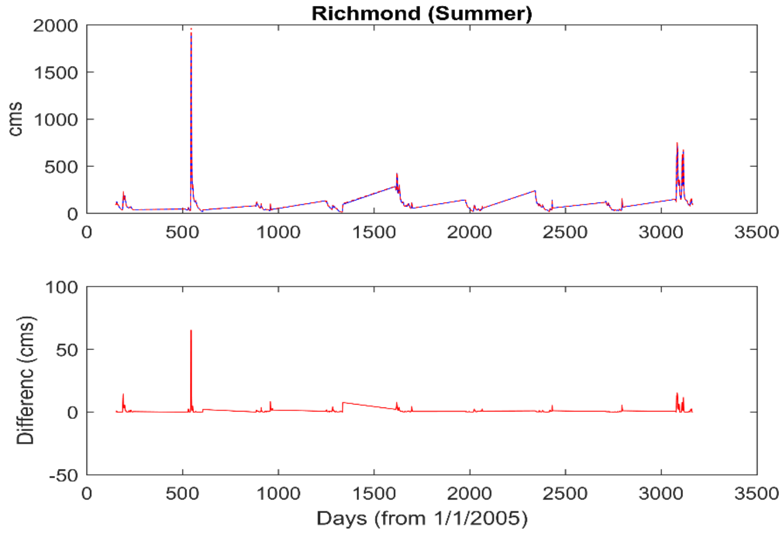
  fct(7) = 1.068016, fct(8) = 1.140655, fct(9) = 1.159039

  fct(10) = 1.059729 , fct(11) = 1.127296 , fct(12) = 1.219462

Changes in freshwater discharge

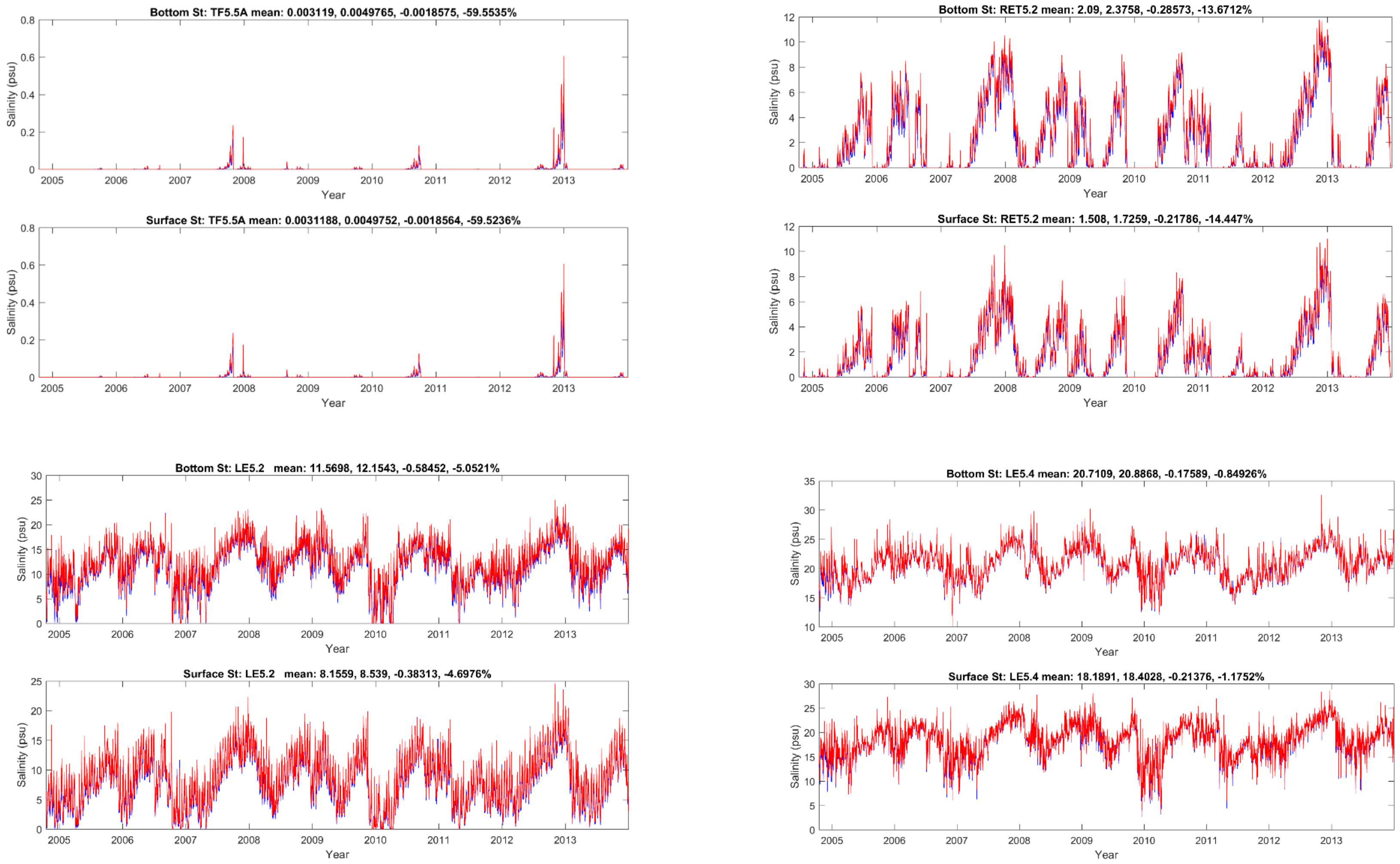






- Short -term change can be upped to 100 cms.
- Less change occurs during the summer period

Comparison of Change in Dynamics due to Climate Changes (Salinity increases at all obs. stations)



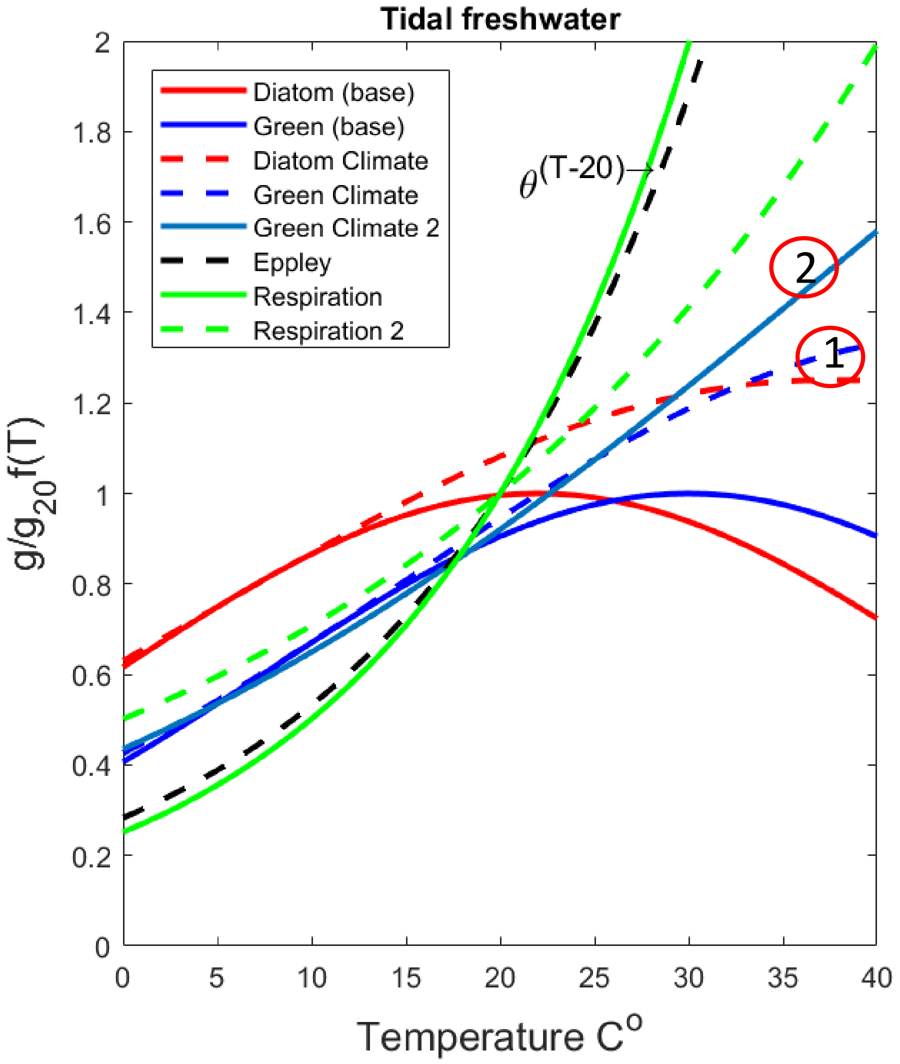
Blue lines are existing condition red lines are climate change condition

Model Sensitivity Runs Using Revised Growth and Respiration Rates

- Use revised temperature curves (2 parameter sets), the model calibration only has minor changes and model results of nutrient limitation are better simulated.
- Revised calibration is appropriate for simulating climate change conditions.

- Model does not simulate current condition if Eppley curve is used (high growth rate).
- Model does not simulate current condition if respiration rate is decreased by half.
- Model does not simulate current condition if further increasing growth rate (increase growth gradient)
- Model does not simulate current condition if change grazing rate. Grazing pressure is not high in James

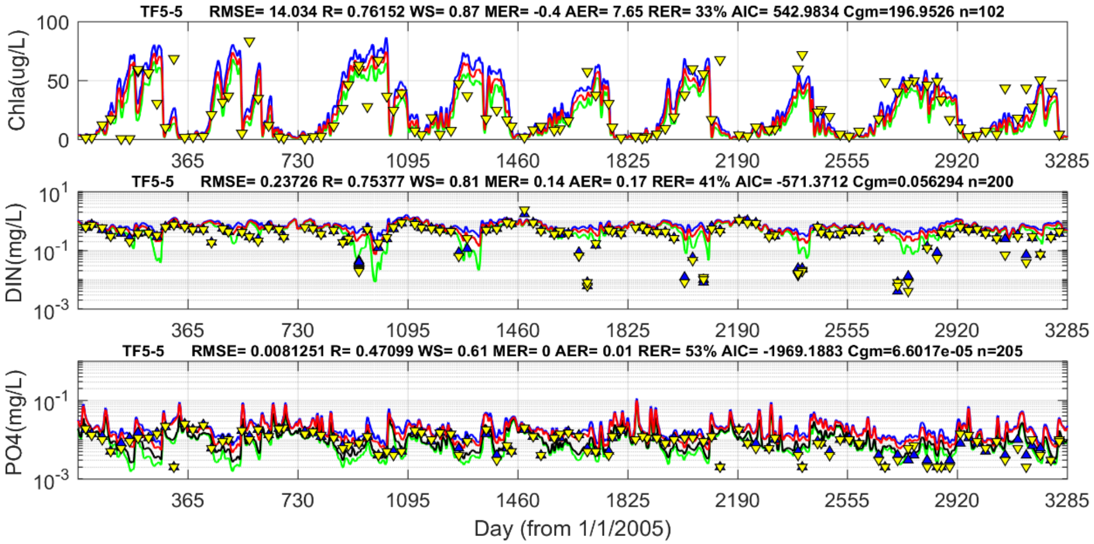
Both Curves used for Green Algae Have the similar results (refers to parameter set 1 and set 2)



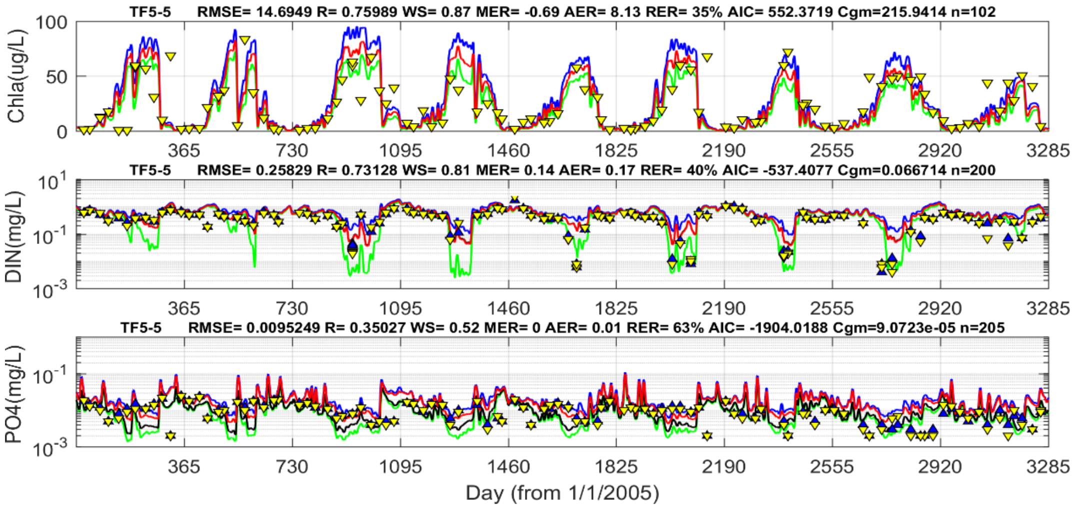
- Increase of gradient (curve 2) has similar calibration results under current condition.
- Suggest using Green Climate 2 curve.

