

Caloosahatchee Estuary Nutrient Loading Model

February 09, 2022

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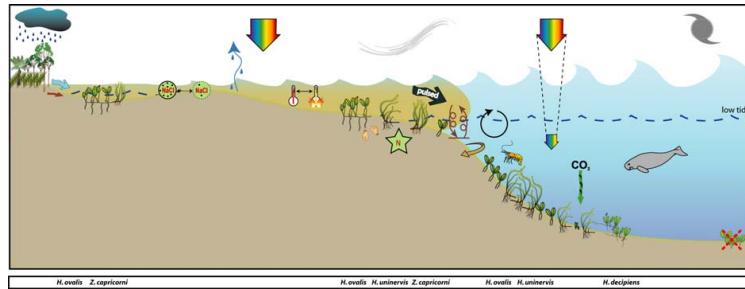


Land Acknowledgement

The land on which we sit have been cared for by innumerable generations of original peoples of the past, whose memory we honor. The 2009 US apology to native peoples inaugurated an American context of reconciliation, which is an opportunity for healing, collaboration, and environmental conservation.

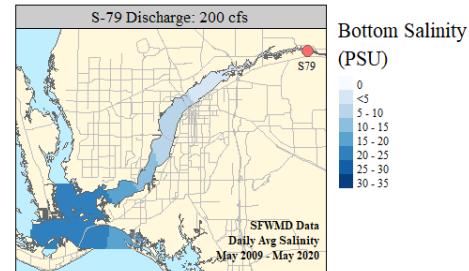
- <https://nativegov.org/news/a-guide-to-indigenous-land-acknowledgment/>
- 2009 US Apology

Estuary Dynamics



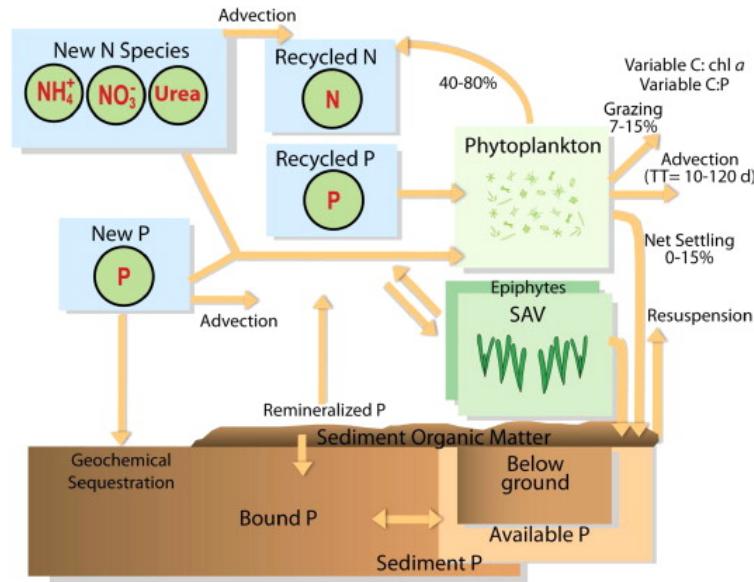
Conceptual diagram of shallow coastal ecosystems from Coles et al (2007).

- Changes in estuarine biogeochemistry and ecological function is driven largely by magnitude and composition of freshwater inputs.
- Upstream nutrient loading to the estuary can be a stressor that can promote algal biomass (i.e. Chl-a) leading to decreased light attenuation and degraded benthic communities.
- Coastal nutrient loading can also promote macro- and epiphytic algae that can directly/indirectly impact seagrass communities (Madden et al 2009)
- Freshwater inputs can also depress salinity at increase colored dissolved organic matter thereby reducing light attenuation (Chen et al 2015).



