# Caloosahatchee Estuary Nutrient Loading Model

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Paul Julian PhD pauljulianphd@gmail.com

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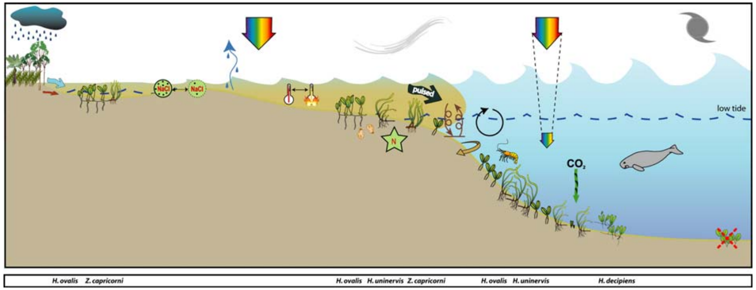
# Land Acknowledgement

**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

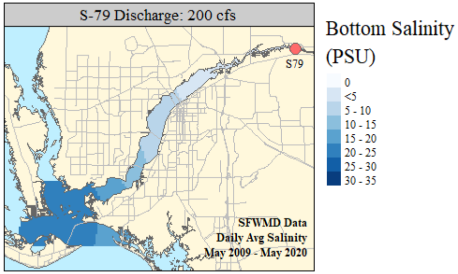



Conceptual diagram of shallow coastal ecosystems from Coles et al (2007).

- Changes in estuarine biogeochemistry and ecological function is driven largely by magnitude and composition of freshwater inputs.

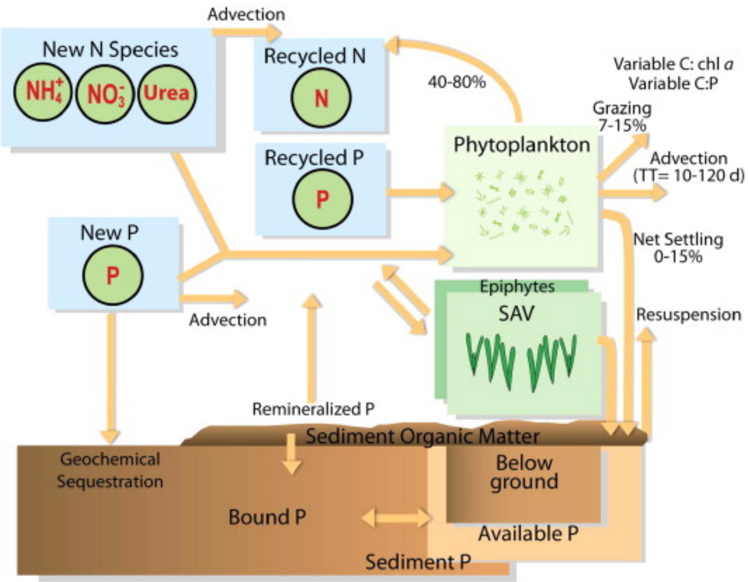
- Upstream nutrient loading to the estuary can be a stressor that can promote algal biomass (i.e. Chl-a) leading to decreased light attenuation and degraded benthic communities.
- Coastal nutrient loading can also promote marco- and epiphytic algae that can directly/indirectly impact seagrass communities (Madden et al 2009)

- Freshwater inputs can also depress salinity at increase colored dissolved organic matter thereby reducing light attenuation (Chen et al 2015).