Comparison of Model Calibration (Parameter set 2)

Original calibration



Revised calibration



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Comparison of Model Calibration (Parameter set 2)

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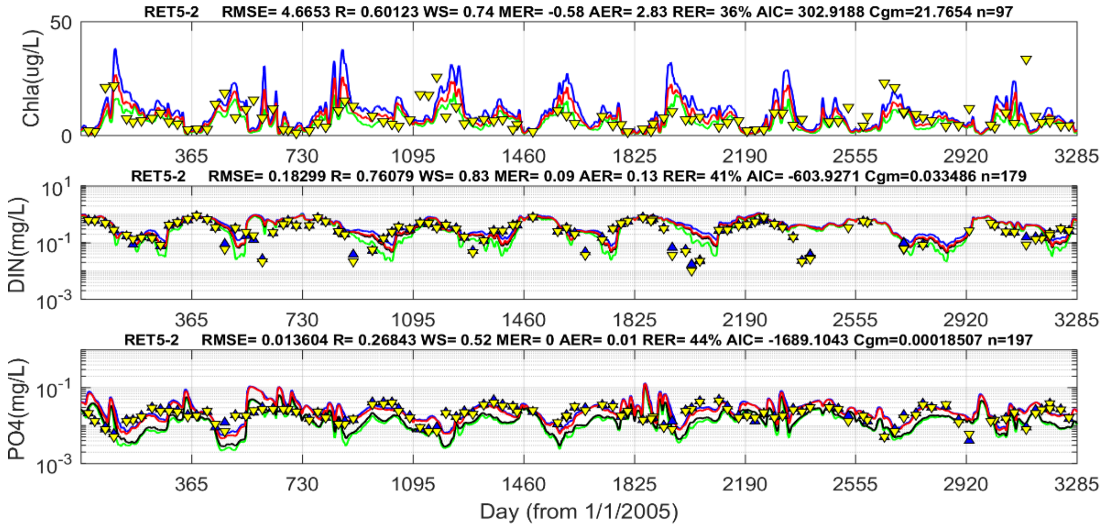

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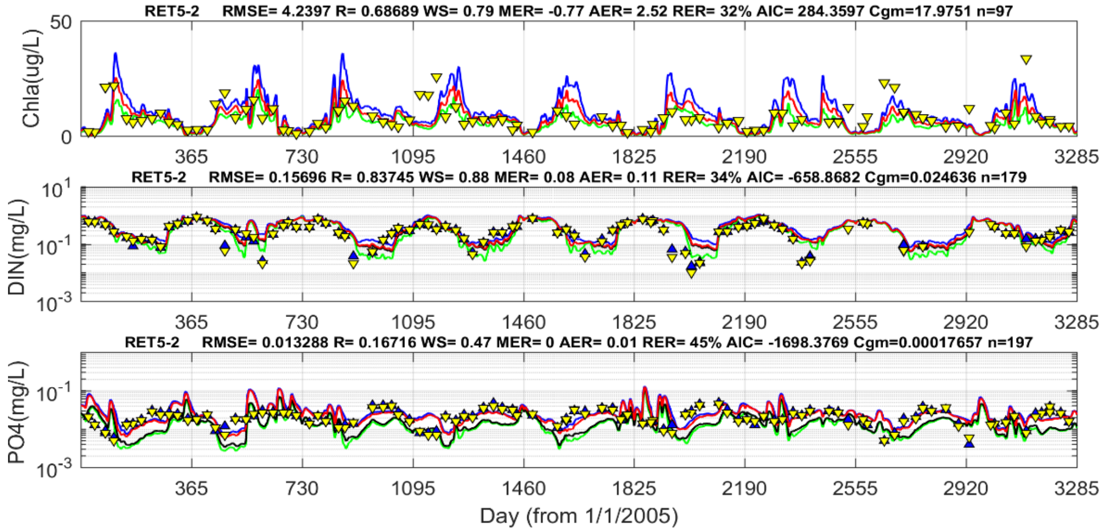

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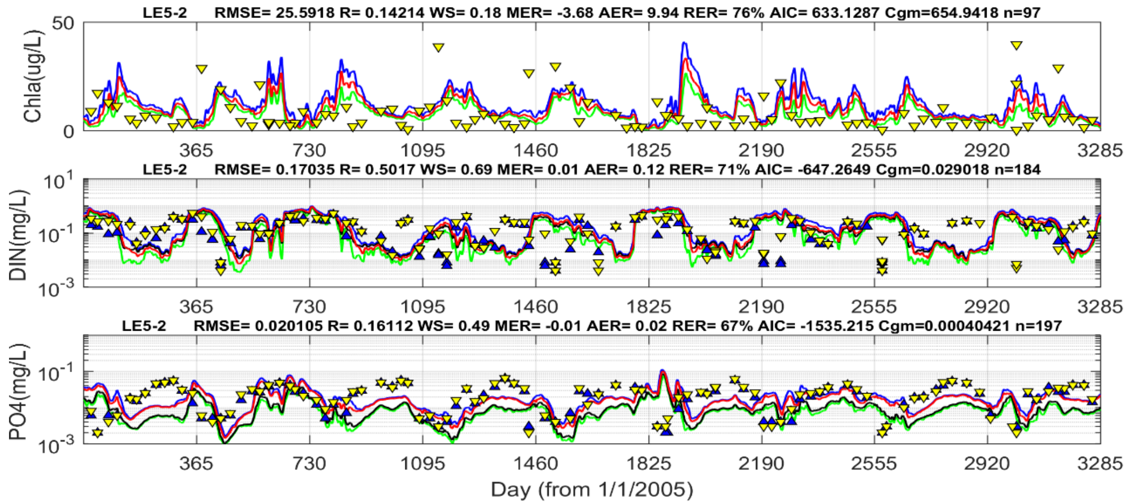
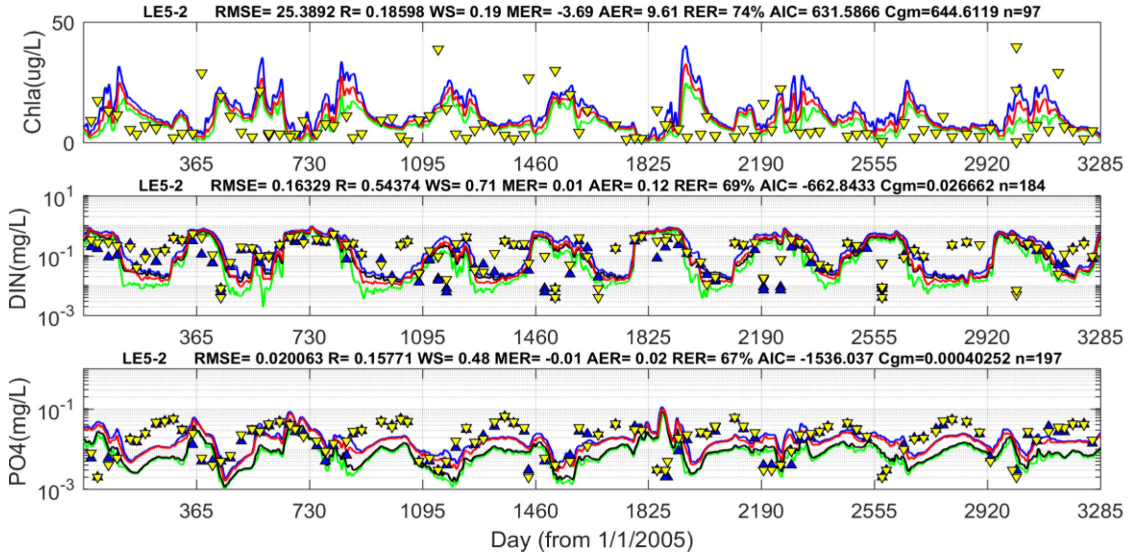


Revised calibration



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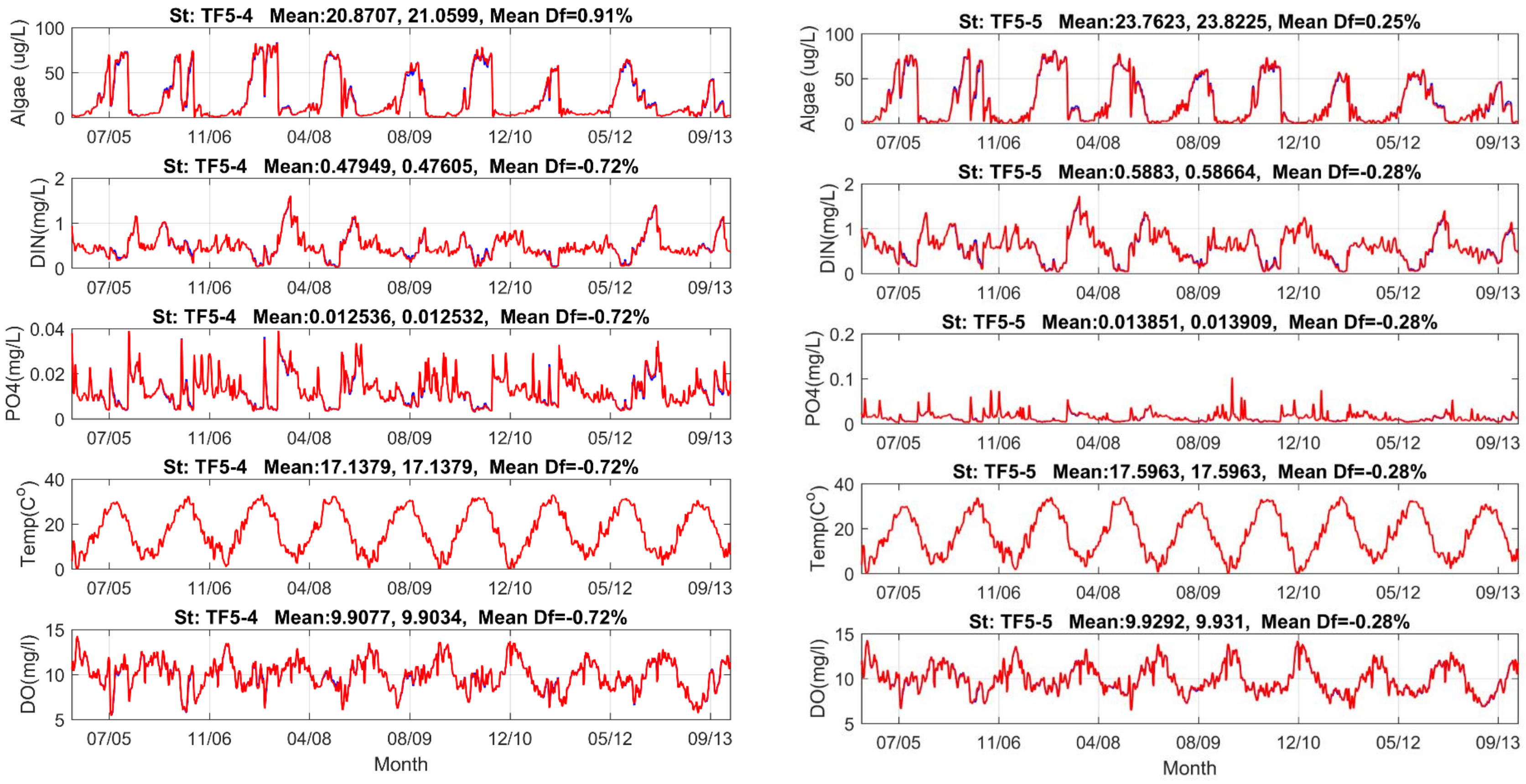
Comparison of 2 Parameter Sets (Model Calibration)