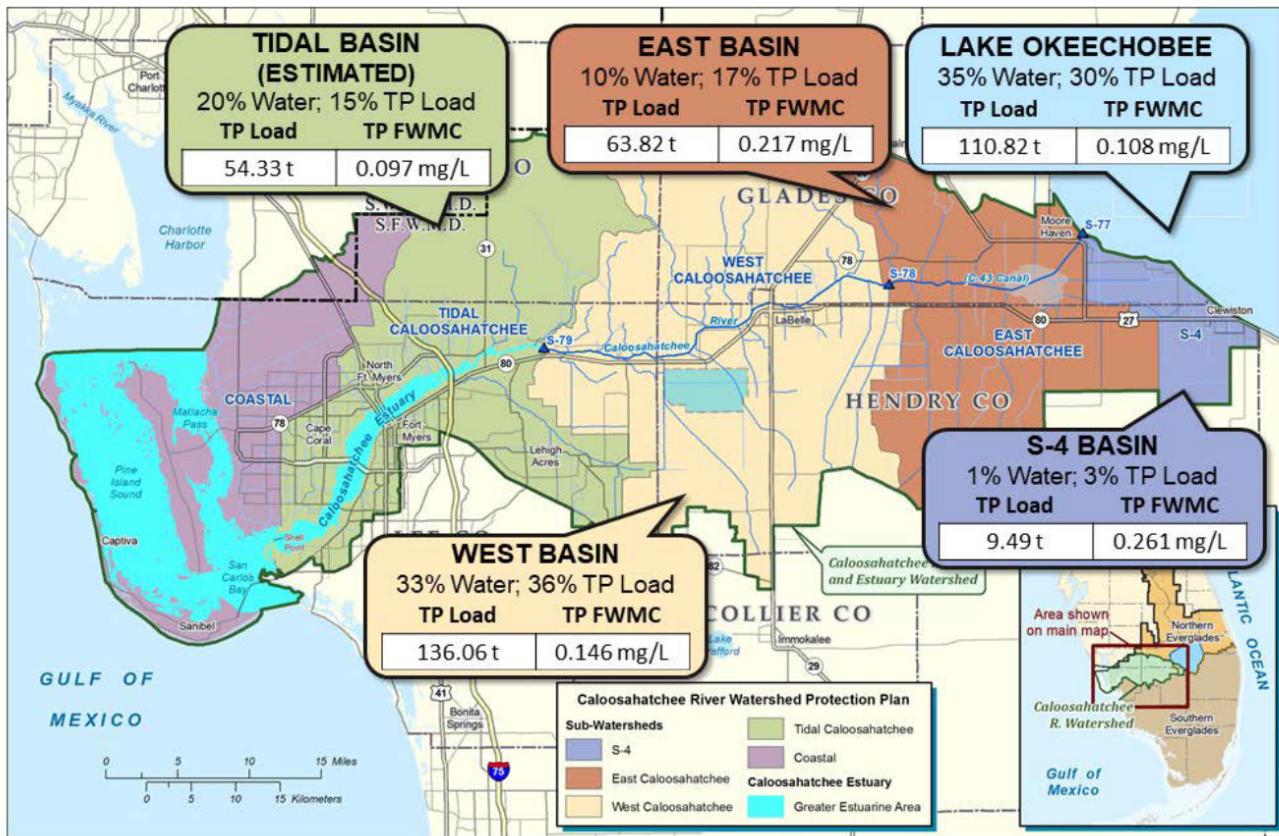
Estuary Nutrient Loading

...and ecological response



Conceptual model of Florida Bay, SAV-phytoplankton ecosystem (Madden et al 2009; Glibert et al 2010).

- Seagrass Ecosystem Assessment and Community Organization Model (SEACOM)
 - mechanistic simulation model of seagrass–water column interactions on an ecosystem scale describing the biomass, production, composition and distribution of submersed aquatic vegetation and phytoplankton



Note: Coastal Basin runoff (west of Shell Point) is not included as Estuary contribution.

Source: 2021 South Florida Environmental Report, Vol I Ch 8 (Figure 8D-19)

Local Basin Runoff accounts for approximately:

- 64% of flow,
- 71% TP load, and
- 61% TN load (not shown)

to estuary (May 2015 - April 2020; WY2016-2020).

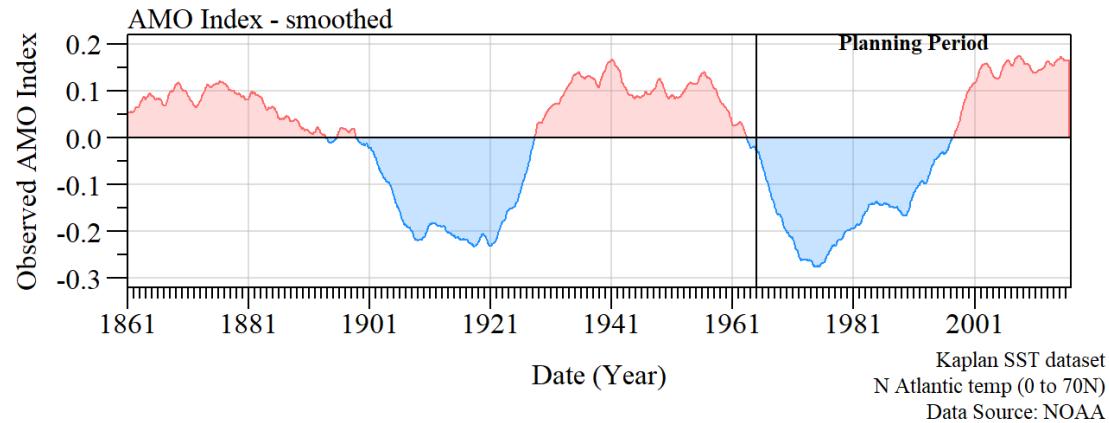
Objective

Due to ongoing planning efforts the goal was to develop a series of water quality models based on hydrodynamic indicators to be used in planning model scenario evaluation using RSMBN.

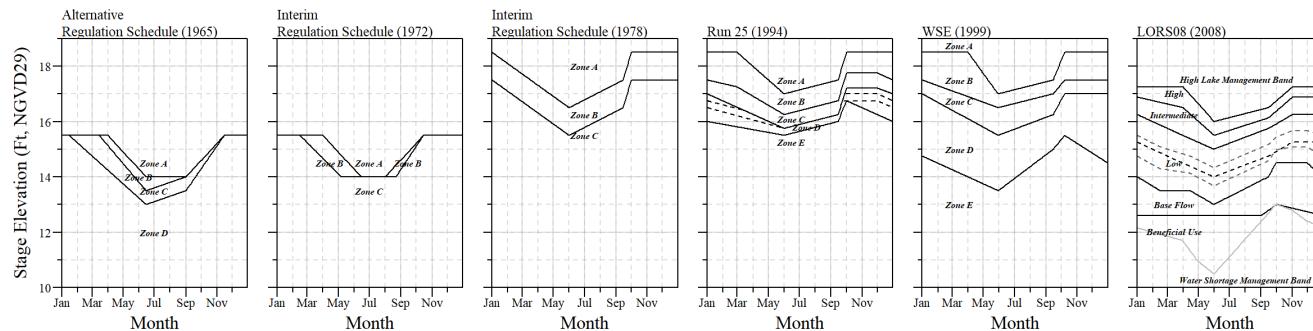
Methods

- **Period of Record:** May 1981 – April 2019 (WY1982 – 2019)
 - Based on available data.
- **Parameters of Interest:** Total Phosphorus and Total Nitrogen.
- **Predictor Variables:** Discharge (S77 and C43 Basin) and Lake Okeechobee stage elevation.
- **Statistical Modeling:**
 - Multiple regression models using training and testing datasets (70:30).
 - Training dataset: randomly sampled 70% of monthly data
 - Testing dataset: remaining 30% was used for model testing
 - Verified with k-fold cross-validation linear modeling.

