Updates and Re-Calibration of the North Florida Groundwater Model

Prepared for the Suwannee River Water Management District

Prepared by

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Executive Summary

In 2011 INTERA, Inc. (INTERA) was authorized by the Suwannee River Water Management District (District) to make revisions to the regional groundwater flow model of North Florida. Version 1 of the North Florida Model was constructed and calibrated by SDII Global Corporation (SDII) and documented in 2008 (SDII, 2008). The objective of the current revisions was to provide the District with an improved tool for consumptive use permit evaluation, regional water supply planning and to improve conceptual understanding of regional groundwater flow interactions of the Floridan aquifer system. Ultimately, the North Florida Model will be used by the District to evaluate impacts of groundwater withdrawals on groundwater levels.

The revised model was constructed using MODFLOW-NWT with a Groundwater Vistas Version 5.51 interface. Key modifications to Version 1 included the development and implementation of a systematic methodology to represent surface water hydrography and numerous springs via river and drain packages. Surface topography and layer thicknesses were also modified using best-available datasets from the United States Geological Survey (USGS). During model calibration, changes were made to the Version 1 conceptualization of North Florida Model though modeling of surficial and thin underlying intermediate aquifer systems as one layer. This was done to mitigate drying and rewetting problems caused by thin surficial and intermediate aquifers in the model domain. In addition, the Version 1 domain was expanded to the southeast for better alignment with hydrologic boundaries. Additional modifications included changes to the distribution of groundwater recharge and evapotranspiration (ET) via ET and recharge packages. The estimates of pumping for 2000, used in Version 1, were replaced with pumping rates for 1995 calendar year.

Automated PEST calibration was performed on the North Florida Model parameters including recharge, ET, hydraulic conductivity, river and springs characteristics. The calibration efforts focused on the surficial and Floridan aquifer systems. Revisions produced a model with updated hydrostratigraphy using best available data that better simulates impacts to Floridan aquifer heads, springflows, and river baseflows.

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Introduction

In 2004 the Suwannee River Water Management District (District) authorized SDII Global Corporation (SDII) to develop a regional groundwater flow model. In 2008 SDII completed the development of a three-dimensional flow model of North Florida (SDII, 2008), herein referred to as Version 1 of the North Florida Model (NF Model). In 2011 INTERA, Inc. (INTERA) was authorized to make revisions to the existing North Florida model. The primary objective of the revisions was to increase the model utility and reliability by modifying boundaries and adding additional calibration constraints. This was accomplished through the following subtasks:

- Realignment and finer discretization (5,000 ft to 2,500 ft) of the uniformly spaced grid;
- Expansion of the model domain to the southeast for alignment with the Northeast Florida model (NEF) further described in the *Previous Groundwater Modeling Efforts* section of this report;
- Modifications to the model stratigraphy and layer elevations based on digital surfaces developed by the USGS;
- Modifications to general head and constant head boundary conditions;
- Enhancement to the representation of surface water features through the development of new river and drain packages;
- Addition of well, baseflow flux, and springflow targets to represent 1995 average hydrologic conditions;
- Recalibration of the model for the period from January 1, 1995 through December 31, 1995 using PEST software for model-independent parameter estimation (Doherty, 2004).

The revised model was constructed using MODFLOW-NWT (Niswonger et al., 2011) with the Groundwater Vistas Version 5.51 (Environmental Simulations Incorporated, 2007) interface. The coordinate system of all digital coverages used in the model development was the Universal Transverse Mercator (UTM) projection, zone 17N of the Florida coordinate system. All work was referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). Units of measure were set to feet and days.

Summary of Existing North Florida Model

The existing version of the North Florida Model (nfm_v1.02.gwv) was provided by the District to be used in the revisions. This section includes a brief summary of the existing North Florida Model.

In 2004 the District authorized SDII Global Corporation (SDII) to develop a regional groundwater flow model known as the North Florida Model. The SDII original model is based on the McDonald and Harbaugh (1988) three-dimensional, finite-difference groundwater flow model (MODFLOW). The original model domain is discretized into a 5,000 by 5,000-foot rectangular grid and consists of 190 rows and 245 columns. The modeled area consists of the Suwannee River Water Management District and the areas outside the District, as shown in Figure 1. The modeled area includes areas outside the District since their drawdown can affect aquifer levels inside the District (SDII, 2008). The model is bounded by the Gulf of Mexico on the west and the Atlantic Ocean on the east. As shown in Figure 1, the active domain of the SDII existing model extends from Tallahassee in the west to the Atlantic Ocean in the east, and from Brooks and Thomas Counties, Georgia in the north to Levy and Marion Counties, Florida in the south. As mentioned earlier, the existing model boundary has been expanded to the southeast for better alignment with geologic and hydrologic boundaries. Active domains by layer of the revised North Florida Model are shown in Figures 16-19.

The existing version of the model consists of five (5) layers: the surficial aquifer system (SAS), intermediate aquifer system (IAS), upper Floridan Aquifer (UFA), middle Floridan Confining Unit (MCU), and lower Floridan Aquifer (LFA). Layer descriptions are shown in Table 1. The same layering scheme was initially adopted in the revised version of the North Florida Model. During model calibration it was decided to model surficial and intermediate aquifer systems as one layer to help mitigate drying and rewetting. This change is described later in the report.

Table 1. SDII Model Layering Scheme (SDII, 2008)

<table>
<tr><th>Model Layer</th><th>Areas Where All Hydrostratigraphic Units are Present</th><th>Area Where IAS Confining Unit is Absent</th><th>Areas Where the MCU Confining Unit is Absent</th></tr>
<tr><td>1</td><td>SAS</td><td rowspan="2">SAS</td><td>SAS</td></tr>
<tr><td>2</td><td>IAS</td><td>IAS</td></tr>
<tr><td>3</td><td>UFA</td><td>UFA</td><td rowspan="3">FAS</td></tr>
<tr><td>4</td><td>MCU</td><td>MCU</td></tr>
<tr><td>5</td><td>LFA</td><td>LFA</td></tr>
</table>

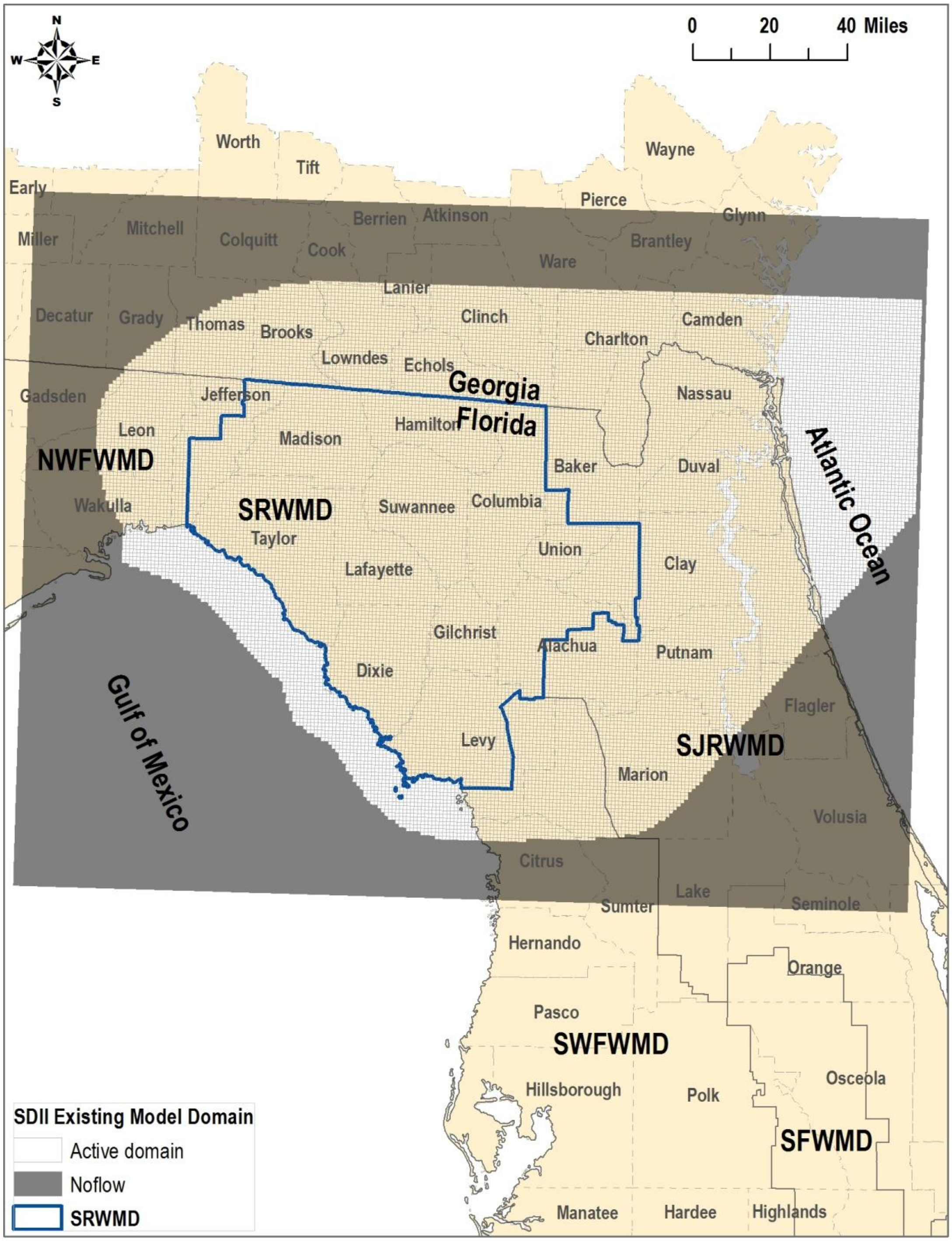

Figure 1. Extent of the Version 1 North Florida Model Showing 5000 ft X 5000 ft Model Grid

All five layers, including confining units, are explicitly represented in the existing SDII model. The confining units (the IAS and the MCU) are not always present in the model domain (Miller, 1990). Since MODFLOW requires some minimum thickness for all layers, three layering schemes were utilized in the existing version of the North Florida model to account for the areas where confining units were absent. The full account is given in the SDII report (2008) but the summary is presented below (Table 1). Three different layering schemes included the following:

1. Areas where all layers are present: the SAS, IAS, UFA, MCU, LFA are represented as layers 1 through 5.

2. Areas where the IAS confining unit is absent: the SAS is used to represent both layers 1 and 2. The properties of the SAS are assigned to both layers. The top of the SAS is assigned to the top of layer 1 and the bottom of the SAS is assigned to the bottom of layer 2.

3. Areas where the MCU is absent: the FAS is used to represent all three layers – layers 3, 4, and 5. The top of the FAS is assigned to the top of layer 3 and the bottom of the FAS is assigned to the bottom of layer 5.

Modifications were made to the layering scheme originally developed by SDII. The changes to stratigraphy are described in the stratigraphy section of this report. Originally, SDII constructed a model using MODFLOW 2000 and the Groundwater Model System (GMS) interface. The GMS interface was later replaced by the Groundwater Vistas Version 5.51 interface.

The existing North Florida model is calibrated to average groundwater heads and flows for the period June 1, 2001 – May 31, 2002. The existing SDII flow model has various boundaries. First, the existing model is bounded by no-flow boundaries in layers 1-5. Second, the existing model utilizes the general-head boundaries (GHB) in layers 1-5. Constant head (CH) cells are utilized along the coast of the Gulf of Mexico and the Atlantic Ocean in the SAS (layer 1) and along the coast of the Gulf of Mexico in the IAS (layer 2). The boundary conditions of the SDII North Florida Model are further described in the Boundary Conditions Development section of this report.

In Version 1 of the model, rivers and springs are represented by the MODFLOW river and drain packages respectively (SDII, 2008). Lakes and swampy areas within the existing model are simulated using the GHB package. Recharge and evapotranspiration (ET) are simulated with the use of the recharge and ET packages, respectively. The groundwater production and injection wells are represented using the well package.

Previous Groundwater Modeling Efforts

INTERA's previous regional scale groundwater modeling efforts in Florida include modifications to Sepúlveda's Peninsular Florida model, also known as the MegaModel (INTERA, 2011a; Sepúlveda,, 2002), and the Northeast Florida model (NEF) (INTERA, 2011b). These groundwater flow models comprised parts of the Suwannnee River Water Management District and were used or referenced in the revisions of the North Florida Model, as described in the *Model Development* section of this report. This section briefly describes these models and their domains. For further descriptions of the models and INTERA's involvement in the modeling efforts, the reader should refer to INTERA (2011a) and INTERA (2011b). The domains and layering schemes of the MegaModel, the NEF, and the North Florida Model are shown in Figures 2 and 3.

Peninsular Florida Model

The MegaModel is a steady-state MODFLOW model calibrated to the average flow conditions from 1993 to 1994. The model is comprised of 4 layers, including the surficial aquifer, intermediate aquifer, upper Floridan aquifer, and lower Floridan aquifer. The model domain extends northward to portions of southern Georgia and southward into portions of Charlotte, Glades and Palm Beach counties. The model is discretized into uniform 5,000-foot square grid cells and is comprised of 300 rows and 210 columns.

Layer 1 of the original version of the MegaModel is defined as constant head boundary; therefore no hydrography exists in the model conceptualization. The MegaModel modifications by INTERA included the activation of the surficial aquifer on layer 1, the addition of a river package, and the use of a net recharge package to account for the existing calibrated constant head fluxes (INTERA, 2011a). The MegaModel properties were used in the North Florida model revisions. In addition, the water use for the North Florida Model outside the District's boundary and the NEF domain was based on the MegaModel well package, previously developed for August 1993 through July 1994 average hydrologic conditions (INTERA, 2011a). Most importantly, the North Florida Model grid was realigned with the MegaModel grid.

Northeast Florida Model

The Northeast Florida (NEF) regional groundwater flow model was developed to support the evaluation of sustainable groundwater resources in the northeast Florida area as part of the District's Water Supply Assessment program. The Northeast Florida model (NEF) is a steady-state, 4-layer, quasi three-dimensional MODFLOW model, with layers representing the surficial aquifer, upper Floridan aquifer, lower Floridan aquifer, and Fernandina Permeable Zone (Figure 2). The model domain is rectangular and contains 260 rows and 200 columns, with a uniform grid spacing of 2500 feet. In 2008, the St. Johns River Water Management District contracted with INTERA to make revisions to version 3 of the NEF model. At that time, layer 1 (the surficial aquifer) of the NEFv3 model contained constant head boundary conditions representing major hydrography. As requested by the District, INTERA developed a new river package to better represent hydrography and add constraint to the baseflow fluxes through additional calibration. INTERA recalibrated the NEFv3 model to average 1995 conditions and conducted a verification of the model using 2004 data. The NEF hydrography and baseflow fluxes served as a starting point in the development of a new river package for the North Florida model. In addition, the NEF 1995 water use pumping data was used in the North Florida Model.

The North Florida Model was expanded to the southeast to align with the NEF groundwater regional model. The NEF groundwater regional model is utilized by the Suwannee River Water Management District and the St. Johns River Water Management District; hence, alignment with the NEF seemed appropriate.

North Florida Model

Group or Formation	Model Layer	Layer Number
Undifferentiated (sand with shell, clay, etc.)	Surficial Aquifer System (SAS)	1
Hawthorn, St. Mark's Formation	Intermediate Aquifer System (IAS)	2
Suwannee, Ocala, Avon Park Formation	Upper Floridan Aquifer (UFA)	3
Avon Park Formation	Middle Confining Unit (MCU)	4
Oldsmar Formation	Lower Floridan Aquifer (LFA)	5

MegaModel

Model Layer	Layer Number
Surficial Aquifer System (SAS)	1
Intermediate Aquifer System (IAS)	2
Upper Floridan Aquifer (UFA)	3
Lower Floridan Aquifer (LFA)	4

Northeast Florida Model

Model Layer	Layer Number
Surficial Aquifer System (SAS)	1
Upper Floridan Aquifer (UFA)	2
Lower Floridan Aquifer (LFA)	3
Fernandina Permeable Zone	4

Figure 2. Layering Scheme and Representation of Geologic Units in the North Florida Model, MegaModel, and the Northeast Florida Model

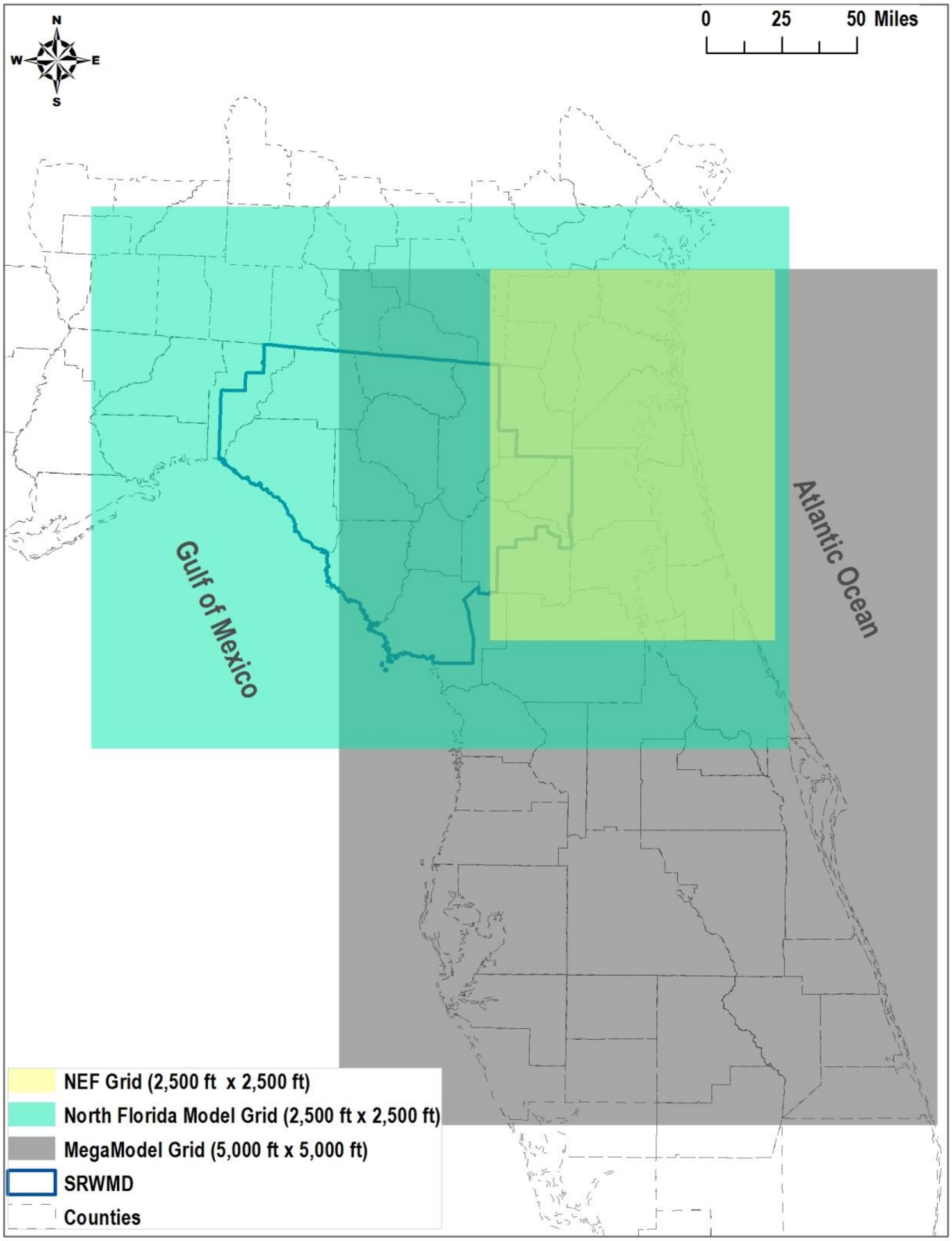

Figure 3. MegaModel, NEF Model, and NF Model domains

Data Collection

Data was collected from various sources including the U. S. Geological Survey (USGS), the District, the St. Johns River Water Management District, the original SDII North Florida Model, and HEC-RAS surface water models developed by INTERA for the District as part of previous modeling efforts.

Data collection included digital surfaces of the top and bottom elevations of the IAS and of the hydrostratigraphic units within the Floridan aquifer, digital topographic coverages, head data, baseflows, hydrography, pumping data, rainfall and recharge. The collected data was utilized in the development of the hydrostratigraphy, boundary conditions, and MODFLOW packages and to constrain the range of adjustable parameters during model calibration.

Land-Surface Elevations

The top of the revised North Florida Model was defined using two data sources: the National Elevation Dataset (NED) (Gesch, 2007; Gesch et al., 2002) and the Digital Line Graph (DLG) (USGS, 1990) are presentations of the elevation contour lines from USGS topographic maps. This was necessary because there were some areas inside the District with erroneous elevation data. Accordingly, the DLG topographic contours were used to define the land-surface elevation inside the District, and the NED was used to define these elevations in areas outside of the District. The National Elevation Dataset (NED), a digital elevation model of the model domain's topographic surface, was downloaded from the USGS website (http://ned.usgs.gov). The NED that was downloaded had a horizontal resolution of 1/3 arc-second (approximately 10 meters). This raster elevation dataset was referenced to the North American Vertical Datum of 1988 (NAVD 88), and the elevation data were expressed in units of meters. A raster dataset of the VERTCON offset values for Florida was provided by the St. Johns River Water Management District (vert94eftfl.grid.aux). VERTCON elevation values were used to convert NED elevation values from NAVD88 to the National Geodetic Vertical Datum of 1929 (NGVD29). The NED digital elevation coverage was used to define the North Florida Model layer 1 top elevation outside the Suwannee River Water Management District boundary.

The USGS DLG dataset of topographic contours derived from the 1:24,000 scale topographic maps (topousgs5.shp) were used to define the elevation of the top of model layer 1 inside the District boundary. The DLG dataset was downloaded from the Suwannee River Water Management District website (http://www.srwmd.state.fl.us/index.aspx?NID=319) and represents the topography with a contour interval of 5 feet.

Stratigraphy

Since the North Florida Model boundary was expanded to the southeast for alignment with the Northeast Florida groundwater regional model, new elevation coverages were needed. The District specified that the hydrogeologic framework developed by Miller (1986; 1990) would be used to update layer elevations. The maps of thickness, top surfaces, and bottom surfaces of the hydrostratigraphic units from Miller's hydrogeologic framework of the Floridan aquifer system were digitized by Bellino (2011), and were used to update the North Florida Model hydrostratigraphy. Miller's hydrostratigraphic maps were published as part of the USGS Regional Aquifer-System Analysis (RASA) Program in the 1980s (Bush and Johnston, 1988). Table 2 summarizes the data used to update hydrostratigraphic coverages in the model.

Table 2. North Florida Model Hydrostratigraphic Coverages

Model Layer	Hydrostratigraphic Unit	Elevation	File Name	Description
1	SAS	Top	a) Several NED rasters; b) topousgs5.shp.	a) 1/3 (10-meter) arc-second NED topographic coverage; b) 5-foot USGS topographic contours from the SRWMD website.
		Bottom	a) plt25_upper_confining_unit.tif (Bellino, 2011); b) plt25_ucu_poly.shp (Bellino, 2011).	a) Scanned image of the extent and thickness of the upper confining unit (IAS); b) Shapefile of the extent of the upper confining unit (IAS).
2	IAS	Top		
		Bottom	fast_surf.zip (Bellino, 2011).	Raster dataset of the top of the Floridan aquifer system.
3	UFA	Top		
		Bottom	a) ufab_surf.zip (Bellino, 2011); b) plt29_ufa_base_cntr.shp (Bellino, 2011); c) Figure 19 (Sepúlveda, 2002).	a) Raster dataset of the base of the upper Floridan aquifer system; b) Shapefile of the contours of the base of the upper Floridan aquifer; c) Map of the estimated altitude of water containing a chloride concentration of 5,000 mg/L in the FAS. **Note**: Raster dataset of the base of the Upper Floridan aquifer (ufab_surf.zip) had erroneous data and was not used. plt29_ufa_base_cntr.shp was used instead.
4	MCU	Top		
		Bottom	a) lfat_surf.zip (Bellino, 2011); b) plate-32.pdf (Miller, 1986); c) Figure 19 (Sepúlveda, 2002).	a) Raster dataset of the top of the lower Floridan aquifer system; b) Map of thickness of the lower Floridan aquifer; c) Map of the estimated altitude of water containing a chloride concentration of 5,000 mg/L in the FAS. **Note**: Map of thickness of the lower Floridan aquifer was used to correct for irregularities near the edge of the middle confining unit (MCU).
5	LFA	Top		
		Bottom	a) fasb_surf.zip (Bellino, 2011); b) Figure 19 (Sepúlveda, 2002).	a) Raster dataset of the base of the Floridan aquifer system; b) Map of the estimated altitude of water containing a chloride concentration of 5,000 mg/L in the FAS. **Note**: Figure 19 (Sepúlveda , 2002) was used to define the salt-water/fresh-water transition zone.

NHD Hydrography

Hydrography was obtained from1:100,000-scale (medium-resolution) the National Hydrography Dataset (NHD)(National Hydrography Dataset, 2012), as shown in Figure 4. In order to develop a river package the NHD hydrography dataset (medium-resolution) was processed in ArcGIS. NHD Flowline arcs were utilized, but NHD Waterbody polygons were not used. The flowline arcs were intersected with the North Florida Model grid. The length of each arc from this intersection was computed for each model grid cell and was utilized in the river package development.

Baseflows

Streamflow data was collected from the USGS in order to develop baseflow targets for additional flux constraint, as shown in Figure 5. Baseflow targets were calculated using stream flow data from the calibration period (calendar year 1995) and a low pass filter baseflow separation method (Perry, 1995; INTERA, 2011a). The low pass filter baseflow separation technique is a commonly used technique for determining the baseflow and runoff components of total streamflow (Perry, 1995; INTERA, 2011a). A moving 120-day window was utilized for baseflow separation for the USGS streamflow stations. For each day, the minimum flow for a 120-day window (60 days prior and 60 days after) was determined. Once the minimum 120-day flow was computed, the average of the minimum time seriesis calculated for each day, again using a centrally-positioned 120-day period. Thus, the baseflow at any given day is equal to the 120-day central average of the 120-day central minimums. Examples of the baseflow separation are shown in Figures 6 and 7. The resultant baseflow time series were averaged for the 1995 calendar year, resulting in 1995 average annual baseflows. The annual average baseflow contributions were calculated, as necessary, to account for baseflows of upstream streamflow gauging stations and their contributing basins. Table 3 shows the calculated 1995 average baseflows for the reaches identified in Figure 5. The stations referenced in Table 3 define the downstream locations of each river reach, and the flow numbers, shown in the table as “1995 Average Baseflow Contribution to River Reach” are differences between baseflows at the upstream and downstream limits of the reach.

Additionally, there were USGS gauging stations located within the model domain but their contributing basins were either in the inactive portion of the model or outside the model domain. These stations could not be utilized as baseflow targets and hence, their reaches were unconstrained. Unconstrained river reaches do not have assigned baseflow targets and are shown as light blue NHD arcs in Figure 5.