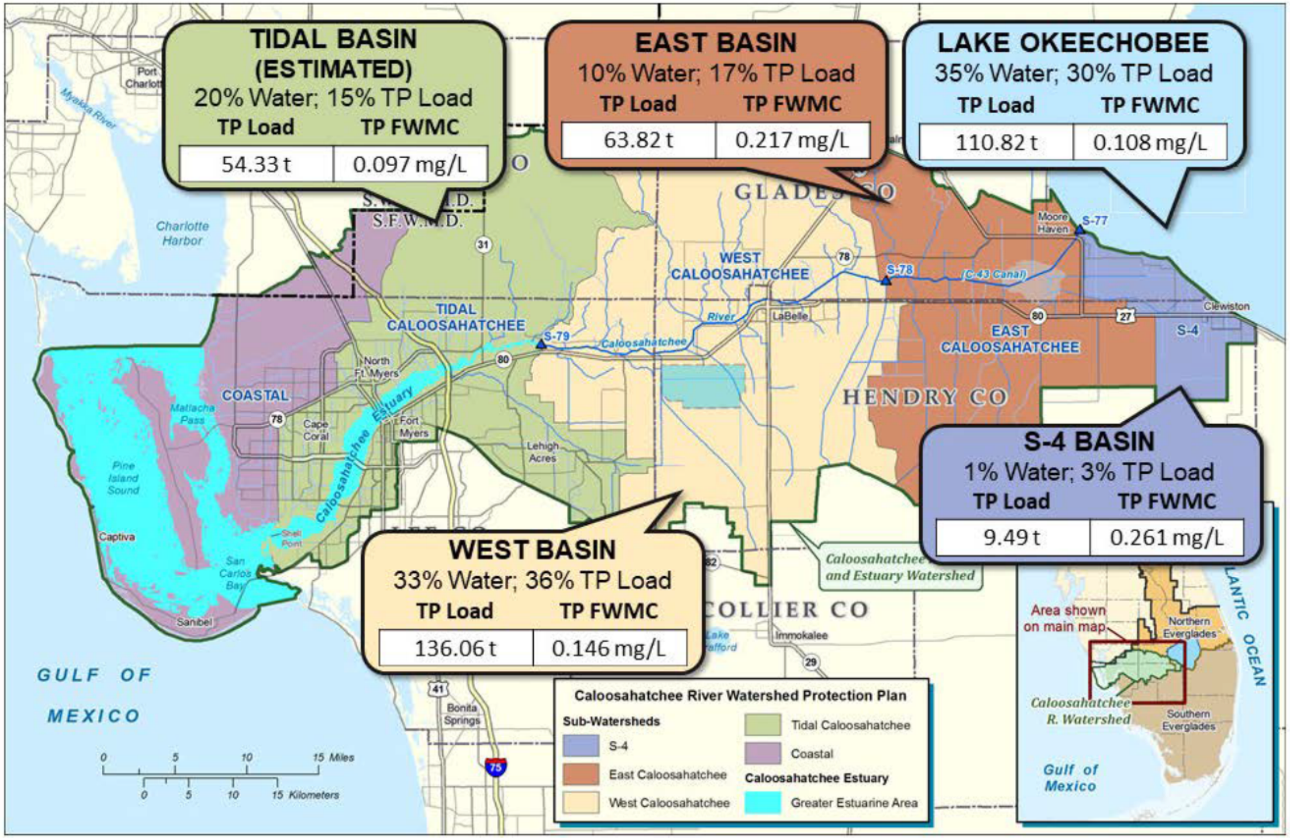
# Estuary Nutrient Loading

...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).

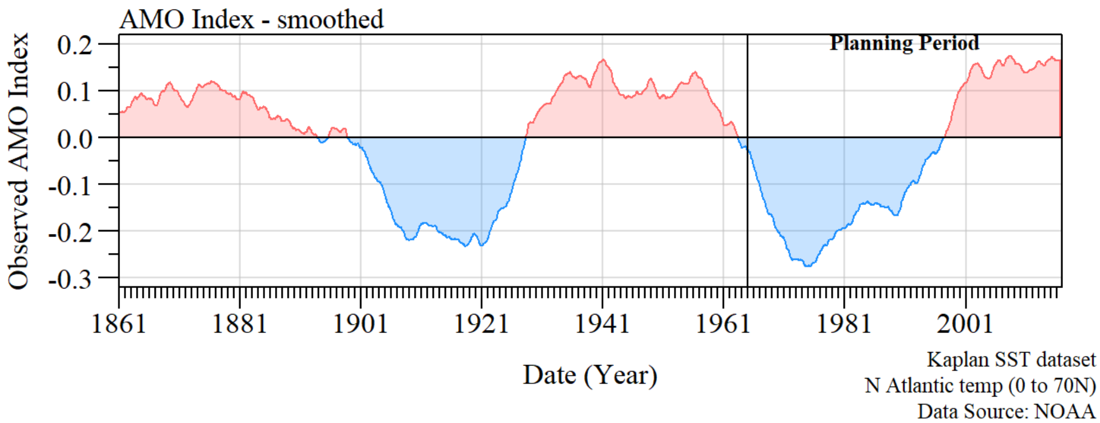
# Objective

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.