Interesting Period

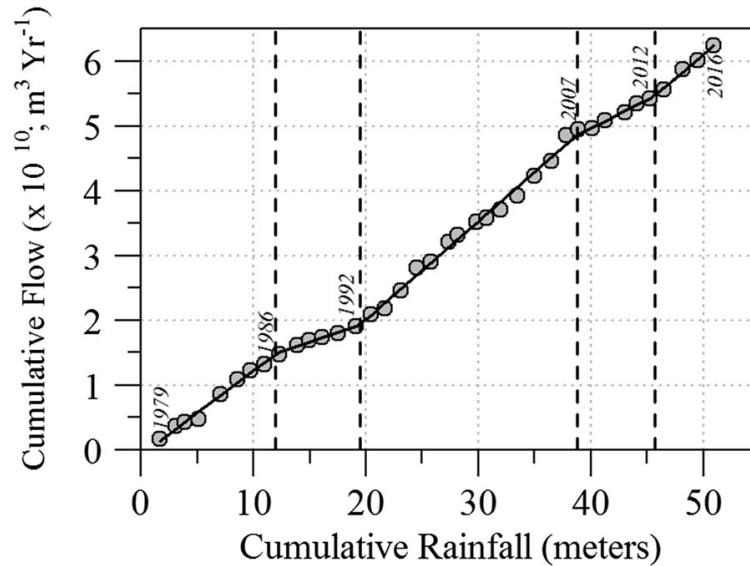


Observed Atlantic Multidecadal Oscillation (AMO) index time-series. Adapted and updated from Enfield et al (2001).



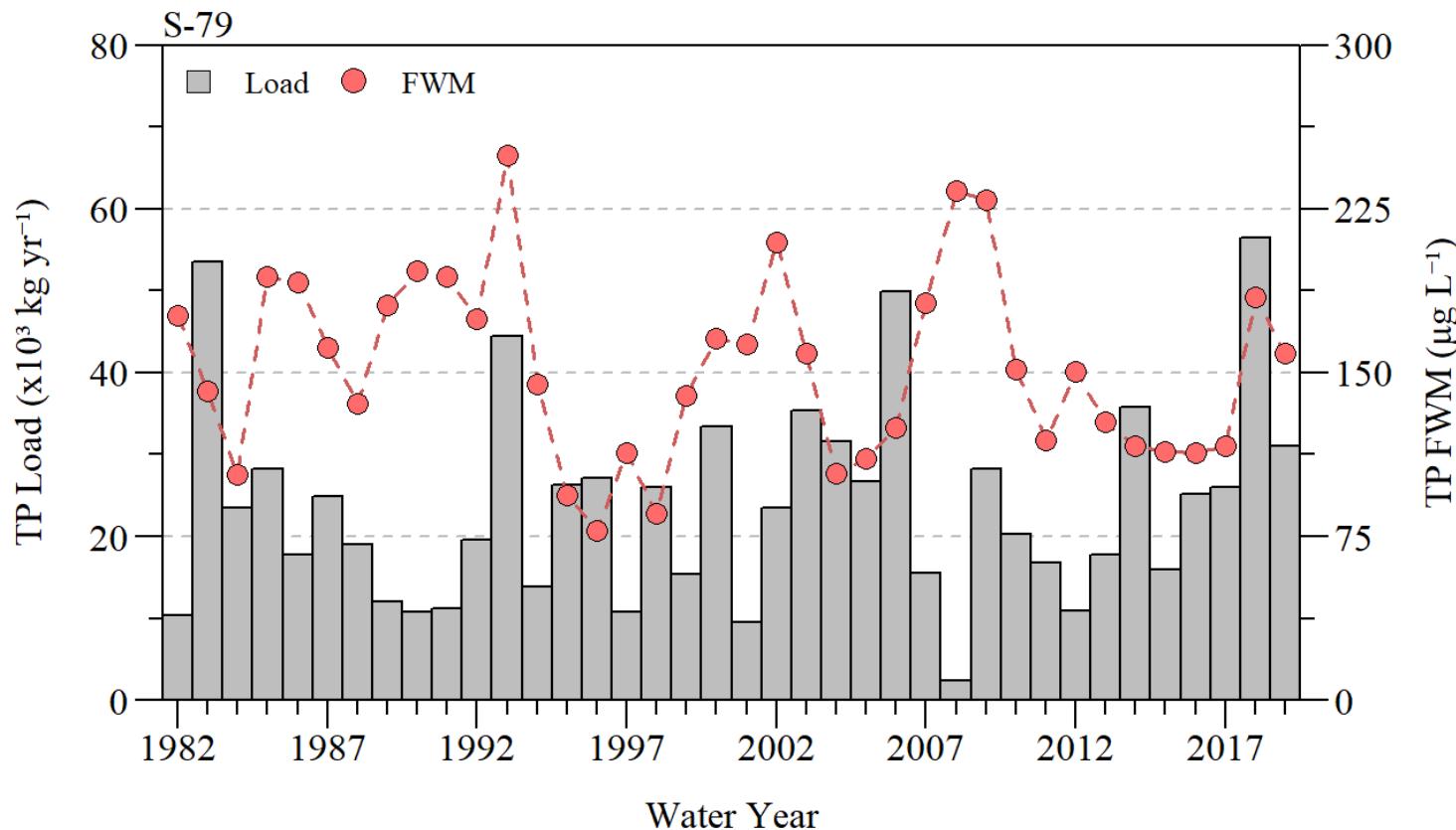
Lake Okeechobee Regulation Schedule History.

