St. Lucie River and Estuary Watershed WaSh Model Baseline Scenario

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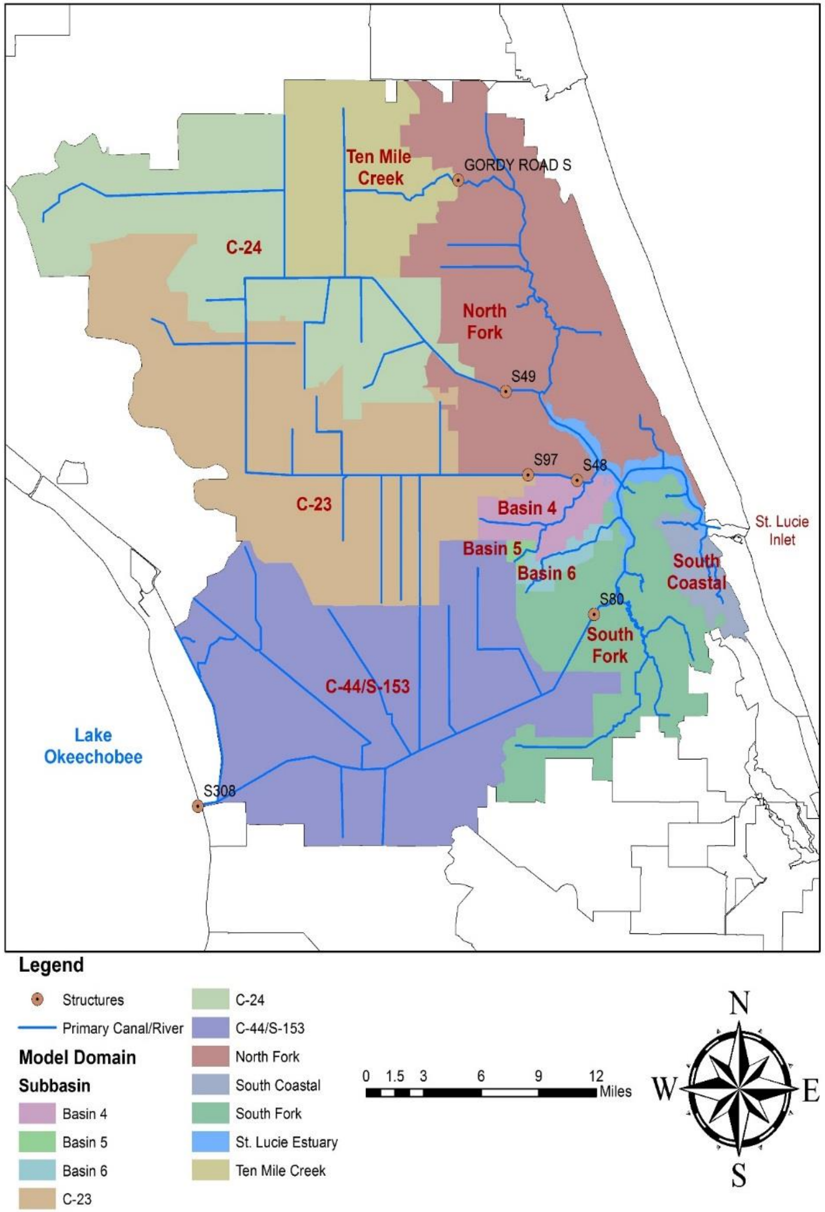
Background

- WaSh model originally developed through a joint effort between URS, Inc. (now AECOM) and SFWMD
- In 2017, SFWMD provided technical support to FDEP by completing model development needed to support the 5-Year BMAP review.
- The FDEP, in consultation with the SFWMD, determined the information necessary for model input and output.
- FDEP provided model scope and assumptions to the SFWMD.

Objectives

- ❑ Development of baseline watershed water quality model (WaSh)
  - ❖ Calibrated using data from 2001 through 2006
  - ❖ Verified using available data from 1995 through 2000.
- ❑ This work describes the development of the WaSh model, including
  - study area description
  - model methodologies
  - data description
  - model calibration and verification
  - simulation results of the baseline scenario.

Study Area


Ten Mile Creek
GORDY ROAD S
C-24
North Fork
S49
S97
S48
C-23
Basin 4
Basin 5
Basin 6
St. Lucie Inlet
South Coastal
S80
South Fork
C-44/S-153
Lake Okeechobee
S308
Legend
Structures
Primary Canal/River
Model Domain
Subbasin
Basin 4
Basin 5
Basin 6
C-23
C-24
C-44/S-153
North Fork
South Coastal
South Fork
St. Lucie Estuary
Ten Mile Creek
0 1.5 3 6 9 12
Miles
N
W
E
S

Periods of Record and Scenarios for Modeling

- Three periods of record (PORs) were defined for modeling:
    - 1995 through 2006 with land use data for 2004
    - 2007 through 2011 with land use data for 2008
    - 2012 through 2016 with land use data for 2012
- Three scenarios were identified for modeling for this modeling effort:
    - Baseline: 1995 to 2016 with septic tanks
    - Large-scale regional projects impact: 2007 to 2016
    - Septic tanks impact: 2007 – 2016

