Watershed Modeling and Operation Optimization

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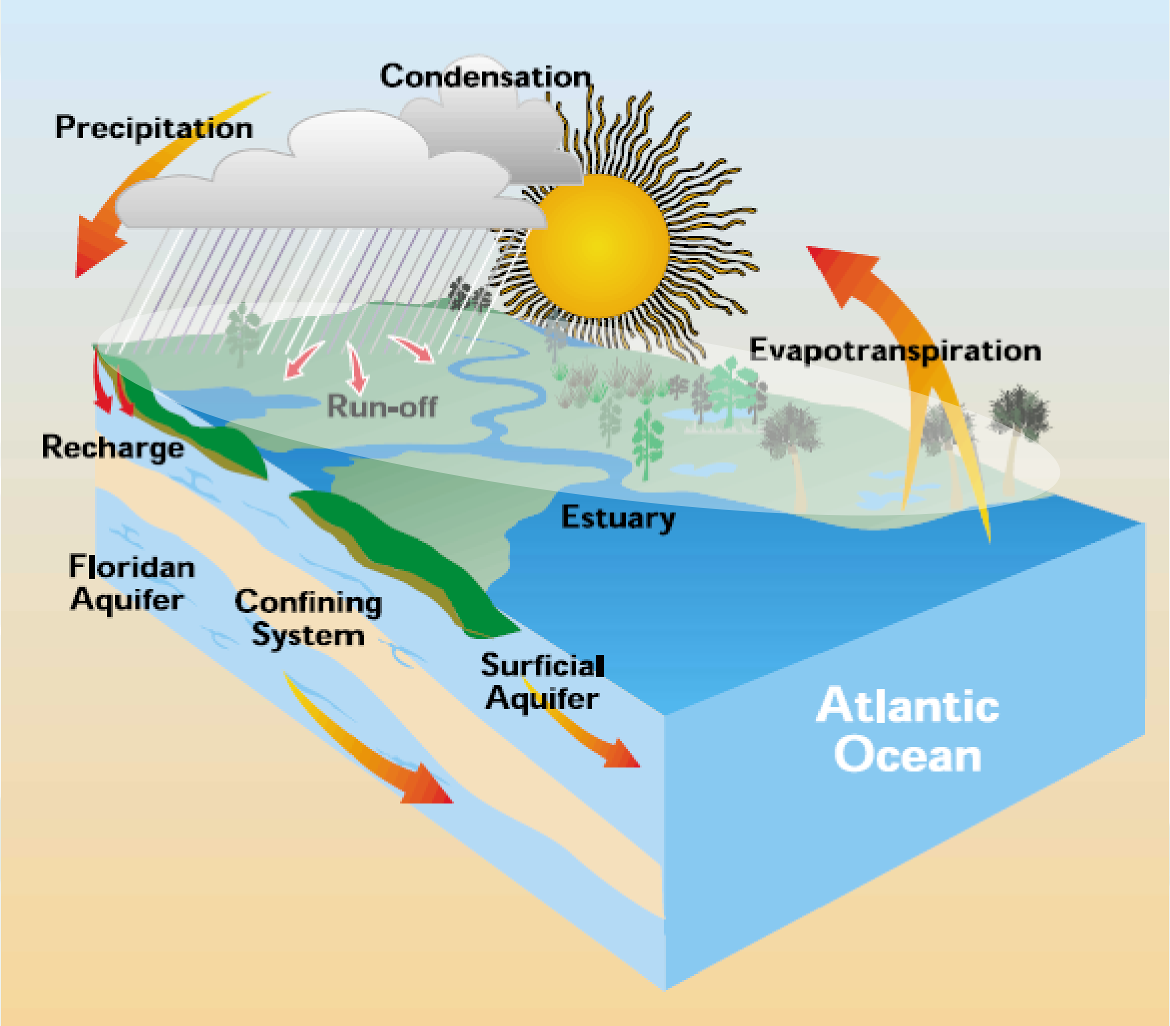
Watershed Modeling

Watershed modeling is to simulate natural processes of the flow of water, sediment, chemicals, nutrients, and microbial organisms within watersheds, as well as quantify the impact of human activities on these processes.



The hydrologic cycle in southern Florida

Watershed Modeling History

Before 1960s, watershed modeling without watershed model

1966, Stanford Watershed Model (SWM), Crawford and Linsley

1970s and 1980s, proliferation period, conceptual lumped-parameter models

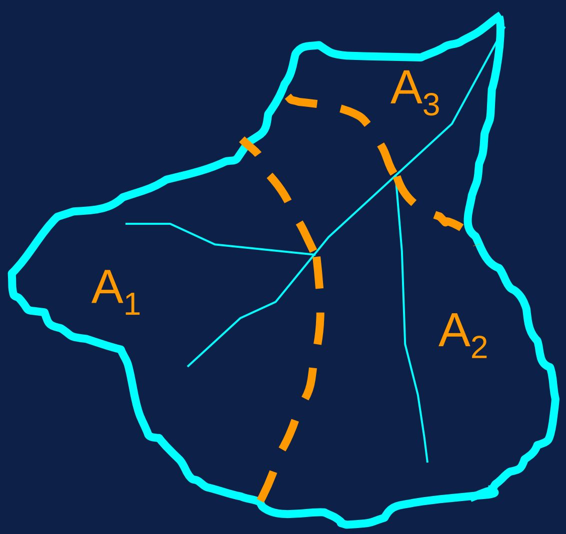
- National Weather Service (NWS) River Forecast System, 1973, Burnash et al.
- Tank model, Sugawara et al., 1976
- TOPMODEL, 1979, Beven and Kirby
- Xin'anjiang Model, 1973, Zhao
- Hydrologic Simulation Program – Fortran (HSPF), 1970s, Bicknell et al.
- Storm Water Management Model (SWMM), 1971, Metcalf & Eddy

Since 1990s, integrated distributed physically based model development

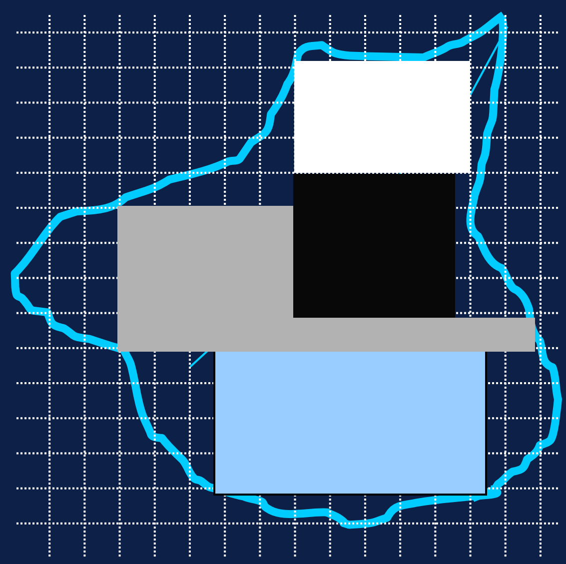
- System Hydrologique Europeen (SHE), 1986, Abbott et al.
- Gridded Surface and Subsurface Hydrologic Analysis (GSSHA) model, 2002, Ogden
- WAterSHed Systems of 1-D RF, 2-D OF, and 3-D GW (WASH123D), 2004, Yeh
- HEC Hydrologic Modeling System (HEC-HMS), USACE-HEC
- WaterShed Water Quality Model (WaSh), SFWMD/URS
- Regional Simulation Model (RSM), SFWMD

Watershed Model Development Trends

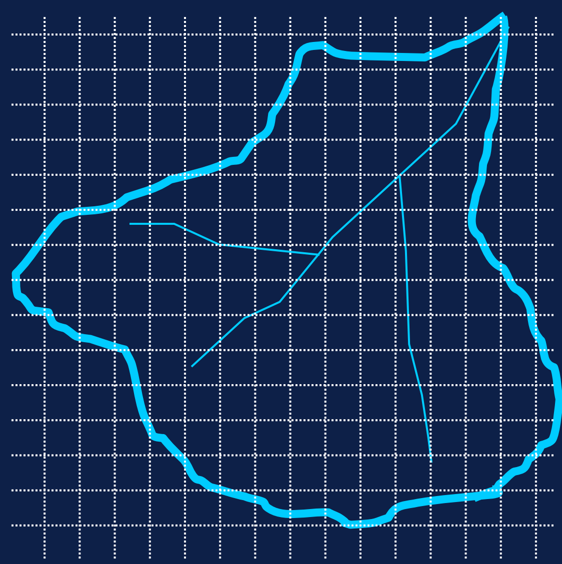
Lumped
Parameters assigned to each subbasin



Semi-Distributed
Parameters assigned to each grid cell, but cells with same parameters are grouped



