NFSEG v1.0 Overview
MODFLOW

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Why is NFSEG needed?

- Needed a tool for evaluations of inter-district and interstate pumping impact
- Needed a common North Florida model jointly developed by SJRWMD and SRWMD
- Needed a comprehensive model developed through a cooperative process including all interested stakeholders
Model Overview

- About 60,000 square miles
- MODFLOW-NWT
- 2500x2500 ft grid
- 7 layers
- HSPF models
- Steady-state calibration (2001 and 2009)
# Model Layers

<table>
<thead>
<tr>
<th>Series</th>
<th>Hydrogeologic Unit</th>
<th>Model Layer</th>
<th>Series</th>
<th>Hydrogeologic Unit</th>
<th>Model Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-Miocene</td>
<td>Surficial Aquifer System</td>
<td>Layer 1(^1)</td>
<td>Post-Miocene</td>
<td>Surficial Aquifer System(^1)</td>
<td>Layer 1(^1)</td>
</tr>
<tr>
<td>Miocene</td>
<td>Intermediate Aquifer System/Intermediate Confining Unit</td>
<td>Layer 2(^1)</td>
<td>Miocene</td>
<td>Intermediate Aquifer System/Intermediate Confining Unit(^1)</td>
<td>Layer 2(^1)</td>
</tr>
<tr>
<td>Oligocene</td>
<td>Upper Floridan Aquifer</td>
<td>Layer 3(^1)</td>
<td>Oligocene</td>
<td>Upper Floridan Aquifer</td>
<td>Layer 3(^1)</td>
</tr>
<tr>
<td>Upper Eocene</td>
<td>Upper Floridan Aquifer</td>
<td>Layer 3(^1)</td>
<td>Upper Eocene</td>
<td>Pearl River Aquifer Confining Unit</td>
<td>Layer 4(^1)</td>
</tr>
<tr>
<td>Middle Eocene</td>
<td>Middle Semicomfining Unit, where present, otherwise Upper Floridan</td>
<td>Layer 4(^1)</td>
<td>Middle Eocene</td>
<td>Pearl River Aquifer</td>
<td>Layer 5</td>
</tr>
<tr>
<td>Lower Eocene</td>
<td>Lower Floridan Aquifer (Upper Zone), where present, otherwise Upper Floridan</td>
<td>Layer 5(^1)</td>
<td>Lower Eocene</td>
<td>Lower Floridan Aquifer (Fernandina Permeable Zone)</td>
<td>Layer 6(^1)</td>
</tr>
<tr>
<td>Paleocene</td>
<td>Lower Semicomfining Unit</td>
<td>Layer 6(^1)</td>
<td>Paleocene</td>
<td>Chattahoochee River Aquifer Confining Unit</td>
<td>Layer 6(^2)</td>
</tr>
<tr>
<td>Upper Cretaceous</td>
<td>Sub-Florian Confining Unit</td>
<td>Inactive</td>
<td>Upper Cretaceous</td>
<td>Chattahoochee River Aquifer</td>
<td>Layer 7(^2) Inactive</td>
</tr>
</tbody>
</table>
Lateral Boundary Conditions
Springs and Rivers

- Springs: GHB
- Lakes and perennial rivers: River Package
- Ephemeral rivers: Drain package
- SRWMD HEC-RAS model
- St. Johns River SW Model

Legend:
- Springs
- St. Johns River SW Model
- SRWMD Major Rivers
- Rivers
- ModelActiveBoundary
## Water Use Data for MODFLOW Well Package

