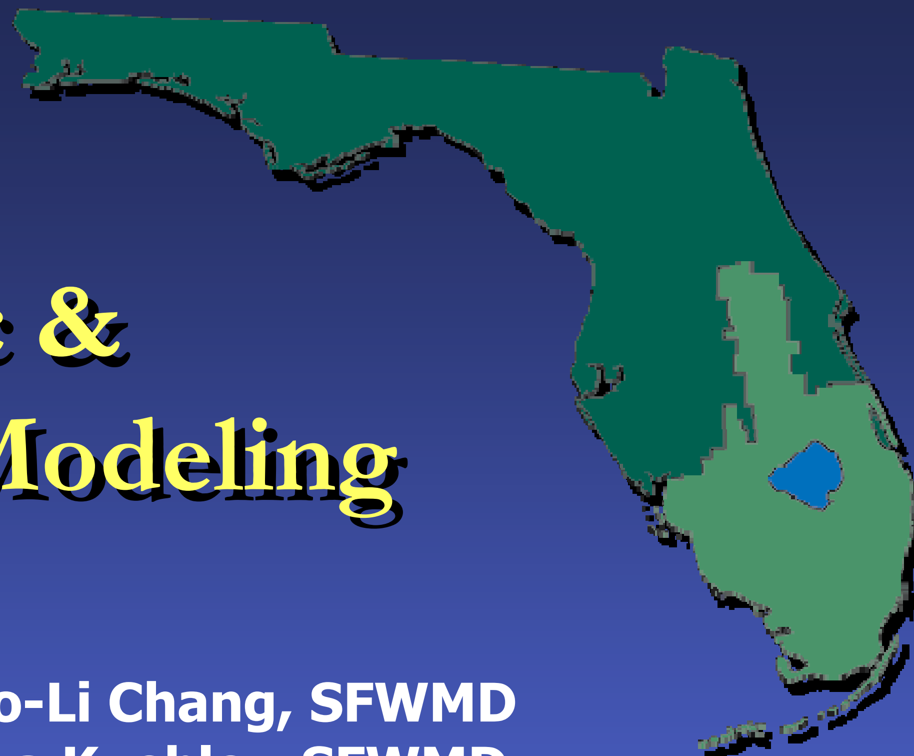
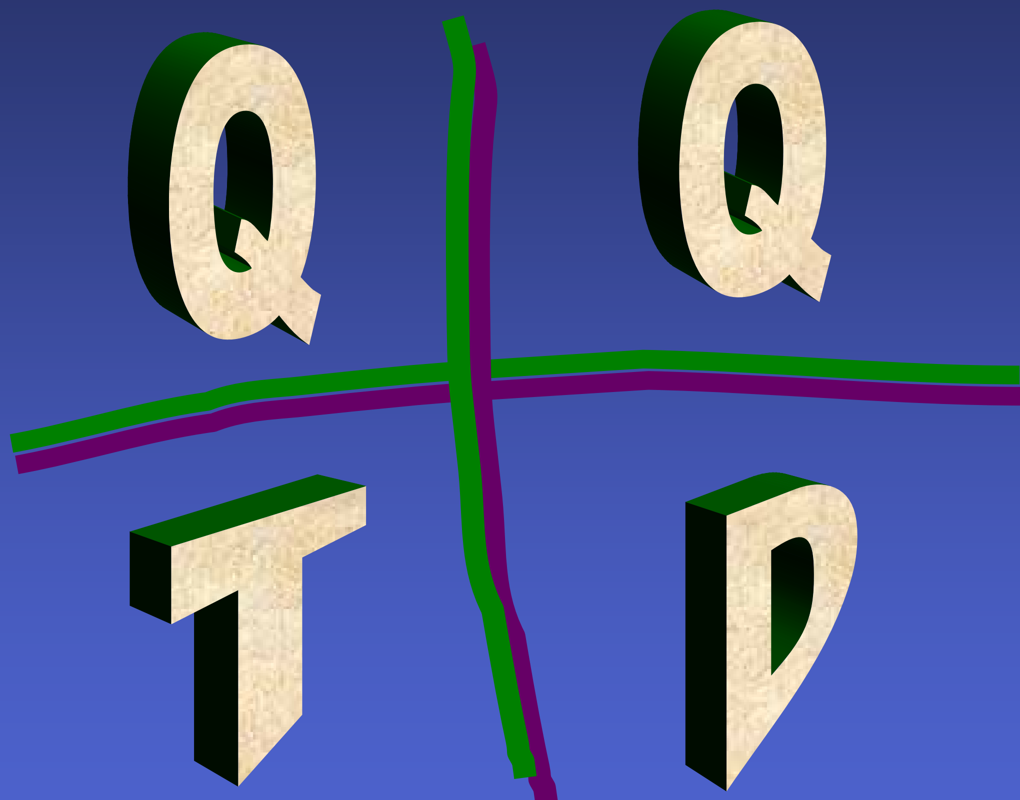
Hydrologic & Hydrodynamic Modeling

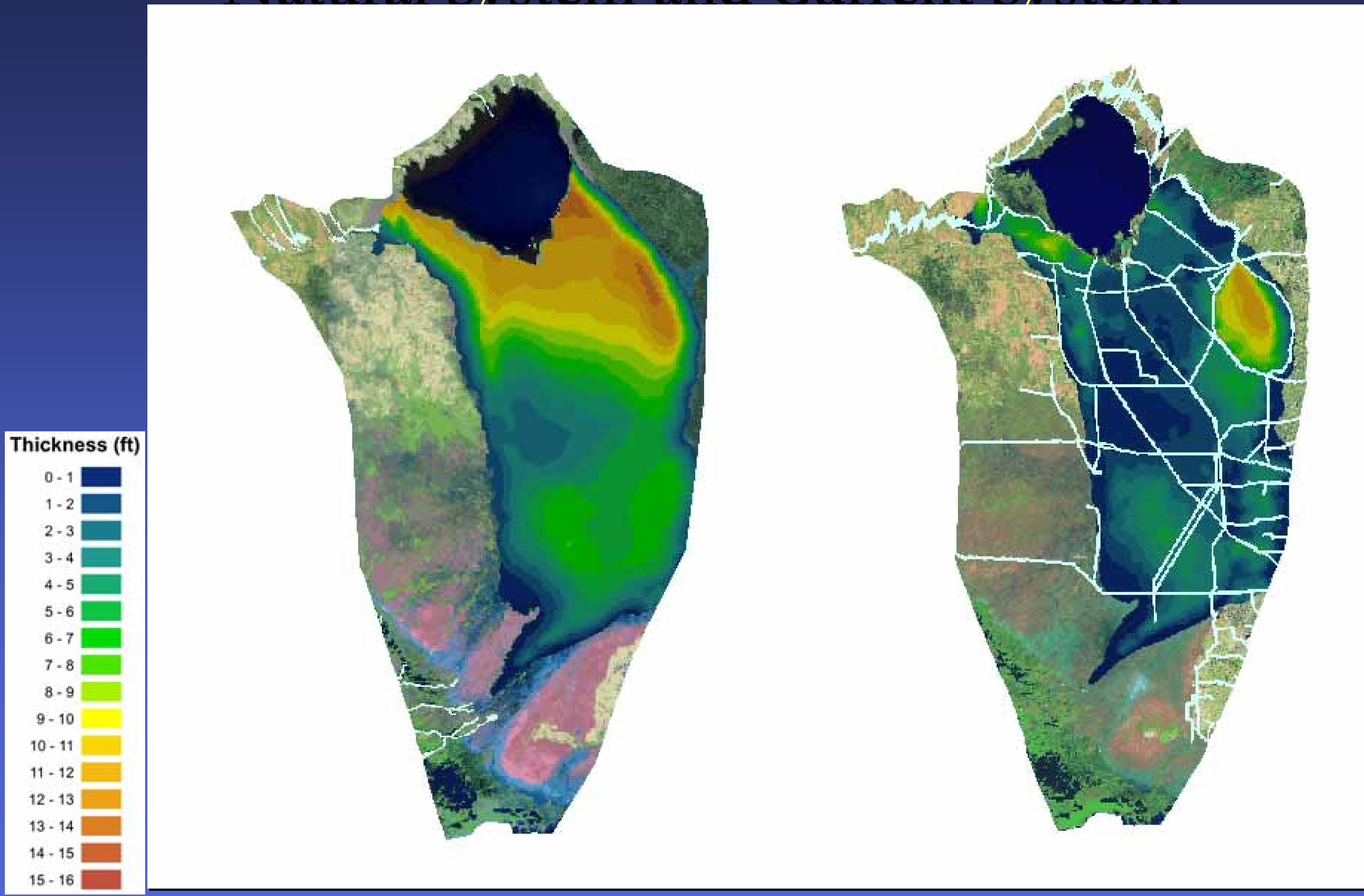


Shabbir Ahmed ,CORPS
Vic Engel, ENP
Christian Langevin, USGS
Eric Swain, USGS
Miao-Li Chang, SFWMD
Laura Kuebler, SFWMD
Jayantha Obeysekera, SFWMD
Yongshan Wan, SFWMD

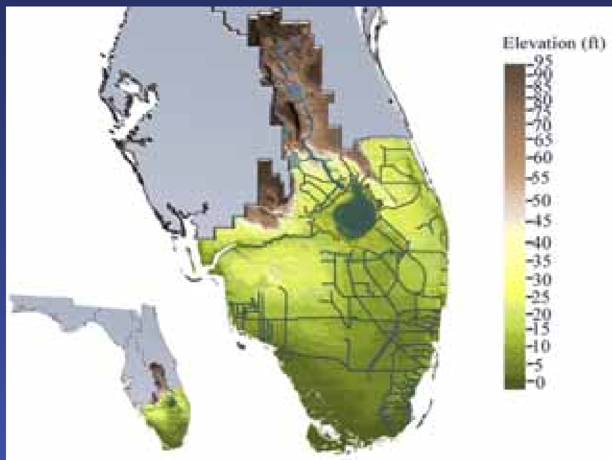
Restoration Focus



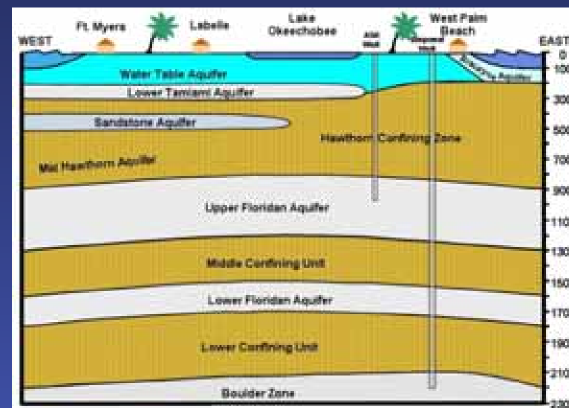
Peat Thickness Comparison
Natural System and Current System



