Hydrologic & Hydrodynamic Modeling

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sfwmd
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NATIONAL PARK SERVICE
science for a changing world
Restoration Focus

Q | Q

T | D
Uniqueness of South Florida Hydrology

Flat Topography

Complex Hydrostratigraphy

Complex Water Management

Sand/Peat soils

Subsidence

Porosity

Transmissivity
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 (system-wide)”  “Subregional-gw”
Decade of the 70s

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

- Daily time series of water levels, flows
- Demands not met

Scenario
- Model output
- Series of water levels, flows
- Demands not met

Performance Measures (Ag, Env, Urban)

Climatic Input
- Rainfall
- ET

Boundary Conditions

Period of Simulation
1965

Landuse/Landcover

Water Demands

Operating Criteria

SFWMM Model

Hydrologic Performance Measures

www.sfwmd.gov/org/pld/restudy/hpm
Lake Okeechobee Monthly Position Analysis

Middle 50%

Water Shortage Management Zone

(See assumptions @ http://www.sfwmd.gov/org/pld/hsm/sfwmm_pa.html)
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.
# Model Applications

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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

WATERSEHD

Watershed/Ground water Model
Hydrology (Surface flow, TSS)/

Watershed/Ground water Model
WQ/Toxic Model
WQ predictions
Ecological Model
Seagrass, oyster, VECs

Hydrodynamic/sediment transport Model
Velocity, Diffusion, Surface Elevation, Salinity, Temperature

WQ/Toxic Model
Temperature, Salinity, TSS, Algae, Carbon, Nitrogen, Phosphorus, COD, DO, Silica, toxics

Sediment Diagenesis Model
Sediment initial condition, Sediment settling rate

Point Source and other loads

ESTUARY

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

Watershed inputs

Flow and Salinity

Hydrodynamic Model-CH3D
Application

NW Fork of Loxahatchee River Restoration

Short term influences in tributary inflow and tide

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

Watershed hydrological model -WaSh
Application
Load Reductions - St. Lucie River and Estuary

Watershed Model - WaSh

Non-Point sources

Watershed inputs

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 planning 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

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

South Florida Regional Simulation Model (SFRSM)
Hydrologic Process Modules

System of integrated waterbodies

Simple landscape

Complex landscape

Rain
ET

Runoff
Recharge
Water Supply

homecell

runoff
recharge
Water supply

homecell
**Diffusive Wave Formulation**

**Mass Balance**

\[
0 = \frac{\partial}{\partial t} \int_{cv} dV + \int_{cs} \left( E \cdot n \right) dA
\]

**Momentum Equation**

\[
F = \frac{\partial}{\partial t} \int_{cv} E \rho \, dV + \int_{cs} E \rho \left( V \cdot n \right) \, dA
\]

\[
F = \begin{pmatrix}
\rho ghS_x - \tau_{bx} \\
\rho ghS_y - \tau_{by}
\end{pmatrix}
\]

*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
- $k_{gw}$: ground water conductivity

$M$: stiffness matrix
$H$: head vector
$Q$: flow vector
$X$: 2D & 1D network matrix markers
- Mesh-network interaction matrix

Surface water flow
Groundwater flow
MSE Water Control Unit Network

Provides one-to-one representation of managerial abstraction

• Structures
• WCU’s
Integration of Management Database with Hydrologic Model

Hydrologic Simulation Engine
State $\Sigma$

Assessor

$f(\Sigma)$

Consolidated Synoptic State Information

Management Simulation Engine

Assessed State

$\Delta (\chi, \mu)$

Control

MSE Network

Constraints & Objectives
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!