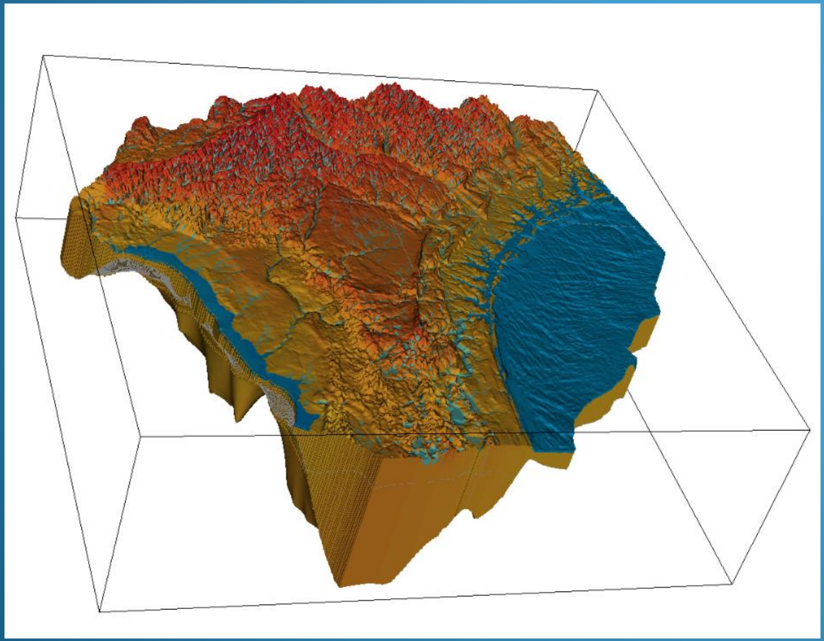
NFSEG v1.0 Overview MODFLOW



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Doug Durden, PE (SJRWMD)
Trey Grubbs (SRWMD)

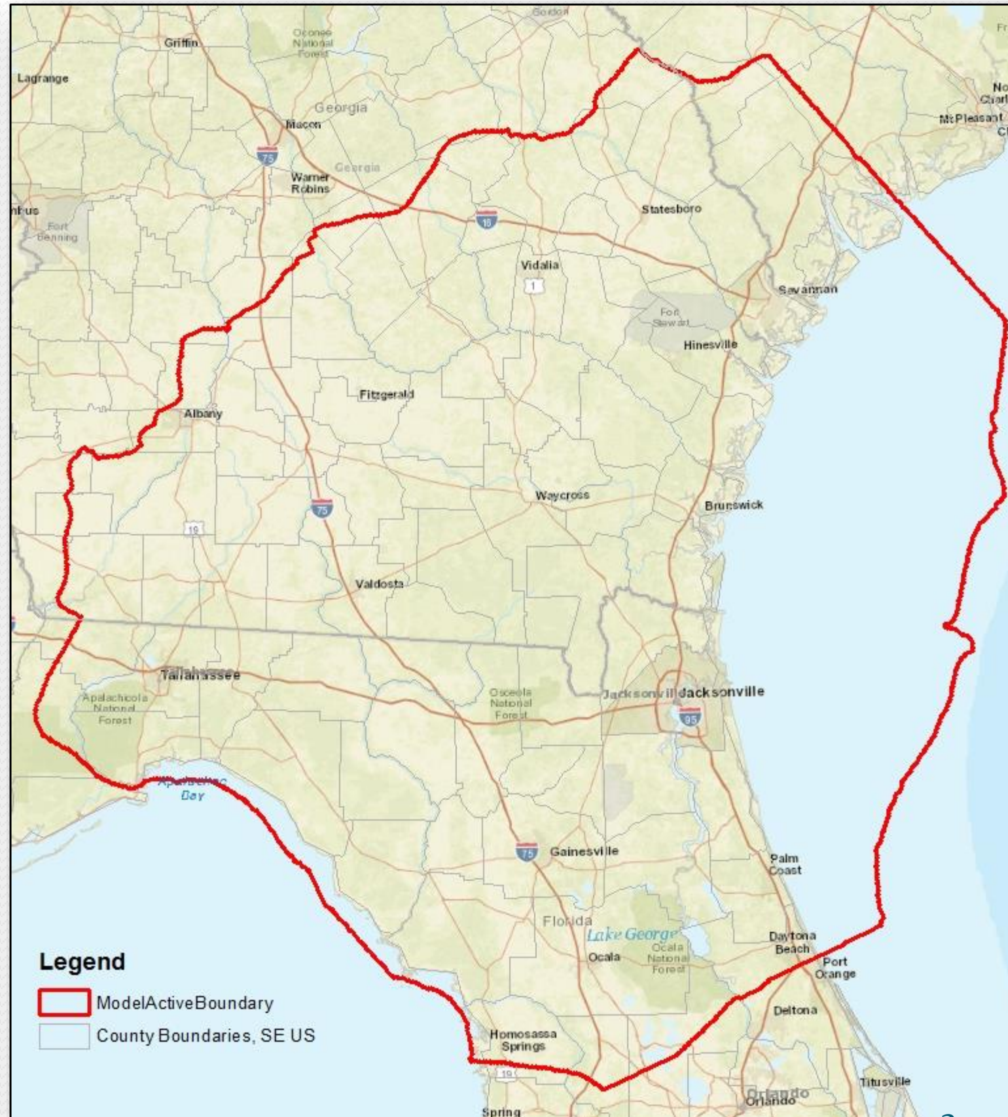
March 29, 2017

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

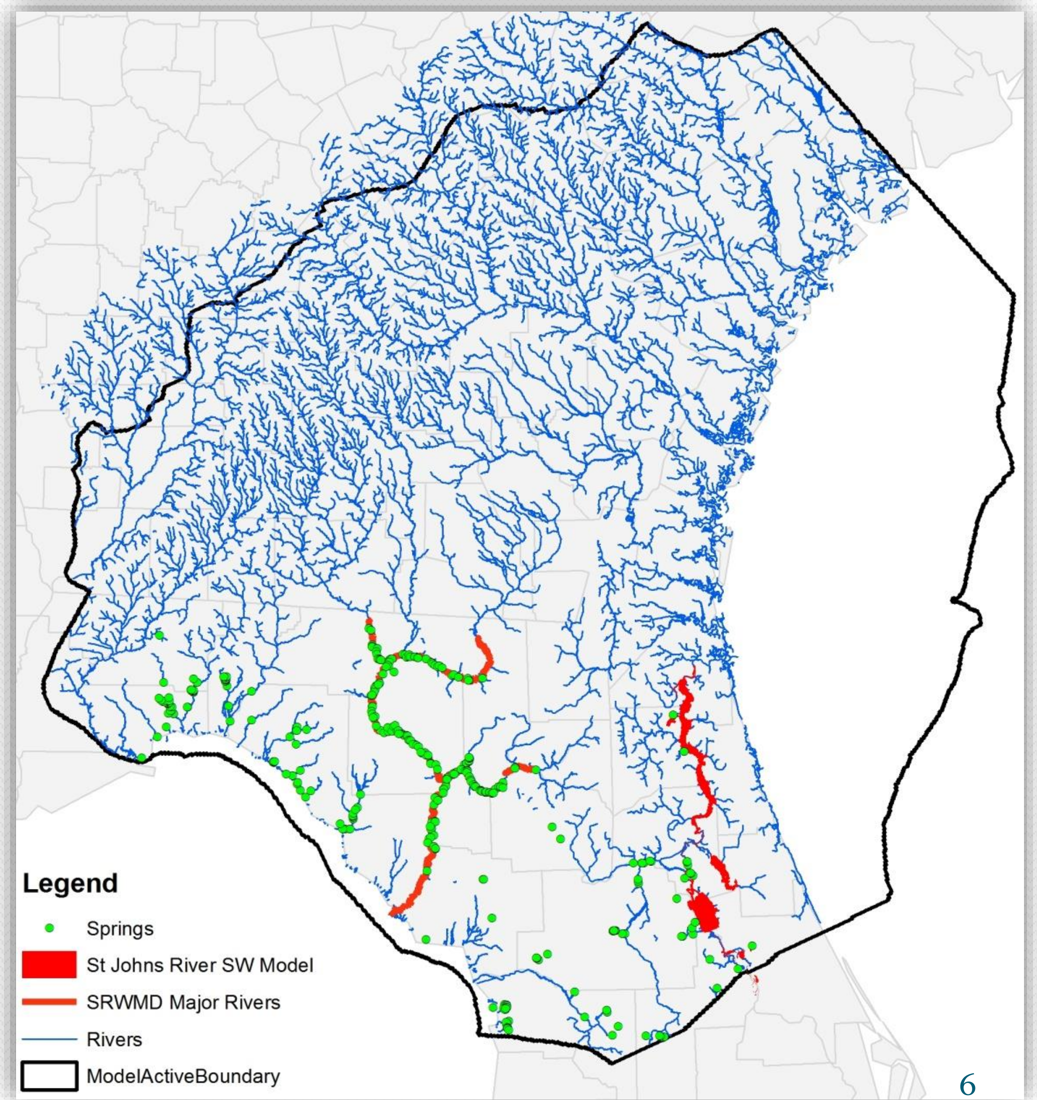
<table>
<tr><th colspan="4">Downdip of Gulf Trough</th></tr>
<tr><th>Series</th><th colspan="2">Hydrogeologic Unit</th><th>Model Layer</th></tr>
<tr><td>Post-Miocene</td><td colspan="2">Surficial Aquifer System</td><td>Layer 1[1]</td></tr>
<tr><td>Miocene</td><td colspan="2">Intermediate Aquifer System/Intermediate Confining Unit</td><td>Layer 2[1]</td></tr>
<tr><td>Oligocene</td><td rowspan="2">Upper Floridan Aquifer</td><td rowspan="8">Floridan Aquifer System</td><td rowspan="2">Layer 3[1]</td></tr>
<tr><td>Upper Eocene</td></tr>
<tr><td rowspan="2">Middle Eocene</td><td>Middle Semiconfining Unit, where present, otherwise Upper Floridan</td><td>Layer 4[1]</td></tr>
<tr><td rowspan="2">Lower Floridan Aquifer (Upper Zone), where present, otherwise Upper Floridan</td><td rowspan="2">Layer 5[1]</td></tr>
<tr><td rowspan="3">Lower Eocene</td></tr>
<tr><td>Lower Semiconfining Unit</td><td>Layer 6[1]</td></tr>
<tr><td rowspan="2">Lower Floridan Aquifer (Fernandina Permeable Zone)</td><td rowspan="2">Layer 7[1]</td></tr>
<tr><td>Paleocene</td></tr>
<tr><td>Upper Cretaceous</td><td colspan="2">Sub-Floridan Confining Unit</td><td>Inactive</td></tr>
</table>

<table>
<tr><th colspan="4">Updip of Gulf Trough</th></tr>
<tr><th>Series</th><th colspan="2">Hydrogeologic Unit</th><th>Model Layer</th></tr>
<tr><td>Post-Miocene</td><td colspan="2">Surficial Aquifer System[1]</td><td>Layer 1[1]</td></tr>
<tr><td>Miocene</td><td colspan="2">Intermediate Aquifer System/Intermediate Confining Unit[1]</td><td>Layer 2[1]</td></tr>
<tr><td>Oligocene</td><td colspan="2" rowspan="2">Upper Floridan Aquifer</td><td rowspan="2">Layer3[1]</td></tr>
<tr><td rowspan="3">Upper Eocene</td></tr>
<tr><td>Pearl River Aquifer Confining Unit</td><td rowspan="8">Southeastern Coastal Plain Aquifer System</td><td>Layer 4[1]</td></tr>
<tr><td rowspan="3">Pearl River Aquifer</td><td rowspan="3">Layer 5</td></tr>
<tr><td>Middle Eocene</td></tr>
<tr><td>Lower Eocene</td></tr>
<tr><td rowspan="2">Paleocene</td><td>Chattahoochee River Aquifer Confining Unit</td><td>Layer 6[2]</td></tr>
<tr><td rowspan="3">Chattahoochee River Aquifer</td><td rowspan="2">Layer 7[2]</td></tr>
<tr><td rowspan="2">Upper Cretaceous</td></tr>
<tr><td>Inactive</td></tr>
</table>

Lateral Boundary Conditions

Springs and Rivers

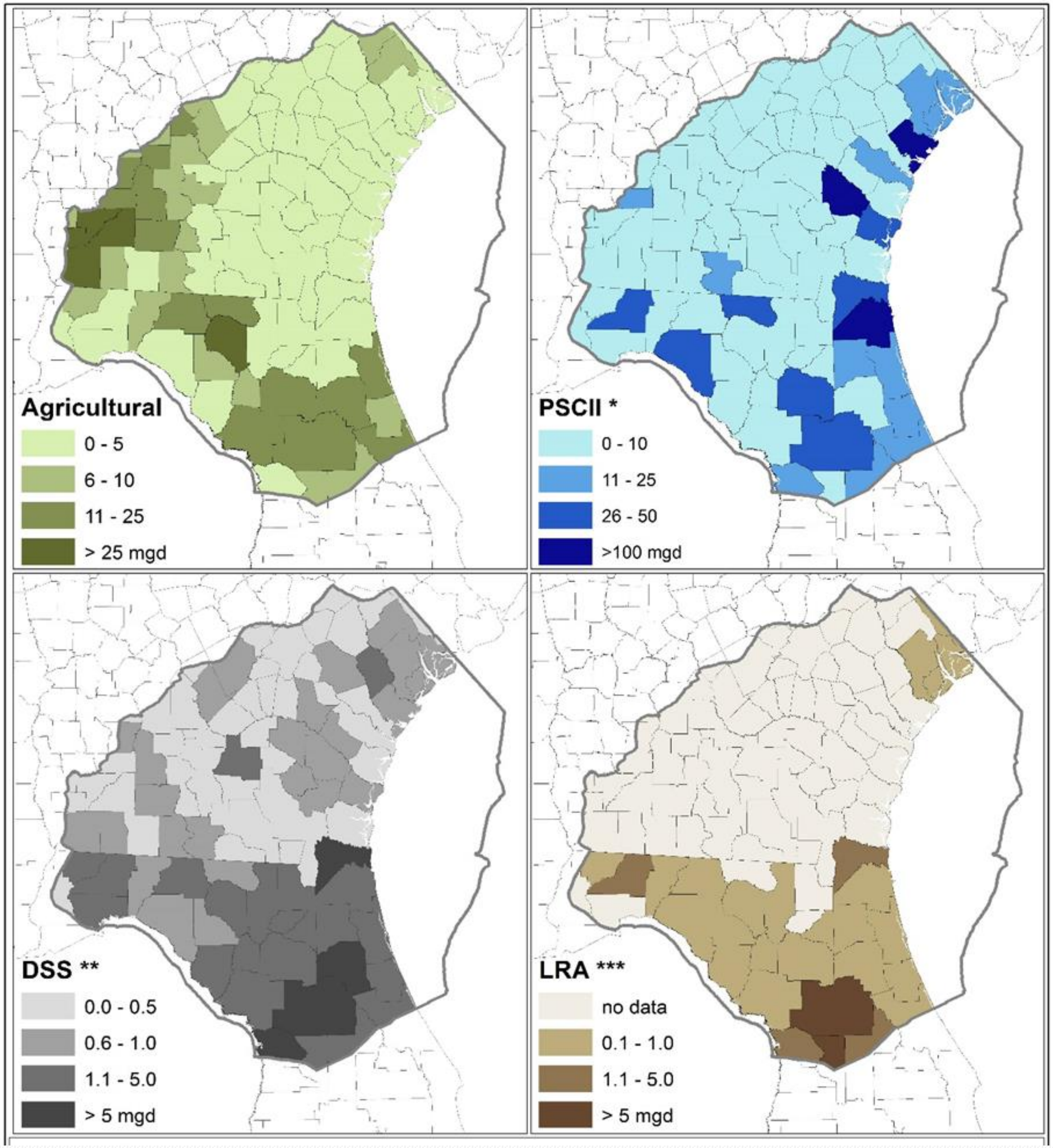
- Springs: GHB
- Lakes and perennial rivers: River Package
- Ephemeral rivers: Drain package
- SRWMD HEC-RAS model
- St. Johns River SW Model



Water Use Data for MODFLOW Well Package

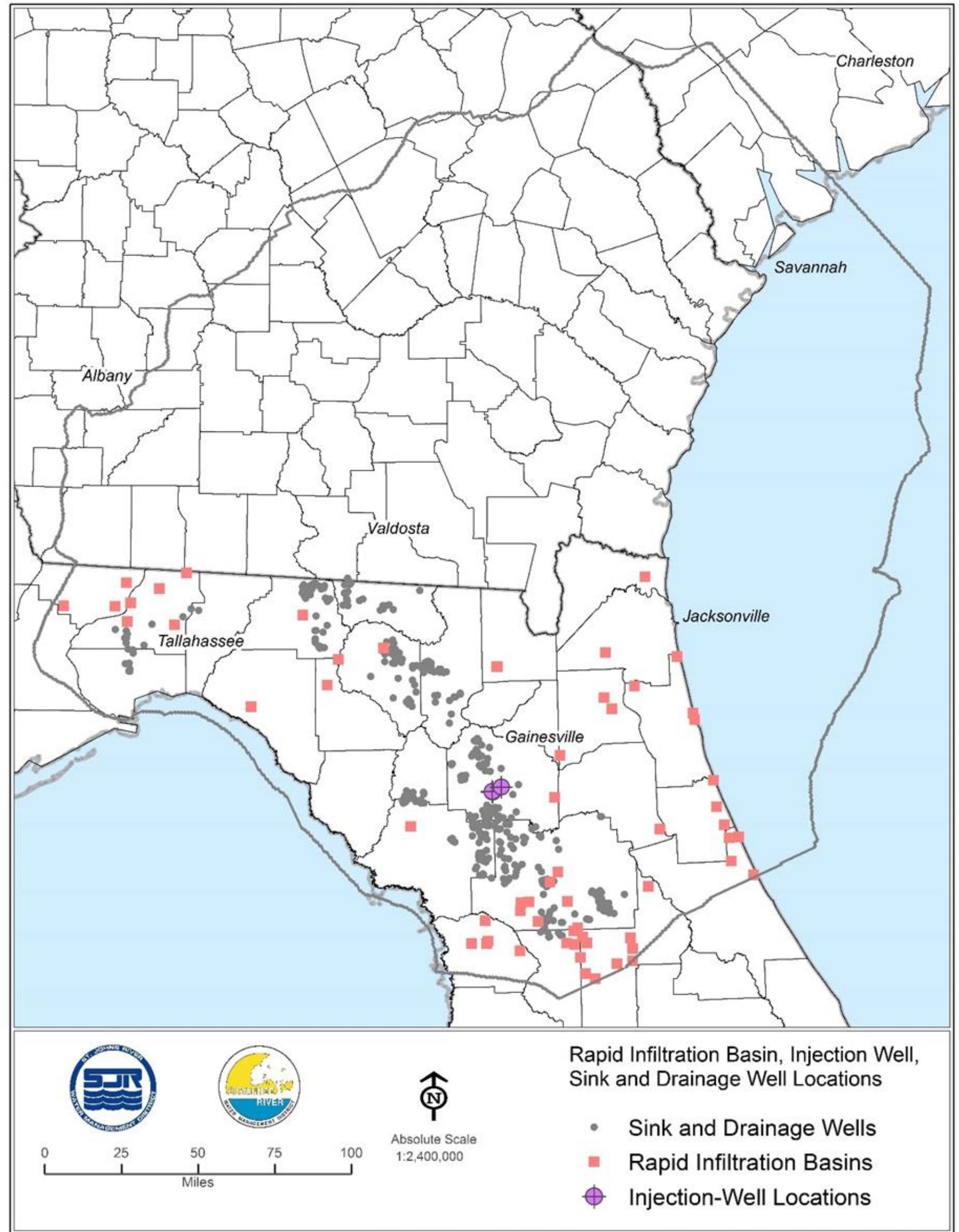
Region	PS/CII/Rec	DSS	AG
FL Water Use	SJRWMD/SRWMD/ SWFWMD/NWFWMD Permit Database	Estimated by SJRWMD using parcel data and well construction database and SWFWMD Database	SJRWMD/SRWMD/ SWFWMD Permit and FSAID Database and Metered/Reported water use
GA Water Use	Provided by USGS	Estimated using Census blocks and USGS estimates	Estimated using AFSIRS and USGS Estimates
SC Water Use	Estimated using Census blocks and USGS estimates	Estimated using Census blocks and USGS estimates	Estimated using AFSIRS and USGS Estimates

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

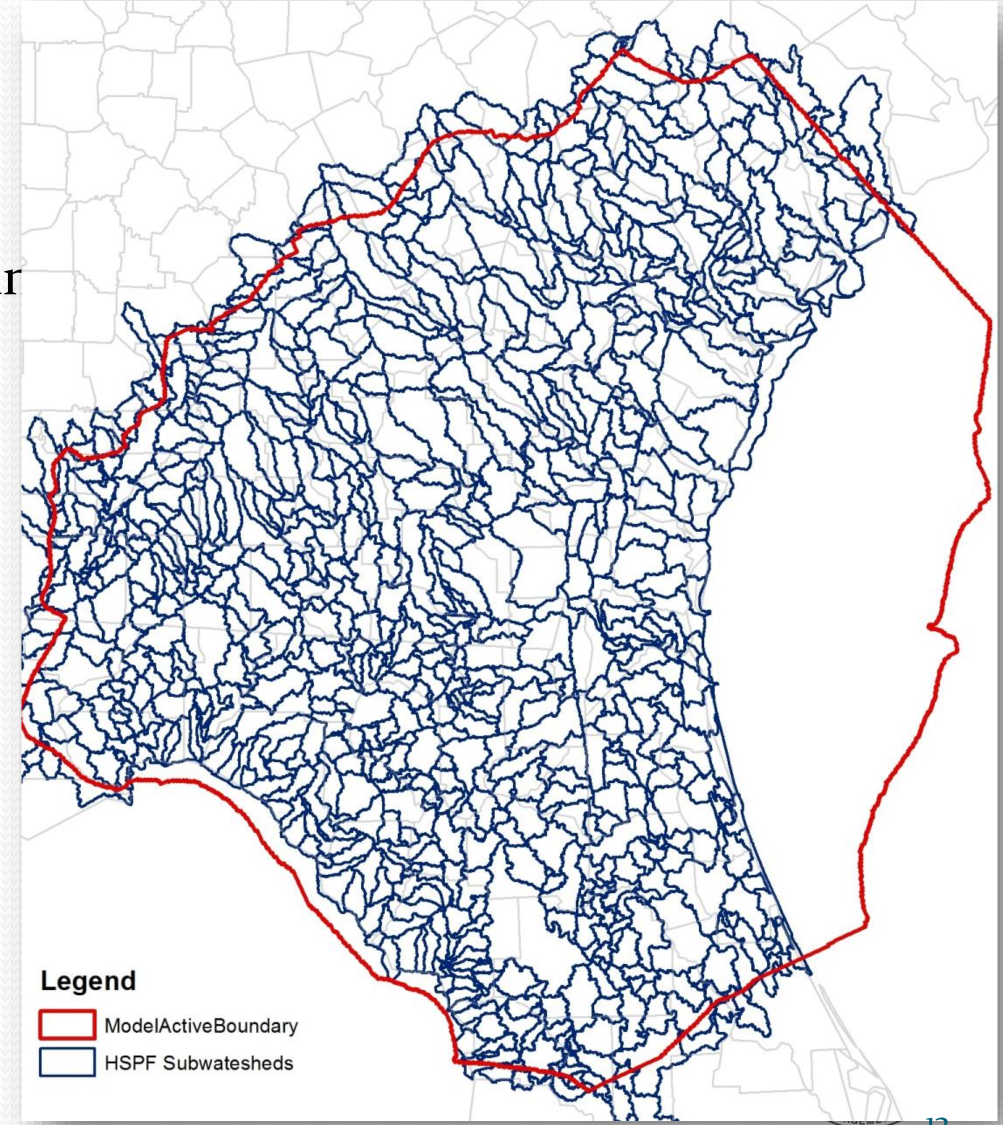
- HSPF
  - Gross Recharge
  - Maximum available saturated ET
  - Sinks and Drainage Well flows
- MODFLOW
  - Recharge Package – for gross recharge input
  - ET Package – for groundwater ET simulations
    - Maximum available saturated ET
    - ET Extinction Depth
- PEST Model Calibration
  - Recharge multipliers per subwatershed
  - MSET multipliers per subwatershed