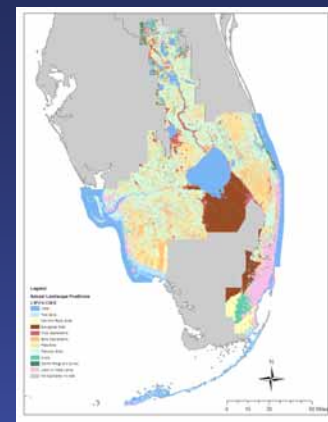
Uniqueness of South Florida Hydrology



Flat Topography



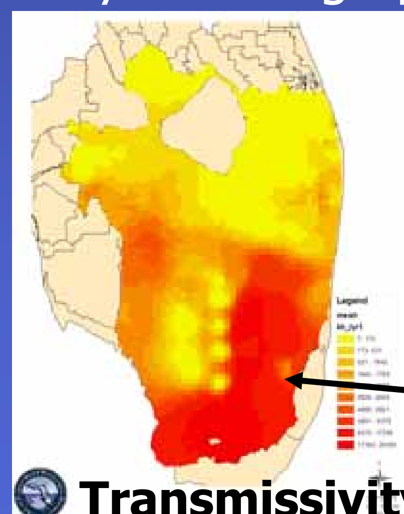
Complex Hydrostratigraphy



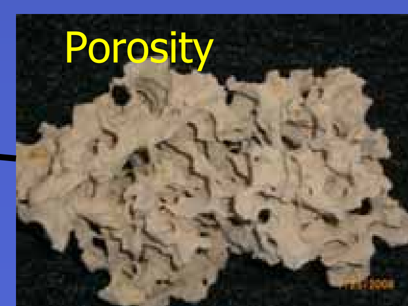
Sand/Peat soils

Subsidence

Complex Water Management



Transmissivity

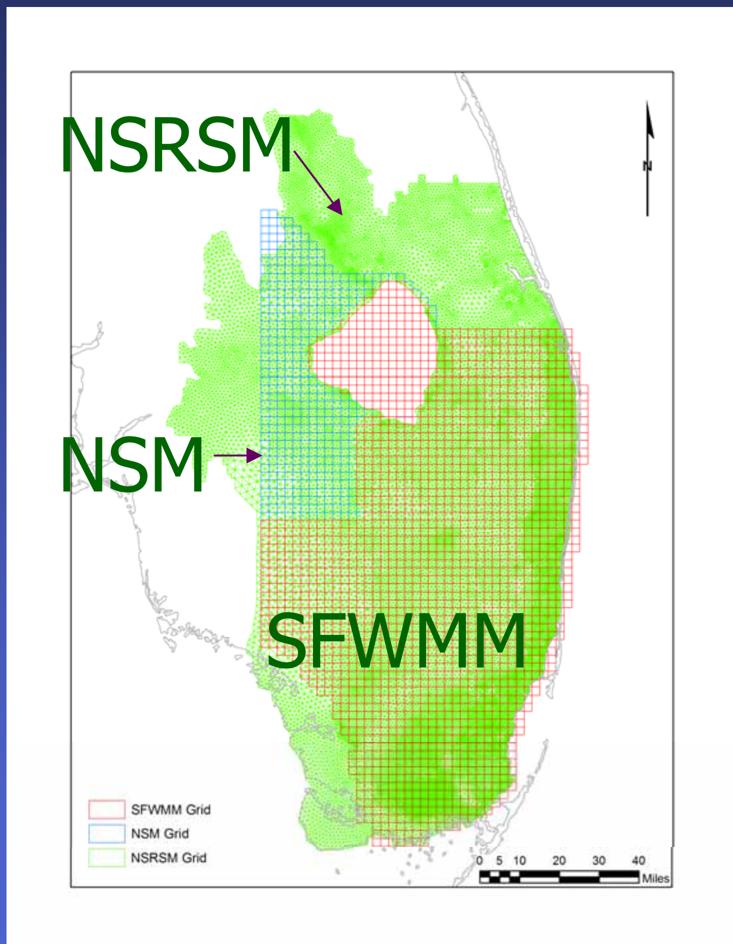


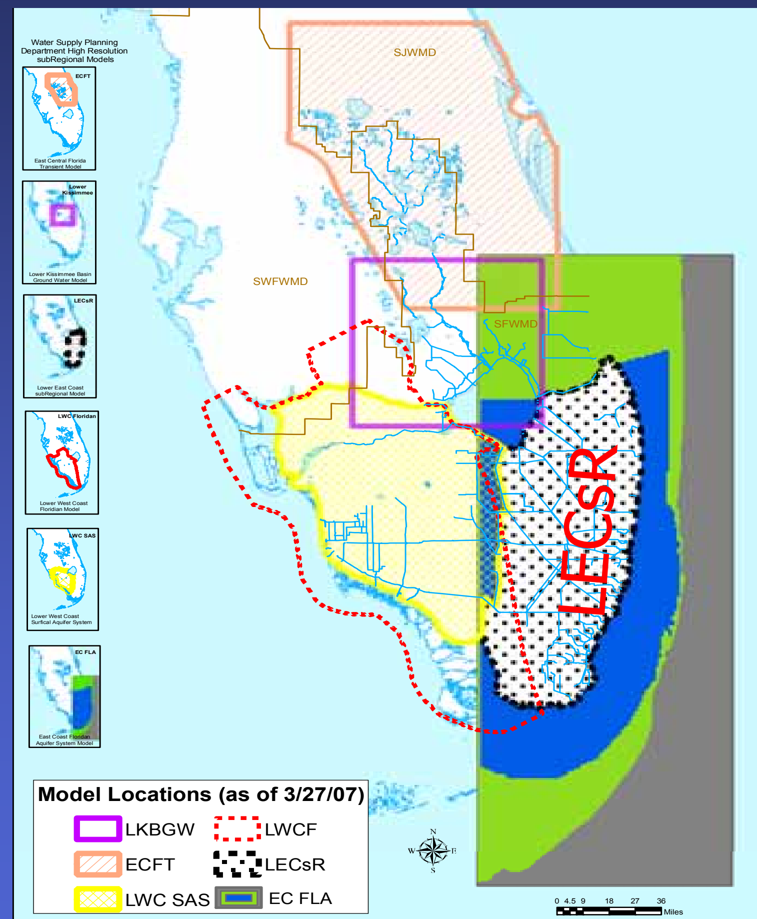
Porosity

Role of Models in Restoration

- A tool (not a substitute for decision making) for
  - Planning and implementation of restoration alternatives ("Getting Water Right")
    - Regional, Subregional and Project-scales (design)
    - Impacts on other users: water supply & agricultural
  - Operational Planning
    - Event, seasonal, multi-seasonal
  - Regulation
    - Water Reservations, Minimum Flows and Levels, Compliance Monitoring

Regional & Subregional Simulation Models

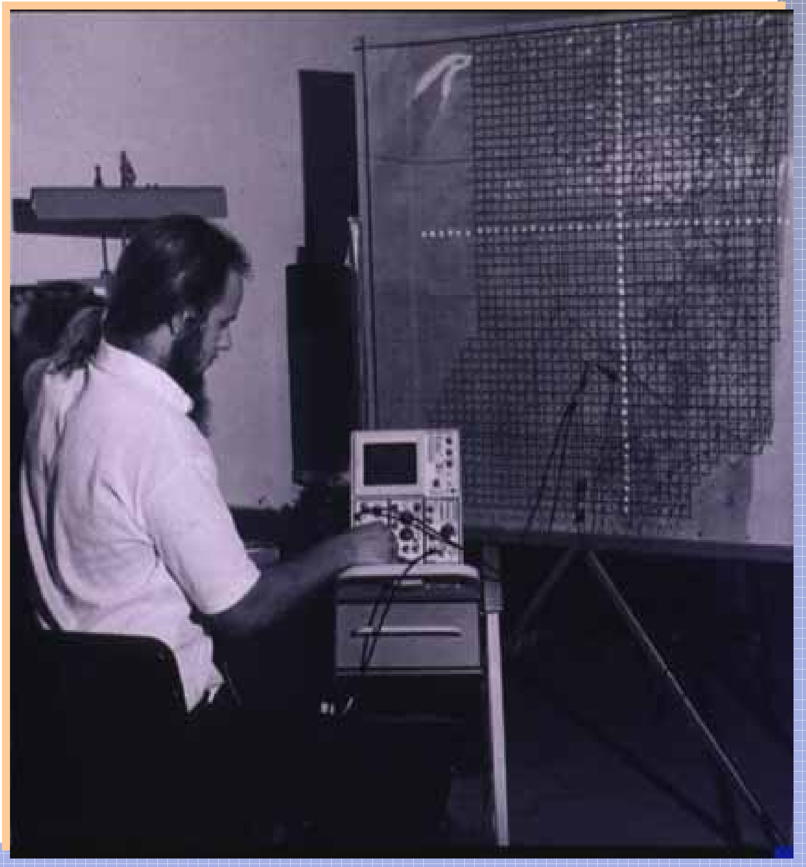




"Regional (system-wide"

"Subregional-gw"

Decade of the 70s



Analog Model

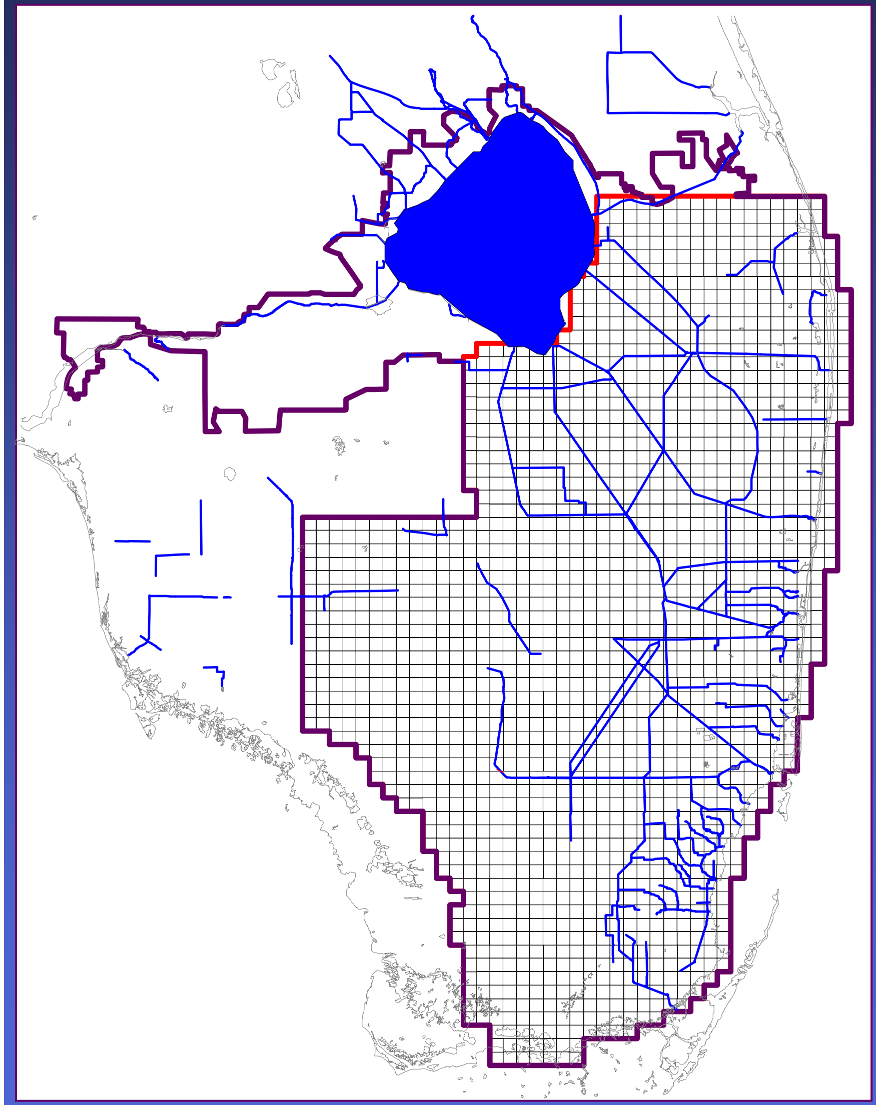
- Electric Analog Model
  - Simulated water levels and flows in coastal region
- Upgraded Regional Routing Model to include daily time step
- Initial development of SFWMM (2x2)- a regional-scale computer simulation model