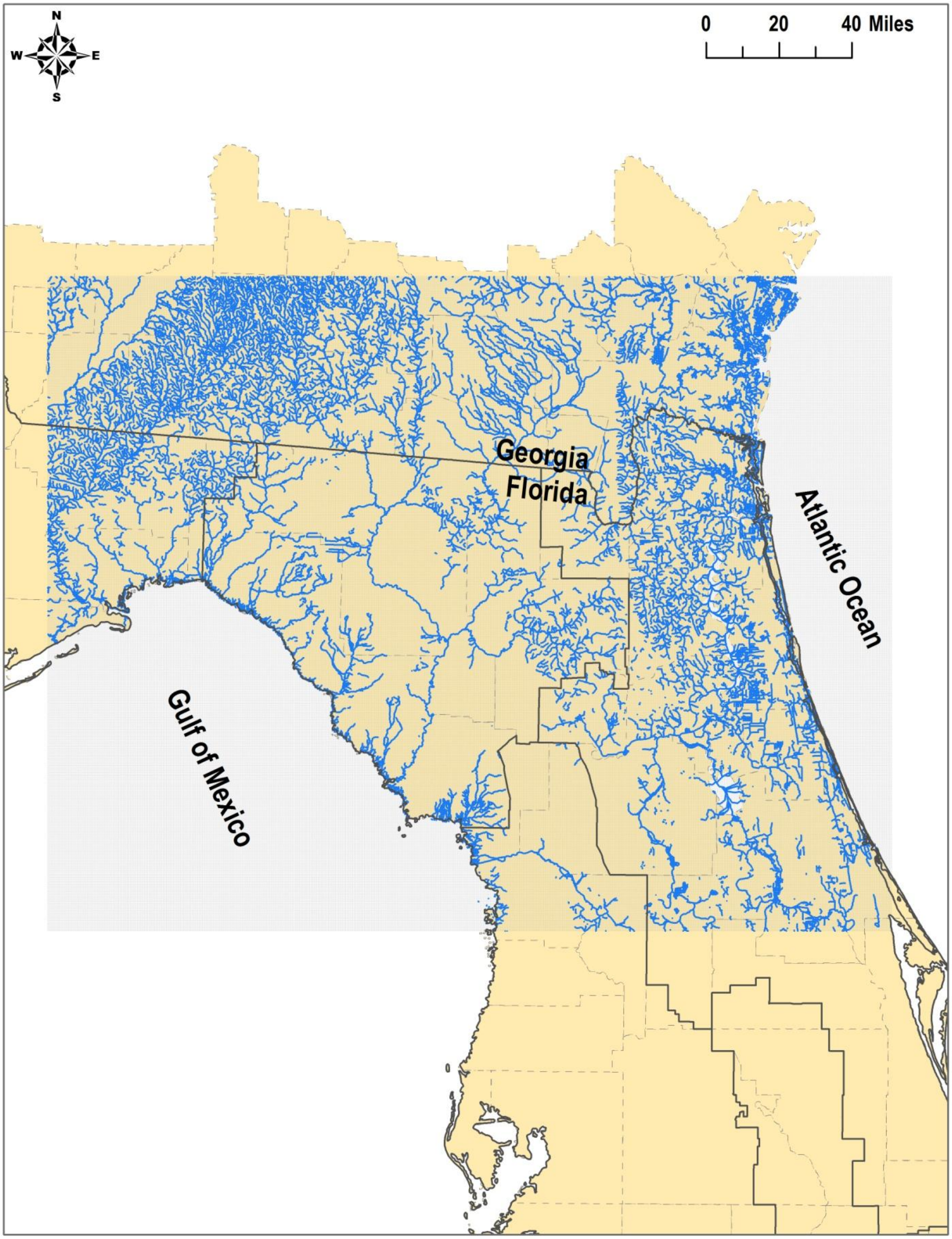

Figure 4. National Hydrography Dataset

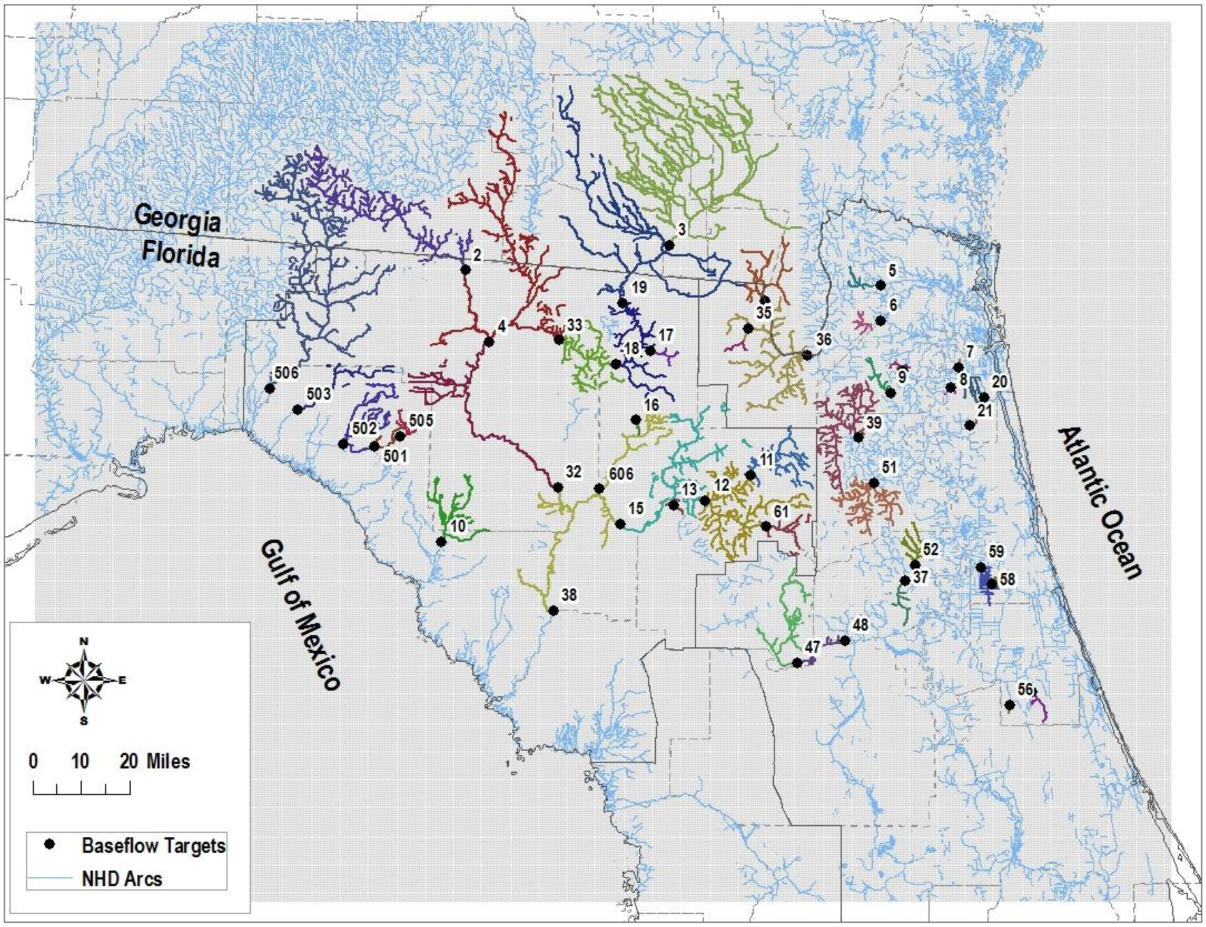

Figure 5. Baseflow Targets (Downstream Reach Limits are Labeled by ReachIDs)

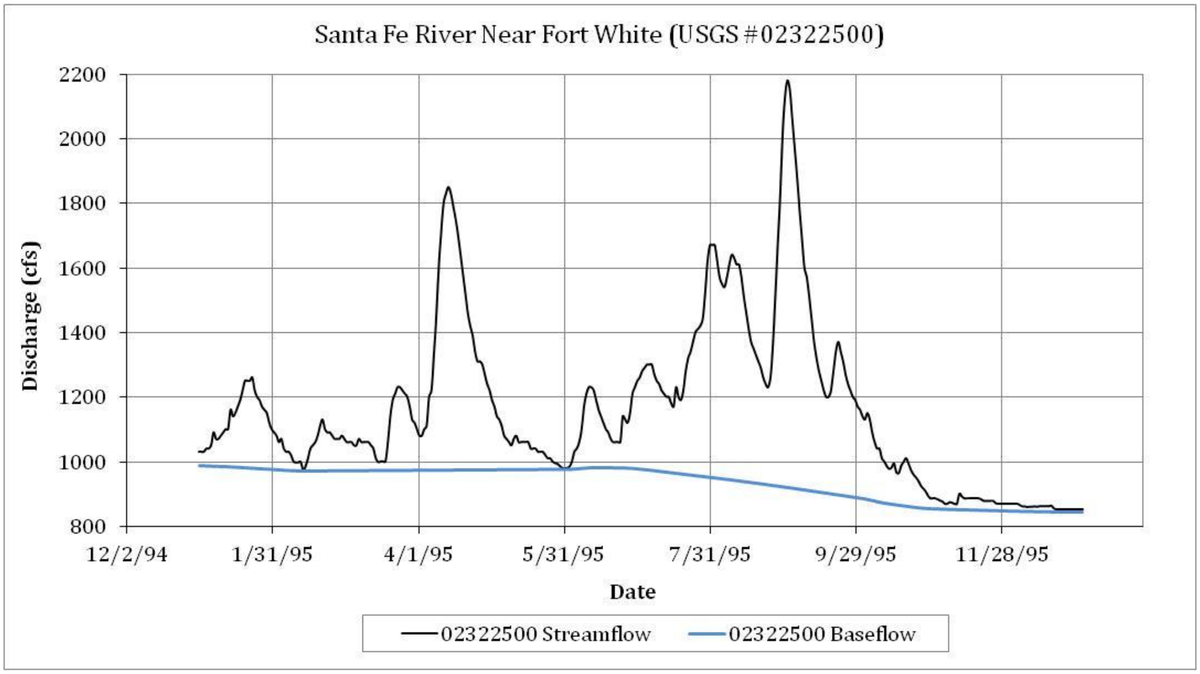

Figure 6. Baseflow Separation: Santa Fe River at Fort White (120-day flow window)

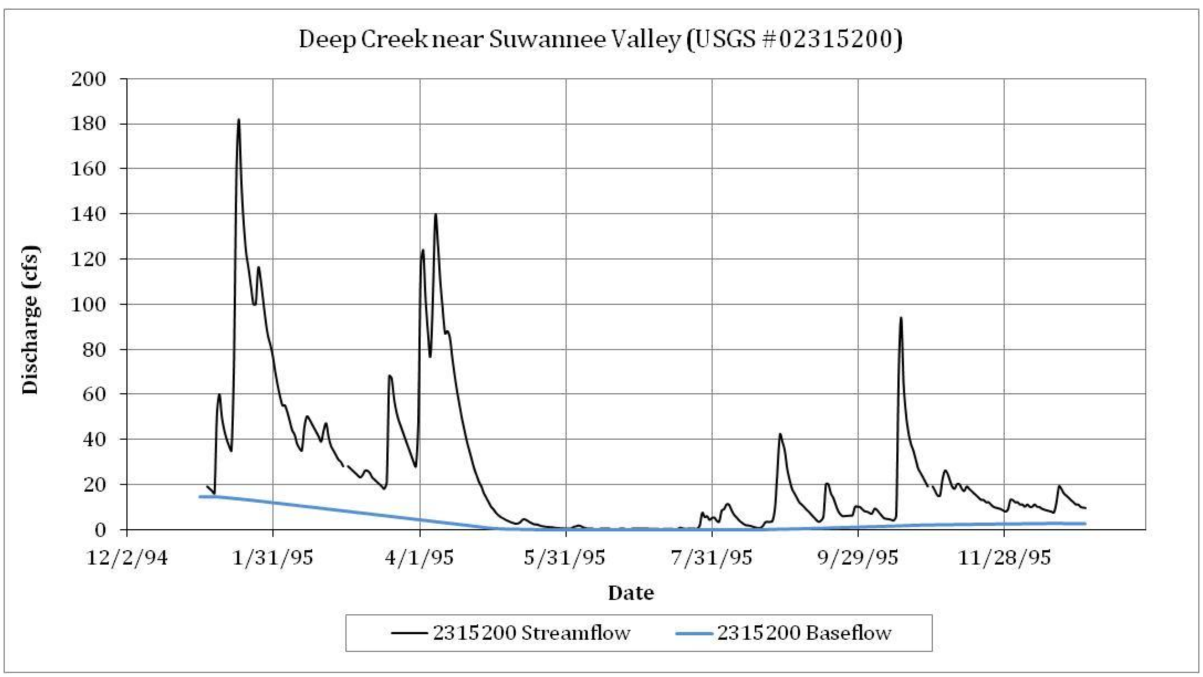

Figure 7. Baseflow Separation: Deep Creek near Suwannee Valley (120-day flow window)

Table 3. 1995 Average Baseflows Calculated for Upstream Reaches

Reach ID	USGS Station Number at Downstream End of Reach	USGS Station Name at Downstream End of Reach	1995 Average Baseflow Contribution to River Reach, in cubic feet per second
2	02319000	WITHLACOOCHEE RIVER NEAR PINETTA	199.69
3	02314500	SUWANNEE RIVER AT FARGO	212.36
4	02319500	SUWANNEE RIVER AT ELLAVILLE	1670.61
5	02231268	ALLIGATOR CREEK AT CALLAHAN, FL	0.83
6	02231280	THOMAS CREEK NEAR CRAWFORD, FL	3.84
7	02246520	STRAWBERRY CREEK NEAR ARLINGTON, FL	3.29
8	02246515	POTTSBURG CREEK NR SOUTH JACKSONVILLE, FLA	8.77
9	02246300	ORTEGA RIVER AT JACKSONVILLE, FL	5.45
10	02324000	STEINHATCHEE RIVER NEAR CROSS CITY	19.52
11	02321000	NEW RIVER NEAR LAKE BUTLER	14.06
12	02321500	SANTA FE RIVER AT WORTHINGTON SPRINGS	42.08
13	02321900	PARENERS BRANCH NEAR BLAND	0.23
15	02322500	SANTA FE RIVER NEAR FT WHITE	869.02
17	02315200	DEEP CREEK NEAR SUWANNEE VALLEY	3.5
18	02315500	SUWANNEE RIVER AT WHITE SPRINGS AT US 41	49.99
19	02315000	SUWANNEE RIVER NEAR BENTON	49.24
20	02246828	PABLO CREEK AT JACKSONVILLE, FL	10.5
21	02246150	BIG DAVIS CREEK AT BAYARD, FL	3.07
32	02320500	SUWANNEE RIVER AT BRANFORD	893.93
33	02315550	SUWANNEE RIVER AT SUWANNEE SPRINGS	105.97
34	02228500	NORTH PRONG ST. MARYS RIVER AT MONIAC, GA	12.93
35	02229000	MIDDLE PRONG ST MARYS RIVER AT TAYLOR, FL	4.4
36	02231000	ST. MARYS RIVER NEAR MACCLENNY, FL	60.92
37	02244473	RICE CREEK NEAR SPRINGSIDE	8.52
38	02323500	SUWANNEE RIVER NEAR WILCOX	659.64
39	02246000	NORTH FORK BLACK CREEK NEAR MIDDLEBURG, FL	60.05
47	02242451	ORANGE LAKE OUTLET NEAR CITRA, FL	3.27
48	02243000	ORANGE CREEK AT ORANGE SPRINGS, FL	12.8
49	02246359	CEDAR RIVER AT MARIETTA, FL	6.76
51	02245500	SOUTH FORK BLACK CREEK NEAR PENNEY FARMS, FL	39.97
52	02245140	SIMMS CREEK NEAR BARDIN, FL	16.6
55	02244320	MIDDLE HAW CREEK NR KORONA, FLA.	2.91
56	02244420	LITTLE HAW CREEK NEAR SEVILLE, FL	7.15
58	02245255	DEEP CREEK NEAR HASTINGS, FL	1.06
59	02245260	DEEP CREEK AT SPUDS, FL	2.71

Reach ID	USGS Station Number at Downstream End of Reach	USGS Station Name at Downstream End of Reach	1995 Average Baseflow Contribution to River Reach, in cubic feet per second
61	02320700	SANTA FE RIVER NEAR GRAHAM	11.38
501	02324500	FENHOLLOWAY RIVER AT FOLEY AT US 19	56.34
502	02325000	FENHOLLOWAY RIVER NEAR PERRY	36.21
503	02326000	ECONFINA RIVER NEAR PERRY	30.83
505	02324400	FENHOLLOWAY RIVER NEAR FOLEY AT US 27	4.1
506	02326512	AUCILLA RIVER NR SCANLON, FLA	107.88
606	02322700	ICHETUCKNEE RIVER AT HWY 27	310.75

Springs and Siphons

Two hundred ninety-seven (297) springs were used in the model as springflow targets and in the drain package. A spatial coverage of two hundred seventy-one (271) springs, located within the District boundary, was provided by the District in a shapefile format (09092011.shp). As requested by the District, two springs, Falmouth Springs (#FAM010C1) and White Springs (#WHS010C1) were included in the shapefile (09092011.shp), but were not included in the drain package. Falmouth Springs, a karst window, was not used in the model because it does not represent a net gain or loss of groundwater within a given model grid cell. White Springs, a streamflow siphon on the Suwannee River, was represented in the model as an injection well to capture streamflow into the aquifer. The White Springs injection well rate was set to 6.9 cfs into the aquifer (INTERA, 2011a). A spatial coverage of twenty-eight (28) springs outside the District was obtained as a 2011 dataset (SPRINGS_FDEP_2011.shp) from the Florida Department of Environmental Protection (FDEP). The FDEP shapefile included best available locations of springs that had any data collection activities. The 28 FDEP first and second magnitude springs outside of the District and 269 springs provided by the District were included in the model.

The flow measurements made at springs within the SRWMD were provided by the District as an Excel file database (SRWMDsprings_POR_Updated_Names_5.xlsx). The database had a unique identifier, *SRWMD SITE ID (SWQ2000*), which was used as a common field to join the data to the shapefile of spring coverages (09092011.shp). Out of 269 springs, 257 had springflow measurements in the Excel file database.

Despite a large number of spring flow measurements, measurements were not always available for the calibration period (calendar year 1995) and many of the springs have been measured once or twice. Hence, best available data was used to estimate 1995 springflow targets (Figure 8). Eight springflow estimates for springs in the Ichetucknee Springs Group were based on the springflow estimates developed by INTERA for the HEC-RAS model of the Lower Santa Fe and Ichetucknee rivers (2012); 211 springflow estimates relied on the ratios of spring and stream baseflows; 38 springflow estimates (Average Springflow Group) were based on springflow averages of any available spring discharge measurements; 12 springflow estimates (Spring Magnitude Group) were based on spring magnitudes. For the 28 FDEP springs located outside the District, various sources of data were used to estimate 1995 springflow targets. The springflow target values are shown in Appendix A. The springflow estimates were developed as follows:

Ichetucknee Springs Group (8 springs)

Ichetucknee Springs group springflow estimates for 8 springs were based on previous modeling efforts of the Lower Santa Fe and Ichetucknee Rivers (INTERA, 2012). The Ichetucknee Springs Group (Figure 9) is unique. The sum of the USGS spring discharge measurements upstream of the Ichetucknee River at the Highway 27 gauging station (USGS # 2322700) exceeds the total flow at the US Highway 27 gauging station. This flow loss on the Ichetucknee River was investigated by the District with the conclusion that the US Highway 27 station "best approximates the actual flow in the Ichetucknee River" (Coarsey, 2012). Linear regression relations were developed between historical spring discharge measurements at each spring location and the US Highway 27 historical discharge record to estimate ratios of springflow to the US Highway 27 total flow (INTERA, 2012). Table 4 shows that the initial regression factors representing ratios of springflow to total flow at US Highway 27 were lowered so that the sum of all springflows was equal to the flow at the Highway 27 gauge. Then the ratios were further reduced by 15 %, as suggested by the District during the HEC-RAS model development of the Lower Santa Fe and Ichetucknee Rivers (INTERA, 2012), to account for diffuse flow and other sources of inflow other than the Ichetucknee springs. An estimate of the average spring discharge during the calibration period (January 1, 1995 through December 31, 1995) was calculated by multiplying the reduced adjusted factor by the US Highway 27 1995 average annual baseflow (Table 4) for each spring. The methodology is thoroughly described in (INTERA, 2012).

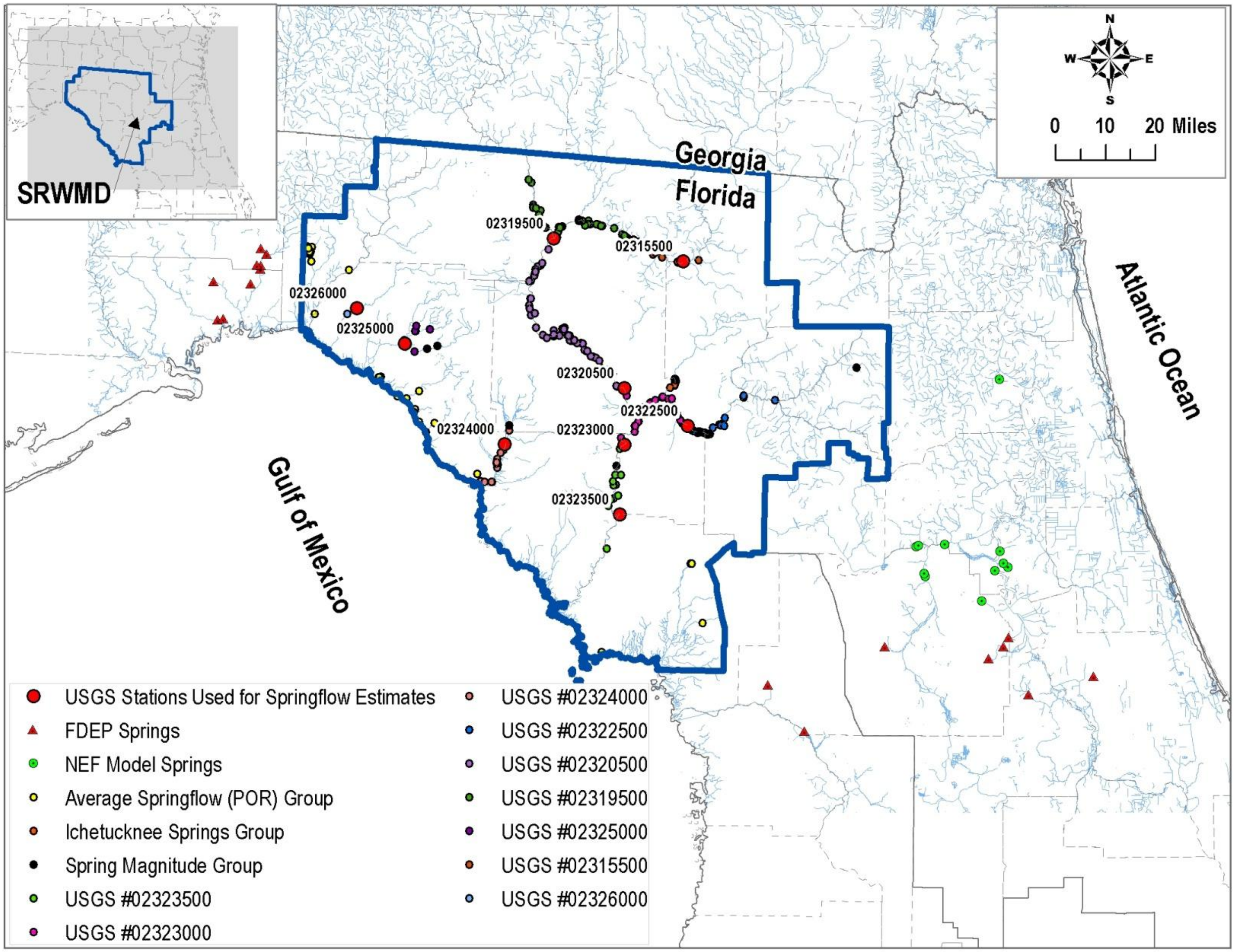

Figure 8. Springflow Estimates and the Source of Springflow Estimates

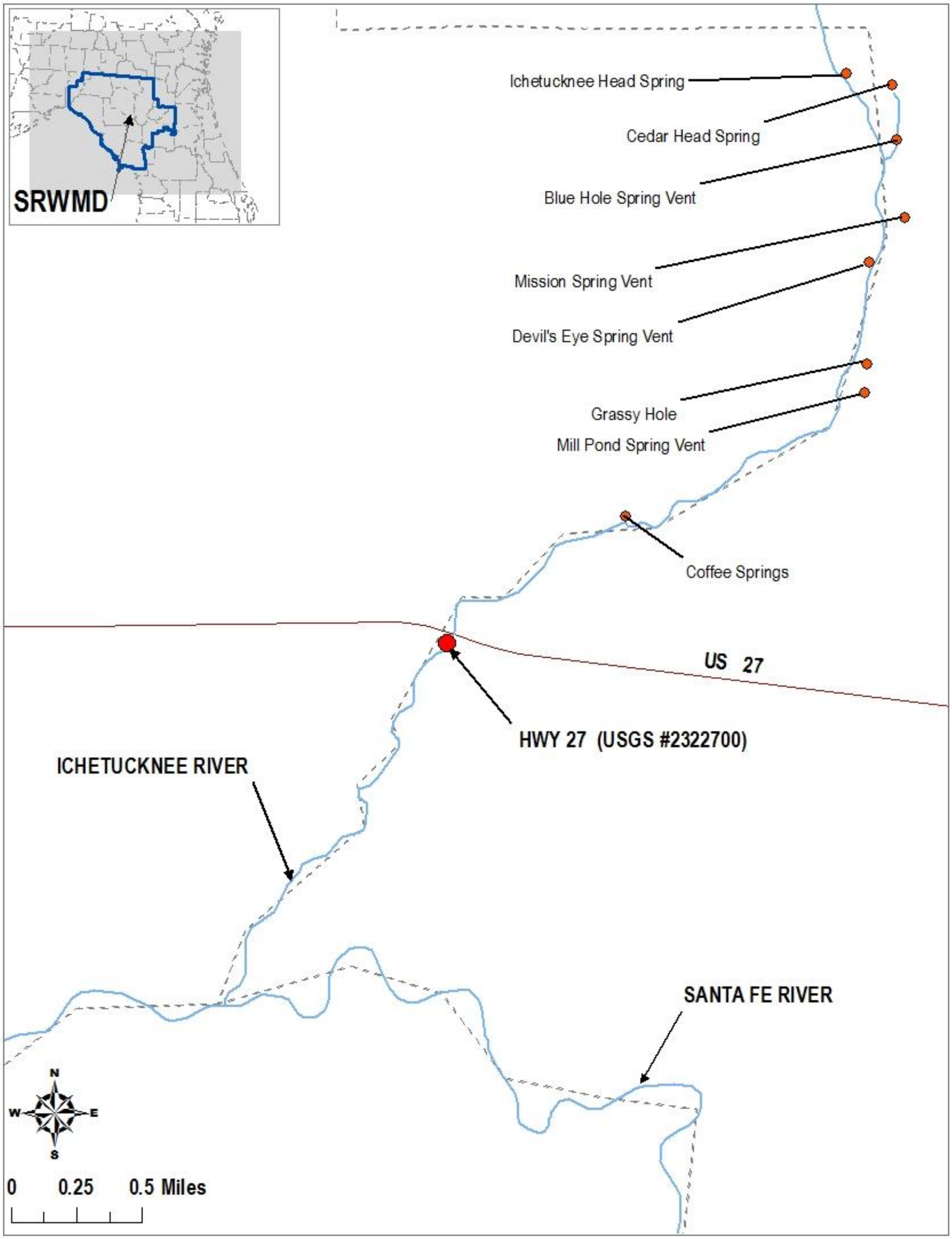

Figure 9. Ichetucknee Springs Group

Table 4. Ichetucknee Springs Group 1995 Estimated Springflow Targets

SRWMD Site ID	Spring Name	Regression Factors of Hwy 27 Total Flow	Adjusted Factors	Adjusted Factors Reduced by 15%	1995 Estimated Springflow Target, in cubic feet per second
ICH001C1	ICHETUCKNEE HEAD SPRING	0.156	0.140	0.119	37.04
ICH002C1	BLUE HOLE SPRING VENT	0.389	0.351	0.298	92.73
ICH003C1	MISSION SPRING VENT	0.288	0.260	0.221	68.62
ICH004C1	DEVILS EYE SPRING VENT	0.152	0.137	0.117	36.25
ICH005C1	MILL POND SPRING VENT	0.086	0.078	0.066	20.53
ICH006C1	CEDAR HEAD SPRING	0.023	0.021	0.018	5.53
ICH007C1	GRASSY HOLE	0.009	0.008	0.007	2.17
ICH008C1	COFFEE SPRINGS	0.005	0.005	0.004	1.26
	Sum of Factors	1.11	1	0.85	264.14

Springflow Estimates Based on Ratios of Estimated Stream Baseflows (211 springs)

Even though a large number of springs had available springflow measurements, only a small number had measurements during the calibration period from January 1, 1995 to December 31, 1995. Many of the springs with available measurements were limited to 1 to 2 measurements during the calibration period. A 1995 average springflow estimate was based on a ratio of average monthly baseflow, in a month when a spring discharge measurement was available, to 1995 average estimated baseflow of a neighboring streamflow station. The period of record (POR) estimated daily baseflow values and available springflow measurements were grouped and averaged by month. As shown in Figure 8, nine USGS streamflow gauging stations with the most complete historical flow record, including the calibration period, were utilized. The springs and the USGS streamflow stations used to estimate springflow target values are shown in Figure 8. The springflow targets are shown in Appendix A.

Springflow Estimates Based on POR Average Springflow Measurements (38 springs)

Thirty-eight (38) springs located near the coast could not be estimated using baseflow ratios because of the incomplete flow records of the streamflow stations in the vicinity (Figure 8). For these springs, the average of any discharge measurements was used as a springflow calibration target.

Springflow Estimates Based on Spring Magnitude (12 springs)

For twelve (12) springs with no available discharge measurements, spring magnitude was used to estimate a springflow target. Table 5 shows a spring magnitude and a corresponding range in flow. The average of the lower and upper limits of the flows defining each spring-magnitude category was used to estimate springflow targets for this group of springs. Springs in this group had spring magnitudes of 2, 3, and 4.

Table 5. Spring Magnitudes and Corresponding Flows

Spring Magnitude	Flow Range, cfs	Springflow Target, cfs
1	100 cfs or more	100
2	10 -100 cfs	55
3	1-10 cfs	5.5
4	0.1-1 cfs	0.55

Additional Springs from the Florida Department of Environmental Protection (28 springs)

For the 28 FDEP springs located outside the District, various sources of data were used to estimate 1995 springflow targets, including the INTERA (2011b), Scott et al. (2004), Barrios (2006), data from the USGS National Water Information System (NWIS), and the spring magnitude. The best available information was used to estimate the 1995 average flow for each of these springs (Table 6).

The St. Marks River springflow targets were a special case because they were part of the river rise system. The flow in the St. Marks River disappears underground into the siphon at Natural Bridge to re-emerge approximately 0.6 miles downstream of the siphon as the St. Marks River Rise (Scott et al,. 2004). Various sources of data were used to estimate springflow targets on the St. Marks River system. The Version 1 model springflow target was preserved at Natural Bridge Spring. Chicken Branch Spring, Horn Spring, Rhodes Springs Group. St. Marks River Rise springflow values were estimated using Scott et al. (2004). In addition, the St. Marks River near Newport USGS gauge (USGS #02326900) period of record flow time series was used for a cursory estimate of 1995 average baseflow at the gauge, located downstream of Natural Bridge, Chicken Branch, Horn, Rhodes, and St. Marks River Rise Springs. The estimated 1995 average baseflow was compared to the estimated St, Marks River springflow values contributing to baseflow at the downstream gauge, and used to estimate the difference between the 1995 average discharge from the Upper Floridan aquifer at the St. Marks River Rise and the combined 1995 average discharge from the springs upstream from the rise.