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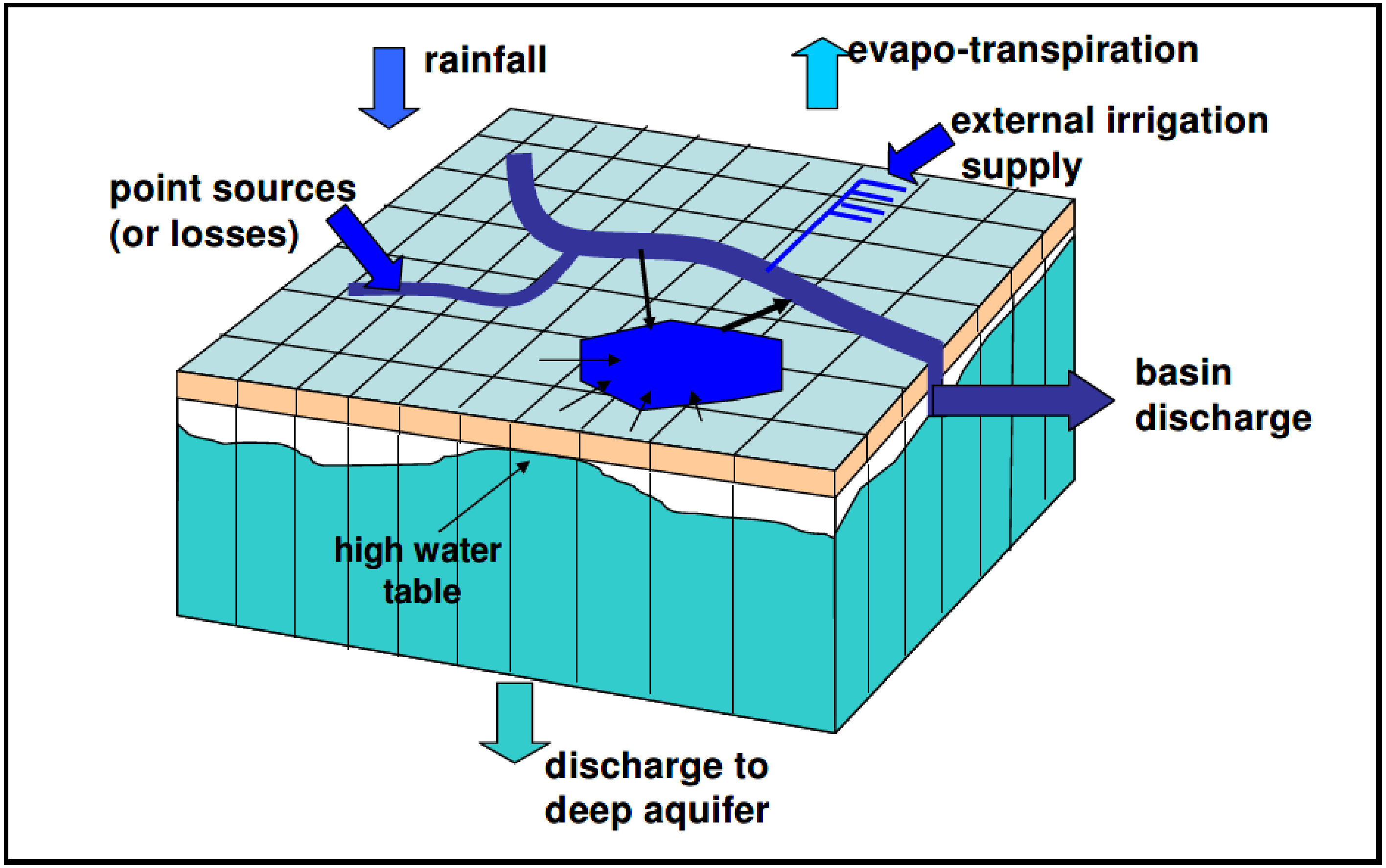
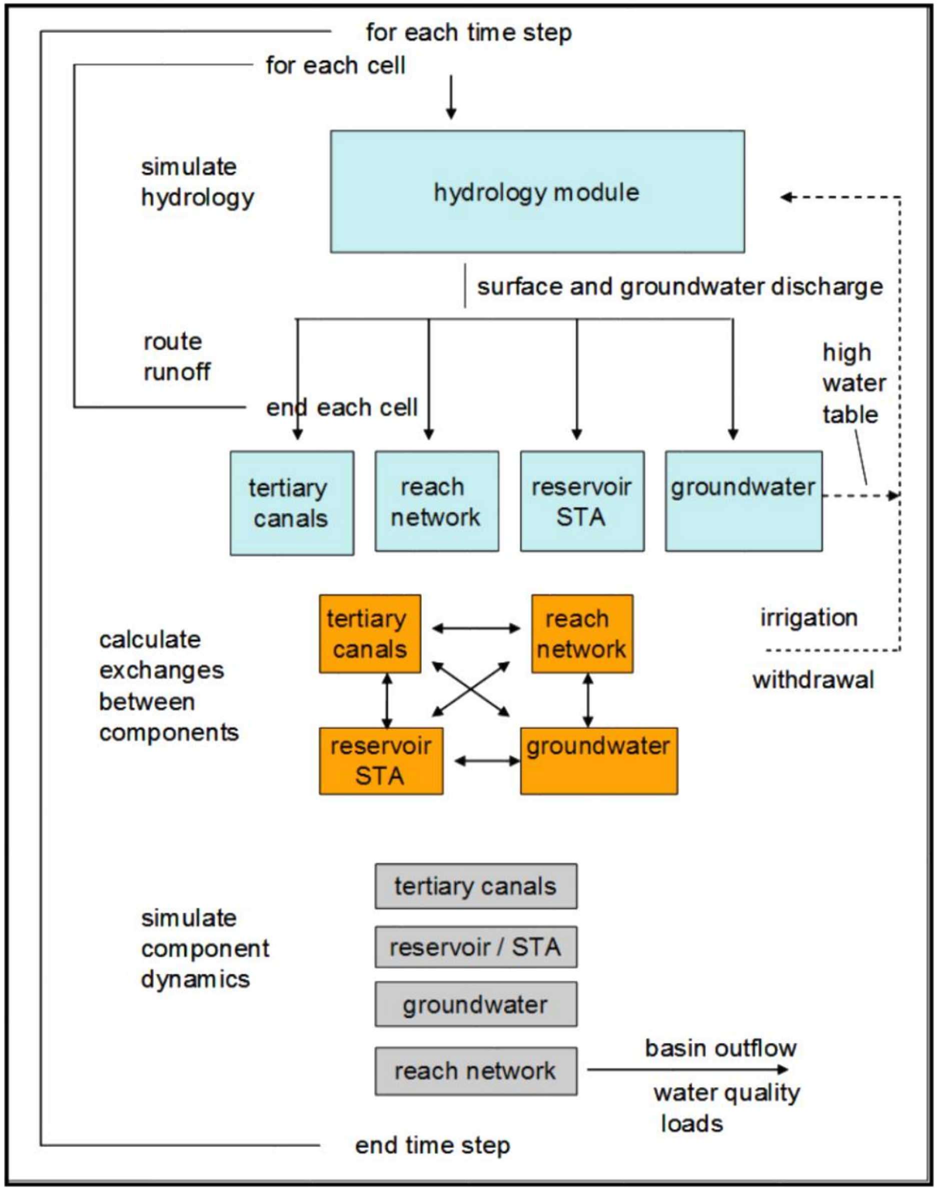
WaSh Model Methodology

- Coupled watershed hydrologic and water quality model
- Cell-based representation of the watershed surface where hydrology is modeled with the Hydrological Simulation Program-Fortran (HSPF) (Version 12) hydrology module PWATER for pervious areas and IWATER for impervious areas
- Infiltrated water is routed to a diffusive wave groundwater model that represents the water table aquifer of simulated watersheds
- Surface runoff is routed to a full dynamic wave drainage network model that has the capacity to simulate bi-directional flow, branches, and common flow structures

WaSh Model System and Elements



Flow Chart for WaSh Model



The model computations are divided into four groups:

(1) Hydrology calculations;

(2) Cell discharge routing;

(3) Component interactions;

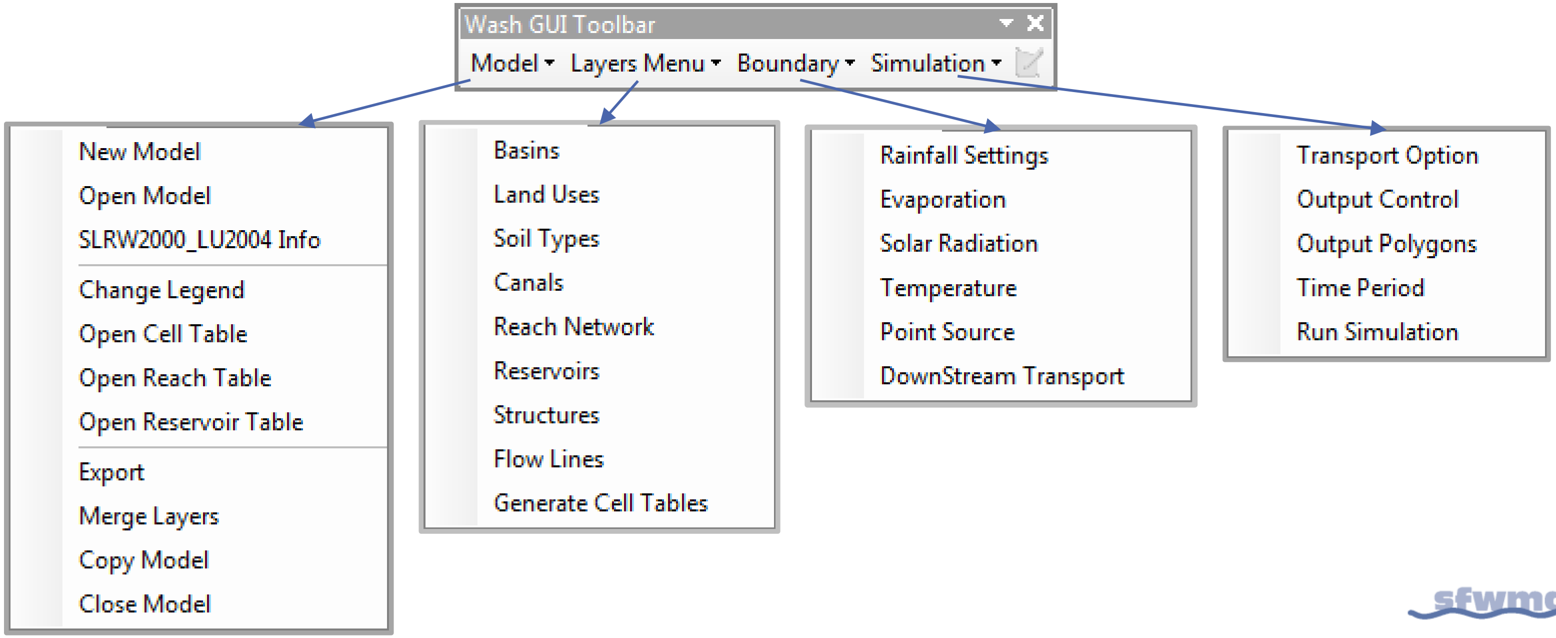
(4) Individual component dynamics.