Interesting Period



C-43 basin average cumulative rainfall versus S-79 cumulative flow from WY1979 to WY2016 (May 1, 1978–April 30, 2016; Julian & Osborne 2018)

S-79 Water Quality Model (Total Phosphorus)



S-79 Water Quality Model (Total Phosphorus)

- No data transformations needed to fit the assumptions of linear modeling
- Model assumptions and verified
 - GVLMA (Global Stats = 3.36, $\rho=0.50$)
- Variance inflation factors (VIF) evaluated for model
- Residuals check for autocorrelation (Breusch-Godfrey test)
 - Breusch-Godfrey (LM test = 0.06, df = 1, $\rho=0.80$)
- Final Model:

$$TPLoad_{S79} = Q_{C43\text{Basin}} + Q_{S77} + MeanLakeStage$$

[Model Diagnostics](#) plots

S-79 Water Quality Model (Total Phosphorus)

$$TPLoad_{S79} = 127156 + 0.20Q_{C43\text{Basin}} + 0.08Q_{S77} - 7689\text{MeanLakeStage}$$

S-79 total phosphorus model results and estimates fitted using all available data during the water year 1982 - 2019 period.

	Estimate	Standard Error	t-value	p-value
(Intercept)	127156.07	103885.73	1.22	0.23
Q_{C43}	0.20	0.05	3.72	≤ 0.01
Q_{S77}	0.08	0.02	3.70	≤ 0.01
Mean Lake Stage	-7689.38	9172.09	-0.84	0.41

Residual standard error: 49112 on 22 degrees of freedom

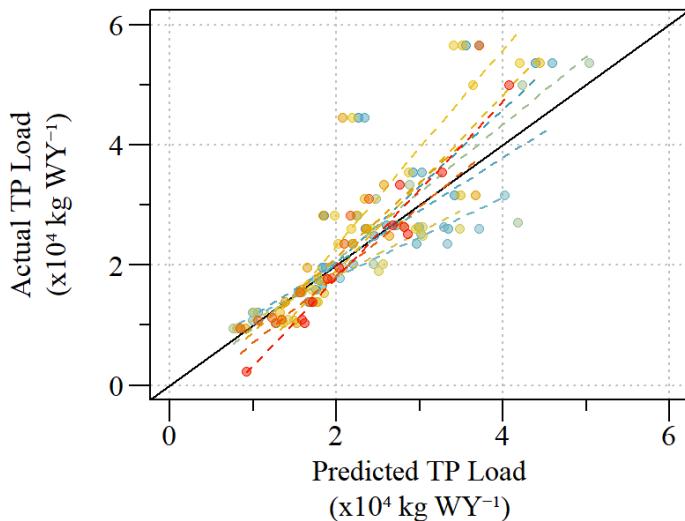
Multiple R-squared: 0.80, Adjusted R-squared: 0.78

F-statistic: 29.84 on 22 and 3, p-value: ≤ 0.01

[Model Diagnostics](#) plots

S-79 Water Quality Model (Total Phosphorus)

$$TPLoad_{S79} = Q_{C43\text{Basin}} + Q_{S77} + MeanLakeStage$$



Actual versus predicted TP loads at S-79 with each k-model presented.

k-fold ($k=10$)

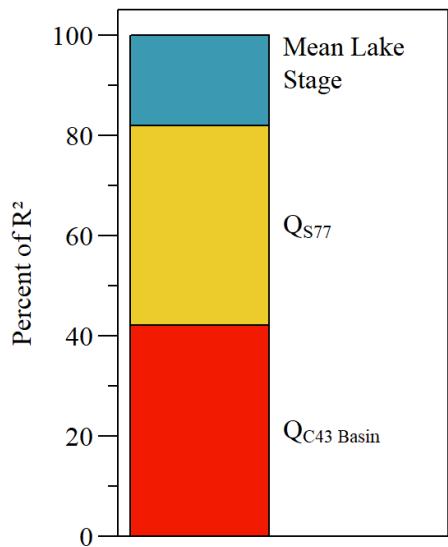
Cross-validation error (average k errors)

	Parameter	Mean	Min	Max
Model	R^2_{adj}	0.71	0.62	0.79
	RMSE	63,461	41,657	76,864
Train:Test	MAPE ¹	21	16	41
	MMA ¹	83	78	86

¹ Mean Absolute Percent Error (MAPE) and Min-Max Accuracy (MMA) expressed in percent

S-79 Water Quality Model (Total Phosphorus)