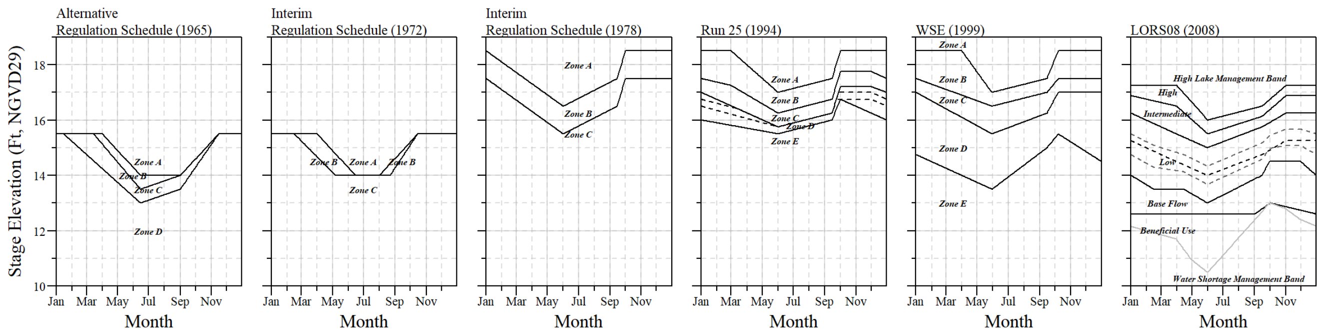
# Methods

- **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

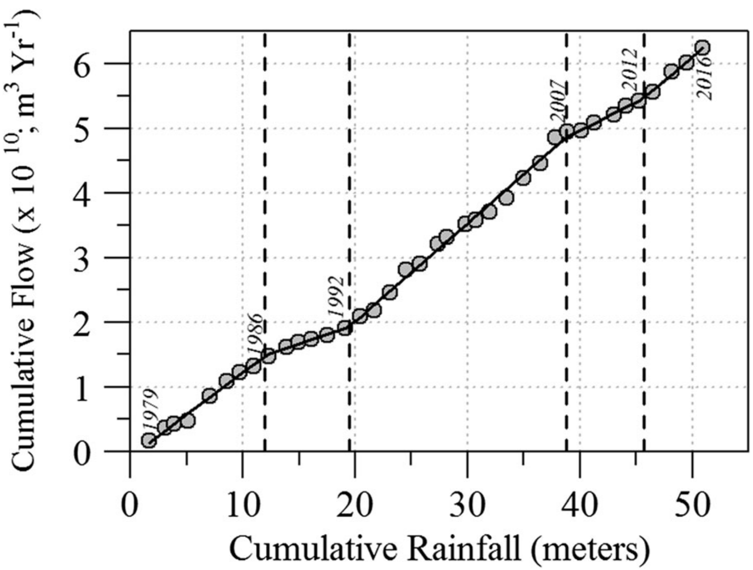



Observed Atlantic Multidecadal Oscillation (AMO) index time-series. Adapted and updated from Enfield et al (2001).



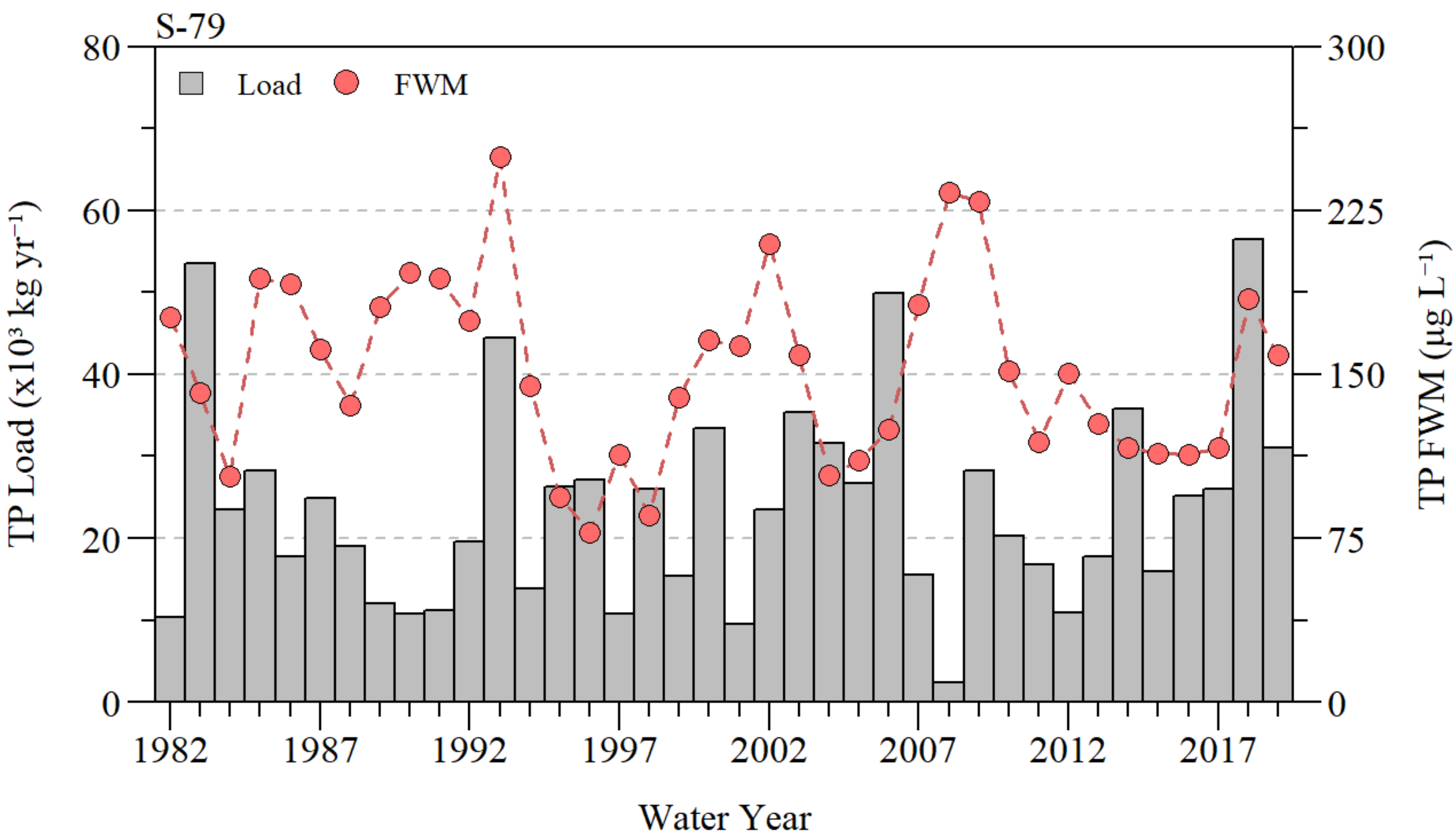

Lake Okeechobee Regulation Schedule History.