Water Quality Module

- The water quality component supports two options: (1) basic water quality and (2) advanced water quality. Advanced is used in this effort
  - The advanced water quality option consists of simulating the production, transport and in-stream processes for: DO, CBOD, NH4, NO3, ON, OP, IP, and phytoplankton carbon
    - The event mean concentrations approach is used for all constituents except for DO
    - Transport is modeled using conservation of mass, including settling
    - In-stream processes are modeled using non-linear kinetic routines (EUTRO 4) adopted from the WASP (Water Quality Analysis Simulation Program) model

Model Configuration

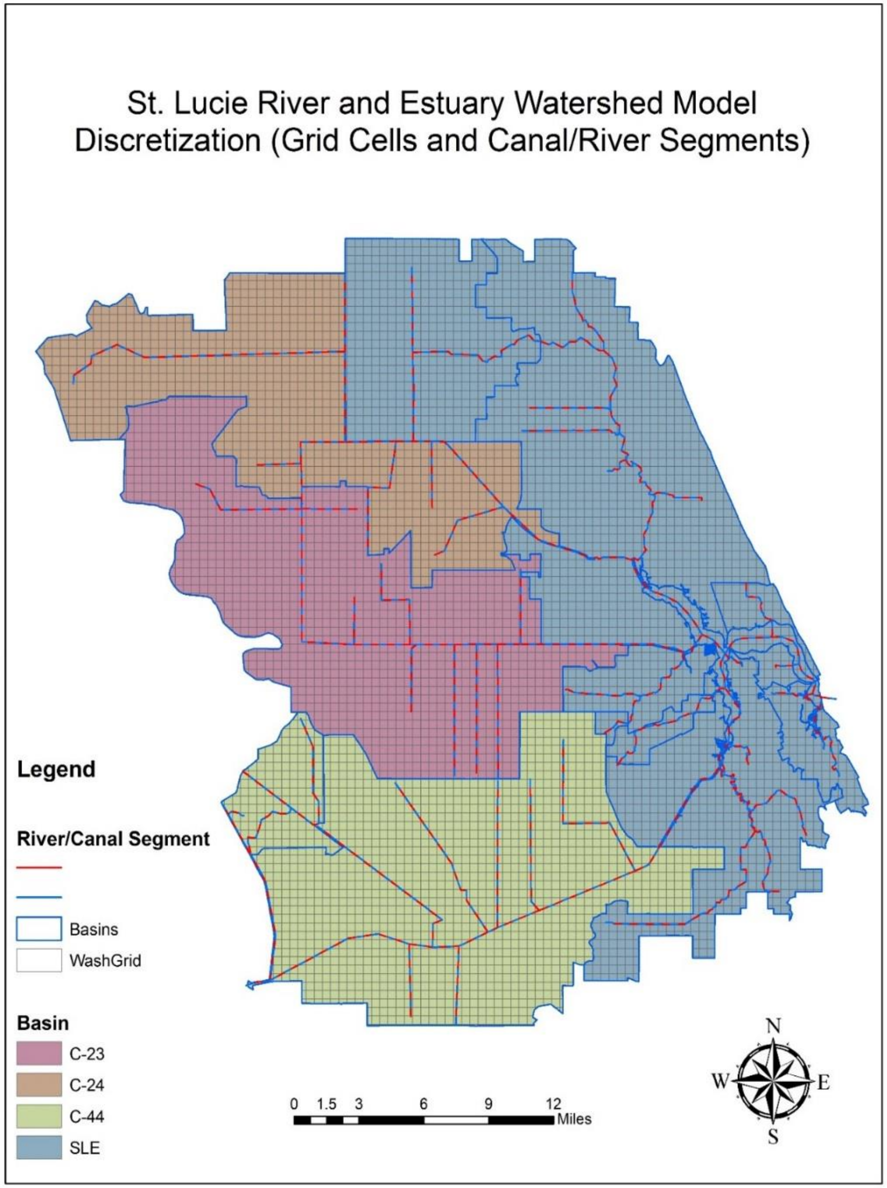
- An ArcGIS graphical user interface (GUI) has been developed to facilitate model configuration, including key watershed management strategies
  - implementation of best management practices
  - land use changes
  - operations of reservoirs or stormwater treatment areas (STAs)



Model Configuration cont.

Watershed Discretization and Canal/River Segmentation:

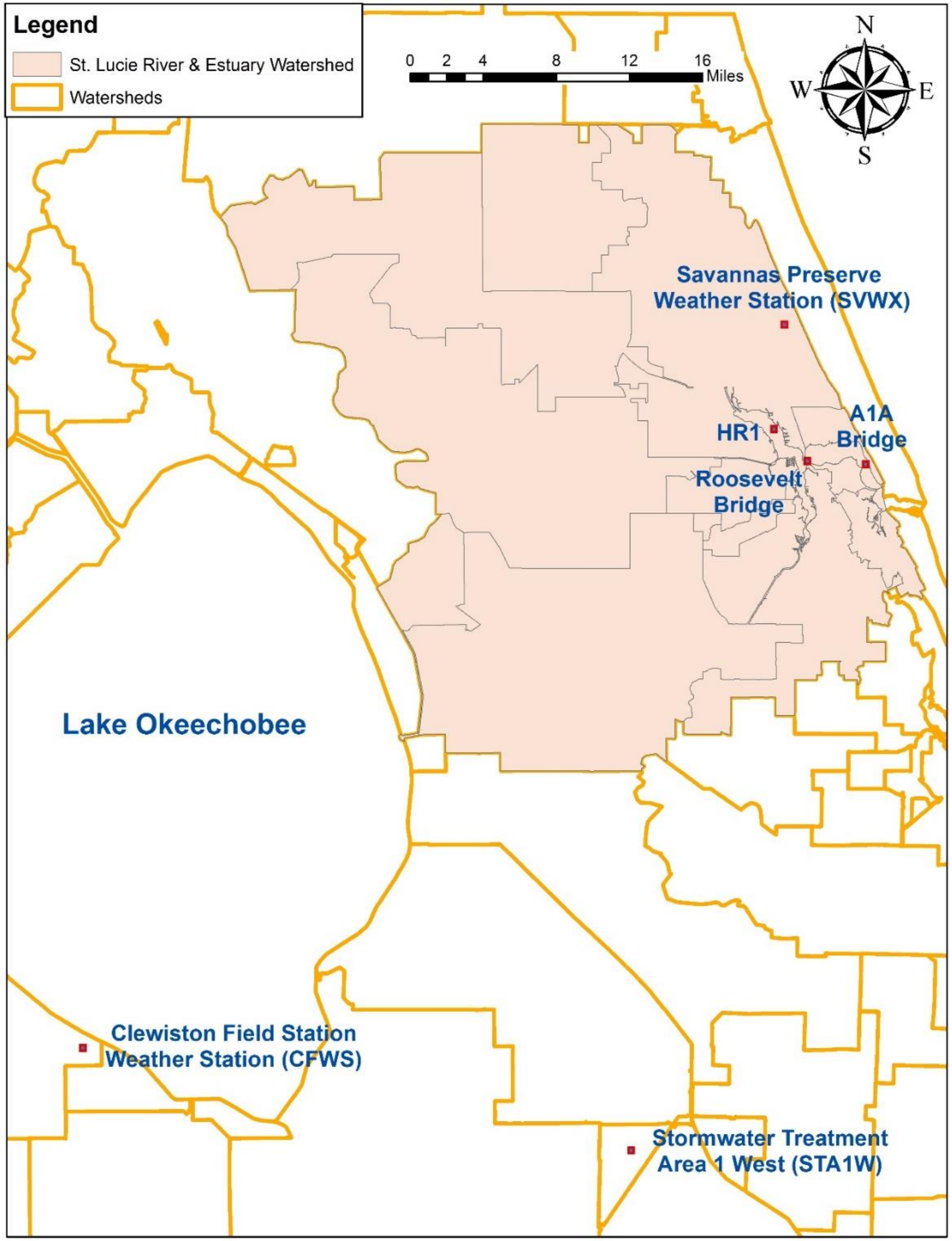
- Grid Cells
  - 2000 ft x 2000 ft
  - 6121 cells
- Canal/River Segments
  - 2000 ft
  - 943 segments