$$TPLoad_{S79} = Q_{C43\text{Basin}} + Q_{S77} + \text{MeanLakeStage}$$



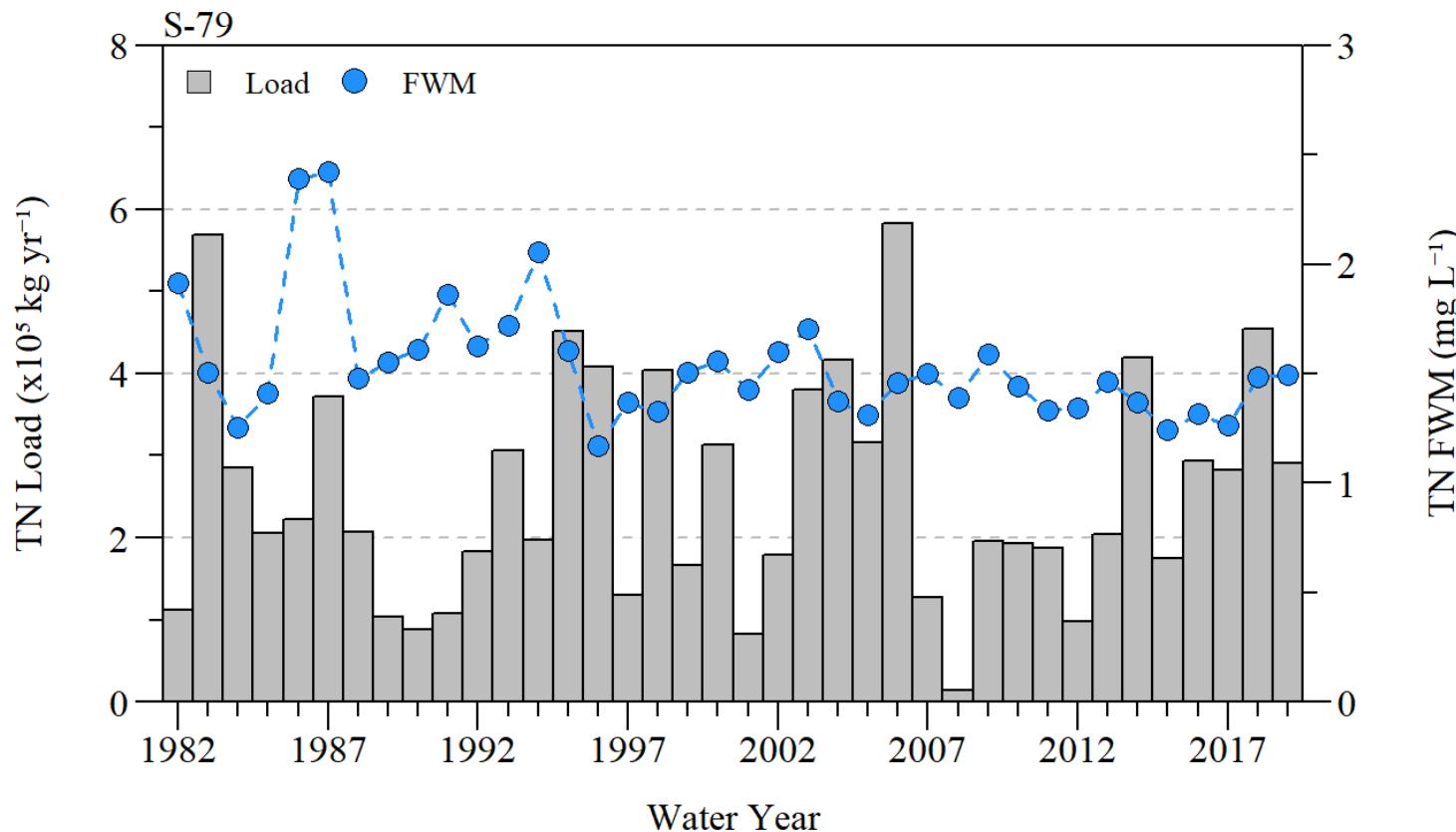
Relative Importance Metrics for the S79 TP Load annual model.

Predictor	Percent of R ²
Q _{C43}	46.5
Q _{S77}	21.0
Mean Lake Stage	32.3

Model R²: 0.78 (Adjusted R²)

Relative importance of each predictor calculated by partitioning R² by averaging sequential sums of squares over all orders of regressors (Lindeman et al 1979). All metrics are normalized to a sum of 100%.

S-79 Water Quality Model (Total Nitrogen)



S-79 Water Quality Model (Total Nitrogen)

- No data transformations needed to fit the assumptions of linear modeling
- Model assumptions and verified
 - GVLMA (Global Stats = 4.77, $\rho=0.31$)
- Variance inflation factors (VIF) evaluated for model
- Residuals check for autocorrelation (Breusch-Godfrey test)
 - Breusch-Godfrey (LM test = 0.73, df = 1, $\rho=0.39$)
- Final Model:

$$TNLoad_{S79} = Q_{C43\text{Basin}} + Q_{S77} + MeanLakeStage$$

[Model Diagnostics](#) plots

S-79 Water Quality Model (Total Nitrogen)

$$TNLoad_{S79} = 27561 + 1.53Q_{C43\text{Basin}} + 1.58Q_{S77} + 20813MeanLakeStage$$

S-79 total nitrogen model results and estimates fitted using all available data during the water year 1982 - 2019 period.

	Estimate	Standard Error	t-value	p-value
(Intercept)	27560.89	690496.68	0.04	0.97
Q_{C43}	1.53	0.35	4.38	≤ 0.01
Q_{S77}	1.58	0.15	10.48	≤ 0.01
Mean Lake Stage	20812.63	60964.10	0.34	0.74

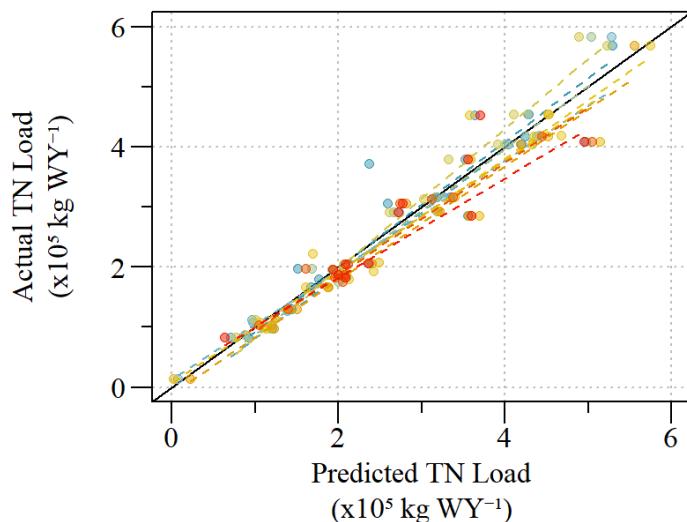
Residual standard error: 326435 on 22 degrees of freedom

Multiple R-squared: 0.95, Adjusted R-squared: 0.94

F-statistic: 140.2 on 22 and 3, p-value: ≤ 0.01

S-79 Water Quality Model (Total Nitrogen)

$$TNLoad_{S79} = Q_{C43Basin} + Q_{S77} + MeanLakeStage$$



Actual versus predicted TN loads at S-79 with each k-model presented.

k-fold ($k=10$)