<table>
<thead>
<tr>
<th>Region</th>
<th>PS/CII/Rec</th>
<th>DSS</th>
<th>AG</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL Water Use</td>
<td>SJRWMD/SRWMD/ SWFWMD/NFWFWMD Permit Database</td>
<td>Estimated by SJRWMD using parcel data and well construction database and SWFWMD Database</td>
<td>SJRWMD/SRWMD/ SWFWMD Permit and FSAID Database and Metered/Reported water use</td>
</tr>
<tr>
<td>GA Water Use</td>
<td>Provided by USGS</td>
<td>Estimated using Census blocks and USGS estimates</td>
<td>Estimated using AFSIRS and USGS Estimates</td>
</tr>
<tr>
<td>SC Water Use</td>
<td>Estimated using Census blocks and USGS estimates</td>
<td>Estimated using Census blocks and USGS estimates</td>
<td>Estimated using AFSIRS and USGS Estimates</td>
</tr>
</tbody>
</table>
Groundwater Withdrawals (2009, mgd)
Injection Wells

- Anthropogenic Features
  - Rapid Infiltration Basins
  - Reuse Injection
  - Drainage Wells
- HSPF Sinks
Well Package

- Regular well package
  - Source aquifer is only one aquifer/model layer
- MNW2 package
  - Source aquifer is more than one aquifer/model layer
Recharge Methodology

- **HSPF**
  - Gross Recharge
  - Maximum available saturated ET
  - Sinks and Drainage Well flows

- **MODFLOW**
  - Recharge Package – for gross recharge input
  - ET Package – for groundwater ET simulations
    - Maximum available saturated ET
    - ET Extinction Depth

- **PEST Model Calibration**
  - Recharge multipliers per subwatershed
  - MSET multipliers per subwatershed
Objectives of using HSPF

- To reduce the uncertainty in the initial estimates of recharge and MSET
- To overcome the shortcomings of the previous methods used in regional models
- To minimize the need to adjust recharge and MSET during groundwater model calibration
Overview of HSPF Models

- Surface Water (HSPF) Models
- More than 900 subwatersheds
- Rainfall: NLDAS (North American Land Data Assimilation System)
- PET: Modified NLDAS based on USGS datasets
- Agricultural Irrigation
- Residential/Commercial Irrigation
- Golf Course Irrigation
- Septic Fields Seepage
Calibration of HSPF Models

- Over 900 subwatersheds
- Transient calibration
- 1992 through 2014
- Hourly simulations

- Precipitation
- Evapotranspiration
- Agricultural Irrigation
- Non-Agricultural Irrigation
- Septic Fields Seepage
MODFLOW - HSPF Interaction

Gross Recharge = Rainfall – Direct Runoff – Interception ET - Unsaturated ET

Maximum available saturated ET = Potential ET - Interception ET – Unsaturated ET
Recharge

2001 Assigned Recharge Rates (shown as white where not applied)
Inches per Year (ipy)
- > 0 - 5
- 6 - 10
- 11 - 15
- >15 ipy

2009 Assigned Recharge Rates (shown as white where not applied)
Inches per Year (ipy)
- > 0 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- > 15 ipy
Maximum Saturated ET
## ET Extinction Depth

(Modified from Shah et al., 2007)

### Extinction Depths (ft) under Forest Land Cover

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Hydric</th>
<th>Partly hydric</th>
<th>Non-hydric</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>4.9</td>
<td>9.8</td>
<td>14.8</td>
</tr>
<tr>
<td>loamy sand</td>
<td>5.6</td>
<td>10.5</td>
<td>15.4</td>
</tr>
<tr>
<td>sandy loam</td>
<td>7.5</td>
<td>12.5</td>
<td>17.4</td>
</tr>
<tr>
<td>sandy clay loam</td>
<td>9.8</td>
<td>14.8</td>
<td>19.7</td>
</tr>
<tr>
<td>sandy clay</td>
<td>10.2</td>
<td>15.1</td>
<td>20.0</td>
</tr>
<tr>
<td>loam</td>
<td>12.0</td>
<td>16.9</td>
<td>21.8</td>
</tr>
<tr>
<td>silty clay</td>
<td>14.3</td>
<td>19.2</td>
<td>24.1</td>
</tr>
<tr>
<td>clay loam</td>
<td>16.6</td>
<td>21.5</td>
<td>26.4</td>
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<tr>
<td>silt loam</td>
<td>16.9</td>
<td>21.8</td>
<td>26.9</td>
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<tr>
<td>silt</td>
<td>17.4</td>
<td>22.3</td>
<td>27.2</td>
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<tr>
<td>silty clay loam</td>
<td>18.0</td>
<td>23.0</td>
<td>27.9</td>
</tr>
<tr>
<td>clay</td>
<td>23.6</td>
<td>28.5</td>
<td>33.5</td>
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</tbody>
</table>