Objectives of using HSPF

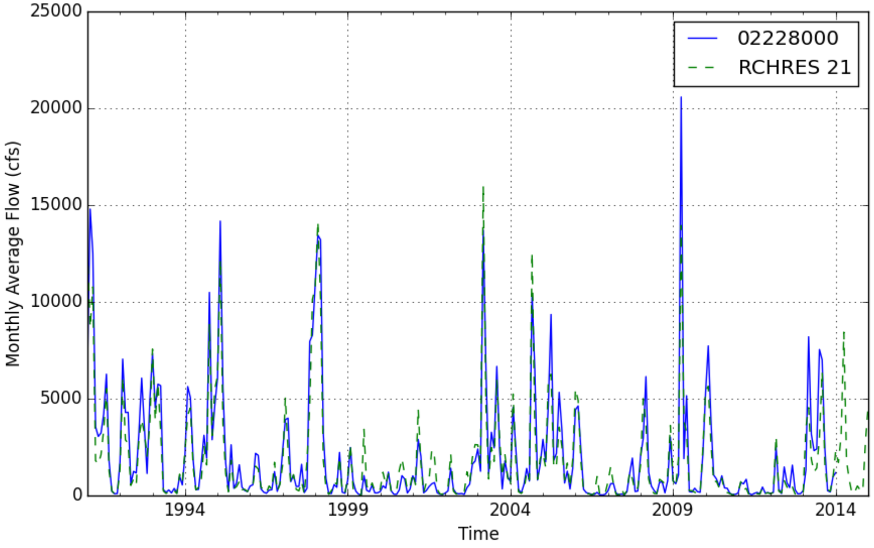
- To reduce the uncertainty in the initial estimates of recharge and MSET
- To overcome the shortcomings of the previous methods used in regional models
- To minimize the need to adjust recharge and MSET during groundwater model calibration

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

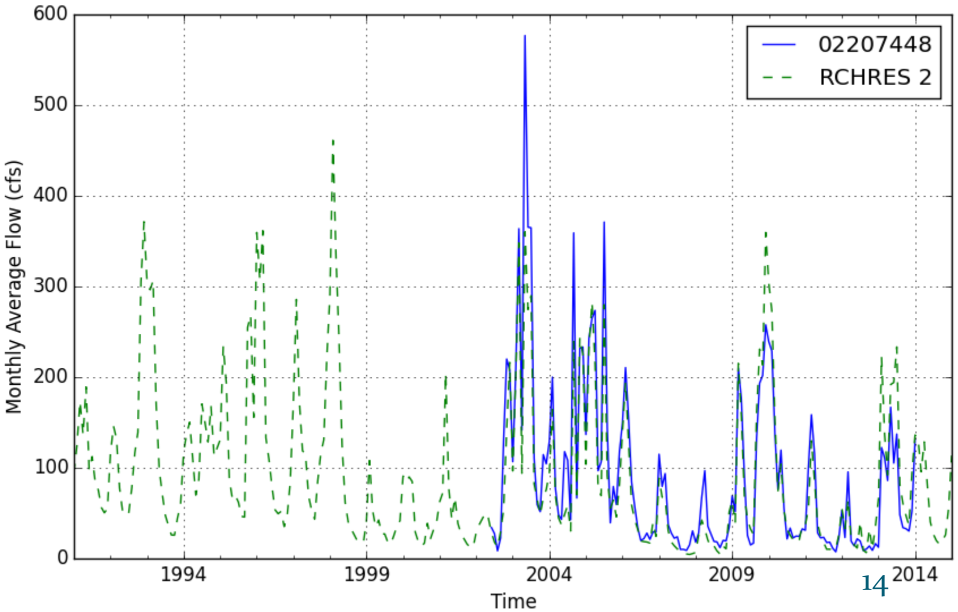


Calibration of HSPF Models



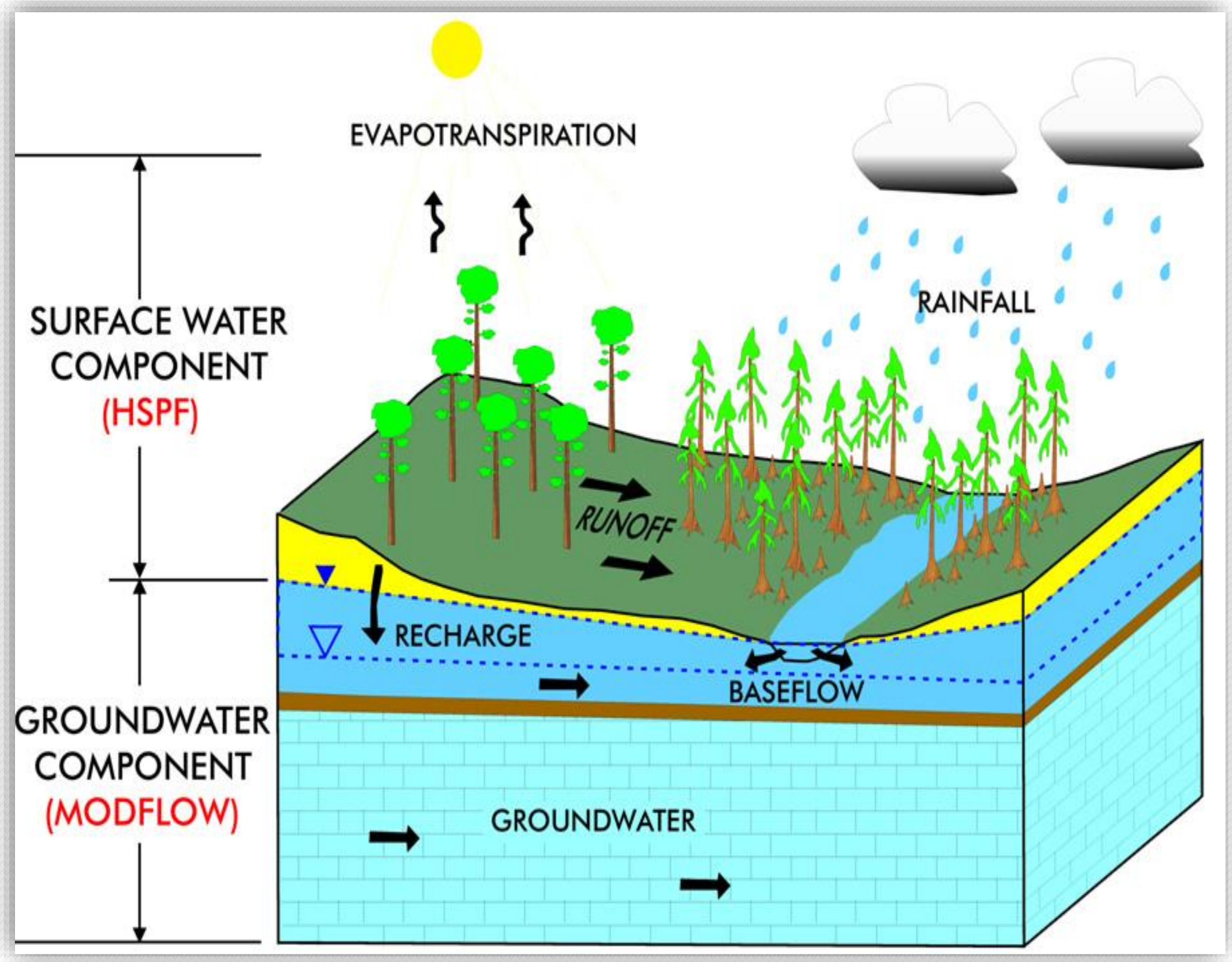
- Over 900 subwatersheds
- Transient calibration
- 1992 through 2014
- Hourly simulations

•Precipitation
•Evapotranspiration
•Agricultural Irrigation
•Non-Agricultural Irrigation
•Septic Fields Seepage

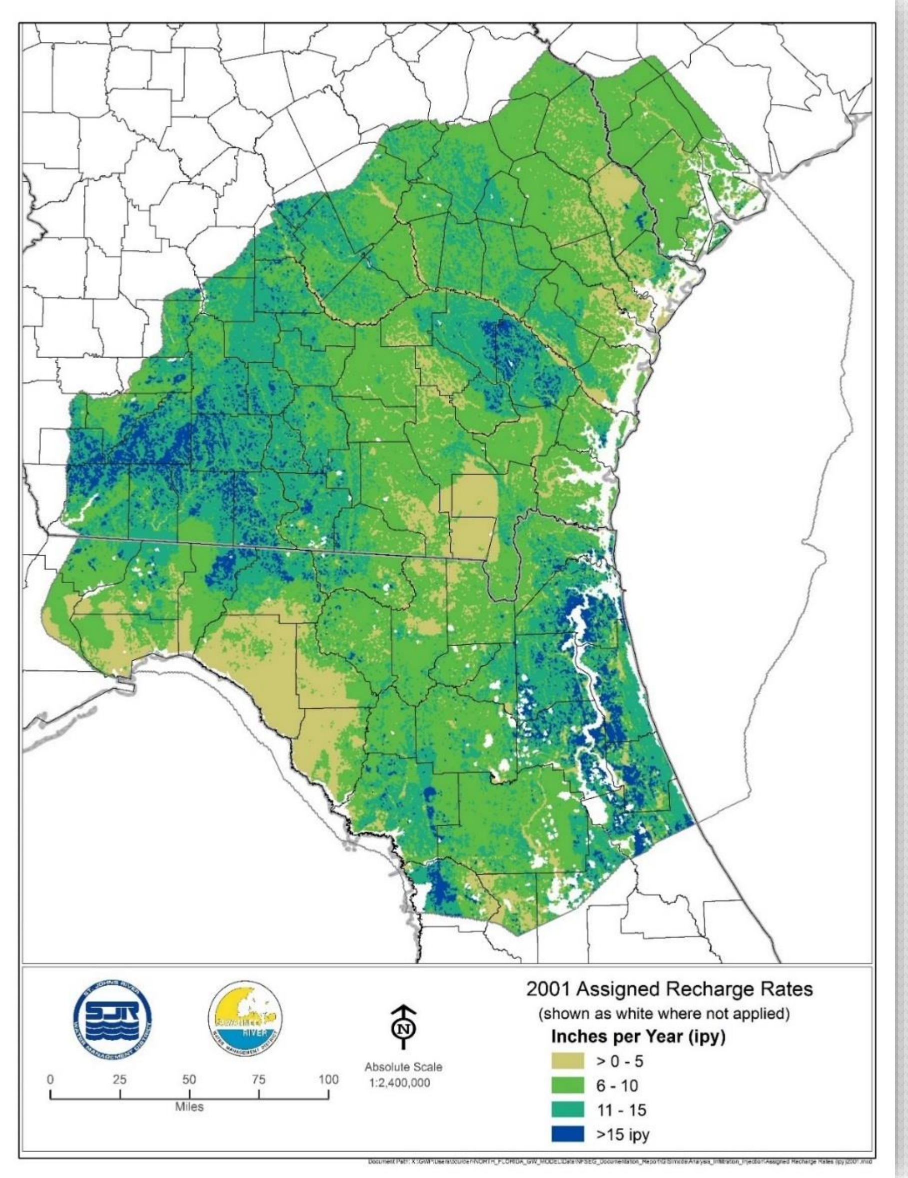


MODFLOW -HSPF Interaction

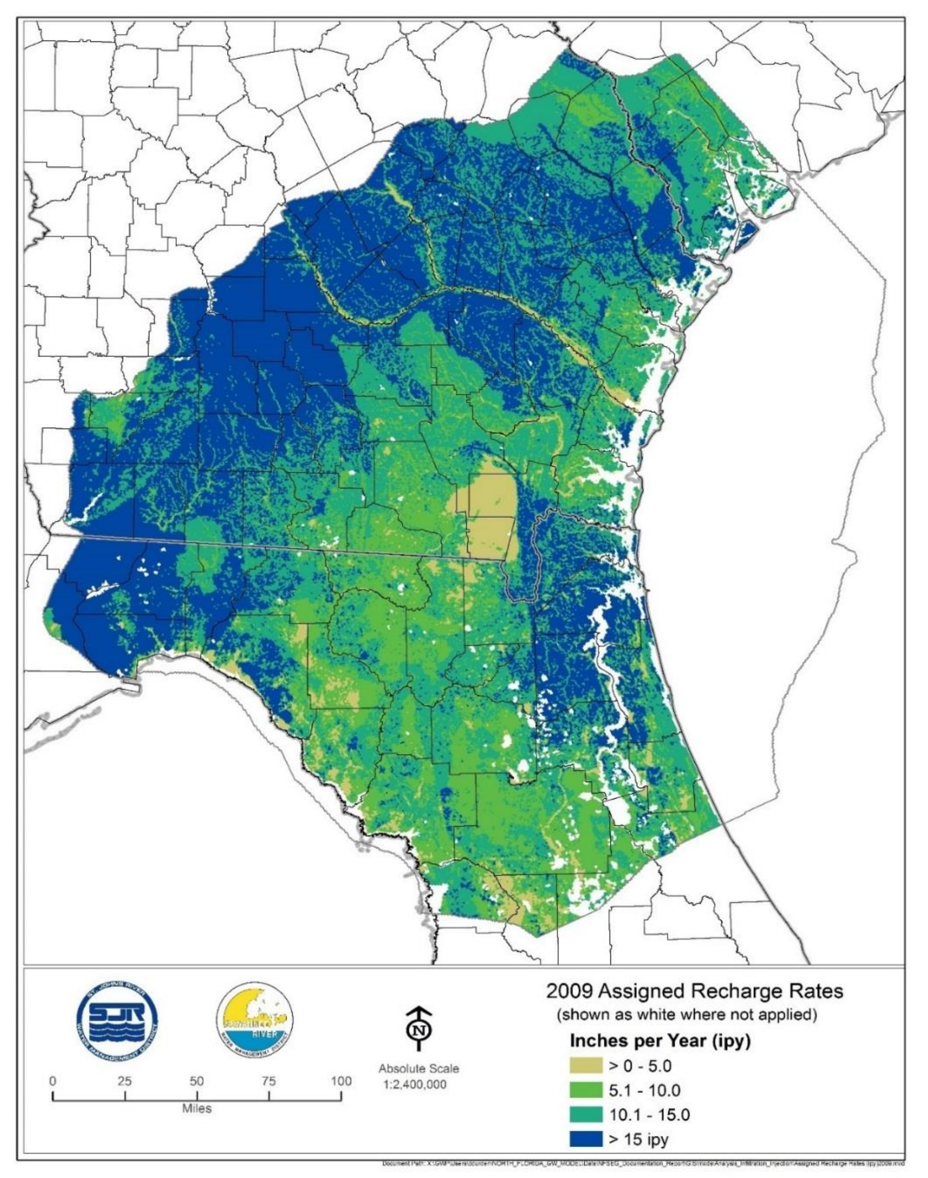
Gross Recharge = Rainfall – Direct Runoff – Interception ET - Unsaturated ET
Maximum available saturated ET = Potential ET - Interception ET – Unsaturated ET



Recharge

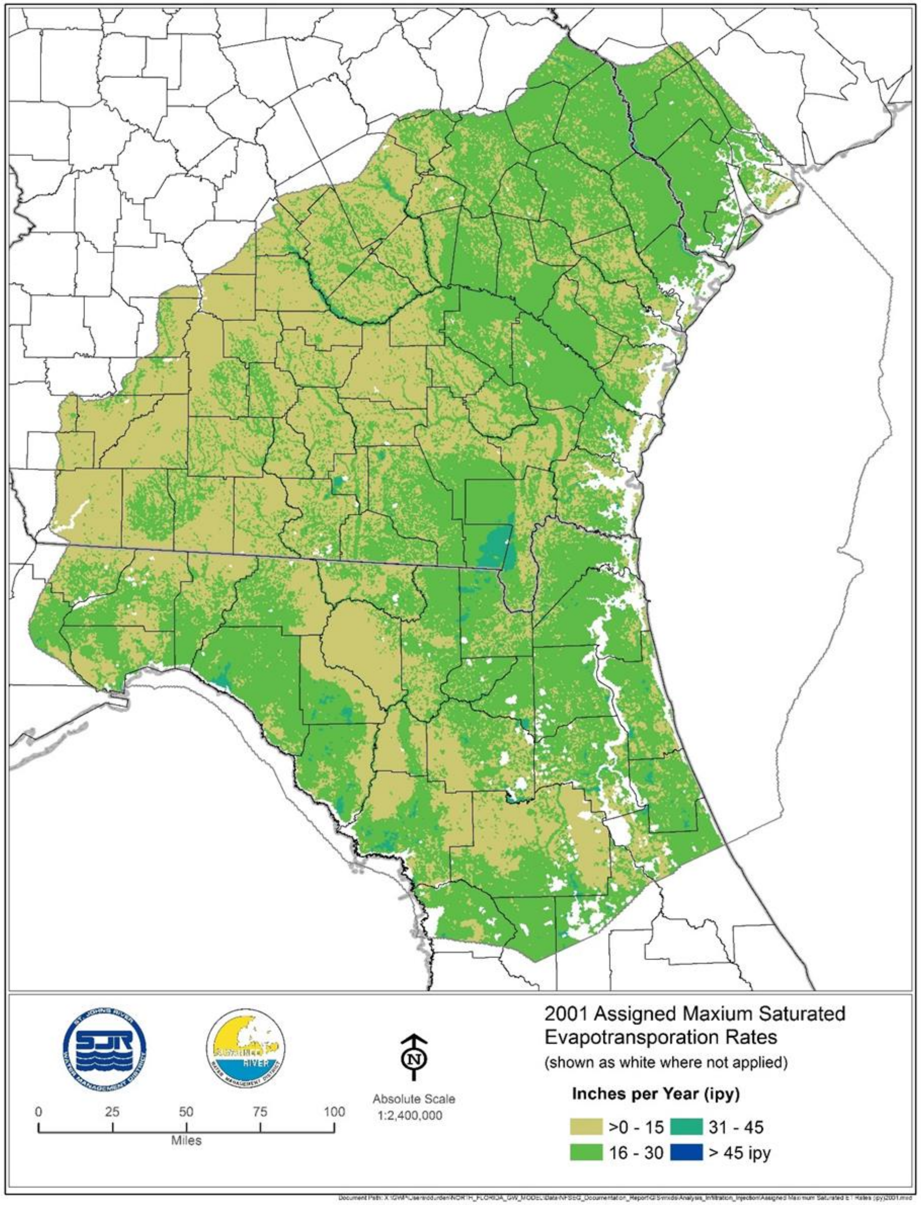


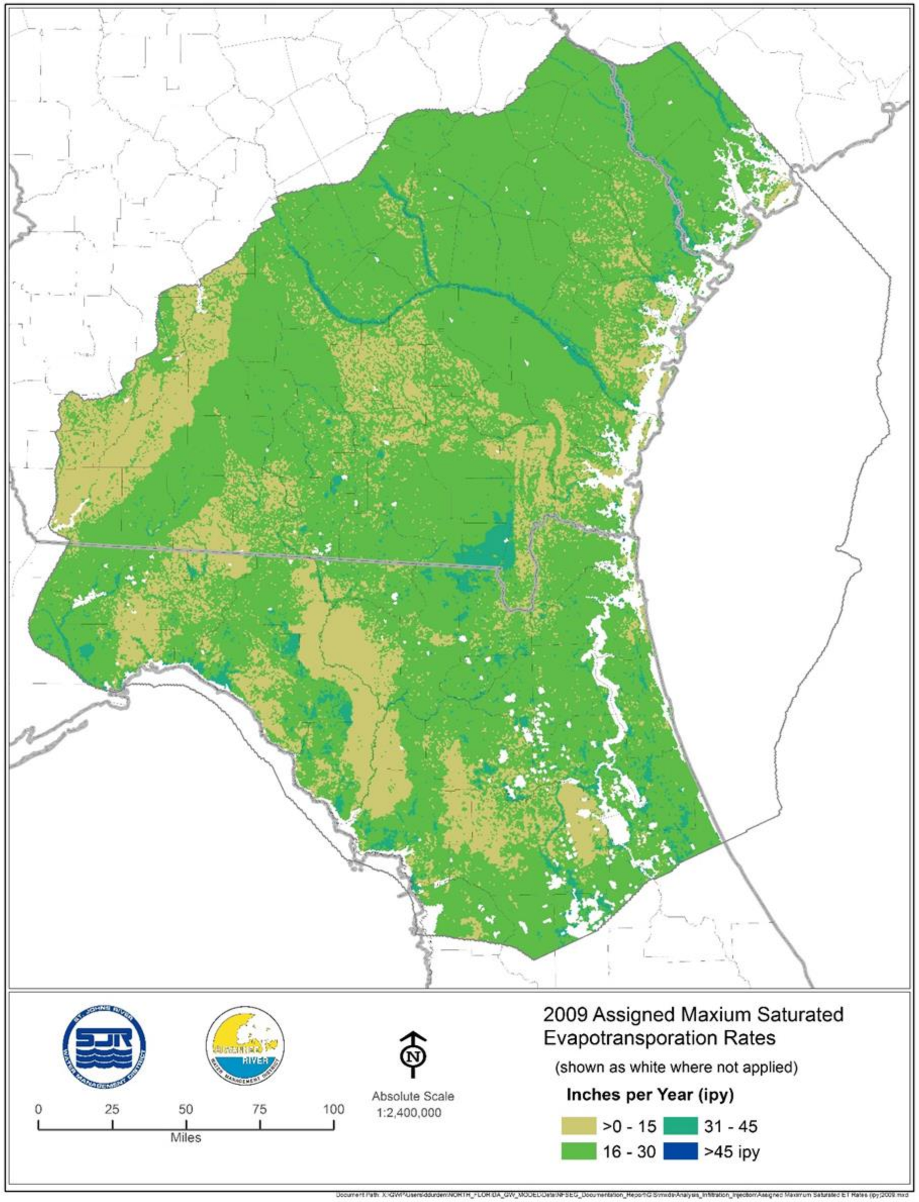
2001 Assigned Recharge Rates
(shown as white where not applied)
Inches per Year (ipy)
> 0 - 5
6 - 10
11 - 15
>15 ipy
Absolute Scale
1:2,400,000
0 25 50 75 100
Miles



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
Absolute Scale
1:2,400,000
0 25 50 75 100
Miles