There are minor changes for the model calibration using 2 different parameters



Blue lines are parameter set 1 and red lines are parameter set 2

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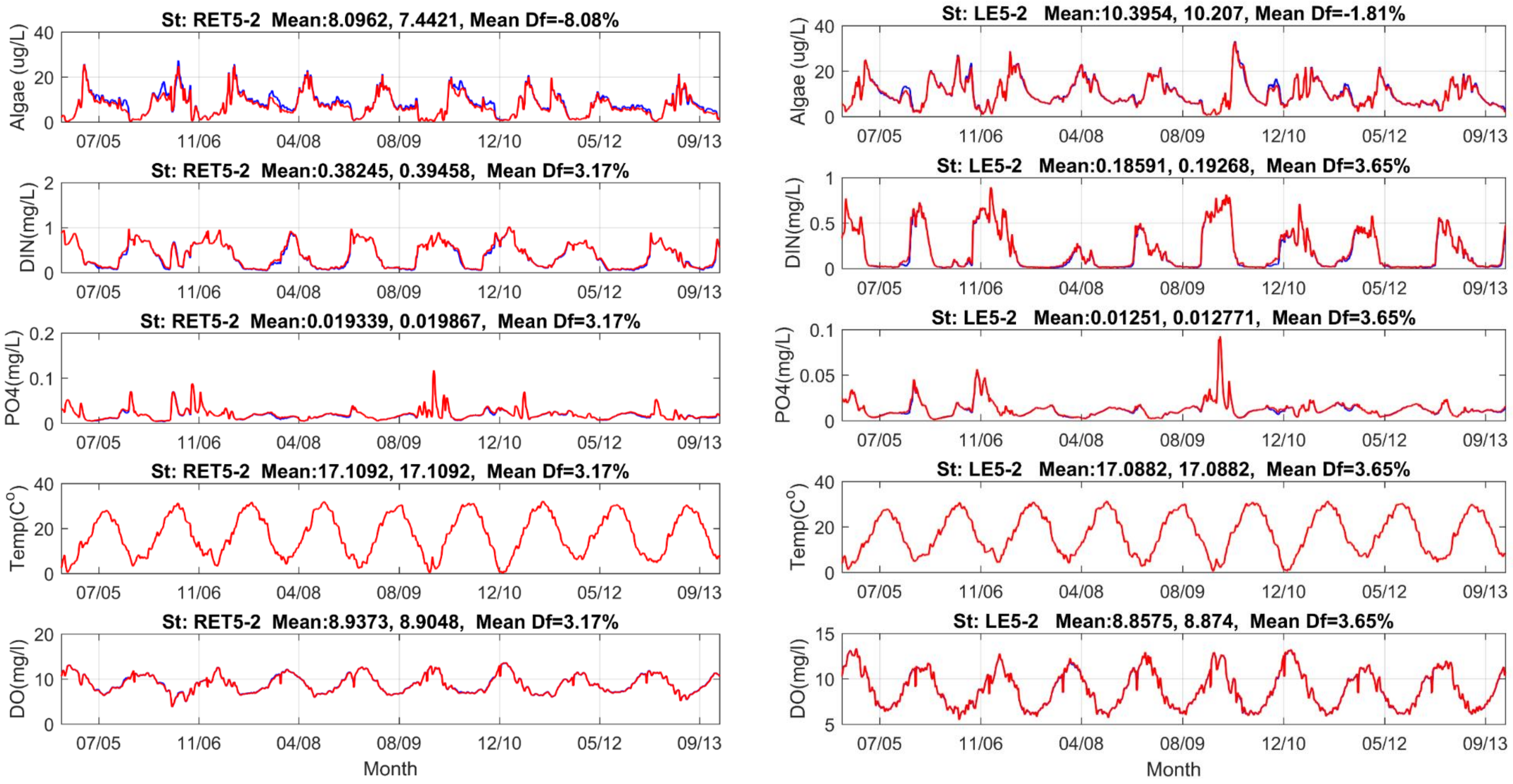
Comparison of 2 Parameter Sets (Model Calibration)



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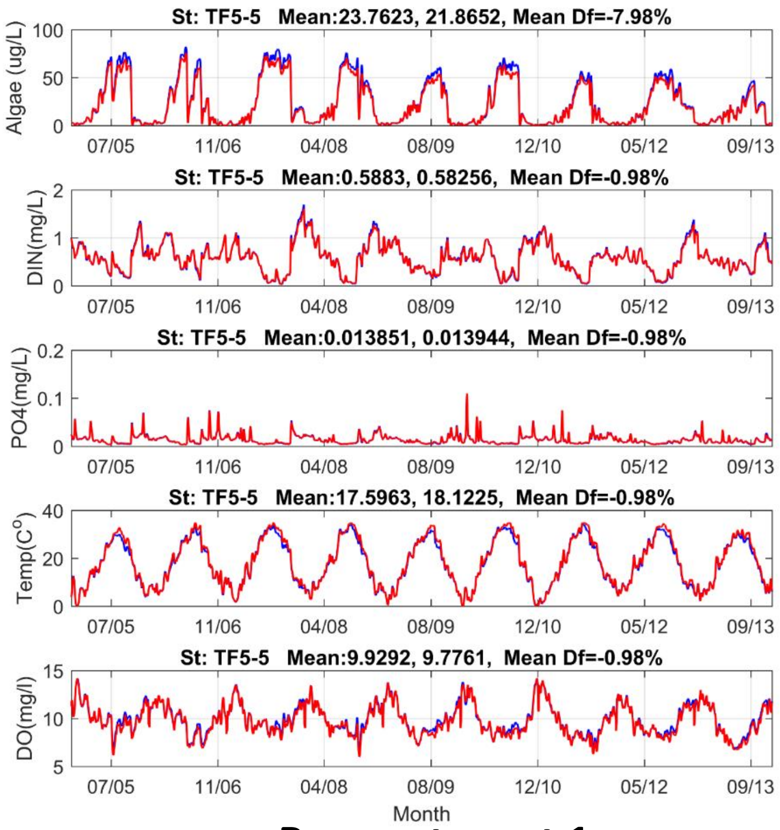
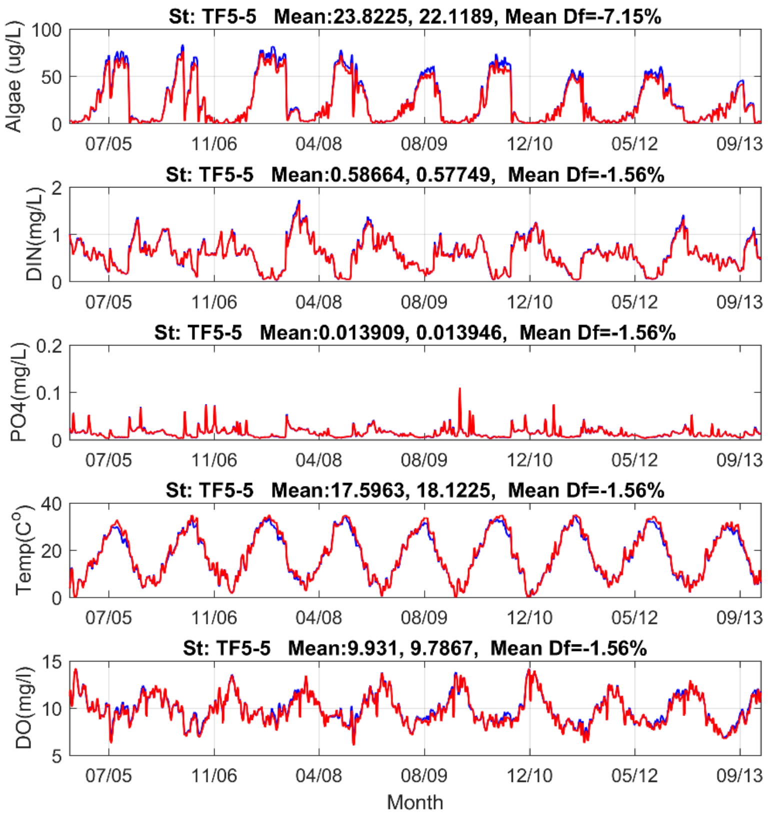
Comparison of 2 Sets of Parameters with and without Climate Change Condition

- Chl a differences are -7.96% and 7.15%, respectively for 2 sets of parameters
- Minor decrease in the upstream



Parameter set 1



Parameter set 2

Blue lines are current condition and red lines are under climate change condition

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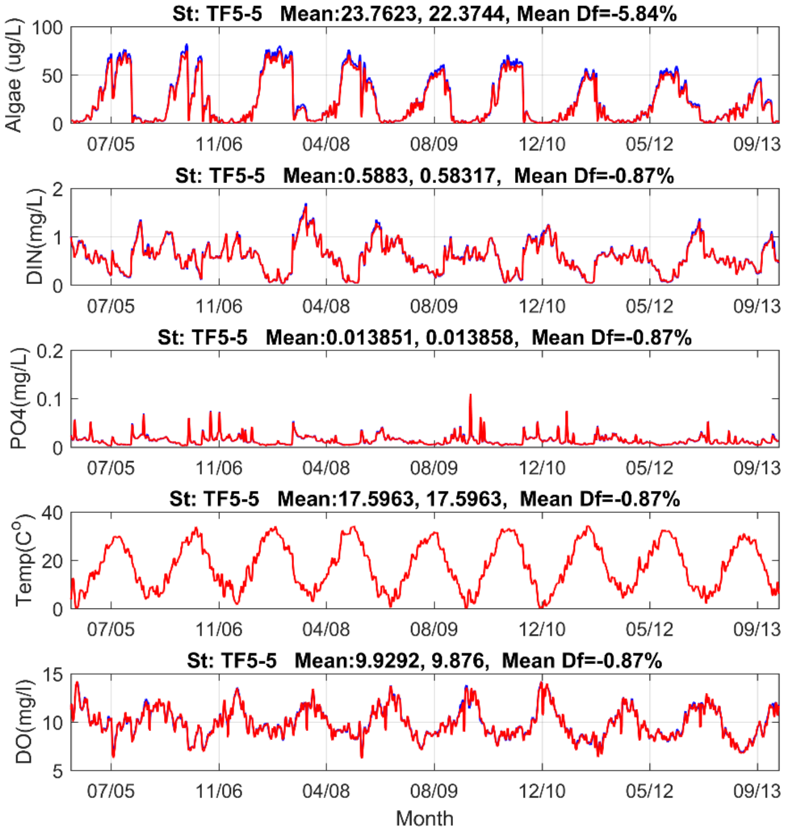
Evaluation Impact due to Transport or Temperature