Decades of the 1980s Physical Modeling at UC-Berkeley

Real System

Model

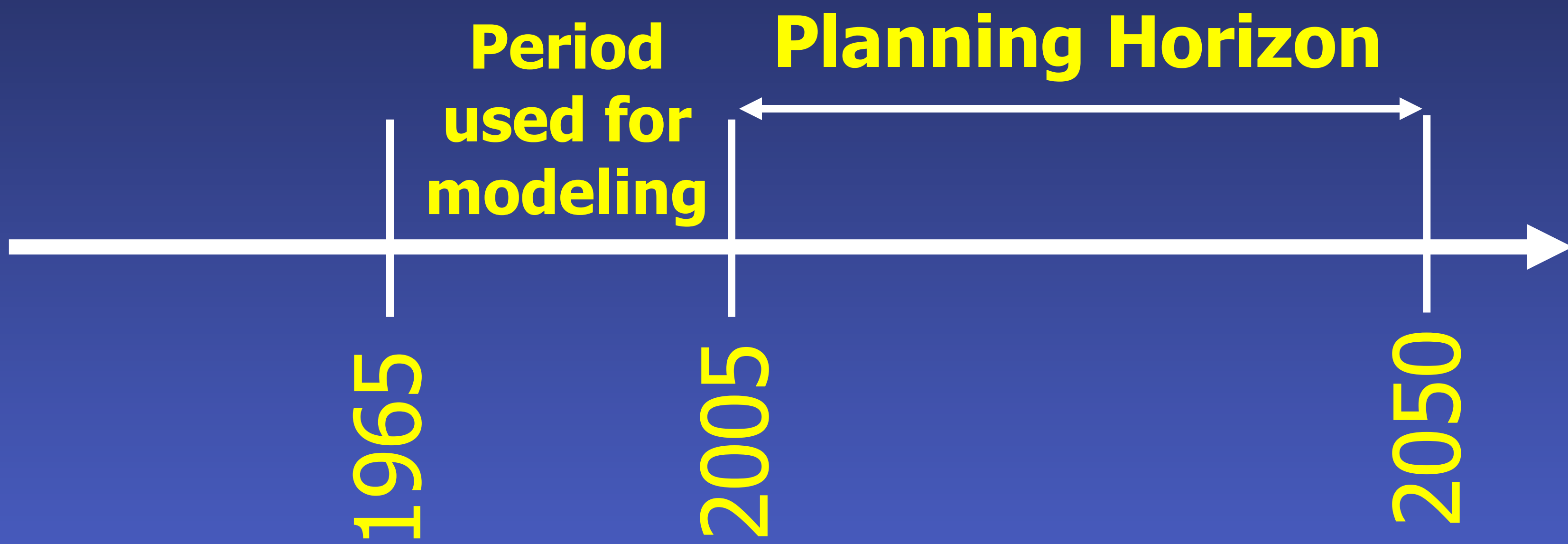
South Florida Water Management Model (SFWMM)



- Integrated surface water groundwater model
- Regional-scale 3.2 x 3.2 km, daily time step
- Major components of hydrologic cycle
- Overland and groundwater flow
- Canal and levee seepage
- Operations of C&SF system
- Water shortage policies
- Extensive performance measures
- Provides input and boundary conditions for other models

www.sfwmd.gov/org/pld/hsm/models

CERP Plan Evaluation



Assumption: 1965-2000 period used for modeling is representative of the climate expected during the future planning horizon ("Stationarity")

Modeling Based On "Stationarity" Assum[...]on

- Climatic Input
  - Rainfall
  - ET
- Boundary Conditions

Period[...] Sim[...] 1965[...]

Scenario[...]

[...]duse/Landcover
[...]Water Demands
- Operating Criteria

SFWMM Model

[...]del [...]put [...]y time series of water levels, flows
- Demands not met

Performance Measures (Ag, Env, Urban)

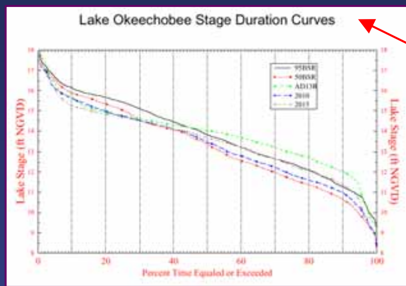
CLIMATE CHANGE

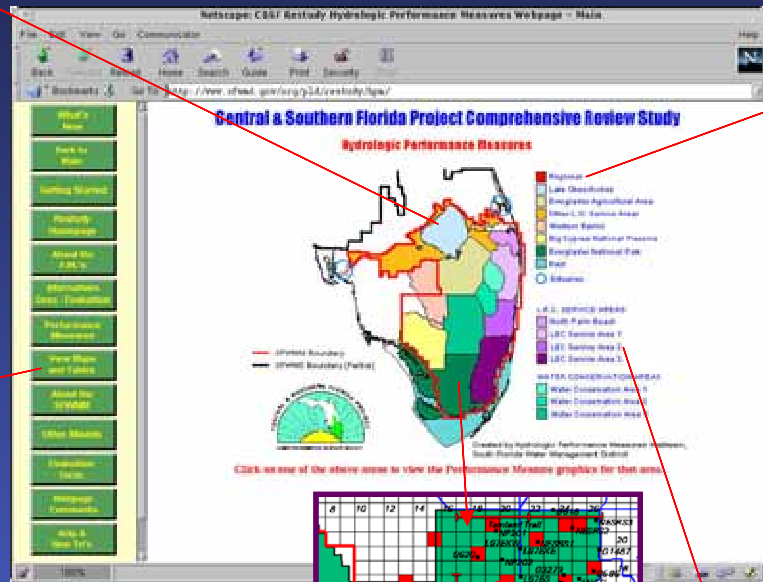
Stationarity Is Dead: Whither Water Management?

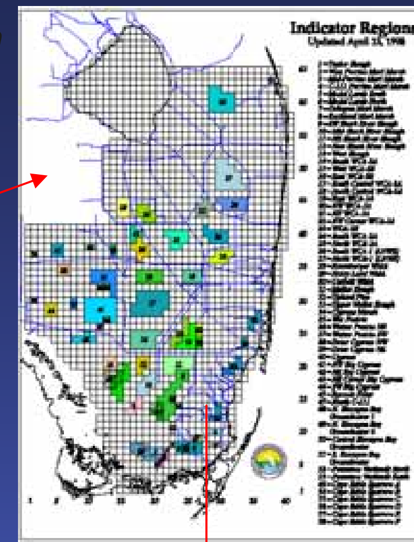
P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