# 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:

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

Model Diagnostics plots

# S-79 Water Quality Model (Total Phosphorus)

$$TPLoad_{S79} = 127156 + 0.20Q_{C43Basin} + 0.08Q_{S77} - 7689MeanLakeStage$$

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 | ρ-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

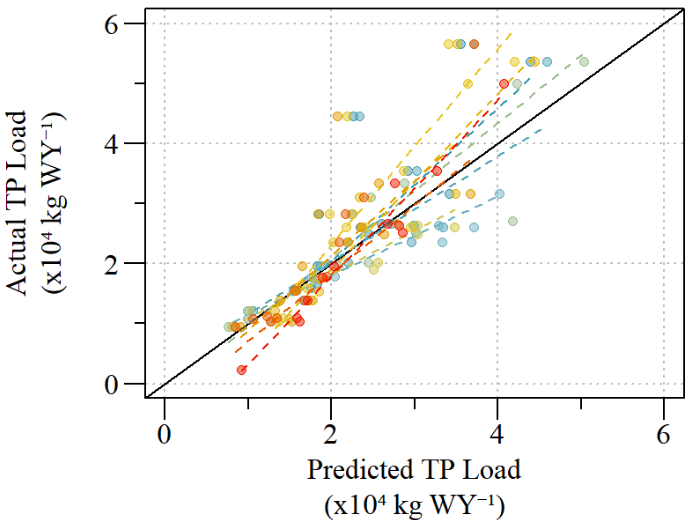
Multiple R-squared: 0.80, Adjusted R-squared: 0.78

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

Model Diagnostics plots

# S-79 Water Quality Model (Total Phosphorus)

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




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

k-fold (k=10)

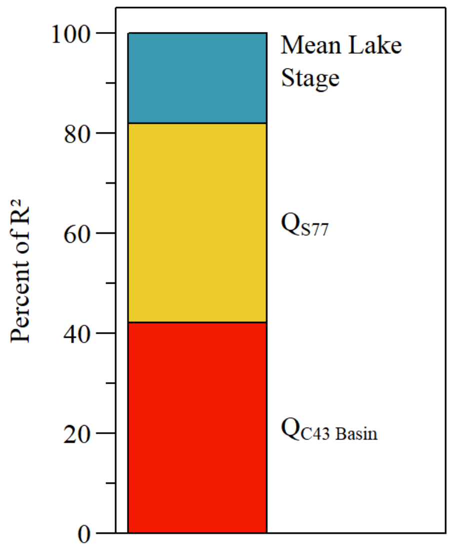
*Cross-validation error (average k errors)*

| | 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)

