Climate Change Impact on Freshwater Inflows to Estuaries:
A case study in South Florida Coastal Watersheds

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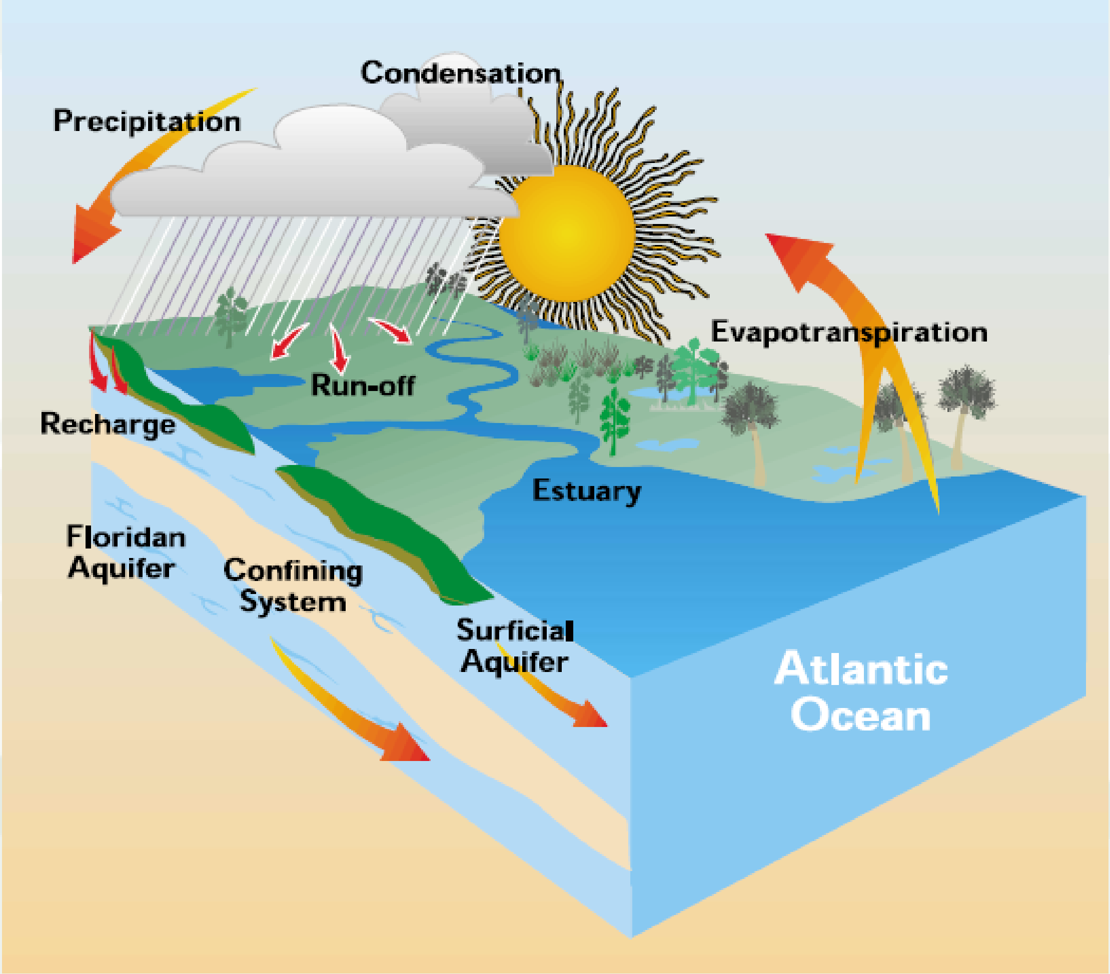
Objective

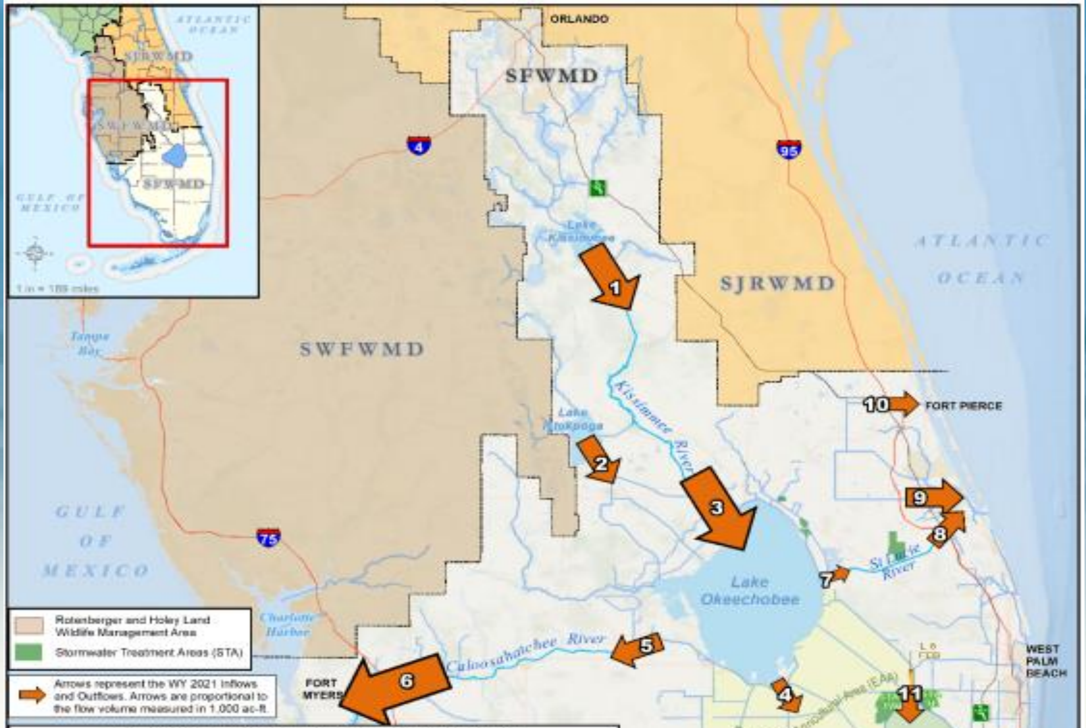
- To develop an integrated surface and groundwater modeling system that can serve as a decision support tool for environmental and water management operations, Sea level rise, climate and land use change impact assessments and, to implement alternative management strategies

Hydrology of South Florida



The hydrologic cycle in southern Florida

WY2021 major surface flow directions.

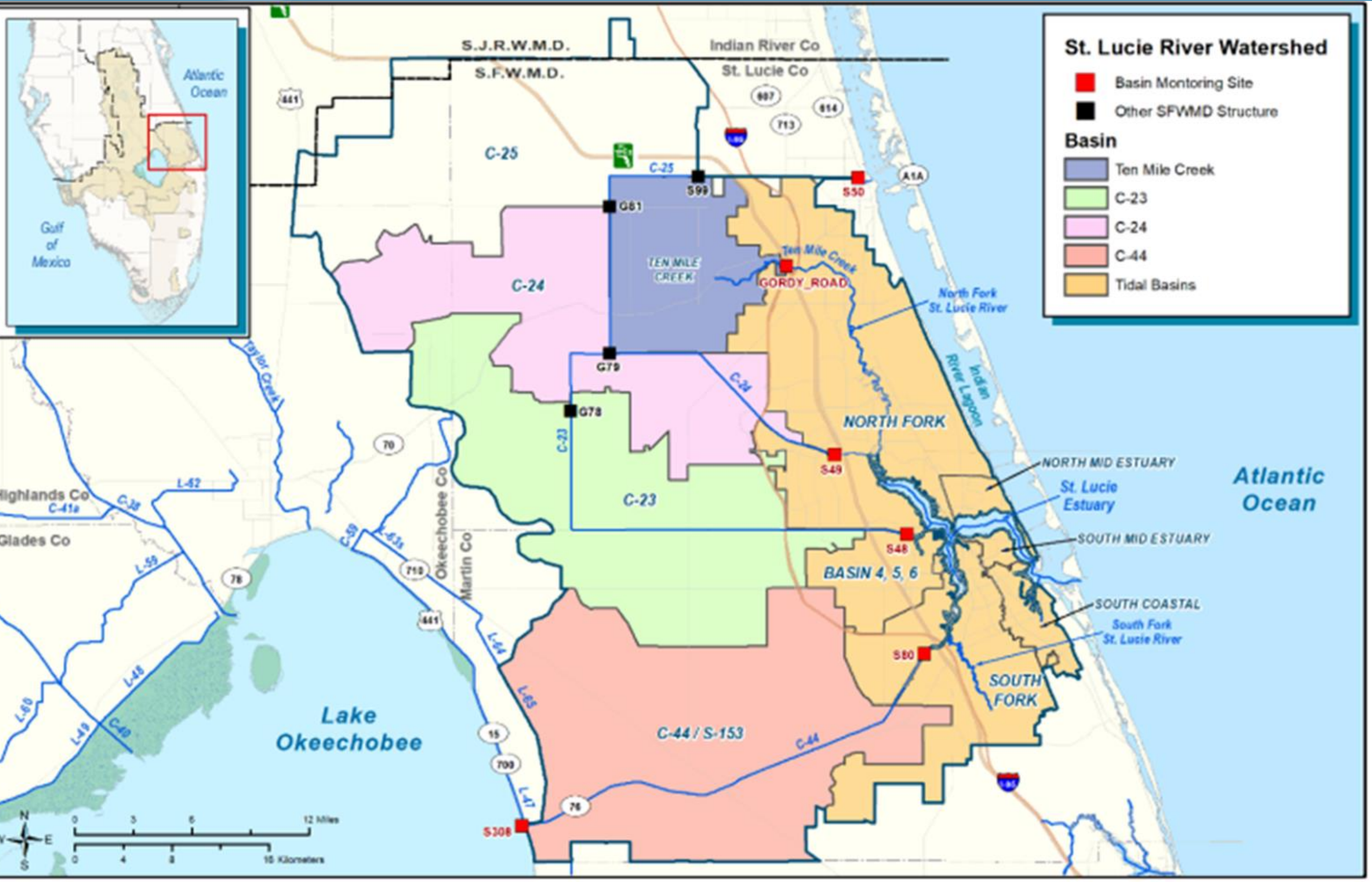


Water Year 2021: Major Surface Flow Directions (in 1,000 acre-feet)