Fully-Distributed
Parameters assigned to each grid cell

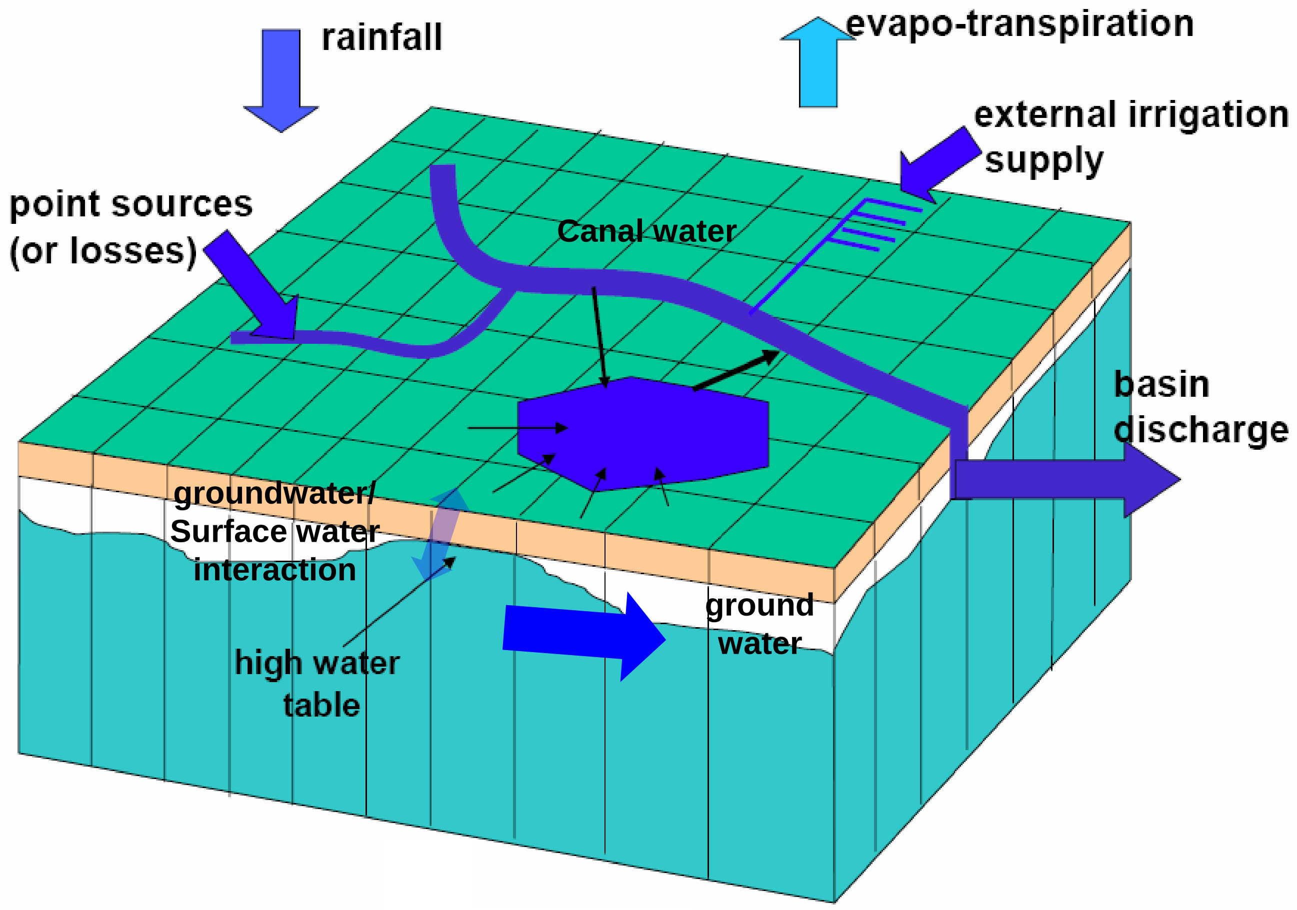


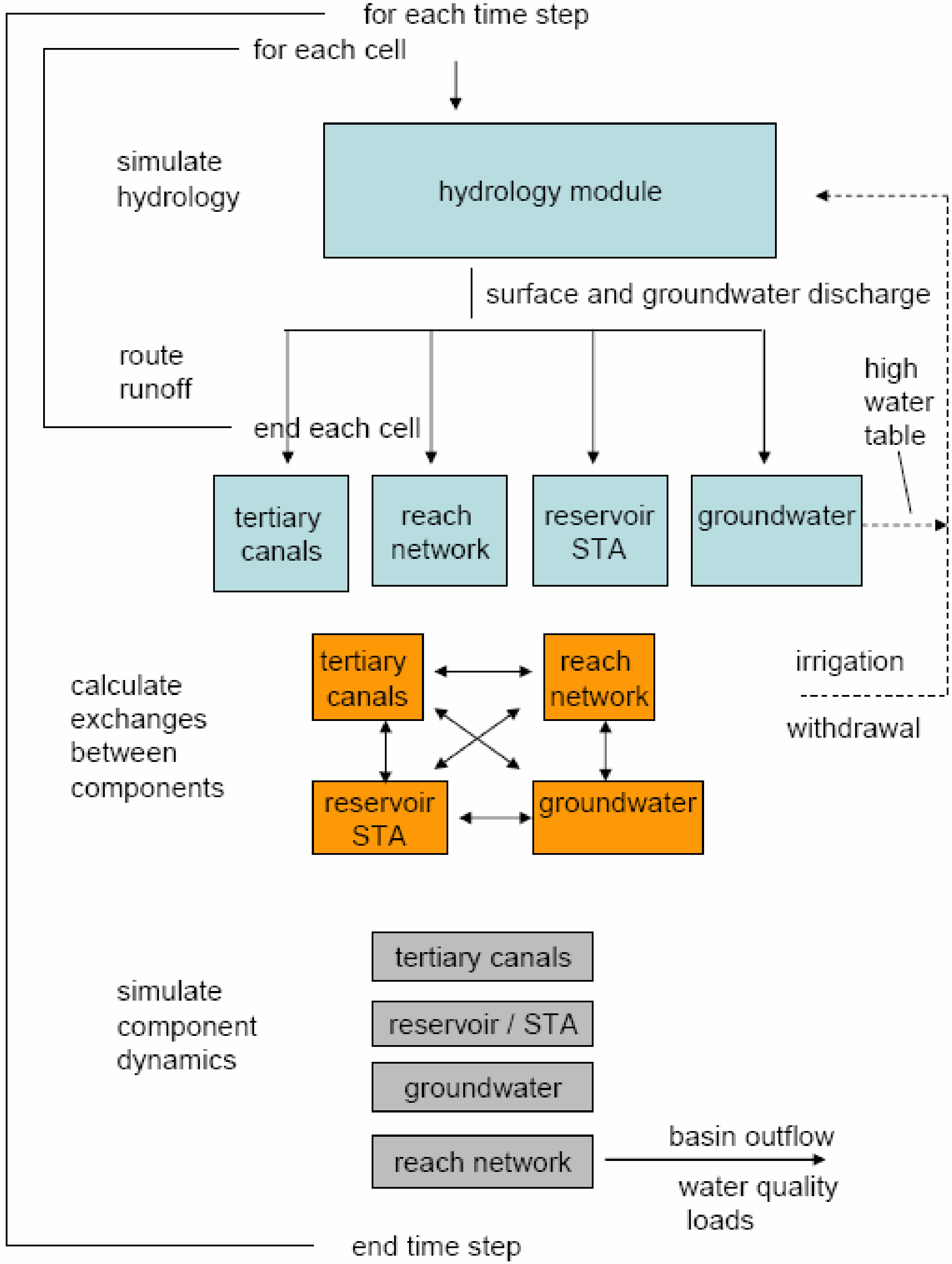
1960s – 1980s

1980s – 1990s - Present

Flow control structures
Agriculture
Urbanization
Natural Land
St. Lucie River & Estuary
St. Lucie Canal (C-44)
Lake Okeechobee
Caloosahatchee River & Estuary
Caloosahatchee River (C-43)
Everglades Agricultural Area
C-51
C-16
LNWR (WCA1)
Hillsboro Canal
WCA 2A
C-14
2B
WCA 3A
C-11
C-9
3B
C-4
C-103
Everglades National Park
Florida Bay

Watershed Water Quality Model (WaSh)





Flow Chart for the WaSh Model

The model computations are divided into four groups:

(1) Hydrology calculations;

(2) Cell discharge routing;

(3) Component interactions;

(4) Individual component dynamics.