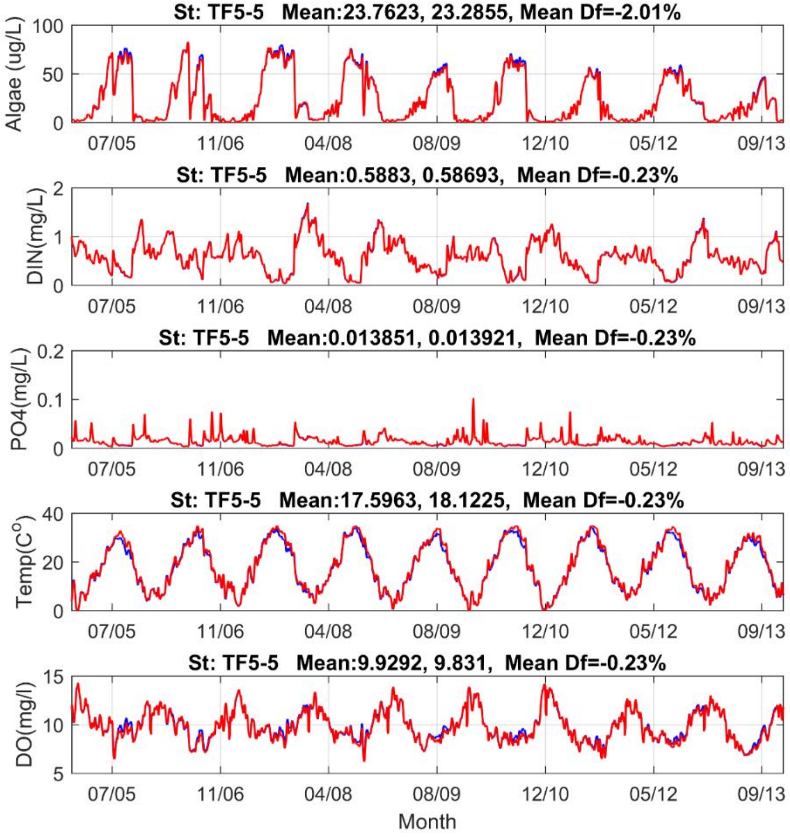
- Change transport only
  - sea-level rise, salinity increase, change in freshwater discharge
- Change temperature
  - Increase heat flux. Change in temperate ranging from 1-2 C^o
- The effect of change in transport on algae is almost same as change in temperature

Evaluation Impact due to Transport or Temperature

Change in transport



Change in temperature



Blue lines are current condition and red lines are under changed condition

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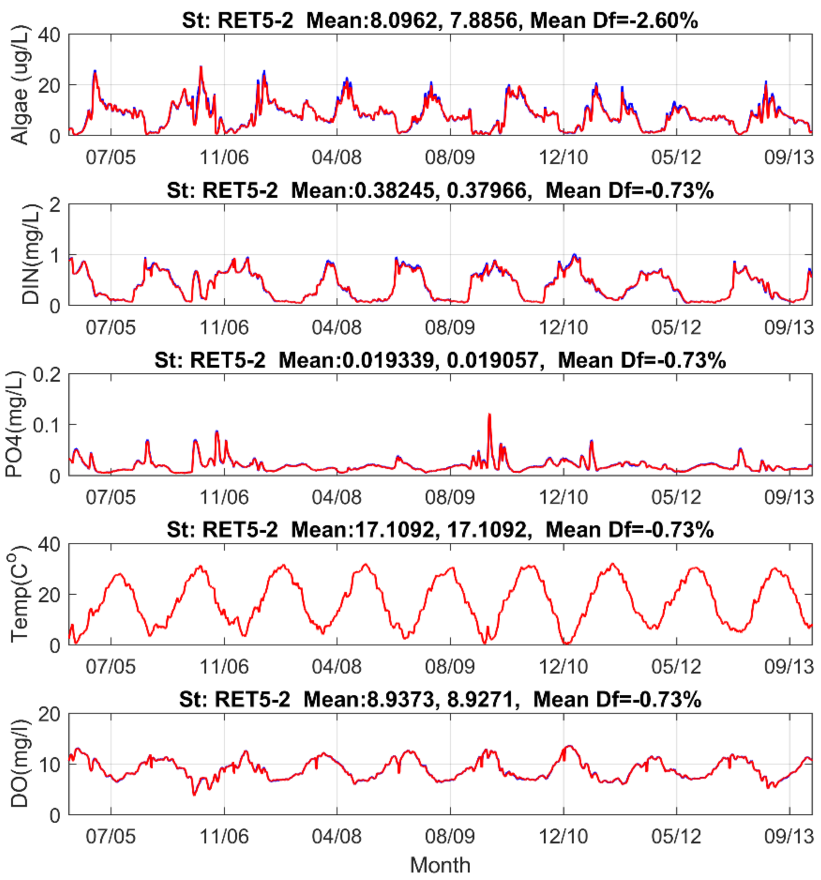
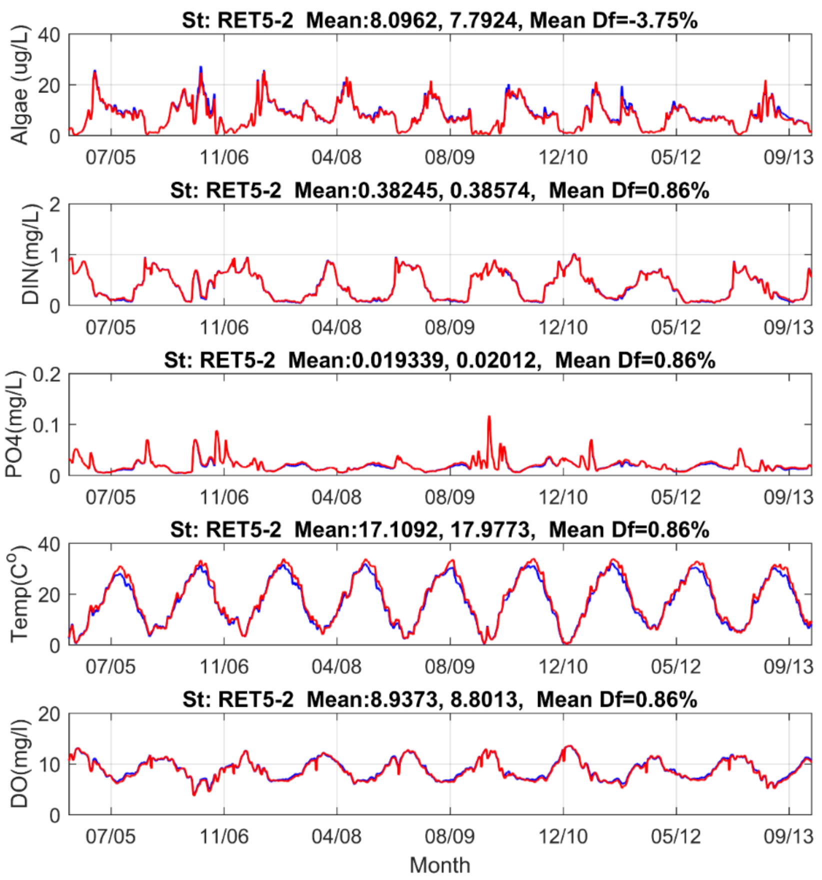
Evaluation Impact due to Transport or Temperature

Change in transport



Change in temperature



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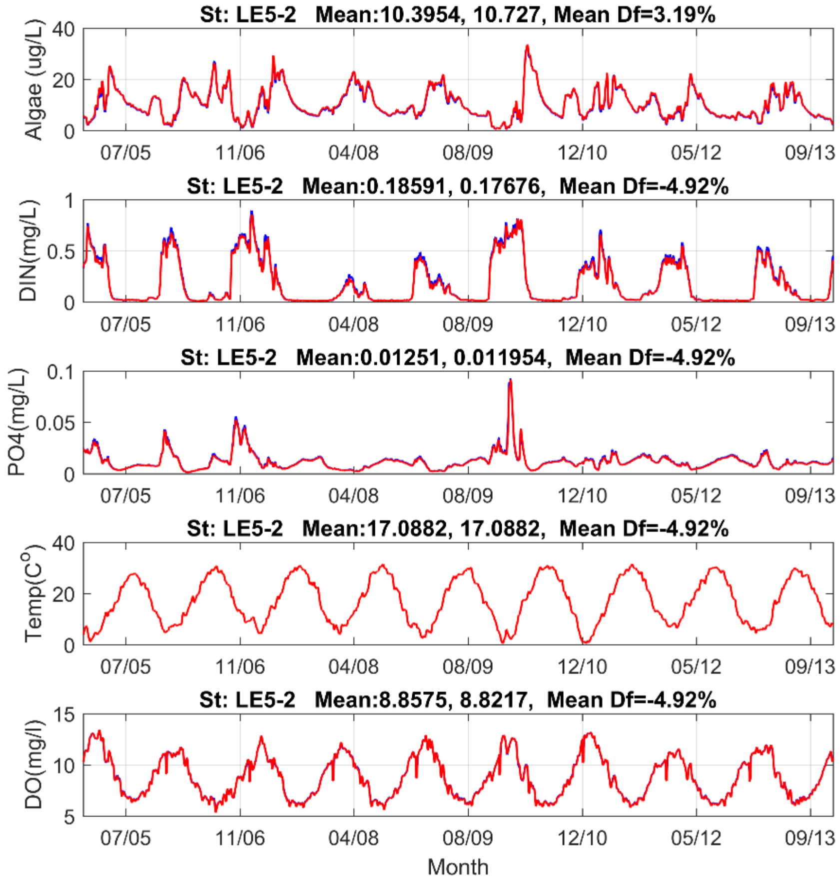
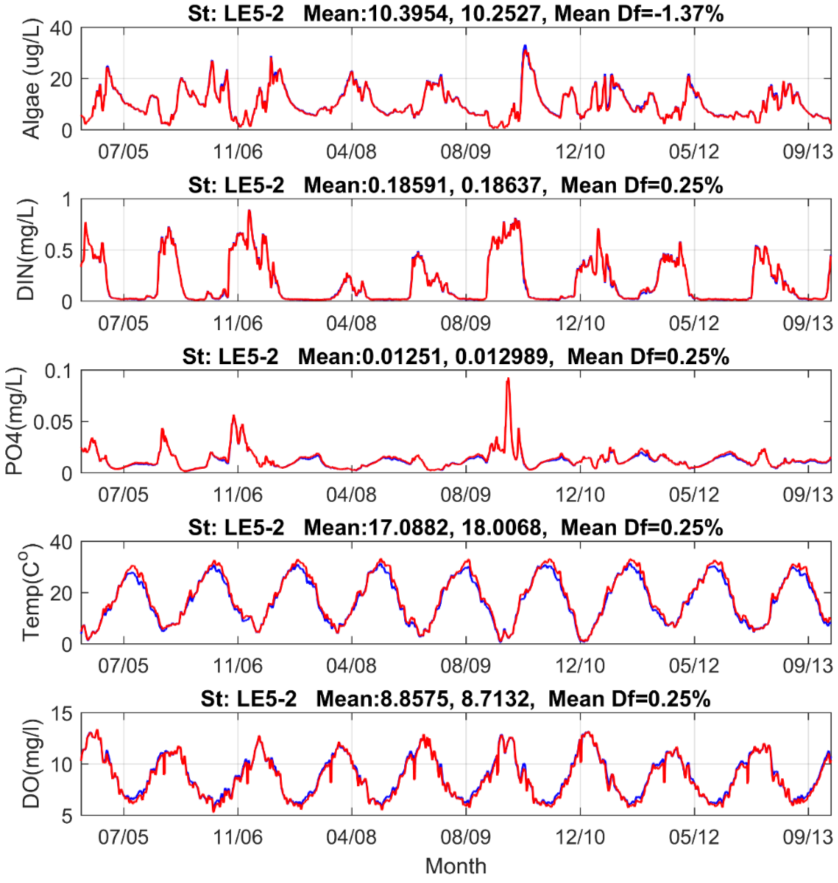