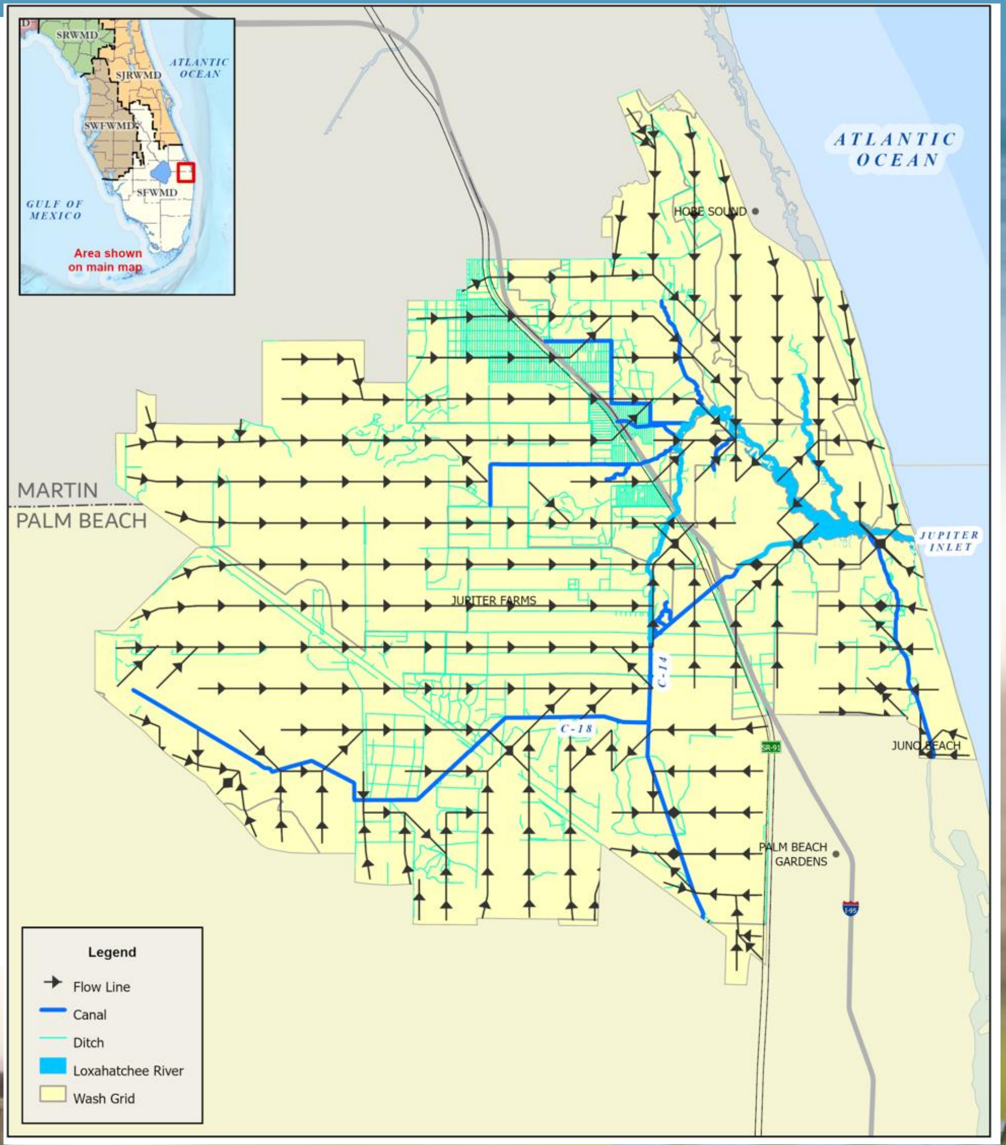
Map ID	Water Body		Total
1	Lake Kissimmee outflows		883
2	Lake Istokpoga outflows		460
3	Lake Okeechobee total inflows		1356
4,5,7	Lake Okeechobee total outflows		797
4	To south (S-351, S-352, and S-354)	239	
5	Caloosahatchee River inflow (S-77)	421	
7	St. Lucie River inflow (S-308)	117	
	Other outflows	20	
6	Caloosahatchee River outflow (S-79)		1818
8	St. Lucie River outflow (S-80)		315
9	North Fork of St. Lucie Estuary inflows (S-48, S-49, and Ten Mile		481
10	Upper East Coast C-25 canal outflow at S-50		230
11	WCA-1 inflows		257
	WCA-1 outflows		633
12	To WCA-2 via S-10s	415	
	To east	218	
12,13	WCA-2 inflows		1242
12	From WCA-1 via S-10s	415	
13	From STAs	827	
14,15	WCA-2 outflows		1275
14	To WCA-3 via S-11s	1071	
15	To east	204	
14,16,17a,17b	WCA-3 inflows		1933
14	From WCA-2 via S-11s	1071	
16	Northwestern (S-8, STA-5/6, S-140, and S-190)	550	
17a,17b	EAA-STA (S-150) and S-9s	311	
18a,19	WCA-3 outflows		1974
18a	To ENP and S-334	1758	
19	Other outflows	216	
18b,20	ENP inflows		2346
18b	Shark River Slough	1896	
20	Taylor Slough and Eastern Panhandle	450	

Source: SFER 2022

St. Lucie River Watershed



Loxahatchee River Watershed



Overview of Watershed Modeling

- Many hydrological and water quality models are developed to describe
  - hydrology
  - water quality
  - erosion and sedimentation processes
- Used as decision support tool to implement alternative management strategies for
  - water resources allocation
  - flood control
  - impact of land use and climate change and sea level rise
  - environmental pollution control
  - Total maximum daily load (TMDL), minimum flows and levels (MFL), Basin Management Action Plan (BMAP)

Climate change impact

- **A major effect of climate change is alterations in hydrologic cycles and water availability.**
- **Increased ET and changes in rainfall, has the potential to affect runoff, floods and droughts**

Climate change impact

- Watersheds are affected by climate changes that are altering the quantity, quality, timing and distribution of water.
- Coastal Florida is vulnerable to impacts from climate change,
  - temperature extremes, intensified storms, increased flooding and sea level rise.
  - threaten to degrade estuaries.

- Increased frequency and intensity of rainfall can lead to greater stormwater runoff, erosion, and sedimentation.
- decreased precipitation can also affect the salinity of coastal waters.
- Estuaries require a natural balance of freshwater and saltwater.

- **Rising sea levels will move ocean and estuarine shorelines by inundating lowlands, displacing wetlands, and altering the tidal range in rivers and bays.**

- **Storm surges resulting from more extreme weather events can increase the areas subject to periodic inundation.**