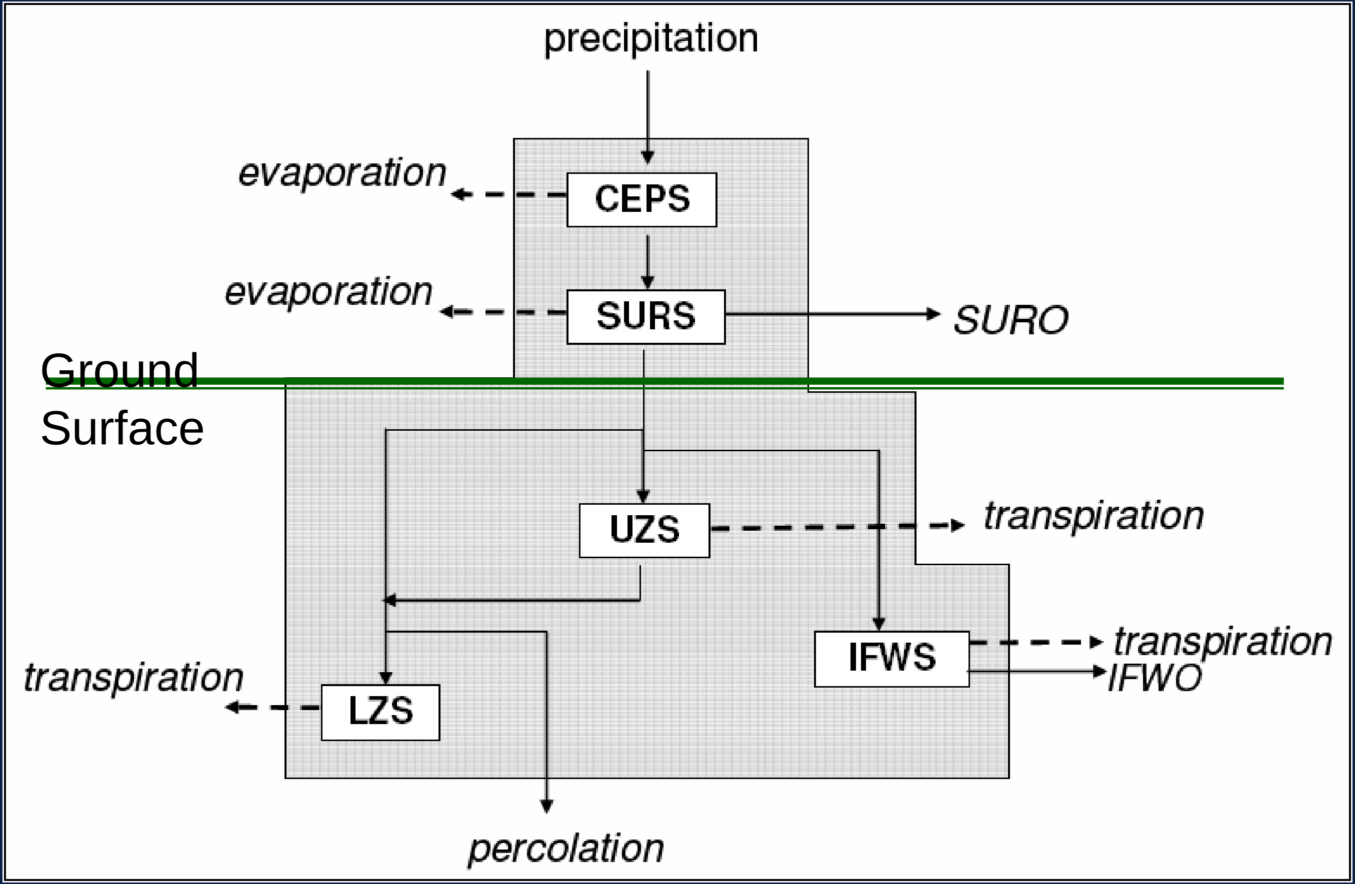
Water Quality simulation has two options:

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

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

Hydrology Module

- Based on Hydrologic Simulation Program – Fortran (HSPF, EPA) algorithms



Grid Cell Discharge Routing Module

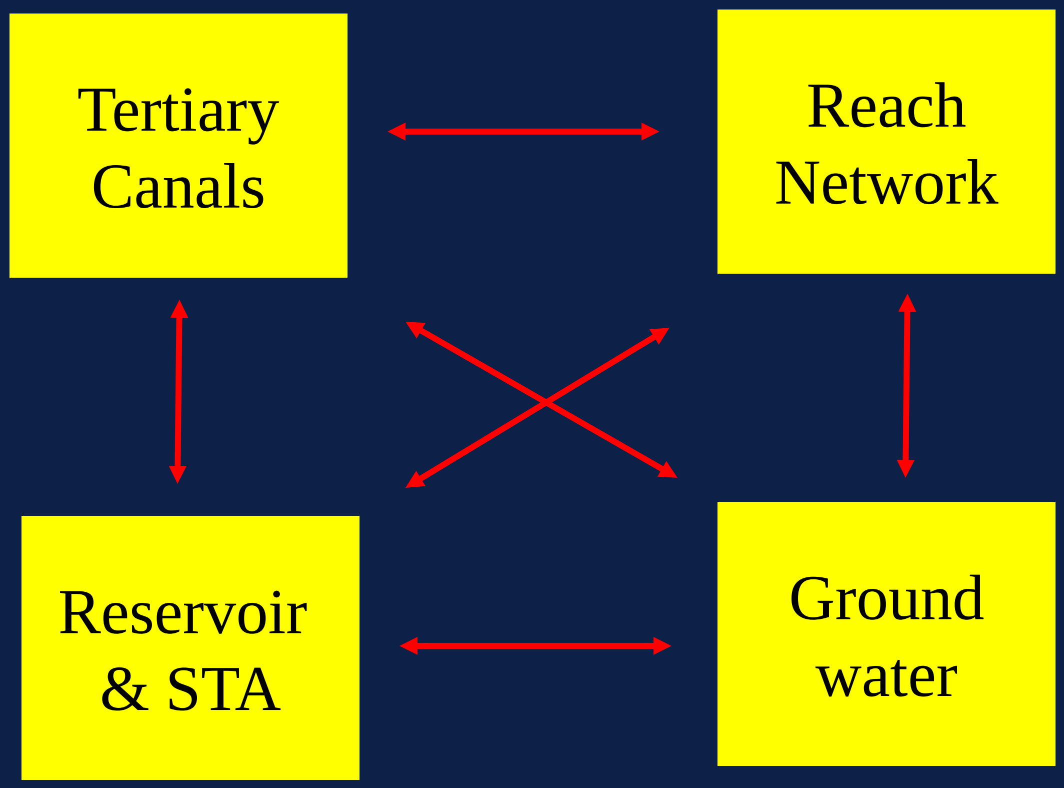
Surface Flow Routing: Chezy-Manning Equation