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



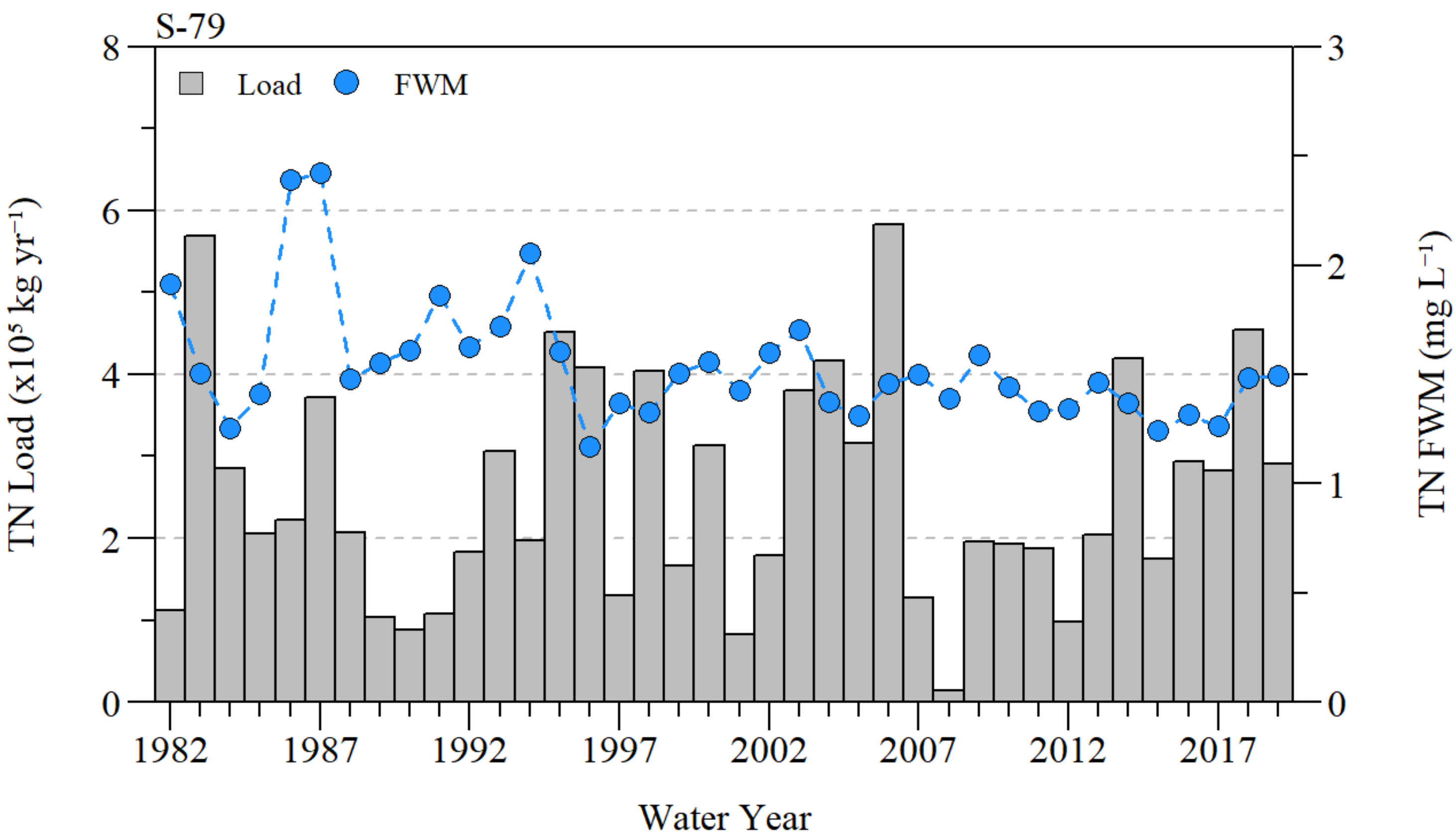

Relative importance of each predictor calculated by partitioning $R^2$ by averaging sequential sums of squares over all orders of regressors (Lindeman et al 1979). All metrics are normalized to a sum of 100%.

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 $R^2$: 0.78 (Adjusted $R^2$)

# 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:

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

Model Diagnostics plots

# S-79 Water Quality Model (Total Nitrogen)

$$TNLoad_{S79} = 27561 + 1.53Q_{C43Basin} + 1.58Q_{S77} + 20813MeanLakeStage$$

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 | ρ-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 |

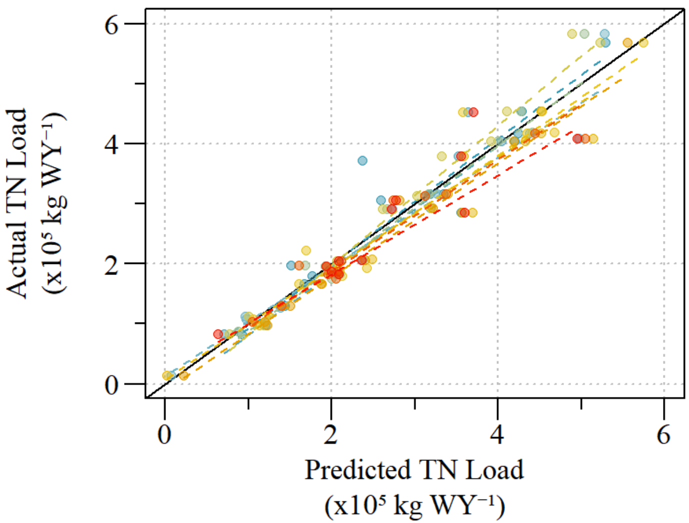
Residual standard error: 326435 on 22 degrees of freedom

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

F-statistic: 140.2 on 22 and 3, ρ-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)

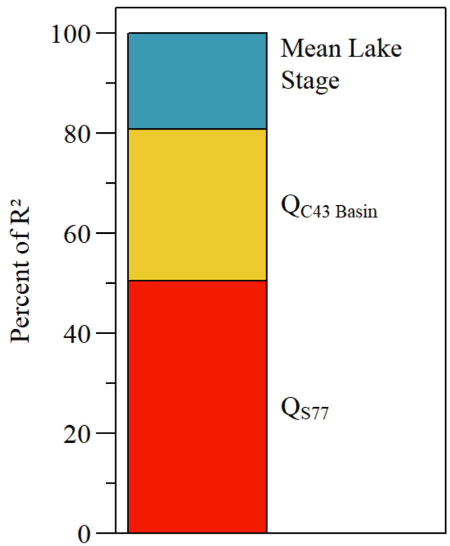
*Cross-validation error (average k errors)*

| | 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)

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




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%.