Table 6. FDEP Springs 1995 Estimated Springflow Targets

Spring Name	1995 Estimated Springflow Target, cfs	Row	Column	Source of Springflow Target
SHEPHERD SPRING	4.99	173	55	Scott et al. (2004)
SILVER GLEN SPRINGS	110.00	307	389	Scott et al. (2004)
SWEETWATER SPRINGS	12.70	311	386	Average, POR [Scott et al. (2004)]
CITRUS BLUE SPRING	15.96	346	303	Average, POR [Scott et al. (2004)]
SILVER SPRING MAIN	707.53	311	336	Average 1995 flow (USGS gauge #02239501)
CHICKEN BRANCH SPRING	50.00	143	73	Estimate [Barrios (2006); Scott et al. (2004); SDII (2008)]
FERN HAMMOCK SPRINGS	13.00	316	380	1995 Annual Mean (Scott et al. (2004))
DELEON SPRING (VOLUSIA)	22.98	323	424	1995 Annual Mean (Scott et al. (2004))
ALEXANDER SPRING	118.19	331	397	Average, POR (Scott et al. (2004))
GANDER SPRING	55.00	173	58	Estimate (Spring Magnitude)
NEWPORT SPRING	8.30	158	69	Scott et al. (2004)
WAKULLA SPRING	669.29	157	54	Average POR flow (USGS gauge #02327022)
ST MARKS RIVER RISE (LEON)	200.00	152	73	Estimate [Barrios (2006); Scott et al. (2004); SDII (2008)]

Spring Name	1995 Estimated Springflow Target, cfs	Row	Column	Source of Springflow Target
NATURAL BRIDGE SPRING (LEON)	152.00	150	73	Estimate [Barrios (2006); Scott et al. (2004); SDII (2008)]
RHODES SPRINGS #2A	60.00	150	72	Estimate [Barrios (2006); Scott et al. (2004); SDII (2008)]
HORN SPRING	30.00	146	76	Estimate [Barrios (2006); Scott et al. (2004); SDII (2008)]
RAINBOW SPRING	652.09	327	287	Average 1995 flow (USGS gauge #02313100)
WELAKA SPRING	7.91	271	385	(INTERA, 2011b)
SALT SPRINGS (MARION)	80.00	292	377	(INTERA, 2011b)
WELLS LANDING SPRING	9.09	281	354	(INTERA, 2011b)
TOBACCO PATCH LANDING SPRING	2.80	280	353	(INTERA, 2011b)
CROAKER HOLE SPRING	76.00	279	383	(INTERA, 2011b)
MUD SPRING (PUTNAM)	0.75	276	386	(INTERA, 2011b)
CAMP SEMINOLE SPRINGS	0.79	269	350	(INTERA, 2011b)
ORANGE SPRING (MARION)	2.40	268	351	(INTERA, 2011b)
MARION BLUE SPRING	5.00	268	362	(INTERA, 2011b)
GREEN COVE SPRINGS	2.86	198	385	(INTERA, 2011b)
BEECHER SPRING	9.04	277	388	(INTERA, 2011b)

Siphons and swallets

Nine siphons or swallets were modeled as 9 fixed rate injection wells simulating locally captured streamflow into the aquifer. Four injection well rates were preserved from Version 1 efforts due to limited data and uncertainty in existing flow measurements at the siphons (SDII, 2008). Table 7 lists the locations (row and column) and fixed injection rates of the siphons used in the model. Further description of the representation of the siphons and swallets in the model is provided in the *Representation of the Siphons and Swallets in the Model* section of the report. A description of the siphons on the Santa Fe River and their groundwater/surface water interactions can be found in Butt et al. (2007).

Table 7. Siphons and Swallets Modeled in the North Florida Model

SRWMD Name*	Name	River	Row	Column	Layer	Well Rate, cfs (Version 1 Modeling Efforts)**	INTERA Model Well Rate, cfs**	Data Source
N/A	Wacissa Sink	Wacissa	171	96	2	360.0	360.0	(SDII, 2008)
N/A	Vinzant Landing Swallet	Santa Fe	208	272	2	68.3	37.7	(INTERA, 2012)
S1/S2	RRSP Suck/Columbia Siphons	Santa Fe	216	268	2	43.3	43.3	(SDII, 2008)
S3	Alligator Siphon	Santa Fe	218	265	2	66.7	66.7	(SDII, 2008)
S4/S5/S6	Big Awesome Suck/Little Awesome Suck/ S6 Swallet	Santa Fe	217	252	2	166.7	166.7	(SDII, 2008)

SRWMD Name*	Name	River	Row	Column	Layer	Well Rate, cfs (Version 1 Modeling Efforts)**	INTERA Model Well Rate, cfs**	Data Source
N/A	Steinhatchee Sink	Steinhatchee	227	176	2	233.0	80.1	Average Streamflow at USGS Station #02324000
N/A	White Springs at White Springs (WHS010C1)	Suwannee	148	249	2	N/A	6.9	(INTERA, 2011a)
N/A	Alapaha Sink	Alapaha	113	215	2	N/A	364.5	Flow Loss between Jennings and Jasper
N/A	O'Leno Sink by the Footbridge	Santa Fe	209	272	2	N/A	348.3	Flow at O'Leno at the Footbridge (District Gauge)

*SRWMD name as it appears in *Swallet/Resurgence Relationships on the Lower Santa Fe River* (Butt et al., 2007)
**A positive well rate indicates flow into the aquifer

All springs of the 269 springs were represented in the model as discharging from layer 2 (UFA) because the source of water for the springs in the District is Floridan aquifer. This was accomplished using the MODFLOW Drain Package (McDonald and Harbaugh, 1988), as described later in the report (Drain Package Development).

Water Use

The District provided 1995 average pumping data within the District boundary with the exception of Bradford and Baker counties, which are partially located within the District (Figure 10). The 1995 water use data were provided in a shapefile format. Additional 1995 water use data in the area defined by the domain of the Northeast Florida (NEF) groundwater model were provided as a well package by the St. Johns River Water Management District. The NEF well package was utilized in counties located outside the District boundary as well as in Bradford and Baker counties. Pumping data were also obtained from the MegaModel well package. As shown in Figure 10, the water use outside the District boundary and the NEF domain was based on the MegaModel well package previously developed (INTERA, 2011a; Sepúlveda, 2000). The Version 1 NF model well package was utilized in the north western portion of the model domain, including the state of Georgia, where 1995 pumping data was not available (SDII, 2008).

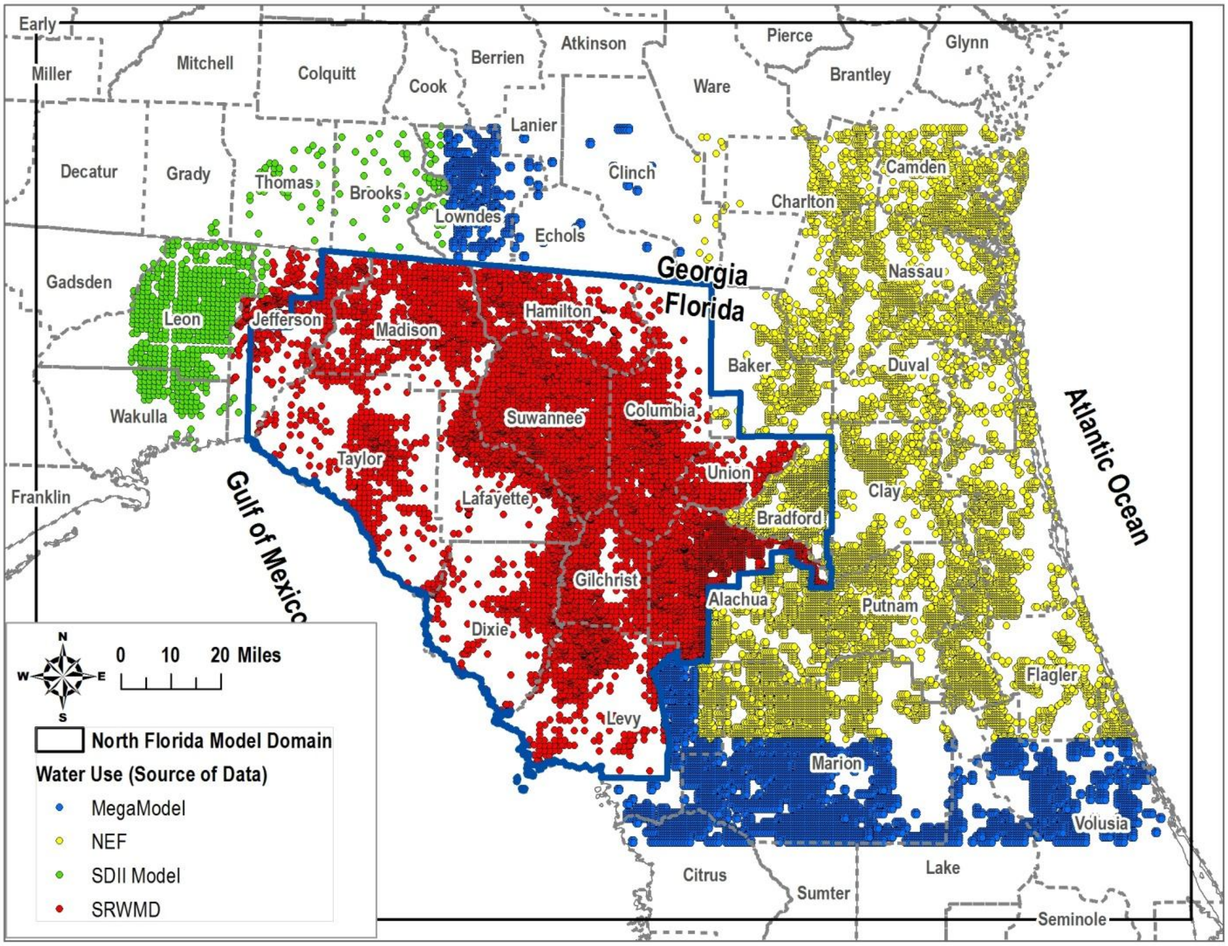

Figure 10. Water Use Data Utilized in the North Florida Model Well Package

Well Level Targets

Well head targets were provided by the District and the St. Johns River Water Management District (Figures 11-13). At locations with continuous time series, groundwater level targets were computed by averaging groundwater levels during 1995. Average statistics and the count of the District's well level targets were calculated for each well. Well targets that were limited to 1 or 2 measurements during the model calibration period were assigned a lower weight during calibration.

Well targets utilized in the Northeast Florida (NEF) modeling efforts were also used in the NF model (INTERA, 2011b). The NEF well targets represented average 1995 aquifer levels. The District's well targets were used in the areas of overlapping and duplicate well head targets.

Additional well head targets in Volusia County were provided by the St. Johns River Water Management District (shown in Figure 11 as "NCF Volusia"). The average 1995 water levels were provided as an Excel file (ncf_volusia_well_below_NEF_domain_above_NF_grid mdb20121218.xlsx). The database had five instances of two wells located at the same site (same Northing and Easting). The St. Johns River Water Management District confirmed that these were occurrences of active wells tapping same aquifer at different depths. In these instances, an average well level value was computed and used in the model calibration.

During model calibration, the District provided 5 additional Upper Floridan well head targets to further constrain a northwestern portion of the model domain and the state of Georgia. Intermittent 1995 water levels for these additional targets were provided in an Excel file (Additional_GWL_1995.xlsx). Generally, these targets had two observations taken in May and September and in these cases the observations were averaged for use in the model calibration.

In the state of Georgia, direct measurements of heads were not available. For these areas, secondary information about the approximate water levels was utilized to develop "soft targets" to constrain the model. As per a recommendation from the District, Kinnaman and Dixon (2011) was used as soft targets in the state of Georgia to provide PEST with some information to estimate stresses and hydraulic properties in southern Georgia. A cursory analysis comparing the Kinnaman and Dixon (2011) well levels and 1995 well levels was performed to evaluate if an adjustment to 2010 water levels (soft targets) was necessary. Linear regression between 1995 and 2010 well levels indicated that a shift was not necessary. These soft targets were utilized in order to encourage PEST to choose parameter combinations that resulted in similar water levels, but because of the uncertainty in these values, they were assigned a lower weight.

North Florida Model well level targets by layer and by source are shown in Table 8 and Figures 11-12. During model calibration, it was decided to model surficial and intermediate aquifer systems as one layer to help mitigate drying and rewetting issues. Thus, surficial and intermediate aquifers are modeled as layer 1 in MODFLOW. Hence, the 26 intermediate aquifer (IAS) well head targets were modeled in layer 1.

Table 8. Well Head Targets Summarized by Source and by Layer

Layer Number	Layer(s) Name	NCF Volusia	NEF	SRWMD GWL	Additional SRWMD GWL	Soft Targets
1	Surficial and Intermediate	41	44	33	N/A	N/A
2	Upper Floridan	93	113	241	5	35
4	Lower Floridan	1	6	N/A	N/A	N/A
Total		135	163	274	5	35

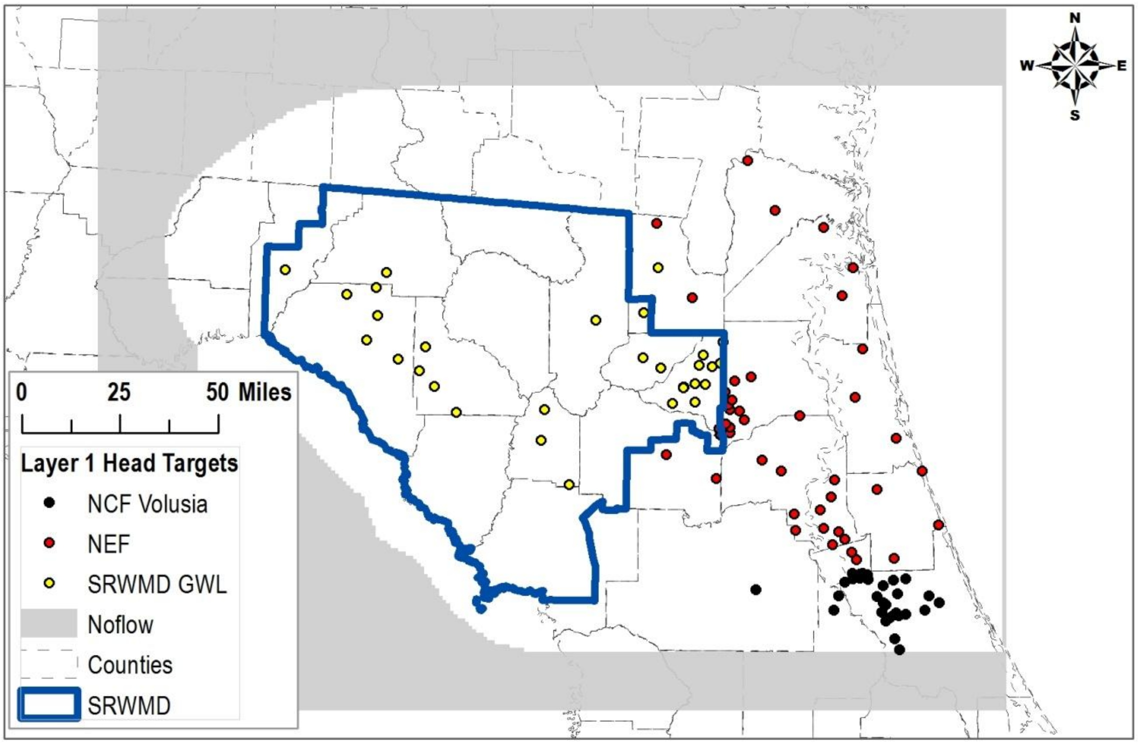

Figure 11. Surficial and Intermediate Aquifers Well Level Targets

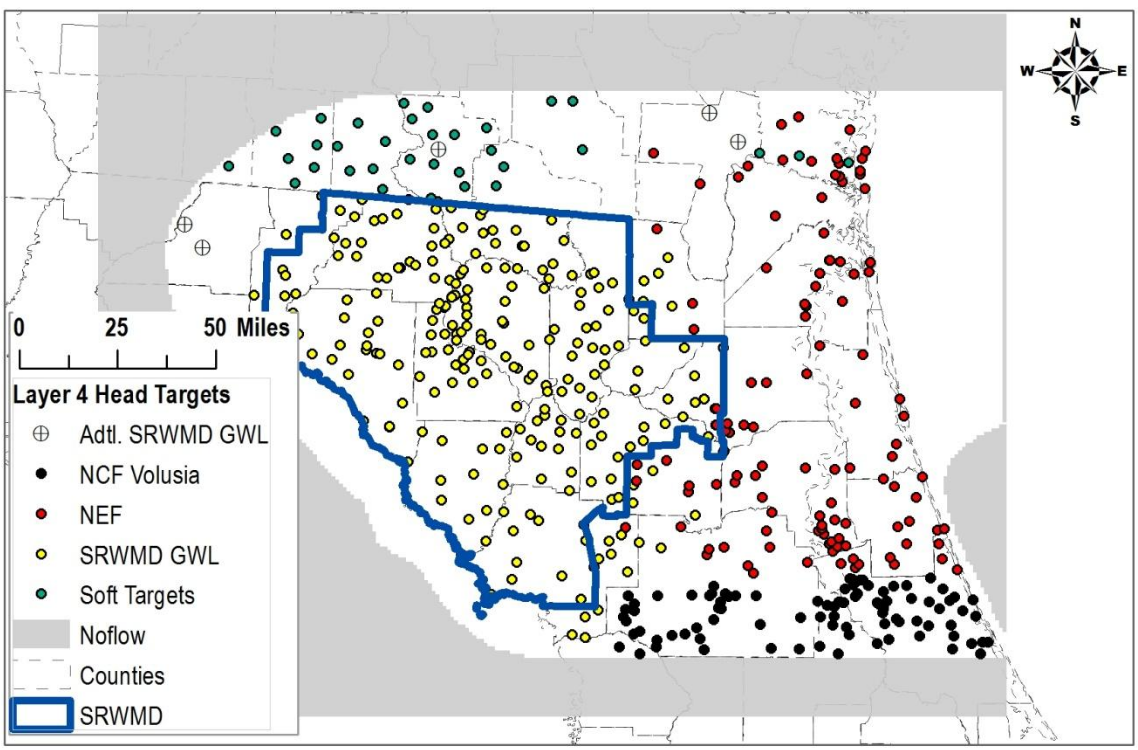

Figure 12. Upper Floridan Aquifer Well Level Targets

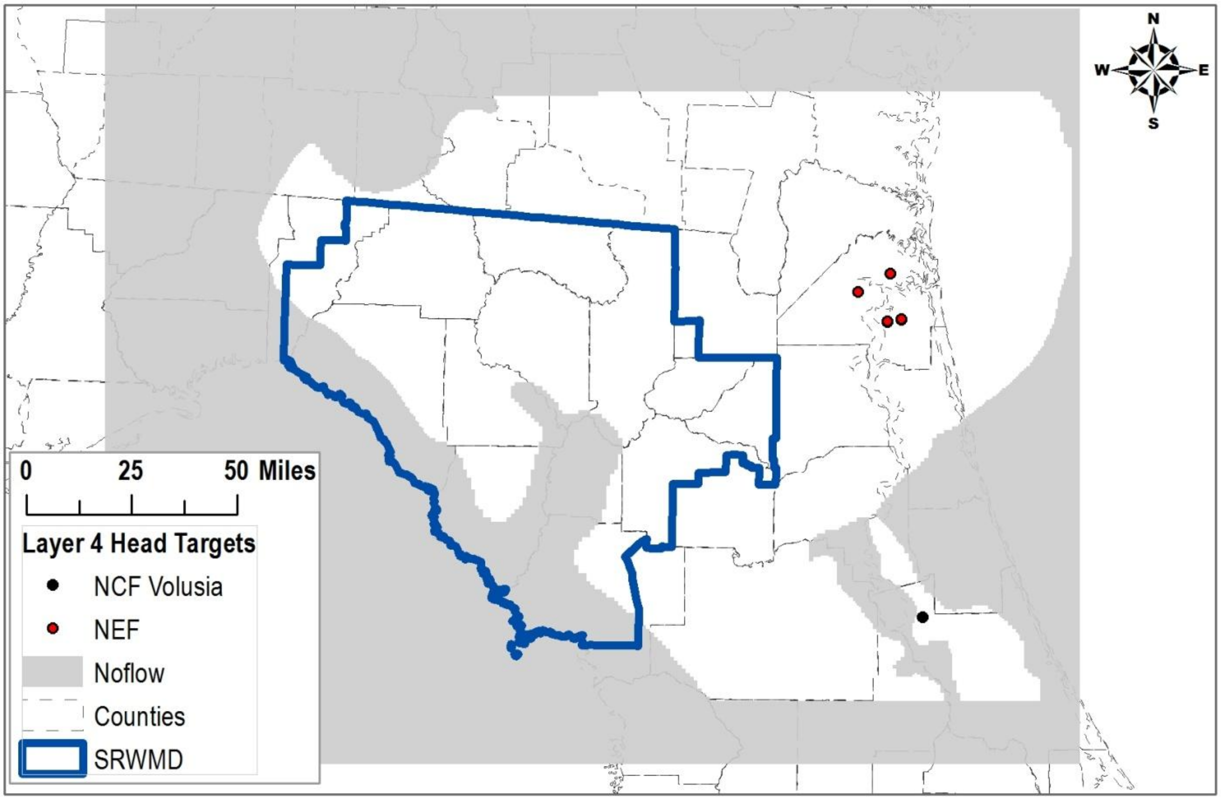

Figure 13. Lower Floridan Aquifer Well Level Targets

General Head Boundaries

Contours of the potentiometric surfaces of the upper Floridan aquifer in the St. Johns River Water Management District (May of 1995 and September of 1995) were used to update the southern general head boundary (Knowles et al., 1995; O'Reilly et al., 1996). The digital shapefiles of the USGS potentiometric contours were obtained from the St. Johns River Water Management District (ftp://ftp.sjrwmd.com/gwp/).

Contour shapefiles of the potentiometric surfaces of the upper Floridan aquifer in Georgia and adjacent parts of Florida were not available for 1995 to update the northern general head boundary. A map of the potentiometric surface of the upper Floridan aquifer in Georgia and adjacent parts of Alabama, Florida, and South Carolina for May 1998 (Peck et al., 1999) was the best available data in that portion of the model domain and was used to update the boundary.

Constant Head Boundaries

MegaModel (INTERA, 2011) final calibrated head values of the upper Floridan aquifer (based on the average hydrologic conditions for August 1993 through July 1994) were used to update layer 2 constant head values in the eastern portion of the model domain. This is further described in the Model Development section of the report

Transmissivity values

Kuniansky et al. (2012) developed a map of transmissivity of the upper Floridan aquifer based on interpolation of 1,487 transmissivity values. The raster dataset of this transmissivity map was available on the USGS website (http://pubs.usgs.gov/sim/3204/) and was used to update the transmissivities of the upper Floridan aquifer (Kuniansky et al., 2012). Hydraulic conductivity, calculated using transmissivity arrays and layer thicknesses, was a calibration parameter and was optimized during PEST iterations.

Rainfall

The PRISM (The PRISM Climate Group, http://prism.oregonstate.edu; Daly et al., 2008) data of the 1995 monthly precipitation values were used in the recharge package development. PRISM or Parameter-elevation Regressions on Independent Slopes Model data utilizes data from individual weather stations, a digital elevation model, and other spatial datasets to generate gridded estimates of several spatial and temporal climatic parameters, including precipitation (the PRISM Climate Group). PRISM is an accepted analytical tool in the meteorological community and provides spatial variability that Theissen polygons do not.

Land Use

The National Land Cover Dataset 1992 (NLCD1992) was used to define land use. The NLCD1992 was downloaded from the Multi-Resolution Land Characteristics Consortium (MRLC) website http://www.mrlc.gov/nlcd92_data.php. The NLCD1992 was used in the North Florida Model development because it is a seamless product of land cover.

The NLCD1992 was completed by the USGS EROS Data Center (EDC) in late 2000 primarily from the 1992 Landsat 5 Thematic Mapper imagery dataset. The USGS developed the NLCD1992 dataset using a 21-class land cover classification scheme applied to the conterminous United States at a spatial resolution of 30 meters (Vogelmann et al., 2001). A 21-class land cover classification scheme is shown in Table 9.

Model Development

Development of the revised North Florida model included the selection of an appropriate calibration period, model discretization and grid re-alignment, modifications to stratigraphy, expansion of the model domain, and the development of revised model boundary conditions.

Calibration Period

As stated by SDII (2008), the advantage of using the 2001-2002 (from June of 2001 through May 2002) calibration period in the Version 1 modeling efforts of North Florida was the availability of a significant amount of spring discharge measurements. The disadvantage was that no actual water use pumping data existed for the calibration period of the Version 1 North Florida Model, and the water use data in the existing model was based solely on water-use estimates for the year 2000 (SDII, 2008). The previous calibration period (2001-2002) was also marked by relatively dry hydrologic conditions. The decision was made to calibrate the revised North Florida Model to aquifer head, spring, and baseflow targets for the period from January 1, 1995 through December

31, 1995. This 1995 calibration period is representative of the average hydrologic conditions in the area. The North Florida Model was calibrated as a steady-state model.

Model Discretization and Grid Re-alignment

The groundwater flow model domain was discretized into a uniformly spaced grid of 2,500 by 2,500 ft cells. A finer grid was selected over the coarser grid of 5,000 by 5,000 ft cells of the existing North Florida Model to minimize a source of numerical errors and to allow for better alignment of the new grid boundaries with natural hydrologic and geologic boundaries. The existing model had 190 rows and 245 columns and the new North Florida Model has 380 rows and 490 columns totaling in 931,000 cells (including noflow cells and all layers). The revised model is in the Universal Transverse Mercator (UTM) projection, zone 17N of the Florida coordinate system, and is referenced to the 1927 North American Datum (NAD27). The existing North Florida Model was in the Florida State Plane North (1983 North American Datum) coordinate system. The change from NAD83 to NAD27 was necessary to align the revised North Florida Model grid with the MegaModel and the NEF groundwater flow model grids (Figure 3). The new lower, left-corner origin of the grid is located at UTM coordinates (X;Y = 465,000; 10,430,000 ft)(Table 10). Figure 14 illustrates the differences between the original North Florida Model and the MegaModel grids. Figure 14 also shows the realigned grid of the North Florida Model.

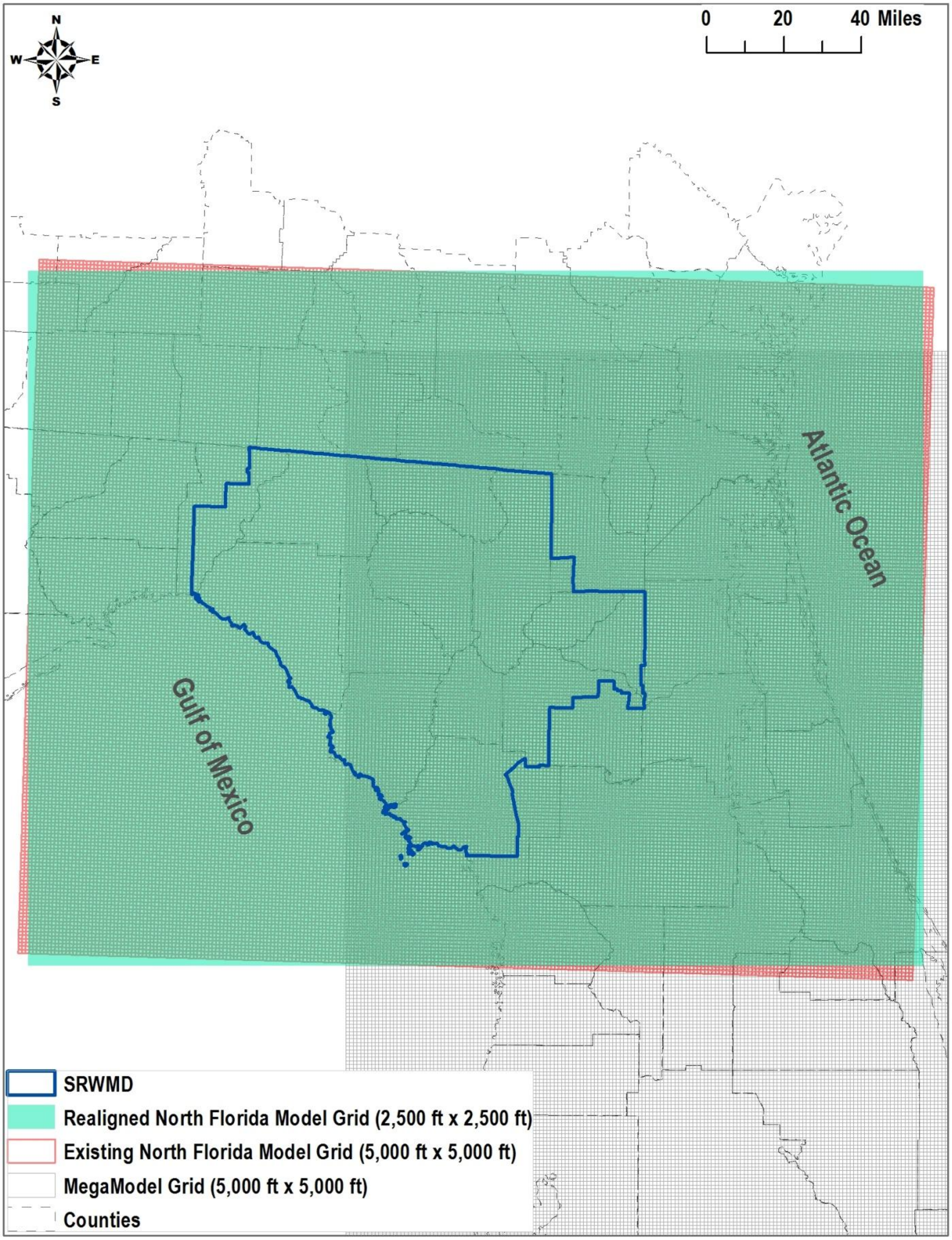

Figure 14. Extents of the MegaModel Grid, Version 1 NF Model Grid, and the Realigned NF Model Grid

Modifications to Stratigraphy

Stratigraphy updates were made using the best data currently available and included a new layering scheme for the North Florida model.

Conceptual Model

This report does not provide the description of the hydrogeology of the study area. Miller (1986) provides a comprehensive description of the hydrogeologic framework of the Floridan aquifer system (FAS). The description of the hydrogeology in the study area can be found in SDII (2008).

The Version 1 layering scheme, shown in Table 1, was initially adopted in the current modeling efforts. The North Florida domain was originally modeled as a three-dimensional flow model with five layers explicitly represented (SDII, 2008). During model calibration, it was decided to model surficial and intermediate aquifers as one layer to help mitigate drying and rewetting; hence, the surficial (SAS) and intermediate (IAS) aquifer thicknesses were combined. The final version of the North Florida Model is four layer model. The SAS and IAS are modeled as a single layer (layer 1), and the UFA, the MCU, and the LFA are simulated as layers 2 through 4, respectively. The revised layering scheme of the North Florida Model is shown in Figure 15. With the exception of layer 1 representing both the SAS and the IAS, the layering scheme followed the Version 1 stratigraphy (SDII, 2008). Another main difference was how the middle confining unit (MCU) was incorporated when it was absent from the stratigraphy. In the areas where the MCU stratigraphic unit was absent, the FAS represented layers 2 through 4. It was desired for model stability that layer 3 thickness was at least 10 feet. Hence, in the area where the MCU was absent or thin, the FAS elevations were used to incorporate layer 3. Similarly to the Version 1 modeling efforts, the salt-water portion of the FAS was not simulated (SDII, 2008; Sepúlveda, 2002).

Group or Formation	***Model Layer***	***Layer Number***
Undifferentiated (sand with shell, clay, etc.), Hawthorn, and St. Mark's Formation	Surficial Aquifer System (SAS) and Intermediate Aquifer System (IAS)	1
Suwannee, Ocala, and Avon Park Formation	Upper Floridan Aquifer (UFA)	2
Avon Park Formation	Middle Confining Unit (MCU)	3
Oldsmar Formation	Lower Floridan Aquifer (LFA)	4

Figure 15. The Revised North Florida Model Layering Scheme

Layer elevations and thicknesses were developed from Bellino's (2011) digital coverages. Although the SAS and IAS were modeled as a single combined layer in the final calibrated version of the North Florida Model, the IAS top elevation was originally developed as if the IAS was being modeled explicitly. The reader should note that layer elevations development in the report is described as if all 5 layers were being modeled explicitly. As mentioned earlier, the SAS and the IAS were combined into a single layer, which is the main difference between the final calibrated model hydrostratigraphy and what is presented in the report.