Data Sources

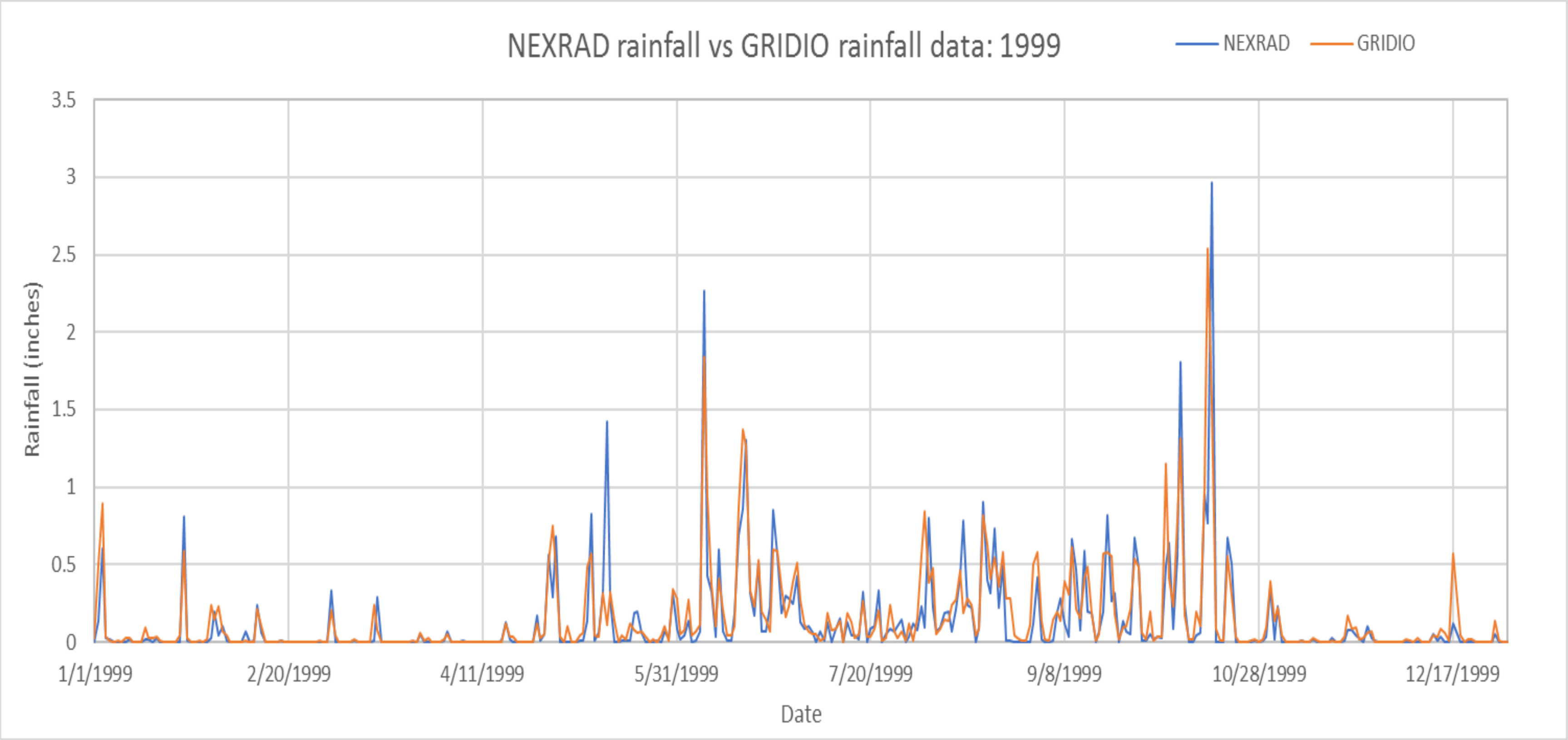
- Rainfall
  - GRIDIO (prior to 1/1/2000)
  - NEXRAD (after 1/1/2000)
- Potential Evapotranspiration
  - Savannas Preserve Weather Station
  - STA 1 West Weather Station
- Solar Radiation
  - Savannas Preserve Weather Station
  - Clewiston Field Station Weather Station
- Water Temperature
  - DBHYDRO* – HR1, A1A, US1 Bridge
- SFWMD Land Use (2004, 2008, 2012)
  - Photo-interpreted aerial photography
  - Digital ortho-photographic quarter quadrangles

* DBHYDRO - South Florida Water Management District's corporate environmental database