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 $R^2$)

# Critical Loads

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

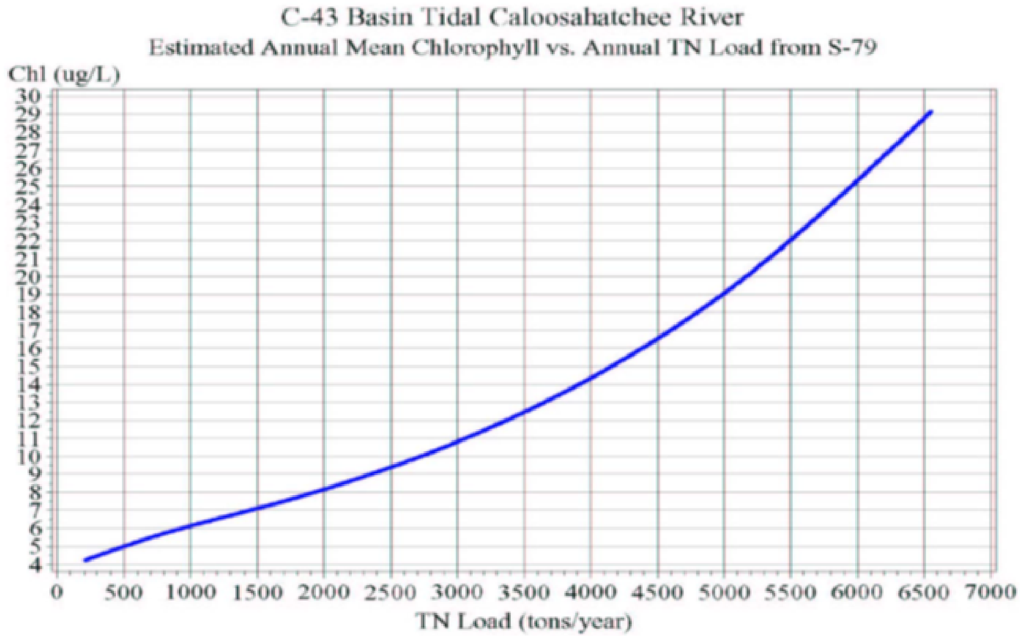
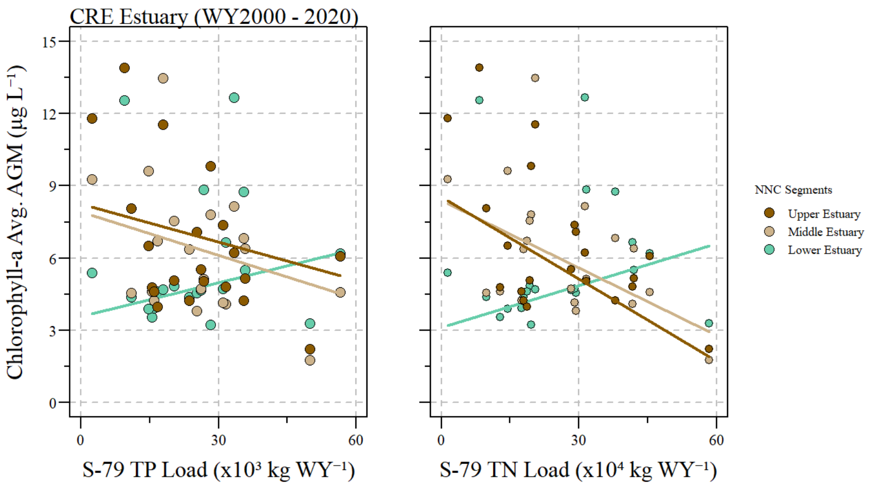



Figure 4-1. The estimated relationship between mean annual chlorophyll-a concentration in the tidal Caloosahatchee River and annual TN load from S-79.

# Critical Loads

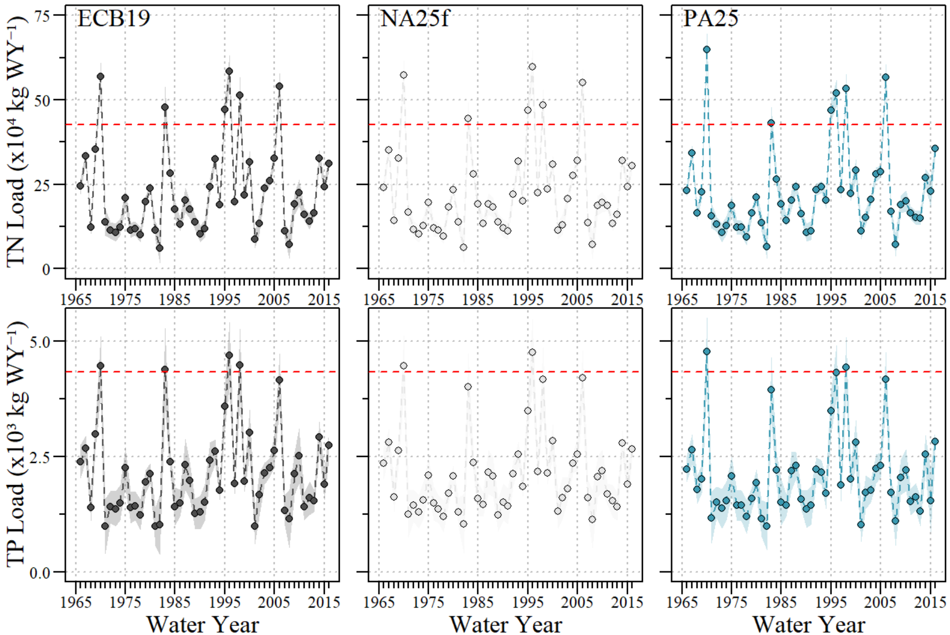
- However, when attempting to verify this relationship for purposes of this evaluation the relationship (based on available data) were not congruent with prior efforts (Janicki 2003) or were not consistent with temporal resolution of the models (Doering et al. 2006).