### Extinction Depths (ft) under Grass Land Cover

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Hydric</th>
<th>Partly hydric</th>
<th>Non-hydric</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>4.9</td>
<td>6.6</td>
<td>8.2</td>
</tr>
<tr>
<td>loamy sand</td>
<td>5.6</td>
<td>7.2</td>
<td>8.9</td>
</tr>
<tr>
<td>sandy loam</td>
<td>7.5</td>
<td>9.2</td>
<td>10.8</td>
</tr>
<tr>
<td>sandy clay loam</td>
<td>9.8</td>
<td>11.5</td>
<td>13.1</td>
</tr>
<tr>
<td>sandy clay</td>
<td>10.2</td>
<td>11.8</td>
<td>13.5</td>
</tr>
<tr>
<td>loam</td>
<td>12.0</td>
<td>13.6</td>
<td>15.3</td>
</tr>
<tr>
<td>silty clay</td>
<td>14.3</td>
<td>15.9</td>
<td>17.6</td>
</tr>
<tr>
<td>clay loam</td>
<td>16.6</td>
<td>18.2</td>
<td>19.8</td>
</tr>
<tr>
<td>silt loam</td>
<td>16.9</td>
<td>18.5</td>
<td>20.3</td>
</tr>
<tr>
<td>silt</td>
<td>17.4</td>
<td>19.0</td>
<td>20.7</td>
</tr>
<tr>
<td>silty clay loam</td>
<td>18.0</td>
<td>19.7</td>
<td>21.3</td>
</tr>
<tr>
<td>clay</td>
<td>23.6</td>
<td>25.3</td>
<td>26.9</td>
</tr>
</tbody>
</table>
Groundwater Model Calibration

PEST Process

Steady-State Calibration
2001 and 2009

START

Run NFSEG (Modflow)

Read Output

Compare Sim with ObsValues

Calculate SSR

Develop Parameter Sensitivities

Update Input Files

Estimate New Set of Parameters

If Reached Min

More than 7,000 model runs in each iteration

FINISH

SSR: Sum of squared residuals

2001 and 2009
Observation Groups

- Observed Water Levels
- Vertical WL Differences (SAS/UFA and UFA/LFA)
- Horizontal WL Differences
- Spring flows
  - Individual springs
  - Spring groups
- Baseflows
  - Baseflow Pickups
  - Cumulative baseflows
- Temporal WL Differences (2009 – 2001)
- Lake Leakages
- Flooding penalty (limited)
Water Level Observation Dataset

- Total - 1599
  - SAS – 296
  - UFA – 1120
  - LFA – 42
  - Others - 141
Parameter Groups

- Hydraulic Conductivities (Pilot Points)
- Vertical Anisotropy (kx/kz)
- Spring Conductances
- River Conductances
- Lake Conductances
- Lake layer 2 kz zone multipliers
- Recharge Multipliers
NFSEG v1.0
Calibration Results
SAS Water Levels

Observed Versus Simulated for Observation Group h2001_lay1

Residual Mean: 0.44
Residual Abs. Mean: 3.78
Residual Std Dev: 5.46
R squared: 0.99

Observed Versus Simulated for Observation Group h2009_lay1

Residual Mean: 1.15
Residual Abs. Mean: 3.36
Residual Std Dev: 4.80
R squared: 0.99
UFA Water Levels
UFA Water Level Residuals
LFA Water Levels
LFA Water Level Residuals