Modeling needs and possible WaSh applications

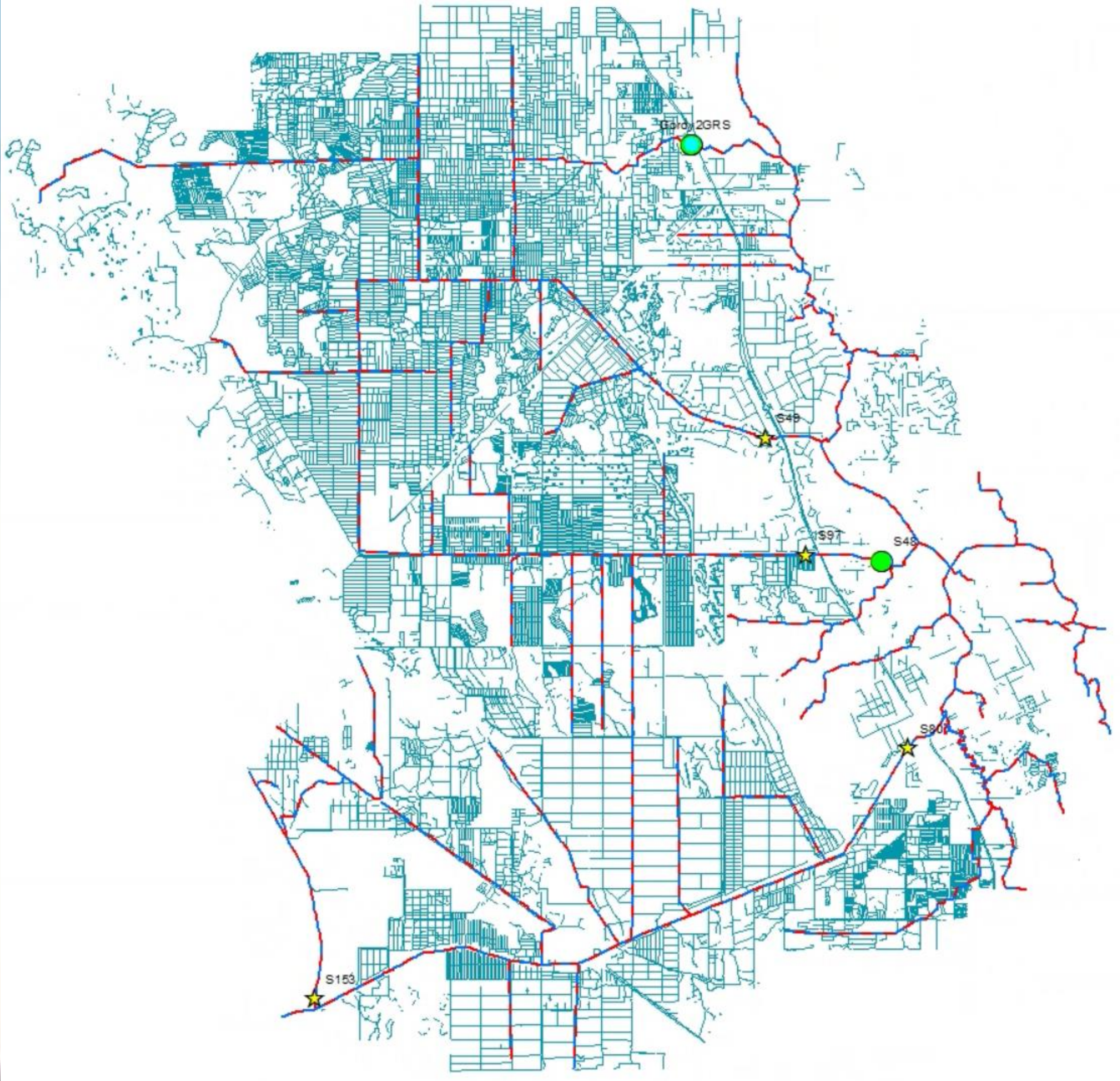
- Freshwater inflow to an estuary is critical for the estuary ecosystem management, such as salinity maintenance for ecosystem habitat.
- Inflow to the St. Lucie, Caloosahatchee and Loxahatchee river estuaries from their tidal basins has been identified as a major information gap in many water resources projects
  - establishment of MFL criteria
  - water reservation projects.

WaterShed Model (WaSh)

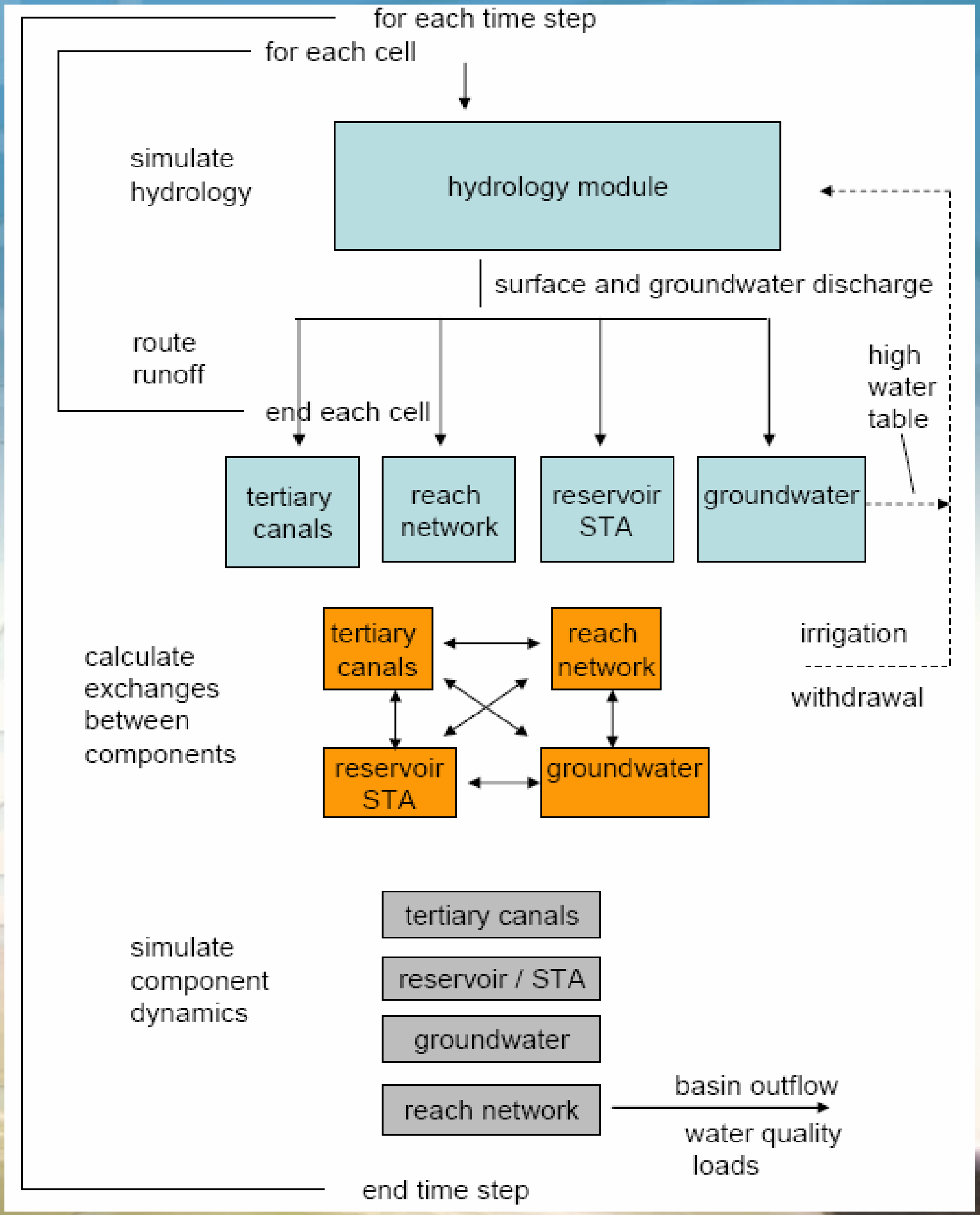
- **WaSh** is coupled watershed hydrologic, hydrodynamic and water quality model
- It includes representation of basic surface hydrology, groundwater flow, surface water flow, point sources and losses, and water quality fate and transport.
- The WaSh model is based on restructuring HSPF

WaSh for a unique ecosystem

- The model is applicable for an area which has unique hydrologic features involving:
  - dense drainage canal systems,
  - high water tables, and
  - multiple irrigation sources typical of South Florida.



Flow Chart for the WaSh Model



Model computations are divided into four groups:

(1) Hydrology calculations;

(2) Cell discharge routing;

(3) Component interactions;

(4) Individual component dynamics.

Water Quality simulation has two options:

(1) Basic Water Quality - simulation of 5 constituents.

(2) Advanced Water Quality - simulation of 8 constituents.

Source: URS, 2008

Cell Discharge Routing and Channel flow

Surface Flow Routing: Chezy-Manning Equation

$$q = \frac{1.486}{n} h^{5/3} S^{1/2} \quad Where \quad h = 1.6\frac{D_e}{L}, \quad D_e = \frac{0.000818 i^{0.6} n^{0.6} L^{1.6}}{S^{0.3}}$$

Interflow Flow Routing: Linear reservoir routing method

$$q = f(p_{recession}, q_{in}, S_{storage})$$

Channel Flow: Saint Venant Dynamic Wave Routing

$$\frac{\partial w_r h_r}{\partial t} + \frac{\partial q_r}{\partial s} = Q_{io}$$

$$\text{where} \quad Q_{io} = \sum_{i,j} Q_{cell} + Q_{re} + Q_e + Q_{c-r} + Q_{r-res} + Q_{r-gw}$$

$$\frac{\partial q_r}{\partial t} + \frac{\partial u q_r}{\partial s} + g w_r h_r \frac{\partial h_r}{\partial s} = -w_r \tau_b - g w_r h_r \frac{\partial \eta_r}{\partial s}$$

Groundwater Flow: Diffusive Wave Routing

$$n\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(K_x (h - h_c)\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y (h - h_c)\frac{\partial h}{\partial y}\right) + S_i - S_e + Q_{c-gw} + Q_{r-gw} + Q_{res-gw}$$

Reservoir Flow: Mass Balance

$$\frac{\partial V_R}{\partial t} = \sum Q_{cell} - Q_{ext} + Q_{io} + R\,A_R - E\,A_R$$