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

Interflow Flow Routing: Linear reservoir routing method

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

Component Interactions



Channel Flow, Groundwater Flow, and Reservoir Flow Module

Channel Flow: Saint Venant Dynamic Wave Routing

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

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

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

Solved by semi-implicit finite difference method

Groundwater Flow: Diffusive Wave Routing

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

Solved by explicit finite difference method

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

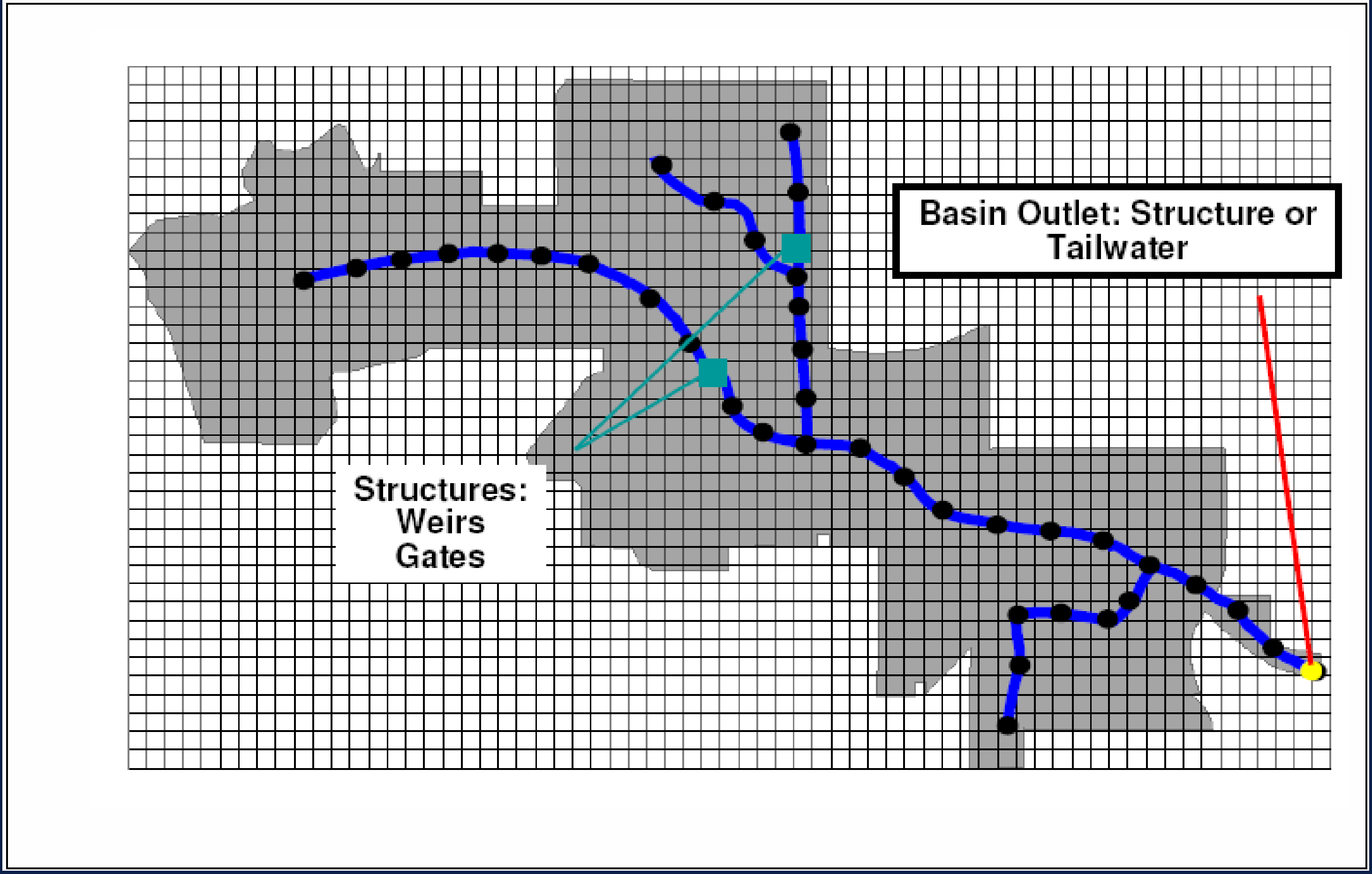
(1) Basic Water Quality

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

(2) Advanced Water Quality

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

Grid Cells and Reach Network

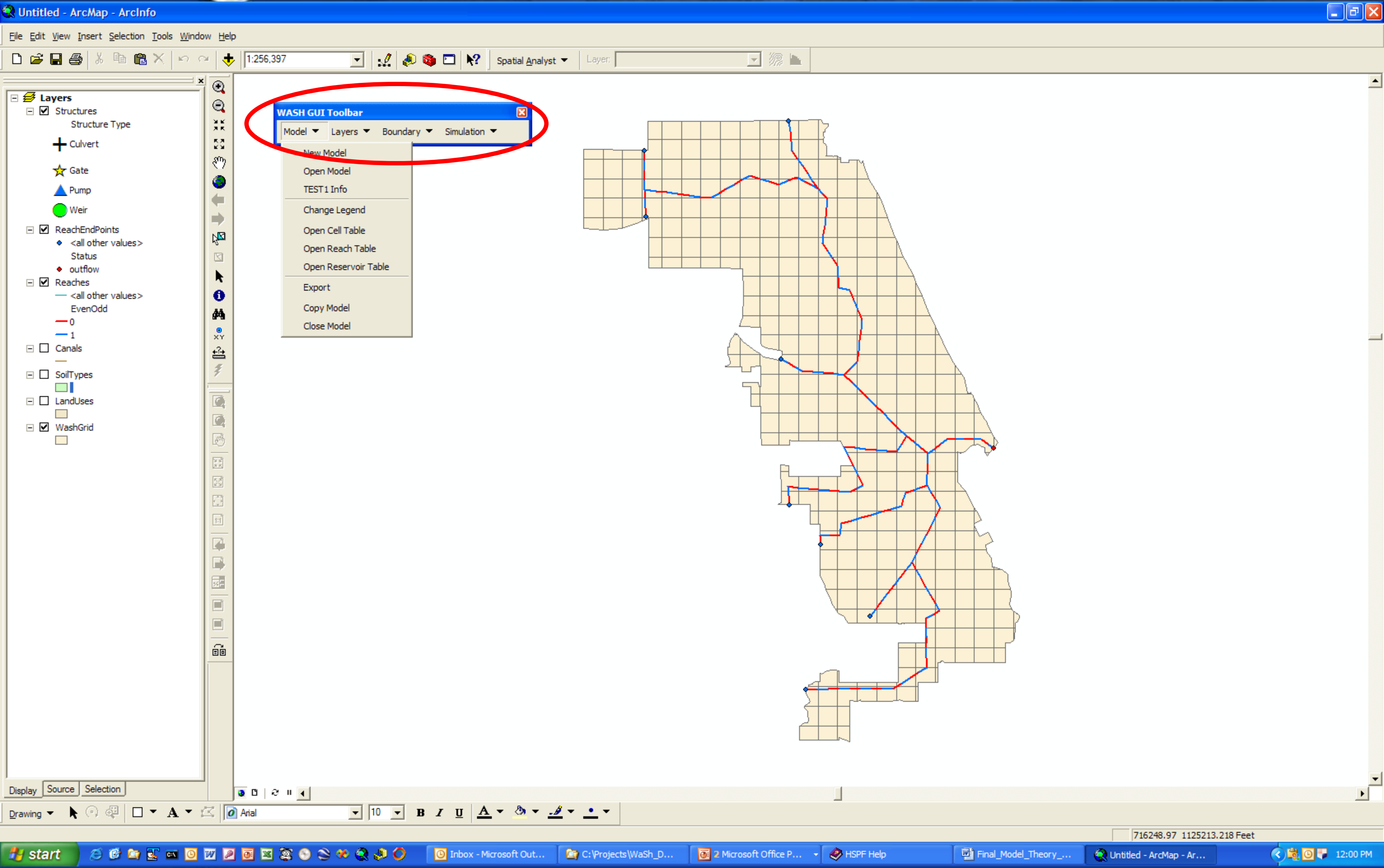


Data needs for the WaSh Model

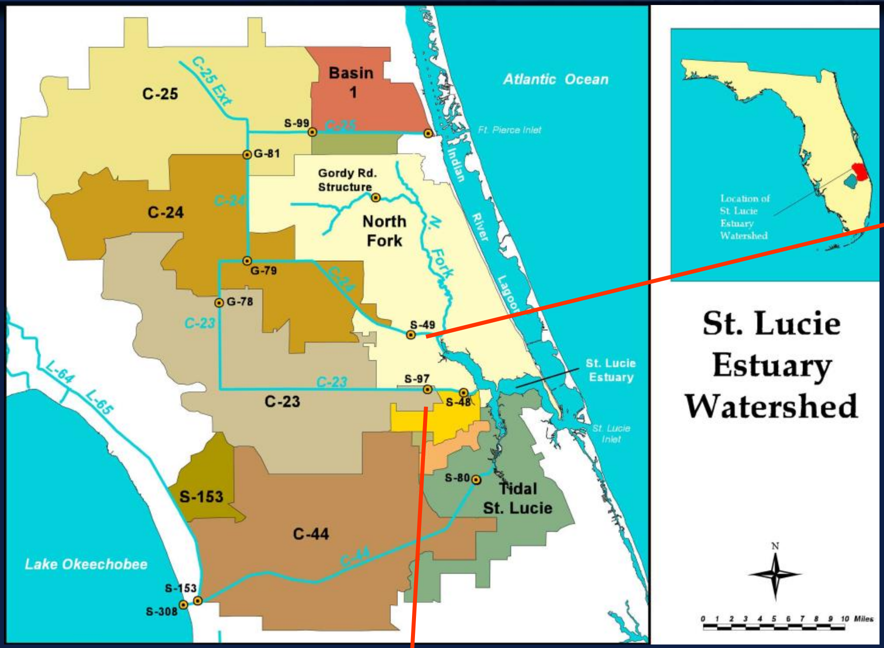
- Meteorological data
- Land use land cover data
- Soil data
- Hydrologic data
- Hydrogeologic data
- Boundary condition

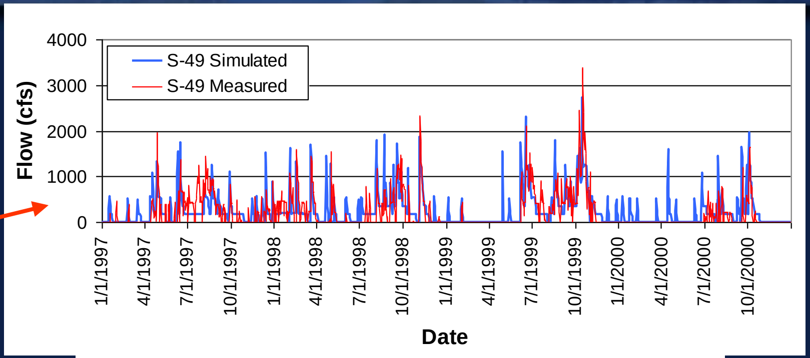
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