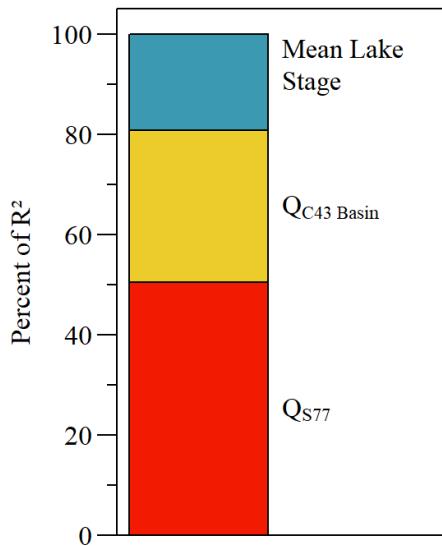
Cross-validation error (average k errors)

	Parameter	Mean	Min	Max
Model	R^2_{adj}	0.93	0.89	0.96
	RMSE	376,894	324,753	411,799
Train:Test	MAPE ¹	11	7	19
	MMA ¹	89	83	93

¹ Mean Absolute Percent Error (MAPE) and Min-Max Accuracy (MMA) expressed in percent

S-79 Water Quality Model (Total Nitrogen)

$$TNLoad_{S79} = Q_{C43\text{Basin}} + Q_{S77} + MeanLakeStage$$



Relative Importance Metrics for the S79
TN Load annual model.

Predictor	Percent of R^2
Q_{C43}	39.6
Q_{S77}	37.9
Mean Lake Stage	22.5

Model R^2 : 0.94 (Adjusted R^2)

Relative importance of each predictor calculated by partitioning R^2 by averaging sequential sums of squares over all orders of regressors (Lindeman et al 1979). All metrics are normalized to a sum of 100%.

Critical Loads

- The concept of critical loads was proposed as a way to evaluate the modeled loads across alternatives.
 - Janicki (2003)

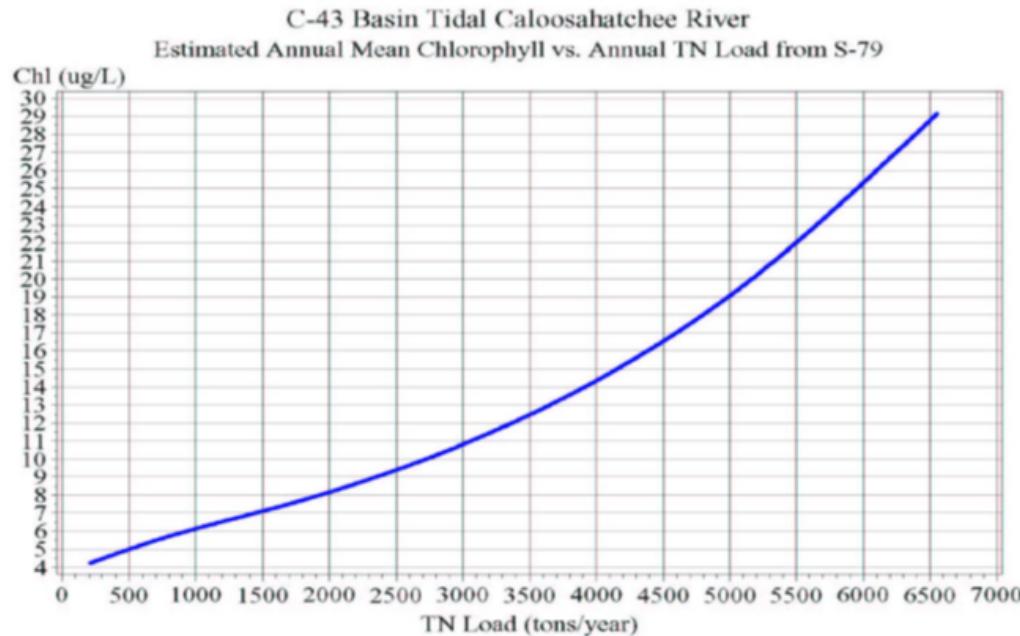
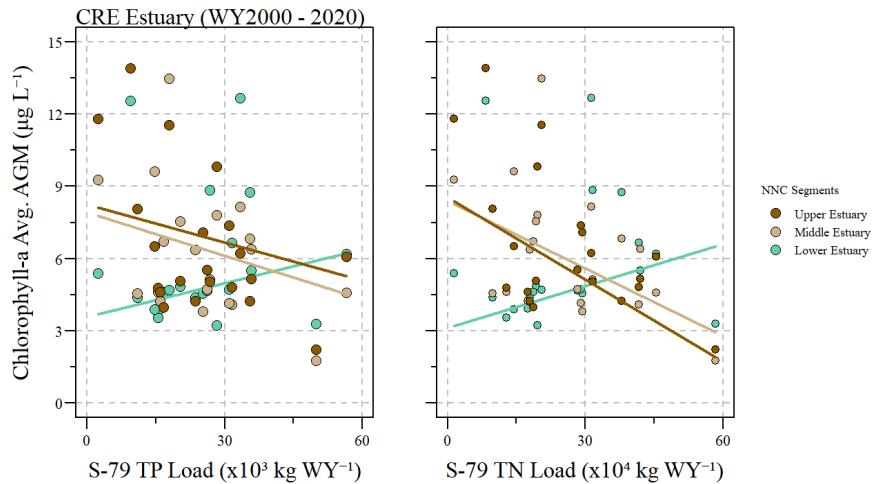


Figure 4-1. The estimated relationship between mean annual chlorophyll-a concentration in the tidal Caloosahatchee River and annual TN load from S-79.