GIS Processing

Miller's (1986) hydrogeologic framework of the Floridan aquifer system was incorporated into the revised hydrostratigraphy using Bellino's (2011) raster and vector datasets in Esri ArcMap 9.3. The revised version of the North Florida Model consists of 4 layers, as shown in Figure 15. A challenging aspect of the modeling efforts was the synthesis of layers in the areas where the stratigraphic units were absent. MODFLOW requires that every simulated layer have a thickness. Hence, some adjustments were made to the stratigraphy to incorporate the MCU stratigraphic unit in the areas where the MCU did not exist. In addition, the FAS top elevations were adjusted to fit the IAS stratigraphic unit – where it was absent in the model domain –while holding the land surface elevations constant. This is described later in the report.

The steps for GIS processing of the hydrostratigraphic coverages are summarized below. The layer thicknesses and elevations in the inactive domain of the North Florida Model were not processed and may be incongruent with the physical thicknesses in that area. The raster coverages of the layer elevations in the Gulf of Mexico and the Atlantic Ocean were not available and were extrapolated using a kriging technique from the elevation values of available raster coverages.

Surficial Aquifer System (SAS) Top Elevation

The USGS five-foot topographic contours, the NED digital dataset with a resolution of 1/3 arc-second (approximately 10 meters), and the VERTCON raster dataset were used to update the top elevations of the surficial aquifer in the North Florida Model. The cell average elevation values of the NED and the VERTCON raster datasets were generated using Esri's ArcMap 9.3 zonal statistics. The VERTCON values were used to convert the NED elevations from NAVD88 to NGVD29. The NED dataset had erroneous data inside the District boundary and the USGS five-foot topographic contours (topousgs5.shp) were utilized inside the District boundary. The contours were converted into a raster surface to obtain land surface cell average elevation values inside the District boundary. The NED and the cell average elevation values generated from the five-foot contours were combined into a continuous coverage.

Intermediate Aquifer System (IAS) Top Elevation

<u>GIS processing of the data in the areas where the IAS stratigraphic unit is present</u>:

1) Obtained SAS top elevations from NED and five-foot topographic contours,
2) Obtained IAS thickness by digitizing contour lines of IAS thickness (plt25_upper_confining_unit.tif (Bellino, 2011)) and converting to a raster surface; IAS thickness values were then extracted from a raster surface to cell centers,
3) IAS top elevations were obtained by adding IAS thickness values to the FAS top elevation values,
4) IAS bottom elevations were obtained from a raster dataset of the FAS top elevations (fast_surf.zip).

<u>GIS processing of the data in the areas where the IAS stratigraphic unit is absent:</u>

1) Obtained SAS top elevations from NED and USGS five-foot topographic contours,
2) Obtained IAS thicknesses and set IAS thickness to 5 feet where IAS stratigraphic unit was absent from the model domain,
3) Obtained UFA top elevations from a raster dataset of the FAS top elevations (fast_surf.zip),
4) Calculated delta (Δ) as:

$$\Delta = [\textit{SAS top elevation} - \textit{FAS top elevation}] - [\textit{IAS thickness}], \qquad (1)$$

5) If calculated delta was less than 5 feet, then UFA top elevation was shifted down by [5- Δ] to get adjusted UFA top elevation,
6) Calculated IAS top elevation using adjusted UFA top elevation and adjusted IAS thickness.

Upper Floridan Aquifer Top Elevation
UFA top elevations were obtained from a raster dataset fast_surf.zip (Bellino, 2011). As described above, in several instances the actual raster FAS top elevations were lowered to ensure that the IAS and/or SAS thicknesses were at least 5 feet.

Middle Confining Unit
GIS processing of the data in the areas where the MCU stratigraphic unit is present:

The raster dataset of the base of the upper Floridan aquifer, ufab_surf.zip, had erroneous data and was not used. Instead, plt29_ufa_base_cntr.shp (shapefile of the contours of the base of the upper Floridan aquifer) was used to obtain MCU top elevations. Contour lines of the shapefile plt29_ufa_base_cntr.shp were digitized and converted to a raster surface. MCU top elevation values were then obtained from a raster surface of the base of UFA.

GIS processing of the data in the areas where the MCU stratigraphic unit is absent:

The areas where the MCU stratigraphic unit was absent was defined by the domain where the raster coverage of the top elevations of the Lower Floridan aquifer (lfat_surf.zip) was missing (Bellino, 2011). The area where the MCU stratigraphic unit is absent represents the domain where the upper and lower Floridan aquifers merge (Miller, 1986). In areas of the model domain where the MCU was not present, a thickness of 10 feet was utilized for layer 3. This was deemed appropriate since the transitional areas near the edges of the middle confining units are relatively thin (Miller, 1986). The steps taken to obtain MCU top elevations are summarized below.

1) MCU top elevations in the area where MCU physically exists were obtained (described above),
2) Using kriging, MCU top elevations in the area where MCU physically exists were extrapolated to the areas where MCU does not exist. This allowed for a transition between the area where the UFA and LFA merge and the area where MCU is physically present.
3) MCU bottom elevations in the area where MCU is not present were obtained by subtracting a thickness of 10 feet from the extrapolated MCU top elevations.

Lower Floridan Aquifer Top Elevation
In the area where the MCU stratigraphic unit was present LFA top elevations were obtained from the raster dataset of the top of the LFA (lfat_surf.zip). In the area where the MCU stratigraphic unit was absent, LFA top elevations were obtained by subtracting a thickness of 10 feet from the extrapolated MCU top elevations (described above).

Lower Floridan Aquifer Bottom Elevation
Lower Floridan aquifer bottom elevations were obtained using the raster dataset of the base of the Floridan aquifer system (fasb_surf.zip). In addition, plate 32 (Miller, 1986) depicting the thicknesses of the lower Floridan aquifer was used to correct for irregularities in the areas where lower Floridan aquifer bottom elevations were greater than lower Floridan aquifer top elevations. Contour lines of the lower Floridan aquifer thicknesses were digitized and converted to a raster surface. Plate 32 thicknesses replaced negative LFA thicknesses (developed from fasb_zurf.zip) by adjusting MCU and LFA bottom elevations. The area of adjustment was limited to the northwestern portion of the MCU III. The reader should refer to plate 29 in Miller's hydrogeologic framework of the Floridan aquifer (1986) for depiction of middle confining units

Freshwater/Saltwater Interface

Similarly to the SDII modeling efforts, the saltwater portion of the Floridan aquifer was not simulated. The model layer 2 (UFA) bottom and layers 3 (MCU) and 4 (LFA) top and bottom elevations were adjusted to account for the freshwater/saltwater transition zone. A map of the estimated altitude of water with chloride concentration of 5,000 mg/L in the Floridan aquifer system (Figure 19 in Sepúlveda, 2002) was used to define the freshwater/saltwater transition zone and to adjust elevations of layers 2 through 4. Bottom elevations of layer 2 (UFA) were set equal to the estimated altitudes of water with chloride concentration of 5,000 mg/L if these elevations were higher than the previously estimated corresponding bottom elevations. In addition, the active domain of layers 3 and 4 was slightly reduced to account for the saltwater interface but generally followed the configuration of the active domain of the Version 1 modeling efforts.

Expansion of the Model Domain

The active domain of the North Florida Model generally follows the configuration of the Version 1 model. However, there are several changes. The southeastern portion of the North Florida model is extended to coincide with noflow and general head boundaries of the MegaModel. In addition, the extent of active domain of layers 3 and 4, representing middle confining unit and Lower Floridan aquifer, is modified to account for freshwater/saltwater interface. Figures 16 through 19 compare the extent of the active domain of the SDII model and the revised North Florida Model.

Boundary Condition Development

Boundary condition development includes lateral boundary conditions, as well as the river package, drain package, recharge package and evapotranspiration package.

Lateral Boundary Conditions

In the Version 1 model, lateral boundary conditions for layer 1, (representing the surficial and intermediate aquifer systems), consisted of specified head boundaries along the coasts and noflow boundaries in the terrestrial area of the model domain (Figure 16). In layer 1 of the revised model, the eastern constant head boundary representing the Atlantic Ocean was extended to the south as shown in Figure 16. Lakes and swampy areas that were simulated in the Version 1 model with a GHB package were not explicitly represented in the revised model, but were instead simulated as areas with higher maximum ET rates. Representation of rivers and springs in the model is described later in the report.

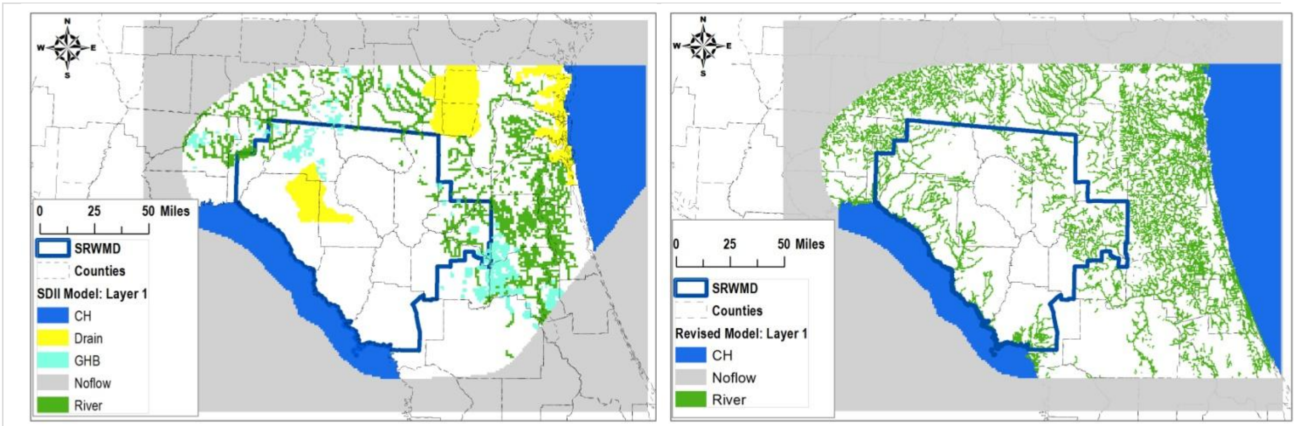

Figure 16. Model Boundary Conditions for Layer 1: Version 1 (left) and Revised (right)

The lateral boundary conditions for layer 3 in the Version 1 model, representing the upper Floridan aquifer, consisted of the general head and noflow boundaries. The locations of the eastern noflow and specified head boundaries in Version 1 model were modified to coincide with the MegaModel noflow boundary. The MegaModel calibrated head values of the upper Floridan aquifer, based on the average hydrologic conditions for August 1993 through July 1994, were used to update upper Floridan aquifer constant head values in the eastern portion of the revised North Florida Model.

As shown in Figure 17, the eastern general head boundary of the Version 1 model was replaced with a constant-head boundary condition in the revised model. The southern general head boundary was extended to the east and the 1995 potentiometric surface of the Upper Floridan aquifer was used to estimate new GHB head values. May 1995 and September 1995 contour shapefiles of the UFA potentiometric surfaces were used (Knowles et al., 1995; O'Reilly et al., 1996) to estimate the 1995 potentiometric surface. GIS processing steps to obtain average 1995 head values included: (a) May 1995 and September 1995 potentiometric contours were converted to raster surfaces using linear interpolation; and (b) the resulting May and September 1995 rasters were then averaged and used to assign estimates of 1995 UFA average. Heads were then estimated at the GHB cell centers. MegaModel upper Floridan aquifer (layer 3) transmissivities were used as the southern general head boundary conductance values.

The northern general head boundary of the revised model was also modified. Potentiometric surfaces of the UFA were not available along the northern boundary for 1995. However, a potentiometric surface of the UFA for May 1998 (Peck et al., 1999) was available, and was used to estimate the GHB heads, under the assumption that the average UFA groundwater levels for 1995 were not significantly different from the 1995 average levels. Since the potentiometric surface of the UFA for May 1998 was the best available data, its use for the regional flow model was deemed appropriate. A contour shapefile of Peck et al. (1999) UFA potentiometric surface for May 1998 was not available, so the PDF file of the map was digitized instead. GIS processing steps to obtain 1998 general head values included: (a) the PDF file was georeferenced; (b) potentiometric contours were digitized; (c) May 1998 potentiometric contours were converted to a raster representation using linear interpolation; and (d)UFA head values were assigned to the northern GHB cell centers from the raster created in the previous. The Version 1 northern GHB conductances were used as initial conductance values in the revised model of North Florida. UFA general head boundary cells were modeled as active cells in the layer representing surficial and intermediate aquifer systems (layer

1). The GHB head and conductance values for layer 2 in the revised model were also assigned to corresponding cells in the underlying layers 3 and 4 of the revised model that represented the middle confining unit and lower Floridan aquifer, respectively.

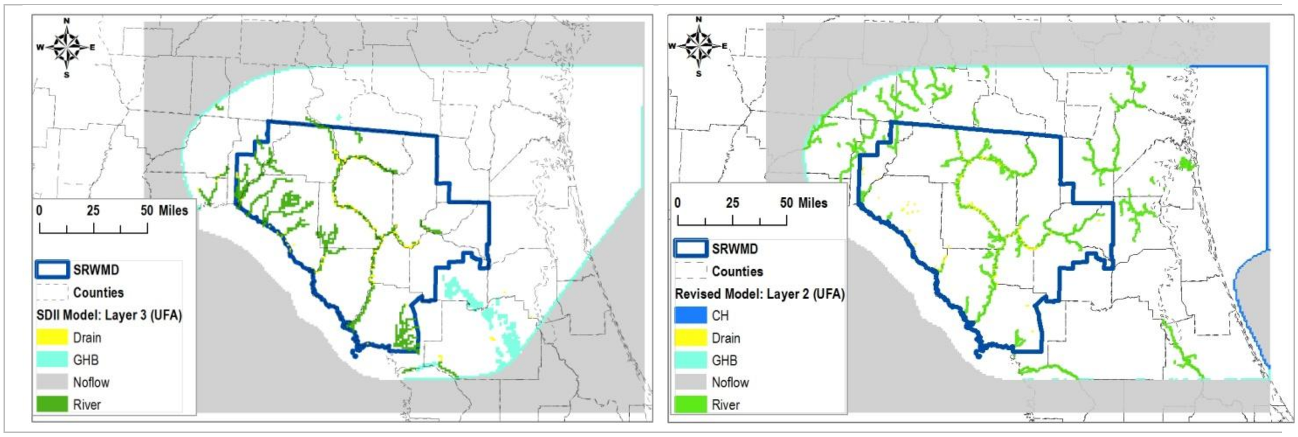

Figure 17. Model Boundary Conditions for Upper Floridan Aquifer: Version 1 (left) and Revised (right)

As previously mentioned, the extent of the active domain of layers 3 and 4, simulating the middle confining unit and lower Floridan aquifer, was extended to the southeast to coincide with noflow and constant head boundaries of the MegaModel. As shown in Figures 18 and 19, the active domain of layers 3 and 4 was modified to account for the saltwater interface. A map of the estimated altitude of water with chloride concentration of 5,000 mg/L in the Floridan aquifer system was used to define the freshwater/saltwater transition zone (Sepúlveda, 2002). The saltwater portion of the Floridan aquifer system is not simulated and is represented in the model with noflow cells.

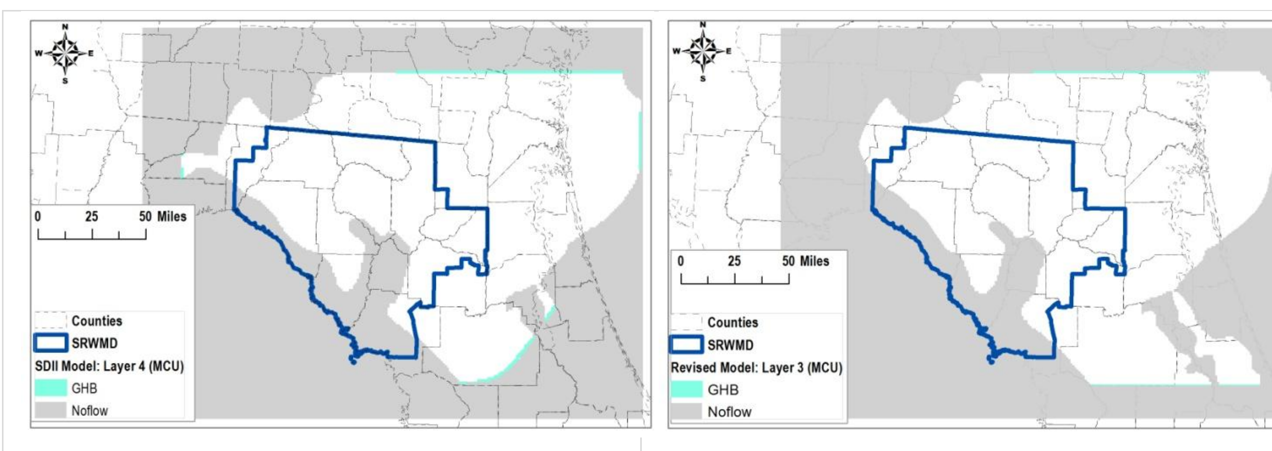

Figure 18. Model Boundary Conditions for Middle Confining Unit: Version 1 (left) and Revised (right)

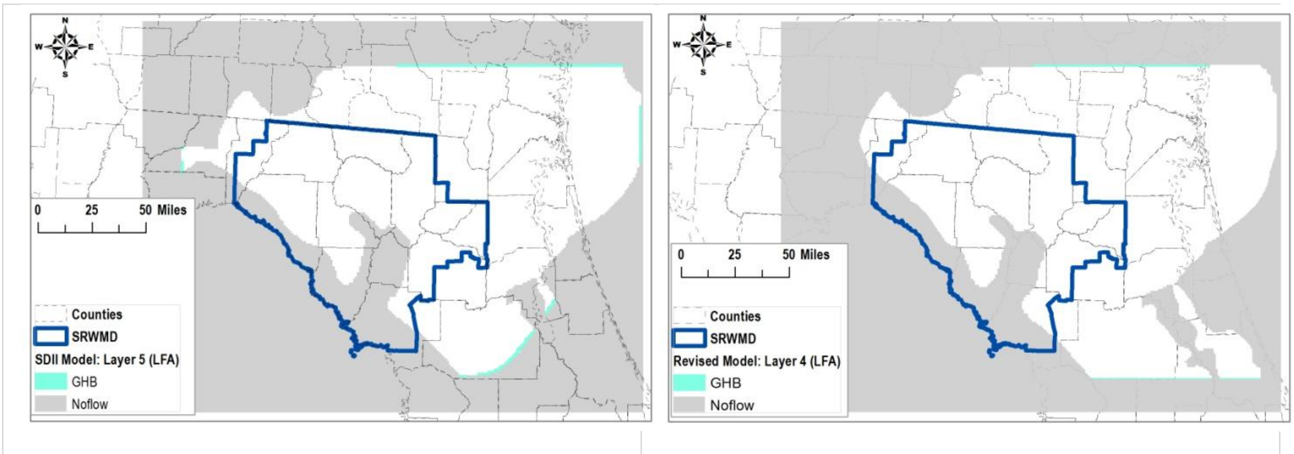

Figure 19. Model Boundary Conditions for Lower Floridan Aquifer: Version 1 (left) and Revised (right)

River Package Development

Version 1 of the North Florida model utilized a MODFLOW River Package (McDonald and Harbaugh, 1988) to represent groundwater interactions with rivers and streams. However, per District request, a new river package was developed in order to systematically represent hydrography in the model and allow for the simulation of impacts to hydrography through the examination of river fluxes and to better simulate groundwater/surface water interactions between the surficial, intermediate, and upper Floridan aquifers and river cells. The river package was based on National Hydrography Dataset (NHD) arcs features that were processed in ArcGIS. The hydrography arcs were first intersected with the North Florida Model grid. The length of each arc was computed for each model cell and was used to compute riverbed conductance values in the model river package development. NHD waterbodies, including lakes and wetlands, were not simulated with the river package.

NHD arcs, shown in Figure 20, were assigned characteristics based on Strahler order. Initial arc characteristics are shown in Table 11. The initial arc characteristics were based on the 1995 calibrated river characteristics of the NEF model (INTERA, 2011b) and knowledge of the river systems in the area of the model domain. Major rivers within the District were identified with assigned Strahler orders 10 through 14.

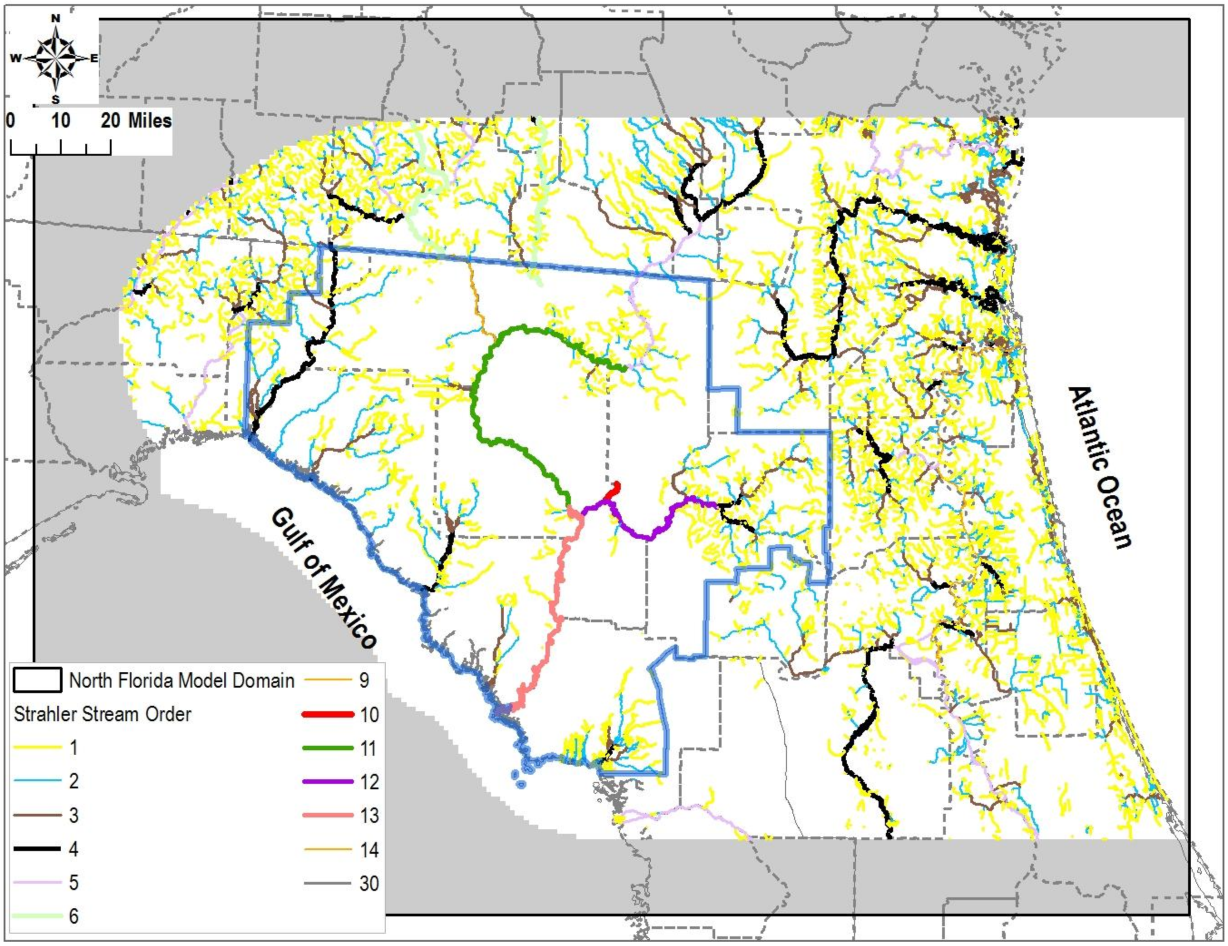

Figure 20. Strahler Orders

Table 9. Initial Reach Characteristics

Strahler Order	Reach Width, ft	Depth to Bed (Db), ft	Depth of Water Above Bed (Dwb), ft	Conductivity (Kv), ft/day	Bed thickness, ft	River Name (If Applicable)
1	3	1.8	1	1.5	1	N/A
2	8	3.81	2	1.5	1	N/A
3	12	5.4	3	1.5	1	N/A
4	20	7.2	4	0.63	1	N/A
5	30	15.63	5	0.07	1	N/A
6	175	11.61	6	1.5	1	N/A
7	180	7.2	6	0.17	1	N/A
8	180	7.2	6	0.17	1	N/A
9	2500	7.2	6	0.17	1	N/A
10	8	3.81	2	1.5	1	Ichetucknee
11	180	7.2	6	0.17	1	Upper Suwannee

Strahler Order	Reach Width, ft	Depth to Bed (Db), ft	Depth of Water Above Bed (Dwb), ft	Conductivity (Kv), ft/day	Bed thickness, ft	River Name (If Applicable)
12	30	15.63	5	0.07	1	Santa Fe
13	30	15.63	5	0.17	1	Lower Suwannee
14	180	7.2	6	0.17	1	Withlacoochee
30	3	1.8	1	1.5	1	N/A

River bed hydraulic conductivity was optimized in PEST during model calibration. For the majority of the river cells, river cell characteristics were optimized in PEST. For the river cells representing reaches of the Ichetucknee, Santa Fe, Suwannee, and Withlacoochee rivers, river bottom elevations and stages were fixed and not optimized in PEST. River bottom elevations for these rivers were instead estimated using minimum channel elevations from the HEC-RAS surface water models previously developed (INTERA, 2012). The HEC-RAS models had surveyed minimum channel elevations at cross sections on the Suwannee, Santa Fe, Ichetucknee, and Withlacoochee rivers. For these river systems, linear relationships were developed using minimum channel elevation and HEC-RAS station number. The relationships were used to estimate river bottom elevations for the cells comprising these systems. Strahler orders 10 through 14 were assigned to these rivers. Average 1995 stage values were computed from daily values at observed USGS gauges on these river reaches. The stage at a given river cell was based on a linear interpolation of the nearest upstream and downstream USGS gauges. Coastal reaches were assigned a Strahler order of 30, a fixed stage of zero, and a river bottom elevation of -2.0 feet. Figure 21 shows the river reaches where stages were fixed (Strahler orders 10 through 14) and optimized in PEST (optimized stage river cells, Strahler orders less than 10 or greater than 14).

For Strahler orders 1 through 9, river bottom (Rbot), conductance, and stage were calculated according to the following equations:

$$Rbot = Top1 - Db \qquad (2)$$

$$Conductance = Kv \times Length \times Width/Bed\ Thickness \qquad (3)$$

$$Stage = Top1 - Db + Dwb \qquad (4)$$

Where: *Top1 = layer 1 top elevation*

Db = Depth to bed, and

Dwb = Depth of water above bed

Kv = hydraulic conductivity of the river bed

In addition to assigning each reach a Strahler order, each river cell was also assigned a reach identifier (Reach ID), in order to accumulate river cell fluxes for comparison to estimated baseflows. Figure 5 shows river reaches and the corresponding Reach IDs. Several USGS gauging stations located within the model domain had contributing basins that were either in the inactive portion of the model domain or outside the model domain. These stations were therefore not utilized as baseflow targets. Table 3 shows adjusted 1995 average baseflow fluxes for the reaches identified in Figure 5. The Reach ID served as a common field linking the river cells to the baseflow targets in order to systematically account for the river fluxes during calibration. Use of the 'Strahler approach' generally assumes that the hydraulic conductivity of a river cell for a given reach can be constrained during calibration even if a baseflow target is not available, as long as there are a sufficient number of reaches of the same Strahler order in other areas that do have corresponding baseflow targets.

Assignment of river cells to layers was based on knowledge of hydrology in the area. The Alapaha, Ichetucknee, Santa Fe, Suwannee, and Withlacoochee rivers were assigned to model layer 2 (the upper Floridan aquifer), since the Floridan aquifer is known to be incised by streams of these systems. These systems' tributaries, coastal river systems, and small streams were simulated assigned to model layer 1, which represents the intermediate and surficial aquifer systems.