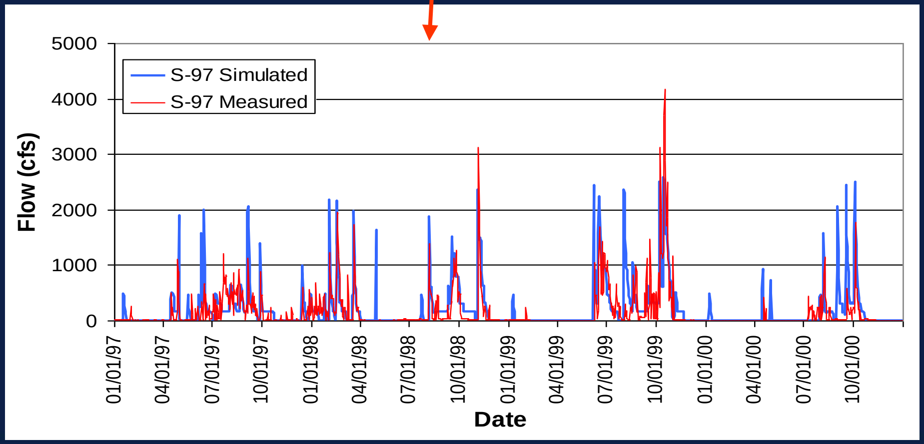
WaSh Model GUI Toolbar (ArcGIS 9.3.1 Extension)

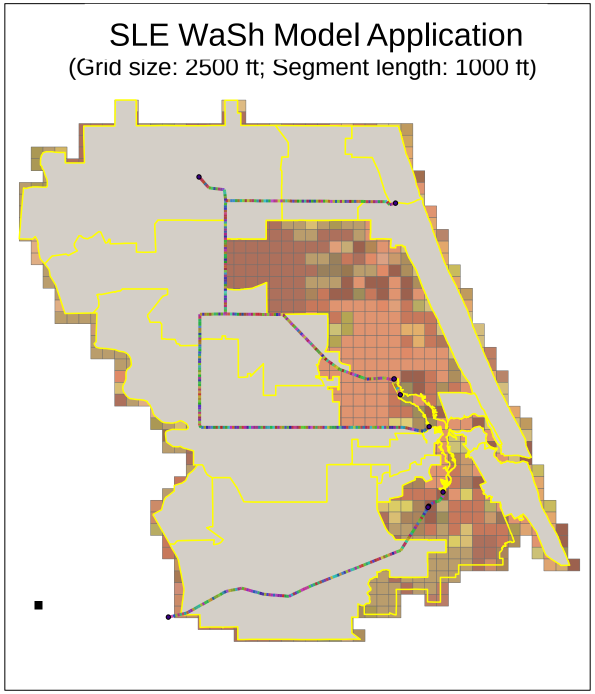


St. Lucie Estuary Watershed Application









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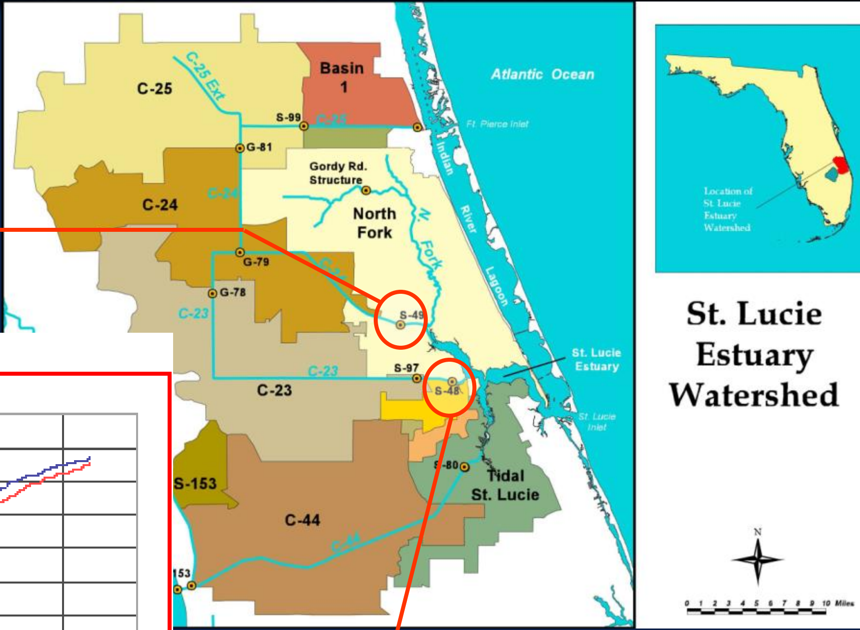
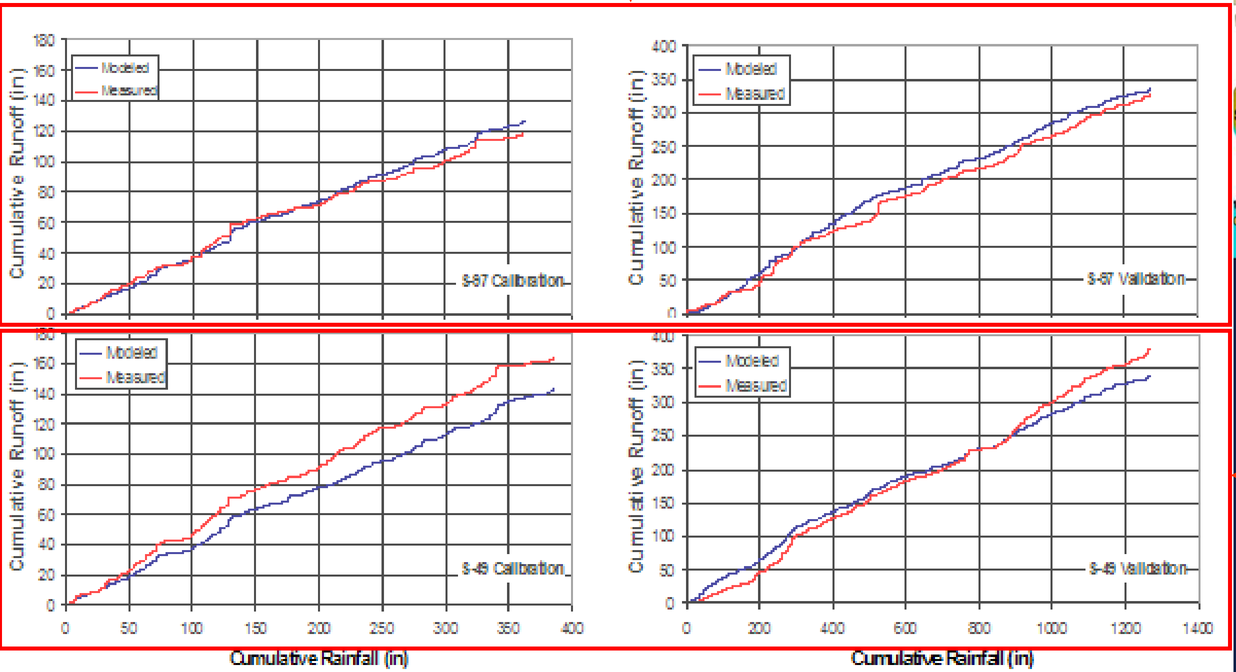
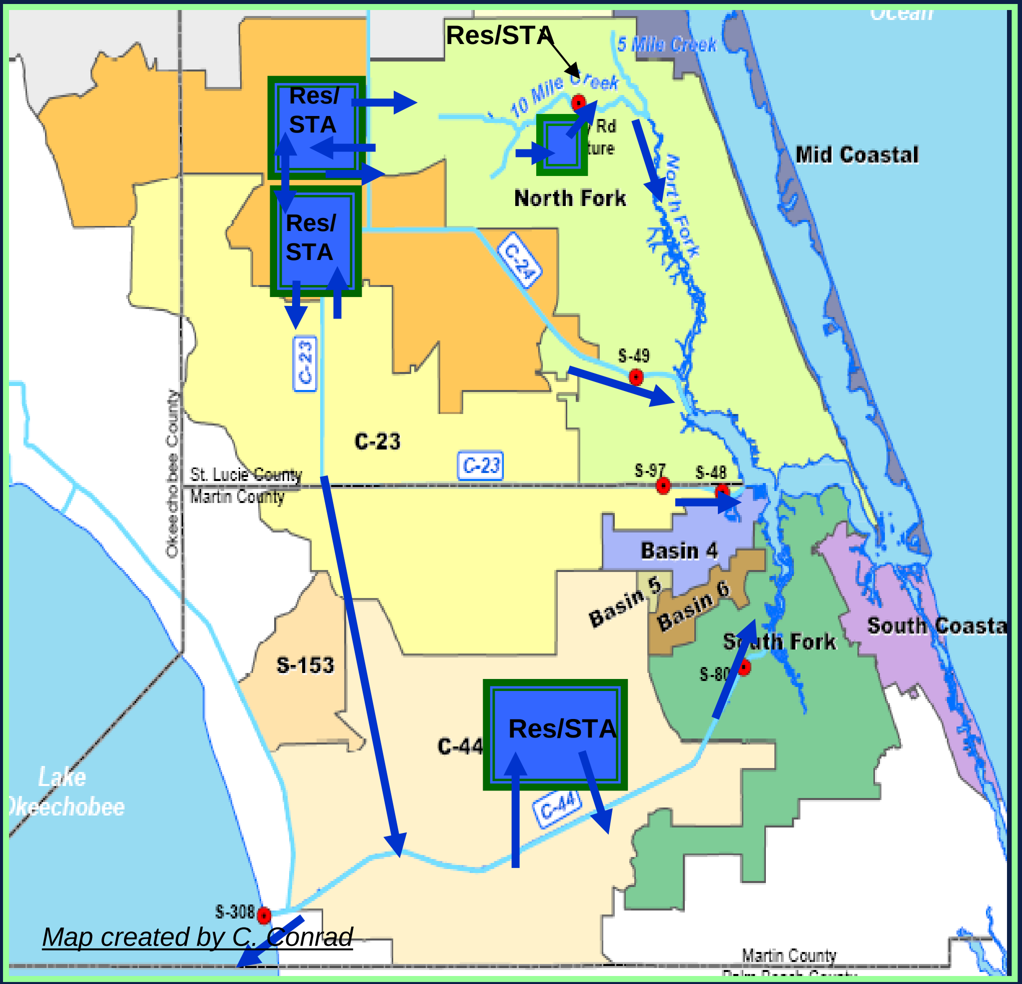
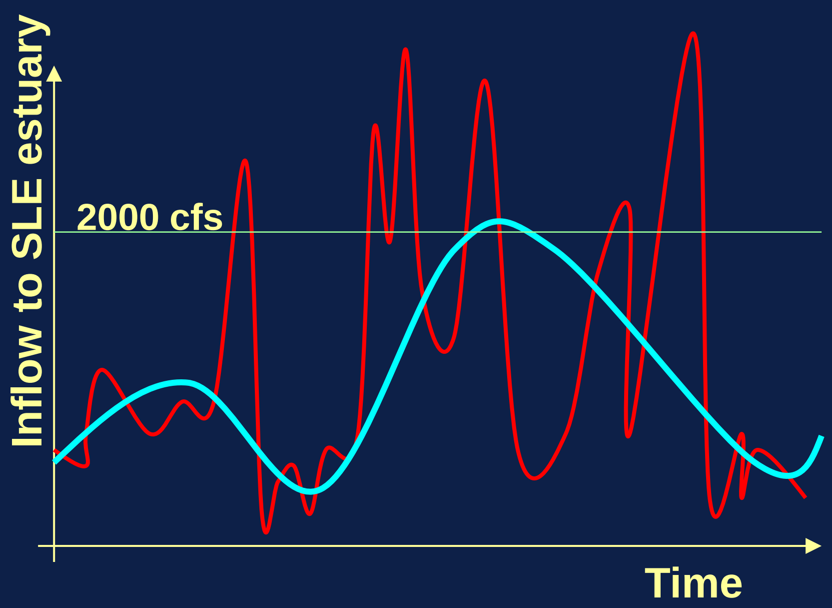