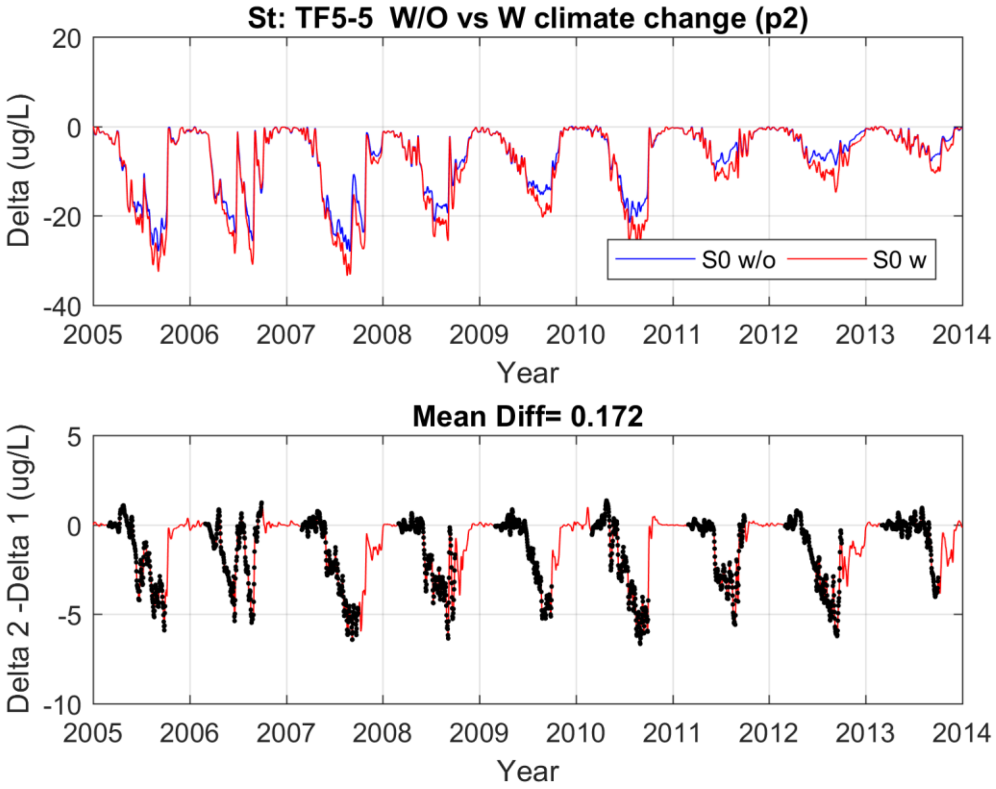
Change in temperature



Blue lines are current condition and red lines are under changed condition

Comparison of Reduction with and without climate change (Parameter set 2)

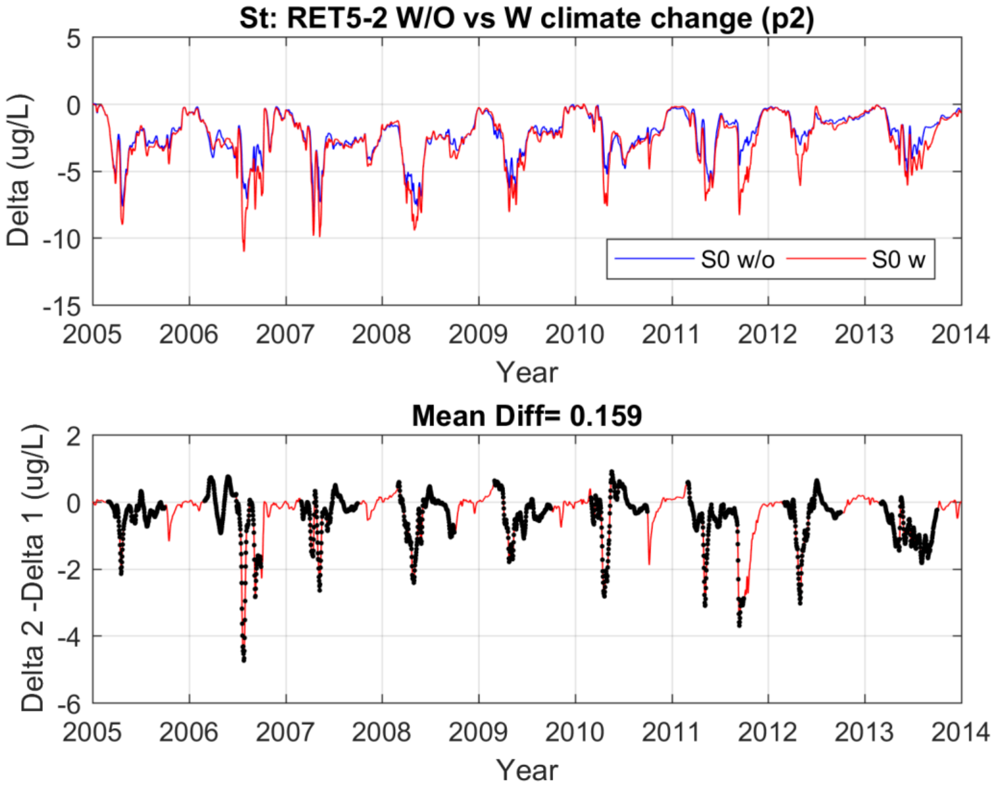
Nutrient reduction scenario S0



With climate change, more reduction occurs in the tidal freshwater region.

Comparison of Reduction with and without climate change (Parameter set 2)

Nutrient reduction scenario S0



DEQ

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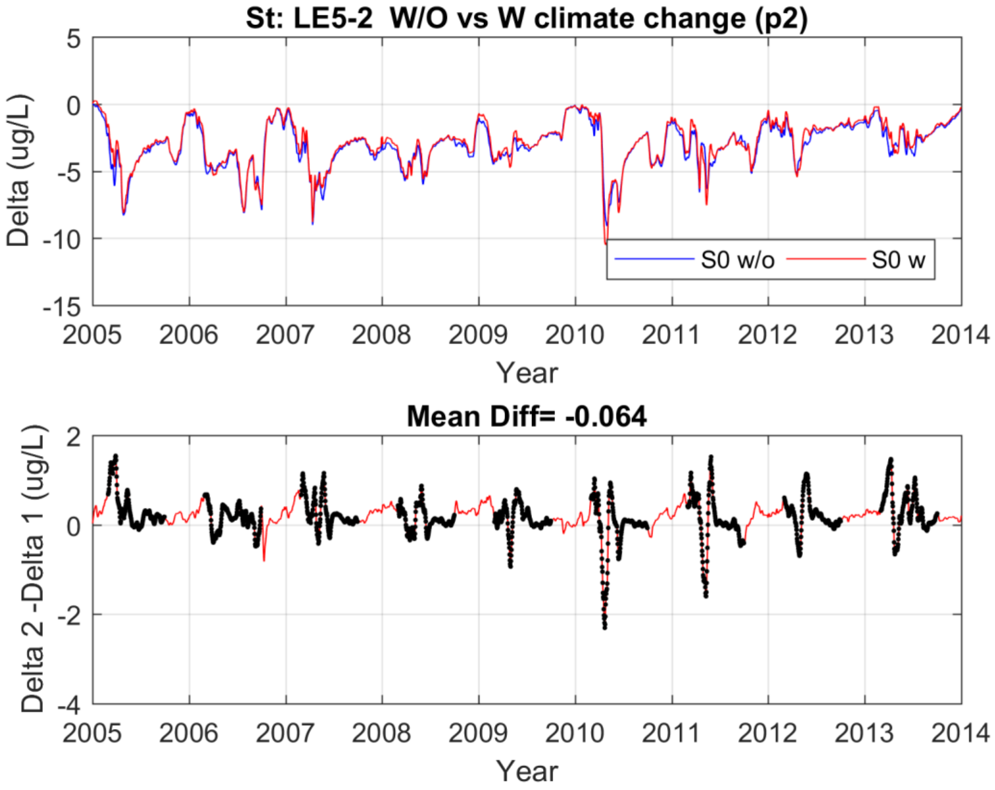

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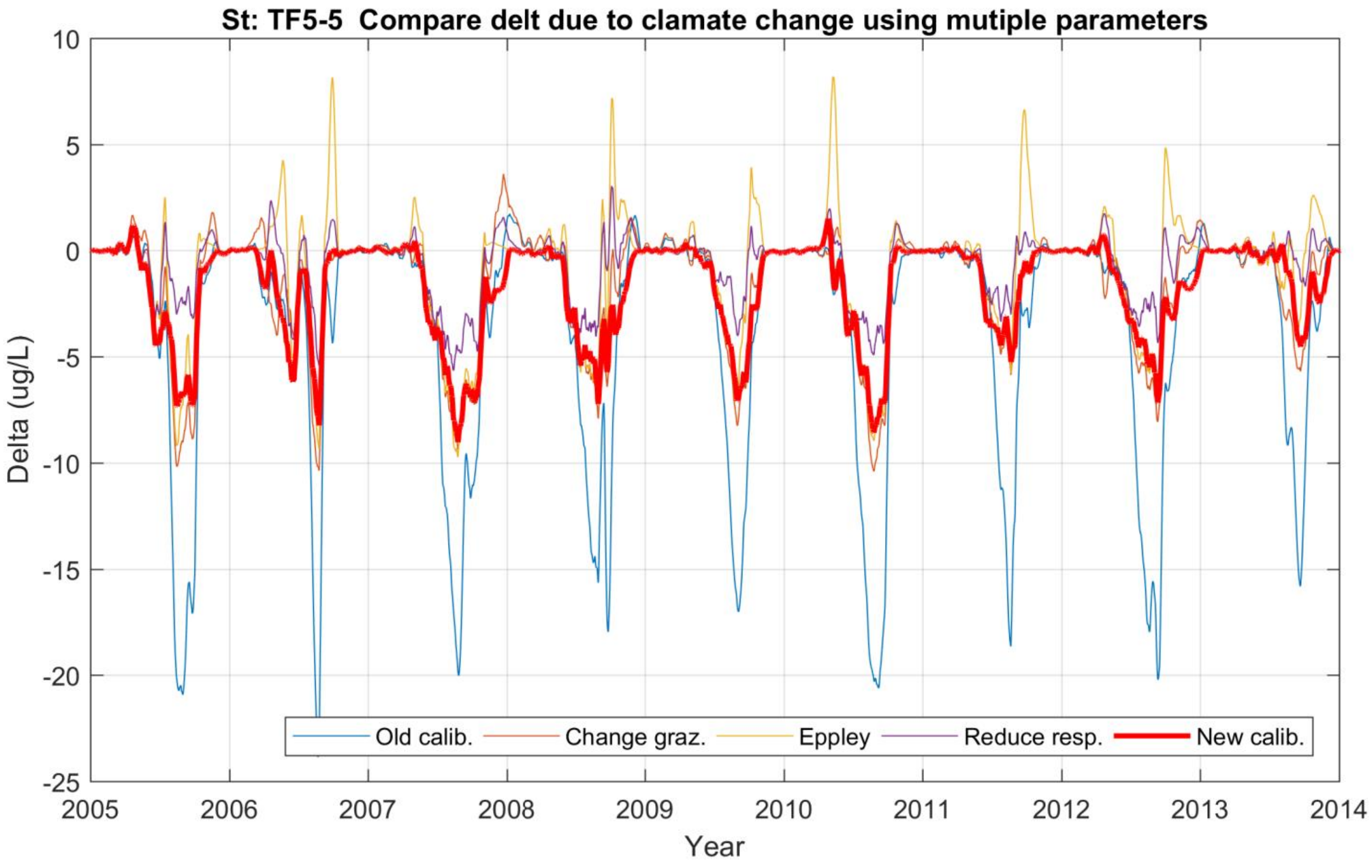
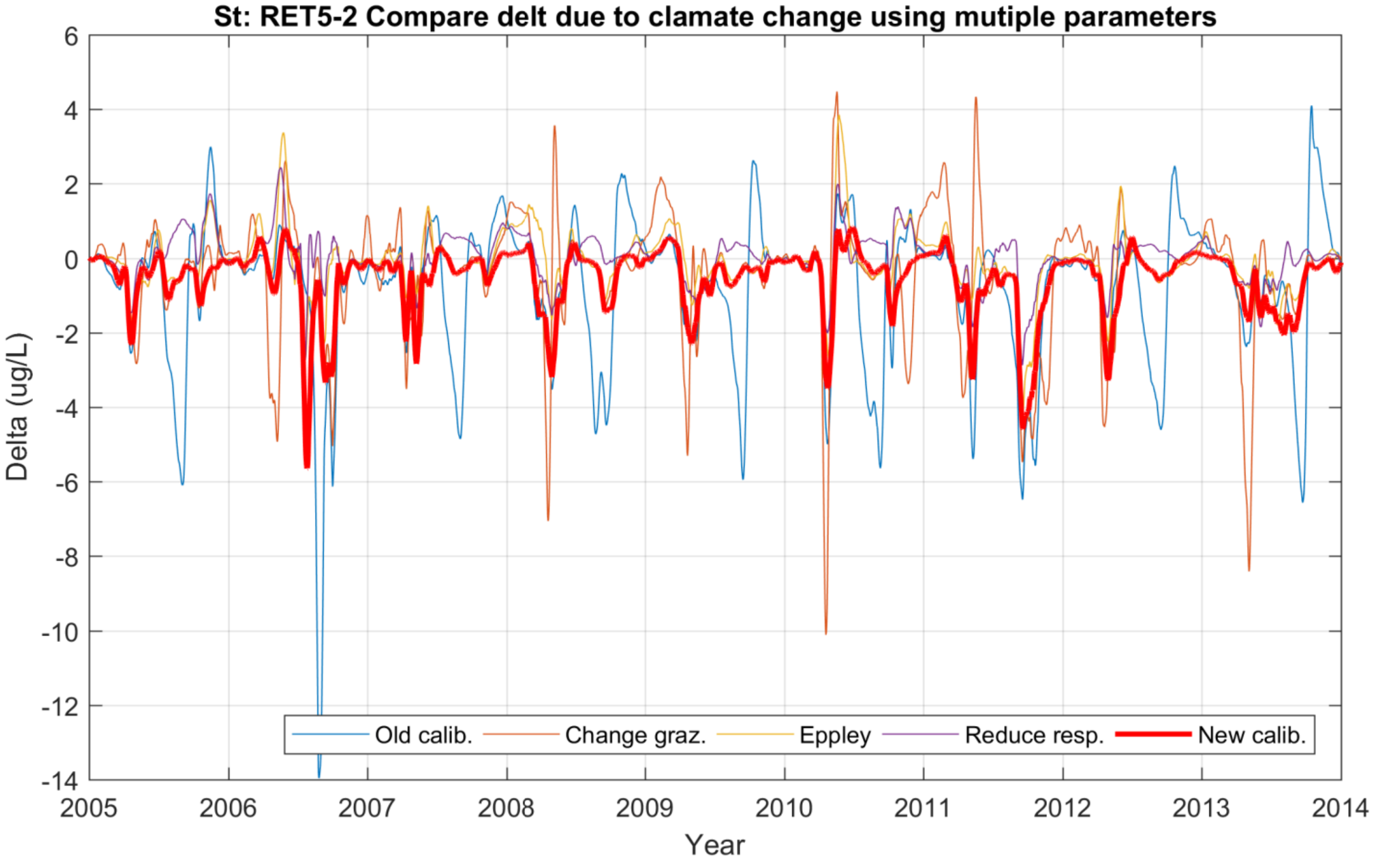
Model Uncertainty Due to Climate Change