Maximum Saturated ET



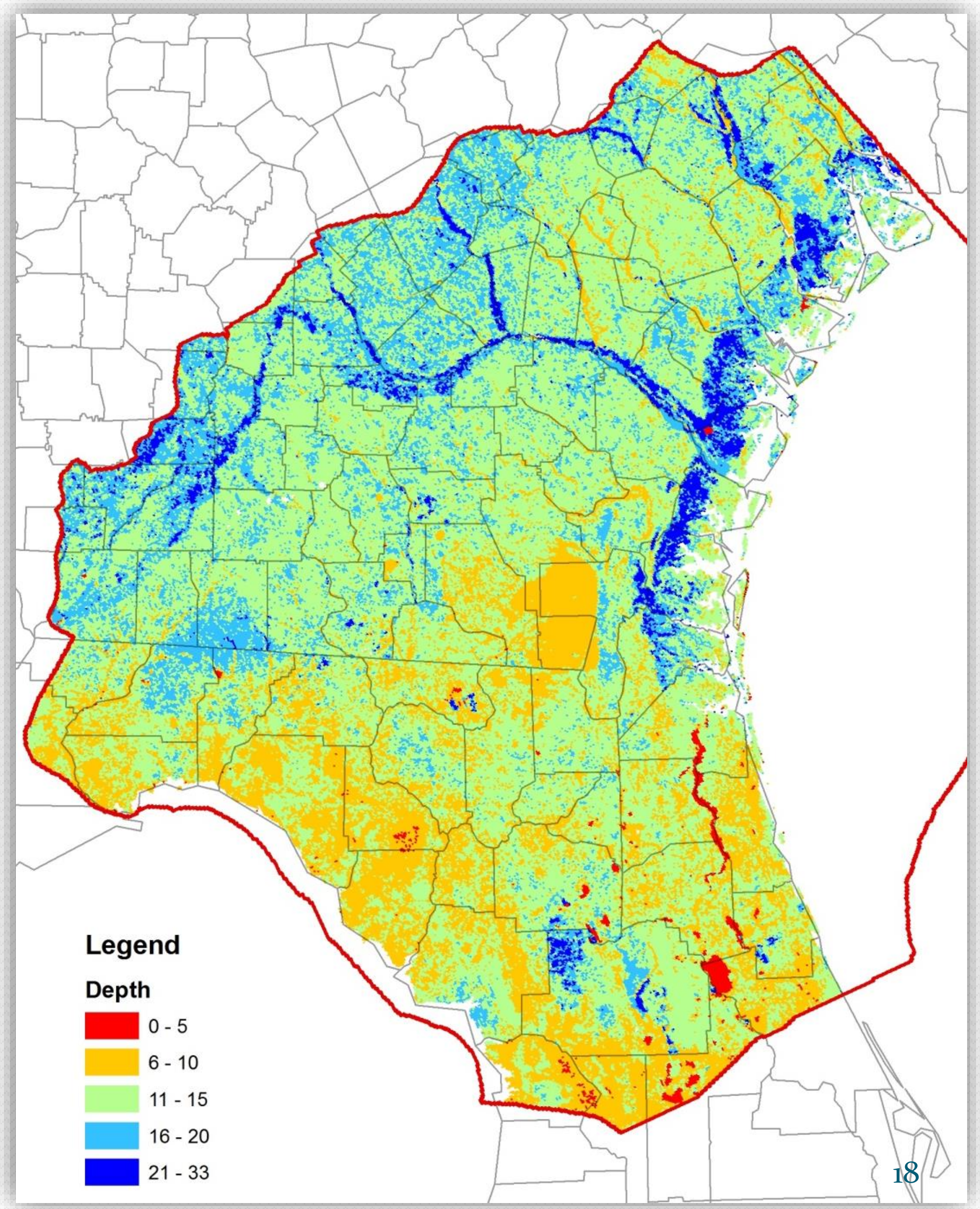


ET Extinction Depth

(Modified from Shah et al., 2007)

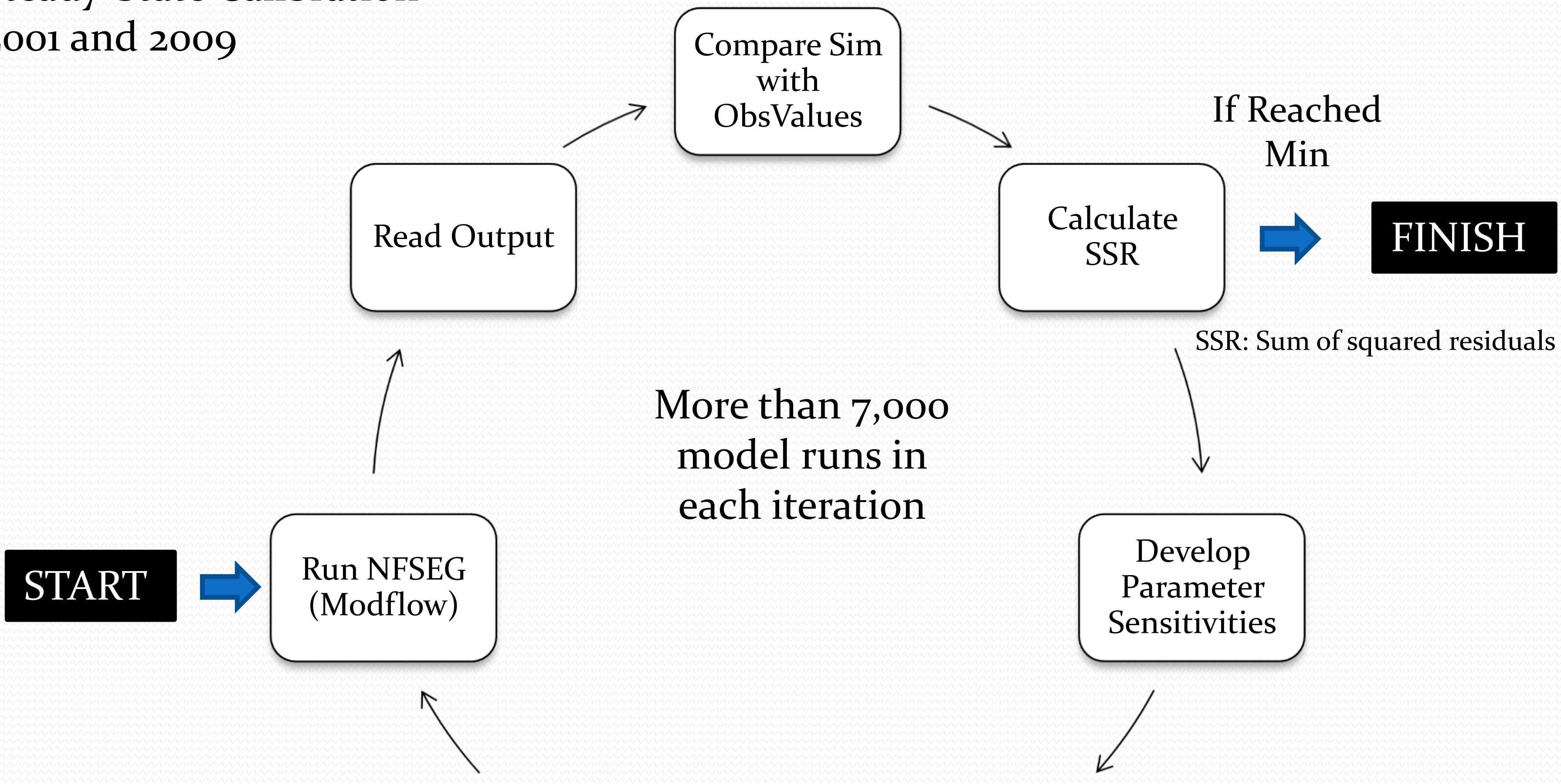
Extinction Depths (ft) under Forest Land Cover			
Soil Type	**Hydric**	**Partly hydric**	**Non-hydric**
sand	4.9	9.8	14.8
loamy sand	5.6	10.5	15.4
sandy loam	7.5	12.5	17.4
sandy clay loam	9.8	14.8	19.7
sandy clay	10.2	15.1	20.0
loam	12.0	16.9	21.8
silty clay	14.3	19.2	24.1
clay loam	16.6	21.5	26.4
silt loam	16.9	21.8	26.9
silt	17.4	22.3	27.2
silty clay loam	18.0	23.0	27.9
clay	23.6	28.5	33.5

Extinction Depths (ft) under Grass Land Cover			
Soil Type	**Hydric**	**Partly hydric**	**Non-hydric**
sand	4.9	6.6	8.2
loamy sand	5.6	7.2	8.9
sandy loam	7.5	9.2	10.8
sandy clay loam	9.8	11.5	13.1
sandy clay	10.2	11.8	13.5
loam	12.0	13.6	15.3
silty clay	14.3	15.9	17.6
clay loam	16.6	18.2	19.8
silt loam	16.9	18.5	20.3
silt	17.4	19.0	20.7
silty clay loam	18.0	19.7	21.3
clay	23.6	25.3	26.9



Groundwater Model Calibration
PEST Process

Steady-State Calibration
2001 and 2009

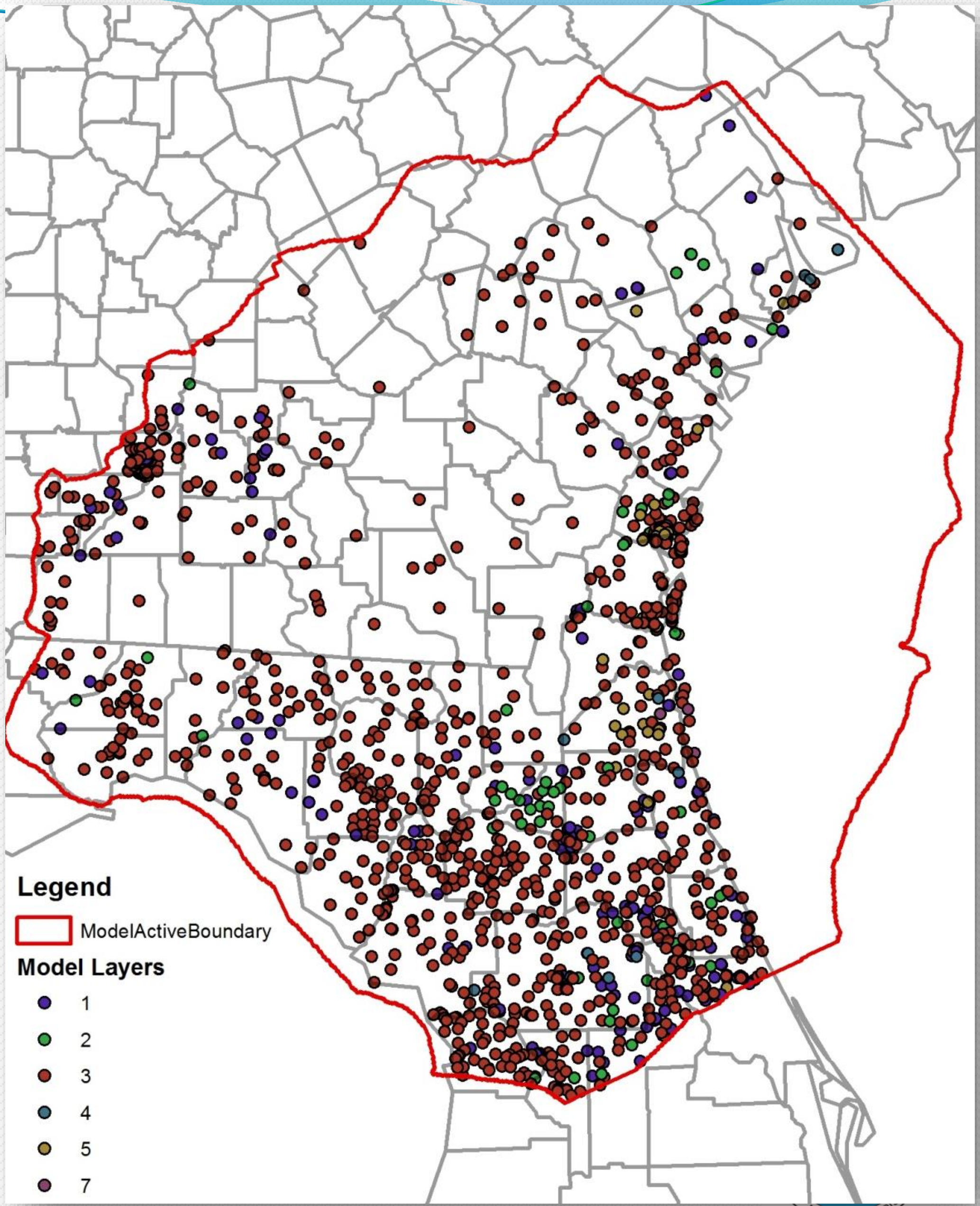


Observation Groups

- 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

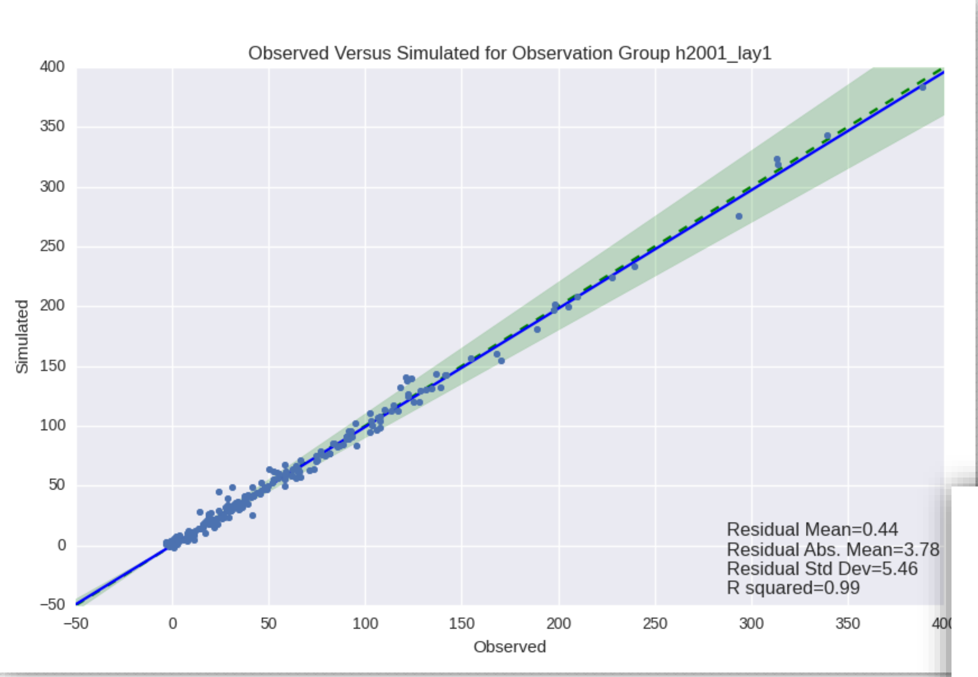


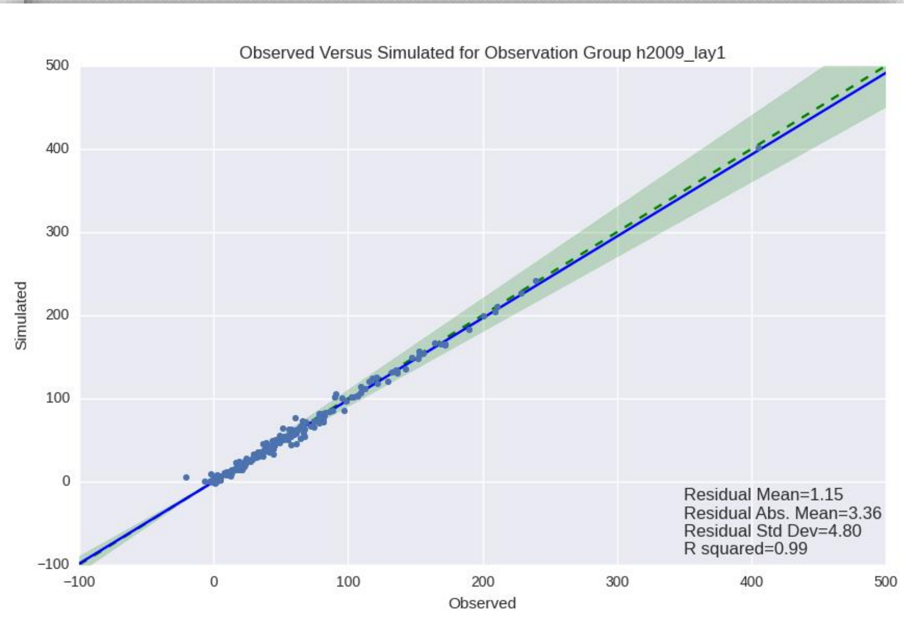
Parameter Groups

- Hydraulic Conductivities (Pilot Points)
- Vertical Anisotropy (kx/kz)
- Spring Conductances
- River Conductances
- Lake Conductances
- Lake layer 2 kz zone multipliers
- Recharge Multipliers