Double mass curve during the calibration period (1994–2000) and validation period (1965-1993) at S-97 and S-49 Stations

OPERATION OPTIMIZATION





OPTI6 Model Structure

Genetic Algorithm

Fuzzy Operation

$$q_i^w(S_{it}, I_{it})$$

$$q_i^s(S_{it}, I_{it})$$

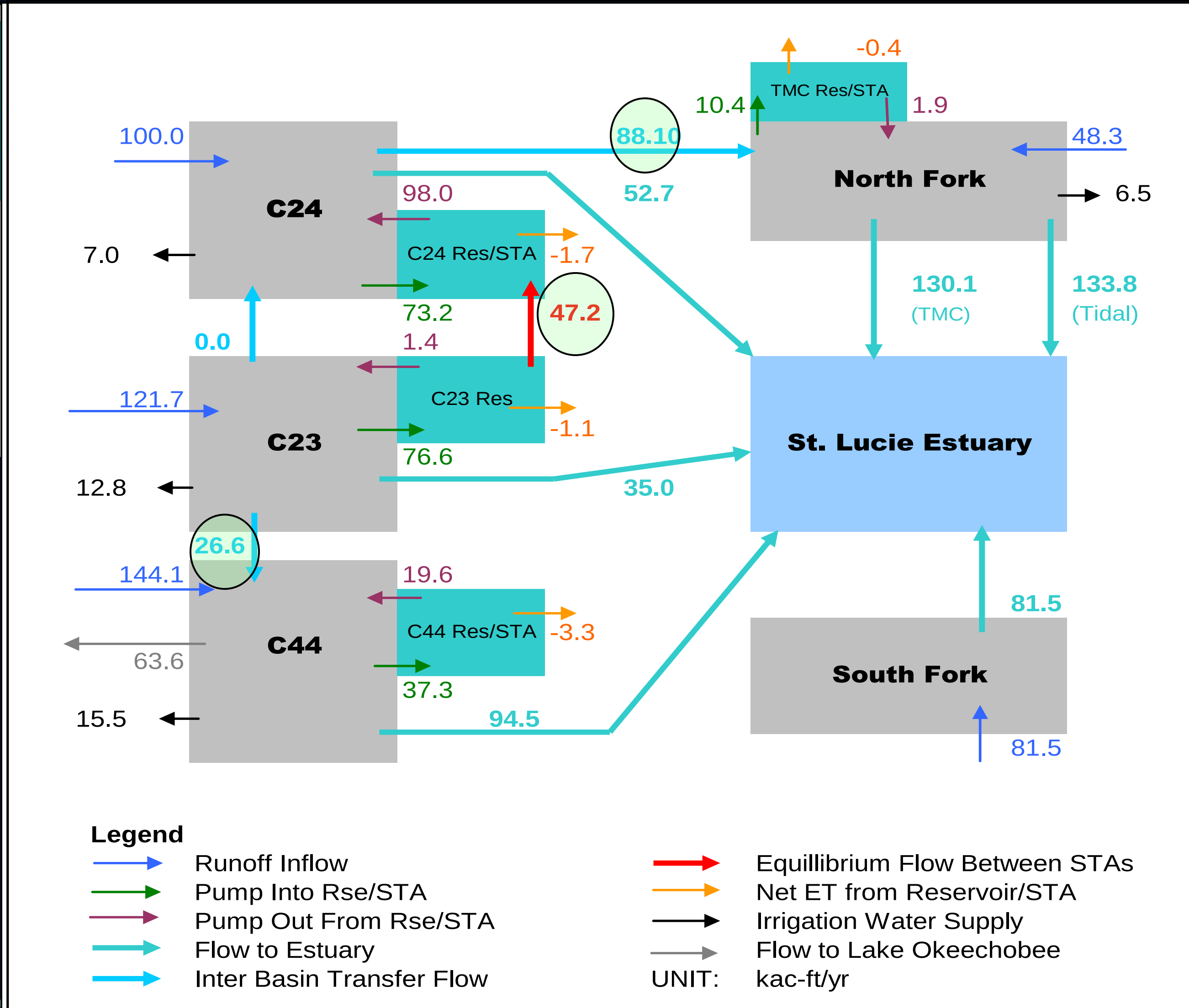
- Frequency Distribution of Mean Monthly Inflows
- Water Supply Failure
- Required Detention Storage Capacity