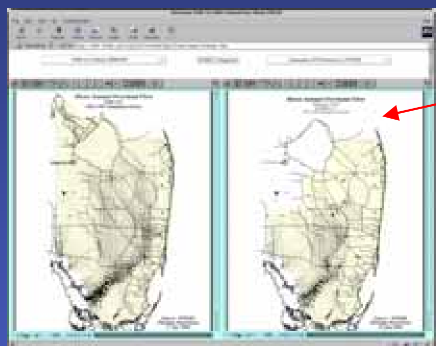
Hydrologic Performance Measures

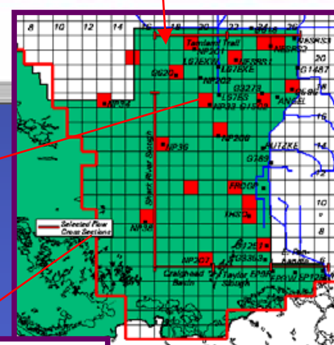
www.sfwmd.gov/org/pld/restudy/hpm

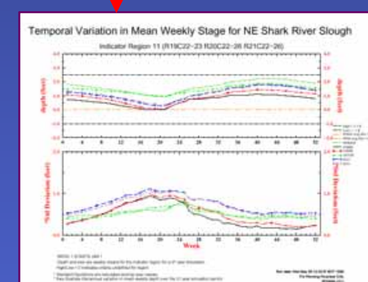


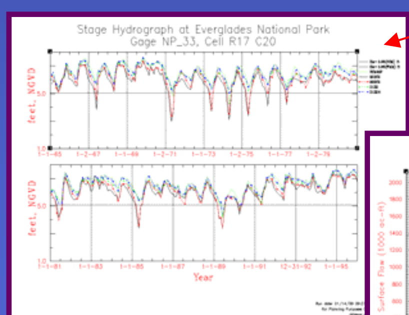


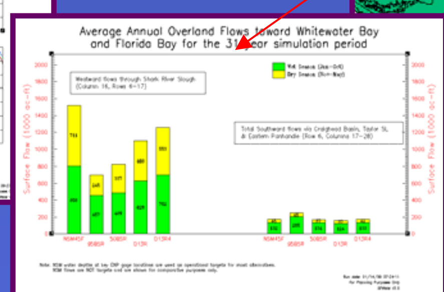


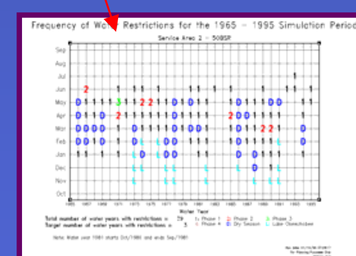




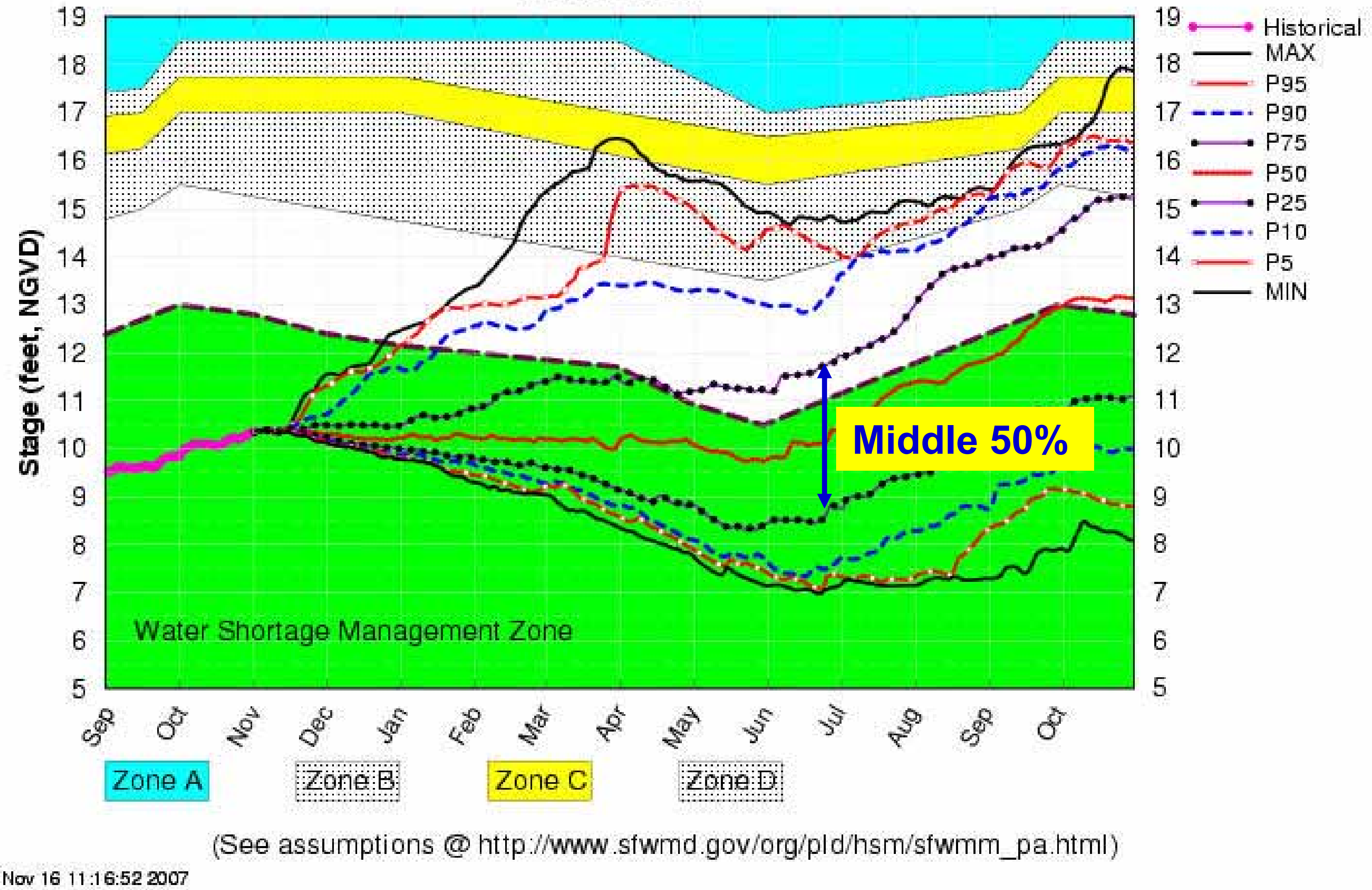








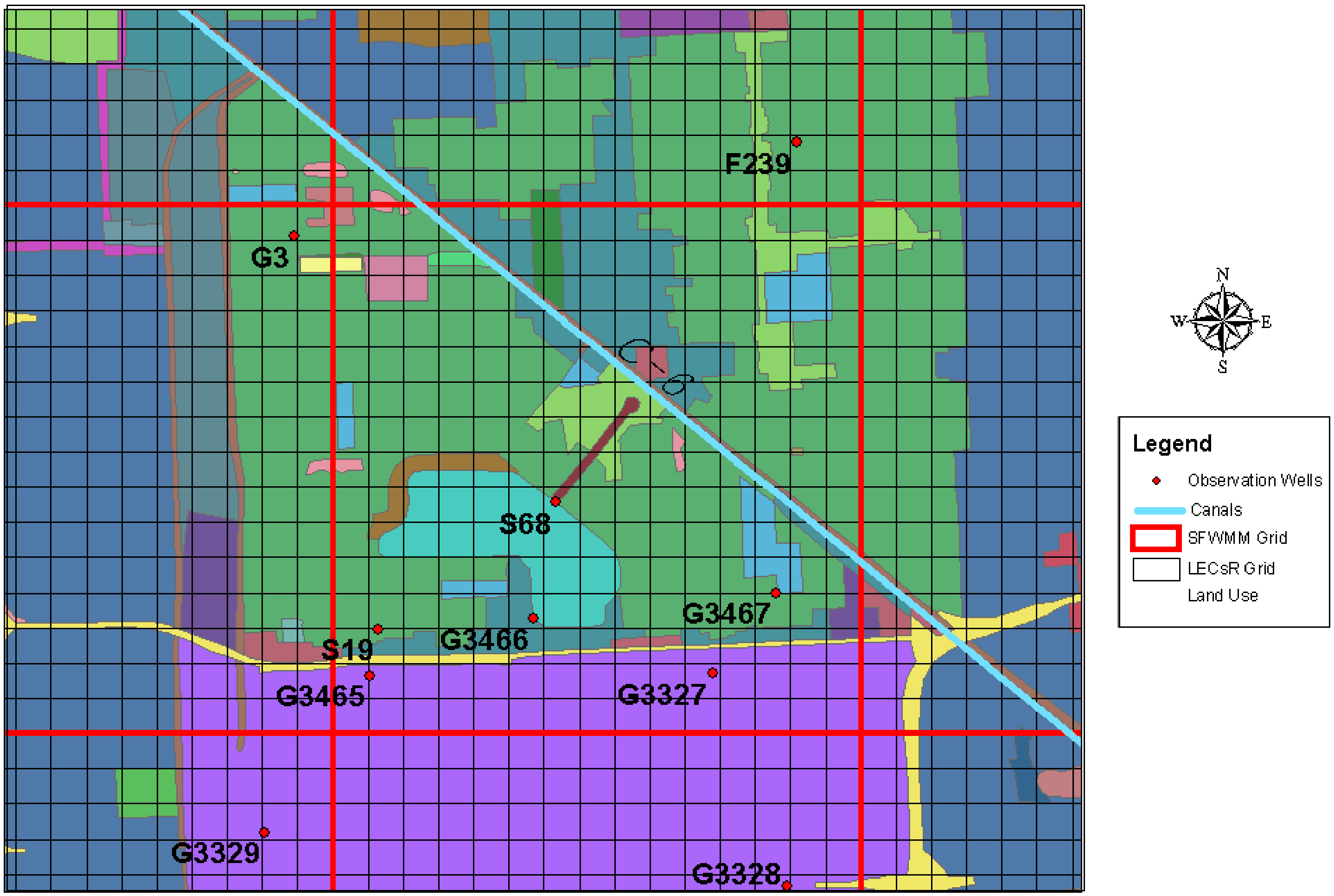
Lake Okeechobee Monthly Position Analysis



Subregional Modeling

Model Scales

Black Cells = LECsR, 704 ft by 704 ft
Red Cells = SFWMM, 2 mi by 2 mi



LECsR Model Abilities

- Manage Groundwater Conditions
- Minimize Water Shortage Restrictions
- Evaluate Wetland Hydropatterns
- Examine Underground Barriers
- Improve Surface Water Operations
- Provide boundary conditions to local-scale models

Model Code and Packages

- In MODFLOW and SEAWAT (USGS)
- Add-on packages
  - Wetland: SW-GW interaction
  - Diversion: Operations
  - Reinjection Drainflow: Operations
  - Trigger: Water restrictions
  - UGEN: Utility
  - Multibud: Budget

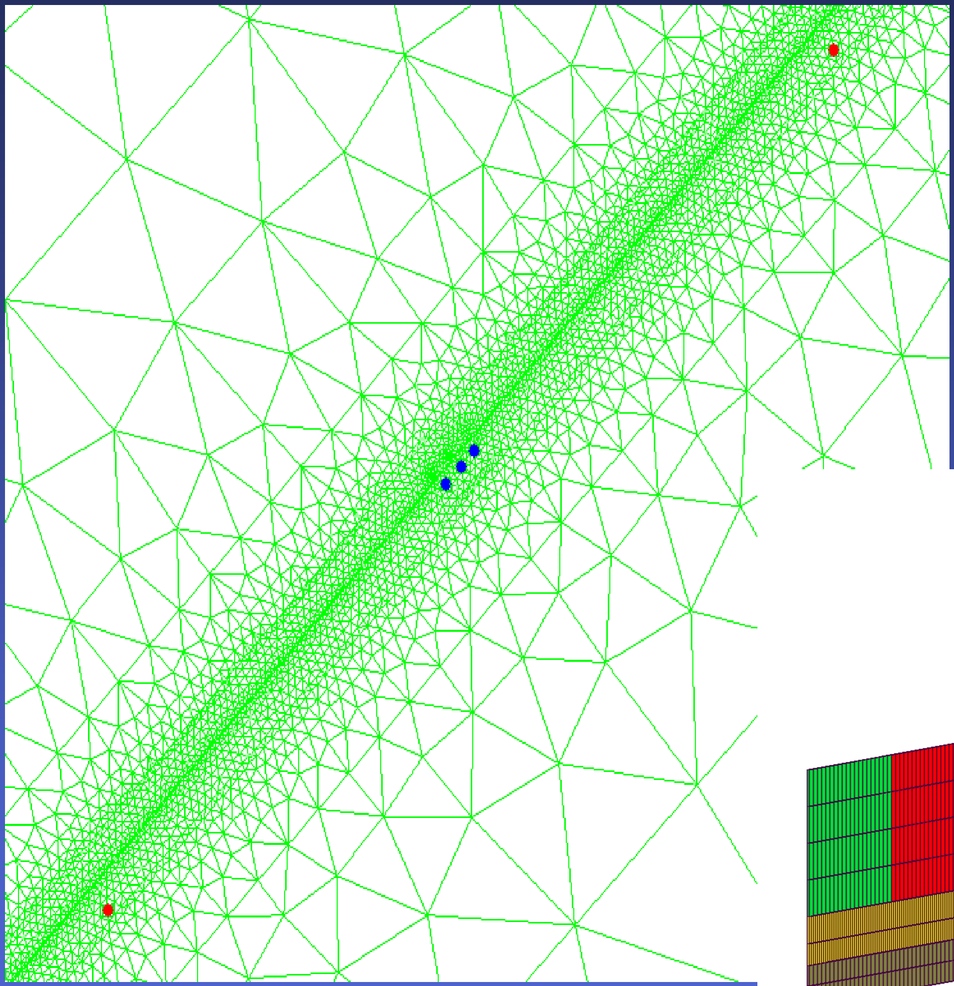
LECsR Model Limitations

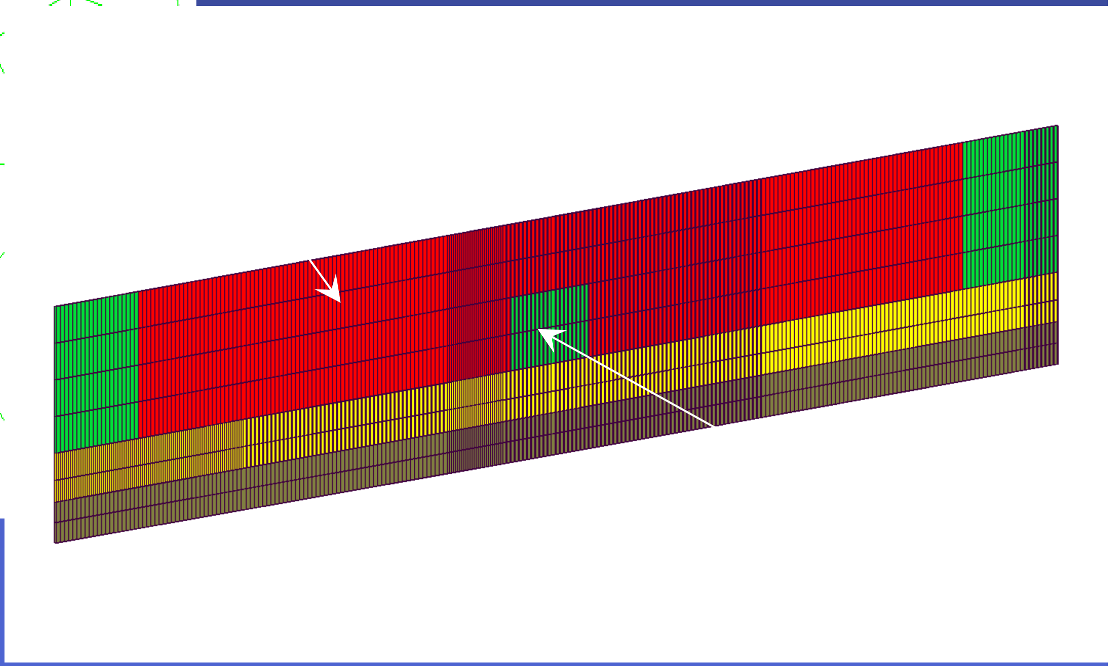
- Uncoupled unsaturated and saturated zones (in non-WTL areas)
- Limited routing capabilities
- No density-dependence