2001 Water Level Residuals

2009 Water Level Residuals
SAS/UFA Water Level Difference

Observed Versus Simulated for Observation Group vd_1to3

- Residual Mean = 0.64
- Residual Abs. Mean = 2.59
- Residual Std Dev = 3.79
- R squared = 0.99
SAS/UFA Water Level Difference Residuals

2001 Residual Vertical Head Differences
Surficial aquifer system vs.
Upper Floridan Aquifer

2009 Residual Vertical Head Differences
Surficial Aquifer System vs.
Upper Floridan Aquifer
UFA/LFA Water Level Difference

Observed Versus Simulated for Observation Group vd_3to5

Residual Mean=0.14
Residual Abs. Mean=1.31
Residual Std Dev=1.79
R squared=0.72
UFA/LFA Water Level Difference Residuals
Individual Springs
Large spring groups
Cumulative Baseflows

Observed Versus Simulated for Observation Group cps01

Residual Mean=-31.84
Residual Abs. Mean=45.89
Residual Std Dev=98.00
R squared=0.93

Observed Versus Simulated for Observation Group cps09

Residual Mean=-72.21
Residual Abs. Mean=75.42
Residual Std Dev=88.03
R squared=0.90
Cumulative Baseflow Residuals 2001
Cumulative Baseflow Residuals 2009
(Less Confidence with the target baseflows)
## Calibration Statistics

<table>
<thead>
<tr>
<th>Statistical Criterion</th>
<th>Proposed Target</th>
<th>All Target Wells</th>
<th>Target Wells (# of WL Data &gt; 1)</th>
<th>North Florida WSP Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5 feet &lt; Residual &lt; 5 feet</td>
<td>80%</td>
<td>81%</td>
<td>83% 82%</td>
<td>86% 87%</td>
</tr>
<tr>
<td>-2.5 feet &lt; Residual &lt; 2.5 feet</td>
<td>50%</td>
<td>55%</td>
<td>55% 57%</td>
<td>63% 67%</td>
</tr>
<tr>
<td>Mean Error</td>
<td>0.2</td>
<td>-0.1</td>
<td>0.0 -0.1</td>
<td>-0.4 -0.1</td>
</tr>
<tr>
<td>Absolute Mean Error</td>
<td>3.2</td>
<td>3.0</td>
<td>2.9 3.0</td>
<td>2.6 2.5</td>
</tr>
<tr>
<td>Root Mean Square of Error</td>
<td>4.4</td>
<td>4.3</td>
<td>4.0 4.2</td>
<td>3.7 3.7</td>
</tr>
<tr>
<td>Nash–Sutcliffe Efficiency</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99 0.99</td>
<td>0.99 0.99</td>
</tr>
<tr>
<td>No of Targets</td>
<td>1242</td>
<td>1260</td>
<td>1115 1114</td>
<td>446 447</td>
</tr>
</tbody>
</table>
North Florida Water Supply Partnership
Area
SAS Water Level Residuals

2009 SAS WL Residuals
North Florida Water Supply Partnership Area

Legend

Model Underestimates (ft)
- >15
- 10.1 - 15.0
- 7.6 - 10.0
- 5.1 - 7.5
- 0.0 - 5.0

Model Overestimates (ft)
- -4.9 - 0.0
- -7.4 - -5.0
- -8.9 - -7.5
- -14.9 - -10.0
- < -15.0
LFA Water Level Residuals
SAS/UFA WL Difference 2009

2009 SAS/UFA WL Differences Residuals
North Florida Water Supply Partnership Area

Legend
- NFWS_Counties
- County Boundaries, SE US
- VHD_Layers_1t03
- Residual
  - -11.5 -- -10.0
  - -9.9 -- -5.0
  - -4.9 -- 5.0
  - 5.1 -- 10.0
  - 10.1 -- 23.3