Drainage Network Simulation Model

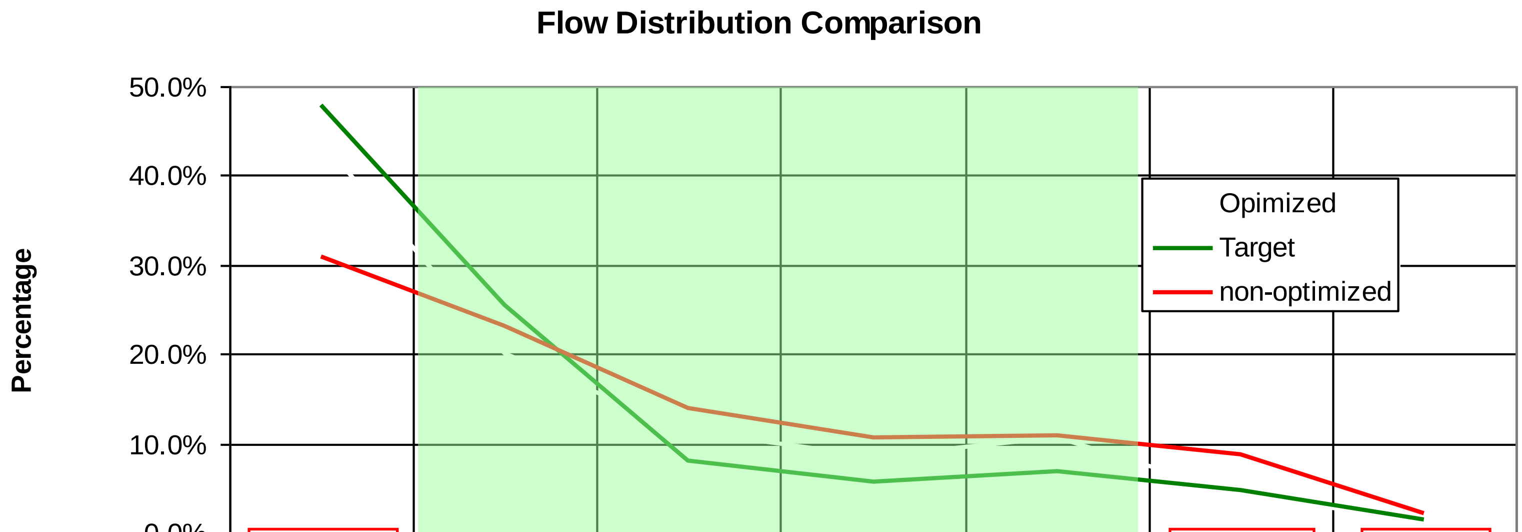
- Storm-water inflows and base flow
- Detention reservoir/STA operation
- Inter-basin transfer of storm-water
- Evaporation losses and seepage
- Irrigation water supply
- Daily time steps over 41 years period
- Frequency analysis of storm-water inflows to estuary

(**Source:** Y. Wan et al., Optimization of Frequency Distribution of Storm-Water Discharges for Coastal Ecosystem Restoration, *J. of Water Resources Planning and Management*., ASCE, Vol. 132, No. 5)

OPTI6 Model Simulation Results



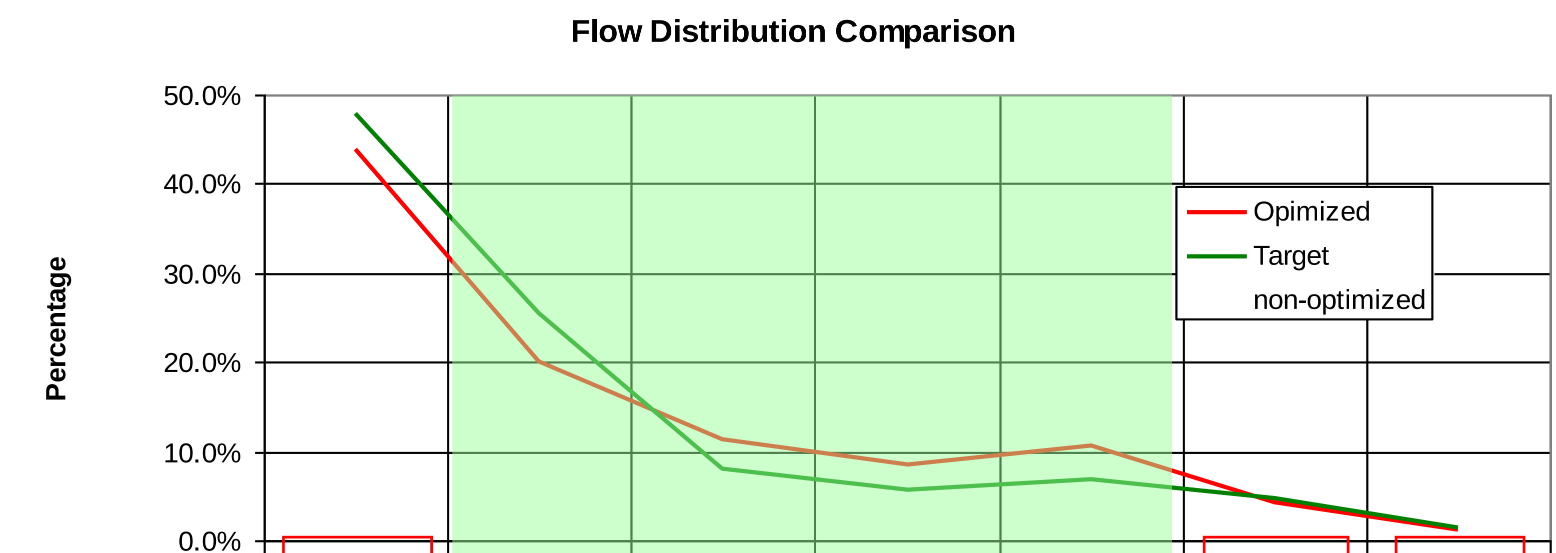
Flow Distribution Comparison



	<350	350~680	680~1010	1010~1340	1340~2000	2000~3000	>3000
Opimized	43.9%	20.1%	11.4%	8.5%	10.6%	4.3%	1.2%
Target	47.8%	25.5%	8.1%	5.7%	6.8%	4.7%	1.4%
non-optimized	30.9%	23.2%	13.8%	10.6%	10.8%	8.7%	2.0%

Flow range (cfs)

Flow Distribution Comparison



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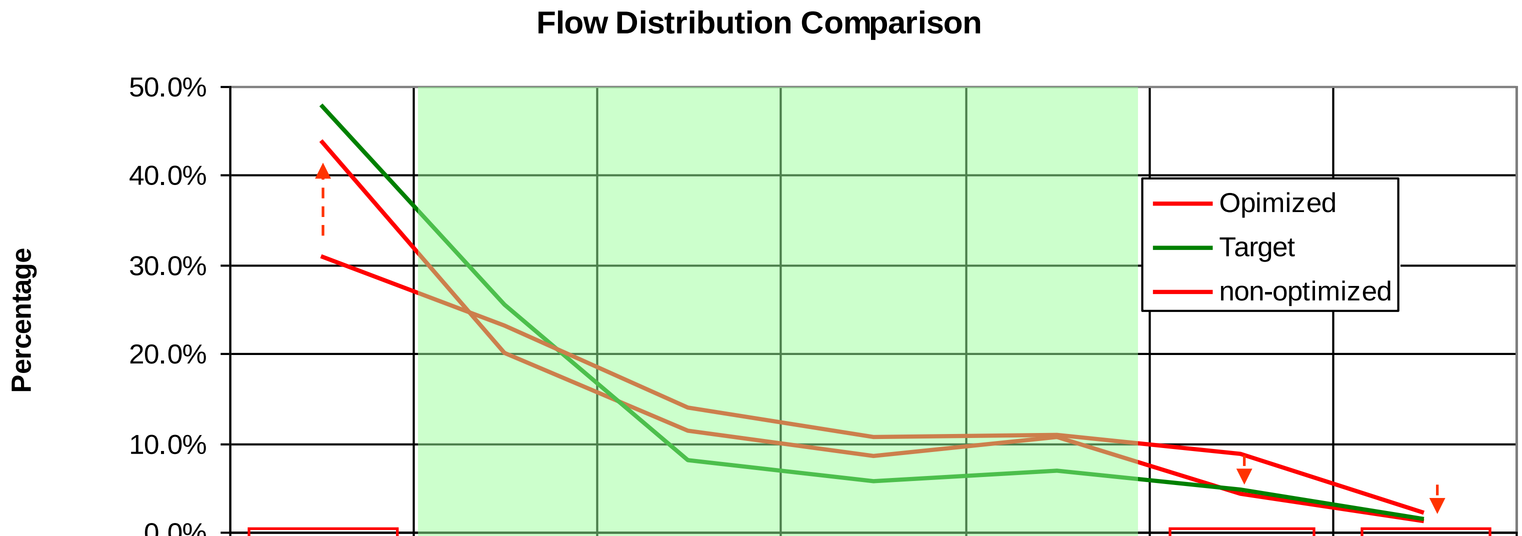