Critical Loads

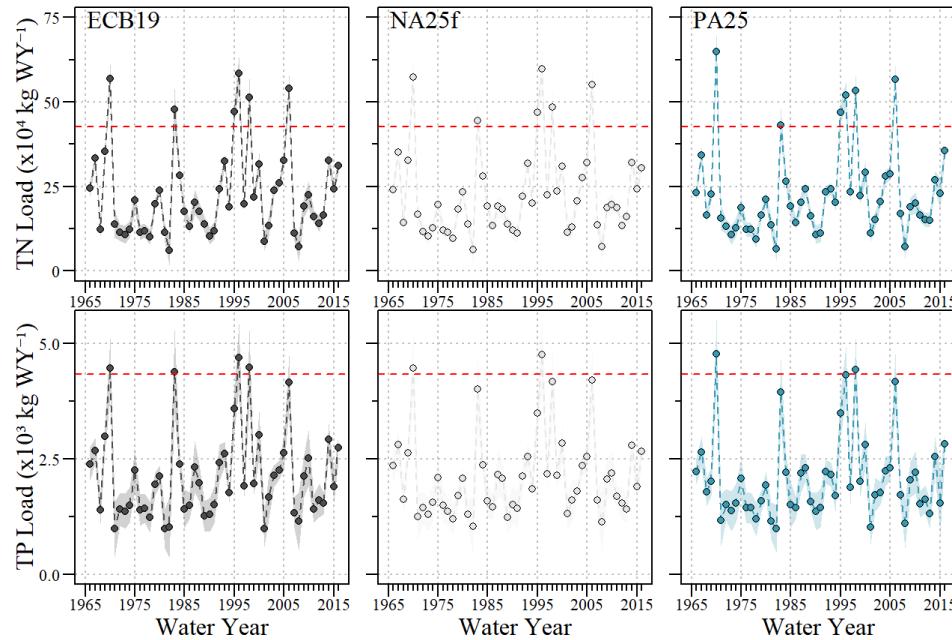
- However, when attempting to verify this relationship for purposes of this evaluation the relationship (based on available data) were not congruent with prior efforts (Janicki 2003) or were not consistent with temporal resolution of the models (Doering et al. 2006).



S-79 TP and TN annual loads compared to spatially averaged annual geometric mean Chlorophyll-a concentration for each segment.

- The effects of season, color (CDOM), biology, and hydrodynamics affect the chlorophyll-load relationship across the estuary.
- Using Lower Estuary Chl-a WQS critical load could be estimated to be ~4262 tons TN & ~434 tons TP.

Application of Models



Predicted TN and TP loads for existing condition (ECB19), no-action (NA25f) and preferred alterantive (PA25) for S-79 during period of simulation for LOSOM.

% Difference to FWO (NA25f vs PA25)

- TP Load: -3.4%
- TN Load: -0.5%
- TP FWM: -4.1%
- TN FWM: -0.04%

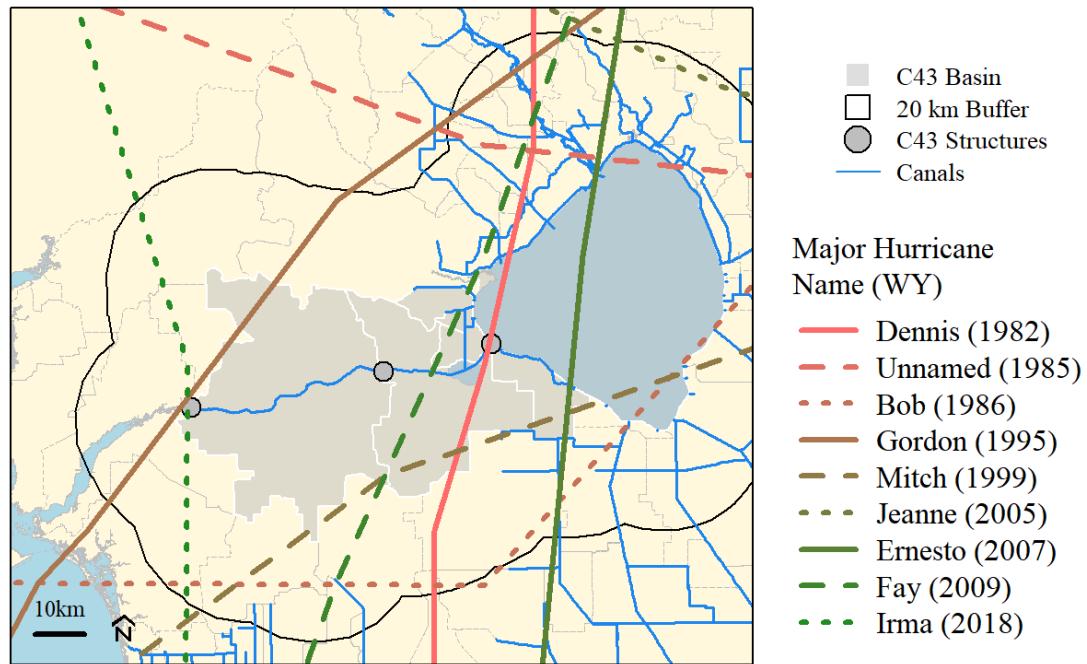
Conclusion

- Total annual nutrient load models were developed to evaluate changes in water management and the potential effect to downstream waters.
 - Presented to LOSOM PDT
- Critical nutrient loads combined with predicted loads provides a means of assess ecological impact due to nutrient loading.
 - *Needs further development*
- Applied to the Lake Okeechobee System Operating Manual (LOSOM) scenario evaluation.
- Dove-tails with other ongoing work.
 - CRE Optical Model development and evaluation
 - WRTDS evaluation of estuarine water quality

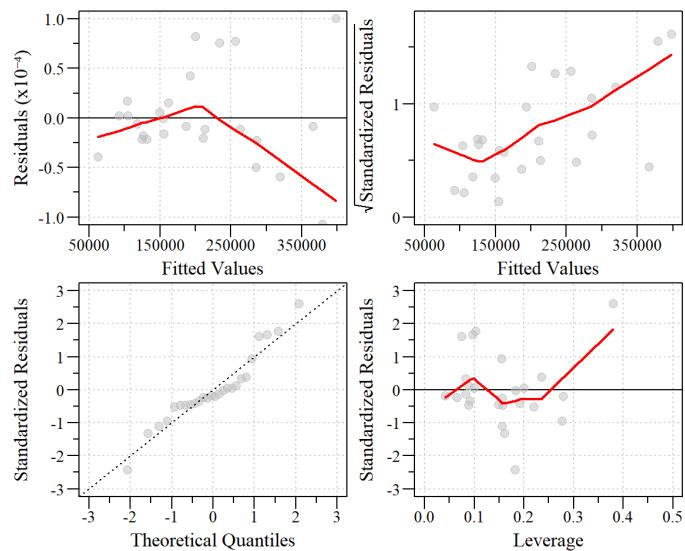
References

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- Madden CJ, Rudnick DT, McDonald AA, et al (2009) Ecological indicators for assessing and communicating seagrass status and trends in Florida Bay. *Ecological Indicators* 9:S68–S82.