Less reliable dataset is shown as highlighted.
UFA/LFA WL Difference 2009

2009 UFA/LFA WL Differences Residuals
North Florida Water Supply Partnership Area

Legend
- NFW Counties
- County Boundaries, SE US
- VHD_Layers_3to5
- Residual09
  - -3.0 - -2.5
  - -2.4 - 2.5
  - 2.6 - 5.1

Less realistic dataset is shown as highlighted.
Water Budget 2009

NFSEG Inflows

- Lateral Boundary (GHB): 11% (1.3 in/yr)
- Recharge Wells/Sinks: 1% (0.13 in/yr)
- Recharge: 88% (9.97 in/yr)

NFSEG Outflows

- Ocean: 3% (0.37 in/yr)
- Pumping Wells: 6% (0.71 in/yr)
- ET: 41% (4.67 in/yr)
- Rivers/lakes: 34% (3.85 in/yr)
- Springs (GHB): 15% (1.69 in/yr)
- Lateral Boundary (GHB): 1% (0.1 in/yr)
Aquifer Parameters
SAS Ks
Layer 2 (ICU where it exists)
UFA Ts
Layer 4
(MCU where it exists)
Layer 5 (LFA where it exists)
Parameter Sensitivity and Predictive Uncertainty Analysis
<table>
<thead>
<tr>
<th>Parameter group name</th>
<th>Parameterization device</th>
<th>Number of parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>k1x, k3x, k5x, k5x3x</td>
<td>pilot points</td>
<td>518, 1767, 201, 556</td>
<td>horizontal hydraulic conductivity – layer 1, layer 3, layer 5, layer 5</td>
</tr>
<tr>
<td>k5x, k7x, k2z, k2z3z</td>
<td>pilot points</td>
<td>364, 55, 556, 333</td>
<td>horizontal hydraulic conductivity – layer 5, layer 7, layer 2, layer 2</td>
</tr>
<tr>
<td>k7x</td>
<td>pilot points</td>
<td>55</td>
<td>horizontal hydraulic conductivity – layer 7</td>
</tr>
<tr>
<td>k2z</td>
<td>pilot points</td>
<td>556</td>
<td>vertical hydraulic conductivity – layer 2</td>
</tr>
<tr>
<td>k2z3z</td>
<td>pilot points</td>
<td>333</td>
<td>vertical hydraulic conductivity multiplier outside ICU – layer 2</td>
</tr>
<tr>
<td>k4z, k4z3z, k4z3z</td>
<td>pilot points</td>
<td>230, 139, 139</td>
<td>vertical hydraulic conductivity – layer 4, layer 4, layer 4</td>
</tr>
<tr>
<td>k6z</td>
<td>pilot points</td>
<td>68</td>
<td>vertical hydraulic conductivity – layer 6</td>
</tr>
<tr>
<td>vanis1</td>
<td>entire layer</td>
<td>257</td>
<td>vertical anisotropy – layer 1</td>
</tr>
<tr>
<td>vanis2</td>
<td>zoned according to ICU/non-ICU</td>
<td>2</td>
<td>vertical anisotropy – layer 2</td>
</tr>
<tr>
<td>vanis3</td>
<td>entire layer</td>
<td>1</td>
<td>vertical anisotropy – layer 3</td>
</tr>
<tr>
<td>vanis4</td>
<td>zoned according to MCU/non-MCU</td>
<td>2</td>
<td>vertical anisotropy – layer 4</td>
</tr>
<tr>
<td>vanis5</td>
<td>zoned according to MCU/non-MCU</td>
<td>2</td>
<td>vertical anisotropy – layer 5</td>
</tr>
<tr>
<td>vanis6</td>
<td>entire layer</td>
<td>1</td>
<td>vertical anisotropy – layer 6</td>
</tr>
<tr>
<td>vanis7</td>
<td>entire layer</td>
<td>1</td>
<td>vertical anisotropy – layer 7</td>
</tr>
<tr>
<td>lcm</td>
<td>zoned according to lakes</td>
<td>1871</td>
<td>multiplier applied to lakebed conductance</td>
</tr>
<tr>
<td>rcm</td>
<td>zoned according to river reaches</td>
<td>377</td>
<td>multiplier applied to river reach conductance</td>
</tr>
<tr>
<td>sc</td>
<td>zoned according to springs</td>
<td>377</td>
<td>GHB conductance at springs</td>
</tr>
<tr>
<td>rechmul</td>
<td>zones (see fig 3.1)</td>
<td>904</td>
<td>multiplier applied to recharge rates</td>
</tr>
<tr>
<td>evtrmul</td>
<td>zones (see fig 3.1)</td>
<td>904</td>
<td>multiplier applied to maximum EVT rates</td>
</tr>
<tr>
<td>lkzmul</td>
<td>zoned according to lakes</td>
<td>246</td>
<td>vertical conductivity multiplier under lakes</td>
</tr>
</tbody>
</table>
Semi-linear Uncertainty Analysis