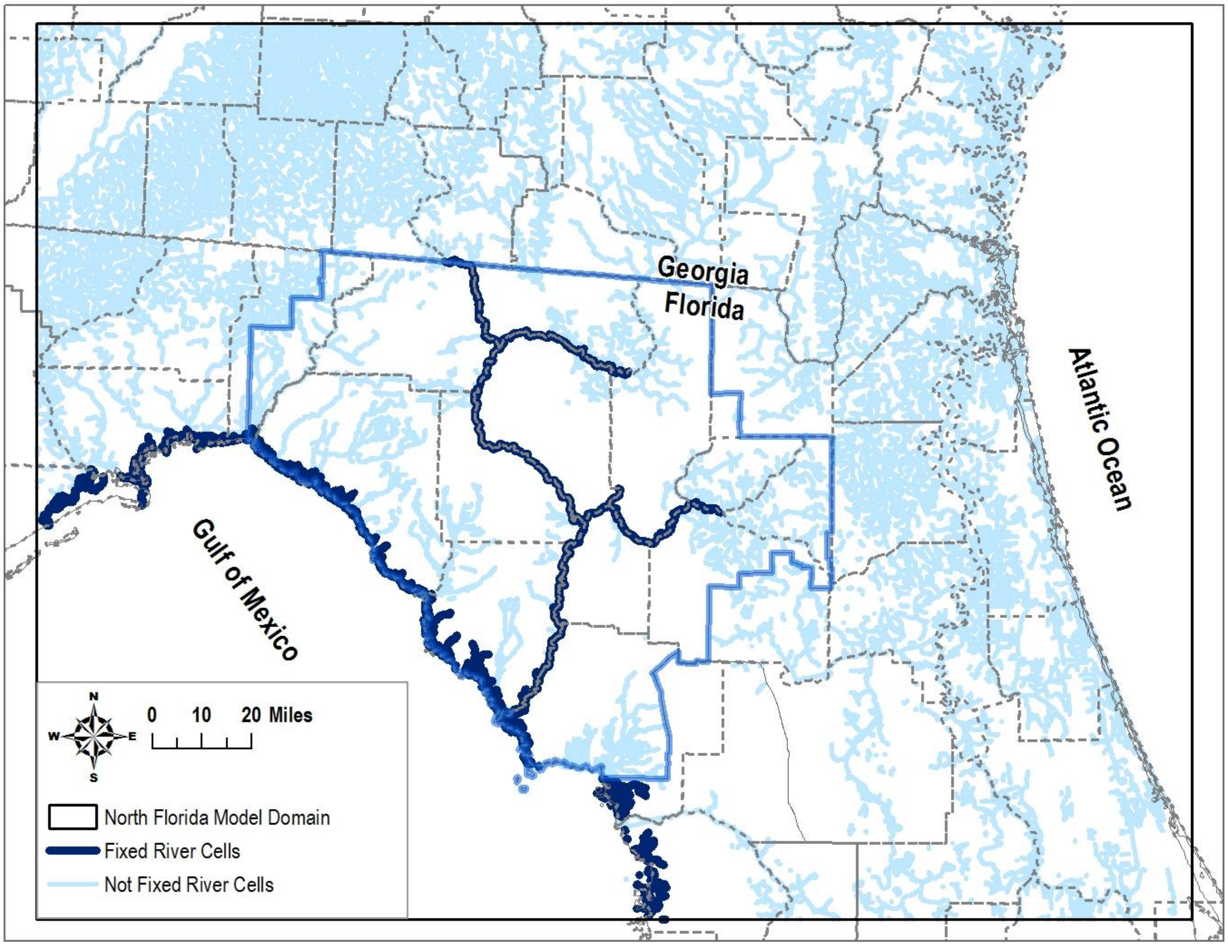

Figure 21. Fixed-Stage and Optimized-Stage River Cells

Drain Package Development

A drain package was developed in order to simulate discharge from the upper Floridan aquifer to 297 springs located within the model domain (Figure 8). As described earlier, a shapefile of 269 springs within the District was provided by the District. A shapefile developed in 2011 by the FDEP was also available, that included the best available locations of springs that had any data collection activities. This dataset was used to identify and locate 28 first and second magnitude springs outside the District for inclusion in the model, in addition to the 269 springs provided by the District.

As described in the Springs and Siphons section of this report, for 269 springs within the District the estimated average 1995 springflow target values were based on the ratios of 1995 average river baseflow estimates, spring discharge measurements, and spring magnitudes. For the 28 FDEP springs located outside the District, INTERA (2011b), Scott et al., (2004), Barrios (2006), and the USGS National Water Information System (NWIS) were utilized to estimate springflow targets.

Creation of a MODFLOW Drain Package input file requires the specification of spring-pool elevations and spring conductance values. The Version 1-calibrated spring conductance values were used to initialize the spring conductance valuess of the revised North Florida Model. These spring conductance values were subsequently optimized using the PEST software. Spring-pool elevations were also optimized in PEST. Based on the available spring data, three levels of constraint were assigned to spring-pool elevations. The level of constraint (1, 2, or 3) assigned to each spring served as a guide as to how much spring pool elevations could vary in PEST. For springs with a constraint level 1, pool elevations were allowed to fluctuate in PEST plus or minus 1 ft; for springs with a constraint level 2, pool elevations were allowed to fluctuate plus or minus 2 ft; and for springs with a constraint level 3, pool elevations were allowed to fluctuate plus or minus 10 ft.

For 205 springs within the District boundary, initial spring-pool elevations were based on the linear relationships developed from 1995 average stage data at the USGS streamflow stations. For the remaining 64 springs within the District boundary, the initial pool elevations were based on the District's estimates of spring pool elevations using LiDAR data. These values were provided by the District in a shapefile format (Springs_with_river.shp, field "MEAN_1" was used to set initial pool elevation for these 64 springs).

For the 28 FDEP springs located outside the District boundary, LiDAR data was not available. The NEF model calibrated spring-pool elevations were assigned to the North Florida Model initial spring pool stages that were further optimized in PEST (INTERA, 2011b). In addition, the National Elevation Dataset was used to estimate initial spring pool elevations as the minimum elevation within a 1000-ft buffer of each spring location.

The NEF model (INTERA, 2011b) spring-conductance values, the Version 1 North Florida Model (SDII, 2008) spring-conductance values, and spring-conductance estimates computed for this project served as initial spring conductance values to be optimized in PEST. For the FDEP springs that were not previously modeled by SDII or INTERA, initial conductance values were assigned on the basis of spring magnitude, as shown in Table 12.

Table 10. Assignment of Initial Conductance Values Based on Spring Magnitudes

Spring Magnitude	Conductance (ft/day)
1	500,000
2	100,000
3	50,000

Recharge Package Development

Precipitation, recharge, and runoff relationships from the Integrated Northern Tampa Bay Model (Geurink et al., 2000) and the National Land Cover Dataset 1992 (NLCD1992) were utilized in the development of the MODFLOW Recharge Package. Using the NLCD1992 dataset and the model grid, the majority land cover type was determined as the most frequently occurring land cover class in each model-grid cell. Land cover classes (or land use classes) and their descriptions are shown in Table 9. Initial estimates of recharge for each grid cell in the revised North Florida Model were based on 1995 average rainfall totals from the PRISM precipitation dataset, the majority land-use classification, and the Integrated Northern Tampa Bay Model (INTB) rainfall-recharge and rainfall-runoff relationships.

Recharge in the model was estimated using relationships developed between recharge and rainfall from the INTB model and was calculated for each model cell according to:

$$\text{Recharge} = b_0 * \text{PRISM} + b_1 \qquad (5)$$

where b_0 and b_1 are the slope and the intercept of the recharge equation for the grid cell's majority land use, as shown in Table 13, and PRISM is the annual total 1995 PRISM rainfall for that grid cell in inches. Similarly, runoff for each cell in the model was estimated using the regressive relationships between runoff and rainfall from the INTB model, and was calculated for each cell in the model according to:

$$\text{Runoff} = b_0 * \text{PRISM} + b_1 \qquad (6)$$

where b_0 and b_1 are the slope and the intercept of the runoff equation for the grid cell's majority land use, as shown in Table 13.

Table 11. INTB Regressive Relationships

IHM Code	LU Type	Recharge Regression		Runoff Regression	
		Slope (b_0)	Intercept (b_1)	Slope (b_0)	Intercept (b_1)
1	Forest	0.42	-8.72	0.44	-18.88
2	Pasture	0.32	3.83	0.58	-23.06
3	Agricultural	0.38	0.57	0.49	-19.51
4	Mining/Other	0.38	-4.17	0.53	-21.37
5	Urban	0.40	-3.87	0.51	-20.83
6	Wetland/Water	1.00	0.00	0.00	0.00

A 2500-foot buffer was developed around the NHD hydrography arcs to define well-drained and poorly drained areas. In poorly drained areas, theoretical runoff was recharge from the INTB model relationship to get total recharge. In well-drained areas, total recharge was simply recharge from the INTB model relationship.

ET Package Development

A land-use based parameterization was used for developing the MODFLOW Evapotranspiration Package (McDonald and Harbaugh, 1988). The elevation at which the maximum ET rate occurs (ET surface) was set to the updated layer 1 top elevations. ET rates were set based on average values for corresponding land-use types from the INTB model. Table 14 shows the ET rates and extinction depths for different land-use types.

Table 12. ET Rates and Extinction Depths for Different Land-Use Types

Land Use	ET Rate (inches/yr)	Extinction Depth (ft)
Forest	15.17	10
Wetland/Water	18.6	5
Agriculture	15.97	5
Pasture	15.86	5
Urban	8.05	5

Well Package Development

As discussed in the Data Collection section of the report, the 1995 estimated water use data for the District counties, with the exception of Bradford and Baker counties, was provided by the District. The water use data developed by the District also contained 1995 water use data outside the District boundary. This water use data overlapped the domains of the NEF and the MegaModel. The most recent 1995 NEF Well Package (V4_95_Base_w_Updated_Well_RCH.wel) was provided by the St. Johns River Water Management District. The decision was made to use the District 1995 pumping rates for the well locations within the District boundary, the NEF well package data for the well locations completely within the NEF model domain, and the MegaModel well package for the well locations outside the District boundary and the NEF model domain. The exception was for Jefferson County for wells located outside the District boundary. For these wells, available District water use rates were also utilized. As mentioned earlier, the NEF well package was utilized in Bradford and Baker counties because these withdrawal estimates were already available in the NEF Well Package input file. As shown in Figure 10, data from the Version 1 North Florida Model Well Package input file was used in the northwestern portion of the model domain where pumping data were not available.

Well locations from four sources were merged into a single shapefile and intersected with the model grid (Figure 10). Withdrawals from these locations are simulated at grid cell centers in MODFLOW. Pumping wells were in the model represented a combined withdrawal of 110,973,293 cubic feet per day (cfd) out of the aquifer. The well package input file also contains 56 injection well records that represented wells injecting stormwater or wastewater into the aquifer, as well as virtual injection wells that represented locations where locally-captured streamflow recharges the aquifer. These injection well records accounted for a large (approximately 1,026 million gallons per day) flux into the aquifer. The injection wells representing locally-captured streamflow are described in the *Springs and Siphons* section of this report. The combined net flux of the groundwater pumping and injection wells in the Well Package input file represents a combined net flux of 26,210,535 cfd (196 million gallons per day) into the aquifer.

Representation of the Siphons and Swallets

Nine siphons or swallets were modeled as injection wells simulating locally captured streamflow into the aquifer. Estimated of injection rates at four of these features were obtained from the Version 1 modeling efforts due to limited data and uncertainty in existing flow measurements at the siphons (SDII, 2008). Table 7 lists the locations, the injection rates, and the source of data associated with siphons and swallets in the revised model. Five injection well rates utilized rates that were different from the Version 1 model (SDII, 2008). This section of the report further describes the development of injection rates for those five siphons and sinks.

Alapaha River Sink

Concerns about the representation of the Alapaha River, Alapaha sink (on the Dead River), and Alapaha Rise were expressed by the District during model calibration. It was important that these hydrologic features were appropriately represented in the model.

The Alapaha River flows from Georgia gaining stormwater and baseflow. It flows past the Alapaha River at Statenville (USGS #02317500) and the Alapaha River near Jennings (USGS #02317620) USGS streamflow stations. There is a sinkhole, also known as the Alapaha sink, located between the Alapaha River near Jennings and the Alapaha River near Jasper (USGS #02317630) gauges. The Alapaha River flows into the Alapaha sink most of the time. The channel downstream of the sinkhole flows during storm discharges over 500 cfs. What is left of the Alapaha River flow (after the flow enters the sinkhole) then flows past the Alapaha River near Jasper gauge. The water entering the sink discharges into the Suwannee River at the Alapaha Rise. The distance from the Alapaha sink and the Alapaha Rise is approximately 9 miles.

The surface water flux into the Alapaha sink was represented in the model as an injection well. The accumulated baseflow that accounts for the Alapaha baseflow, including the Alapaha sinkhole, is included in the computation of the baseflow target at the Suwannee River at Ellaville gauge approximately 6 miles downstream of the Alapaha and Suwannee River confluence. The discharge at the Alapaha Rise (USGS #02315648) was also used as a springflow target during the calibration of the revised model.

The surface water flux into the Alapaha sink is essentially a loss in surface water flow between Jennings and Jasper gauging stations. Daily flow time series were not available at the Jennings gage for 1995 and flow data at Jasper during 1995 was limited to only two field measurements. The Alapaha River at Statenville USGS gauge has a daily flow record from 12/10/1931 until present. Using Statenville daily flow values, linear relationships were developed to estimate 1995 flow time series at the Jennings and Jasper gages in order to estimate the loss at the sink. Figure 22 shows the relationship between Jennings and Statenville daily flows. This relationship was based on a simple linear regression (SLR) in which the intercept was forced through zero, as shown in Figure 22. When the Statenville flow is 0 cfs, the flow is also likely to be 0 cfs at Jennings; hence, the assumption of an intercept equal to zero was deemed appropriate. A simple linear regression between flows at the Statenville and Jasper gages was developed using field flow measurements at the Jasper gage and daily flows from the Statenville gage (Figure 23). These regression relationships were then used to get 1995 daily flow time series at Jennings and Jasper. The developed flow time series were averaged using a moving 30-day window. A 30-day window average was run on the data as a smoothing mechanism and to account for the delay in response between Jasper and Jennings. The difference between 30-day window averaged Jasper and Jennings flow time series was calculated and then averaged for 1995 to be used as the injection well flux into Alapaha sink (Figure 24). The 1995 estimated flow loss into the Alapaha sink that resulted from this calculation was 364.5 cfs.

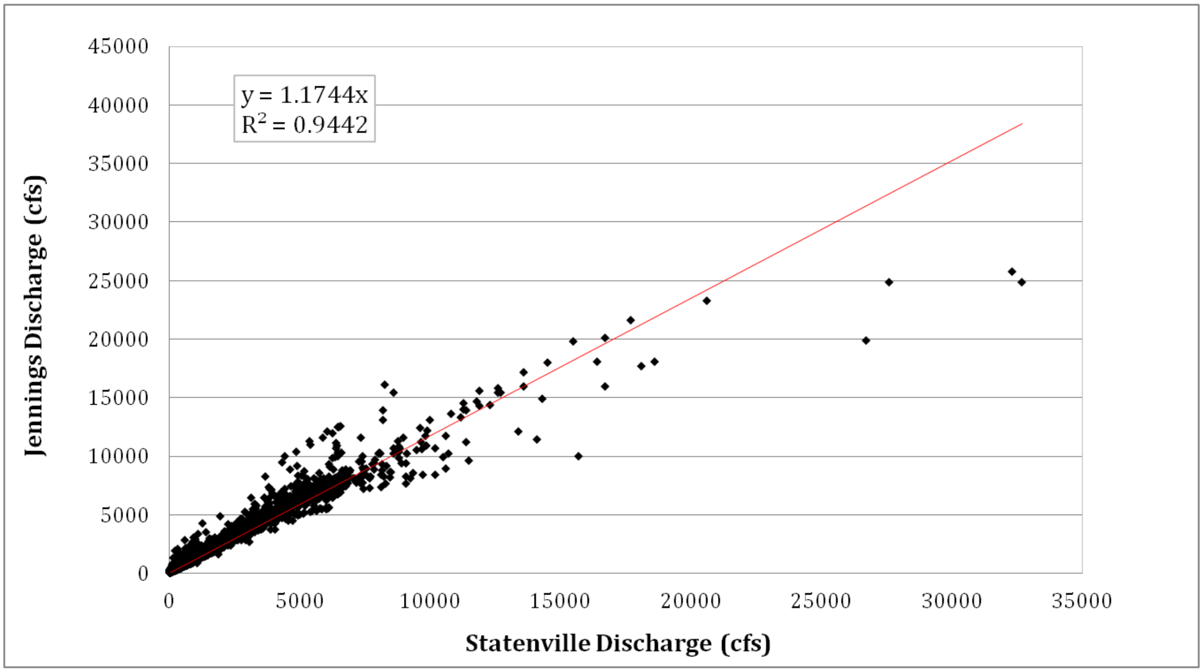

Figure 22. SLR: Jennings Discharge vs. Statenville Discharge

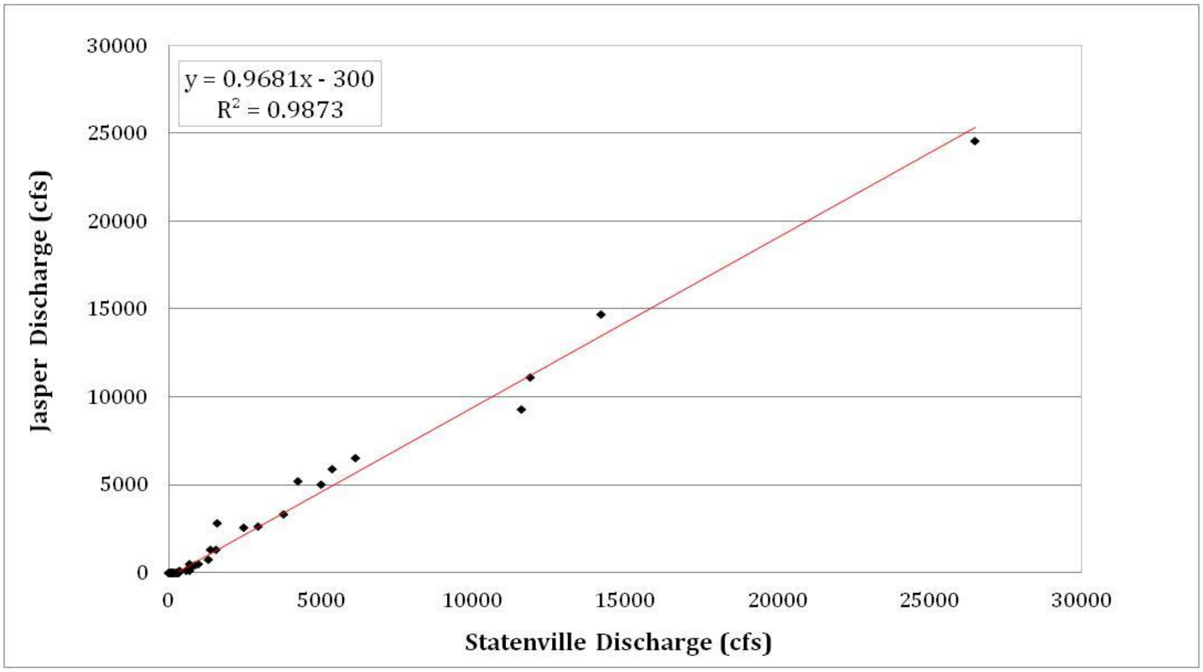

Figure 23. SLR: Jasper Discharge vs. Statenville Discharge

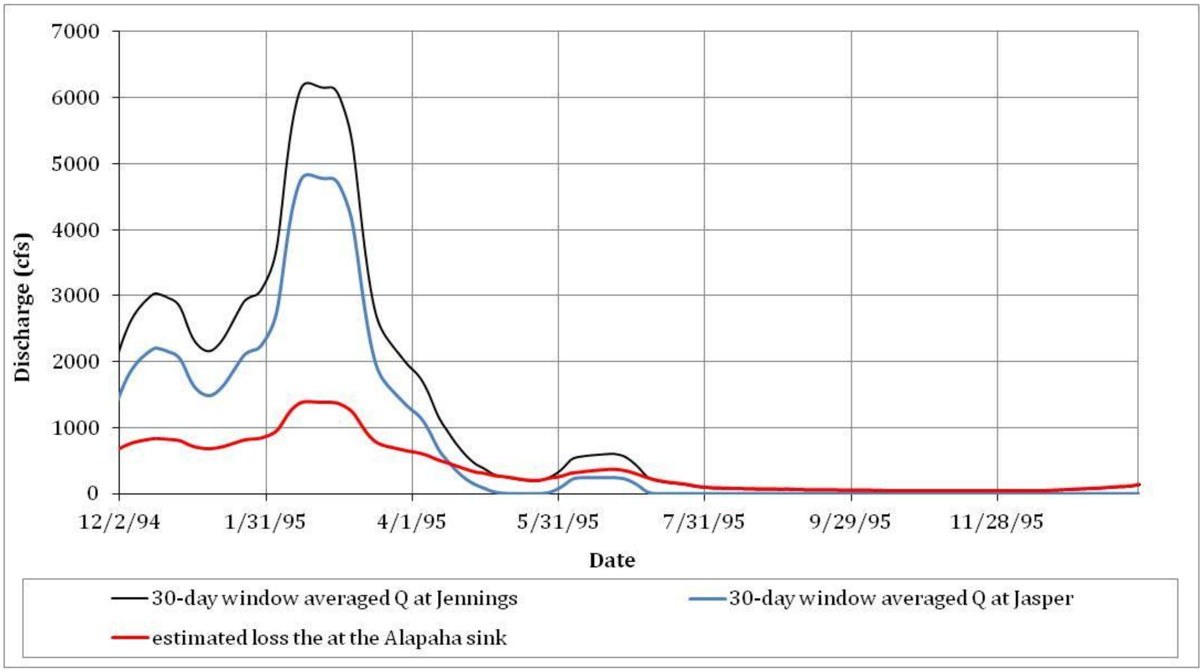

Figure 24. Synthesized Time Series of the Alapaha River Flow Loss at the Alapaha Sink

Vinzant Swallet

The surface water flux into the Vinzant Landing Swallet was modeled as an injection well. The Vinzant Landing Swallet is approximately 1 mile downstream of I-75, near Vinzant Landing. No flow measurements were available at the Vinzant Landing Swallet, and the objective was to use the best available data to estimate the flow that disappeared into the sink.

The injection well rate was estimated using a synthesized daily time series at Vinzant Landing from the calibrated HEC-RAS model of the Lower Santa Fe and Ichetucknee Rivers (INTERA, 2012) and average 1995 flow at the USGS Worthington gauge (USGS #2321500). The Vinzant Landing Swallet synthesized time series (2002-2011) was developed by first running the HEC-RAS model without negative or positive inflows that accounted for the swallet and then taking the difference between the HEC-RAS model output flow values and the observed flow values at the O'Leno by the Footbridge streamflow gauge (District gauge). The generated time series was revised to ensure that no more than 200 cfs was diverted into the Vinzant sink on any day (Figure 25). Finally, a 1995 average estimate of flow loss into the Vinzant Landing Swallet was estimated using a ratio of synthesized time series, averaged for the HEC-RAS modeled time period (2002-2011), and the average flow at Worthington gauge (Table 15). A rate of 37.7 cfs was estimated for the Vinzant Landing Swallet injection well in the revised model using this approach (Table 15).

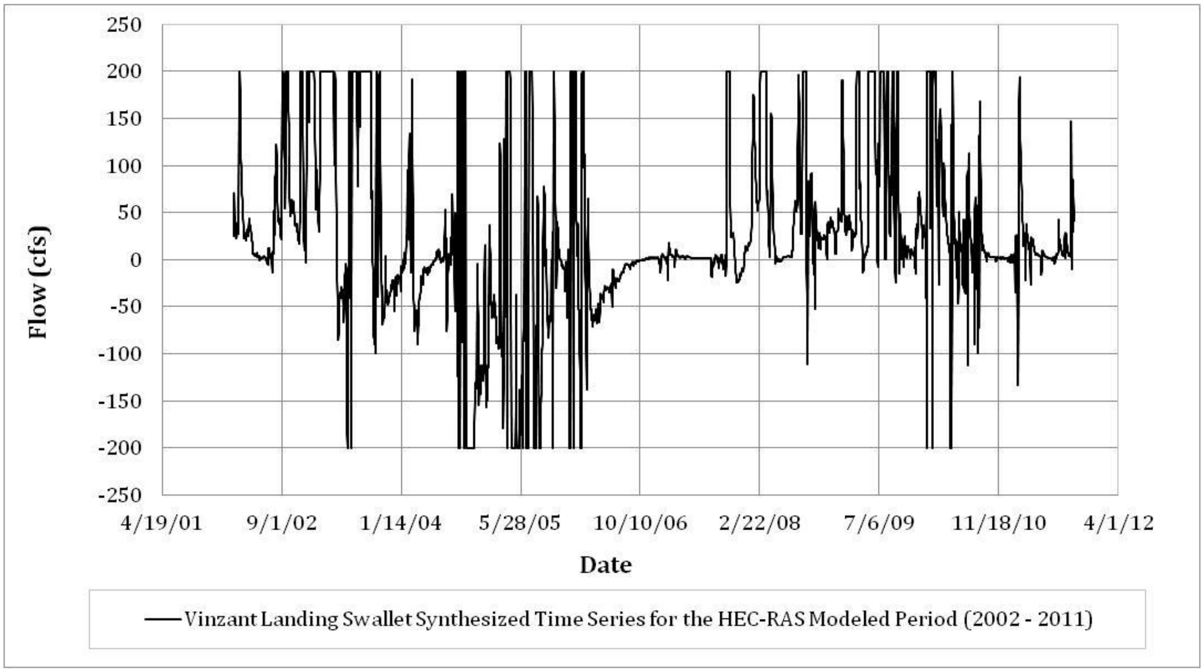

Figure 25. Vinzant Landing Swallet Synthesized Flow Time Series for 2002-2011

Table 13. Vinzant Landing Swallet Flow Loss

Period	Average Flow at Worthington Gauge	Estimated Average Loss into the Vinzant Landing Swallet (cfs)
1/1/1995 - 12/31/1995 (North Florida Model modeled period)	383.7	37.7
2/13/2002 - 9/29/2011 (HEC-RAS modeled period)	273.5	26.9
6/1/2001 - 5/31/2002 (SDII modeled period)	90.1	68.3

Steinhatchee Sink and White Springs

The Steinhatchee Sink well rate was set to the 1995 estimated average discharge at Steinhatchee River near Cross City streamflow gauge (USGS #2324000). USGS (2012) data for the Steinhatchee River near Cross City station states that below about 500 cfs, all flow measured at the gauging station enters the Steinhatchee sink. This information was used when estimating the Steinhatchee sink injection well rate. Based on this USGS remark, the Steinhatchee Sink was represented in the model as the average 1995 flow at the USGS Steinhatchee streamflow station since all of the daily discharge values in 1995 were lower than 500 cfs. White Springs (#WHS010C1), a streamflow siphon on the Suwannee River, was represented as an injection well with a rate of 6.9 cfs into the aquifer (INTERA, 2011a).

O’Leno Sink by the Footbridge

The surface water flux into O’Leno Sink by the Footbridge was represented in the model as an njection well. O’Leno Sink is where the Santa Fe River typically disappears underground only to reemerge at the River Rise. The portion of the river between O’Leno Sink and River Rise is known as the land bridge. O’Leno by the Footbridge gauge is located just upstream of O’Leno Sink. The District monitored O’Leno by the Footbridge streamflow gauge and collected flow measurements from 1997 until 2009.

Most of the time the flow measured at O’Leno by the Footbridge gauge disappears underground at O’Leno Sink and the land bridge portion of the Santa Fe River is not flowing. It is not known how much water is diverted underground at O’Leno Sink and how much stays in the Santa Fe River. When estimating 1995 average O’Leno Sink fixed injection well rate, the assumption was made that flows below 1050 cfs are diverted into O’Leno Sink. This was based on the results of the calibrated HEC-RAS model of the Lower Santa Fe and Ichetucknee Rivers system (INTERA, 2012). The dynamic HEC-RAS model (INTERA, 2012) showed that most of Santa Fe River is diverted underground with the exception of high peak flow events.

O’Leno by the Footbridge flow measurements were provided by the District for the period from October 1, 1997 until September 30, 2009 (“02321898_Discharge.xls”) and were used to estimate the loss into O’Leno Sink. A simple linear regression between O’Leno by the Footbridge flow measurements and the Worthington Springs flow measurements was developed (Figure 26). The relationship was used to estimate a time series at thr O’Leno by the Footbridge gauge for 1995 (Figure 27). The average 1995 flow at the O’Leno by the Footbridge gauge from this estimated time series is the O’Leno Sink loss.

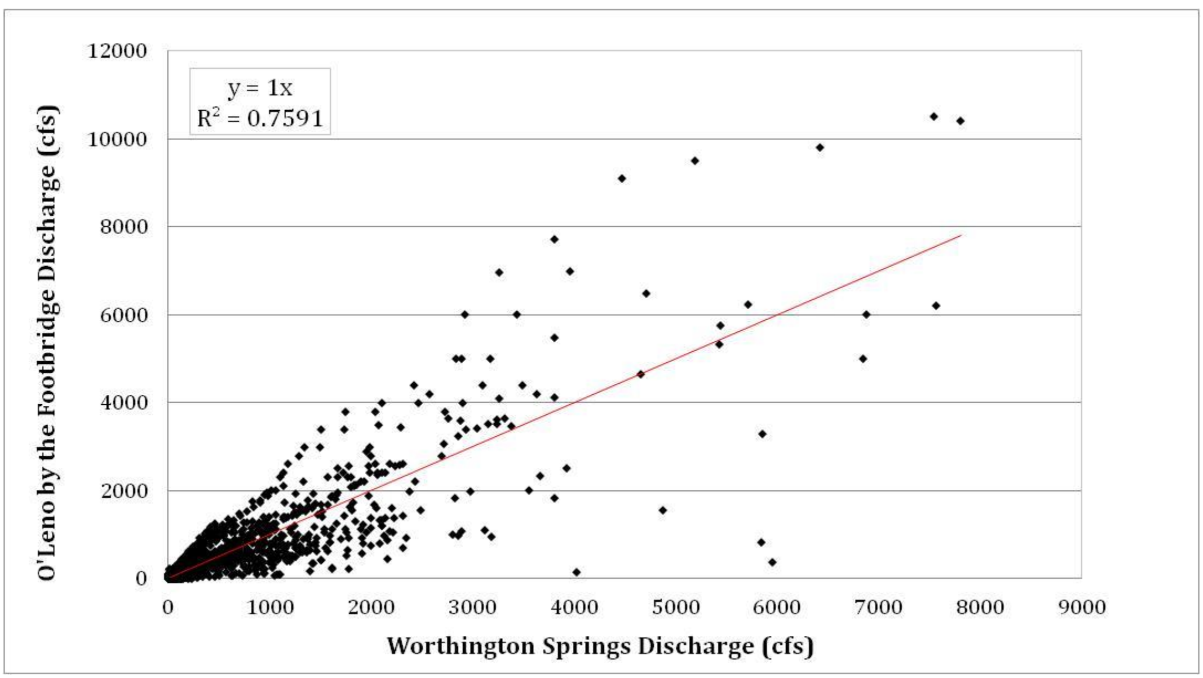

Figure 26. SLR: O’Leno by the Footbridge Discharge vs. Worthington Springs Discharge

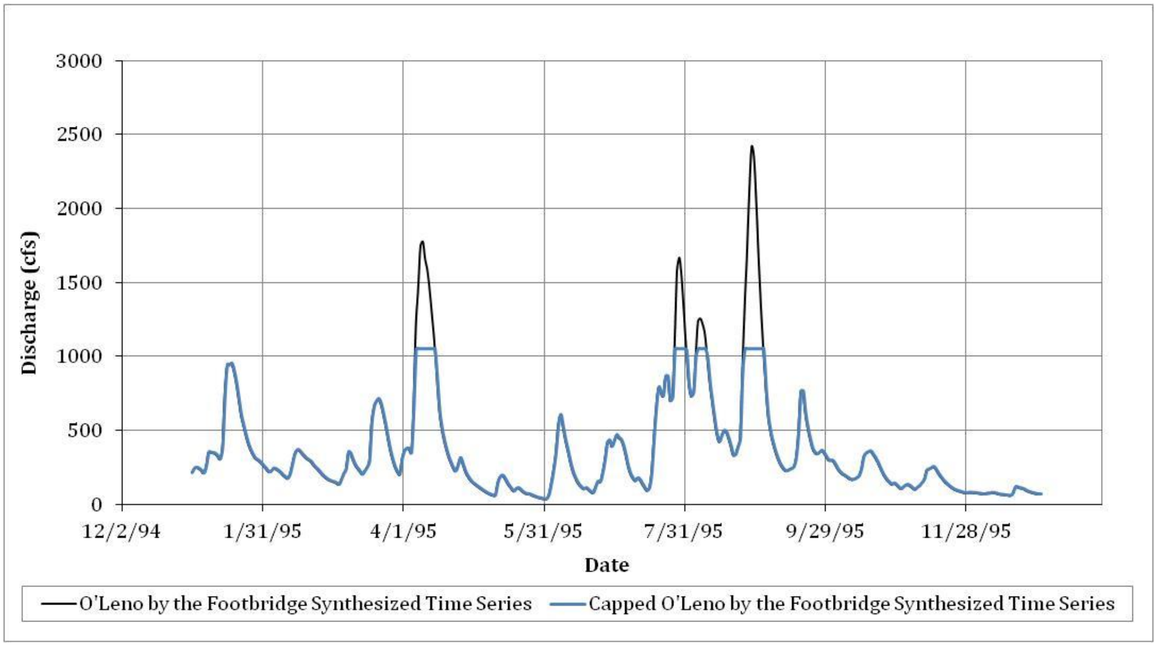

Figure 27. O'Leno by the Footbridge Synthesized Discharge Time Series for 1995

Model Calibration and PEST

Model calibration involves adjusting parameters within reasonable ranges to improve the fit between simulated and measured values. The Version 1 North Florida model was calibrated by modifying recharge, hydraulic conductivities, and river bed conductance to reduce the error in modeled and observed heads and spring and river flow targets. Due to the significant updates made to the original model, the revised model needed to be recalibrated. The goal in the calibration process for the enhanced model was to match head and flux targets as closely as possible, while constraining the model parameters within reasonable ranges. In addition, instances of flooding in the surficial layer were reduced by defining a flooding objective that penalized any heads above the top of surficial model layer.