L-31 N (L-30) Seepage Management Pilot Project

- To investigate seepage management technologies by controlling wet season seepage while minimizing impacts to existing legal users and the environment
- Modeled (using FEMWATER) a 1,000-ft seepage control barrier along with a 100-ft wide window including injection-extraction wells

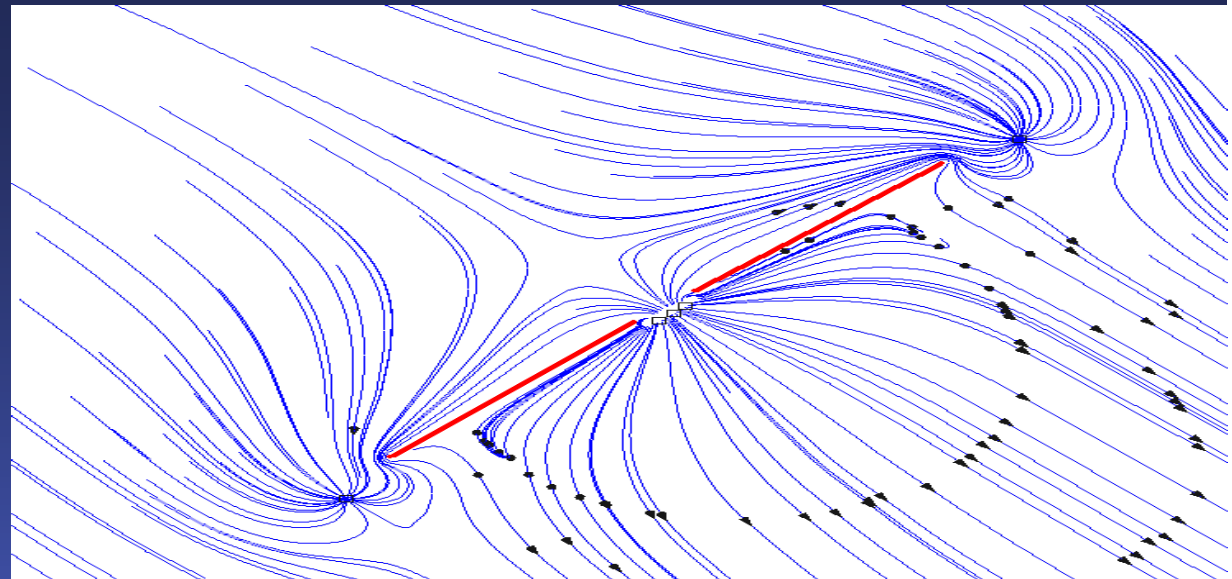
Barrier, window, two extraction wells (red) @ 3 cfs and three injection wells (blue) @ 2 cfs in FEMWATER finite element mesh

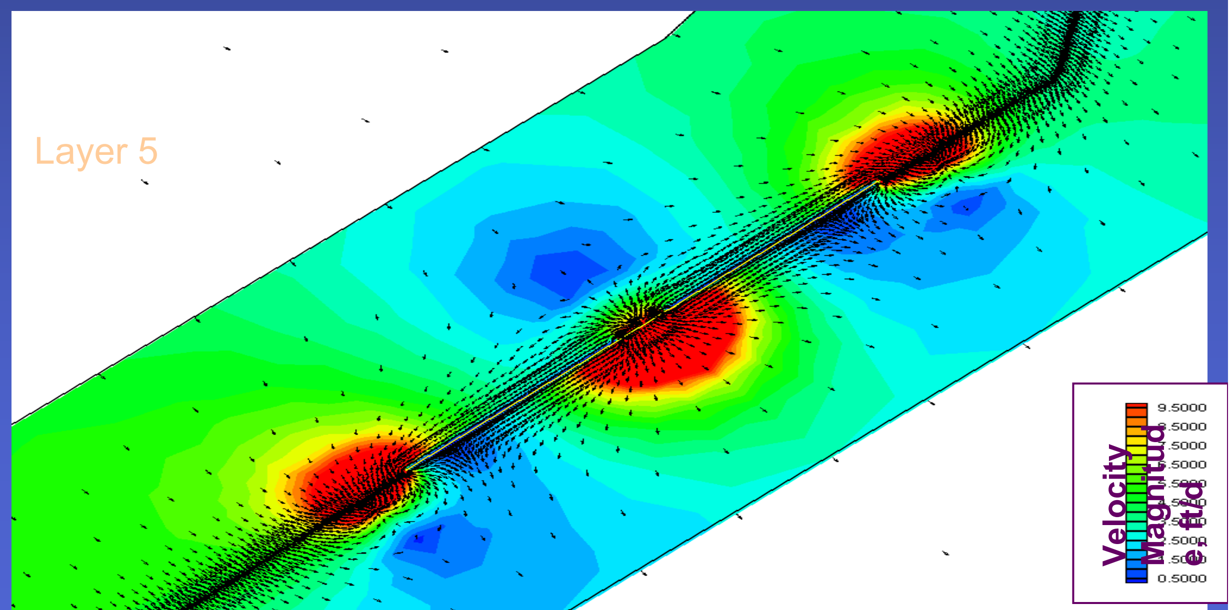




Simulated Pathlines and Velocities

- Pathlines showing the effects of barrier, window, and extraction-injection wells.
- Red represents high velocity and blue represents low velocity for extraction-injection wells. Injection wells are able to block flow through the window opening.

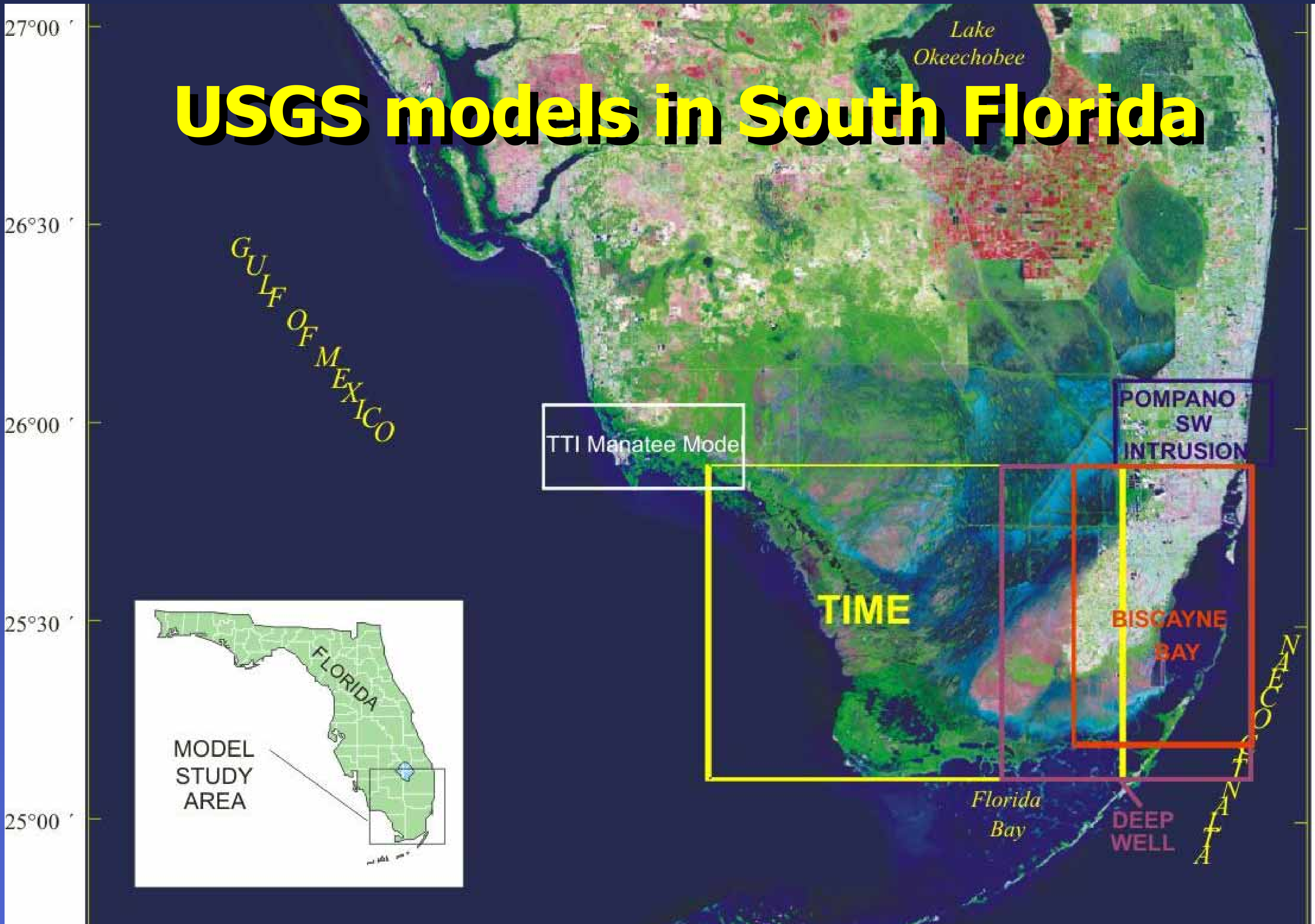




USGS Modeling Focus

- Characterize the interaction between marine and terrestrial waters.
- Develop computer programs that simulate flows and salinities in coastal wetlands and aquifers.
- Apply these programs to evaluate the effects of ecosystem restoration, population growth, sea-level rise, and management practices in South Florida.