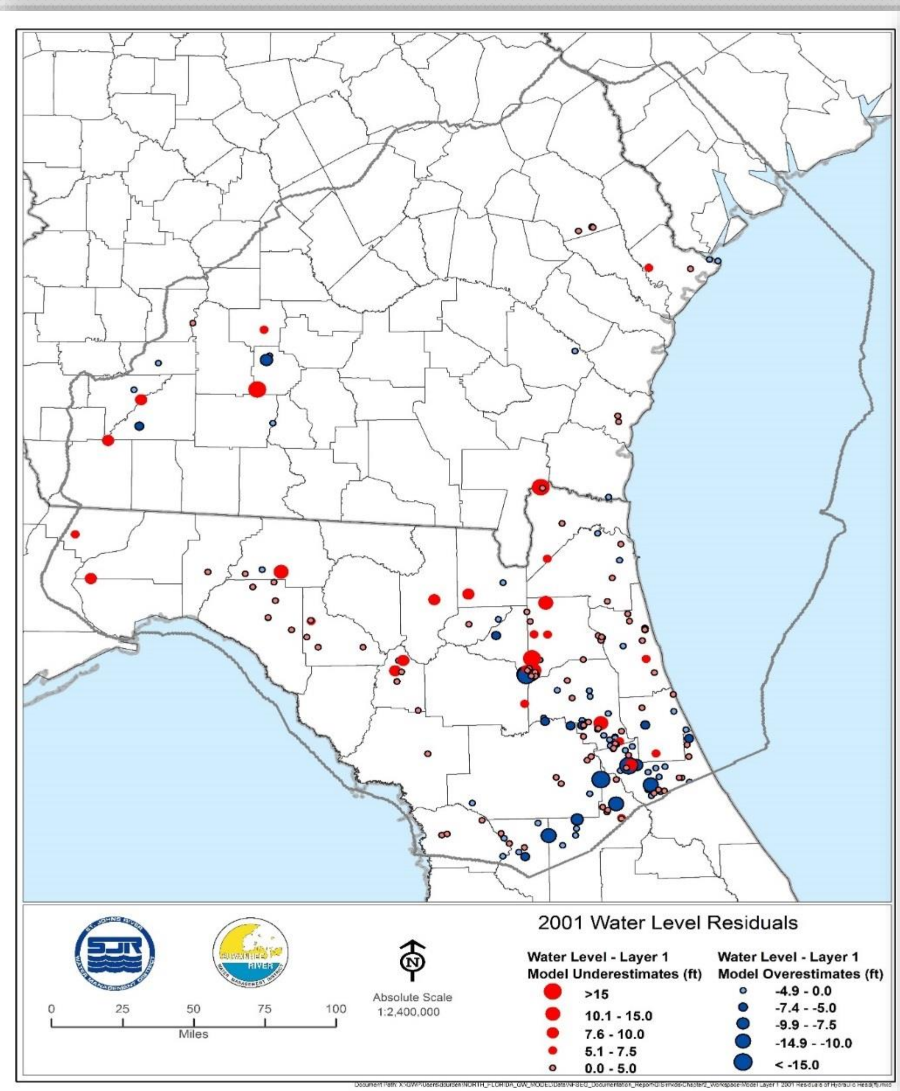
NFSEG v1.0
Calibration Results

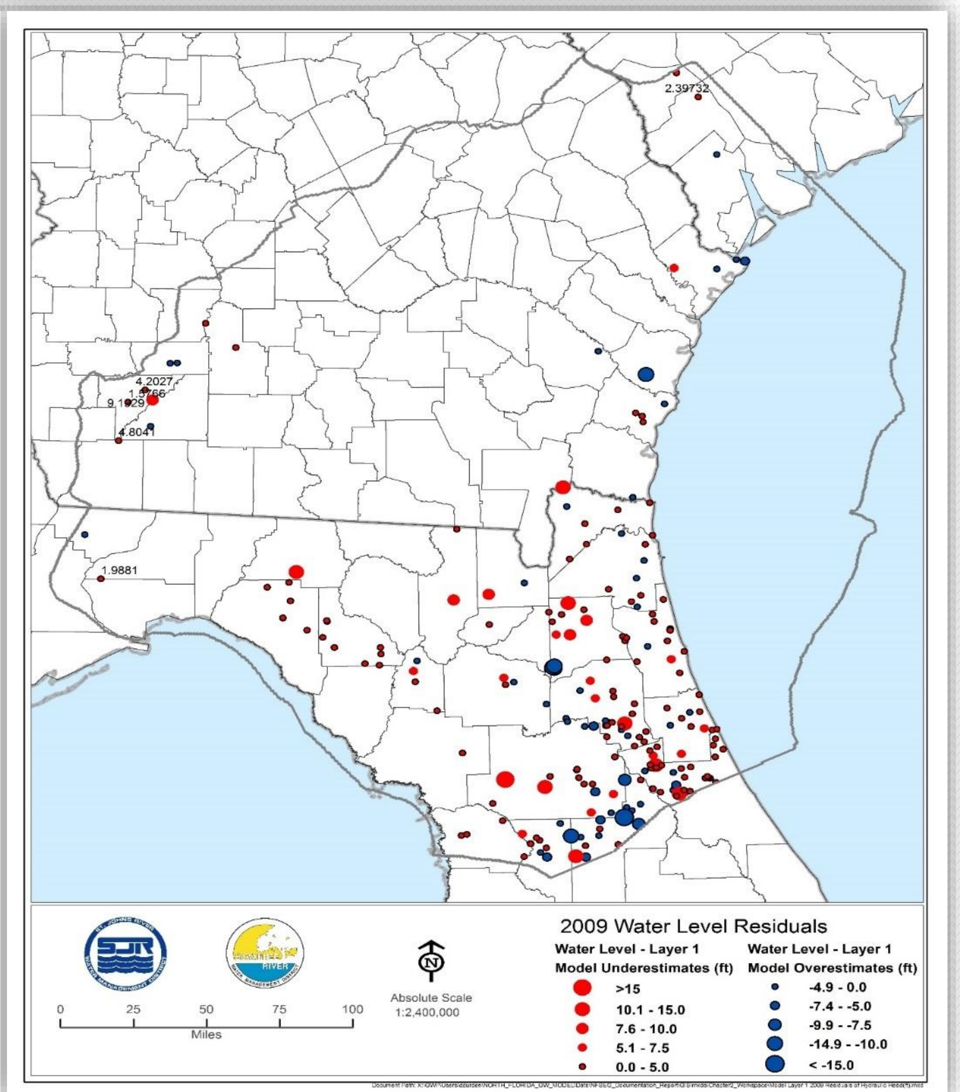
SAS Water Levels



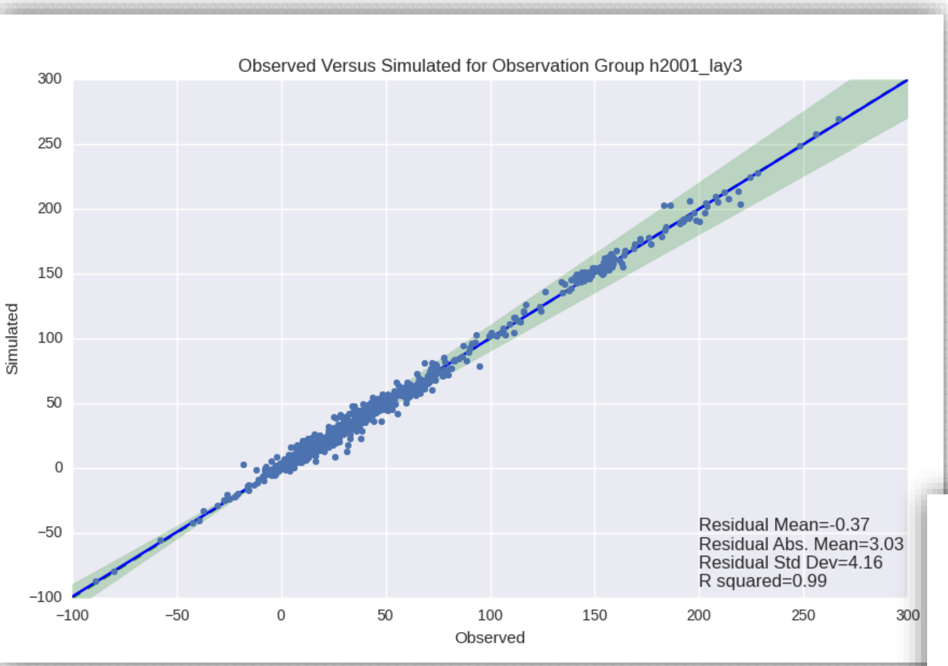


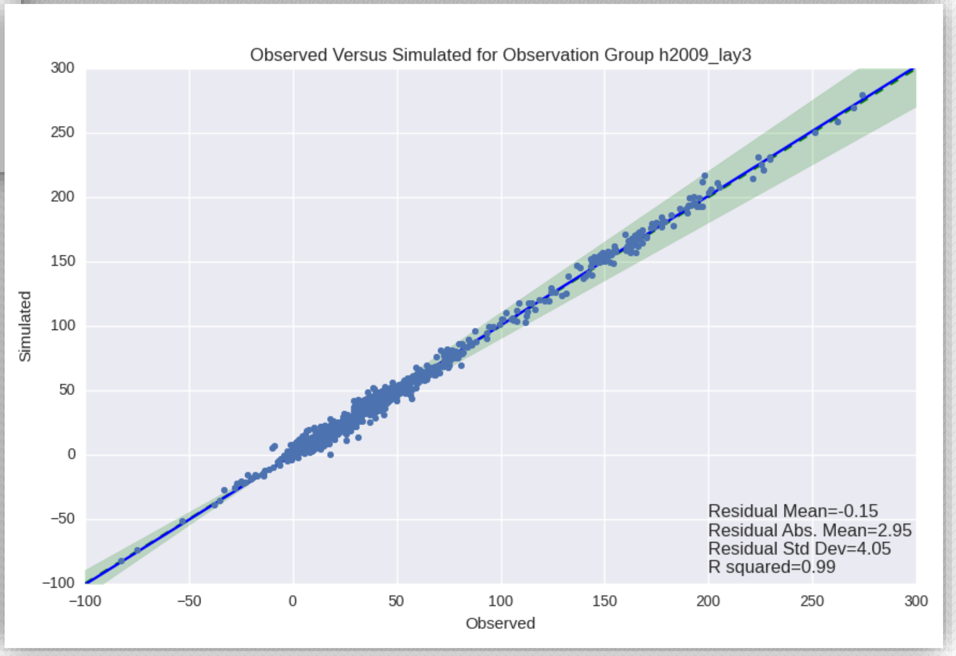
SAS Water Level Residuals



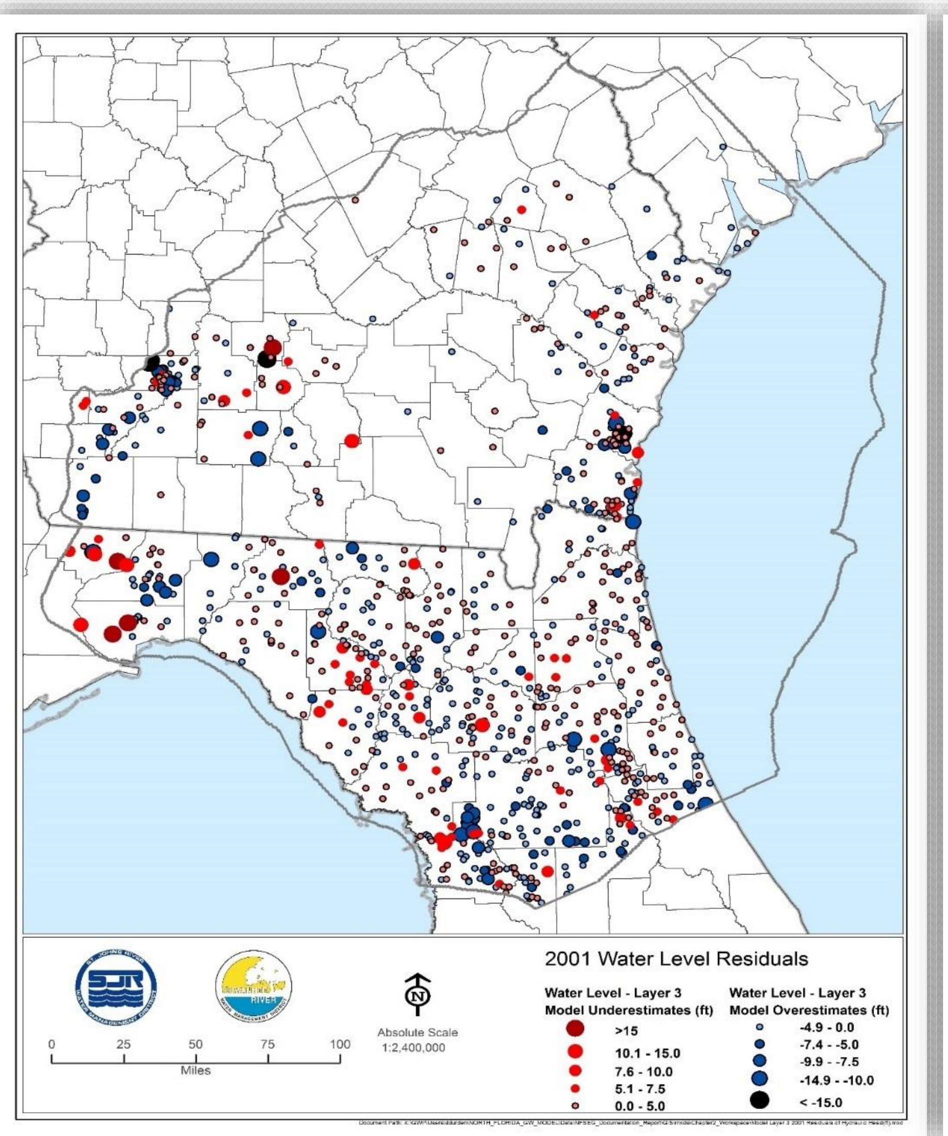


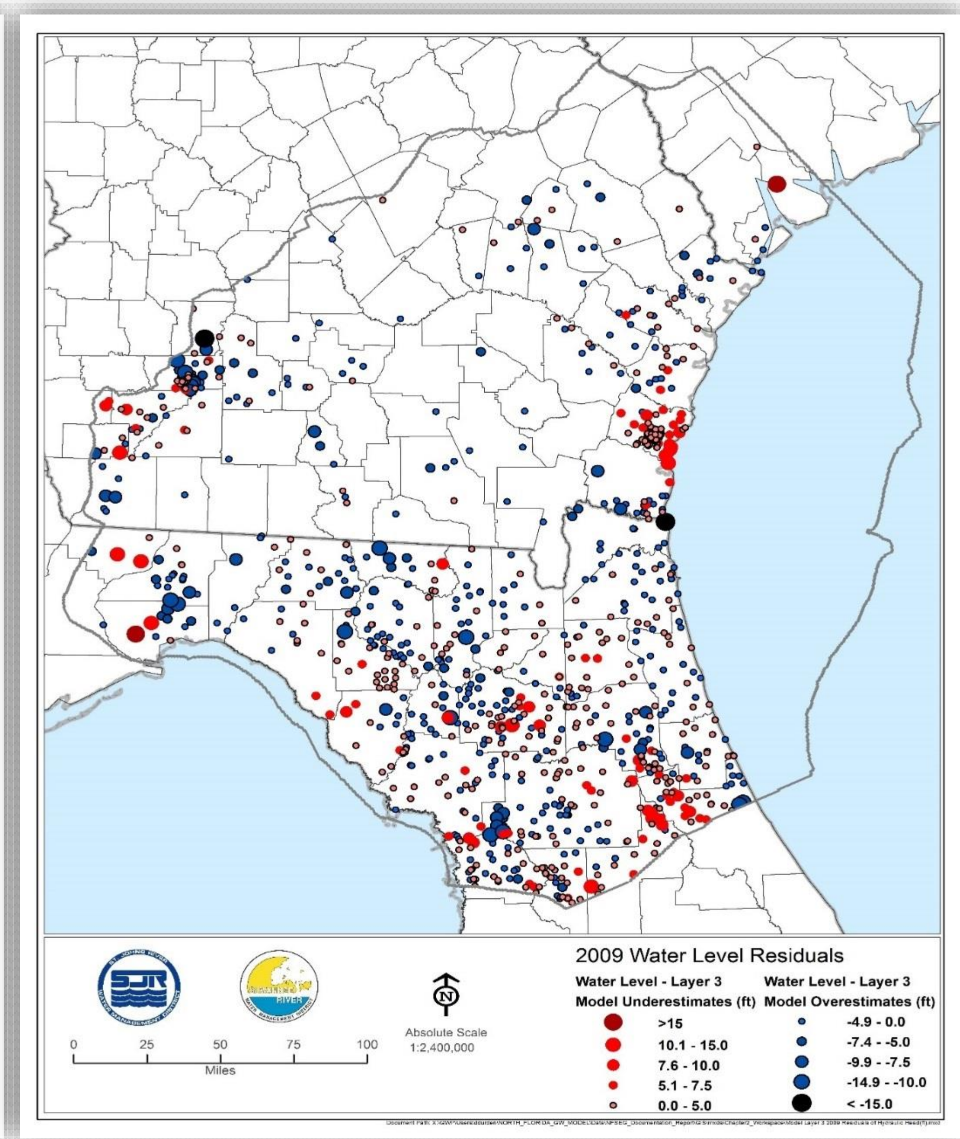
UFA Water Levels



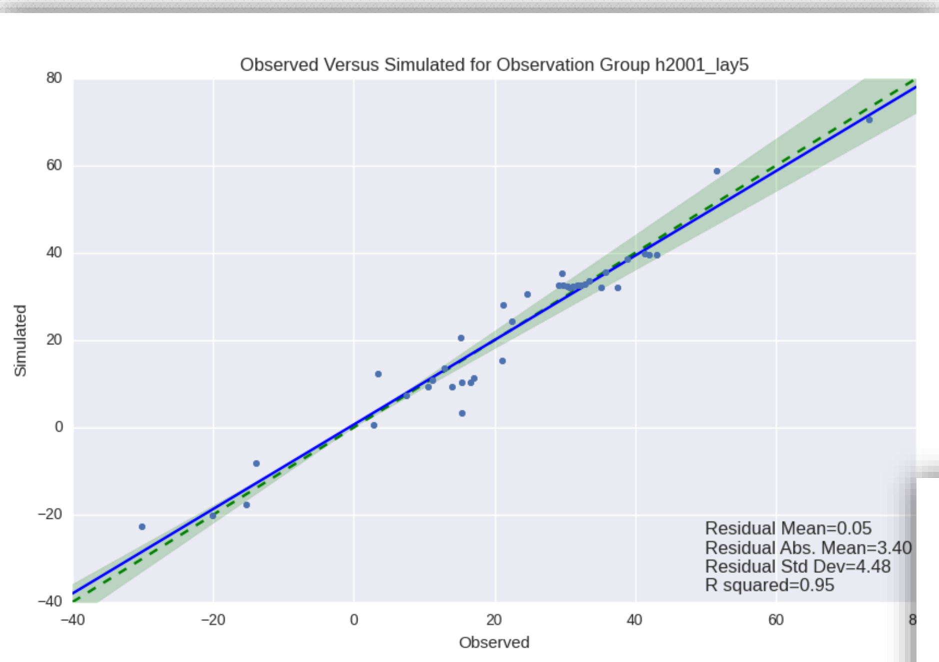


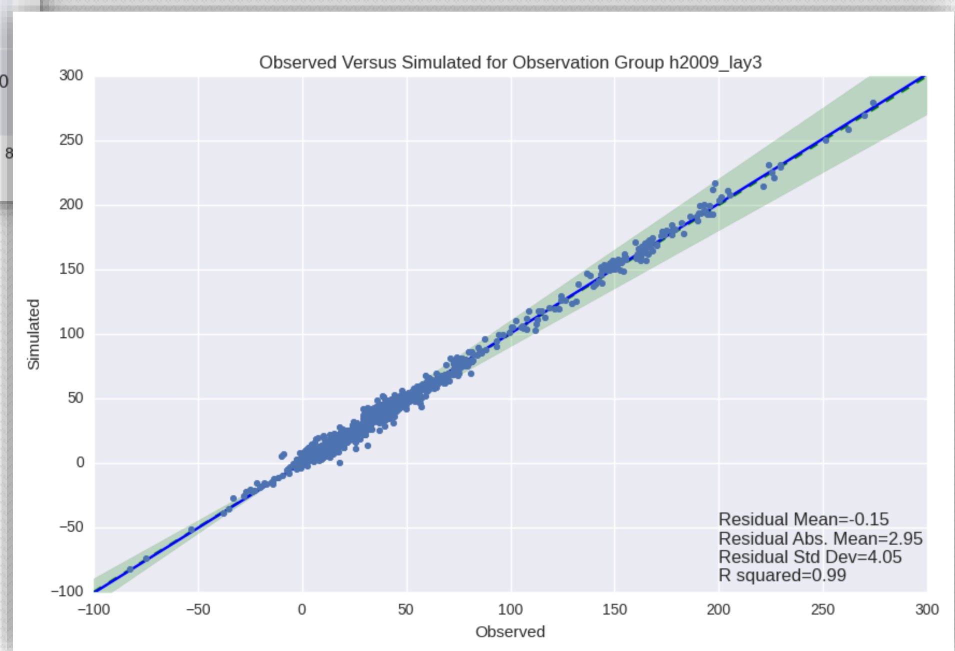
UFA Water Level Residuals



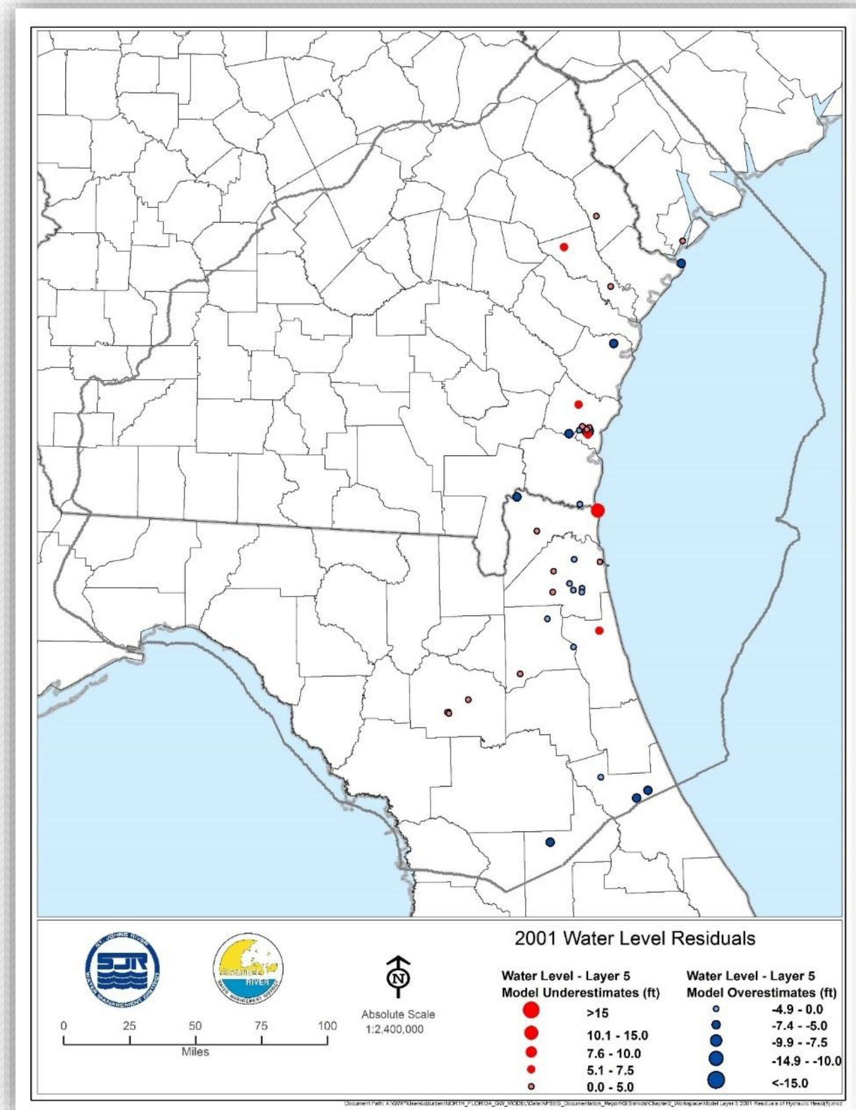


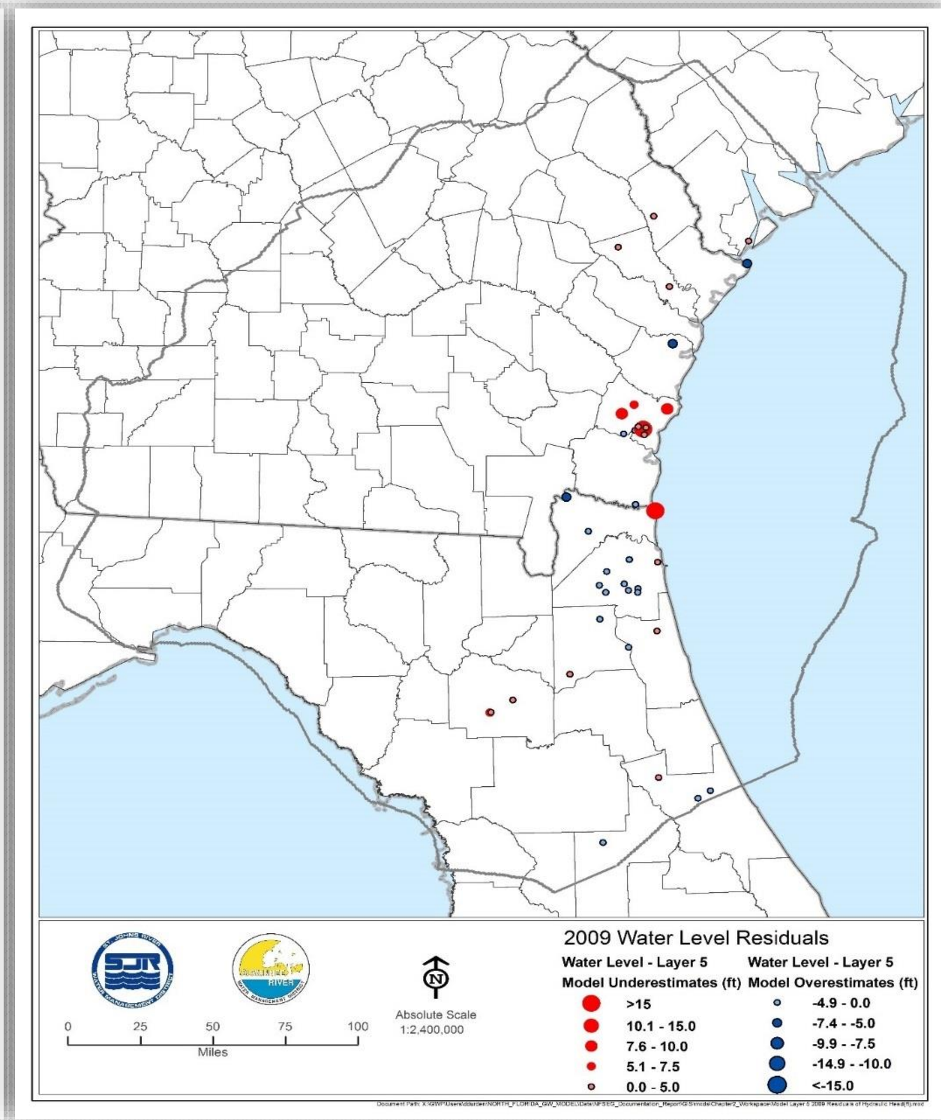