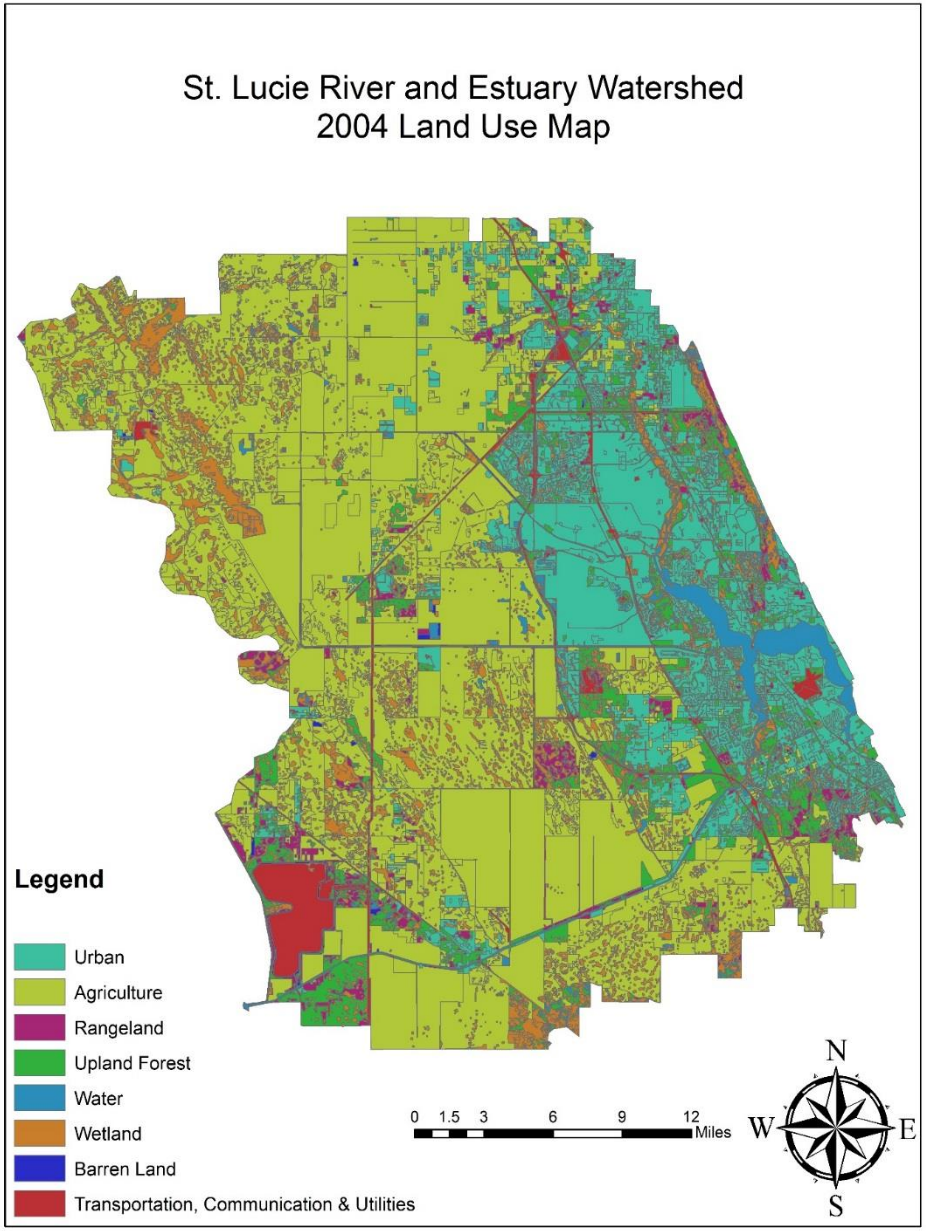


Location of Continuous Data Sources

Rainfall Data Source Comparison



2004 Land Use



- ❑ 53% agriculture
- ❑ 19% urban
- ❑ 11% wetland
- ❑ 7% upland forest
- ❑ 5% water
- ❑ 3% rangeland
- ❑ 2% transportation, communication, and utilities
- ❑ 1% barren

Data Sources cont.

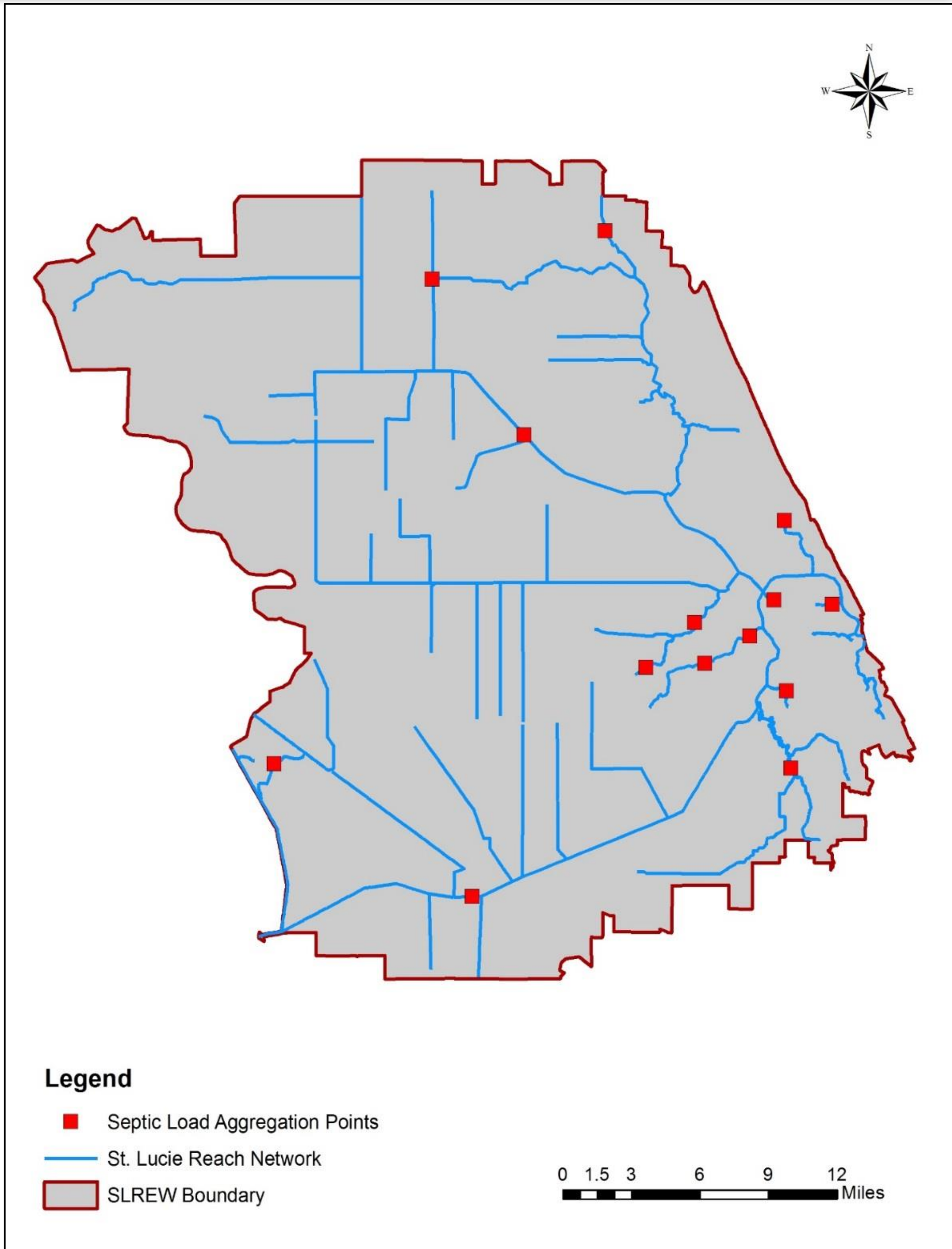
- Hydrography
  - SFWMD AHED* GIS database
- Soil
  - FDEP Soil Survey Geographic Database
- Topography
  - SFWMD GIS database
- Estuarine Bathymetry
  - SFWMD GIS database
- Flow
  - DBHYDRO

* AHED - Arc Hydro Enhanced Database

Data Sources cont.

- Event Mean Concentrations (EMCs)
  - IFAS ISCO dataset (2001~2004)
  - FDEP ISCO dataset (2005)
  - Urban Runoff Study (SFWMD SLT) (2001 ~ 2005)
  - FDEP BMP Study (1998 ~ 2000)
  - Grassy Waters Preserve Sampling Project (2004)
- Water Quality
  - DBHYDRO – Estuarine sampling stations, structures
- Septic Tanks
  - Martin County Study – Nitrogen loading estimate (Ye and Sun, 2013)
  - Septic tank loading is included as point source inputs to the model, data are pre-processed into time series inputs for this simulation (provided by FDEP).

Septic Tank Loading Points



Model Calibration and Verification

- **Model Calibration** - the process of adjusting model parameter values within reasonable ranges, determined from site-specific studies or literature values, until the simulated results closely match the observed data.
  - The model was calibrated using data from 2001 through 2006
- **Model Verification** - the process by which a calibrated model is shown to be capable of reproducing a set of field observations or predicting future conditions without further adjustment to the calibrated parameters
  - The model was verified using data from 1995 through 2000.