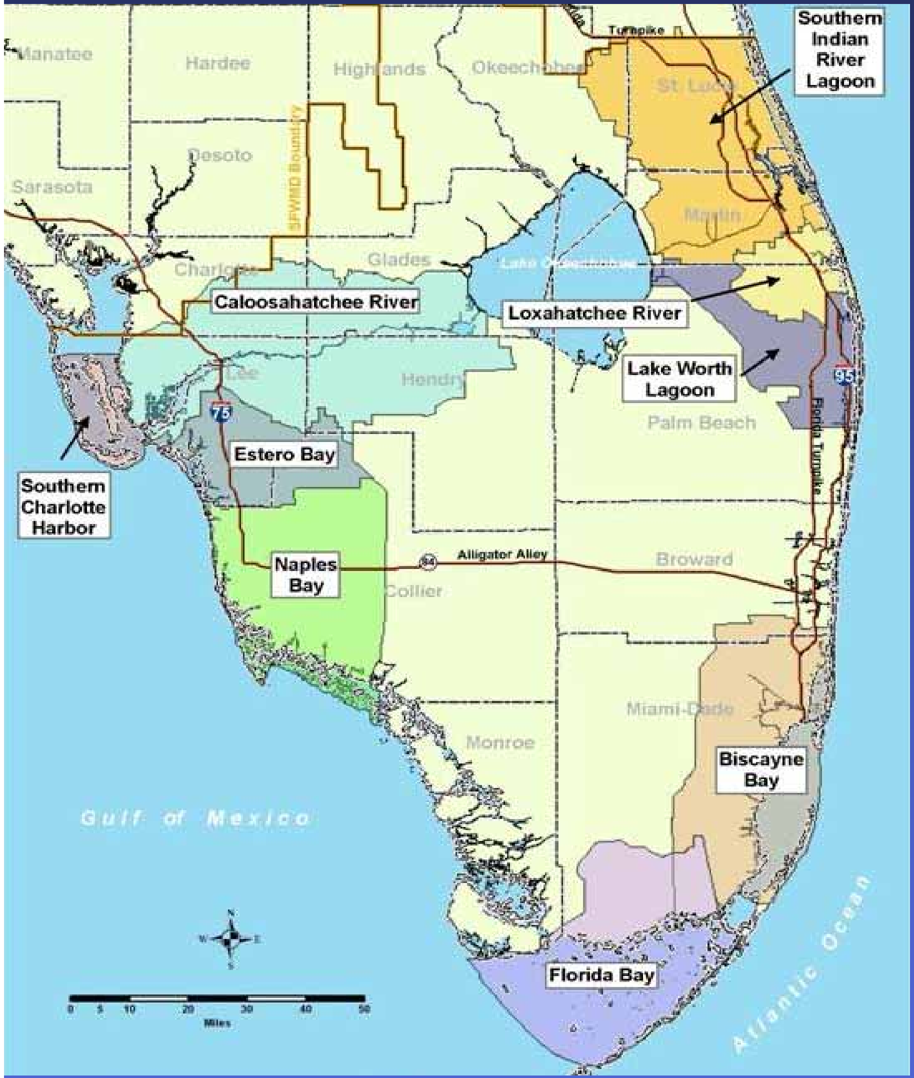
USGS models in South Florida



MODEL APPLICATIONS

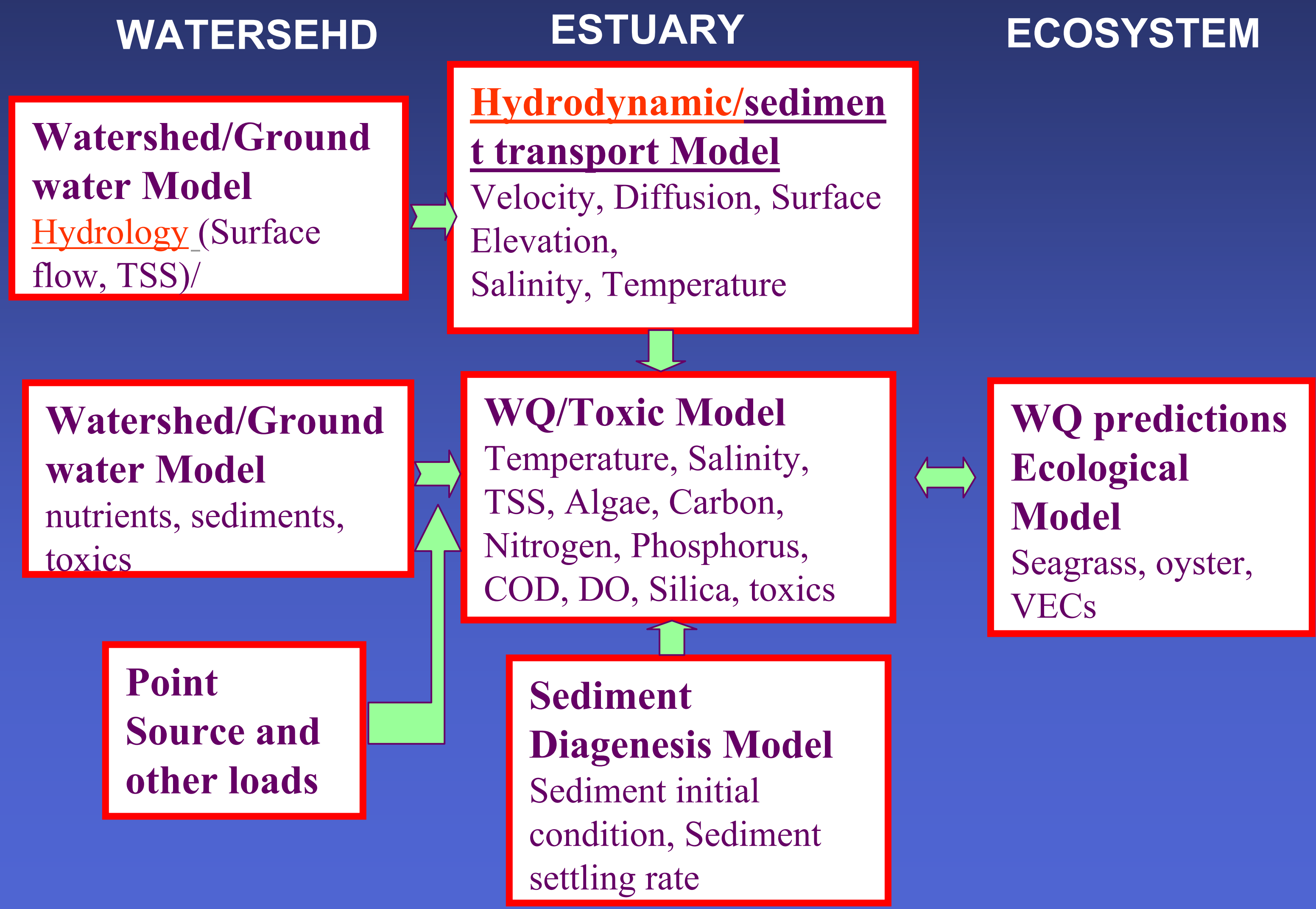
MODEL	ISSUE ADDRESSED
TIME	**Coastal flow and salinity changes due to Everglades restoration**
TTI	**Potential changes in temperature and salinity conditions in manatee refugia**
Biscayne	**Response of Biscayne Bay hydrology to proposed water-management changes**
Pompano Intrusion	**Causes of saltwater intrusion near a municipal well field**
Deep Well Injection	**Fate and transport of injected wastewater in the Floridan aquifer**
Northwest Well Field	**Effects of turbulent flow conditions in close proximity to pumping wells**

South Florida Estuaries/Bays



- Southern Indian River Lagoon/St. Lucie River & Estuary
- Loxahatchee River
- Lake Worth Lagoon
- Biscayne Bay
- Florida Bay
- Naples Bay
- Estero Bay
- Caloosahatchee River
- Southern Charlotte Harbor

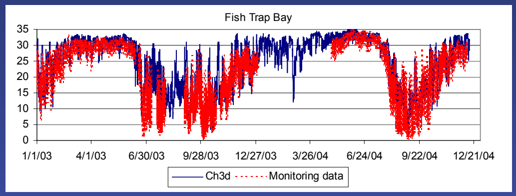
Integrated Modeling Framework



Application

Water Quantity - Caloosahatchee MFLs

Watershed inputs



Flow and Salinity

Hydrodynamic Model-CH3D

Salinity tolerance: The response of the VECs to salinity in the estuary is examined to determine the flow quantity

Application

NW Fork of Loxahatchee River Restoration

Short term influences in tributary inflow and tide

Watershed hydrological model -WaSh

Hydrodynamic /Salinity Model -2D RMA

Long-term salinity management model -LSMM model

Salinity tolerance: The response of the VECs to salinity in the estuary is examined to determine the flow quantity

Predicting daily salinity in the estuary

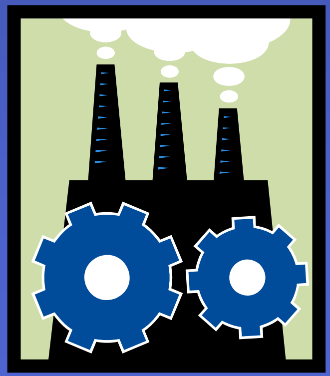
Application

Load Reductions -St. Lucie River and Estuary

Watershed Model -WaSh

Non-Point sources

Watershed inputs



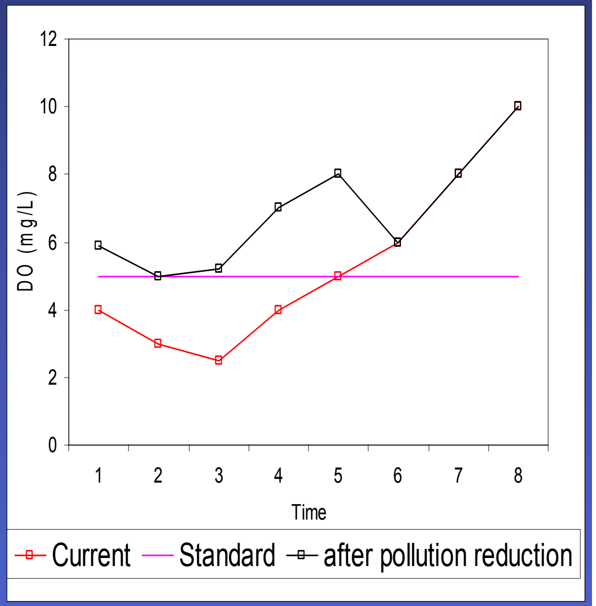
Point sources

Estuary Models

Water Quality Model

Hydrodynamic Model – CH3D

Water Quality Targets/Standards



Next Generation Regional Tool:
Regional Simulation Model

RSM Design Considerations

- Regional in nature – simplifications may be needed
- Reproduce the functionality of the legacy code SFWMM (daily, continuous simulation for <u>planning</u> applications)
- Reasonable run times
- Improved process and solution algorithms, use of advances in computer technology including programming languages, GIS and databases
- Better resolution than SFWMM in areas where it is needed
- Eliminate or minimize “hard coding” of simulation alternatives

RSM Engines

HSE

RSM

MSE

South Florida Regional Simulation Model
SFRSM

Hydrologic Simulation Engine (HSE)