LFA Water Levels



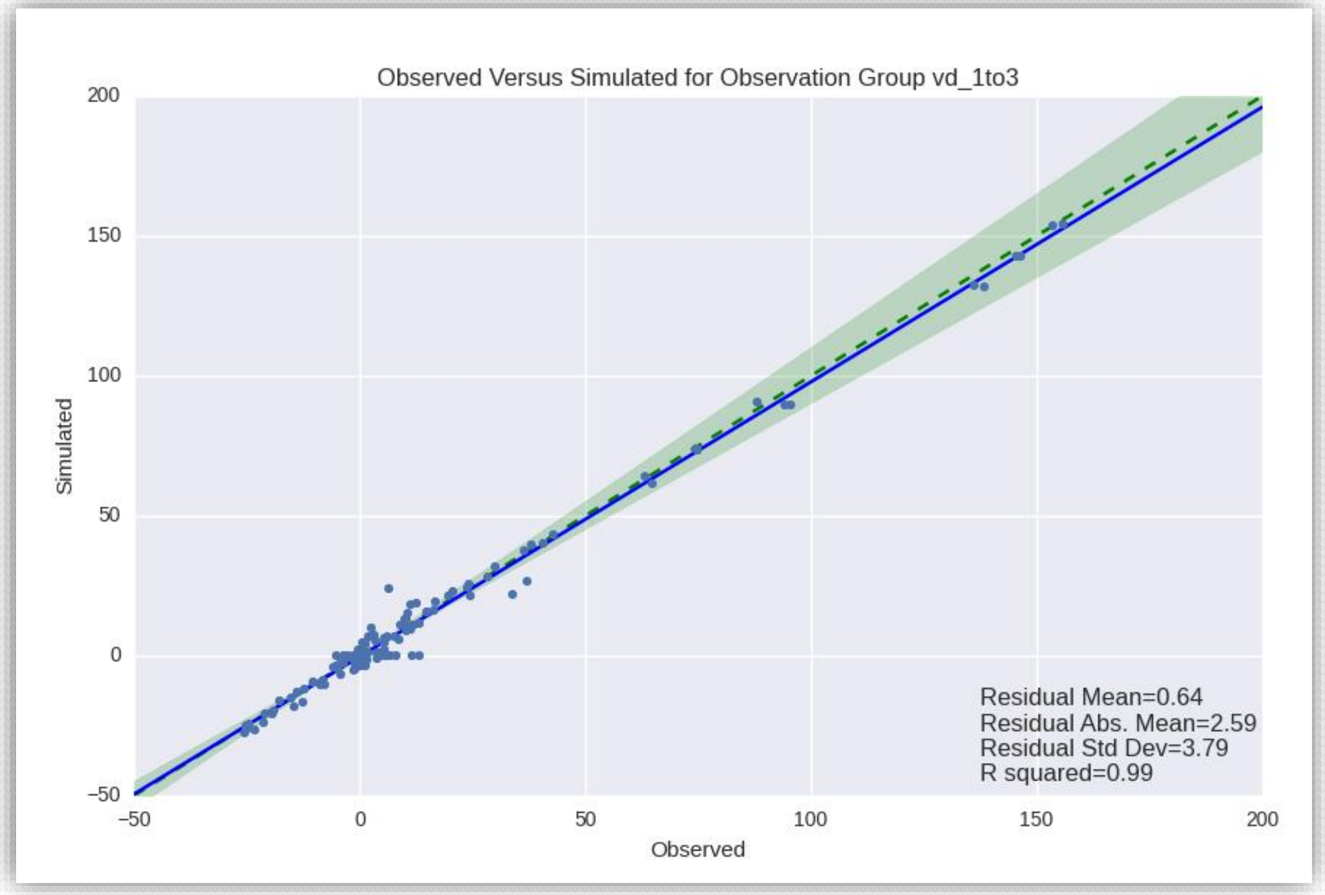


LFA Water Level Residuals

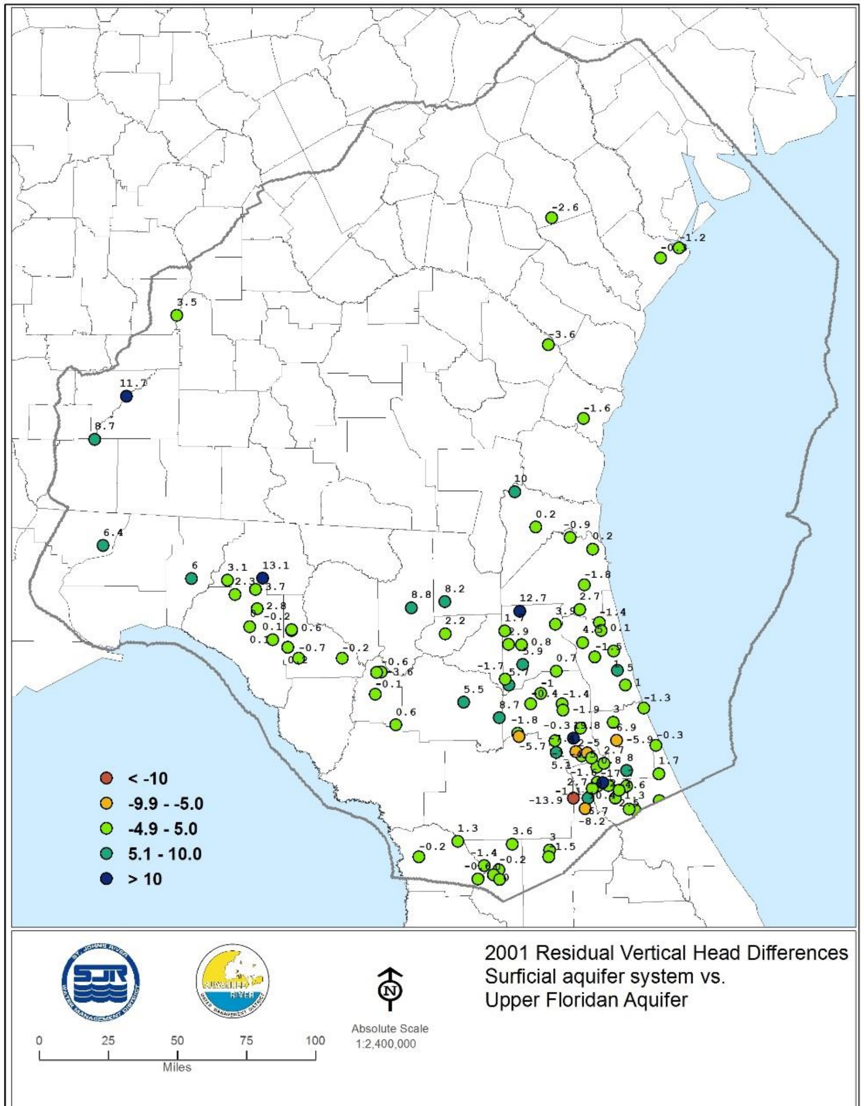


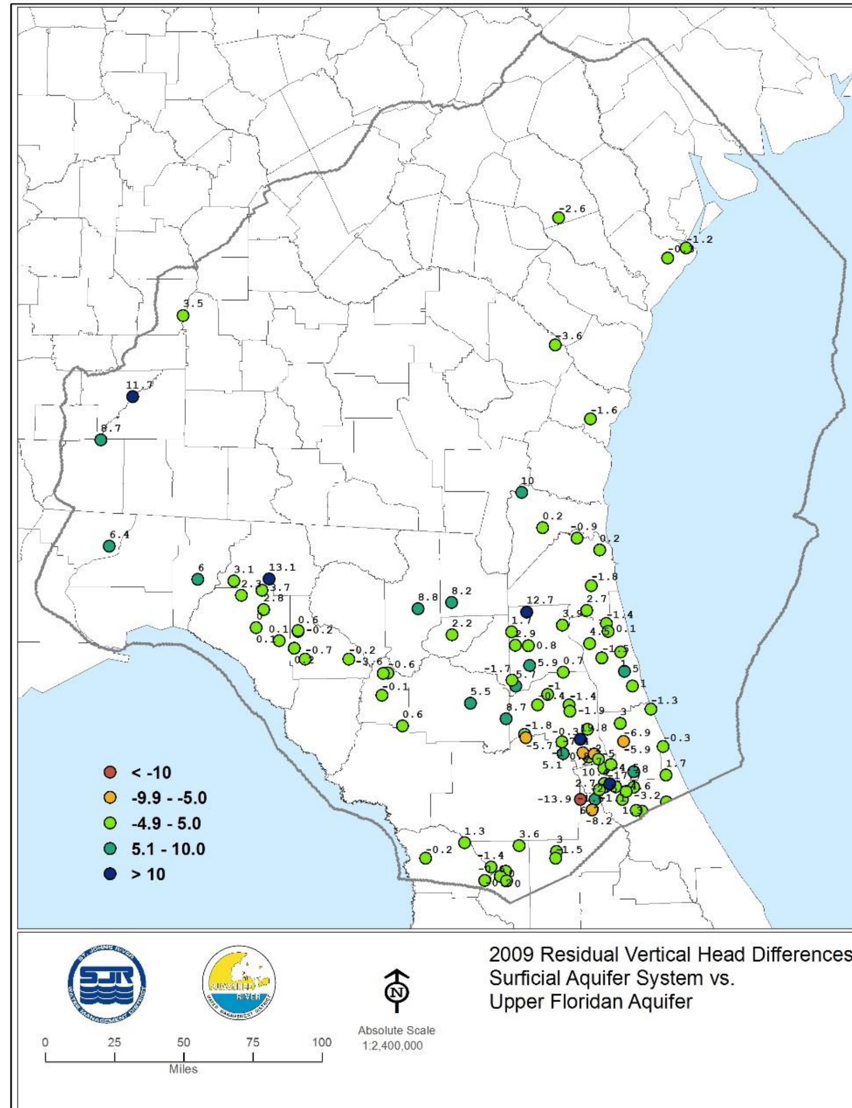


SAS/UFA Water Level Difference

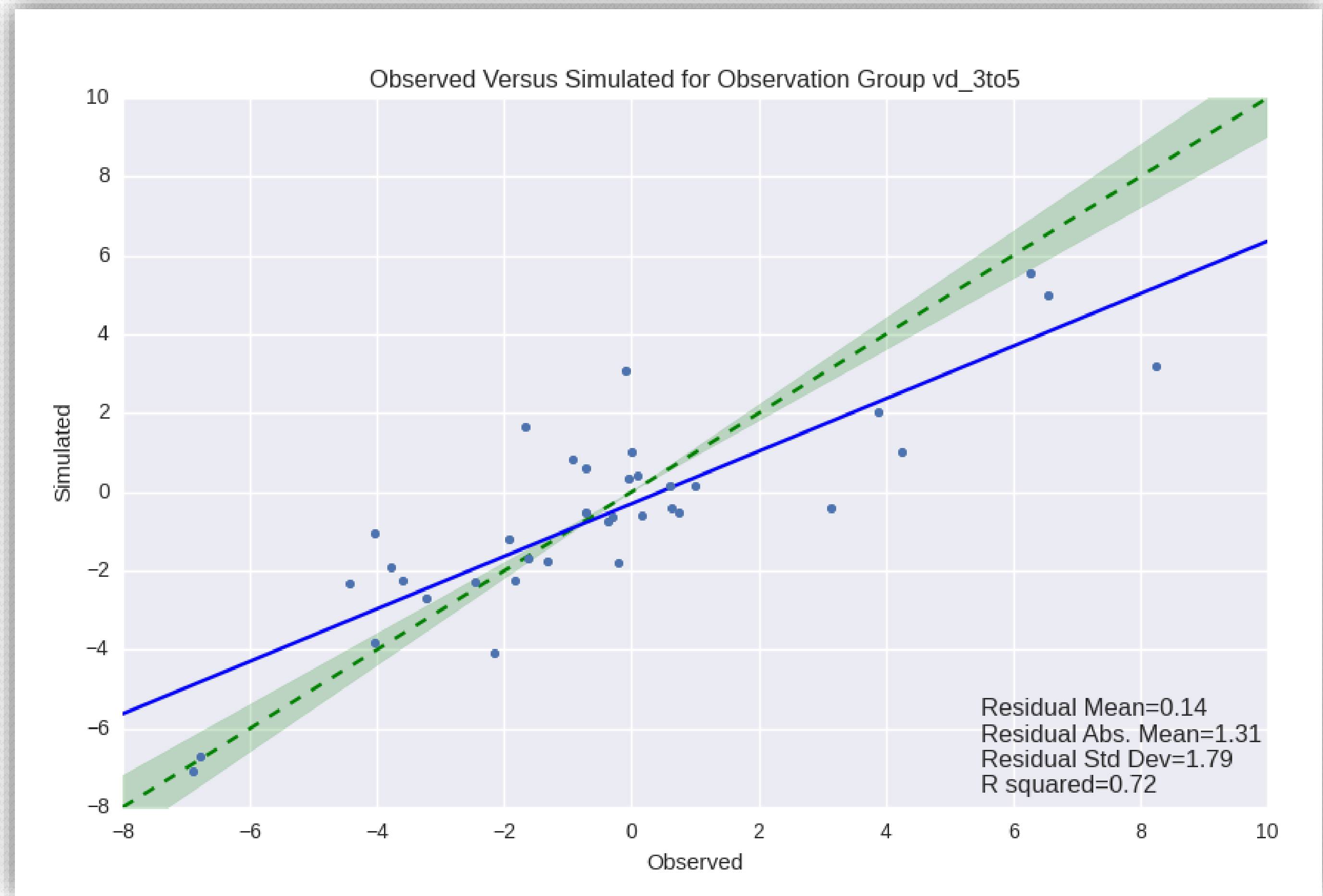


SAS/UFA Water Level Difference Residuals

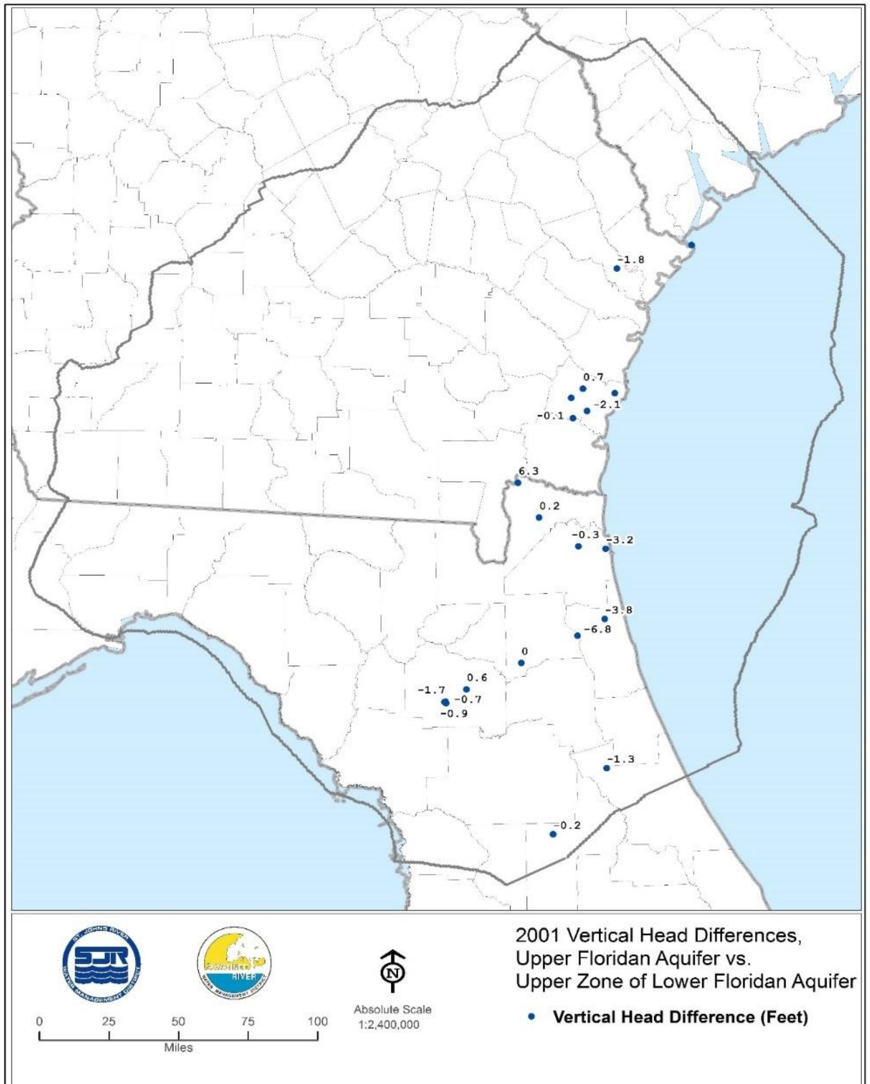


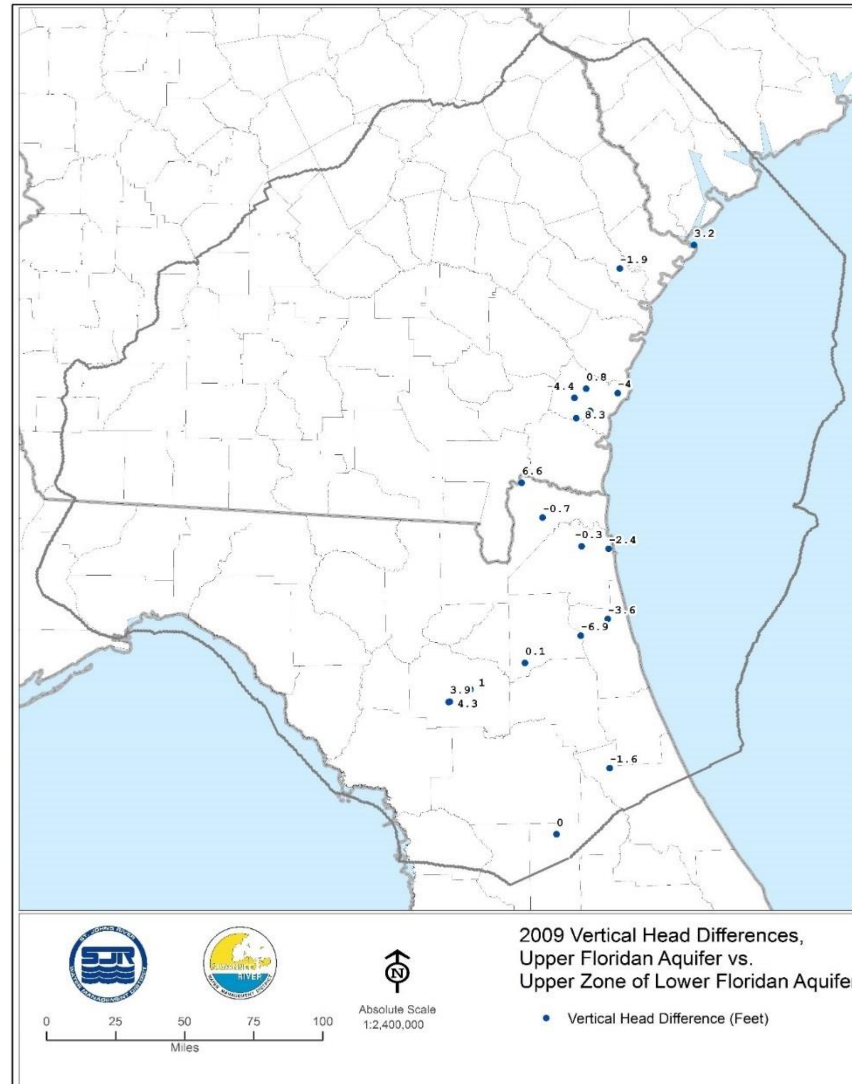


UFA/LFA Water Level Difference

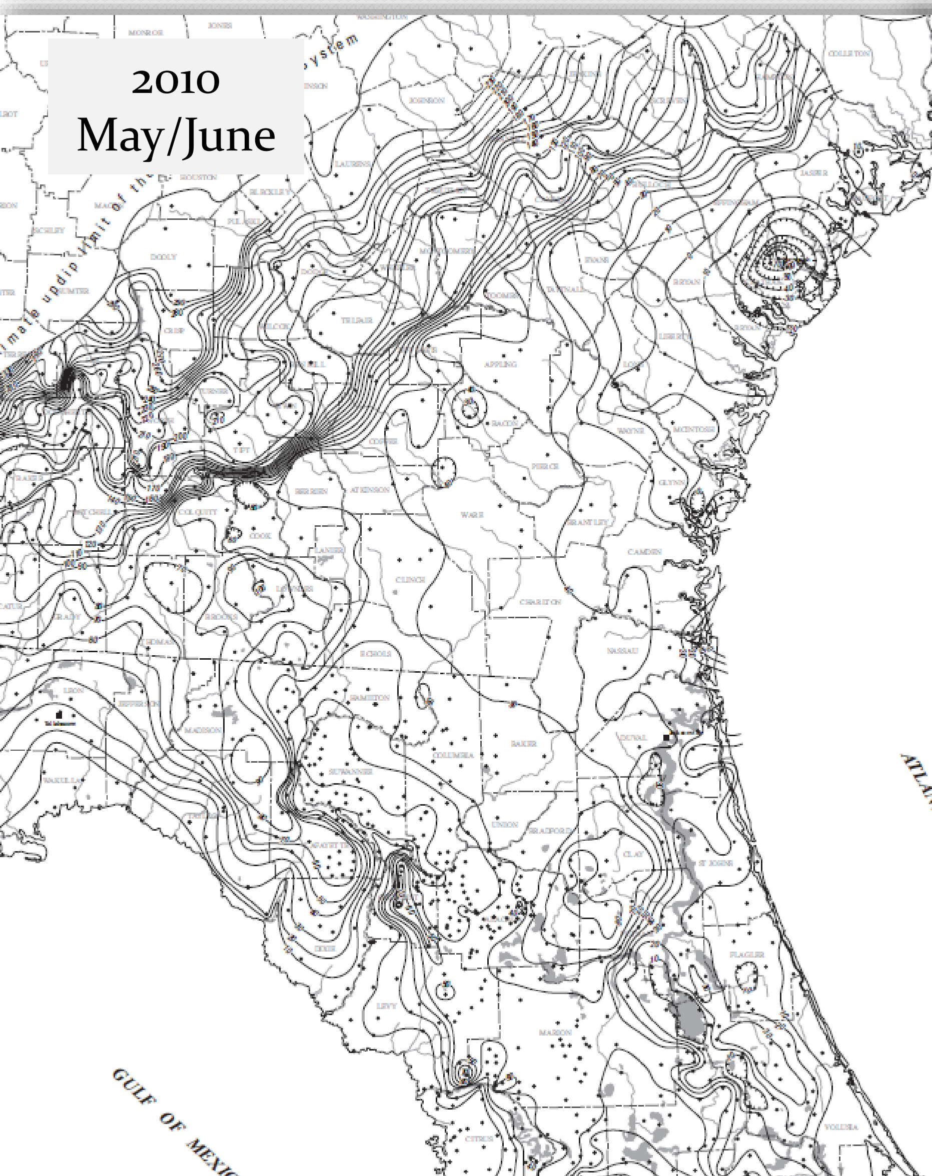


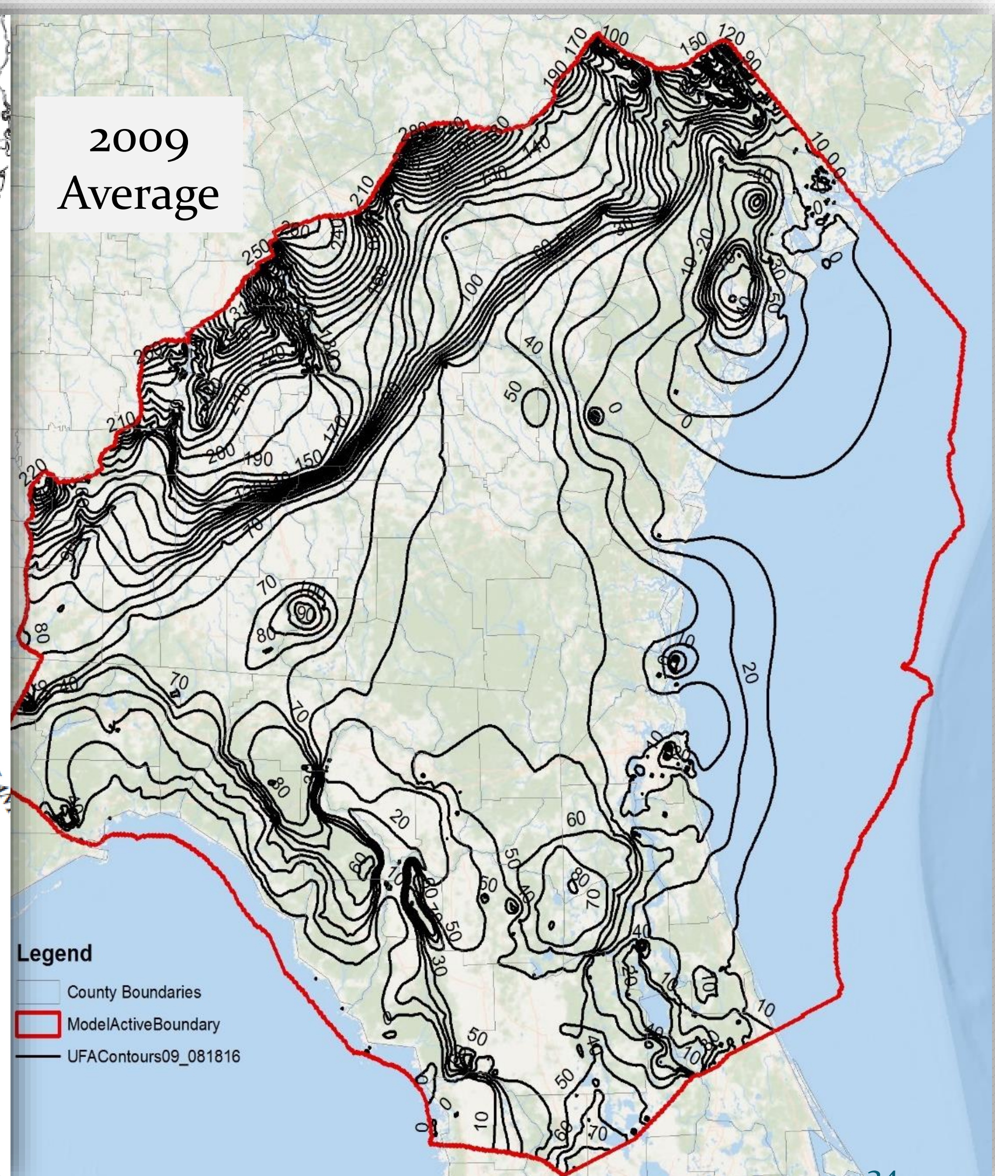
UFA/LFA Water Level Difference Residuals