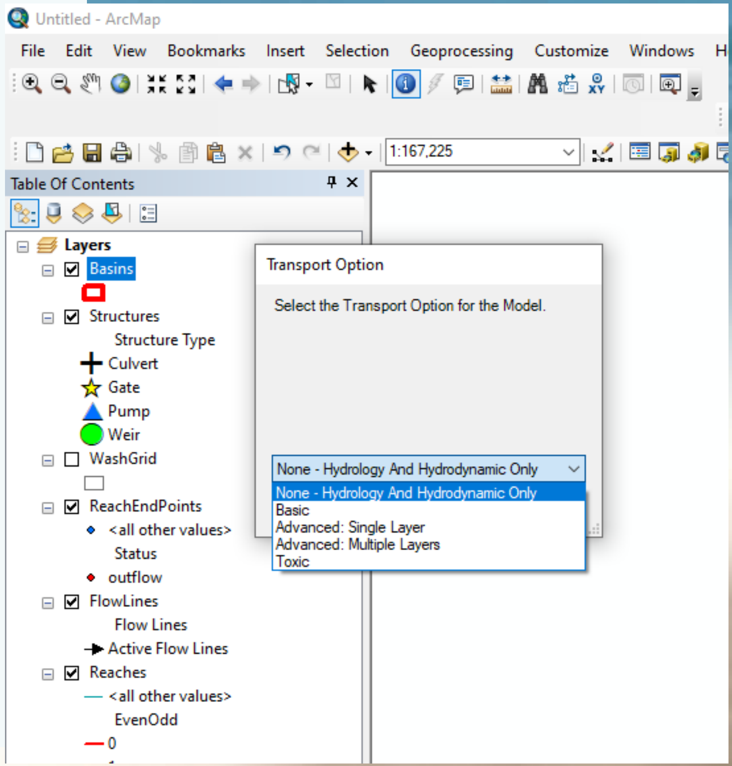
Water Quality Module

➢ Basic Water Quality

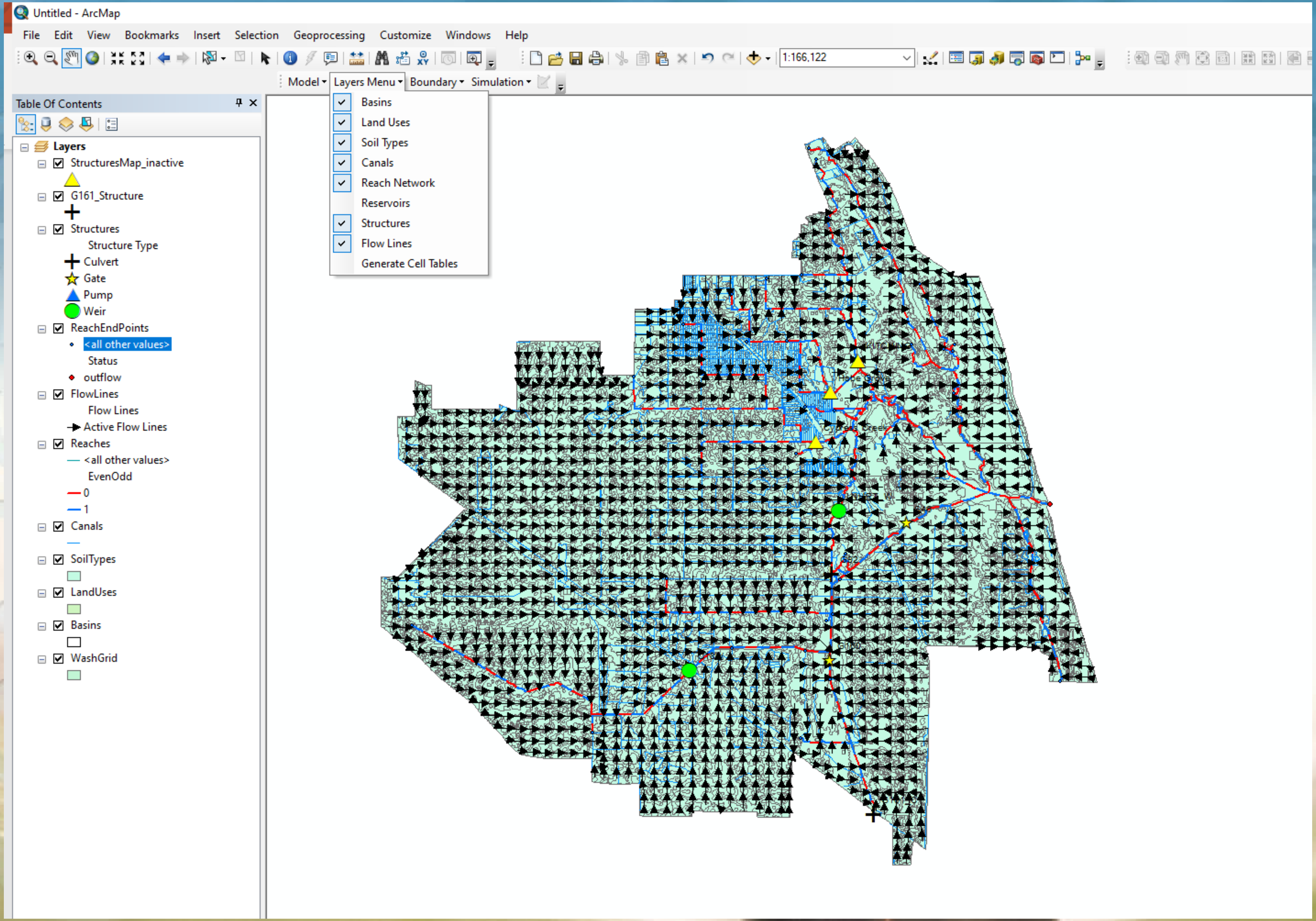
- TSS, PN, PP, SN, SP
- Transport is modeled using mass conservation and first-order decay/settling through canal, reach and reservoir system

➢ Advanced Water Quality

- NH_4^+-N, NO_3-N, IOP, Phytoplankton C, CBOD, DO, ON, OP.
- Transport is modeled using mass conservation
- In-stream processes is simulated by non-linear kinetic routing from WASP model.



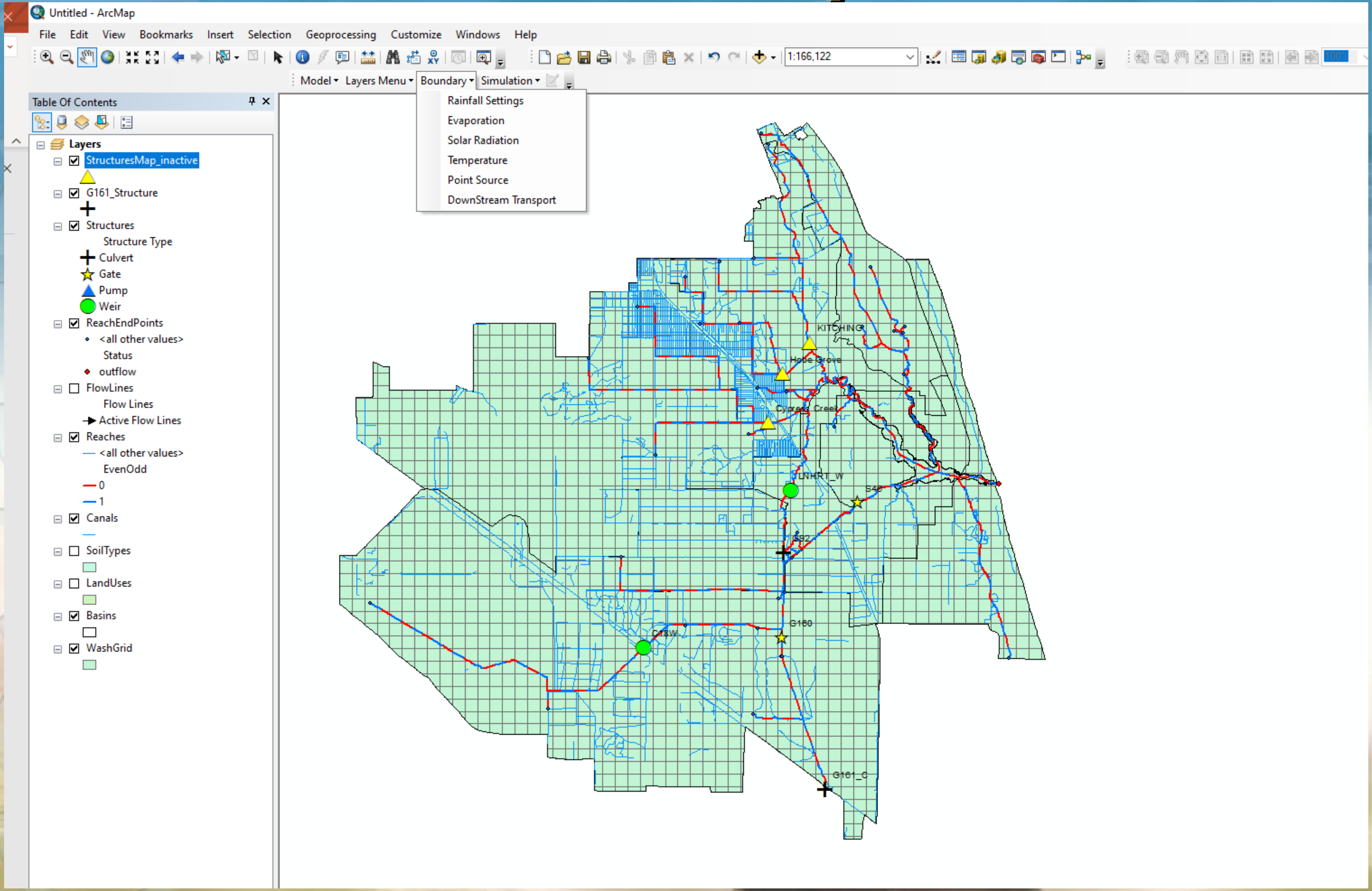
Data needs for the WaSh model



Geospatial Layers

- Basin and sub-basin boundary
- DEM
- Land use
- Soil
- Canals
- Reach Network
- Reservoirs
- Structure