- Model is sensitive to model parameters used for climate change model
- Diverse changes in Chl a can be observed due to change in sea-level rise and temperature

Comparison of Model Results with and without climate change



Comparison of Model Results with and without climate change



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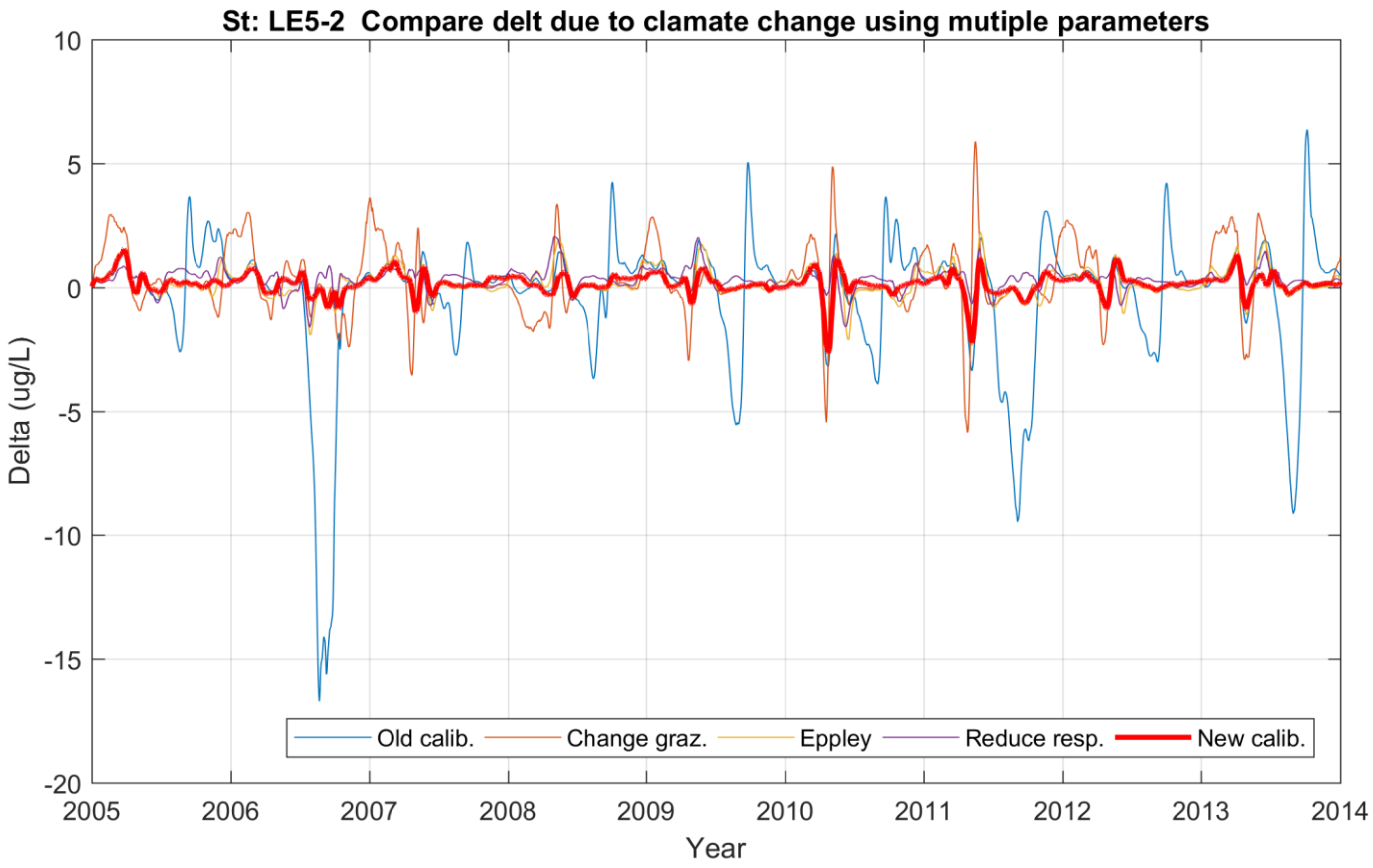
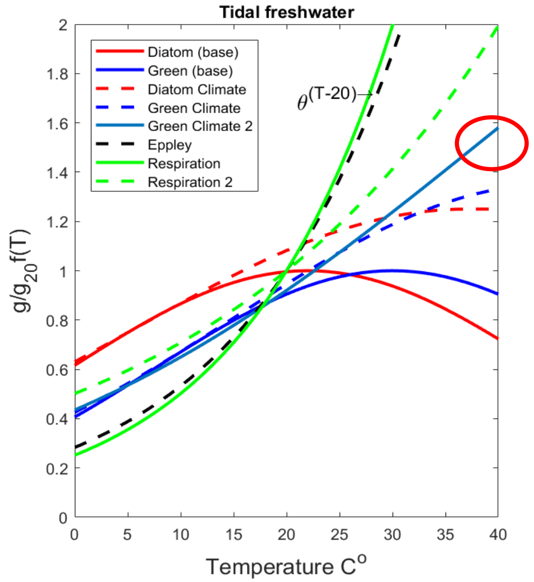


Conclusions

- Based on model calibration and multiple sensitivity tests, the revised parameter set (Green Climate 2) works for both existing and climate change conditions. The change in growth rate with temperature is a good approximation for evaluating algal growth due to climate changes.
- The multiple test runs suggest that the model is sensitive to model kinetic parameters, but the differences due to climate change are within 5% (exclude original model parameter, which did not include climate change effect)



Suggesting using this parameter set for modeling point scenarios

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31 scenarios were run

attainment | nonattainment

The first nine scenarios

2005-2013 Hydrology
2025 Climate Change
WIP3 NPS Loadings

highest

TN Load

lowest

Scenario	Seasonal Criteria	Short-duration Criteria
Observed 2005-2013	JMSTFL, JMSPH	Upper JMSTFL
2017 WGP Waste Load		Upper & Lower JMSTFL
VAMWA B+		
VAMWA B/D		Lower JMSTFL
VAMWA C		Upper & Lower JMSTFL
POTWs at Design-Q: TN=4, TP=0.3		Upper & Lower JMSTFL
VAMWA D		
WIP2 LOE		Upper & Lower JMSTFL
WIP3 PS Discharged Loads		Lower JMSTFL
WIP3 Final on 2025 Land Use		Lower JMSTFL

attainment

nonattainment

Edge-of-Stream Δ Relative to 2017WGP	Scenario	Seasonal Criteria	Short-duration Criteria
	Observed 2005-2013	JMSTFL, JMSPH	Upper JMSTFL
	2017 WGP Waste Load		Upper & Lower JMSTFL
13% reduction in TP, no change in TN	VAMWA B+		
3% reduction in TP, 1% reduction in TN	VAMWA B/D		Lower JMSTFL
8% reduction in TP, 6% reduction in TN	VAMWA C		Upper & Lower JMSTFL
6% reduction in TP, 6% reduction in TN	POTWs at Design-Q: TN=4, TP=0.3		Upper & Lower JMSTFL
13% reduction in TP, 8% reduction in TN	VAMWA D		
11% reduction in TP, 10% reduction in TN	WIP2 LOE		Upper & Lower JMSTFL
10% reduction in TP, 13% reduction in TN	WIP3 PS Discharged Loads		Lower JMSTFL
10% reduction in TP, 13% reduction in TN	WIP3 Final on 2025 Land Use		Lower JMSTFL

highest

TN Load

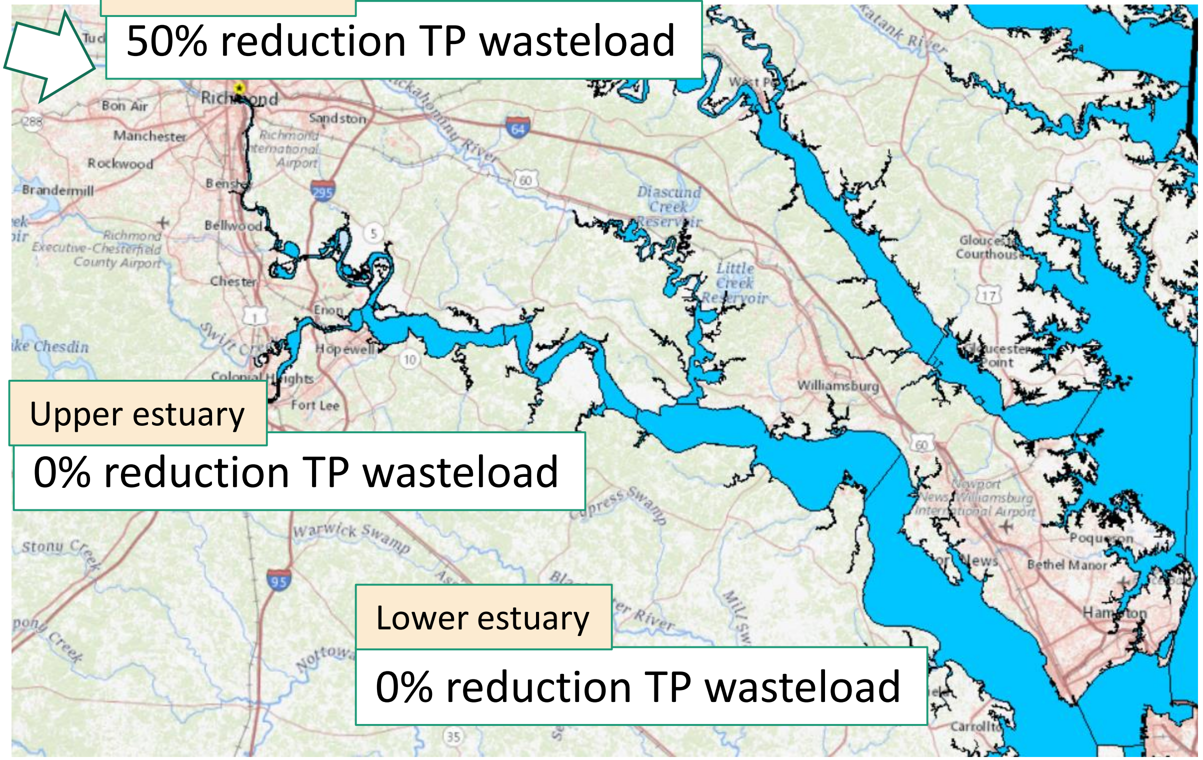
lowest

The next eight scenarios were variations on the two “attaining” scenarios from the previous batch.