1. Conduct initial linear uncertainty analysis
2. Generate parameter sets expected to produce predictions that are one standard error above or below the value predicted using the calibrated model
3. Run predictive scenarios using the parameter combinations
4. Estimate the uncertainty in model predictions using standard prediction error
## Predictive Uncertainties

<table>
<thead>
<tr>
<th>Prediction name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>w00202_09</td>
<td>UFA observation well near Lake Brooklyn</td>
</tr>
<tr>
<td>w00878_09</td>
<td>UFA observation well near Putnam County MFL lakes</td>
</tr>
<tr>
<td>qro9_iche_sprgrp</td>
<td>Ichetucknee Springs Group</td>
</tr>
<tr>
<td>qs09_2320500</td>
<td>Baseflow to the Suwannee River near Branford, Florida</td>
</tr>
<tr>
<td>qs09_2321500</td>
<td>Baseflow to the Santa Fe River near Worthington Springs</td>
</tr>
<tr>
<td>qs09_2322500</td>
<td>Baseflow to the Santa Fe River near Fort White</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Value of prediction calculated using $k$</th>
<th>Value of predictive change from 2009 to 2035 calculated using $k$</th>
<th>Value of predictive change from 2009 to 2035 calculated using $k-\delta k$</th>
<th>Value of predictive change from 2009 to 2035 calculated using $k+\delta k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>w00202_09</td>
<td>78.37</td>
<td>1.34</td>
<td>1.23</td>
<td>1.42</td>
</tr>
<tr>
<td>w00878_09</td>
<td>27.16</td>
<td>-1.22</td>
<td>-1.45</td>
<td>-0.99</td>
</tr>
<tr>
<td>qro9_iche_sprgrp</td>
<td>-255.54</td>
<td>-12.82</td>
<td>-13.18</td>
<td>-12.49</td>
</tr>
<tr>
<td>qs09_2320500</td>
<td>-4067.08</td>
<td>-65.38</td>
<td>-65.47</td>
<td>-63.94</td>
</tr>
<tr>
<td>qs09_2321500</td>
<td>-36.00</td>
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<td>-0.15</td>
<td>-0.14</td>
</tr>
<tr>
<td>qs09_2322500</td>
<td>-676.95</td>
<td>-23.69</td>
<td>-24.37</td>
<td>-22.93</td>
</tr>
</tbody>
</table>

1Values are in feet. Positive predictive changes mean drawdown.
2Values are in cubic feet per second. Negative predictive changes mean reduction in flows.
Conclusion

- Uncertainties associated with the predictive differences from this analysis are very small.
- The results are consistent with the findings of the uncertainty analysis performed for East-Central Florida Transient model (Sepulveda and Doherty, 2014).
- Non-linear uncertainty analysis will be explored for NFSEG v1.1.
Questions