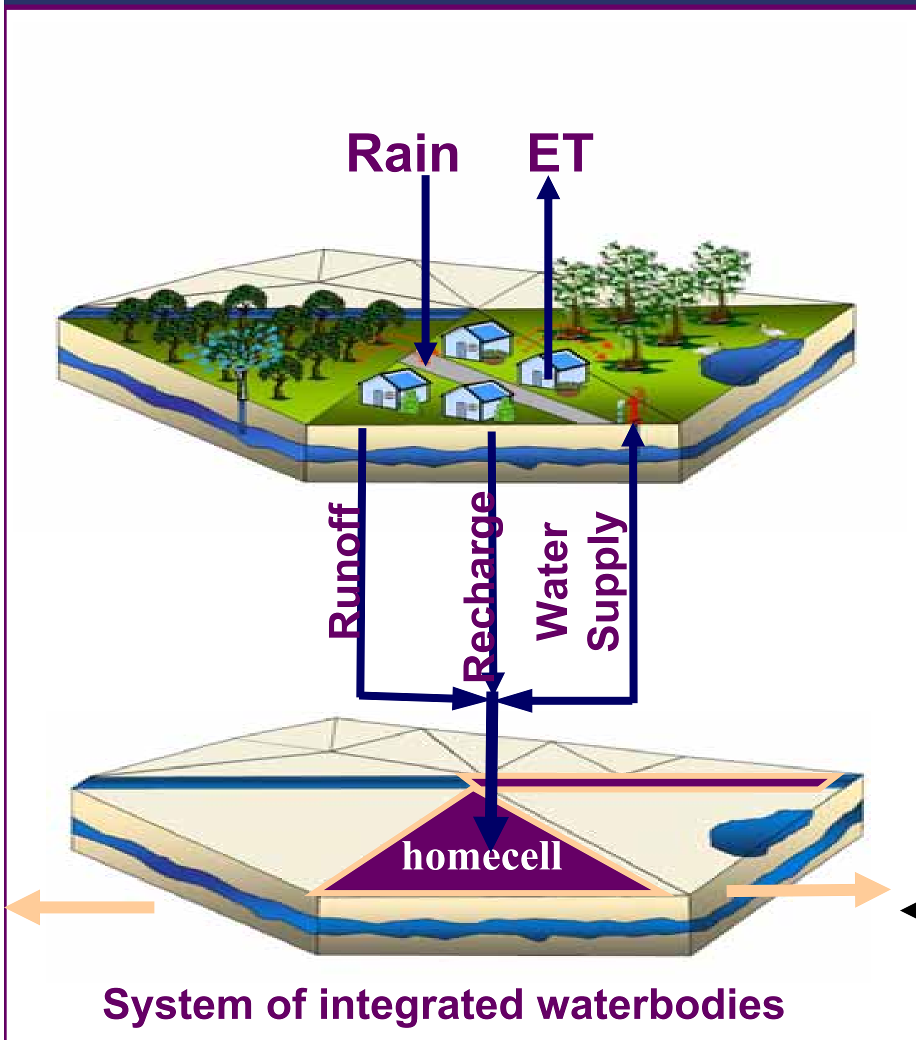
- Model physical setup
- Simulate hydrologic processes
- Overland flow
- Groundwater flow
- Canal network
- Calibration/validation of model parameters
- Use observed structure flows

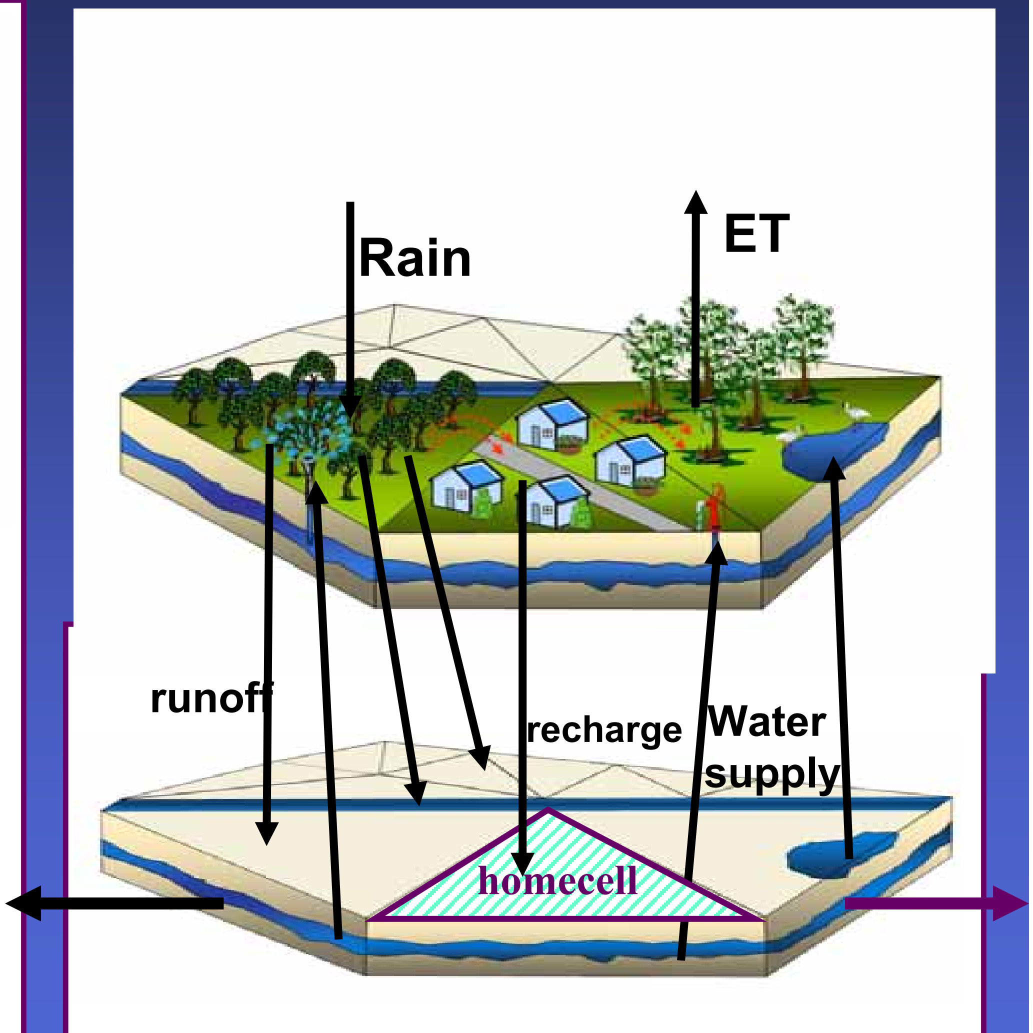
Management Simulation Engine (MSE)

- Simulate structure operations
- Implementation of operational rules
- Flood control rules
- Water supply policies
- Maintain minimum flows & levels
- Regional operational coordination

Hydrologic Process Modules

Simple landscape *Complex landscape*





Diffusive Wave Formulation

Mass Balance

$$0 = \frac{\partial}{\partial t}\int_{cv} d\mathcal{V} + \int_{cs} (\mathbf{E}\cdot\mathbf{n})\, dA$$

Waterbody *Watermover*

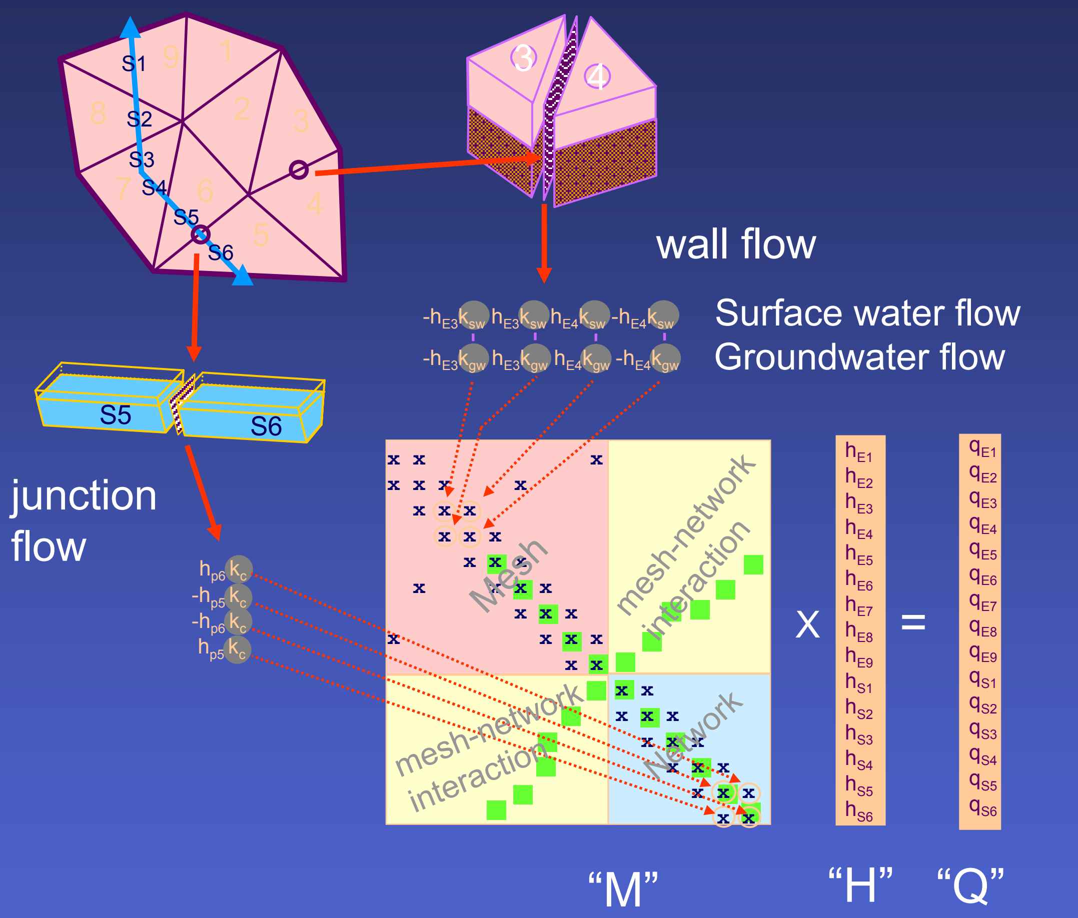
Momentum Equation

$$\mathbf{F} = \frac{\partial}{\partial t}\int_{cv} \mathbf{E}\rho\, d\mathcal{V} + \int_{cs} \mathbf{E}\rho(\mathbf{V}\cdot\mathbf{n})\, dA$$

$$F = \begin{pmatrix} \rho g h S_x - \tau_{bx} \\ \rho g h S_y - \tau_{by} \end{pmatrix}$$

*For diffusive formulation, neglect all the inertia terms in RHS

Watermover to Sparse Matrix Interaction



- **Simultaneous solution**
  - **surface / groundwater**
  - **canal network**
  - **Interactions**
- **Watermovers' submatrices fall into place in overall matrix**
- **All components of the system are coupled**

Legend

S_n - segment
E_n - cell
h_n - head in cell & segment
k_c - segment hydraulic conductivity
k_{sw} - surface water conductivity markers