attainment nonattainment

Scenario	Seasonal Criteria	Short-duration Criteria
3A-Modified VAMWA B+		Upper & Lower JMSTFL
3B-Modified VAMWA B+		2% (excess attain’t)
3C-Modified VAMWA B+		<0.1%(excess attain’t)
3D-Modified VAMWA B+		Upper JMSTFL
5A-Modified VAMWA D		Lower JMSTFL
5B-Modified VAMWA D		Lower JMSTFL
5C-Modified VAMWA D		Lower JMSTFL
5D-Modified VAMWA D		Lower JMSTFL

Scenario 3A



Above fall line

50% reduction TP wasteload

Upper estuary

0% reduction TP wasteload

Lower estuary

0% reduction TP wasteload

TN Wasteload = 2017Watershed General Permit TN Load

WIP3 Nonpoint source

attainment nonattainment

Scenario	Seasonal Criteria	Short-duration Criteria
3A-Modified VAMWA B+		Upper & Lower JMSTFL
3B-Modified VAMWA B+		2% (excess attain't)
3C-Modified VAMWA B+		<0.1%(excess attain't)
3D-Modified VAMWA B+		Upper JMSTFL
5A-Modified VAMWA D		Lower JMSTFL
5B-Modified VAMWA D		Lower JMSTFL
5C-Modified VAMWA D		Lower JMSTFL
5D-Modified VAMWA D		Lower JMSTFL

DEQ

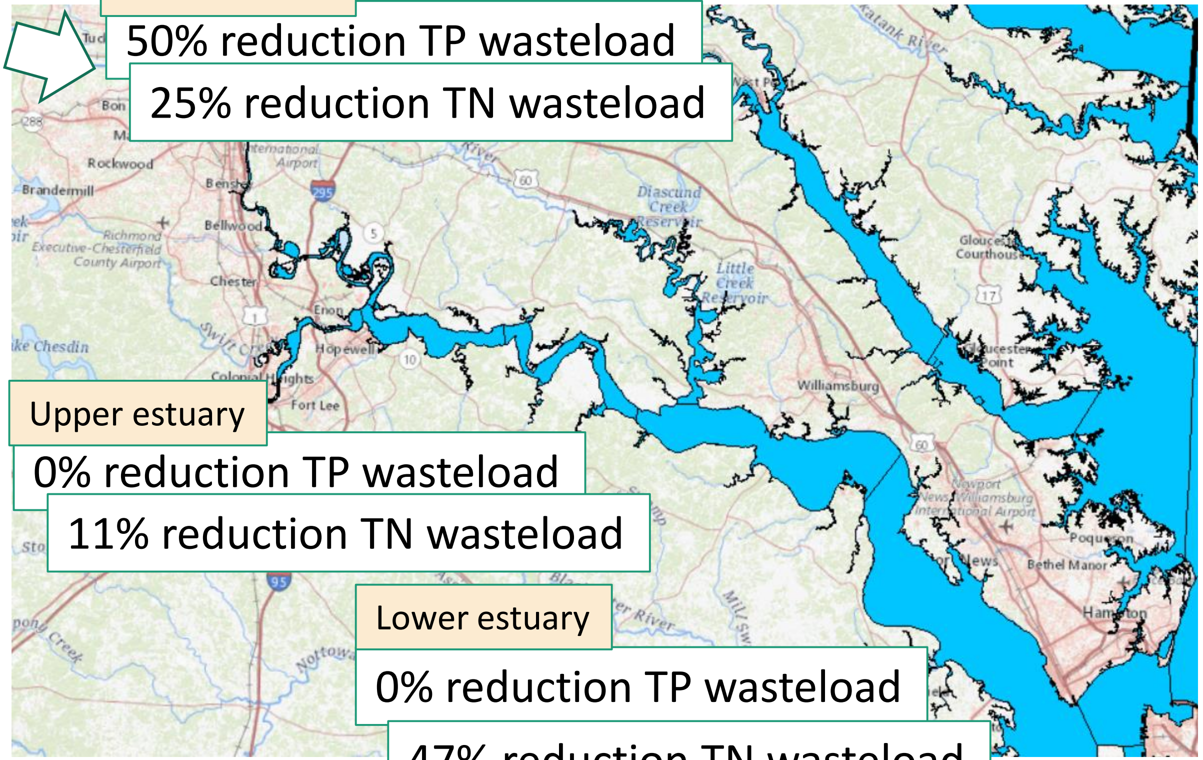
Scenario 5A

attainment nonattainment

Above fall line

50% reduction TP wasteload

25% reduction TN wasteload



Upper estuary

0% reduction TP wasteload

11% reduction TN wasteload

Lower estuary

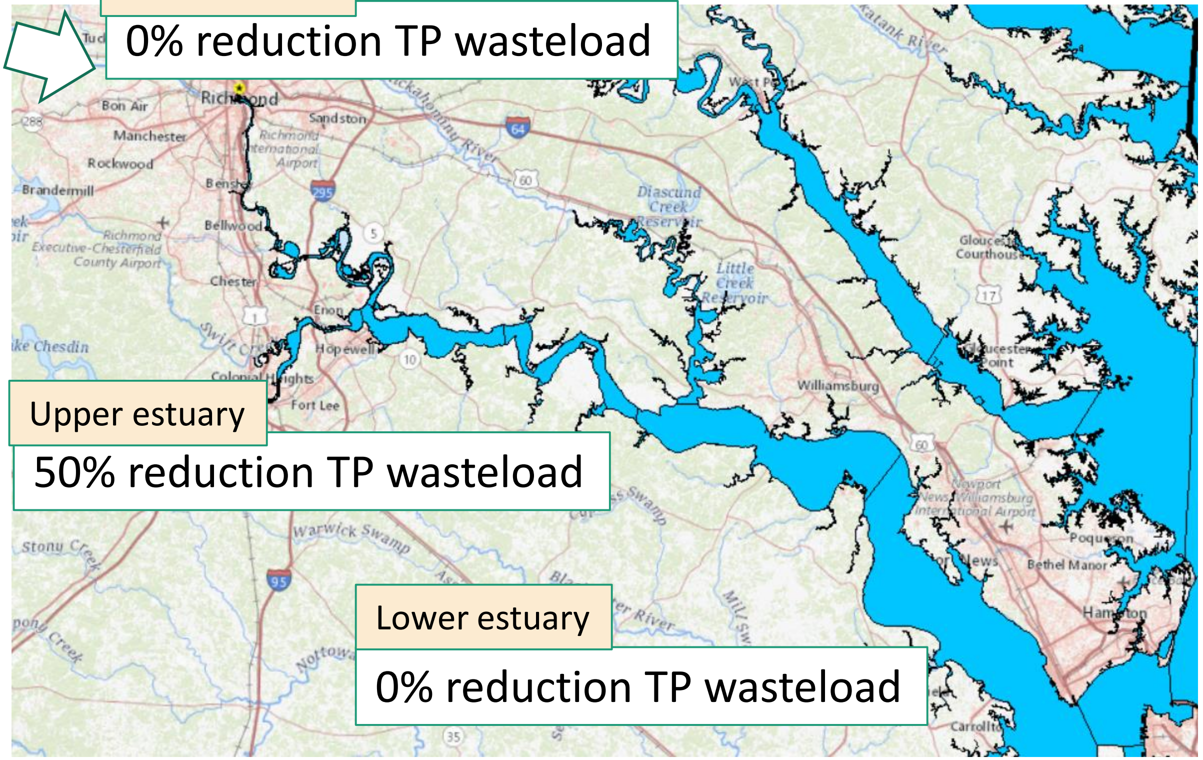
0% reduction TP wasteload

47% reduction TN wasteload

WIP3 Nonpoint source

Scenario	Seasonal Criteria	Short-duration Criteria
3A-Modified VAMWA B+		Upper & Lower JMSTFL
3B-Modified VAMWA B+		2% (excess attain't)
3C-Modified VAMWA B+		<0.1%(excess attain't)
3D-Modified VAMWA B+		Upper JMSTFL
5A-Modified VAMWA D		Lower JMSTFL
5B-Modified VAMWA D		Lower JMSTFL
5C-Modified VAMWA D		Lower JMSTFL
5D-Modified VAMWA D		Lower JMSTFL

Scenario 3B



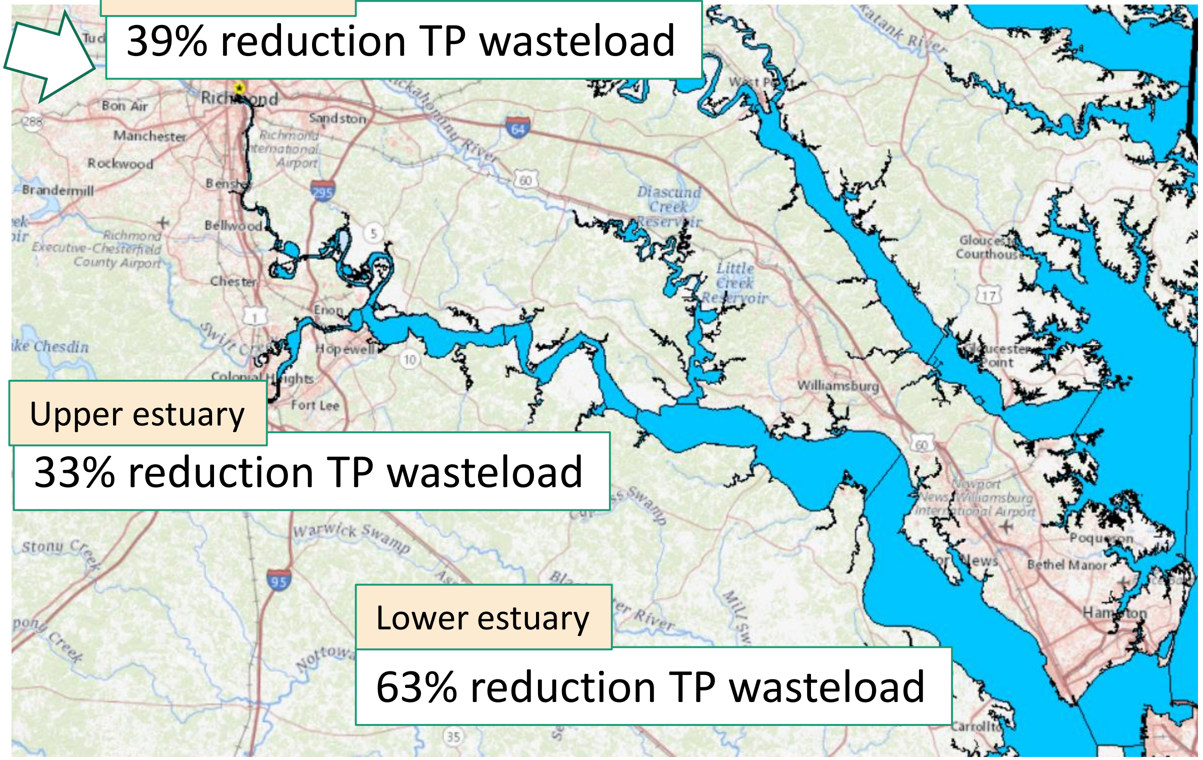
TN Wasteload = 2017Watershed General Permit TN Load
WIP3 Nonpoint source

attainment   nonattainment

Scenario	Seasonal Criteria	Short-duration Criteria
3A-Modified VAMWA B+		Upper & Lower JMSTFL
3B-Modified VAMWA B+		2% (excess attain't)
3C-Modified VAMWA B+		<0.1%(excess attain't)
3D-Modified VAMWA B+		Upper JMSTFL
5A-Modified VAMWA D		Lower JMSTFL
5B-Modified VAMWA D		Lower JMSTFL
5C-Modified VAMWA D		Lower JMSTFL
5D-Modified VAMWA D		Lower JMSTFL