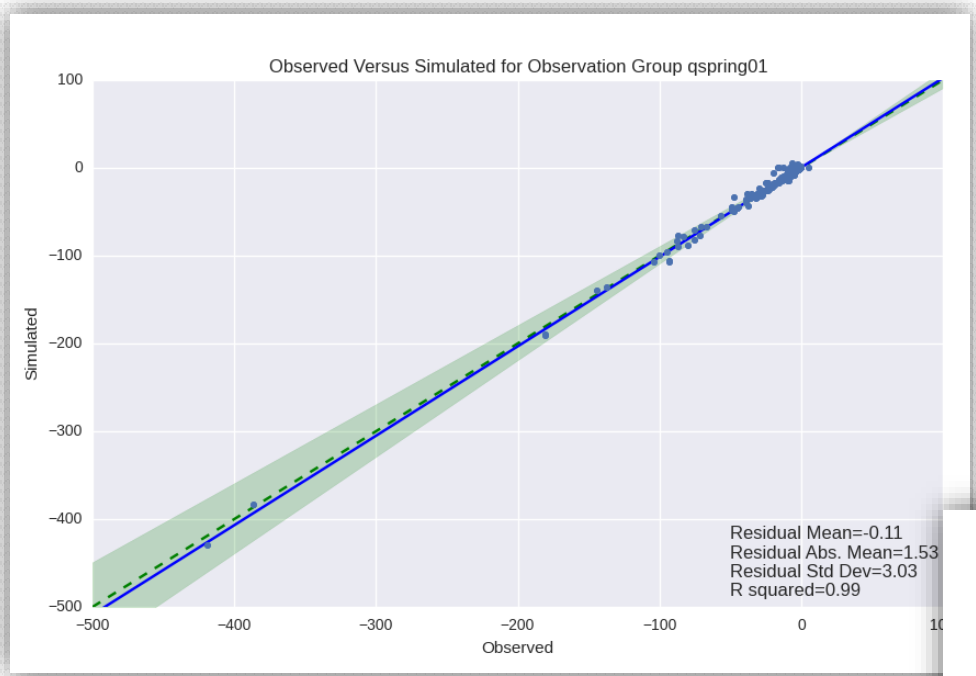


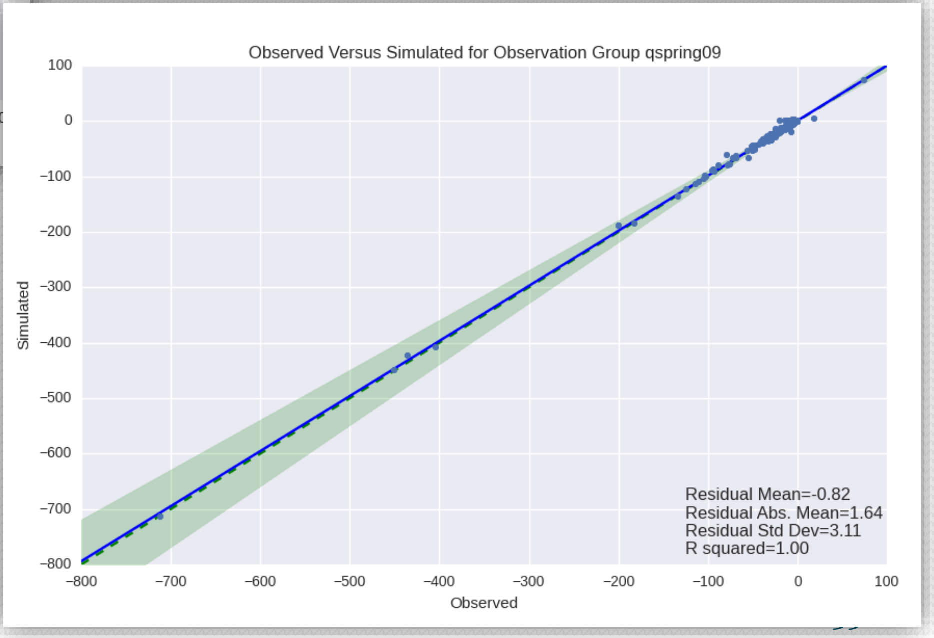
UFA Potentiometric Map



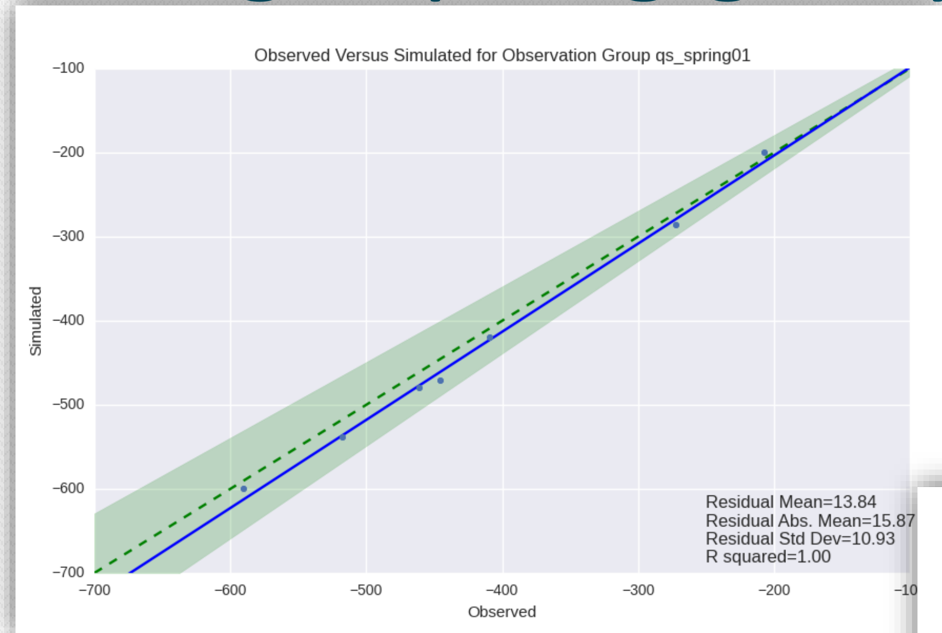


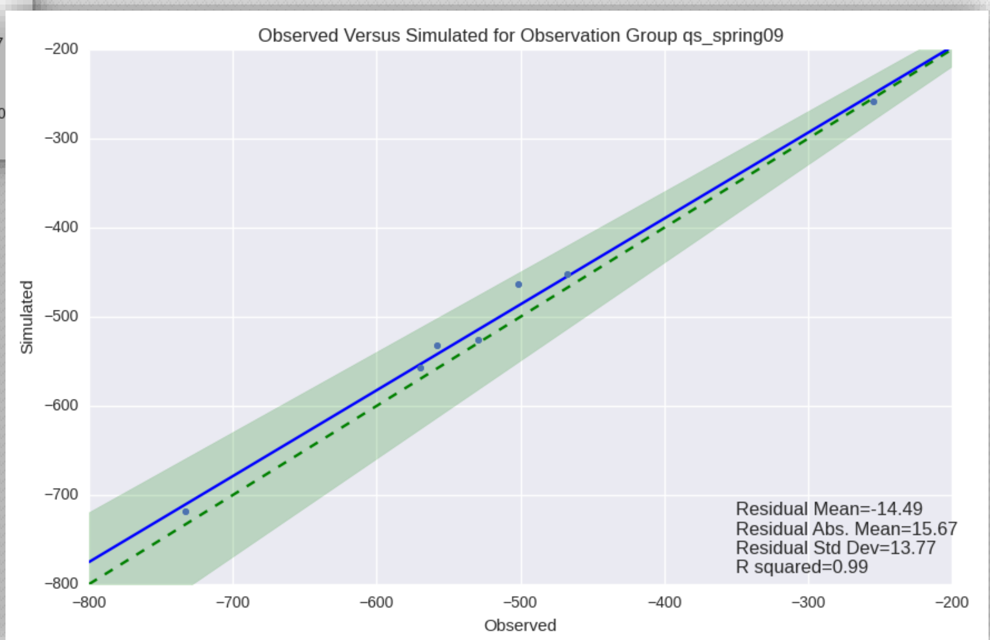
Individual Springs



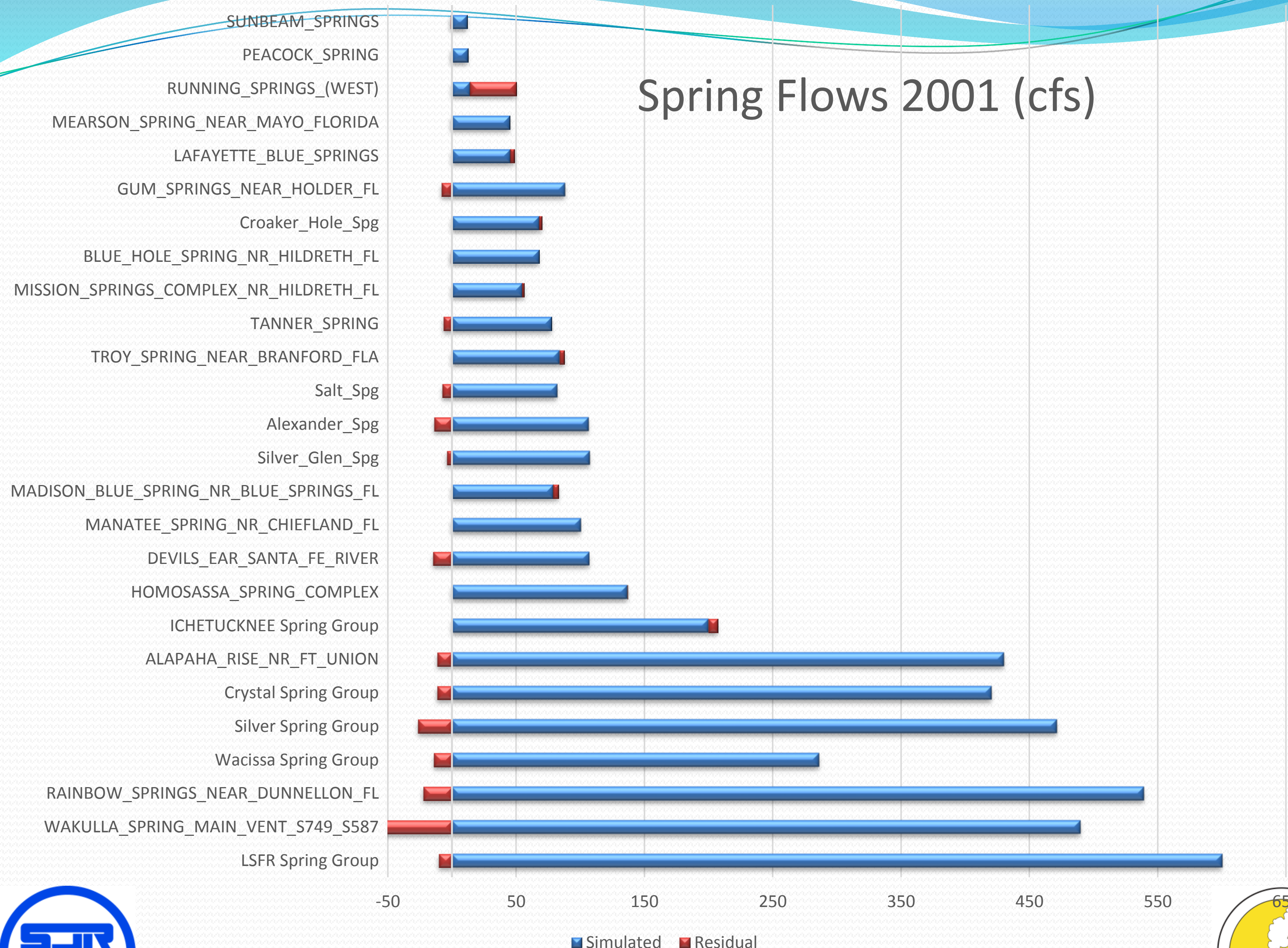


Large spring groups

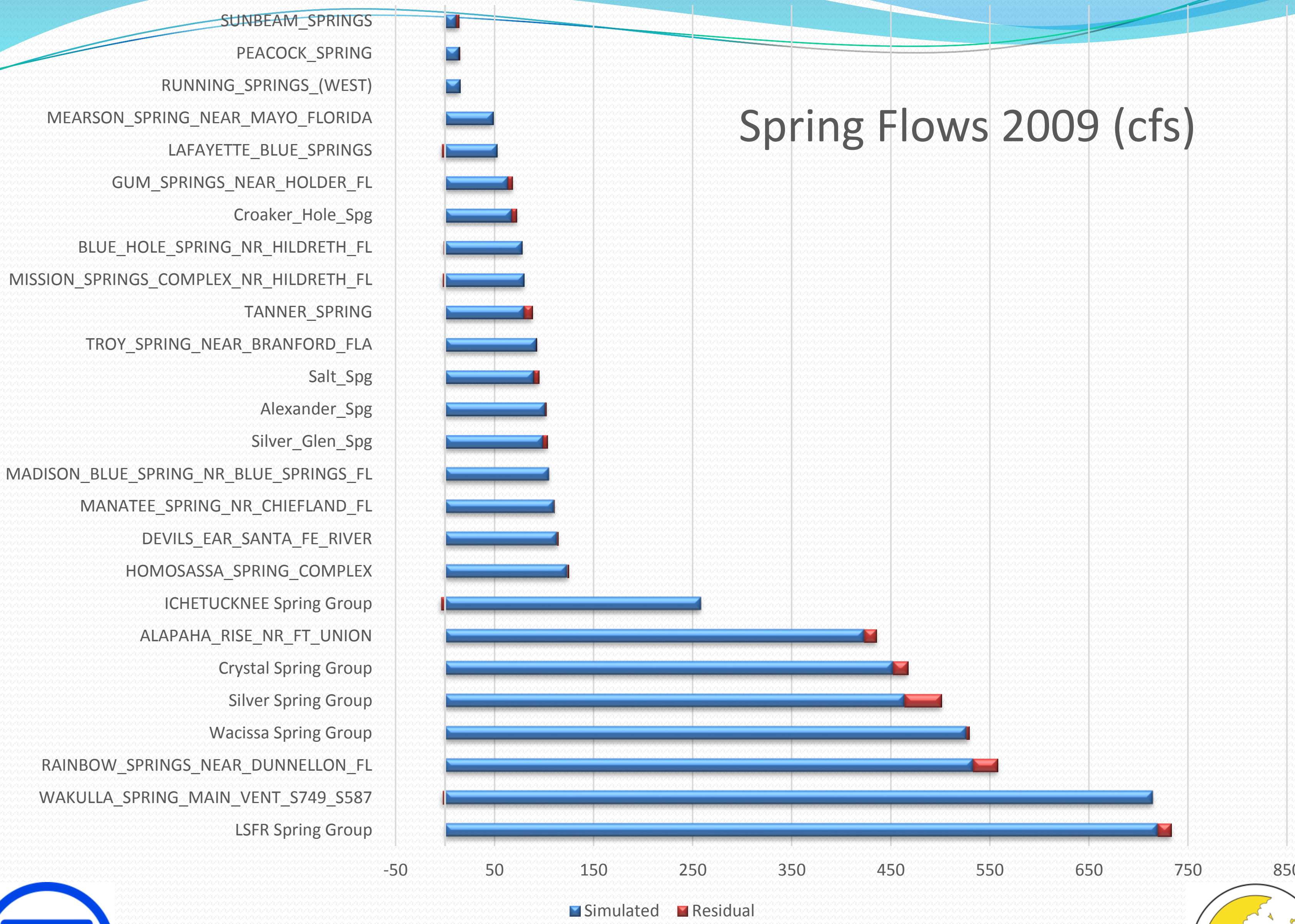




Spring Flows 2001 (cfs)

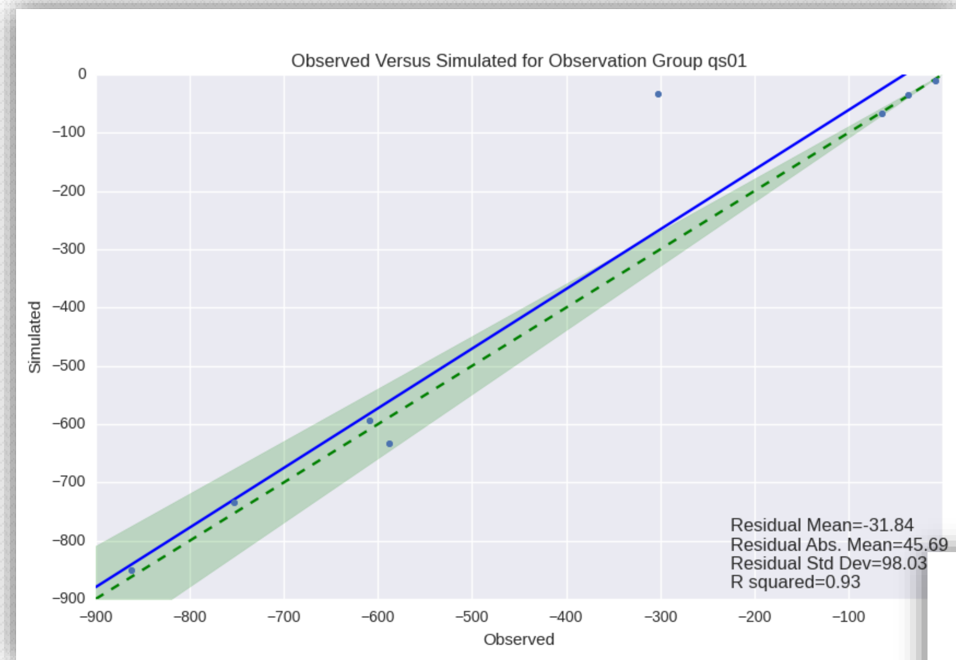


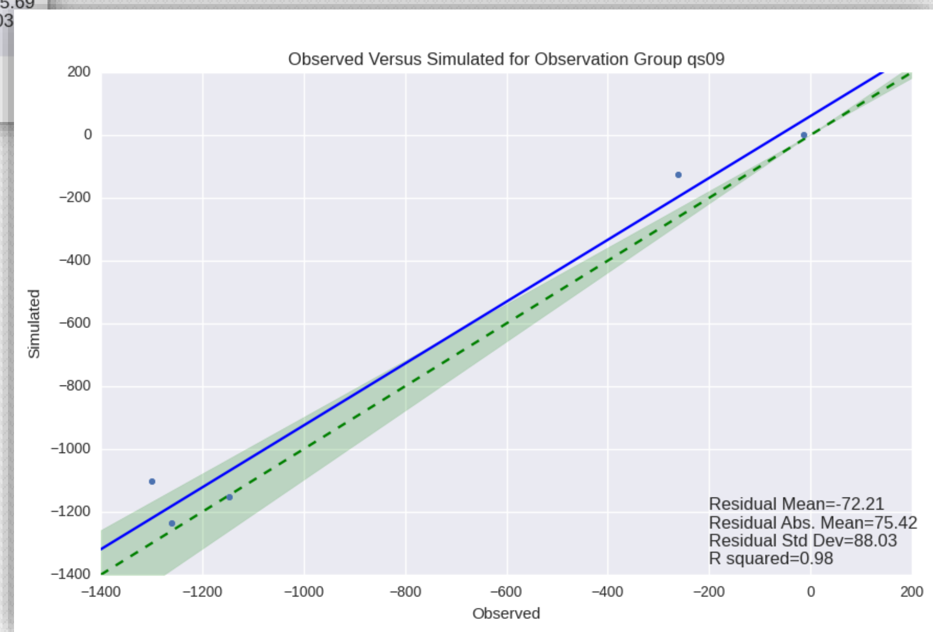
Spring Flows 2009 (cfs)



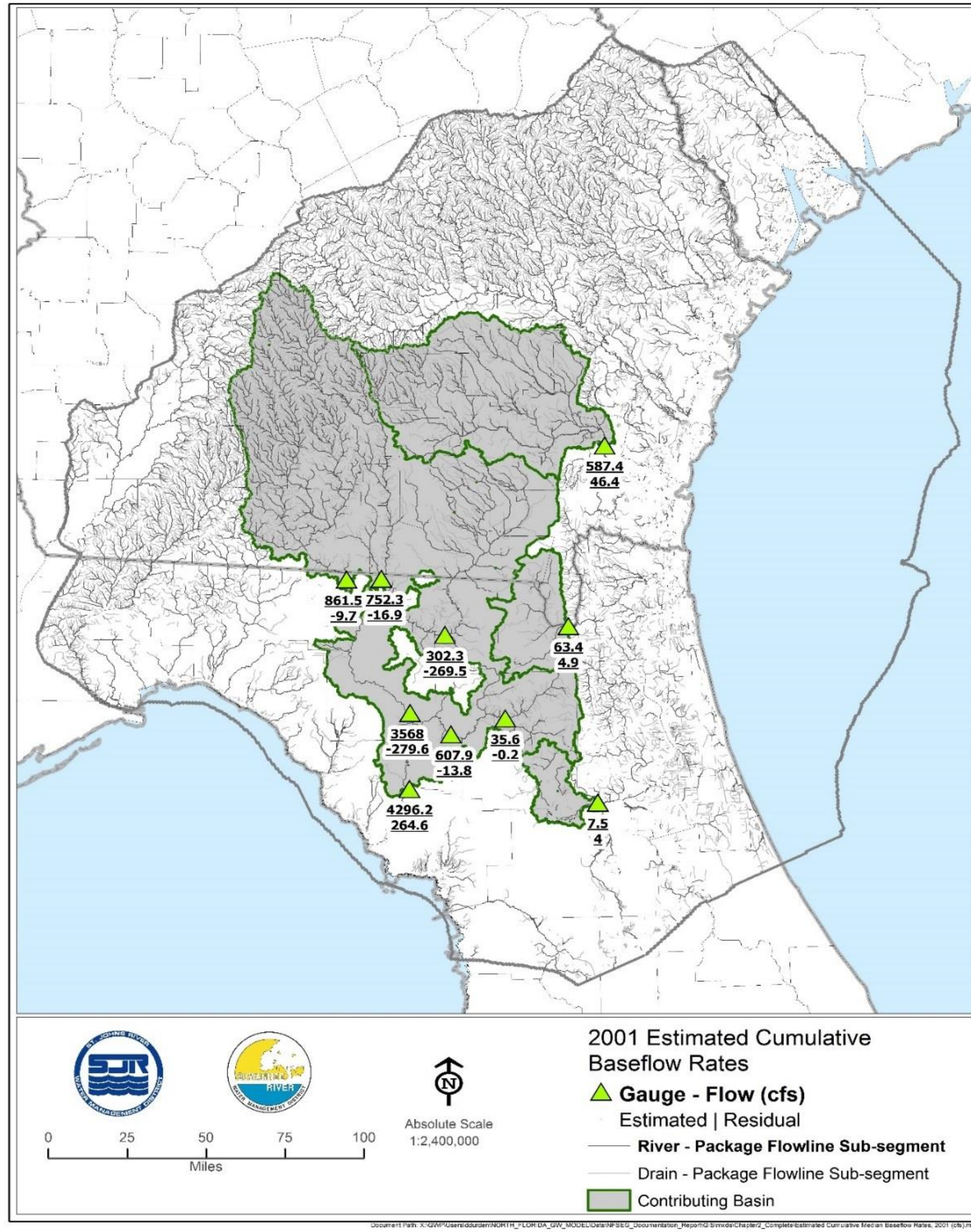
SUWANNEE RIVER WATER MANAGEMENT DISTRICT

Cumulative Baseflows



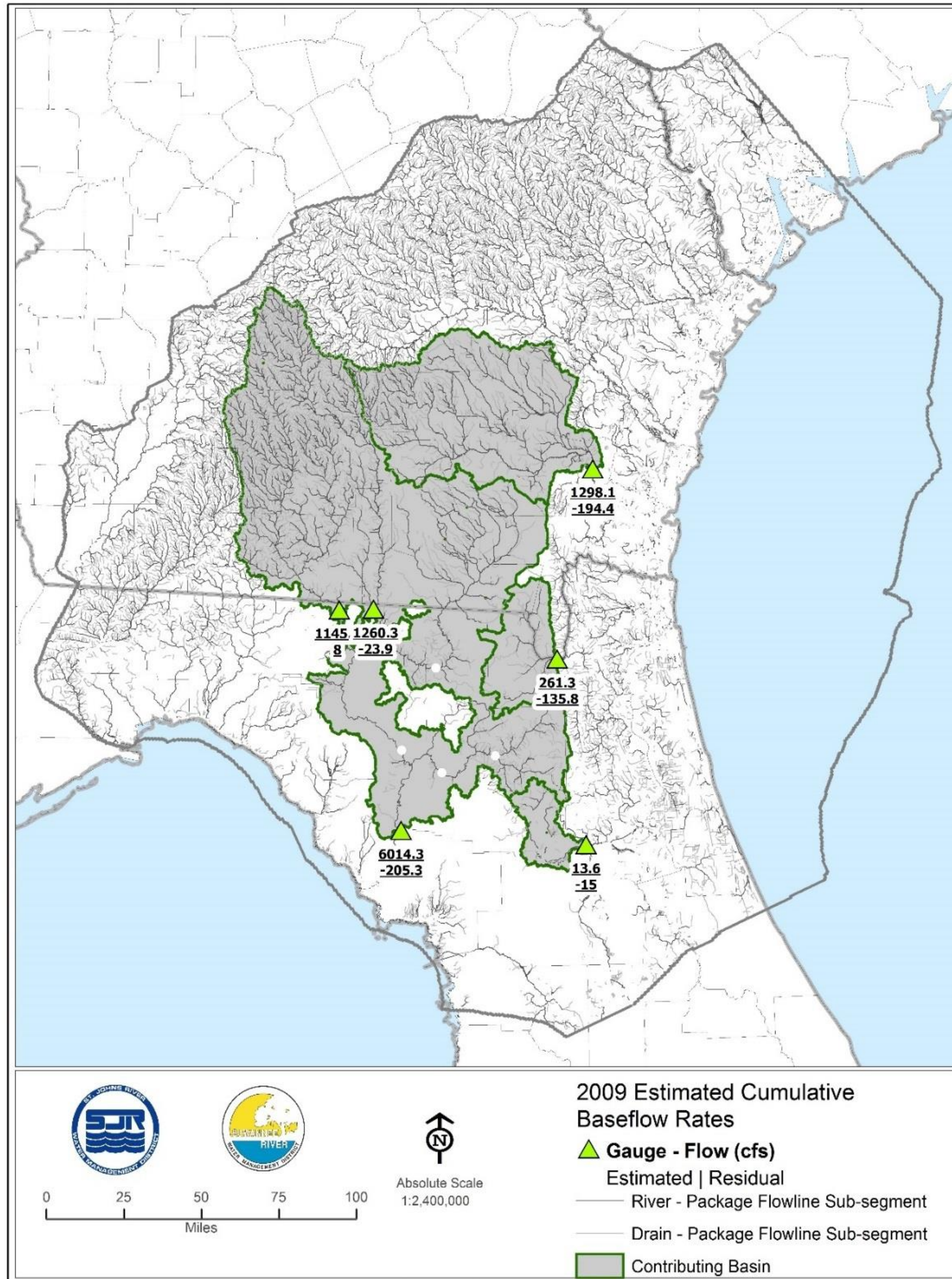


Cumulative Baseflow Residuals 2001



Cumulative Baseflow Residuals 2009

(Less Confidence with the target baseflows)