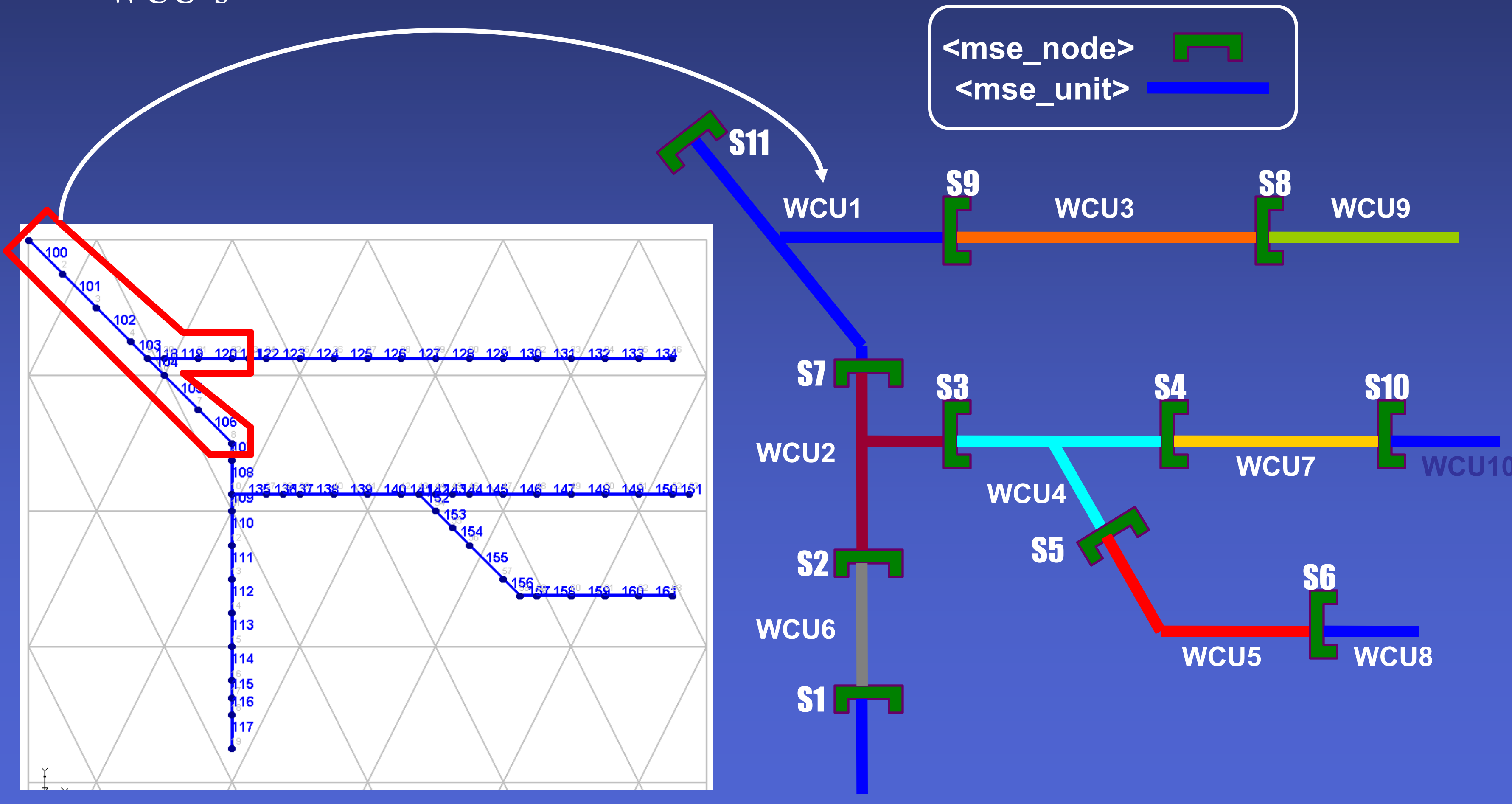
M - stiffness matrix
H - head vector
Q - flow vector
x - 2D & 1D network matrix markers
■ - mesh-network interaction matrix

k_{gw} - ground water conductivity

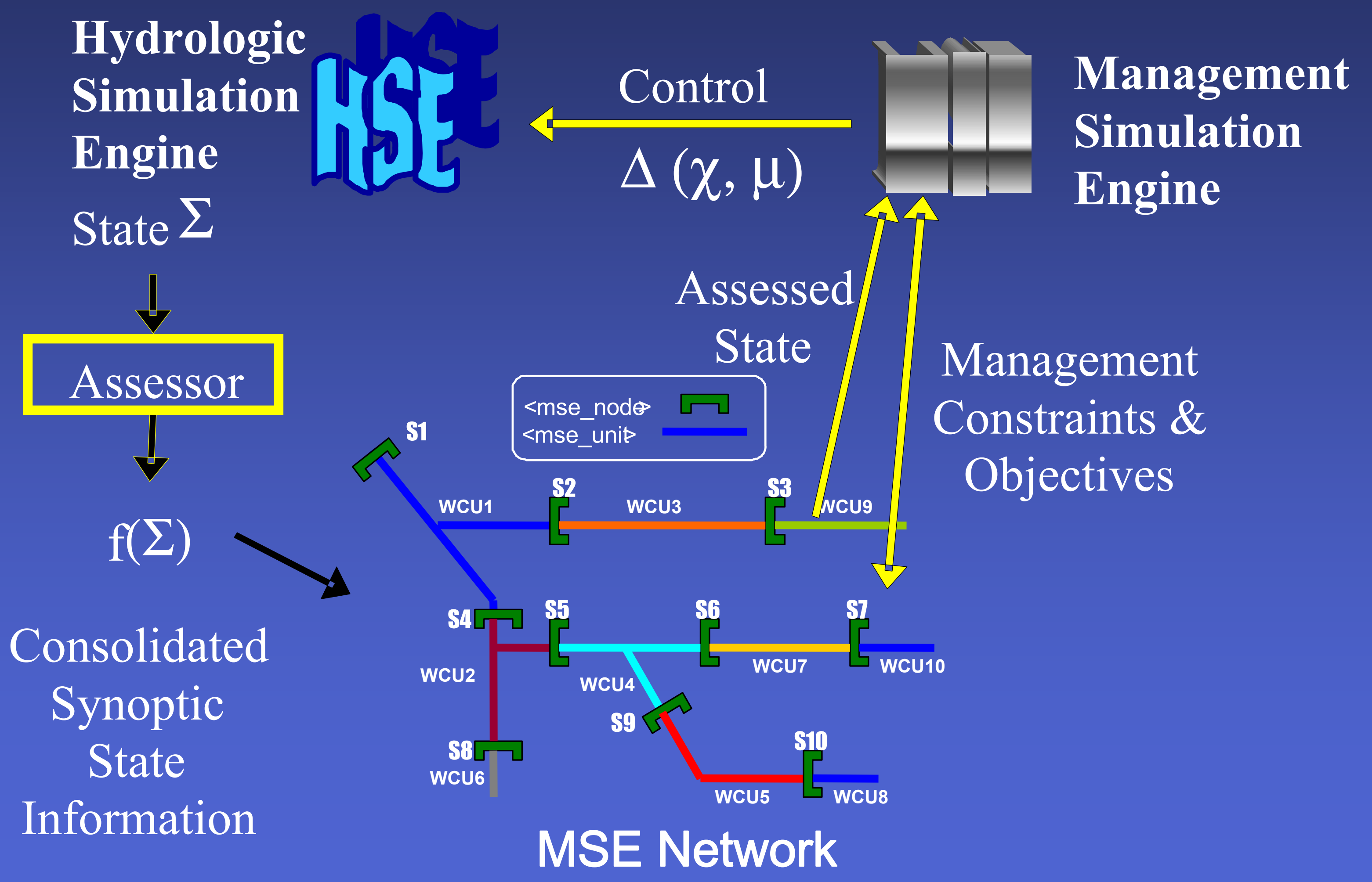
MSE Water Control Unit Network

Provides one-to-one representation of managerial abstraction

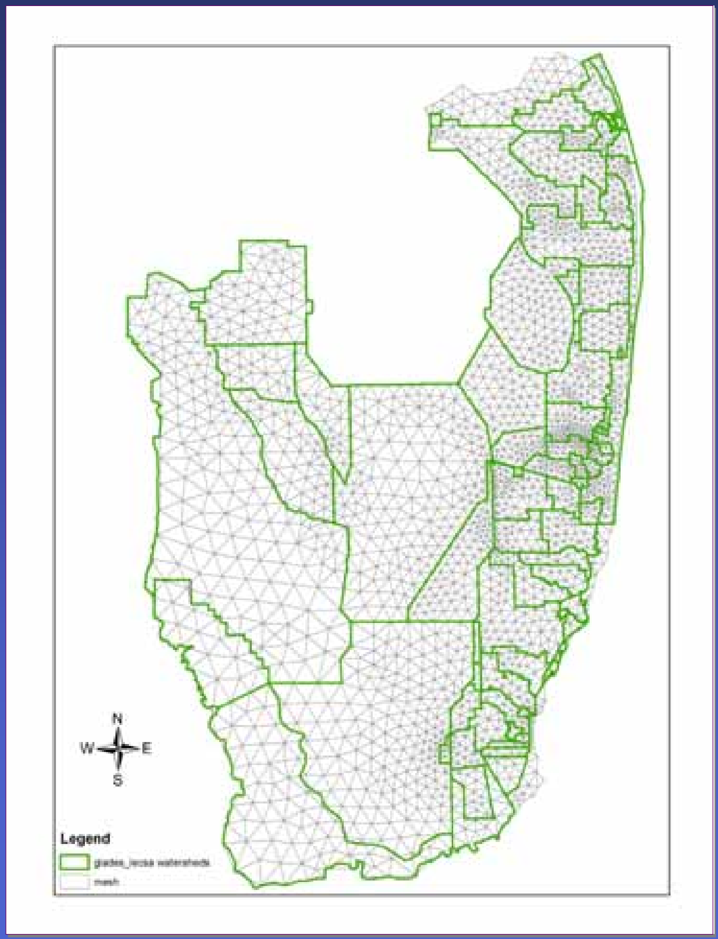
- Structures
- WCU’s



Integration of Management Database with Hydrologic Model

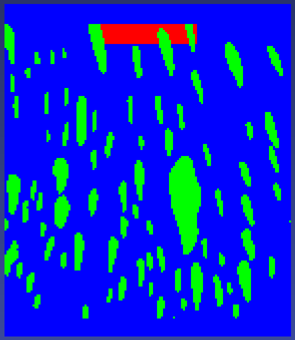


Glades-LECSA Model Domain

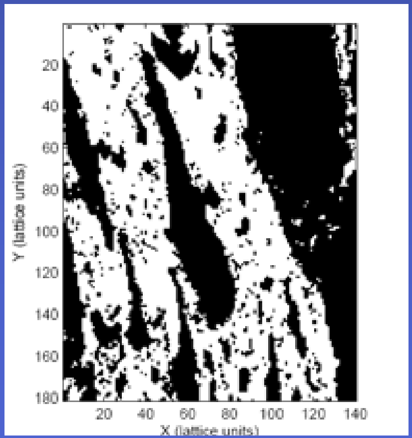


Lattice Boltzmann Modeling

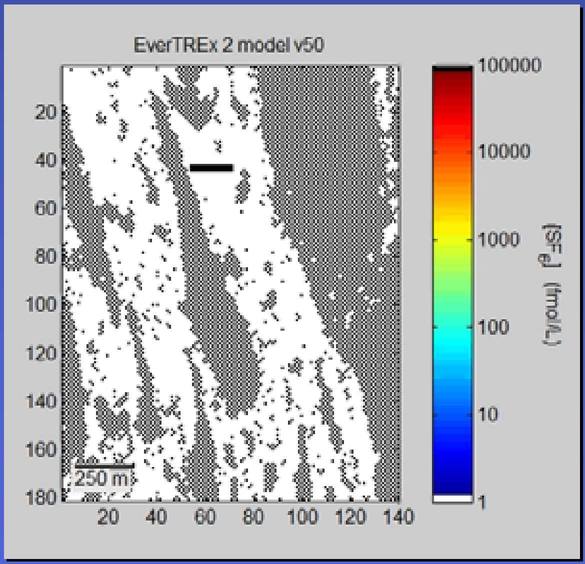
- Microscopic (particle) approach to model macroscopic dynamics
- Adapted to solve Navier-Stokes Equations
- Application (Variano et. al 2008?)



Ridge & Slough image



Bitmap



LBM results

Questions!