PEST as a Tool for Calibration

Calibration was performed with assistance from PEST, a model-independent parameter estimation code (Watermark Numerical Computing, 2010). PEST is model independent because it has the capacity to communicate with any code through text based input and output files. PEST can then modify input parameter values and test the outputs "on-the-fly" to pursue an optimal solution.

When using PEST, the modeler assigns an initial value and ranges to adjustable parameters and defines an overall metric by which the calibration is judged. This metric is called the objective function. PEST adjusts the parameter values within their ranges to find the combination that minimizes the objective function. In this case, the objective function consisted of five components – 1) misfit between the simulated and observed heads at observation wells, 2) misfit between simulated and observed vertical head gradients at companion wells (pairs of proximal wells completed in the surficial and the Floridan, respectively), 3) misfit between simulated and estimated/observed springflows, 4) misfit between simulated and estimated/observed base-flow for gauged sections of rivers, and 5) the aggregate of all heads above the top of the surficial layer (excluding water bodies). Adjustable parameters for the updated North Florida model consisted of depth of water above river bed, river bed conductance, recharge, horizontal and vertical conductivities for various layers, as well as stage and conductance of all springs (represented as drains in the model).

Because the estimation process requires multiple forward runs for each optimization iteration (where each iteration will typically improve the fit), PEST has a parallel version that can take advantage of computing clusters, with networked computers or multi-core/multiprocessor systems. During calibration of the updated North Florida model, PEST was run on a 56-node cluster consisting of 28 dual-core machines. The use of the computing cluster allowed simultaneous calibration of over 3,500 parameters.

Using PEST is not a substitute for the guidance of the modeler during calibration. PEST does not consider the plausibility of parameter values (or combinations of parameter values) during parameter estimation. Constraining the parameter ranges, and judging whether the final parameter sets are reasonable is an essential task that is left to the modeler. More than thirty PEST optimization runs were run with different constraints, parameter ranges, and target configurations in order to reach the current calibration. The physical plausibility of the final parameter values and their spatial distributions were carefully considered to ensure that the model was not calibrated with physically-unrealistic parameter values.

Adjustable Parameters

The adjustable parameters are the model parameters that are optimized by PEST. The optimization process adjusts the selected model parameters in an attempt to minimize the error in the defined objective function. Adjustable parameters can be classified into two categories: single value or zone, and pilot points. The single value parameter is simply replaced as PEST iterates to an optimal solution. The pilot points utilize an additional step. The pilot points are optimized individually just as a single value. The additional step takes the many points and generates a continuous surface. Thus, pilot points are instrumental in calibrating spatially continuous and heterogeneous parameters such as recharge and hydraulic conductivity. The parameter types are discussed in more detail in the following sections.

Single Values or Zone Parameters

Both input fluxes and physical properties were adjusted as part of the calibration. The parameters that were adjusted are shown in Table 16, along with their ranges and a short description. The "PEST Name" refers to the name of the parameter in the PEST input files.

Pilot Points

The last six rows in Table 16 describe the parameter types where pilot points were used to calibrate the spatial distribution of the parameters. These include recharge, horizontal and vertical conductivity for layers 1 (surficial and intermediate system), horizontal conductivity and (horizontal-to-vertical) anisotropy for layer 2 (upper Floridan), vertical conductivity of layer 3 (middle confining unit), and horizontal conductivity of layer 4 (lower Floridan). Note that the layer numbering for the parameter follows the original 5 layer terminology described in the Stratigraphy section of the report.

In the pilot point approach, values are assigned to a series of points (typically regularly spaced) covering a region. These points are then interpolated (by kriging) to produce a continuous field. The interpolation typically produces a smooth distribution across the region. For each optimization iteration, PEST assigns new values to all of the pilot points and the field is re-interpolated, until an optimal interpolated field is produced. During the calibration process, spatial distributions of recharge and conductivities (between layers 1-2 and layers 2-3) were adjusted using the pilot point approach. Because almost 3000 pilot points were required for all the distributed parameters, the use of pilot points increases the computational burden significantly. However, the pilot point approach was necessary for these parameters to maintain a good head calibration, while approximately fitting the more local target fluxes in the streams and springs. Use of the pilot point approach also made it possible to use head and flux targets to more effectively and objectively represent spatial variability in model parameters. Figure 28 shows the locations of the pilot points that were used for these parameters. 294 coincident pilot points (shown as black points on Figure 28) uniformly distributed at every 20th model grid center were used for recharge, layer 1 horizontal and vertical conductivities, layer 2 anisotropy, layer 3 vertical conductivities, and layer 4 horizontal conductivity. A higher resolution – every 10th model grid center - of pilot points (shown as green points on Figure 28) was used for the horizontal conductivity of the upper Floridan (layer 2) leading to a total of 1182 pilot points for this parameter field.

Note that the pilot points were used as multipliers on prior defined recharge and conductivity distributions. The prior field for recharge was developed from the average precipitation map for the year 1995 using the PRISM dataset. Prior distributions for conductivities of layers 1, 3, and 4 were set to a uniform value equal to the average conductivity of the layer from the original North Florida model. For layer 2, the prior horizontal conductivity was set to the original hydraulic conductivity field, with an anisotropy factor of 0.3. The prior for the Floridan conductivity was modified in the area of the Waccassassa Flats to reflect hydrogeologic knowledge in that area. This was done based on recommendations made by District hydrogeologists, and is consistent with Grubbs (2011).

Table 14. Adjustable parameters for the PEST-aided calibration. Minimum and maximum refer to allowable range for PEST during optimization.

PEST Name	Description	Min	Max
rdwbmult(1-30)	Multipliers for depth of water above river bed for Strahler orders 1 – 30 (only orders 1-6 and 9 were adjusted, while others were kept fixed)	0.5	4.0
rkv(1-30)	Streambed conductance for streams of Strahler orders 1-30 (orders 7 and 8 were kept fixed)	variable*	variable *
kh_ratio	Overall multiplier for horizontal conductivity (for Layers 1, 2, 3, and 4)	0.1	10
kv_ratio	Overall multiplier for vertical hydraulic conductivity (for Layers 1, 2, and 3)	0.001	10
kani1	vertical anisotropy factor for Layer 1, used where intermediate system is absent)	0.1	1
d_e_	Spring elevation (feet above mean sea level)	variable*	variable*
d_k_	Spring conductance (feet^2/day)	variable*	variable*
rch_	Recharge pilot point multiplier values – total of 294	0.01	1.99
kh1_	Horizontal hydraulic conductivity pilot point multiplier values for Layer 1 – total of 294	0.01	100
kv2_	Vertical hydraulic conductivity pilot point multiplier values for Layer 1 – total of 294	0.01	100
kh3_	Horizontal hydraulic conductivity pilot point multiplier values for Layer 2 – total of 1182	0.01	300
kv3_	Vertical anisotropy pilot point multiplier values for Layer 2 – total of 294	0.001	1
kv4_	Vertical hydraulic conductivity pilot point multiplier values for Layer 3 – total of 294	0.01	100
kh5_	Horizontal hydraulic conductivity pilot point multiplier values for Layer 4 – total of 294	0.01	100

*Ranges were specific to the respective Strahler order or Spring

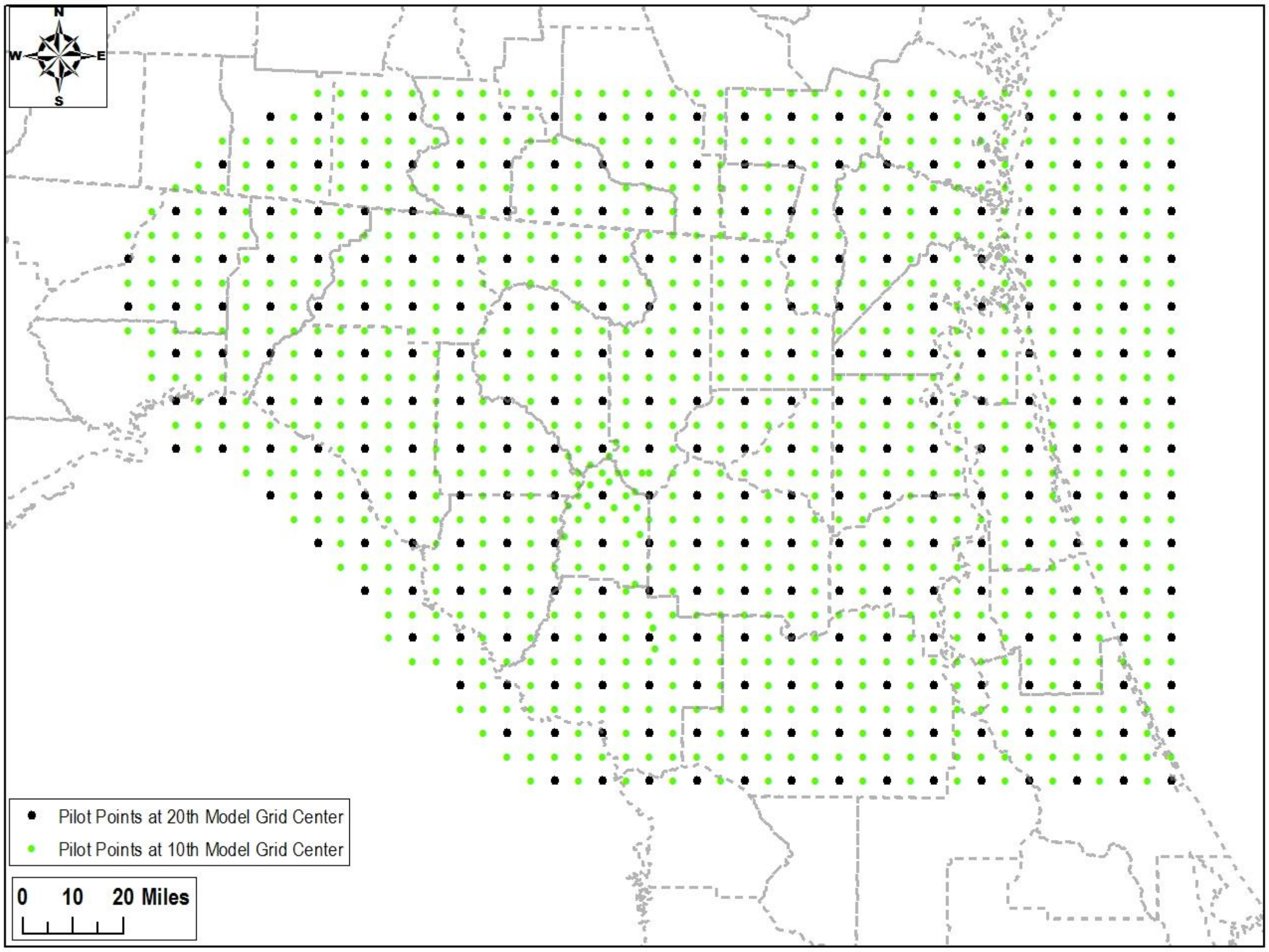

Figure 28. Pilot Points

Additional Target Constraints

As described earlier, water levels measured in wells completed in the various aquifers were used to develop head targets, and average baseflow values (obtained through baseflow separation) were utilized to constrain and help define the river cell parameters. In addition to the observed targets, soft targets were also defined to provide information to guide the calibration in some areas (such as within the NEF model domain) of the model that were poorly constrained because of an insufficient density of observed data. Other soft targets were introduced globally to constrain the parameter estimation to realistic or reasonable results. These soft targets included water above land, various lake levels as an indication of surficial aquifer head, and depth to water.

Flooded cells

The original calibrated model had a significant number of flooded cells, where the water table was 5 or more feet above ground surface. During the PEST optimization, parameter combinations that resulted in flooded cells were quantitatively penalized. To this end, the model domain was divided into 294 zones each measuring 20 x 20 model grids blocks. A post-processing script was written to sum the total feet of head above ground surface for each zone. Targets (with ideal flooding equal to zero) were included in the PEST calibration framework to minimize flooding across the model domain. The weight assigned to these flooding targets was scaled to keep the magnitude similar to other parts of the objective function.

Depth to Water

In general, the water table is conceptualized to be relatively close to land surface in the region simulated by the NF. In some local areas, the water table was simulated to be too far below ground surface. To reduce the extent of the areas with large depths, a similar approach as one for minimizing flooding was used. A post-processing script was used to calculate the total feet of water below 50 feet of the ground surface for each of the 294 zones defined above. Targets were included to minimize the amount of water below 50 feet of ground surface. Similar to the flooding targets, weights for the depth to water targets were adjusted to keep this objective commensurate with other parts of the calibration objective function.

Soft Head Targets

In some areas of the model, direct measurements of head were not available, but secondary information about the approximate water level based on surface water body levels was available. For these cases, "soft targets" were utilized in order to encourage PEST to choose parameter combinations that resulted in similar water levels. These soft targets were treated similarly to actual head measurements as part of the objective function, but were not included in calculation of calibration statistics.

Calibration Results

As mentioned earlier, the model was calibrated to average 1995 hydrologic conditions using the constraints provided by the available data. This included estimated baseflow and springflow fluxes as a flux constraint and aquifer levels as a head constraint. The depth to water table and the flooded cells were also examined as a head constraint for the surficial aquifer. Overall head statistics are shown in Table 17. Residuals for each target were calculated as the observed value minus the simulated value. As shown in the table, the overall residual mean of the model was -0.77 feet, indicating little bias in the model. The mean residuals of layers 1 (surficial aquifer) and 2 (Upper Floridan aquifer), indicate, on average, only a slight overestimation of head. Final surficial aquifer and Upper Floridan aquifer heads were also examined and shown in Figures 29-30.

Table 15. Overall Calibration Statistics

Category	Mean Residual	Root-Mean-Square-Error RMSE
Head Difference (ft)	0.22	2.99
Head Surficial (ft)	-0.79	7.43
Head Floridan (ft)	-0.90	4.07
Head All Layers (ft)	-0.88	4.90
Baseflow (CFS)	1.60	6.60
Springflow (CFS)	3.16	7.92

Aquifer Head Comparison

After calibration, the model results were post-processed and analyzed. Final simulated values of heads for the surficial aquifer system (SAS or layer 1) and Upper Floridan aquifer (UFA or layer 2) are shown in Figures 29-30, respectively.

Figure 30 shows final Upper Floridan aquifer (UFA) simulated heads and contours of the potentiometric surfaces of the Upper Floridan aquifer in 1995. A comparison of the 1995 potentiometric contours and UFA heads indicate that calibrated heads are in general agreement with the contours (Figure 30).

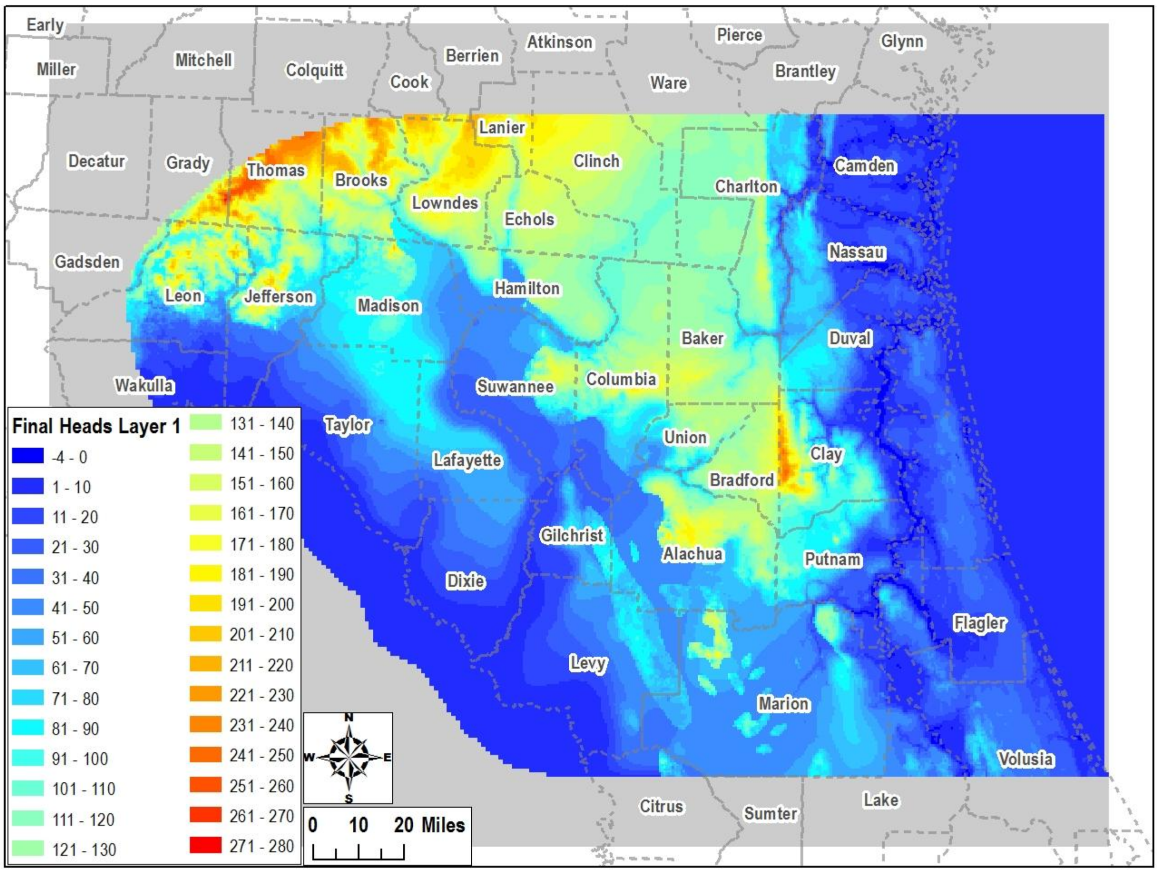

Figure 29. Layer 1 Final Heads

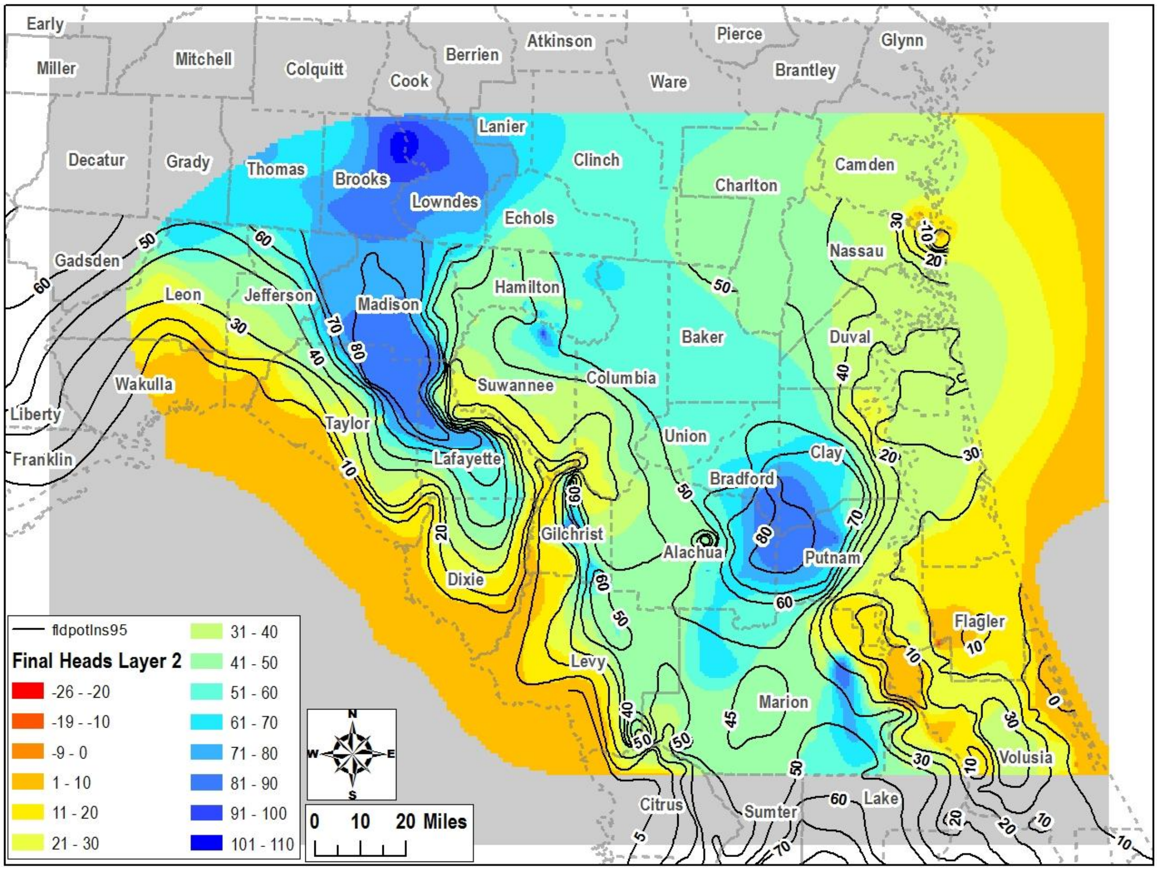

Figure 30. Layer 2 Final Heads and 1995 Upper Floridan Aquifer Contours

Version 1 of the North Florida model had a significant number of flooded cells, where the water table was above ground surface. During the PEST optimization, the goal was to ultimately limit the number of flooded cells by decreasing recharge and/or increasing hydraulic conductivities while staying true to calibration targets. Parameter combinations that resulted in flooded cells were quantitatively penalized. The final calibrated model of North Florida has a minimum number of flooded cells and the water table does not exceed 5 feet above ground surface (Figure 31).

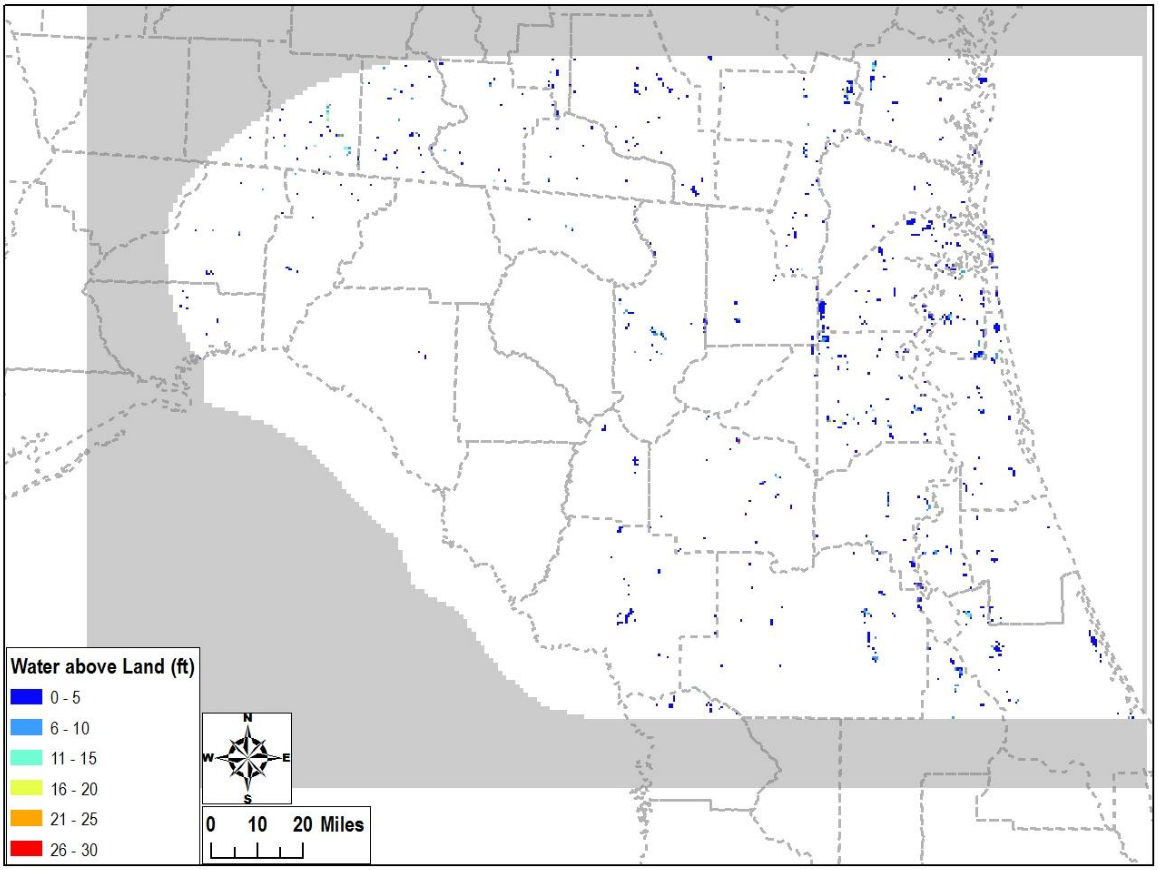

Figure 31. Water above Land (ft)

Target Statistics

Target statistics were calculated and examined for both head and flux targets. Target statistics were calculated and examined for surficial aquifer system, Upper Floridan Aquifer, and Lower Floridan Aquifer. Head targets included measured aquifer head elevations at wells. Flux targets consisted of both baseflow and springflow targets within the model domain. For each type of target, scatter plots were constructed in order to look for outliers and overall model bias. Summary statistics for each type of target were also calculated. A graphical representation of final head residuals and tabulated frequencies is also provided.

During calibration, different weights were assigned to head targets. Higher weights were applied to head and head difference targets with a higher number of observations. Since surficial targets were relatively sparse and clustered across the model domain, the weights for surficial targets also reflected the relative density of observation points. Lower weights were given to surficial aquifer observation wells with nearby wells and higher weights were given to surficial aquifer wells in isolated regions. This was done to ensure that heads remain constrained to the observed data in areas with few surficial targets.

Overall Head Statistics

Residuals for each target were calculated as the observed value minus the simulated value in order to be consistent with the convention adopted in Groundwater Vistas and PEST. Thus, a positive residual indicates an underestimation of head, and a negative value indicates overestimation of head.

The recalibrated North Florida model shows improvement in the residual standard deviation, the root mean squared error (RMSE), the sum of squares, and the absolute mean residual (Table 18).

Table 16. Overall Head Target Statistics: Recalibrated and Version 1 Model (make sure matches final values)

Statistics	Recalibrated Model	Version 1 Model (nfm_v1.02.gwv)
Residual Mean	-0.88	-0.48
Res. Std. Dev.	4.82	7.54
Residual Sum of Squares	14708.71	44152.27
RMSE	4.90	7.55
Min. Residual	-48.94	-32.96
Max. Residual	15.86	36.72
Number of Observations	612.00	774.00
Absolute Residual Mean	3.13	5.00

Aquifer Head Targets

Individual residuals for all targets are shown by layer in Figures 34, 37, and 38. Both negative residuals, representing overestimation of head, and positive residuals, representing underestimation of head, are shown. As shown, layer 2, representing upper Floridan aquifer, has the most spatially extensive set of targets. Layers 1, representing surficial aquifer system, and 4, lower Floridan aquifer, had a limited number of targets. Scatter plots of aquifer head targets by layer are shown in Figures 33 and 36. Histograms of final head residuals by layer are shown in Figures 32 and 35.