Boundary Conditions

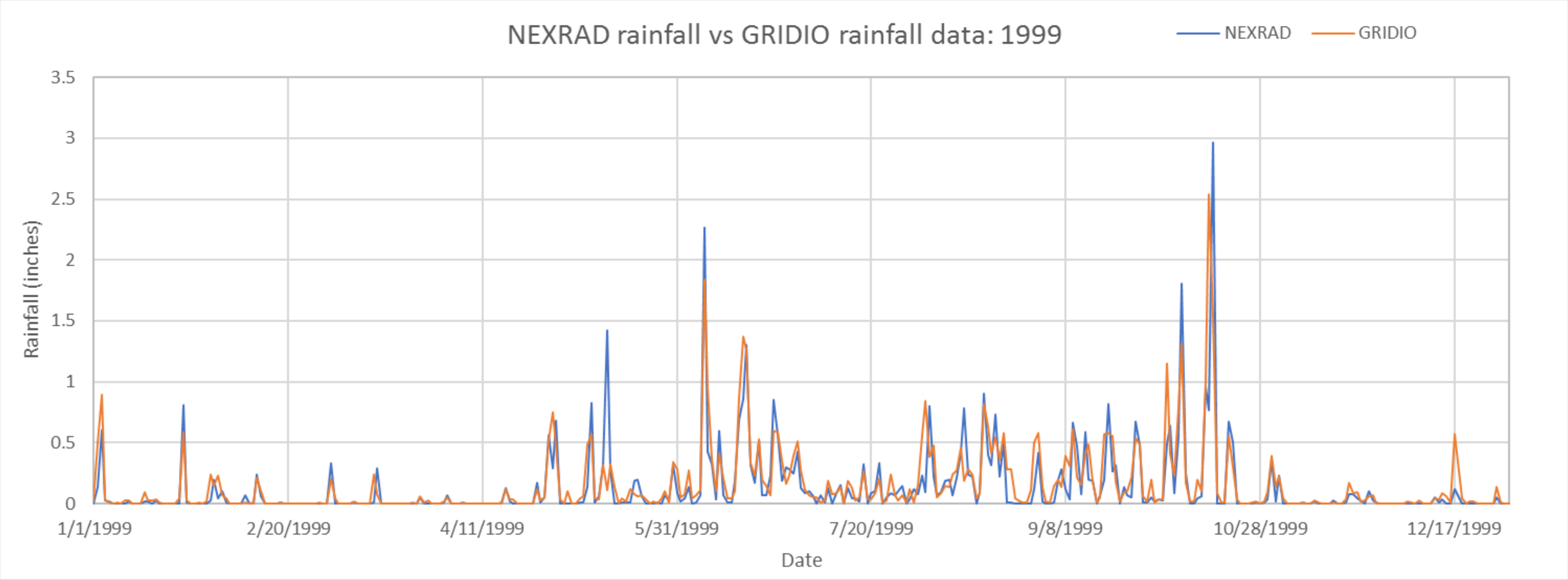


- Rainfall
- Evaporation
- Point Sources and Sinks
- Water Temperature
- Solar Radiation
- Tidal Elevation

Required input data for Hydrology

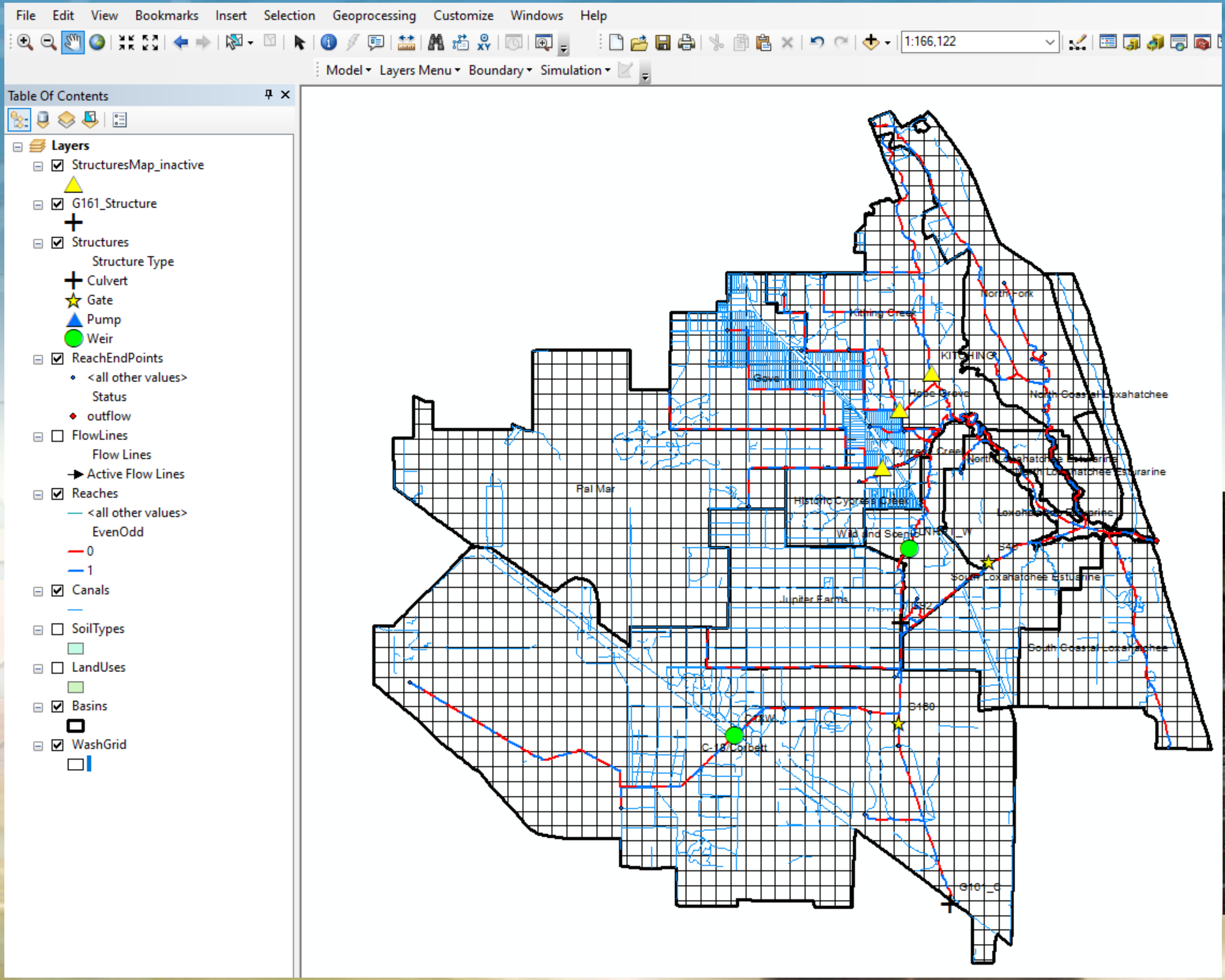
- Hydrology modeling in WaSh is dependent on accurate representation of rainfall and evapo-transpiration.

- The WaSh model can operate using NEXRAD/GridIO (2X2) rainfall data.
  - NEXRAD Doppler Radar data available in 2 by 2 km grid cells across the State of Florida, 1996-present
  - The GridIO (2X2) data covers a majority of the southern portion of Florida in a 2X2 grid and is available from 1965-2000