Calibration and Verification Sites

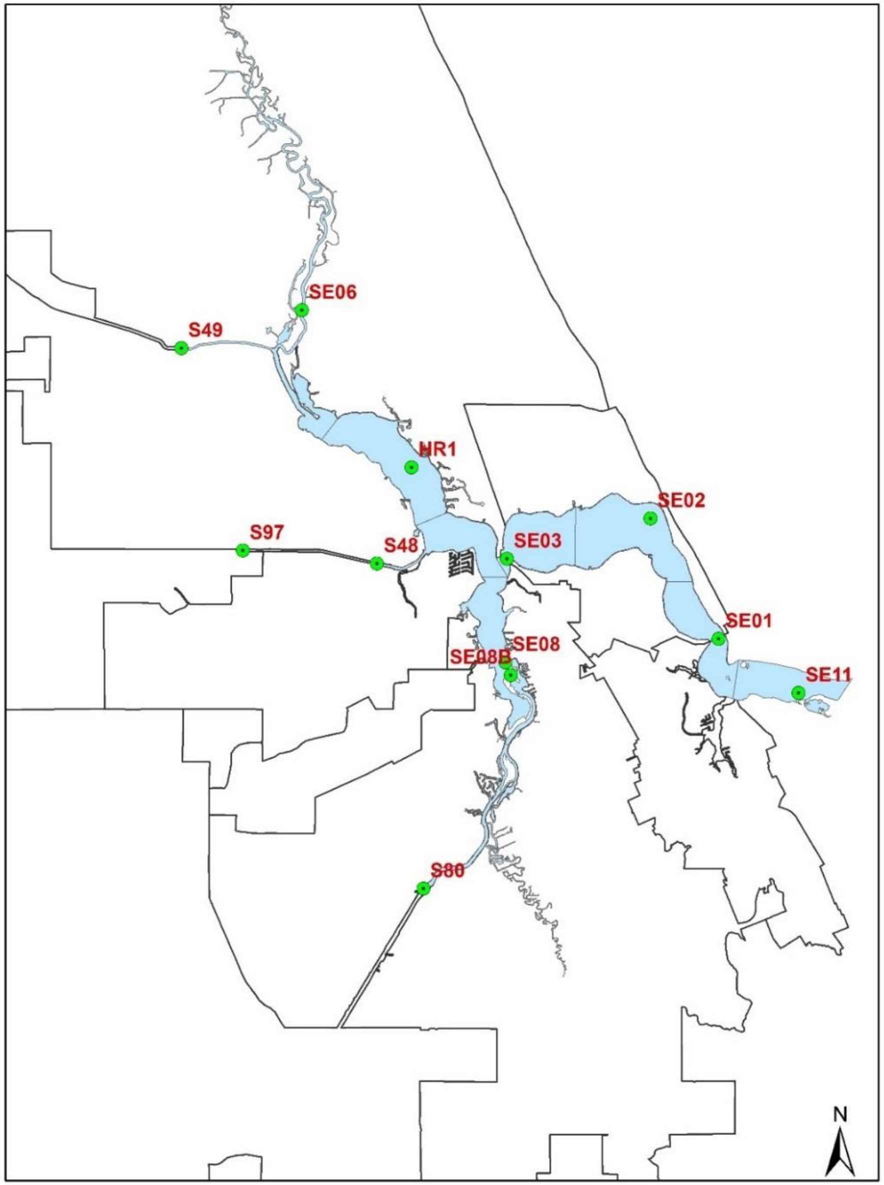


Table for site use

Site	Calibration/Verification	
	Flow	WQ
S-49	X	X
S-97	X	
S-48		X
S-80	X	X
SE01		X
SE02		X
SE03		X
HR1		X
SE06		X
SE08(B)		X
SE11		X

Model Performance Evaluation Statistics

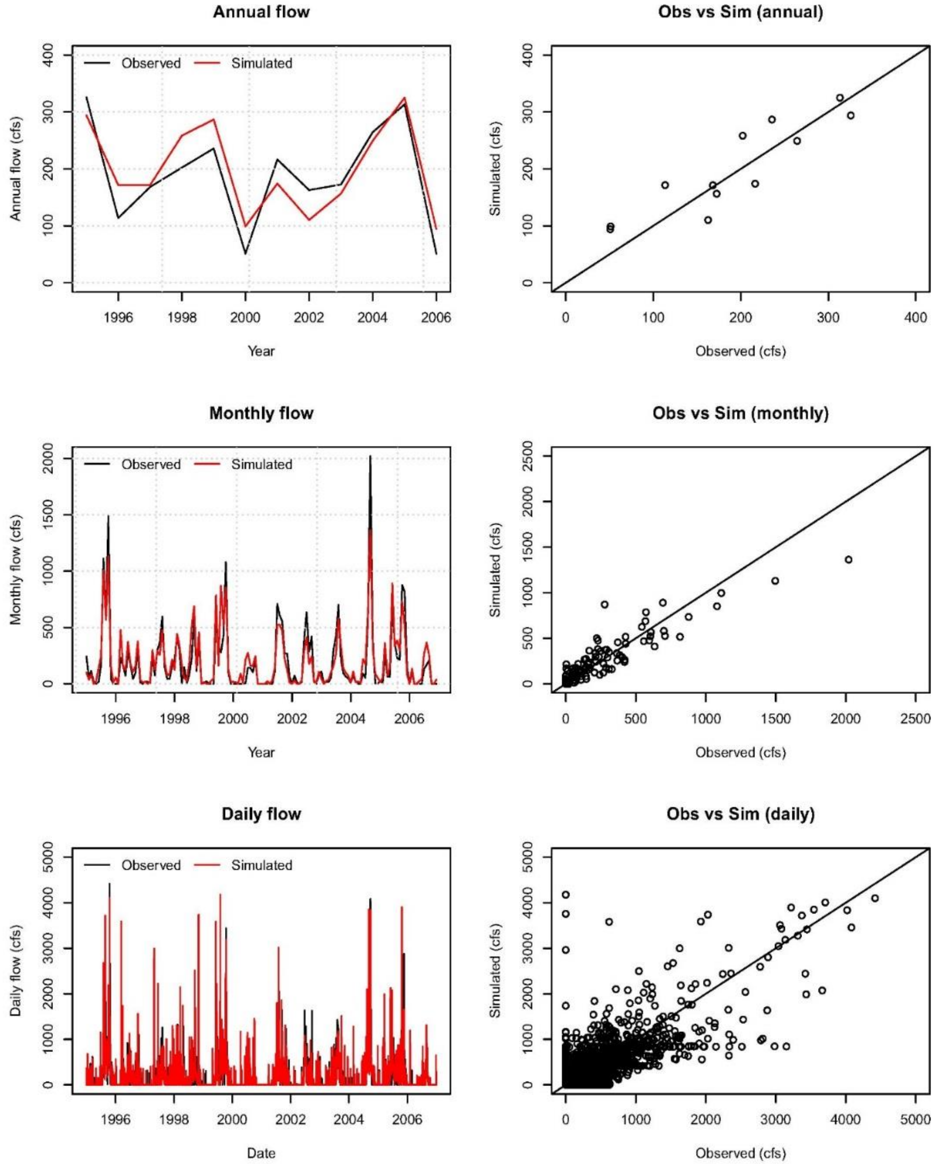
- ❑ Coefficient of Determination (R^2)
- ❑ Bias
- ❑ Percent of Bias (PBIAS)
- ❑ Root Mean Square Error (RMSE)
- ❑ Relative RMSE (RRE)

- ❖ Flow simulations rated by PBIAS, RRE, and R^2 for daily and monthly data
- ❖ Water Quality simulations rated by PBIAS and RRE

Criteria for model performance evaluation (Donigian, 2002; Moriasi et al., 2015).