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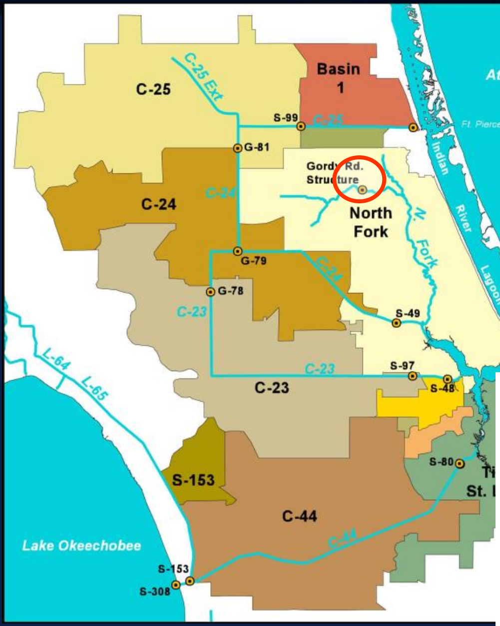
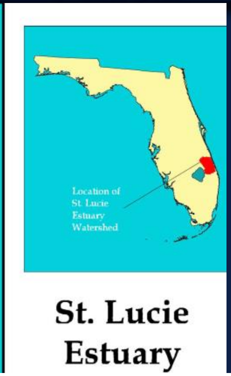
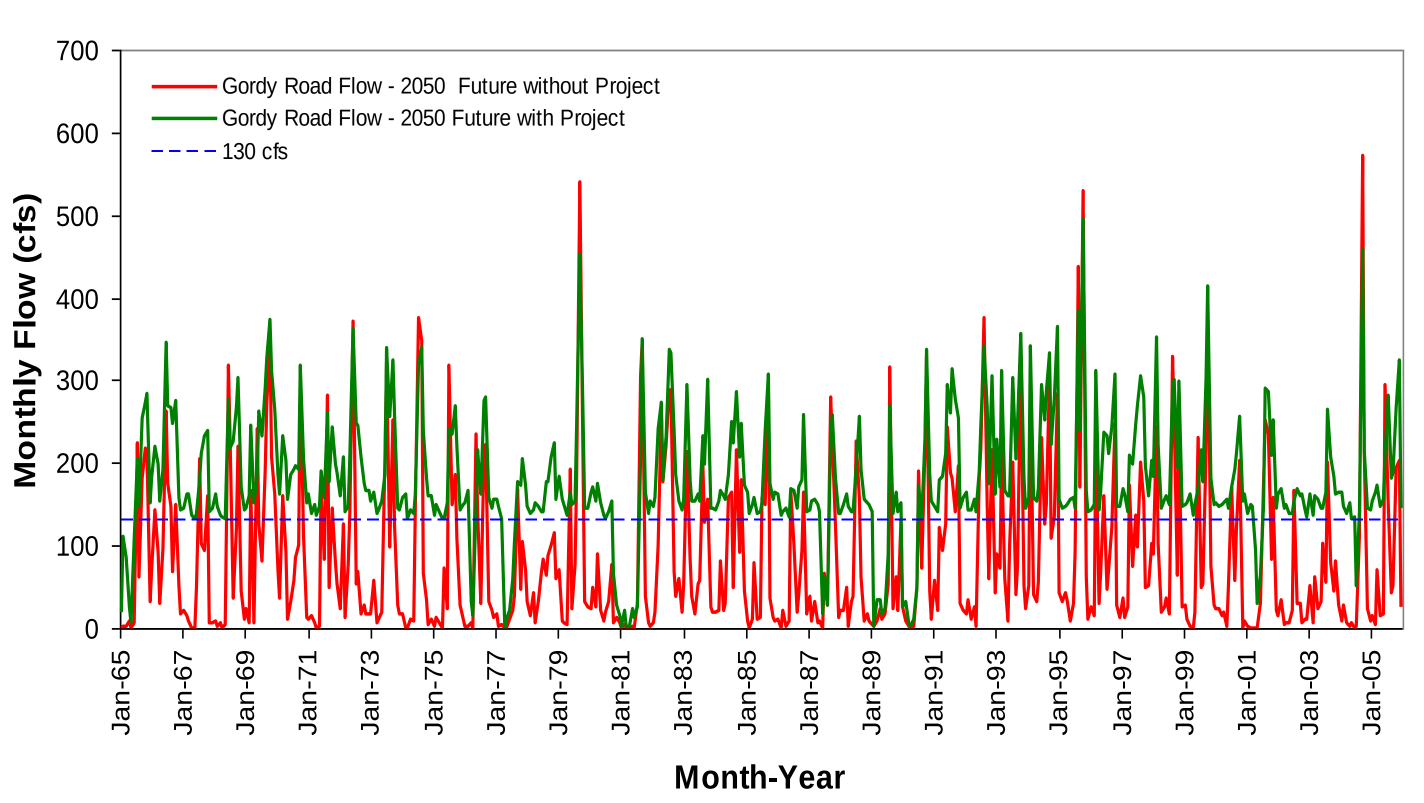
Flow range (cfs)

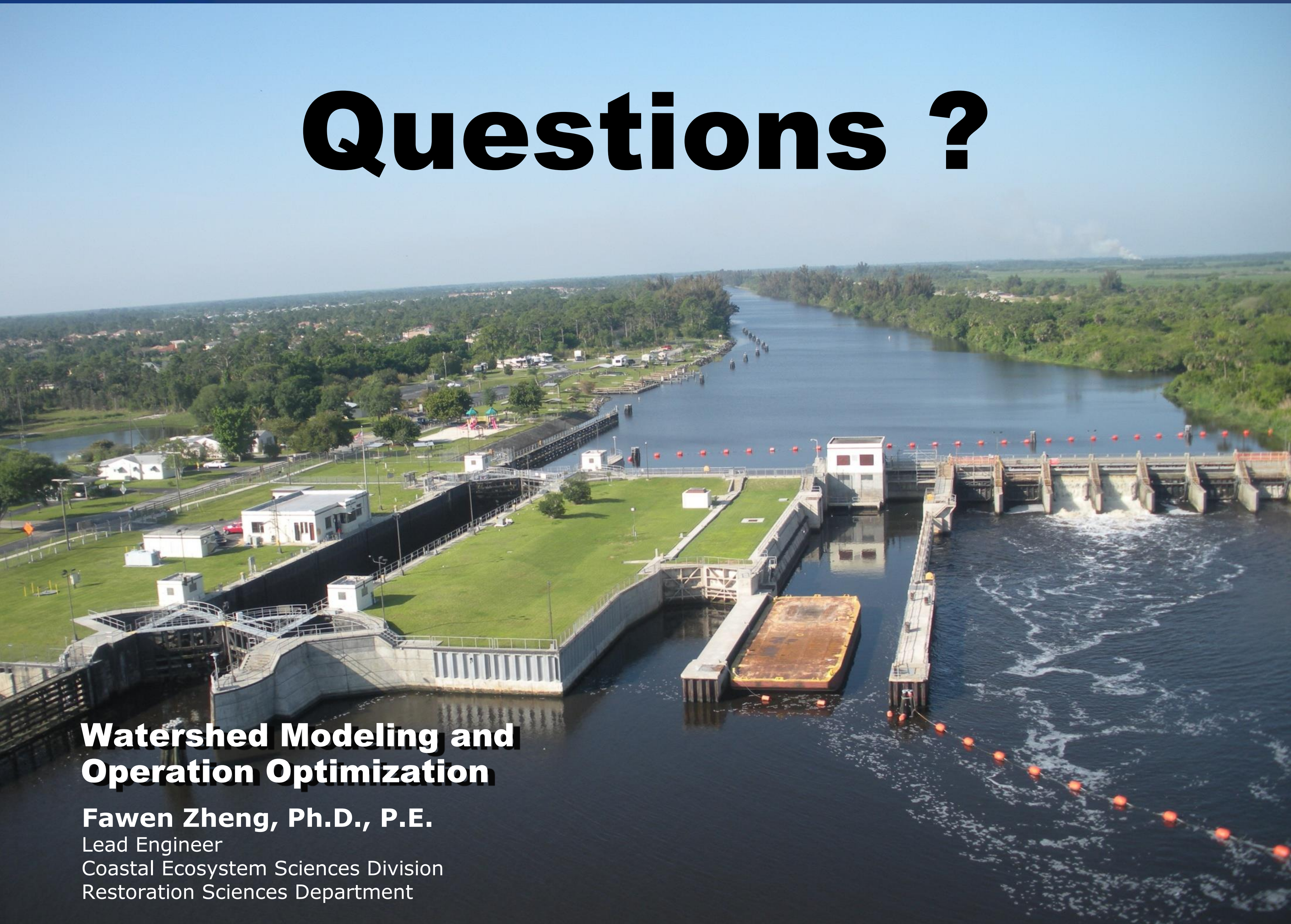
Monthly Flow over Gordy Road Structure







Questions ?



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