Table 17. Head Target Statistics: Layer 1

Residual Mean	-0.79
Res. Std. Dev.	7.39
Sum of Squares	6522.26
RMS Error	7.43
Min. Residual	-48.94
Max. Residual	15.85
Number of Observations	118
Absolute Residual Mean	4.54

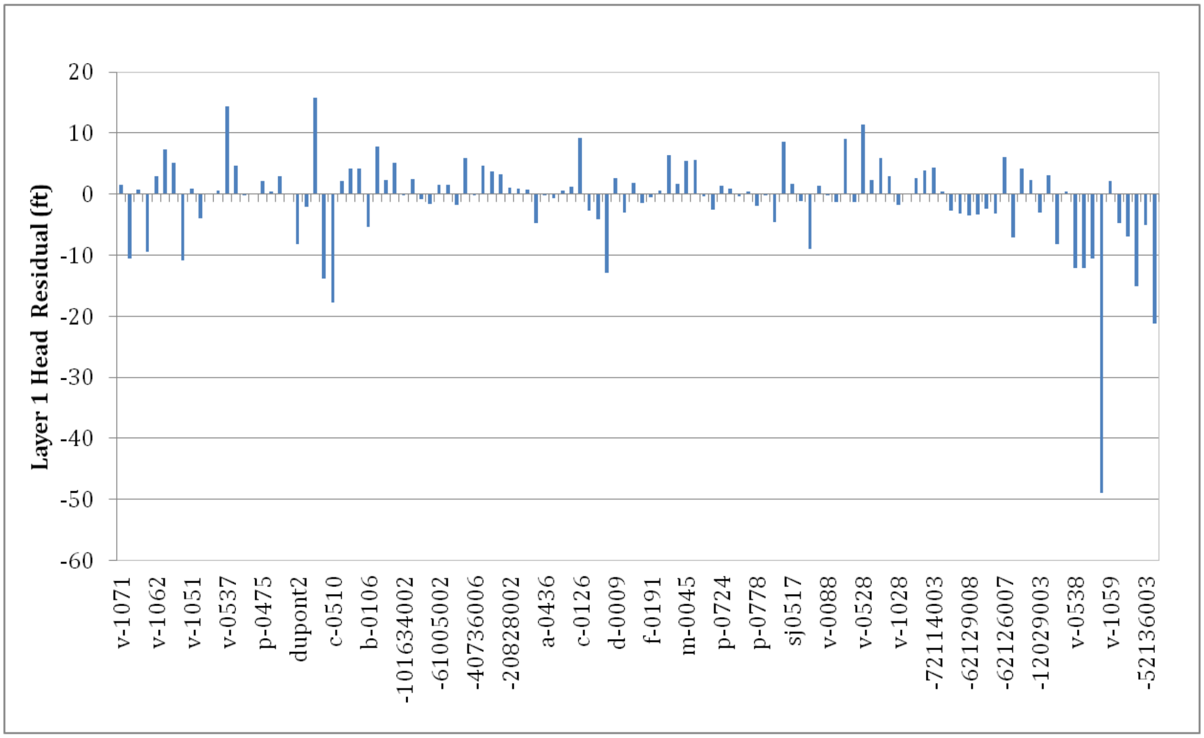

Figure 32. Layer 1 Head Residuals

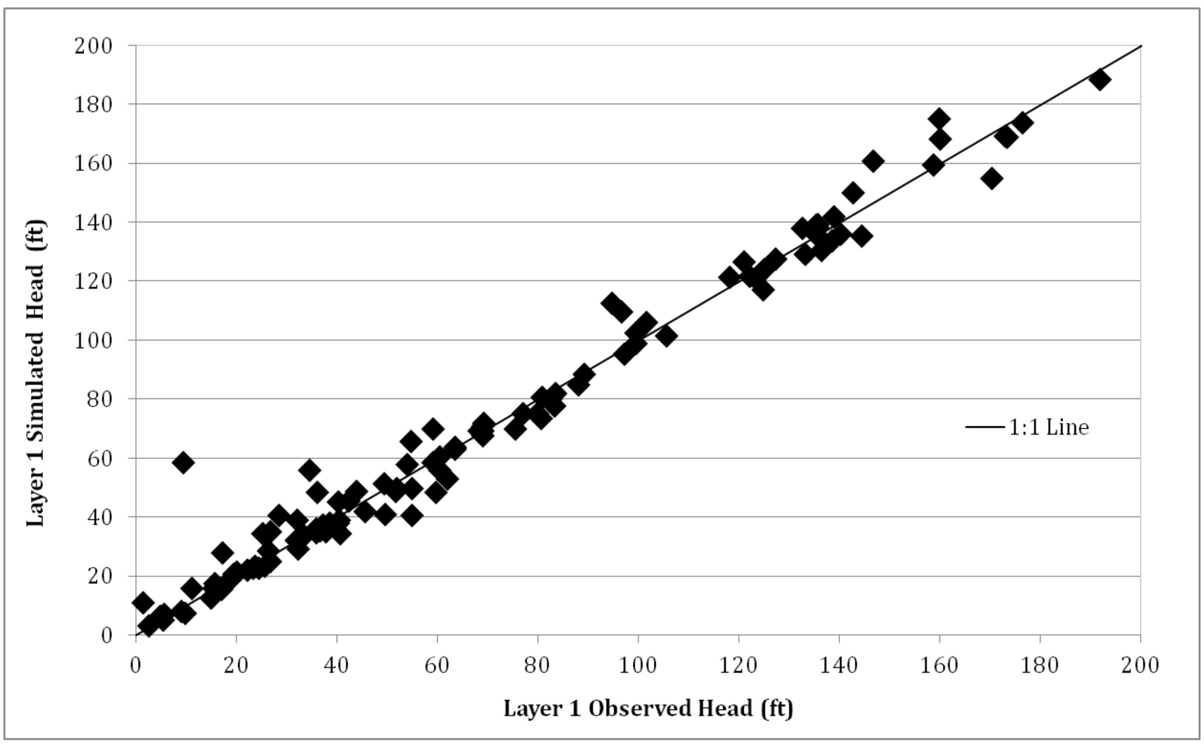

Figure 33. Aquifer Head Statistics: Layer 1

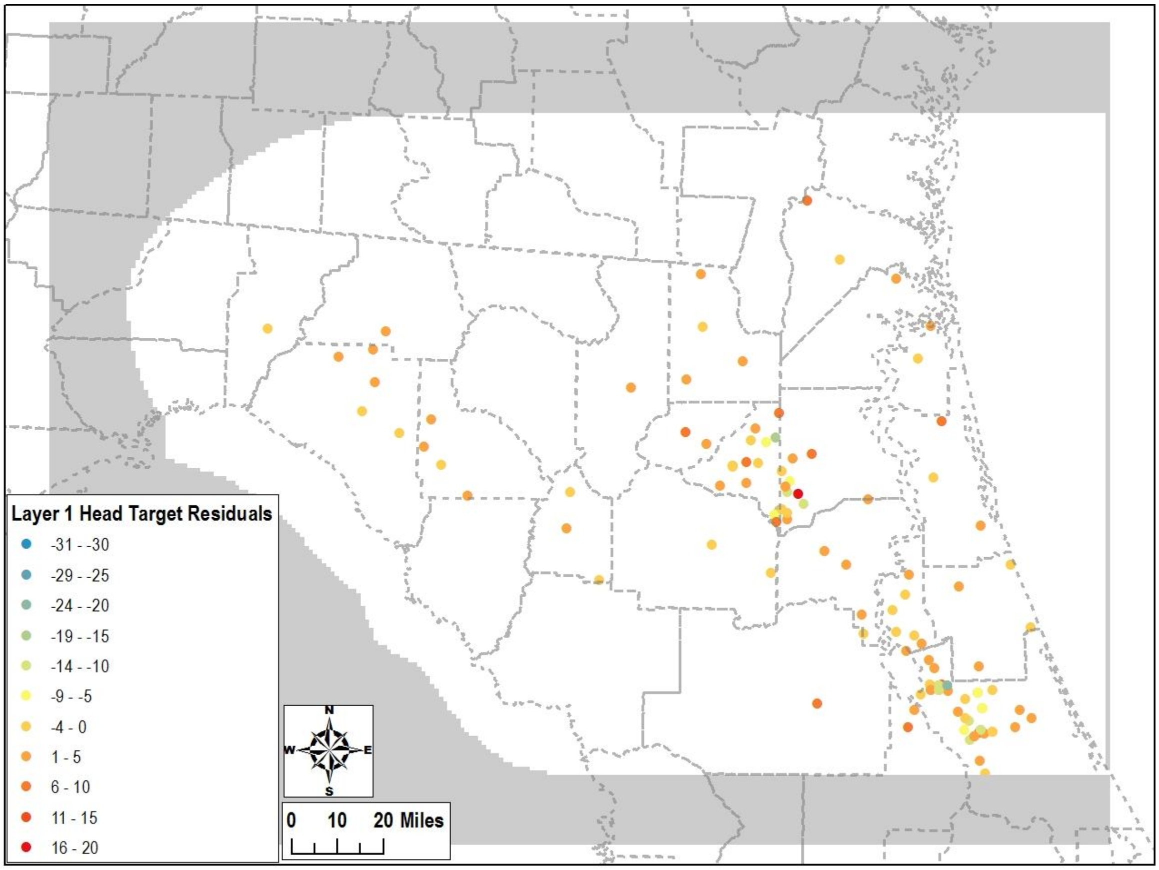

Figure 34. Layer 1 Head Target Residuals

Table 18. Head Target Statistics: Layer 2

Residual Mean	-0.95
Res. Std. Dev.	3.98
Sum of Squares	8133.27
RMS Error	4.09
Min. Residual	-23.60
Max. Residual	15.86
Number of Observations	487
Absolute Residual Mean	2.80

Table 19. Head Target Statistics: Layer 4

Residual Mean	2.41
Res. Std. Dev.	1.33
Sum of Squares	53.19
RMS Error	2.76
Min. Residual	0.63
Max. Residual	3.99
Number of Observations	7
Absolute Residual Mean	2.41

Table 20. Head Target Statistics: Layer 2 and 4 (Combined)

Residual Mean	-0.90
Res. Std. Dev.	3.97
Sum of Squares	8186.46
RMS Error	4.07
Min. Residual	-23.60
Max. Residual	15.86
Number of Observations	494
Absolute Residual Mean	2.79

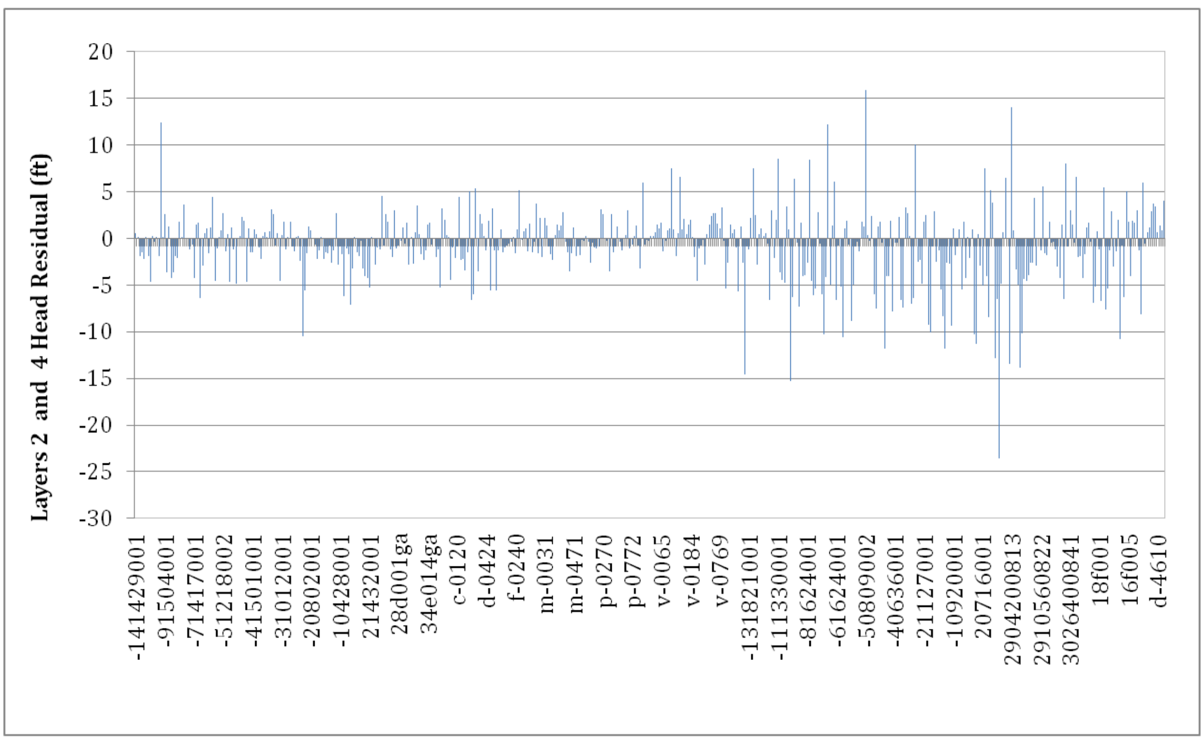

Figure 35. Layers 2 and 4 Head Residuals

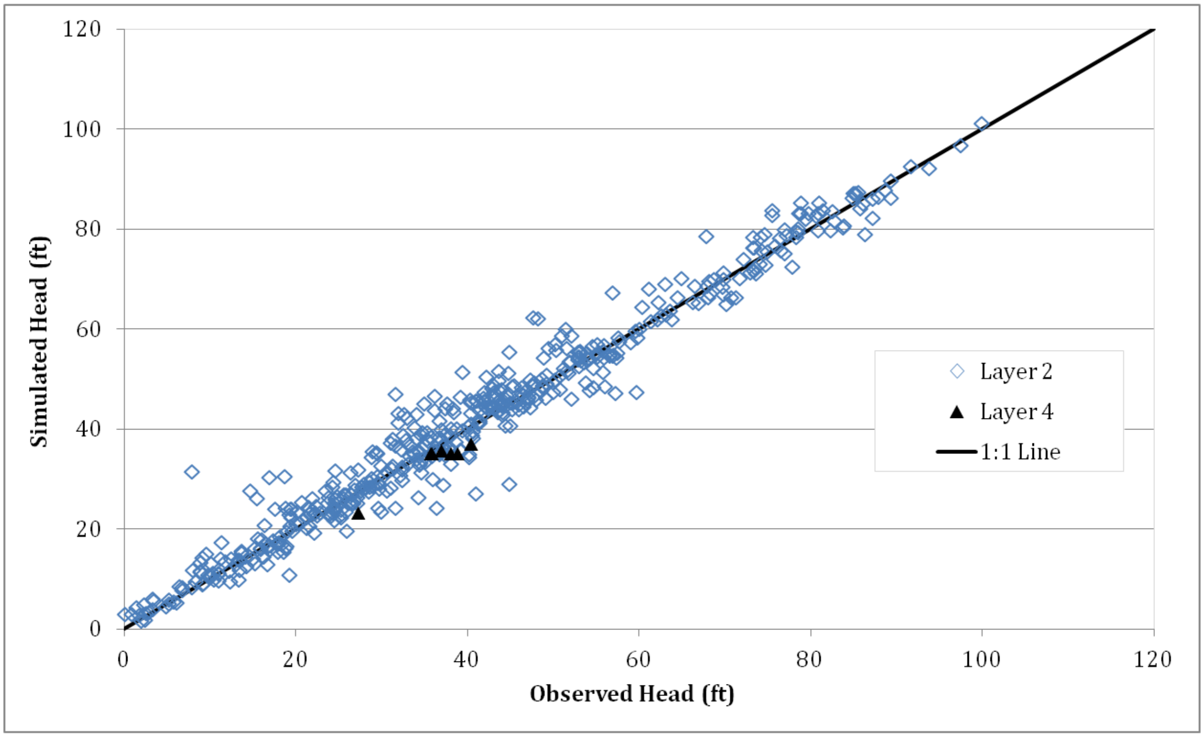

Figure 36. Aquifer Head Statistics: Layers 2 and 4

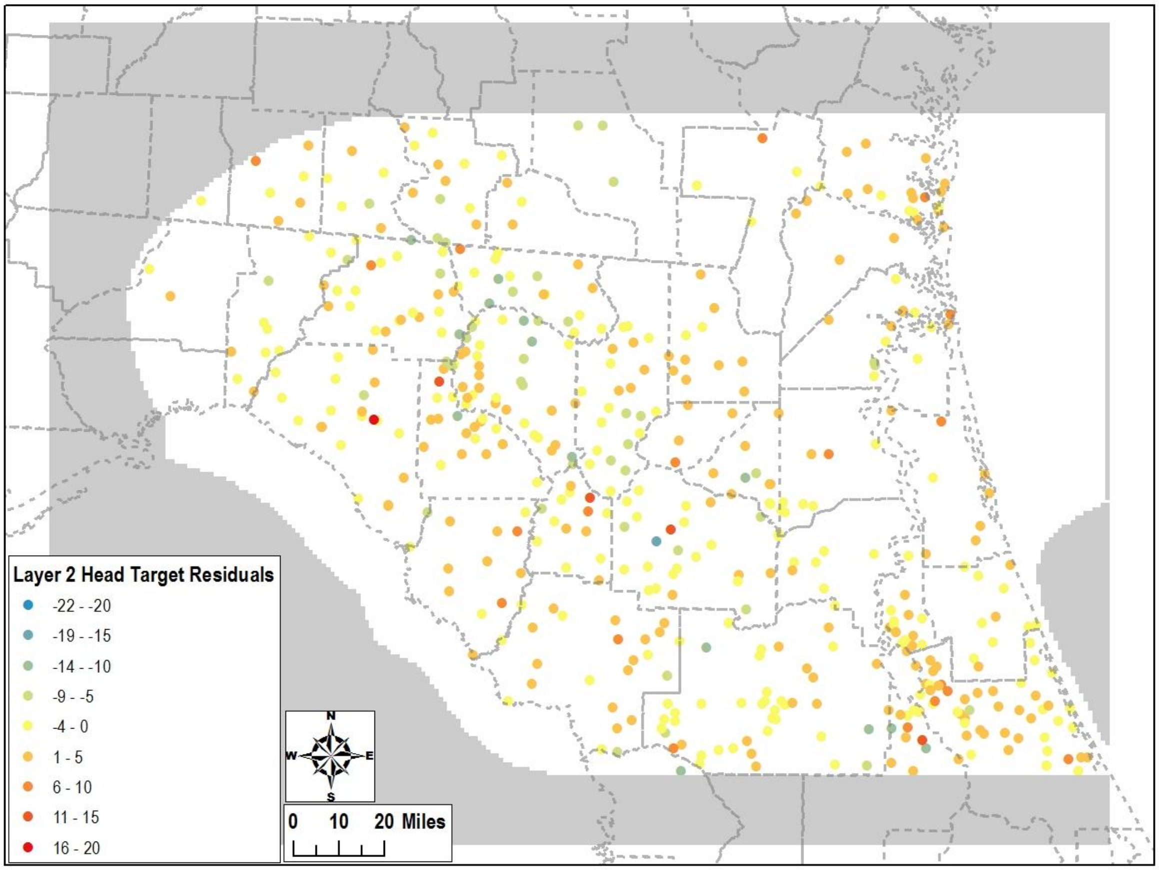

Figure 37. Layer 2 Head Target Residuals

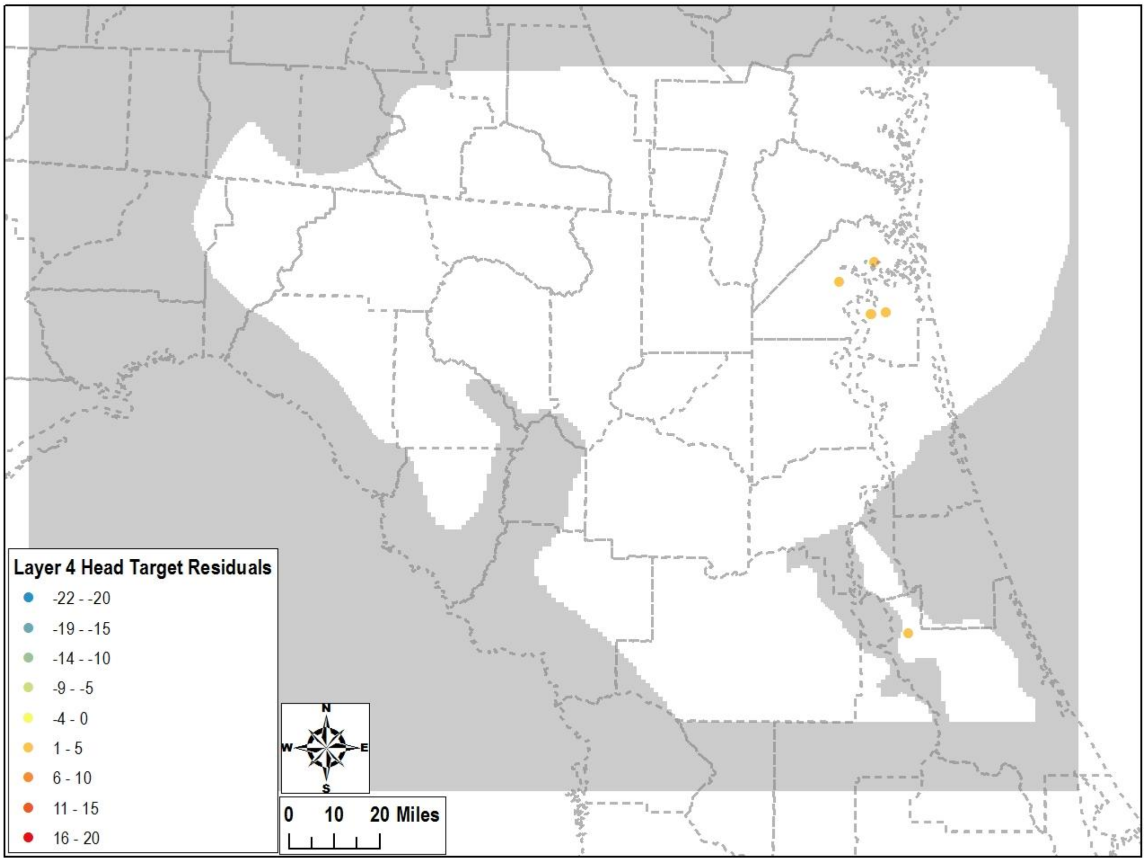

Figure 38. Layer 4 Head Target Residuals

Companion Wells/Head Difference Statistics

The purpose of companion wells was to ensure that the head gradient between aquifers was maintained. A histogram of the residuals, a scatter plot, and general target statistics are provided below (Figures 41 and 42; Table 23). Residuals of head differences between surficial aquifer system wells and companion Upper Floridan aquifer wells are shown in Figure 39. Residuals of head differences between Lower Floridan aquifer wells and Upper Floridan aquifer companion wells are shown in Figure 40.

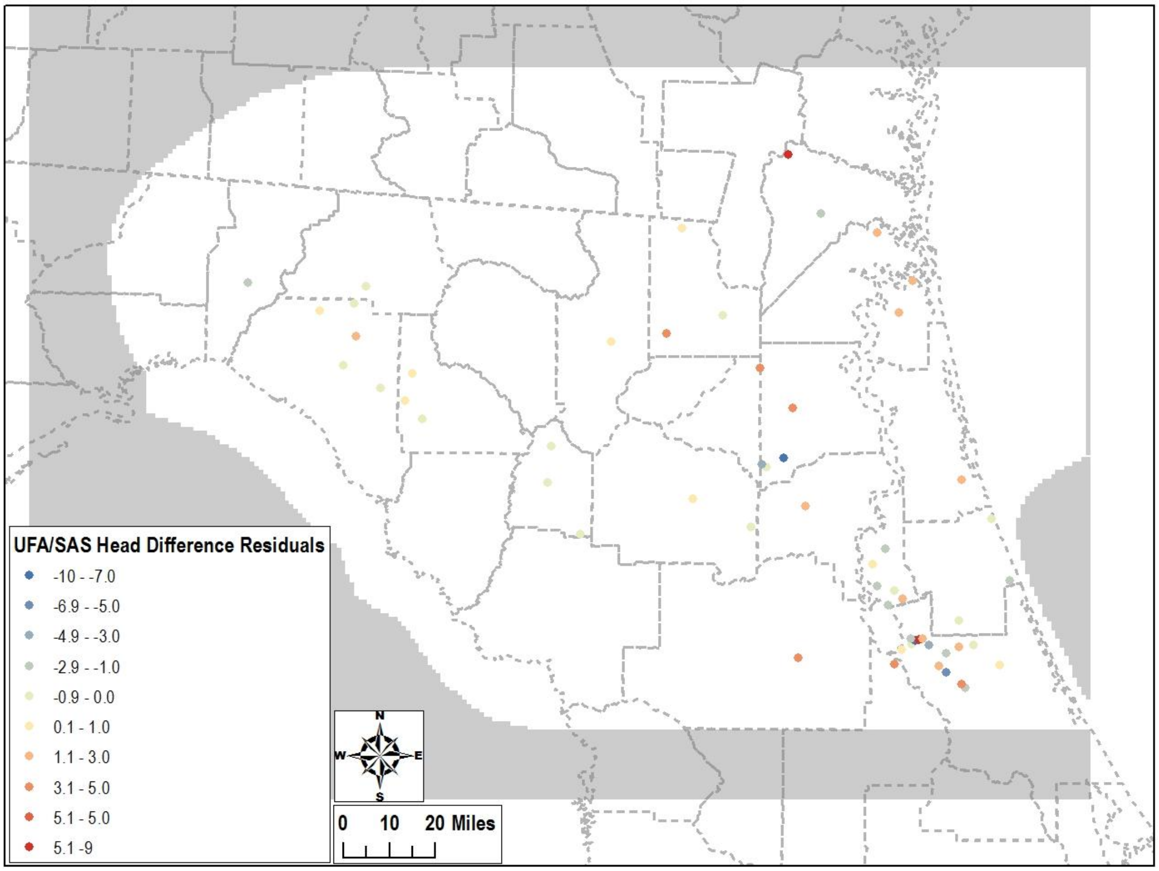

Figure 39. Surficial Aquifer System Companion Wells to Upper Floridan Aquifer Wells

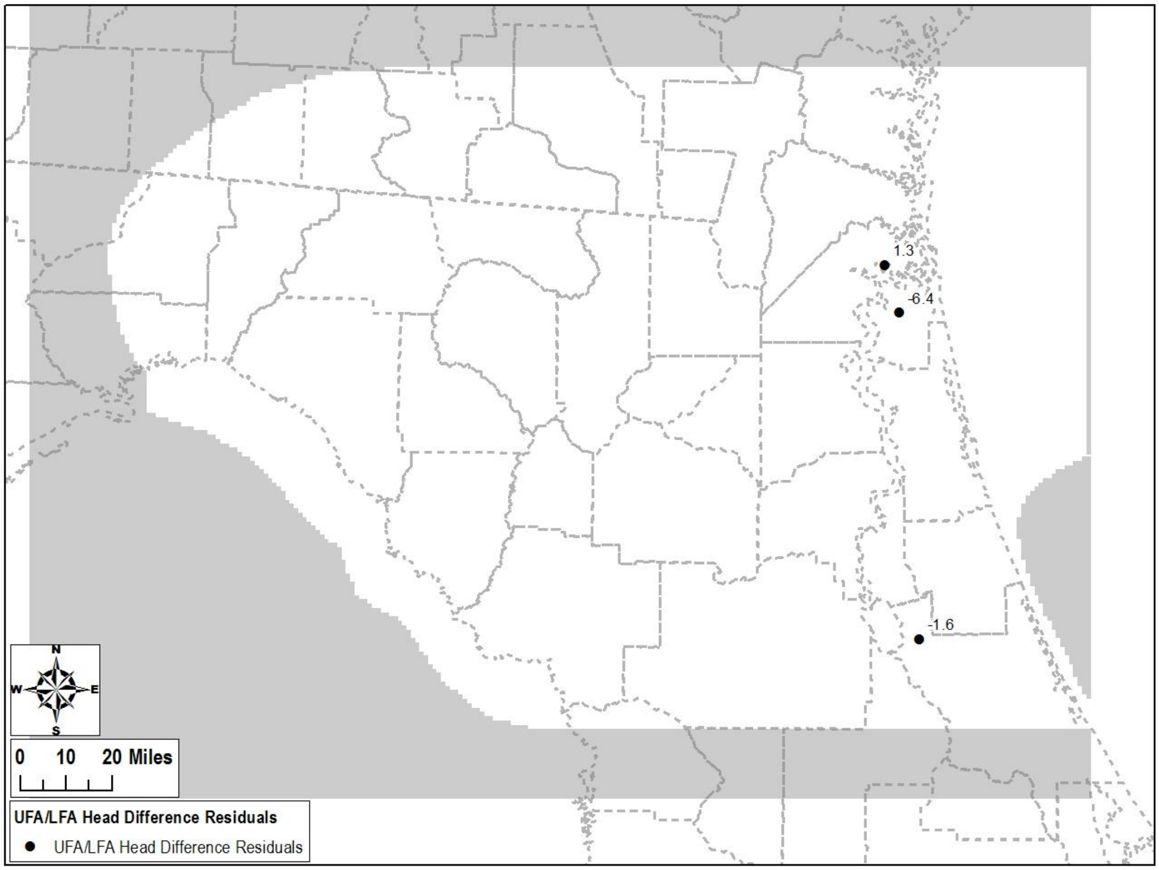

Figure 40. Lower Floridan Aquifer Companion Wells to Upper Floridan Aquifer Wells

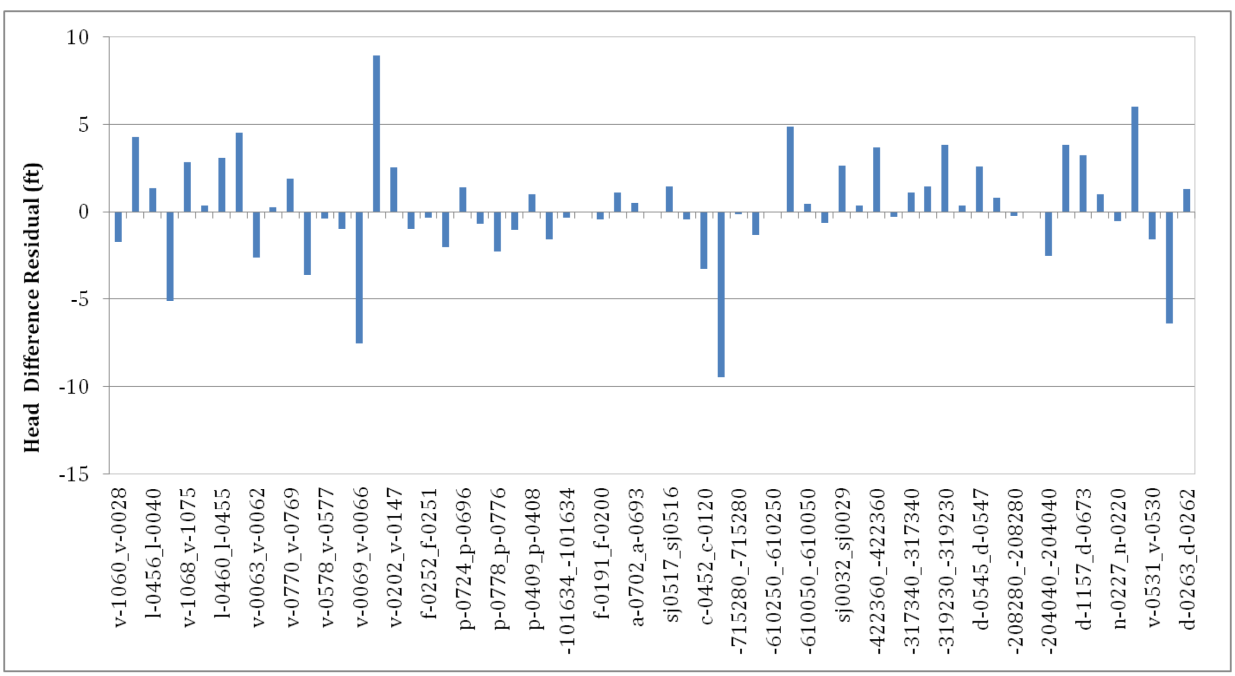

Figure 41. Head Difference Residuals (Companion Wells)

Table 21. Target Statistics: Head Difference (Companion Wells)

Residual Mean	0.22
Res. Std. Dev.	2.98
Sum of Squares	562.94
RMS Error	2.99
Min. Residual	-9.47
Max. Residual	8.94
Number of Observations	63
Absolute Residual Mean	2.09

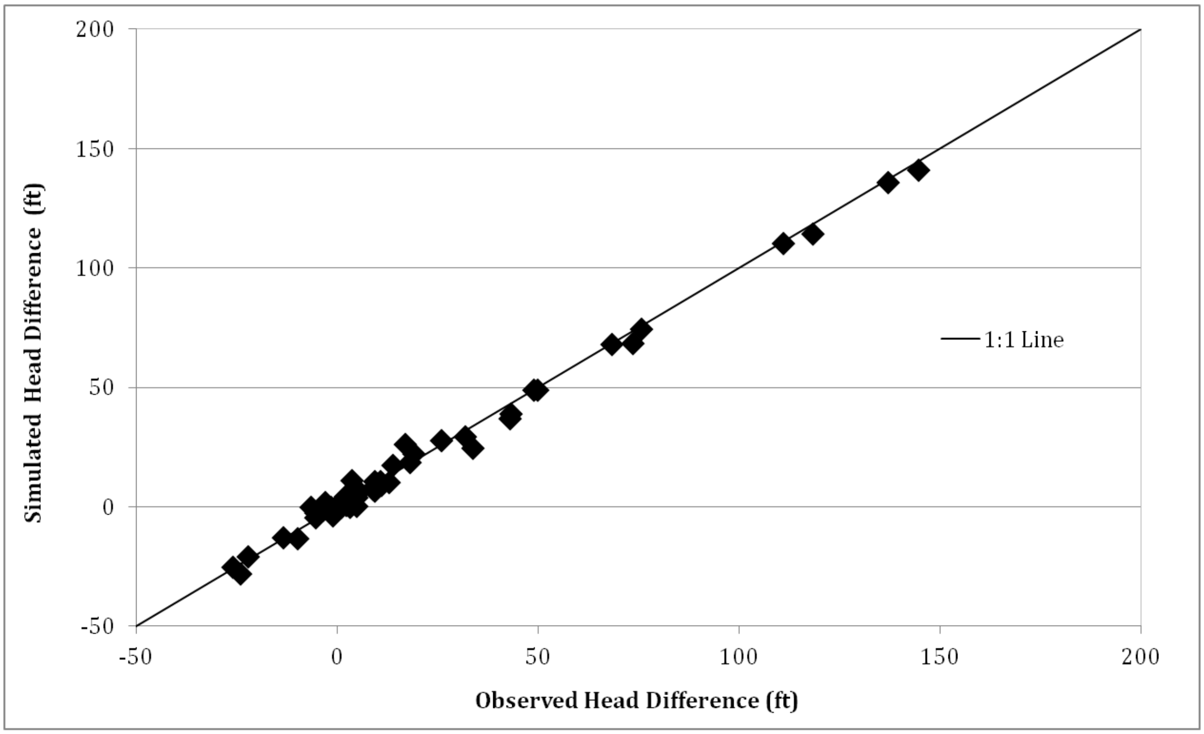

Figure 42. Aquifer Head Statistics: Head Difference

Baseflow

Baseflow residuals are shown by reach in table 24, and summarized in figures 43 and 44. As shown, the overall fit of the baseflows period demonstrates high regression coefficients and slopes close to 1.0, indicating little bias in baseflow simulation. The average baseflow residual is 1.6 indicating that overall, the model underestimates baseflow by 1.6 cfs. Figure 43 indicates that the absolute value of the majority of the residuals is less than 5 cfs.