Model (and Reference)	Response Output	Performance Evaluation Criteria				
BASINS/HSPF (Duda et al., 2012)		Difference between Simulated and Recorded Values (%)				
		Very Good		Good		Fair
	Hydrology/flow	<10		10 to 15		15 to 25
	Sediment	<20		20 to 30		30 to 45
	Water temperature	<7		8 to 12		13 to 18
	Water quality/nutrients	<15		15 to 25		25 to 35
	Pesticides/toxics	<20		20 to 30		30 to 40
		Statistical Evaluation Criteria				
	Hydrology/flow	Statistic	Very Good	Good	Fair	Poor
	Daily	R	≥0.89[a]	≥0.84	≥0.77	<0.77
	Monthly	R	≥0.92	≥0.87	≥0.81	<0.81
	Daily	R^2	≥0.80	≥0.70	≥0.60	<0.60
	Monthly	R^2	≥0.85	≥0.75	≥0.65	<0.65

S-49 Flow Data Comparison



Comparison plots of observed vs simulated flow at S−49

Flow Calibration Ratings

Evaluation Statistics	S-49	S-97	S-80
R^2 (Daily)	0.69	0.64	0.84
PBIAS (Daily, %)	5.8	6.6	-1.7
RRE (Daily, %)	5.87	5.53	6.99
R^2 (Monthly)	0.89	0.90	0.95
PBIAS (Monthly, %)	5.8	6.7	-1.7
RRE (Monthly, %)	5.9	6.0	4.6

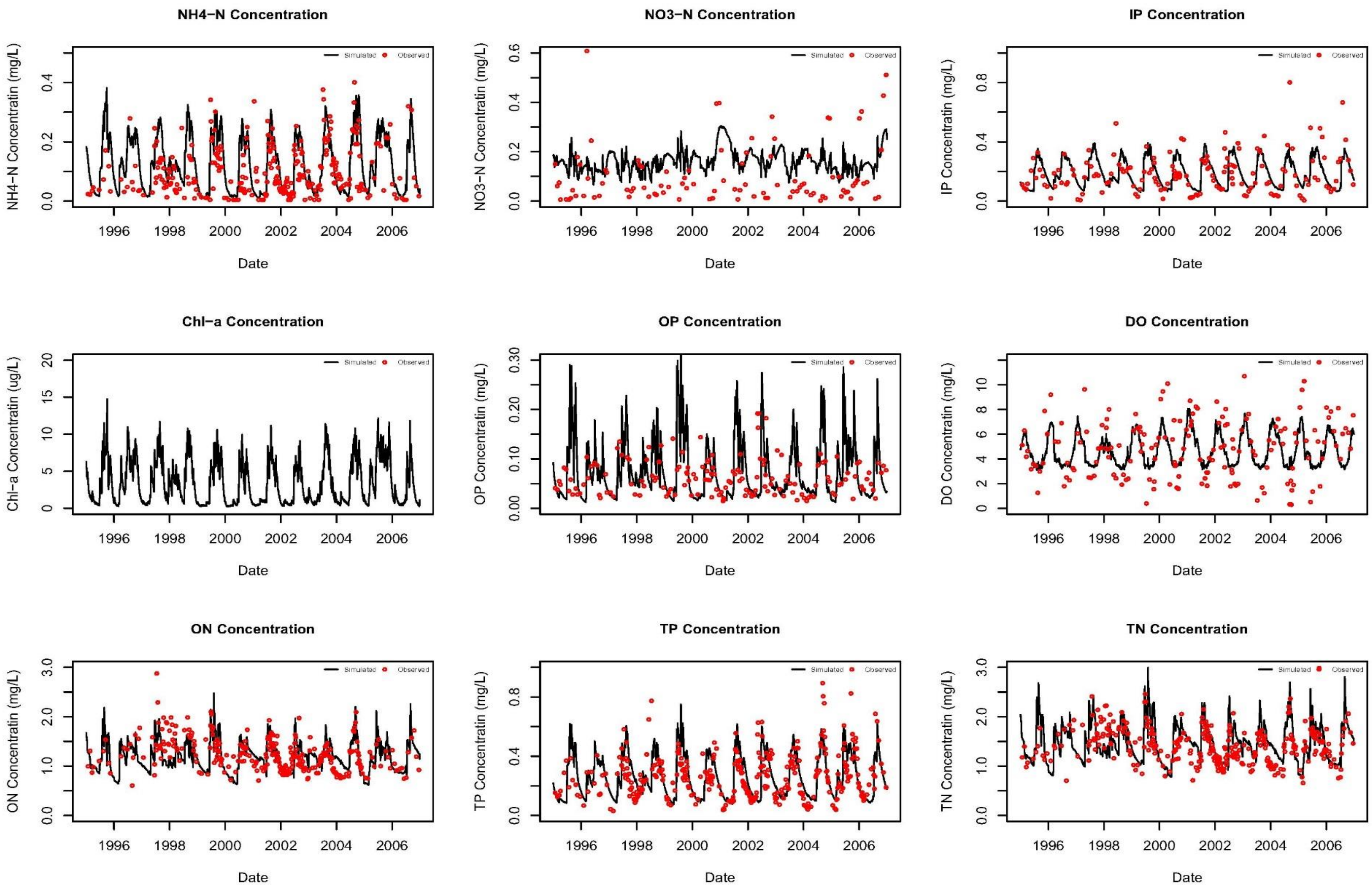
Very Good
Good
Fair
Poor

Flow Verification Ratings

Evaluation Statistics	S-49	S-97	S-80
R^2 (Daily)	0.60	0.66	0.93
PBIAS (Daily, %)	-17.5	-19.5	-7.6
RRE (Daily, %)	6.32	6.24	4.56
R^2 (Monthly)	0.82	0.87	0.99
PBIAS (Monthly, %)	-17.6	-19.7	-7.6
RRE (Monthly, %)	8.2	6.4	2.3

Very Good
Good
Fair
Poor

S-49 Water Quality Comparison



Comparison plots of observed vs simulated constituent at S−49

Water Quality Calibration Ratings

Comparison is to monthly grab samples

Monitoring Station	Statistics	NH3	NO3	IP	DO	ON	TP	TN	CHLA
S-48	PBIAS(%)	-6.9	-28.5	3.4	12.5	-11.2	-5.4	-14.3	NA
	RRE (%)	16.1	29.1	16.5	17.7	15.9	19.9	18.4	NA
S-49	PBIAS(%)	-16.7	-46.9	6.8	5.4	-3.5	-5.4	-9.7	NA
	RRE (%)	18.6	25.5	16.6	17.6	8.0	15.3	8.2	NA
S-80	PBIAS(%)	-38.8	1.9	3.1	8.9	-4.1	-10.2	-3.4	NA
	RRE (%)	14.3	14.2	15.6	16.9	20.1	21.7	16.8	NA
HR1	PBIAS(%)	-10.7	-58.2	7.1	11.2	-1.2	7.2	-4.7	25.6
	RRE (%)	13.2	20.4	11.8	18.4	20.2	11.1	18.7	14.0
SE01	PBIAS(%)	16.9	-26.3	4.9	-0.3	1.9	-4.0	2.1	1.2
	RRE (%)	16.0	10.0	10.2	19.1	16.9	10.5	13.5	19.6