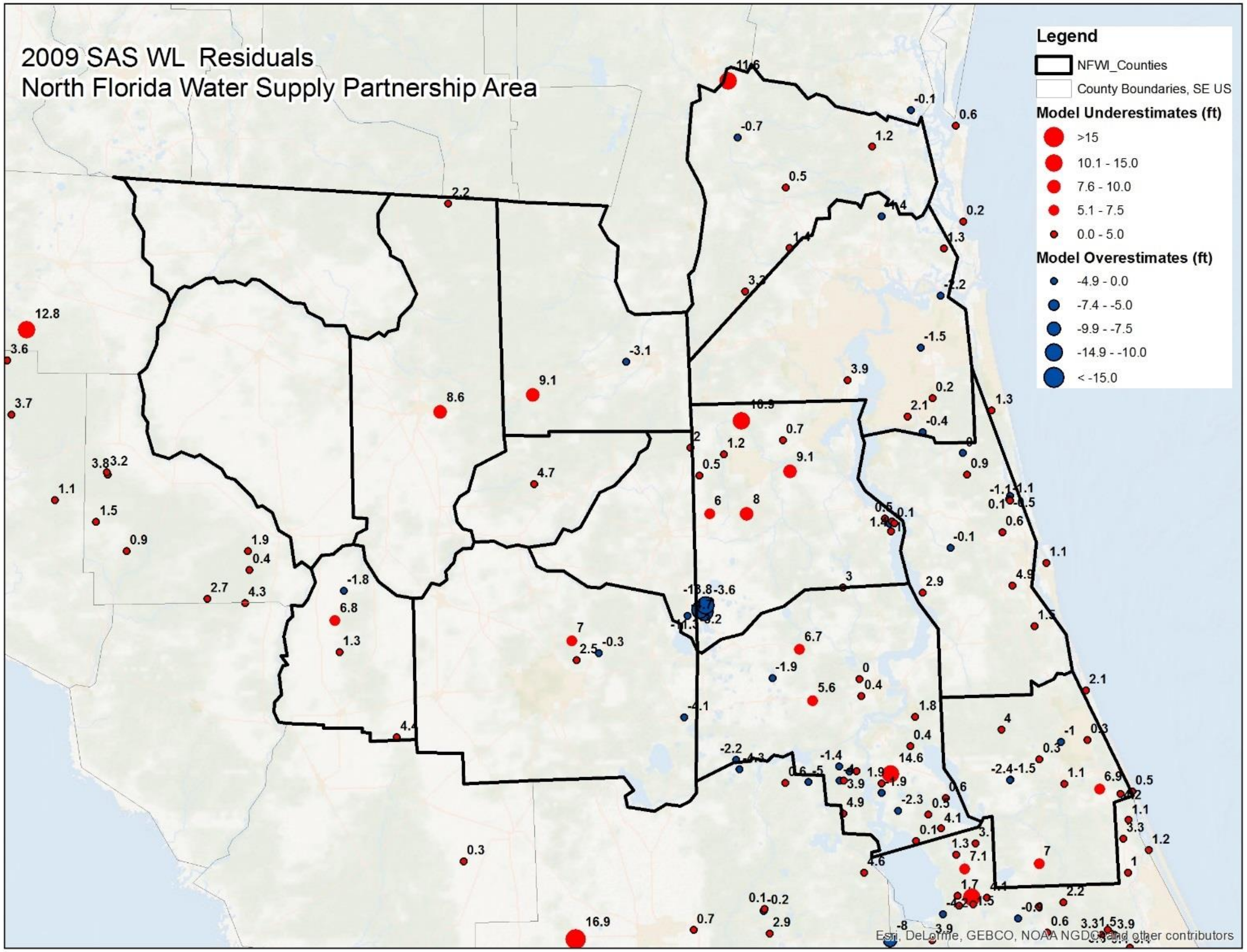


Calibration Statistics

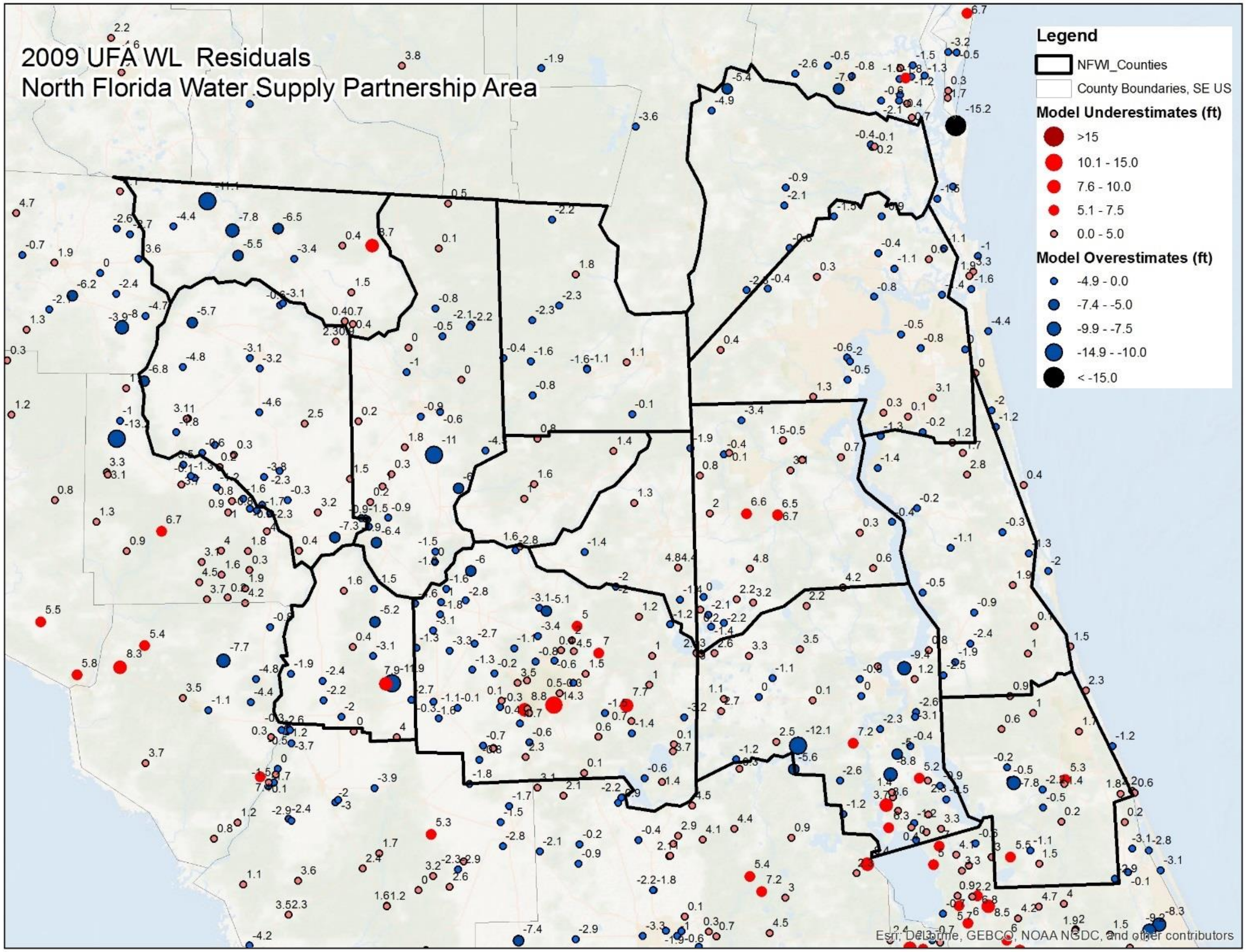
Statistical Criterion	Proposed Target	All Target Wells		Target Wells (# of WL Data > 1)		North Florida WSP Area	
		2001	2009	2001	2009	2001	2009
-5 feet < Residual < 5 feet	80%	80%	81%	83%	82%	86%	87%
-2.5 feet < Residual < 2.5 feet	50%	53%	55%	55%	57%	63%	67%
Mean Error		0.2	-0.1	0.0	-0.1	-0.4	-0.1
Absolute Mean Error		3.2	3.0	2.9	3.0	2.6	2.5
Root Mean Square of Error		4.4	4.3	4.0	4.2	3.7	3.7
Nash–Sutcliffe Efficiency		0.99	0.99	0.99	0.99	0.99	0.99
No of Targets		1242	1260	1115	1114	446	447