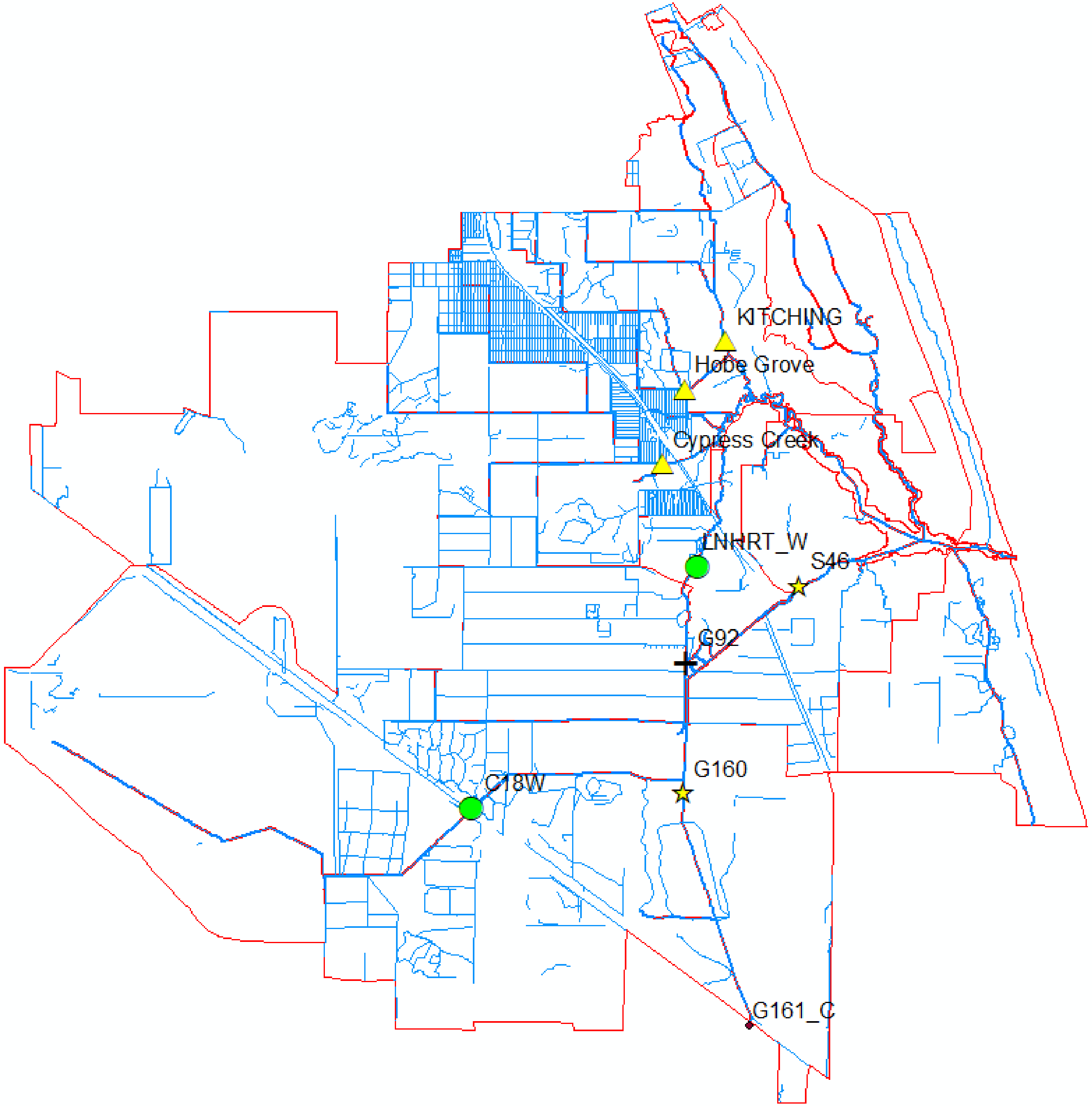
Source: SFWMD 2018

Lox model grid, sub-basins boundaries & reach/river segments



Model Grid
2000 ft x 2000ft

DEM 4ft resolution



Structure locations

S46 - maintains optimum upstream water control stages in Canal 18 and discharges runoff into the South Fork of the Loxahatchee River.

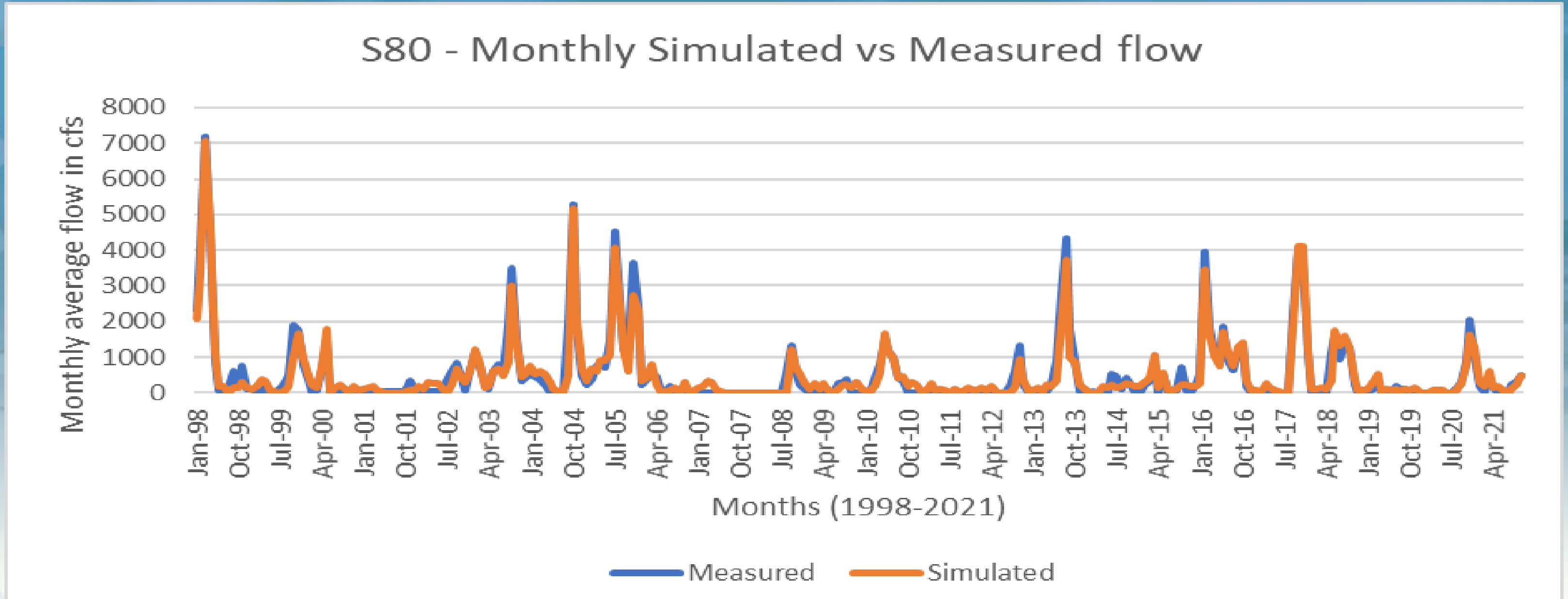
G92 - to divert flows from the C-18 canal to the C-14 canal then to the NWF.

Lainhart Dam – allows flows come from local runoff and G-92 inflows to the headwaters of the NWF

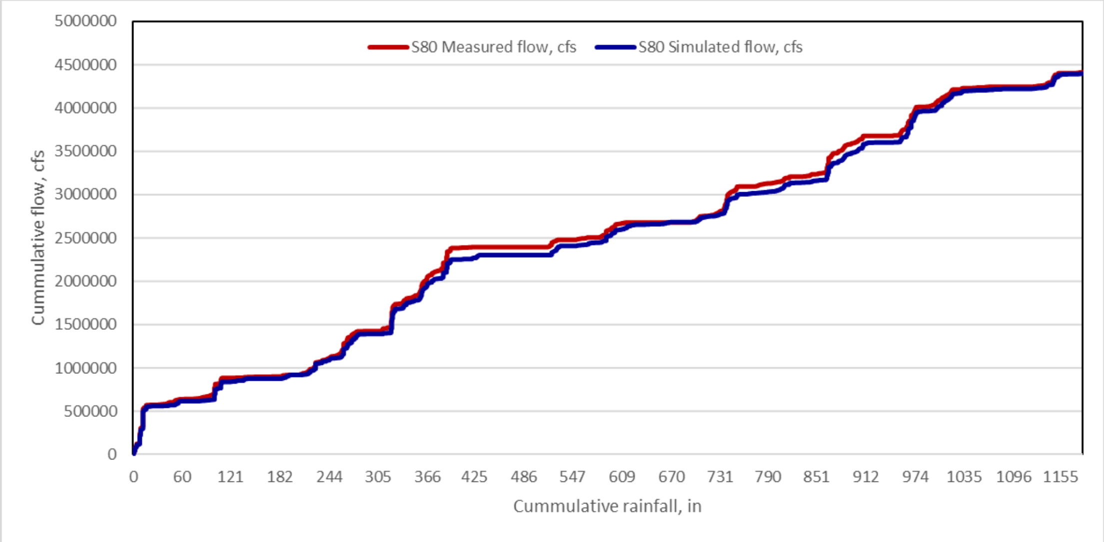
G160 - enhance delivery of the MFL to the Northwest Fork of the Loxahatchee River and to improve environment in the C-18 Basin.