DEQ

Scenario 3C



TN Wasteload = 2017Watershed General Permit TN Load
WIP3 Nonpoint source

attainment   nonattainment

Scenario	Seasonal Criteria	Short-duration Criteria
3A-Modified VAMWA B+		Upper & Lower JMSTFL
3B-Modified VAMWA B+		2% (excess attain't)
3C-Modified VAMWA B+		<0.1%(excess attain't)
3D-Modified VAMWA B+		Upper JMSTFL
5A-Modified VAMWA D		Lower JMSTFL
5B-Modified VAMWA D		Lower JMSTFL
5C-Modified VAMWA D		Lower JMSTFL
5D-Modified VAMWA D		Lower JMSTFL

DEQ

attainment   nonattainment

Δ Relative to 2017 Watershed General Permit WLAs

	Scenario 3B	**Scenario 5B**
Above Fall Line	**0% reduction TP WLA** 0% reduction TN WLA	**0% reduction TP WLA** 25% reduction TN WLA
Upper Estuary	**50% reduction TP WLA** 0% reduction TN WLA	**50% reduction TP WLA** 11% reduction TN WLA
Lower Estuary	**0% reduction TP WLA** 0% reduction TN WLA	**0% reduction TP WLA** 47% reduction TN WLA

Scenario	**Seasonal Criteria**	**Short-duration Criteria**
3A-Modified VAMWA B+		Upper & Lower JMSTFL
3B-Modified VAMWA B+		2% (excess attain't)
3C-Modified VAMWA B+		<0.1%(excess attain't)
3D-Modified VAMWA B+		Upper JMSTFL
5A-Modified VAMWA D		Lower JMSTFL
5B-Modified VAMWA D		Lower JMSTFL
5C-Modified VAMWA D		Lower JMSTFL
5D-Modified VAMWA D		Lower JMSTFL

attainment | nonattainment

The next nine scenarios tested seasonality + TP sensitivity

Scenario	Seasonal Criteria	Short-duration Criteria	Description (TN WLA Loads = 2017 WGS Allocations)
3E-Modified 3B		Upper JMSTFL	50% TP WLA reduction in the tidal fresh April-Sept
3F-Modified 3B		Upper JMSTFL	50% TP WLA reduction in the tidal fresh March-Sept
3G-Modified 3C		Upper JMSTFL	39% TP WLA reduction in above fall line and tidal fresh April-Sept
3H-Modified 3C		Upper JMSTFL	39% TP WLA reduction in above fall line and tidal fresh March-Sept
3I-Modified 3B		Upper JMSTFL	44% TP WLA reduction in the tidal fresh **(TP limit = 0.225 instead of 0.2)**
3J-Modified 3B		Upper JMSTFL	44% TP WLA reduction in the tidal fresh in April-Sept
3K-Modified 3B		Upper JMSTFL	44% TP WLA reduction in the tidal fresh in March-Sept
3L-Modified 3C		Upper JMSTFL	44% TP WLA reduction in above fall line and tidal fresh in April-Sept
3M-Modified 3C			44% TP WLA reduction in above fall line and tidal fresh in March-Sept

DEQ

attainment nonattainment

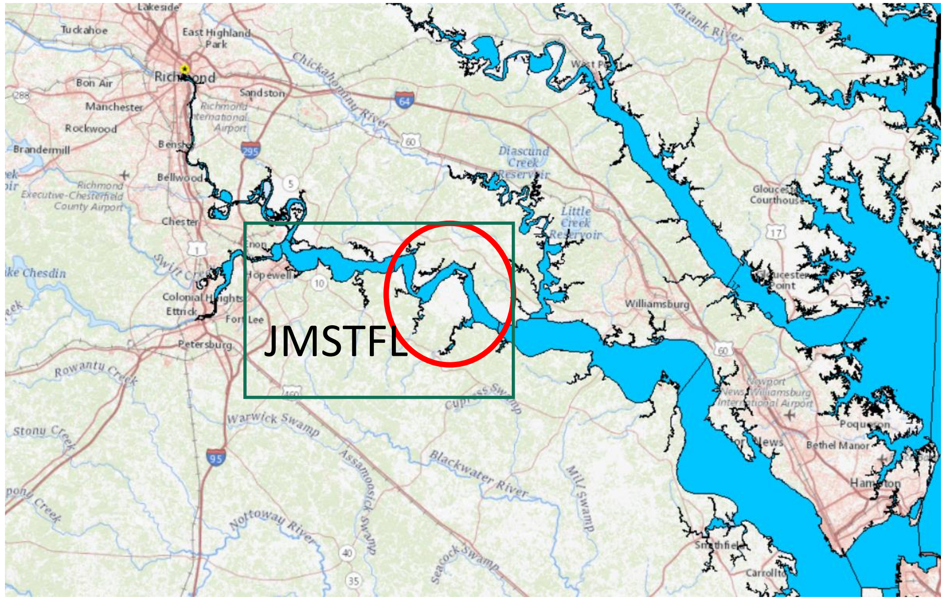
The last five scenarios tested seasonality/TP sensitivity given allocation transfer agreements between dischargers

Scenario	Seasonal Criteria	Short-duration Criteria	Descriptions
3B(i)-Modified VAMWA B+			44% TP WLA reduction in the tidal fresh **(TP limit = 0.225)**
3C(i)-Modified B+			38% and 33% TP WLA reduction above fall line and tidal fresh **(TP limit = 0.25),** respectively
3(i)-Modified B+			50% and 44% TP WLA reduction above fall line and tidal fresh **(TP limit = 0.2),** respectively
3M(i)-Modified 3C		Upper JMSTFL	44% and 22% TP WLA reduction in above fall line and tidal fresh **(TP limit = 0.225)** in March-Sept
5(i)-Modified VAMWA D			25%TN & 50%TP WLA reductions above fall line 11% TN & 44% TP WLA reductions in the tidal fresh

DEQ

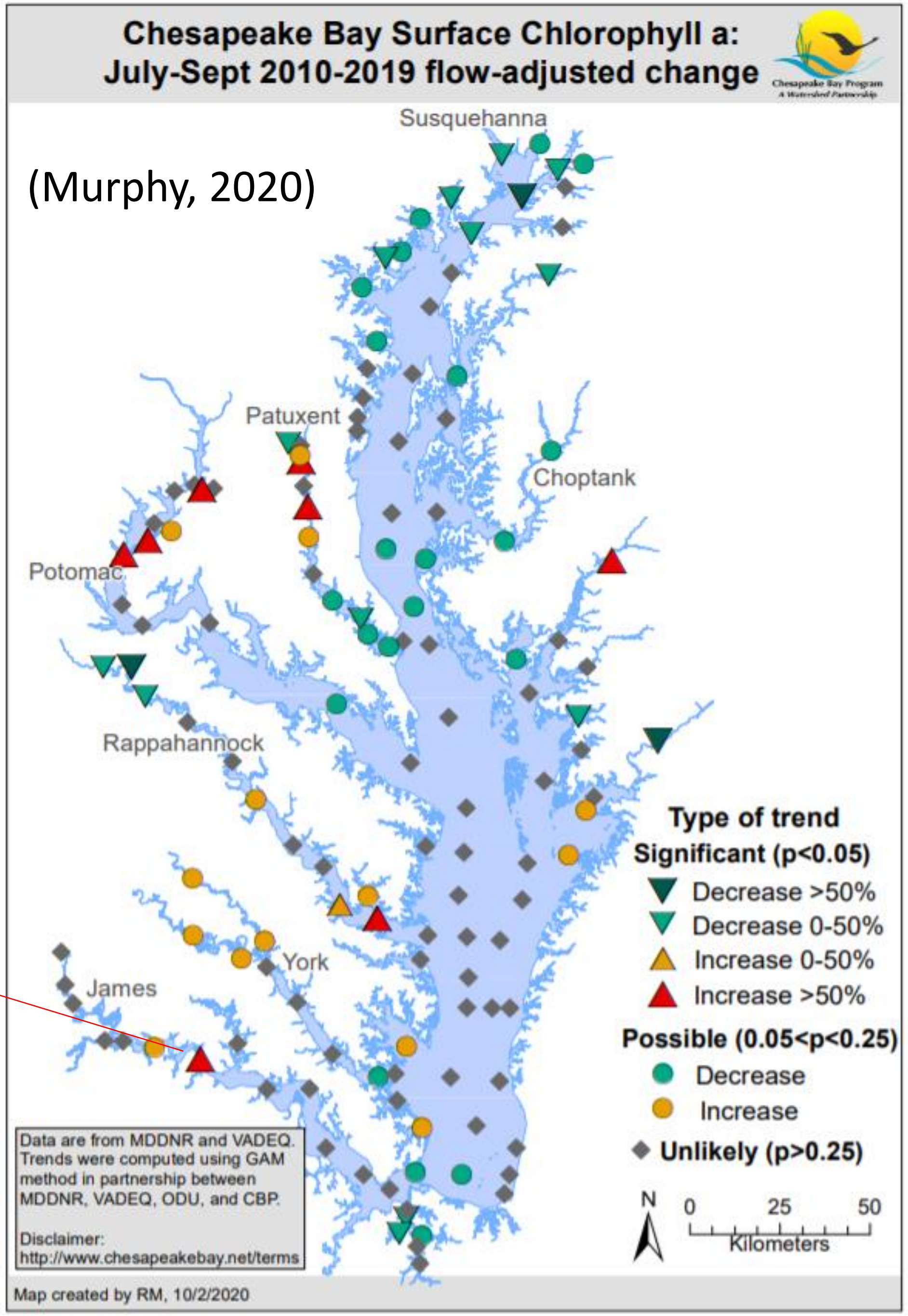
General conclusions from the modeling work

- Given the effects of climate change, more stringent reduction of nutrient loads in the James R. may be needed to ensure attainment of the new chlorophyll criteria.
- We may start to see more frequent criteria exceedances in the lower portion of JMSTFL because of climate change.



DEQ

Trend analysis of monitoring data indicates that chlorophyll concentrations are increasing over recent years at station TF5.6.



DEQ

General conclusions from the modeling work

- Given the effects of climate change, more stringent reduction of nutrient loads in the James R. may be needed to ensure attainment of the new chlorophyll criteria.
- We may start to see more frequent criteria exceedances in the lower portion of JMSTFL because of climate change.
- Reducing TP loads alone may produce slightly better results for JMSTFL than the same level of TP reduction combined with TN reduction.

Reducing TP loads alone may produce slightly better results for JMSTFL than the same level of TP reduction combined with TN reduction.

attainment

nonattainment

Edge-of-Stream Δ Relative to 2017WGP	Scenario	Seasonal Criteria	Short-duration Criteria
	Observed 2005-2013	JMSTFL, JMSPH	JMSTFL
	2017 WGP Waste Load		JMSTFL
13% reduction in TP, no change in TN	VAMWA B+		7% (excess attain't)
3% reduction in TP, 1% reduction in TN	VAMWA B/D		JMSTFL
8% reduction in TP, 6% reduction in TN	VAMWA C		JMSTFL
6% reduction in TP, 6% reduction in TN	POTWs at Design-Q: TN=4, TP=0.3		JMSTFL
13% reduction in TP, 8% reduction in TN	VAMWA D		2% (excess attain't)
11% reduction in TP, 10% reduction in TN	WIP2 LOE		JMSTFL
10% reduction in TP, 13% reduction in TN	WIP3 PS Discharged Loads		JMSTFL
10% reduction in TP, 13% reduction in TN	WIP3 Final on 2025 Land Use		JMSTFL

highest

TN Load

lowest

DEQ

Thanks so much for your help!

Questions?