- Annual TP and TN loads were estimated by interpolating water quality concentration daily from grab samples collected at each respective structure during days of observed flow (consistent with SFWMD Nutrient Load Program).
 - Period of Record was restricted to WY 1982 – 2019.

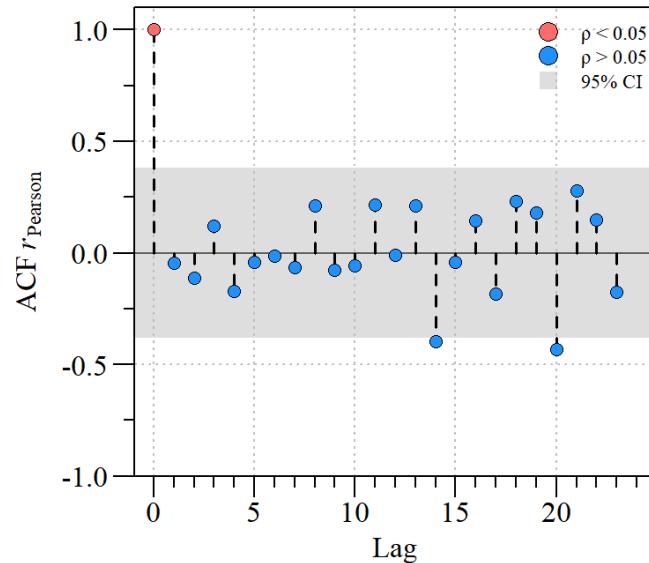


S79 TP Model diagnostics



S79 TP model diagnostics plots (Top Left: Residuals vs Fitted, Bottom Left: Normal Q-Q, Top Right: Scale-Location, Bottom right: Residuals vs leverage.).

- GVLMA (Global Stats = 3.36, $\rho = 0.50$)
- Shapiro-Wilk normality test ($W=0.92$, $\rho = 0.05$)

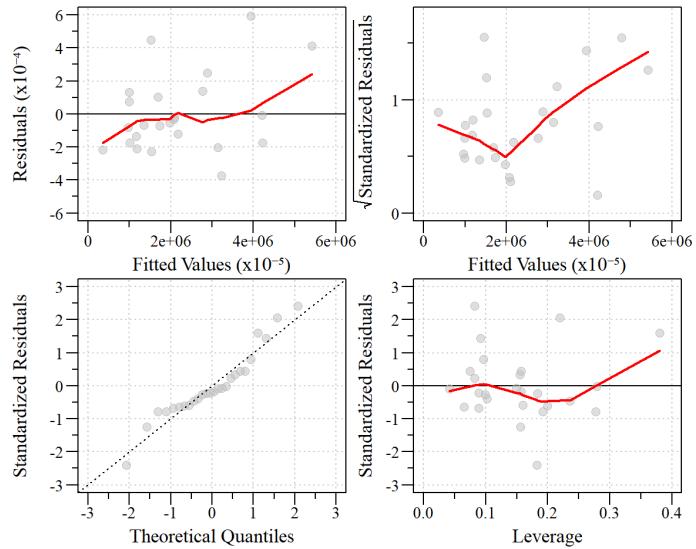


S79 TP Model residual Autocorrelation Function.

- Breusch-Godfrey (LM test = 0.06, df = 1, $\rho=0.80$)

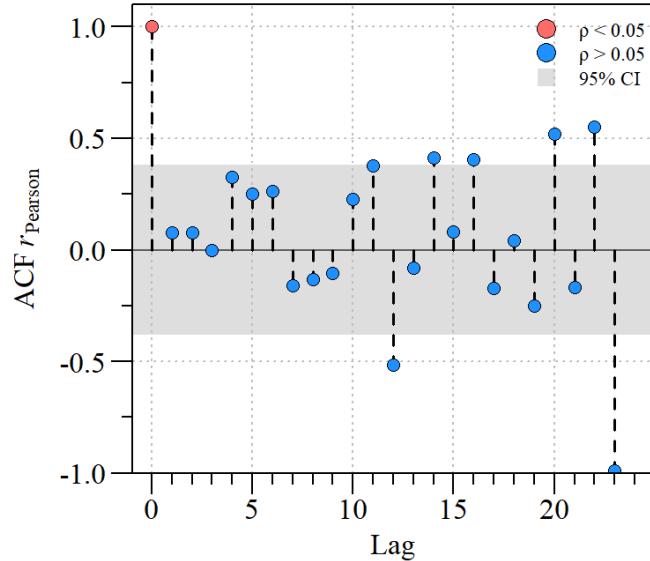
TP Model plots

S79 TN Model diagnostics



S79 TN model diagnostics plots (Top Left: Residuals vs Fitted, Bottom Left: Normal Q-Q, Top Right: Scale-Location, Bottom right: Residuals vs leverage.).

- GVLMA (Global Stats = 6.25, $\rho = 0.18$)
- Shapiro-Wilk normality test ($W=0.94$, $\rho = 0.12$)



S79 TN Model residual Autocorrelation Function.

- Breusch-Godfrey (LM test = 0.19, df = 1, $\rho=0.66$)

TN Model plots