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 could be ~4262 tons TN & ~434 tons TP.

# Application of Models




Predicted TN and TP loads for existing condition (ECB19), no-action (NA25f) and prefered 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%

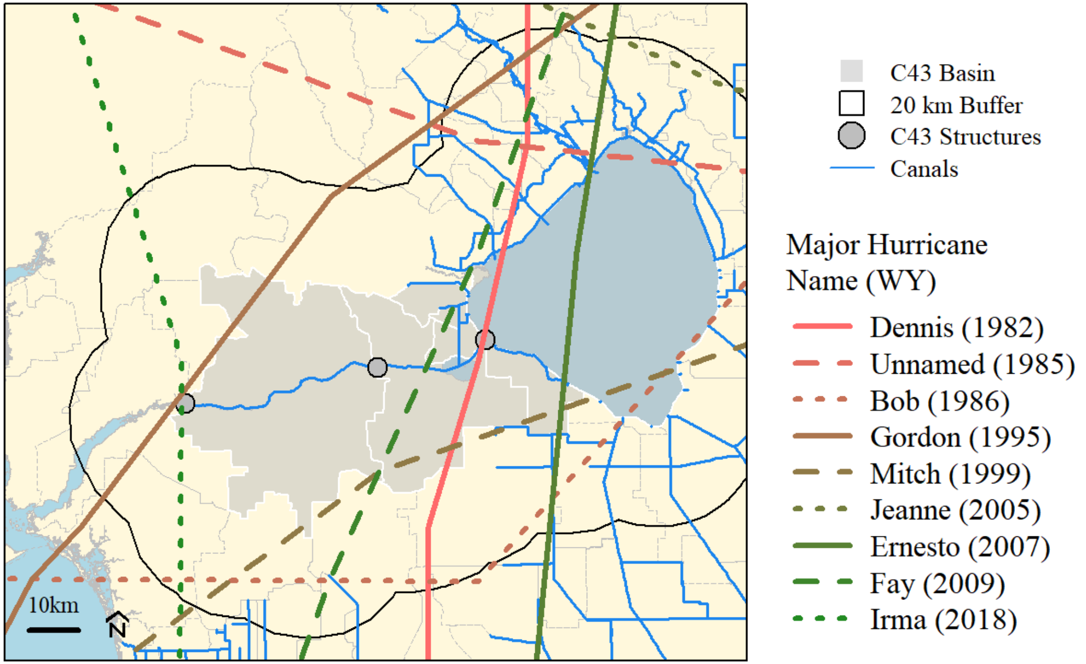
# Conclusion

- 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

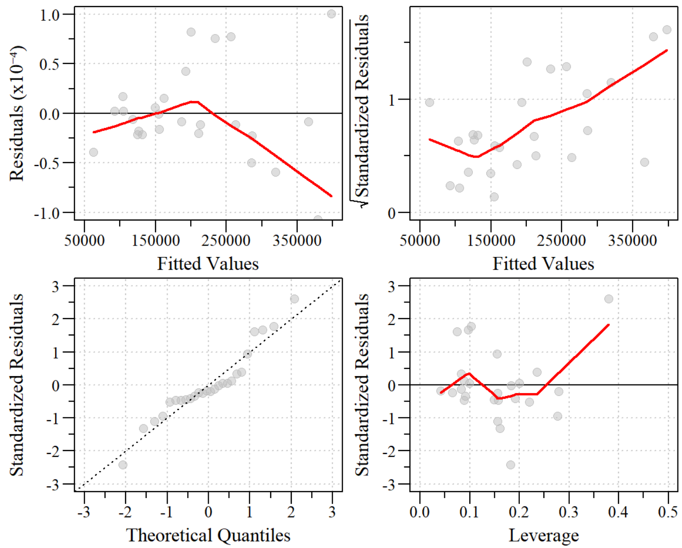
# References


- Chen Z, Doering PH, Ashton M, Orlando BA (2015) Mixing Behavior of Colored Dissolved Organic Matter and Its Potential Ecological Implication in the Caloosahatchee River Estuary, Florida. Estuaries and Coasts 38:1706–1718.
- Coles R, McKenzie L, Rasheed M, et al (2007) Status and Trends of Seagrass Habitats in the Great Barrier Reef World Heritage Area. Reef and Rainforest Research Centre Limited, Cairns, Australia
- Doering PH, Chamberlain RH, Haunert KM (2006) Chlorophyll-a and its use as an indicator of eutrophication in the Caloosahatchee Estuary, Florida. Florida Scientist 69:51–72.