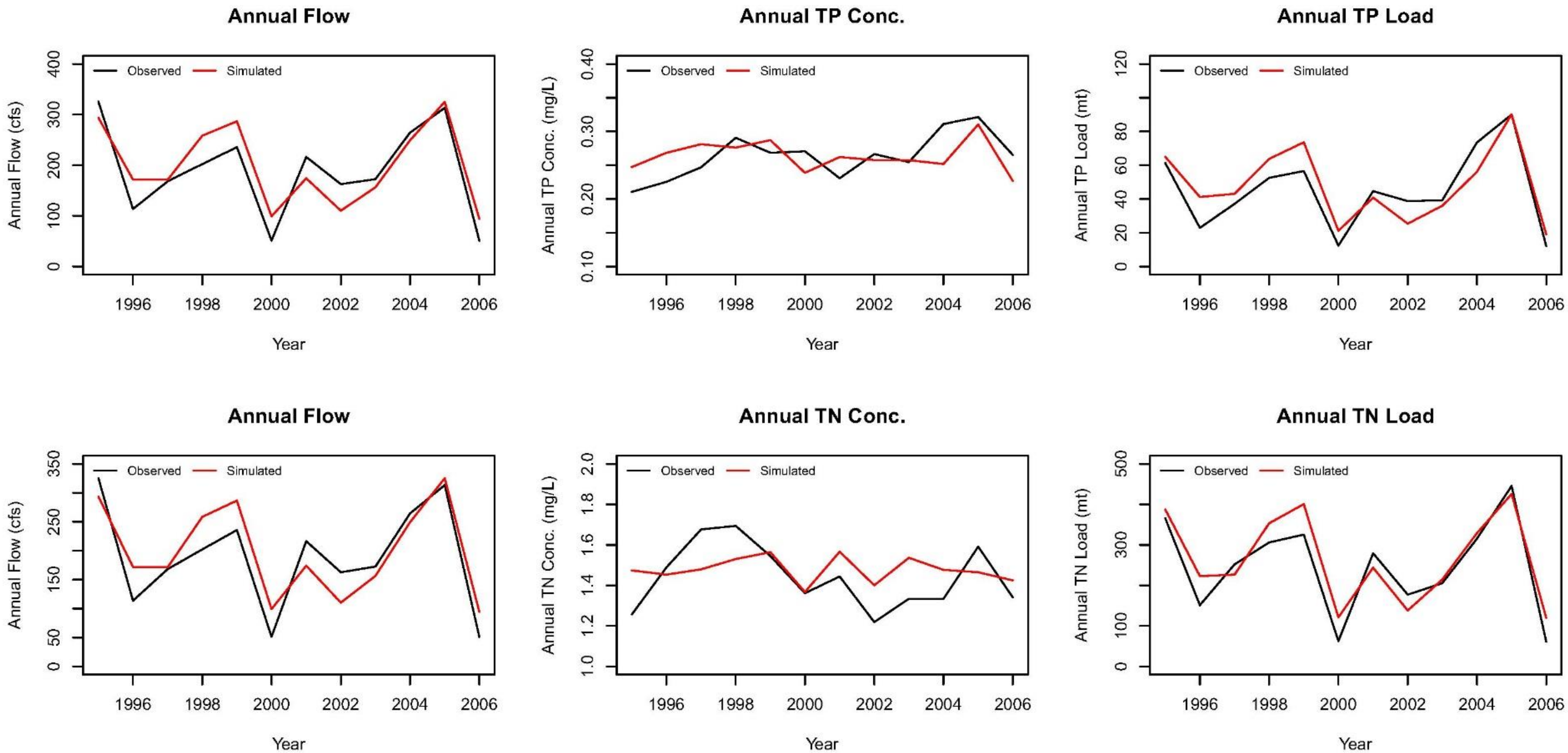
Very Good
Good
Fair
Poor

Water Quality Verification Ratings

Monitoring Station	Statistics	NH3	NO3	IP	DO	ON	TP	TN	CHLA
S-48	PBIAS(%)	0.1	-14.5	-9.4	9.5	-7.4	-15.3	-7.9	NA
	RRE (%)	13.0	20.1	22.9	15.0	13.6	17.7	13.7	NA
S-49	PBIAS(%)	-75.2	-58.7	-10.7	4.1	5.2	-22.4	-3.8	NA
	RRE (%)	29.9	20.5	20.9	17.4	18.2	19.9	24.8	NA
S-80	PBIAS(%)	-58.7	14.1	-8.0	8.0	-11.5	-26.2	-7.7	NA
	RRE (%)	15.2	21.1	15.6	15.8	22.9	27.2	24.6	NA
HR1	PBIAS(%)	4.5	-2.5	5.4	9.2	9.5	-5.5	5.5	9.8
	RRE (%)	22.8	18.1	15.6	16.0	20.0	18.3	21.6	16.8
SE01	PBIAS(%)	42.5	-7.8	-15.8	-1.2	12.6	-27.9	2.6	7.9
	RRE (%)	31.1	17.8	12.4	13.8	19.9	19.3	16.8	16.1

Very Good
Good
Fair
Poor

S-49 Nutrient Loading Comparison



Comparison plots of observed vs simulated flow, concentration, and load at S49

Nutrient Loading Calibration Ratings

	S-48		S-49		S-80	
Statistics	TP Load	TN Load	TP Load	TN Load	TP Load	TN Load
R^2	0.90	0.95	0.90	0.92	0.98	1.0
BIAS (metric tons)	7.5	-2.3	5.2	2.18	-22.3	-77.4
PBIAS (%)	10.9	-0.9	10.5	0.9	-19.3	-7.8
RMSE (metric tons)	13.8	32.2	9.7	35.3	39.7	132.5
RRE (%)	11.9	7.0	12.4	9.2	12.4	5.1

Very Good
Good
Fair
Poor

Nutrient Loading Verification Ratings

	S-48		S-49		S-80	
Statistics	TP Load	TN Load	TP Load	TN Load	TP Load	TN Load
R^2	0.84	0.83	0.91	0.90	1.0	0.99
BIAS (metric tons)	-12.0	-62.5	-10.6	-37.9	-26.9	3.9
PBIAS (%)	-24.0	-28.5	-26.3	-15.5	-23.7	0.36
RMSE (metric tons)	16.6	84.6	11.9	50.9	29.6	105.8
RRE (%)	21.1	25.6	24.3	16.8	12.8	4.4

Very Good
Good
Fair
Poor

Sensitivity Analysis

- The impact of diffusion is very minor in the St. Lucie canal and river system.
- Algal self-shading attenuation does not play a very sensitive role in the system
- Respiration rate is a very sensitive factor in phytoplankton kinetics. Determination of its value is critical in model development.
- Phytoplankton growth rate and non-algal light attenuation are critical in phytoplankton kinetics and nitrogen cycle, but does not appear to be for the phosphorus cycle.

Baseline Scenario Summary

- The comparison of simulated with measured data indicates that the model closely reproduced the patterns of the flow and captured the variation of nutrient dynamics.
  - The simulated daily, monthly, annual flows show good agreement with measured data. The monthly variation was well simulated with $R^2 \geq 0.82$, $-19.7\% \leq \text{PBIAS} \leq 6.7\%$, and $\text{RRE} \leq 8.2\%$.
  - The comparison of simulated and measured time series plots for the water quality data were generally in good agreement. The rating metrics in calibration and verification based on statistics PBISA and RRE for model performance were 86% good or very good, 9.7% fair, and 4.2% poor for daily data. The poor performance was observed for chlorophyll *a*, ammonia, and nitrate, mostly likely due to the lack of chlorophyll *a* Event Mean Concentration data, and extremely reactive ammonia and nitrate.
  - The comparison plots and evaluation statistics indicate that the model can simulate annual TN and TP loads reasonably well.

Acknowledgement

- Dr. Christopher Reed, URS (now AECOM)
- Dr. Yongshan Wan, EPA