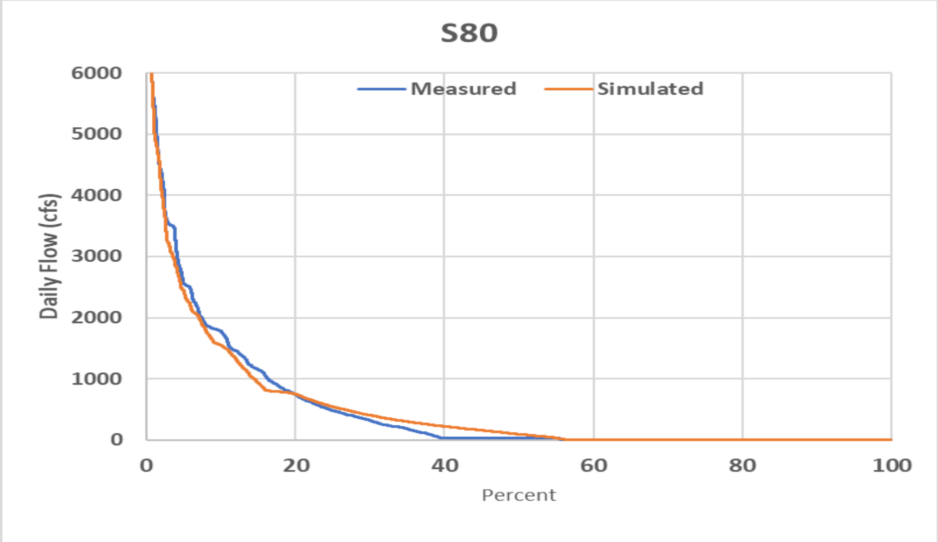
G161 - allows flow from the Grassy Waters Preserve northward into the C-18 extension.

Model calibration and validation plots at S80 station (1998–2021):



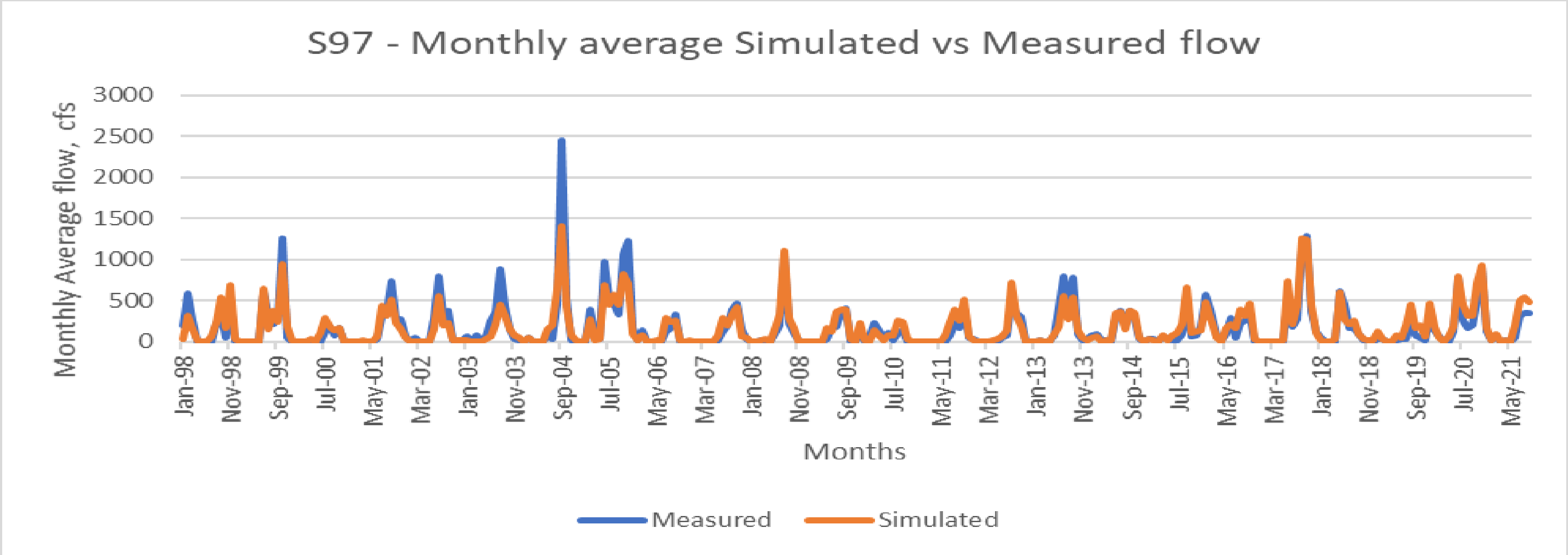
R^2 = 0.94
NSE = 0.93
(Nash-Sutcliffe Coeff)

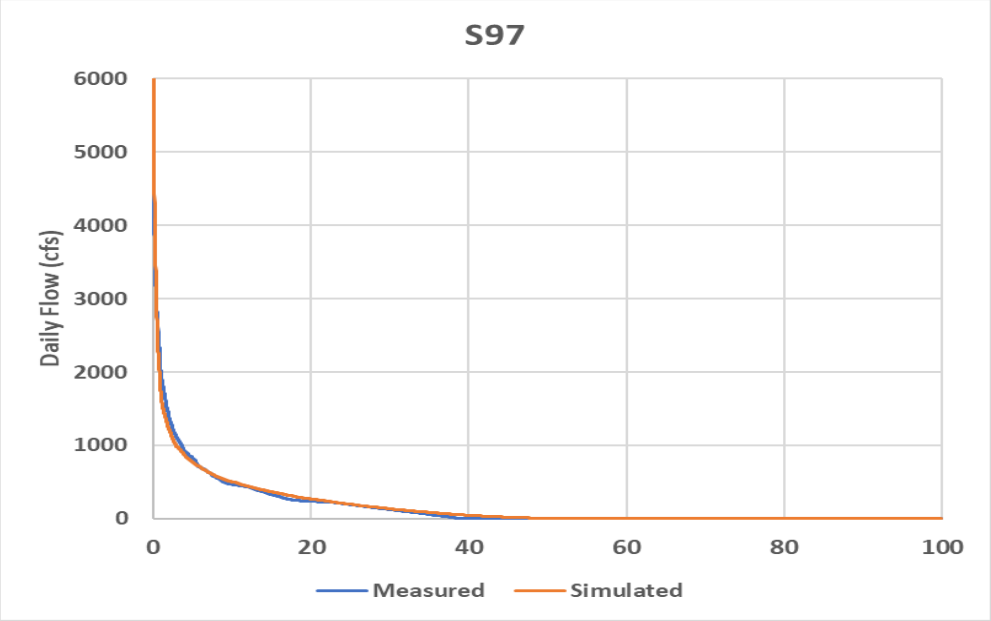




Daily flow distribution at S80 structure

Double Mass curve at S80 structure





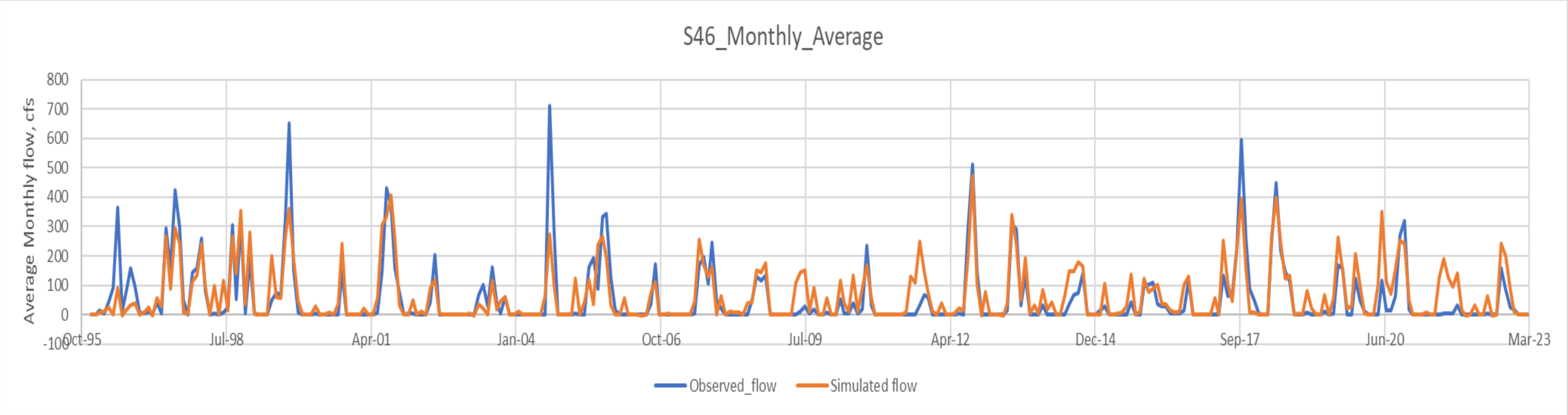
Daily flow distribution at S97 structure

Sub-Basin	Measured flow, cfs	Simulated flow, cfs	Difference-%	R2		NSE	
				Daily Simulation		Monthly Simulation	
S80	510.05	508.03	-0.4	0.85	0.83	0.94	0.93
S97	168.25	173.25	3	0.63	0.6	0.83	0.76
S49	172.89	169.92	-1.7	0.63	0.61	0.85	0.78
S48	186.94	175.74	-6	0.63	0.6	0.83	0.75