- Enfield DB, Mestas-Nuñez AM, Trimble PJ (2001) The Atlantic Multidecadal Oscillation and its relation to rainfall and river flows in the continental U.S. Geophysical Research Letters 28:2077–2080.
- Glibert PM, Allen JI, Bouwman AF, et al (2010) Modeling of HABs and eutrophication: Status, advances, challenges. Journal of Marine Systems 83:262–275.
- Janicki Environmental (2003) Development of Critical Loads for the C-43 Basin, Caloosahatchee River. Florida Department of Environmental Protection, Tallahassee, FL
- Julian P, Osborne TZ (2018) From lake to estuary, the tale of two waters: A study of aquatic continuum biogeochemistry. Environment Monitoring and Assessment 190:1–24.
- 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.

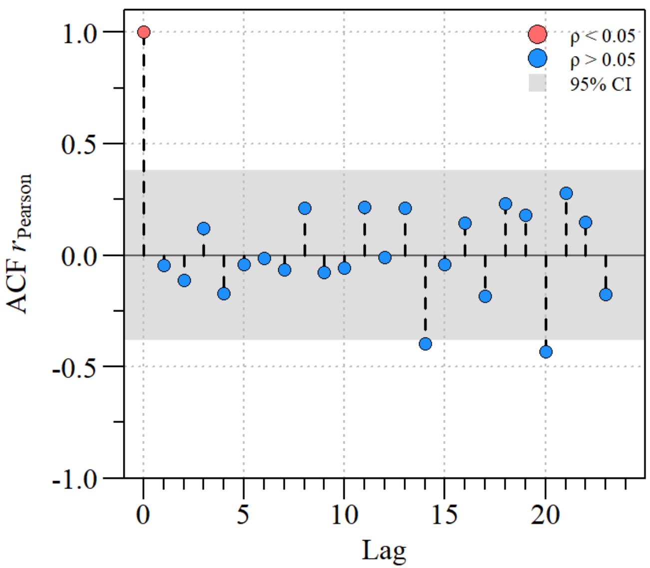


# S79 TP Model diagnostics




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)

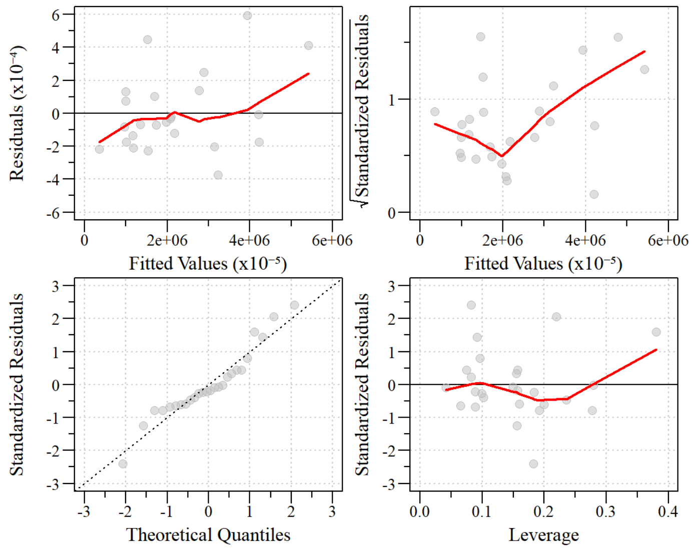



S79 TP Model residual Autocorrelation Function.

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

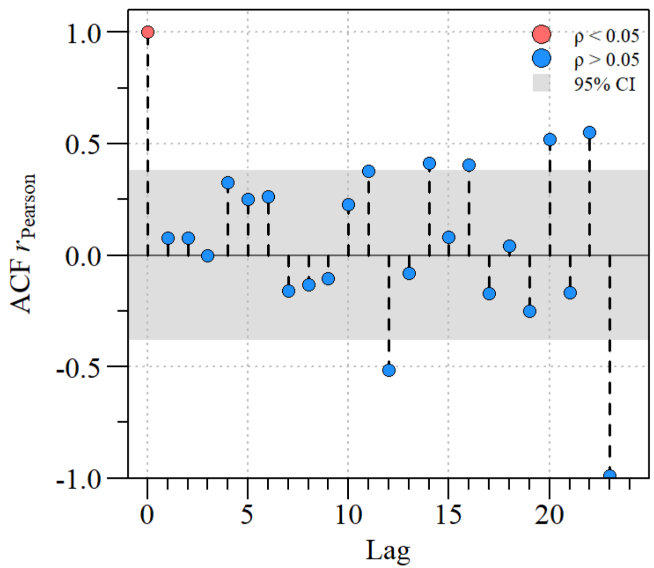
TP Model plots

## 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