North Florida Water Supply Partnership Area

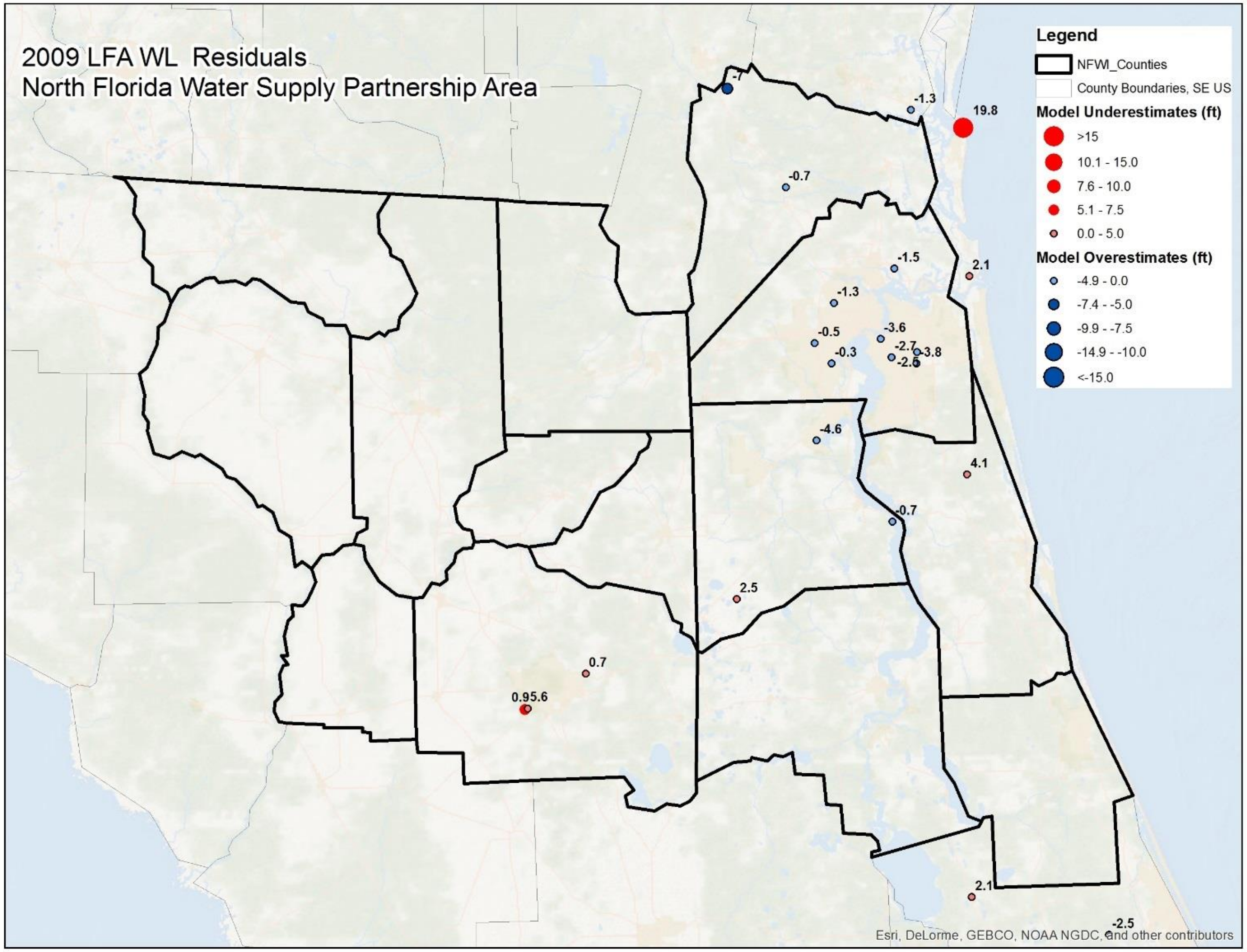
SAS Water Level Residuals



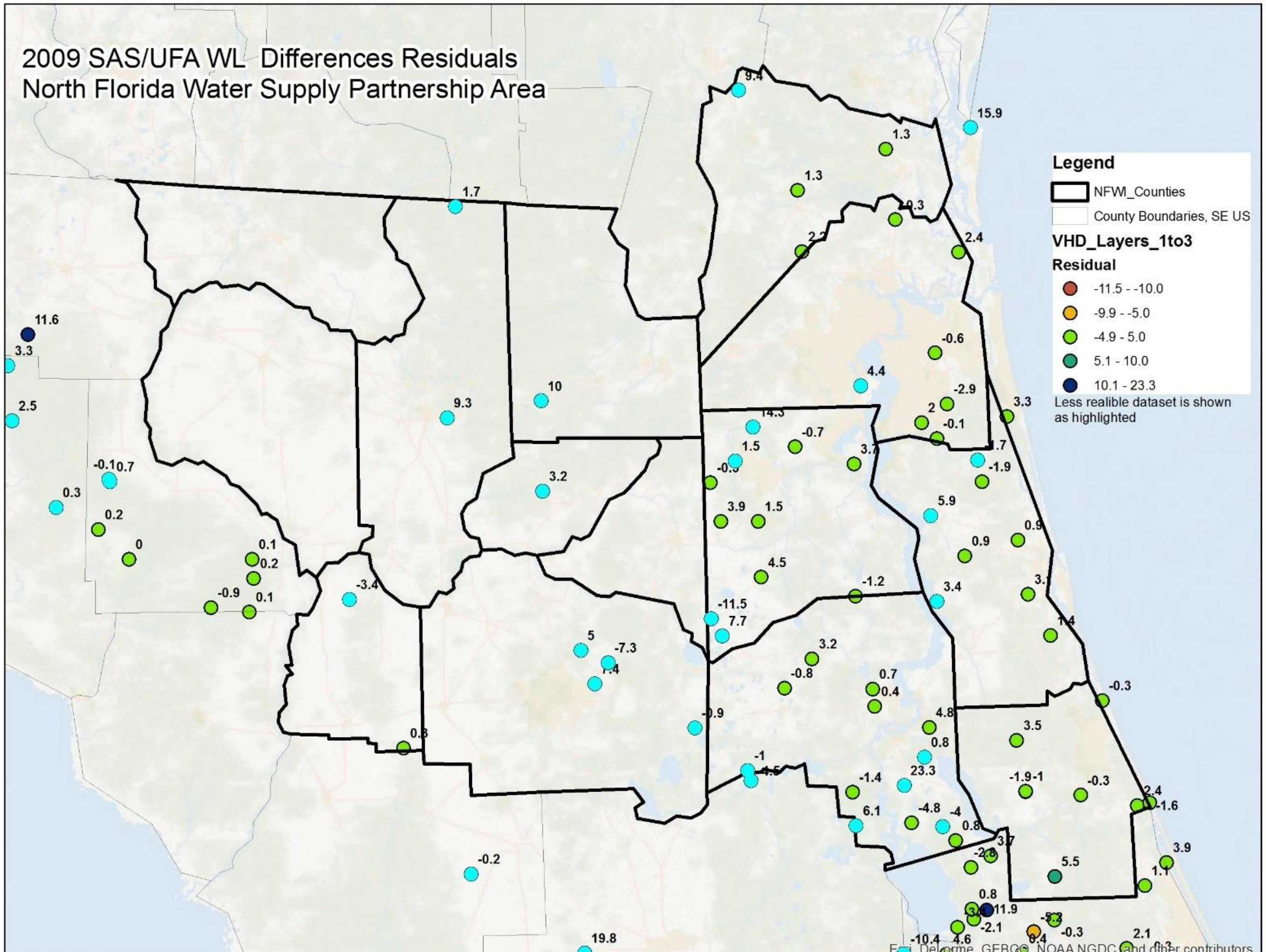
UFA Water Level Residuals



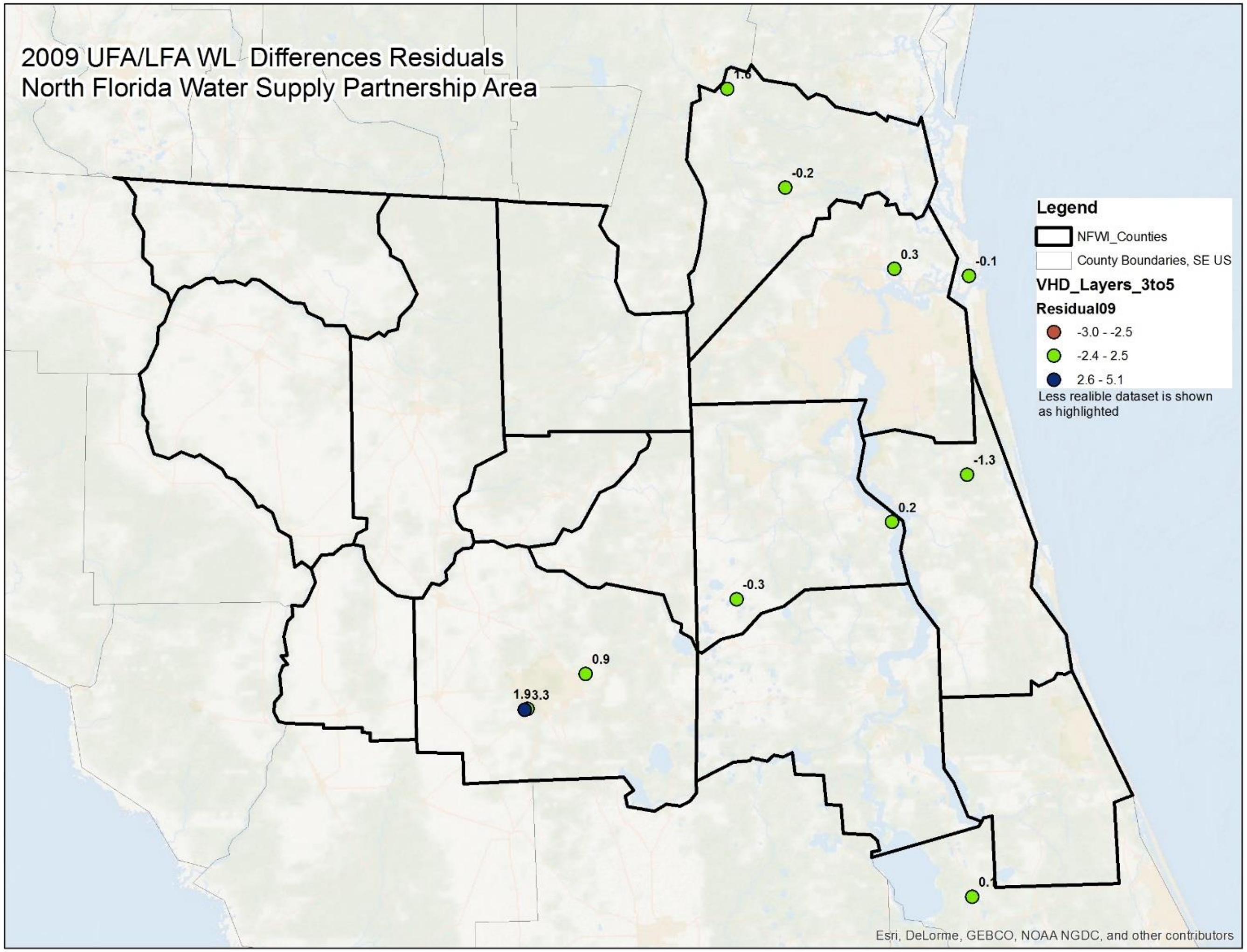
LFA Water Level Residuals



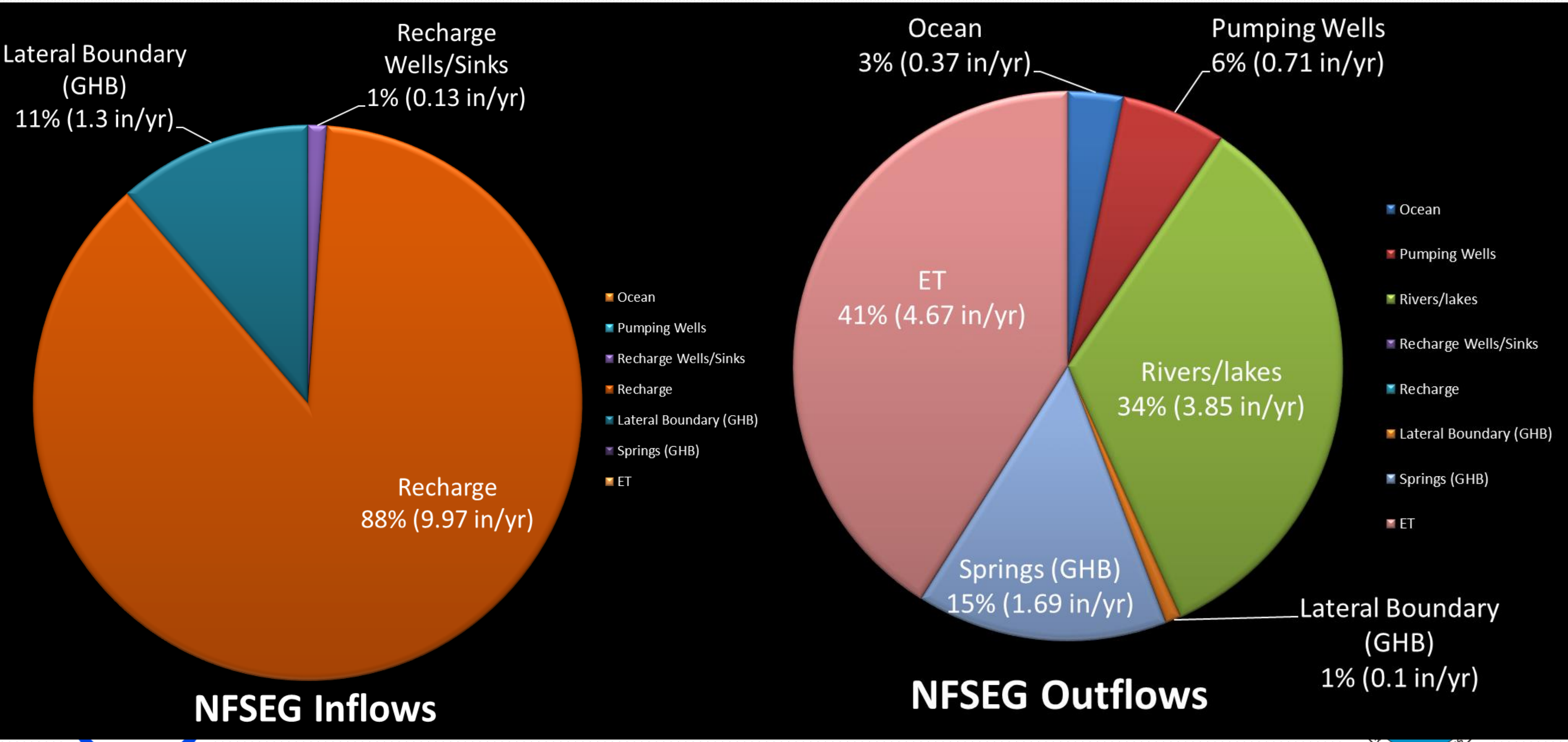
SAS/UFA WL Difference 2009



UFA/LFA WL Difference 2009

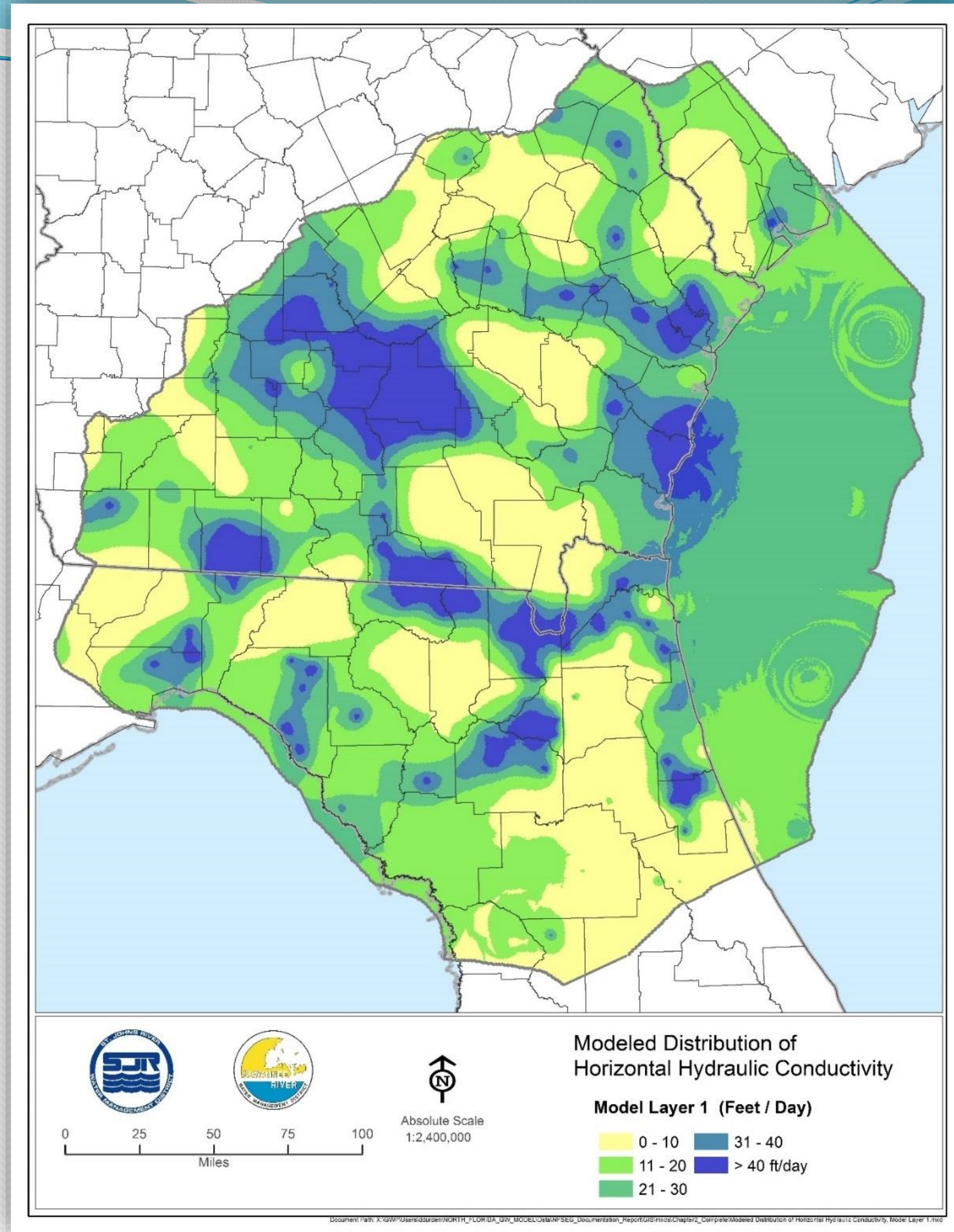


Water Budget 2009

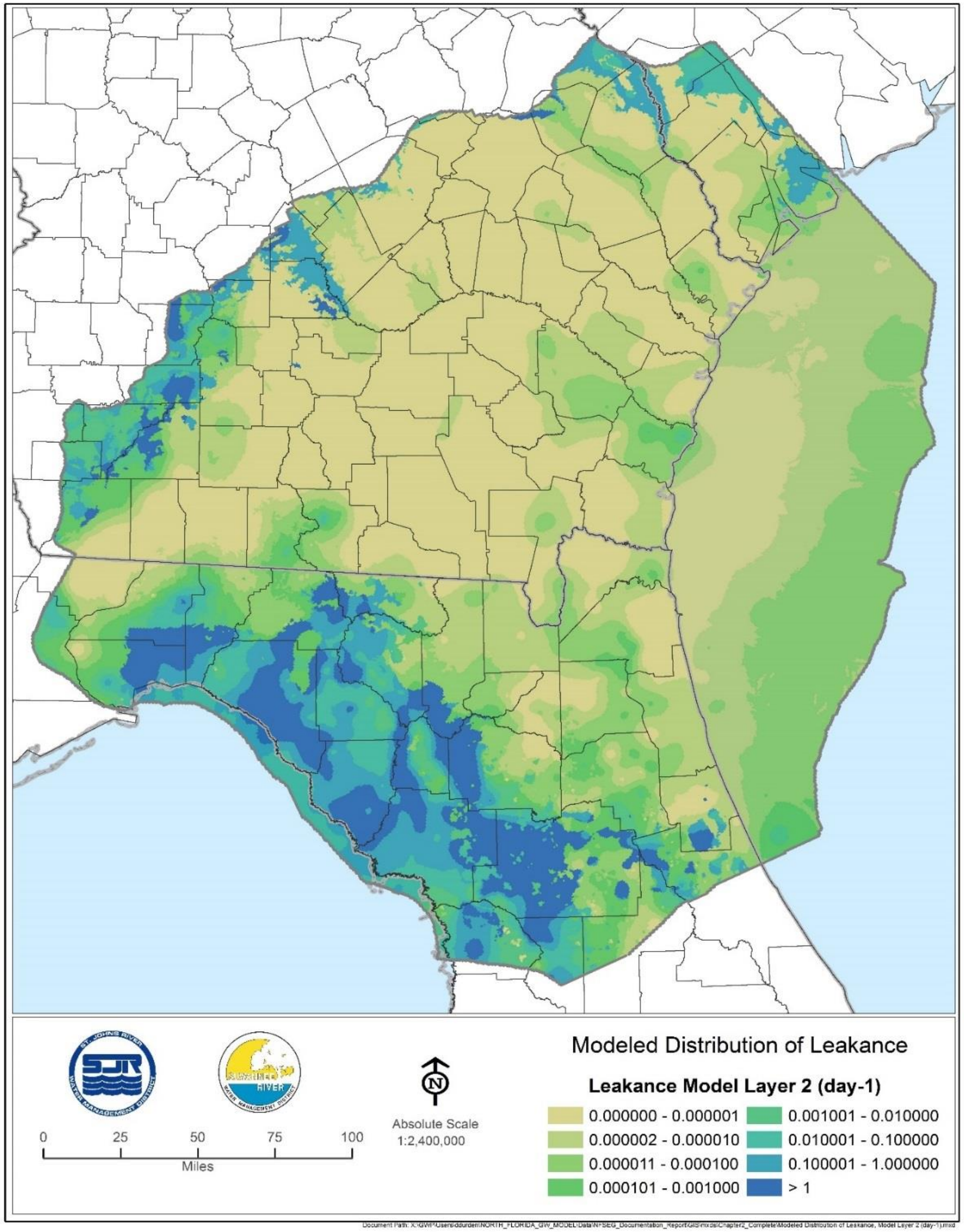


Aquifer Parameters

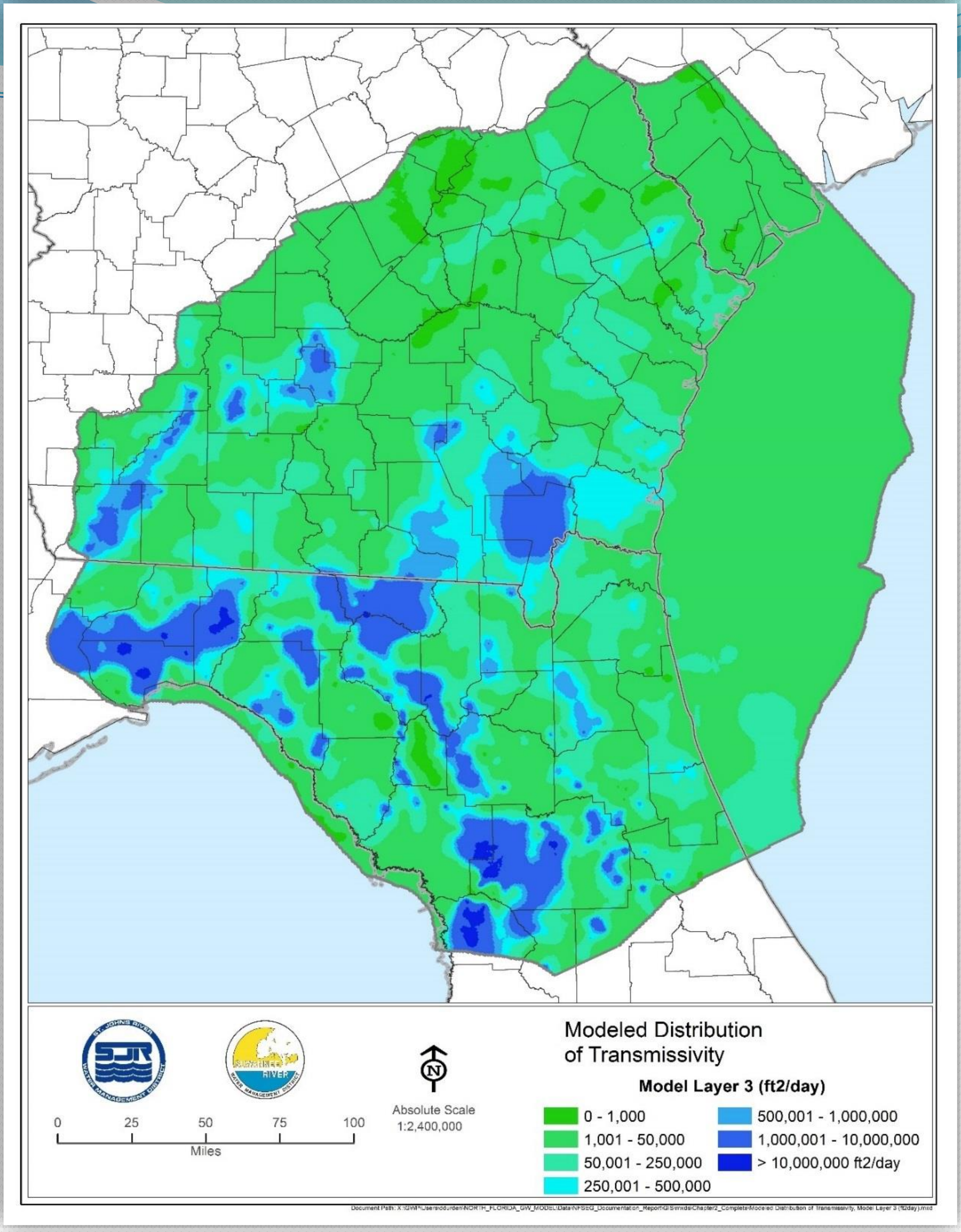
SAS Ks


Modeled Distribution of
Horizontal Hydraulic Conductivity
Model Layer 1 (Feet / Day)
0 - 10
11 - 20
21 - 30
31 - 40
> 40 ft/day
0
25
50
75
100
Miles
Absolute Scale
1:2,400,000
N

Layer 2 (ICU where it exists)

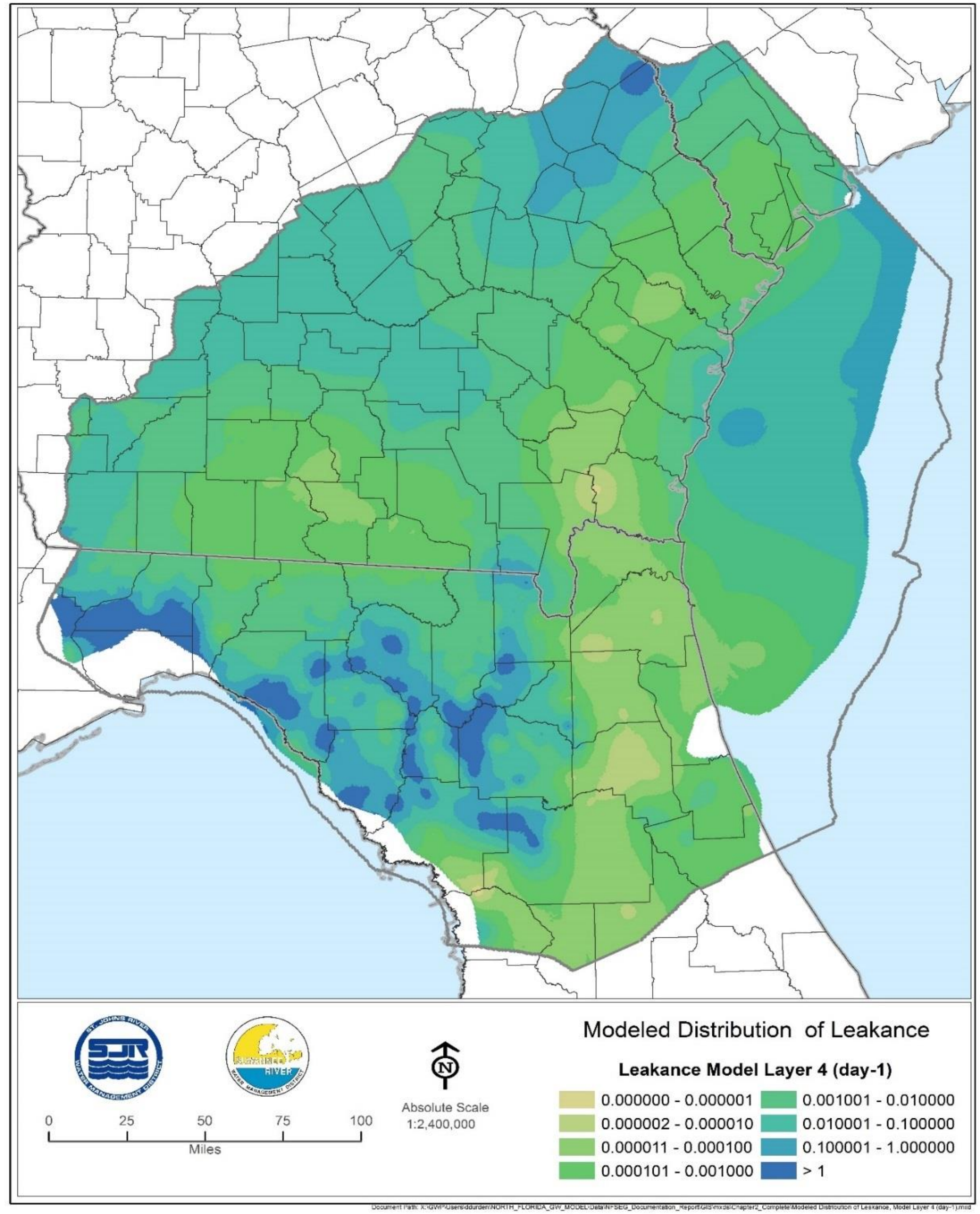


UFA Ts

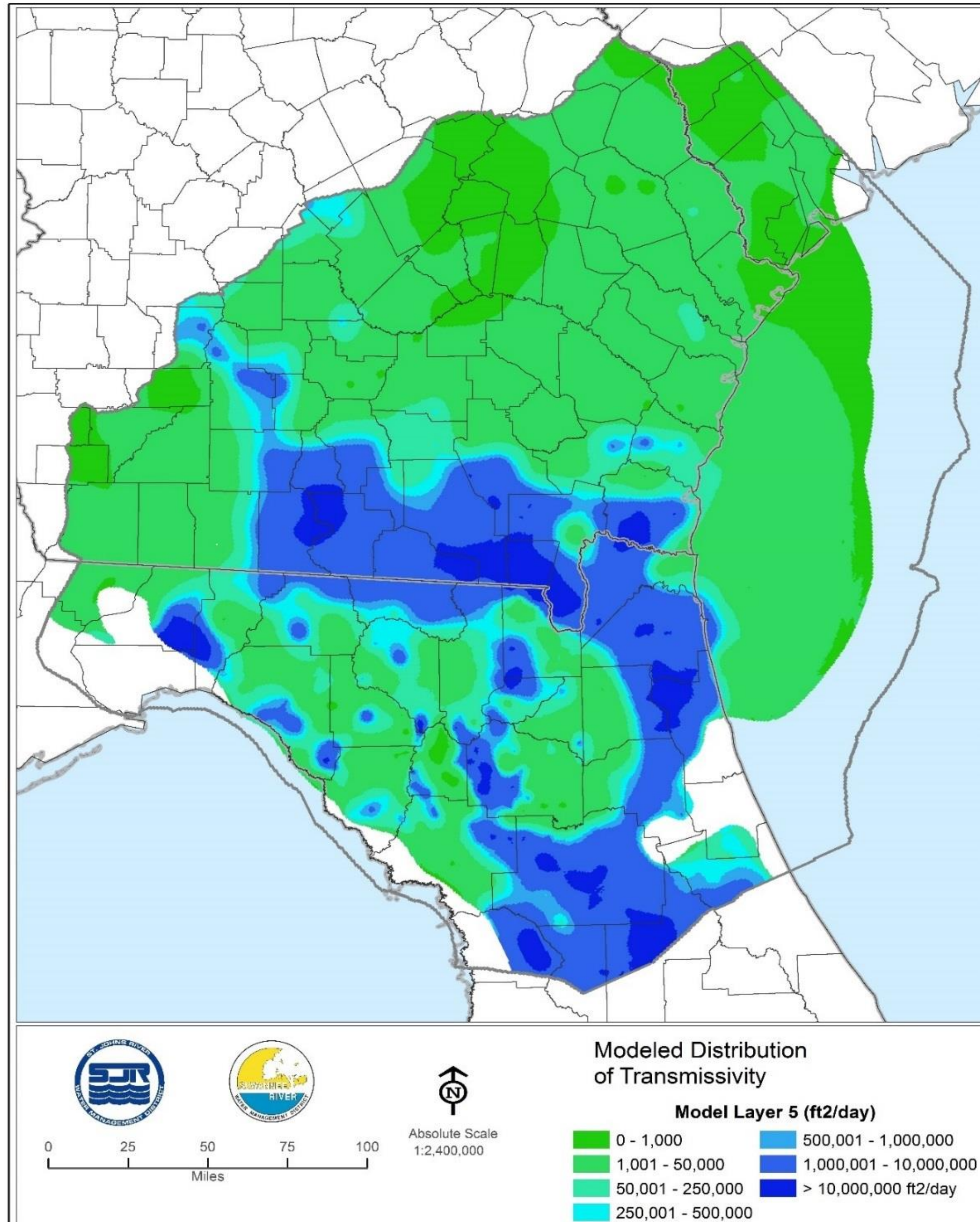


Modeled Distribution
of Transmissivity
Model Layer 3 (ft2/day)
0 - 1,000
1,001 - 50,000
50,001 - 250,000
250,001 - 500,000
500,001 - 1,000,000
1,000,001 - 10,000,000
> 10,000,000 ft2/day
0 25 50 75 100
Miles
Absolute Scale
1:2,400,000
N

Layer 4 (MCU where it exists)



Layer 5 (LFA where it exists)



Parameter Sensitivity and Predictive Uncertainty Analysis

Parameters used in the analysis

Parameter group name	Parameterization device	Number of parameters	Description
k1x	pilot points	518	horizontal hydraulic conductivity – layer 1
k3x	pilot points	1767	horizontal hydraulic conductivity – layer 3
k5xk3x	pilot points	201	horizontal hydraulic conductivity multiplier outside MCU – layer 5
k5x	pilot points	364	horizontal hydraulic conductivity – layer 5
k7x	pilot points	55	horizontal hydraulic conductivity – layer 7
k2z	pilot points	556	vertical hydraulic conductivity – layer 2
k2zk3z	pilot points	333	vertical hydraulic conductivity multiplier outside ICU – layer 2
k4zk3z	pilot points	139	vertical hydraulic conductivity multiplier outside MCU – layer 4
k4z	pilot points	230	vertical hydraulic conductivity – layer 4
k6z	pilot points	68	vertical hydraulic conductivity – layer 6
vanis1	entire layer	1	vertical anisotropy – layer 1
vanis2	zoned according to ICU/non-ICU	2	vertical anisotropy – layer 2
vanis3	entire layer	1	vertical anisotropy – layer 3
vanis4	zoned according to MCU/non-MCU	2	vertical anisotropy – layer 4
vanis5	zoned according to MCU/non-MCU	2	vertical anisotropy – layer 5
vanis6	entire layer	1	vertical anisotropy – layer 6
vanis7	entire layer	1	vertical anisotropy – layer 7
lcm	zoned according to lakes	257	multiplier applied to lakebed conductance
rcm	zoned according to river reaches	1871	multiplier applied to river reach conductance
sc	zoned according to springs	377	GHB conductance at springs
rechmul	zones (see fig 3.1)	904	multiplier applied to recharge rates
evtrmul	zones (see fig 3.1)	904	multiplier applied to maximum EVT rates
lkzmul	zoned according to	246	vertical conductivity multiplier under lakes

Semi-linear Uncertainty Analysis

Conduct initial linear uncertainty analysis

Generate parameter sets expected to produce predictions that are one standard error above or below the value predicted using the calibrated model

Run predictive scenarios using the parameter combinations

Estimate the uncertainty in model predictions using standard prediction error

Predictive Uncertainties

Prediction	Value of prediction calculated using k	Value of predictive change from 2009 to 2035 calculated using k	Value of predictive change from 2009 to 2035 calculated using k-δk	Value of predictive change from 2009 to 2035 calculated using k+δk
w00202_09[1]	78.37	1.34	1.23	1.42
w00878_09[1]	27.16	-1.22	-1.45	-0.99
qr09_iche_sprgrp[2]	-255.54	-12.82	-13.18	-12.49
qs09_2320500[2]	-4067.08	-65.38	-65.47	-63.94
qs09_2321500[2]	-36.00	-0.15	-0.15	-0.14
qs09_2322500[2]	-676.95	-23.69	-24.37	-22.93

[1]Values are in feet. Positive predictive changes mean drawdown.

[2]Values are in cubic feet per second. Negative predictive changes mean reduction in flows.

Prediction name	Description
w00202_09	UFA observation well near Lake Brooklyn
w00878_09	UFA observation well near Putnam County MFL lakes
qr09_iche_sprgrp	Ichetucknee Springs Group
qs09_2320500	Baseflow to the Suwannee River near Branford, Florida
qs09_2321500	Baseflow to the Santa Fe River near Worthington Springs
qs09_2322500	Baseflow to the Santa Fe River near Fort White

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