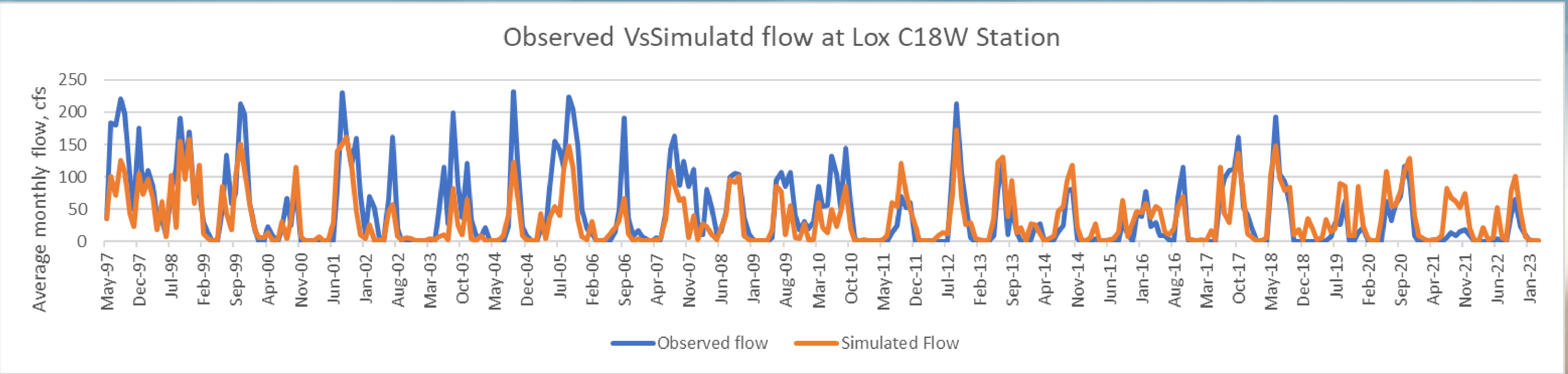
Loxahatchee WaSh model default Simulation outputs

Observed and simulated flow at S46 Station (1996 – 2023)

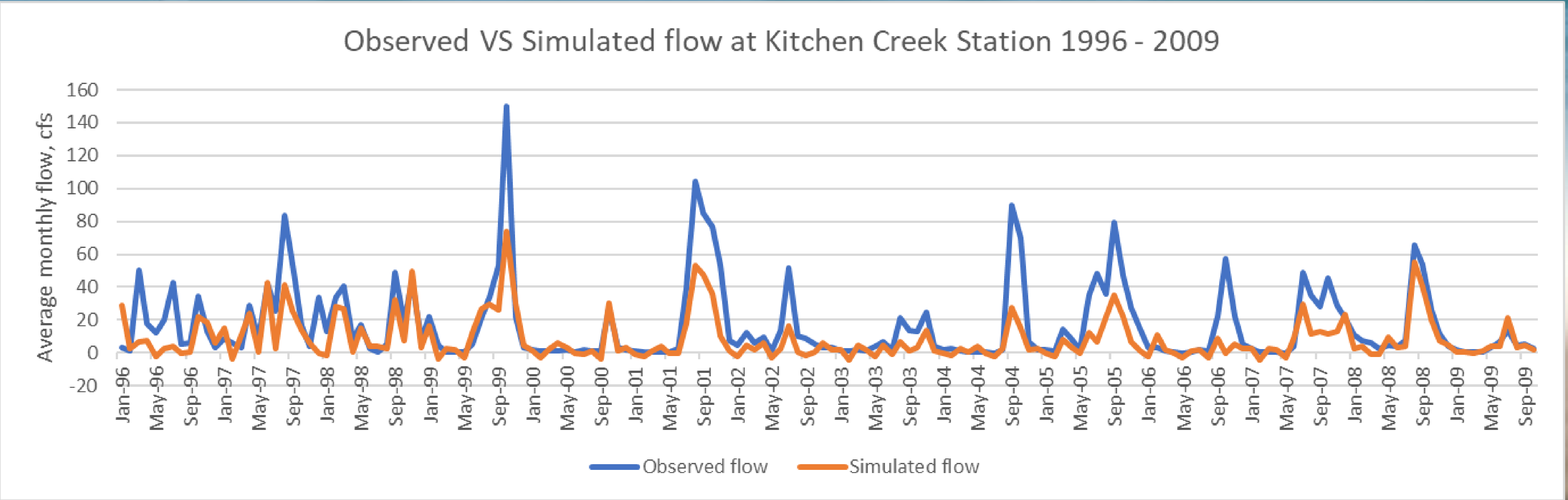
R^2 = 0.7
NSE = 0.7
(Nash-Sutcliffe Coeff)



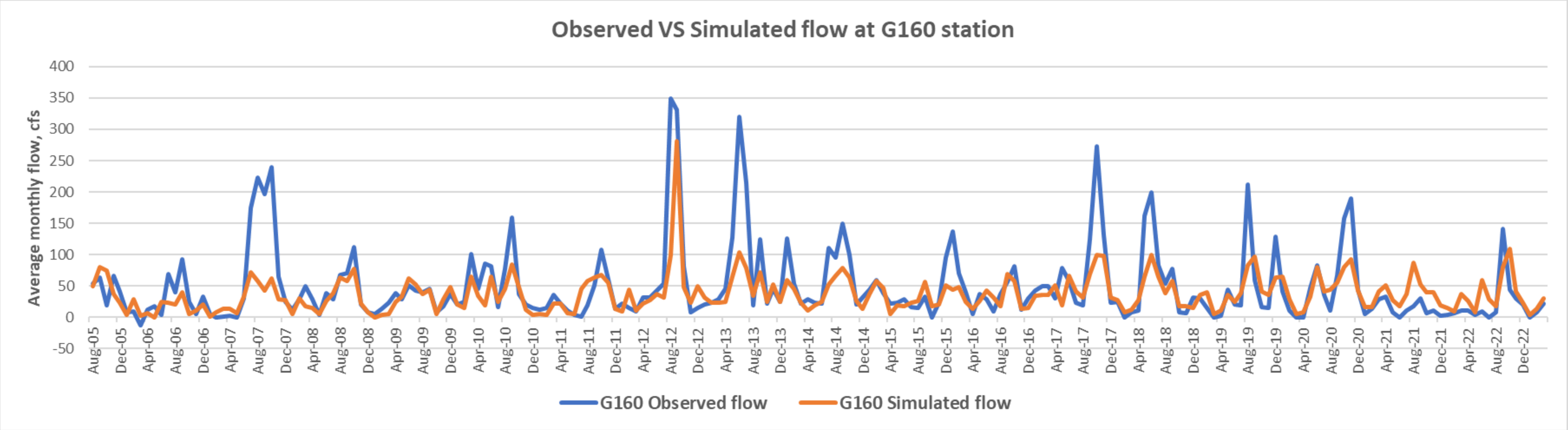
Observed and simulated flow at C18W Station (1996 – 2023)



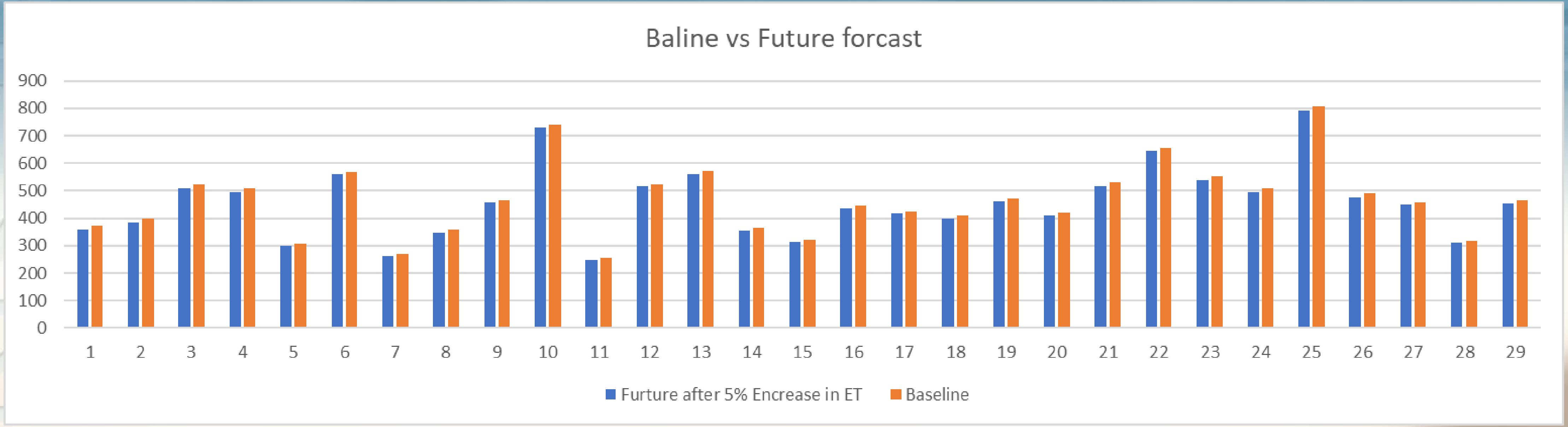
Observed and simulated flow at Kitchen Creek Station (1996 – 2009)



Observed and simulated flow at G160 Station (1996 – 2023)



Five Percent ET reduction Scenario, Constant rainfall



2.4% reduction in freshwater inflow from Tidal Basin

Model Applications

- Simulation of freshwater inflows - gauges and ungauged basins
- MFL and TMDL
- BMAP
- Assessment of climate change impact
- Assessment of land use change impact and watershed management scenarios
- Sea level rise impact
- Watershed Hydrological Water Balance
- Water Balance components for wet and dry years
- Spatial Distribution of Hydrological Processes

CONSERVE

Thank You