Table 22. Calibrated Baseflow Fluxes by Reach

Name	Reach ID	USGS Station Number at Downstream End of Reach	USGS Station Name at Downstream End of Reach	Simulated Baseflow, cfs	Target Baseflow, cfs	Residual (Observed - Simulated) , cfs
bf4	4	2319500	SUWANNEE RIVER AT ELLAVILLE	1669.38	1670.61	1.23
bf5	5	2231268	ALLIGATOR CREEK AT CALLAHAN, FL	3.59	0.83	-2.76
bf6	6	2231280	THOMAS CREEK NEAR CRAWFORD, FL	1.40	3.84	2.44
bf7	7	2246520	STRAWBERRY CREEK NEAR ARLINGTON, FL	1.35	3.29	1.94
bf8	8	2246515	POTTSBURG CREEK NR SOUTH JACKSONVILLE, FLA	4.54	8.77	4.23
bf9	9	2246300	ORTEGA RIVER AT JACKSONVILLE, FL	8.45	5.45	-3.00
bf10	10	2324000	STEINHATCHEE RIVER NEAR CROSS CITY	16.40	19.52	3.12
bf11	11	2321000	NEW RIVER NEAR LAKE BUTLER	12.66	14.06	1.40
bf12	12	2321500	SANTA FE RIVER AT WORTHINGTON SPRINGS	42.06	42.08	0.02
bf13	13	2321900	PARENERS BRANCH NEAR BLAND	-10.50	0.23	10.73
bf15	15	2322500	SANTA FE RIVER NEAR FT WHITE	879.20	869.02	-10.18
bf17	17	2315200	DEEP CREEK NEAR SUWANNEE VALLEY	1.72	3.50	1.78
bf18	18	2315500	SUWANNEE RIVER AT WHITE SPRINGS AT US 41	49.17	49.99	0.82
bf19	19	2315000	SUWANNEE RIVER NEAR BENTON	49.50	49.24	-0.26
bf20	20	2246828	PABLO CREEK AT JACKSONVILLE, FL	1.87	10.50	8.63
bf21	21	2246150	BIG DAVIS CREEK AT BAYARD, FL	3.36	3.07	-0.29
bf32	32	2320500	SUWANNEE RIVER AT BRANFORD	889.02	893.93	4.91
bf33	33	2315550	SUWANNEE RIVER AT SUWANNEE SPRINGS	101.35	105.97	4.62
bf34	34	2228500	NORTH PRONG ST. MARYS RIVER AT MONIAC, GA	7.63	12.93	5.30
bf35	35	2229000	MIDDLE PRONG ST MARYS RIVER AT TAYLOR, FL	1.79	4.40	2.61
bf36	36	2231000	ST. MARYS RIVER NEAR MACCLENNY, FL	61.06	60.92	-0.14
bf37	37	2244473	RICE CREEK NEAR SPRINGSIDE	5.49	8.52	3.03
bf38	38	2323500	SUWANNEE RIVER NEAR WILCOX	684.32	659.64	-24.68
bf39	39	2246000	NORTH FORK BLACK CREEK NEAR MIDDLEBURG, FL	38.74	60.05	21.31
bf47	47	2242451	ORANGE LAKE OUTLET NEAR CITRA, FL	3.78	3.27	-0.51
bf48	48	2243000	ORANGE CREEK AT ORANGE SPRINGS, FL	13.38	12.80	-0.58
bf49	49	2246359	CEDAR RIVER AT MARIETTA, FL	5.25	6.76	1.51
bf51	51	2245500	SOUTH FORK BLACK CREEK NEAR PENNEY FARMS, FL	37.32	39.97	2.65
bf52	52	2245140	SIMMS CREEK NEAR BARDIN, FL	8.04	16.60	8.56
bf55	55	2244320	MIDDLE HAW CREEK NR KORONA, FLA.	1.22	2.91	1.69
bf56	56	2244420	LITTLE HAW CREEK NEAR SEVILLE, FL	-0.17	7.15	7.32
bf58	58	2245255	DEEP CREEK NEAR HASTINGS, FL	0.16	1.06	0.90
bf59	59	2245260	DEEP CREEK AT SPUDS, FL	3.10	2.71	-0.39
bf61	61	2320700	SANTA FE RIVER NEAR GRAHAM	1.59	11.38	9.79
bf501	501	2324500	FENHOLLOWAY RIVER AT FOLEY AT US 19	52.77	56.34	3.57
bf502	502	2325000	FENHOLLOWAY RIVER NEAR PERRY	36.02	36.21	0.19

Name	Reach ID	USGS Station Number at Downstream End of Reach	USGS Station Name at Downstream End of Reach	Simulated Baseflow, cfs	Target Baseflow, cfs	Residual (Observed - Simulated) , cfs
bf503	503	2326000	ECONFINA RIVER NEAR PERRY	29.63	30.83	1.20
bf505	505	2324400	FENHOLLOWAY RIVER NEAR FOLEY AT US 27	4.84	4.10	-0.74
bf506	506	2326512	AUCILLA RIVER NR SCANLON, FLA	107.47	107.88	0.41
bf606	606	2322700	ICHETUCKNEE RIVER AT HWY 27	311.30	310.75	-0.55

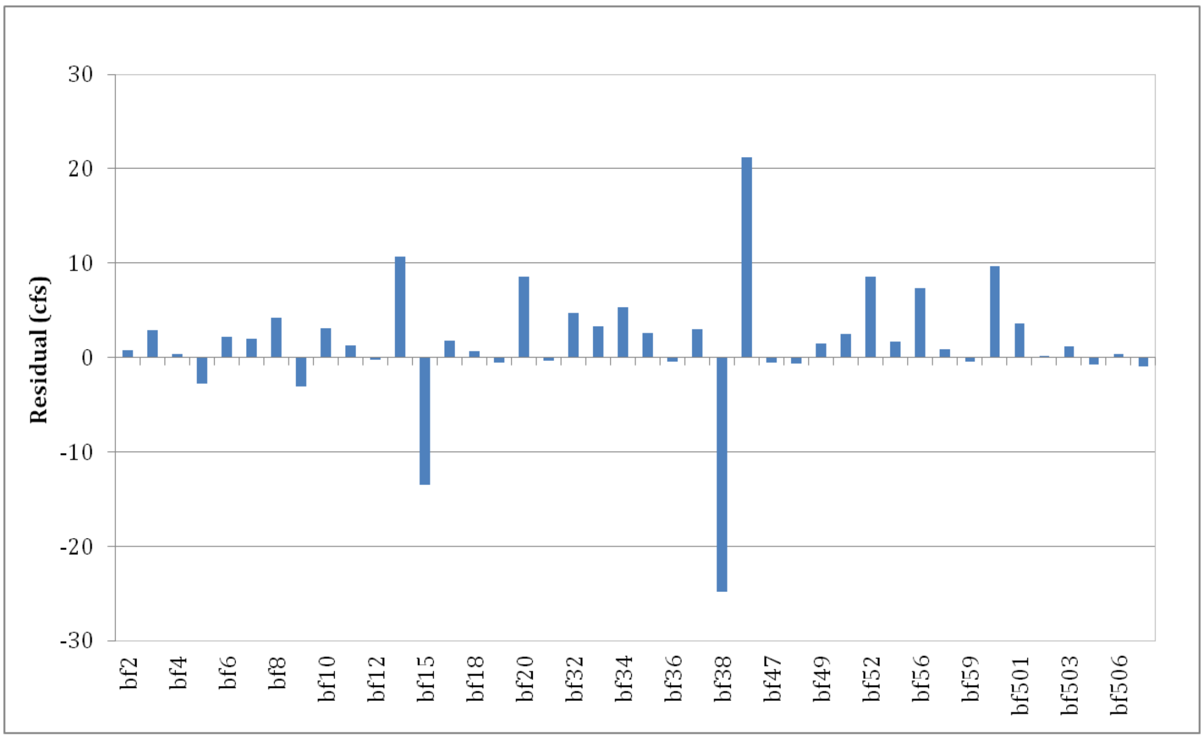

Figure 43. Baseflow Residuals

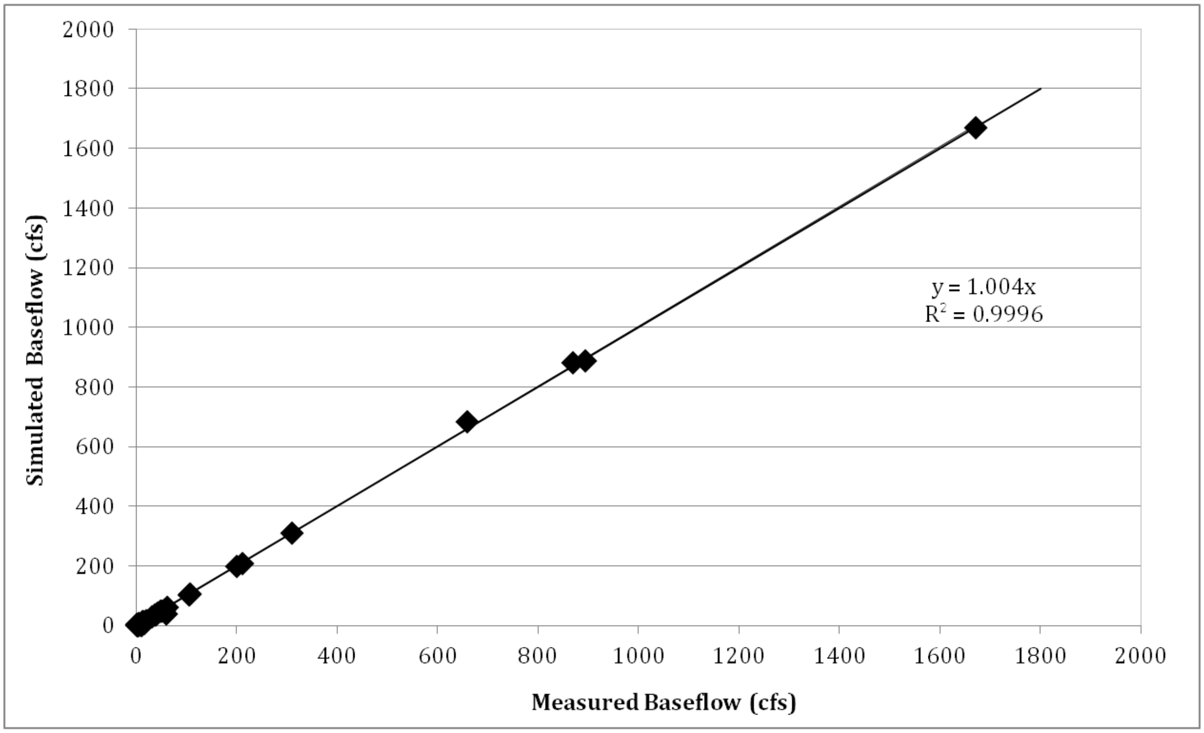

Figure 44. Calibrated Baseflow Fluxes

Spring Fluxes

Simulated spring fluxes (categorized by target weight values) are shown in Figures 46 through 48. Estimated 1995 springflow targets, simulated springflow values, and residuals are presented in tabular format in Appendix A.

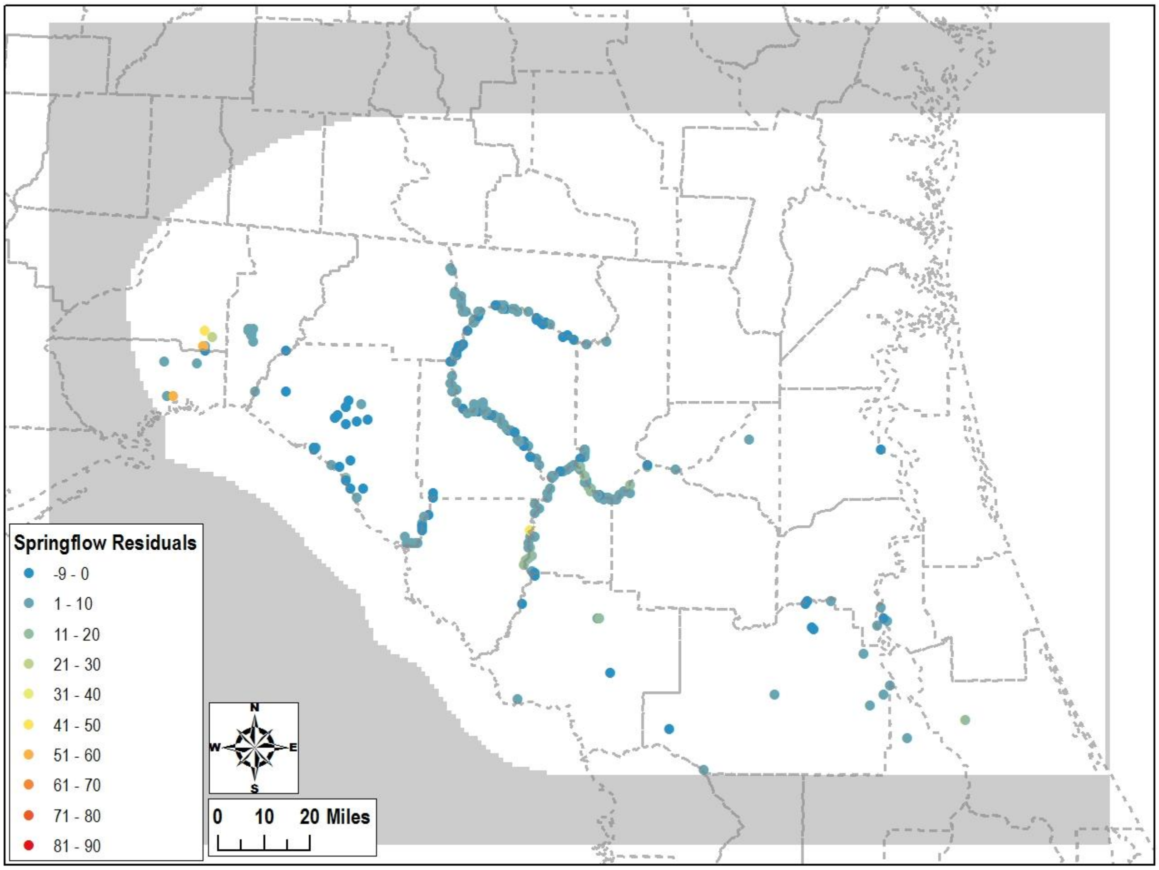

Figure 45. Springflow Residuals

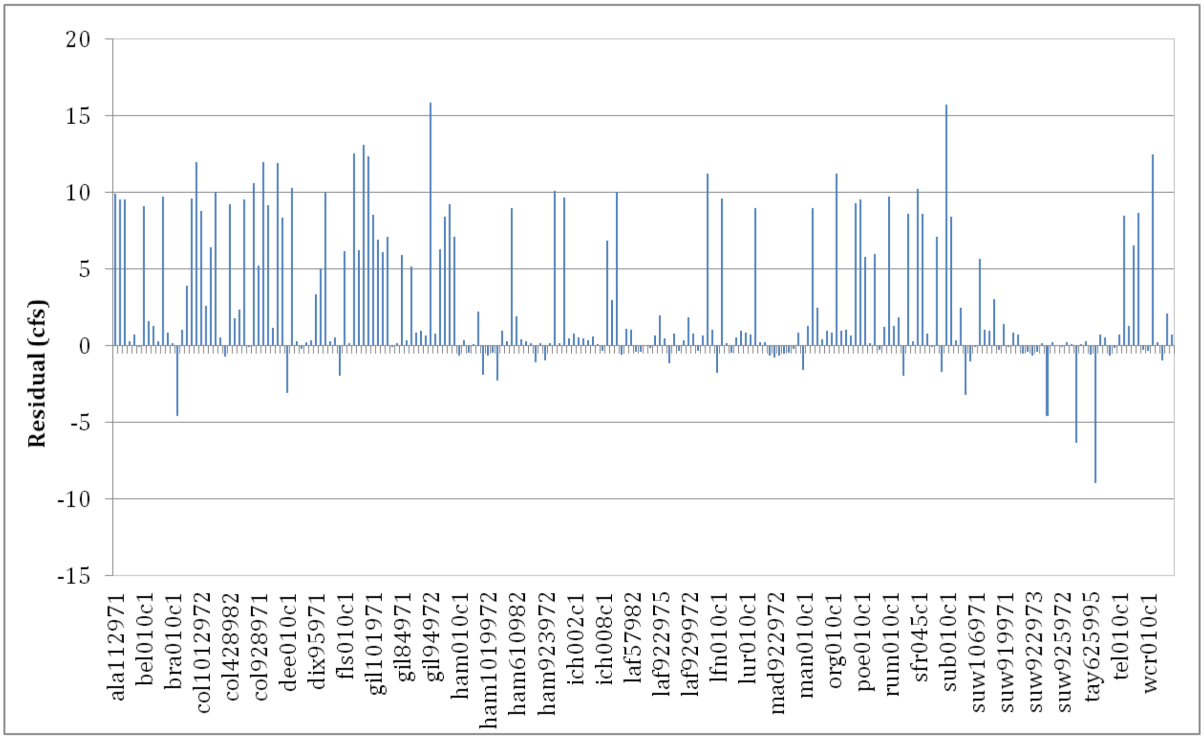

Figure 46. Springflow Residuals (Wt=1)

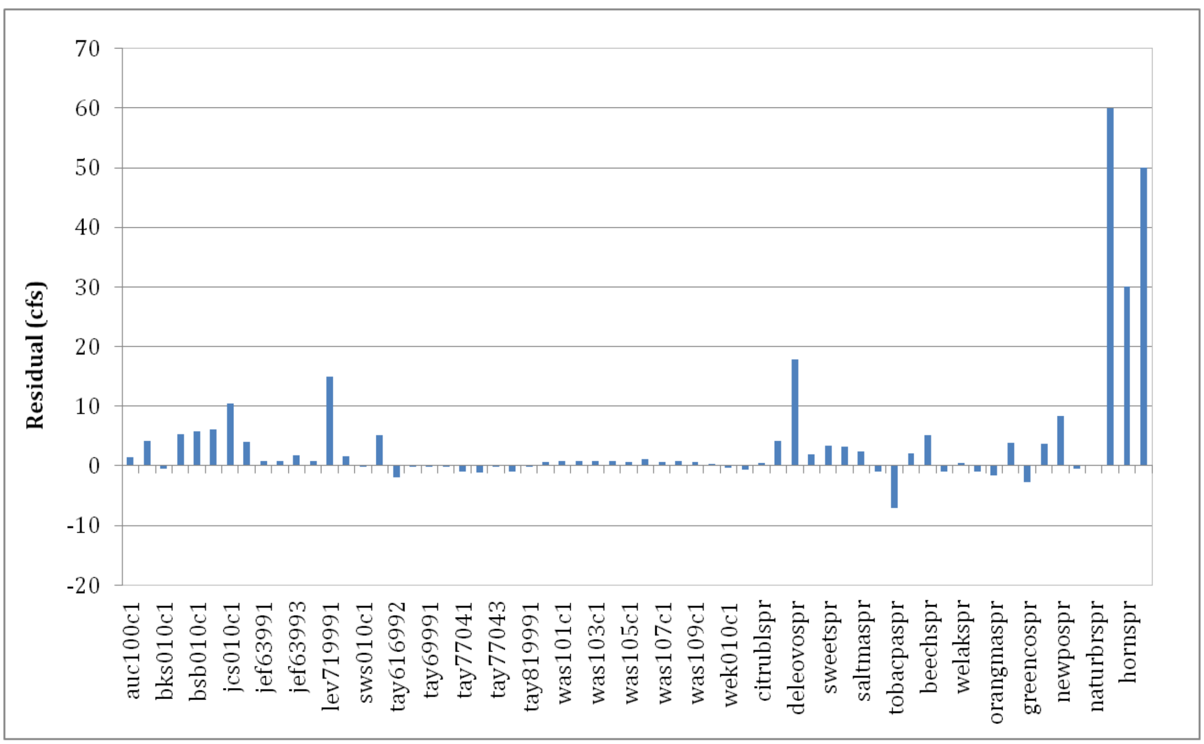

Figure 47. Springflow Residuals (Wt=1/2)

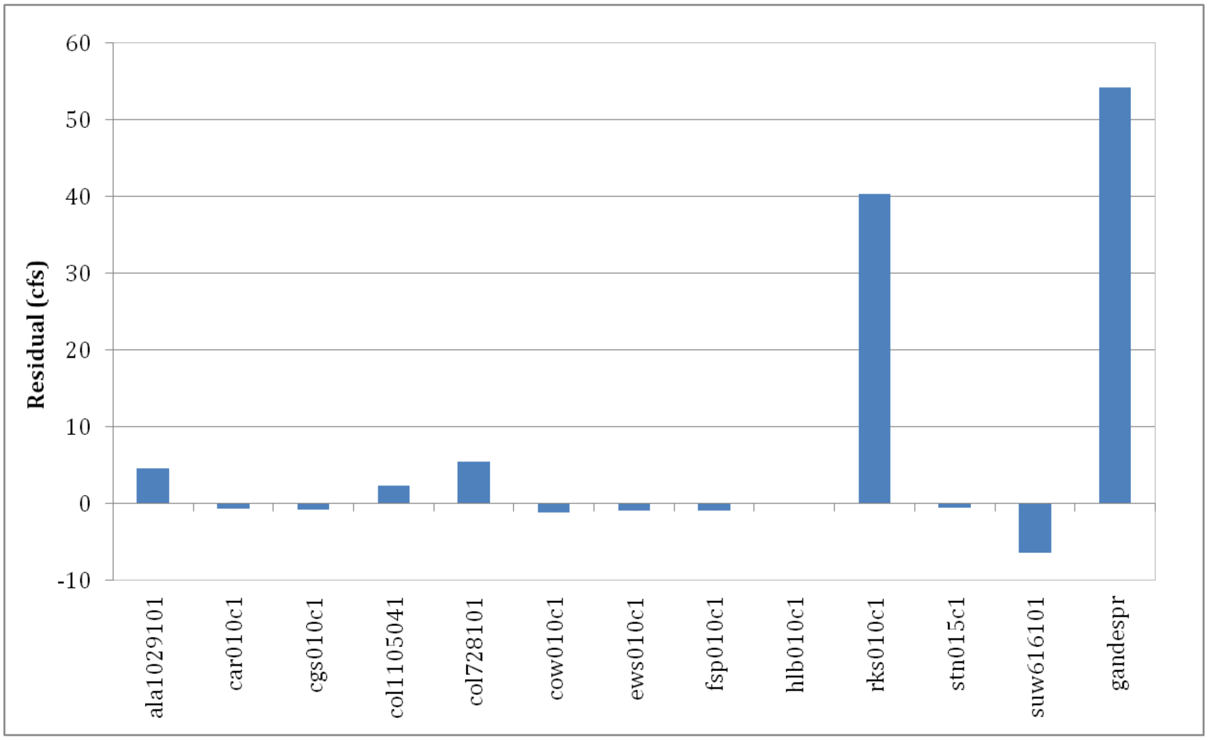

Figure 48. Springflow Residuals (Wt=1/3)

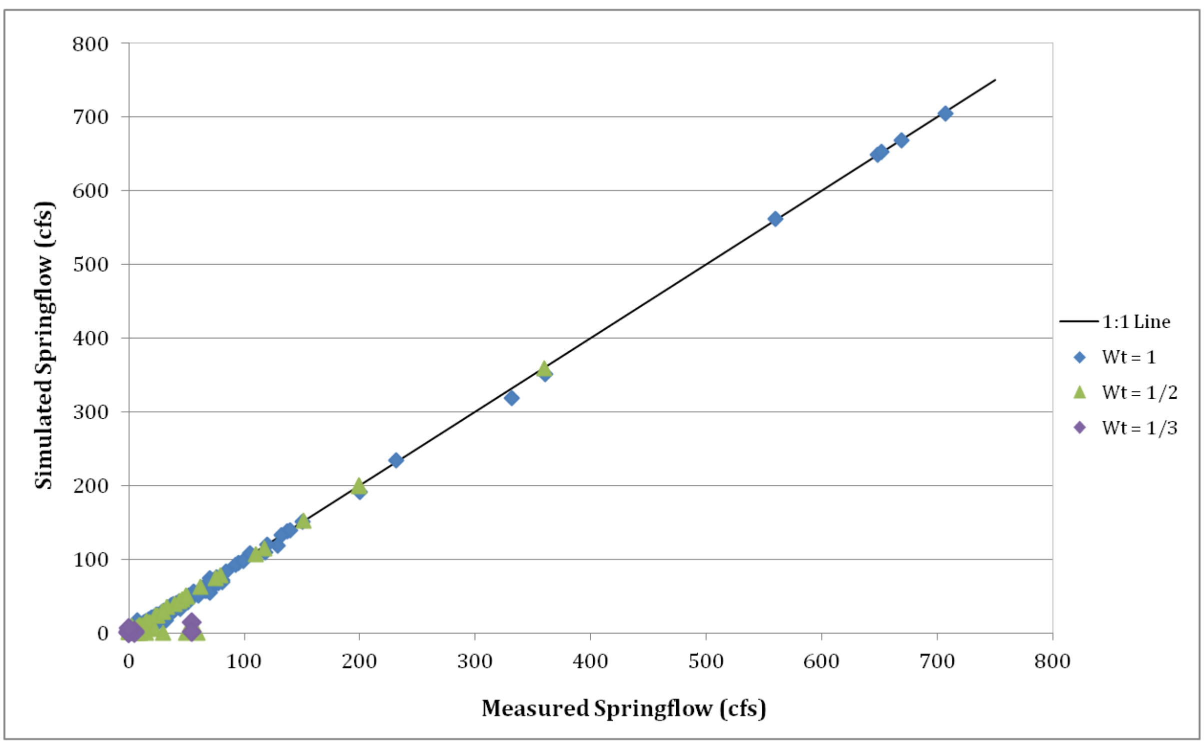

Figure 49. Calibrated Springflow Fluxes

Calibrated Parameters

The final values of the parameters optimized by PEST for the calibrated North Florida model are described in this section. The optimized parameters included the recharge array, hydraulic and vertical conductivity arrays, and river and spring elevations and conductances.

Calibrated Conductivity Fields

The calibrated horizontal and vertical hydraulic conductivity fields for layers 1 through 4 are shown in Figures 50 through 57.

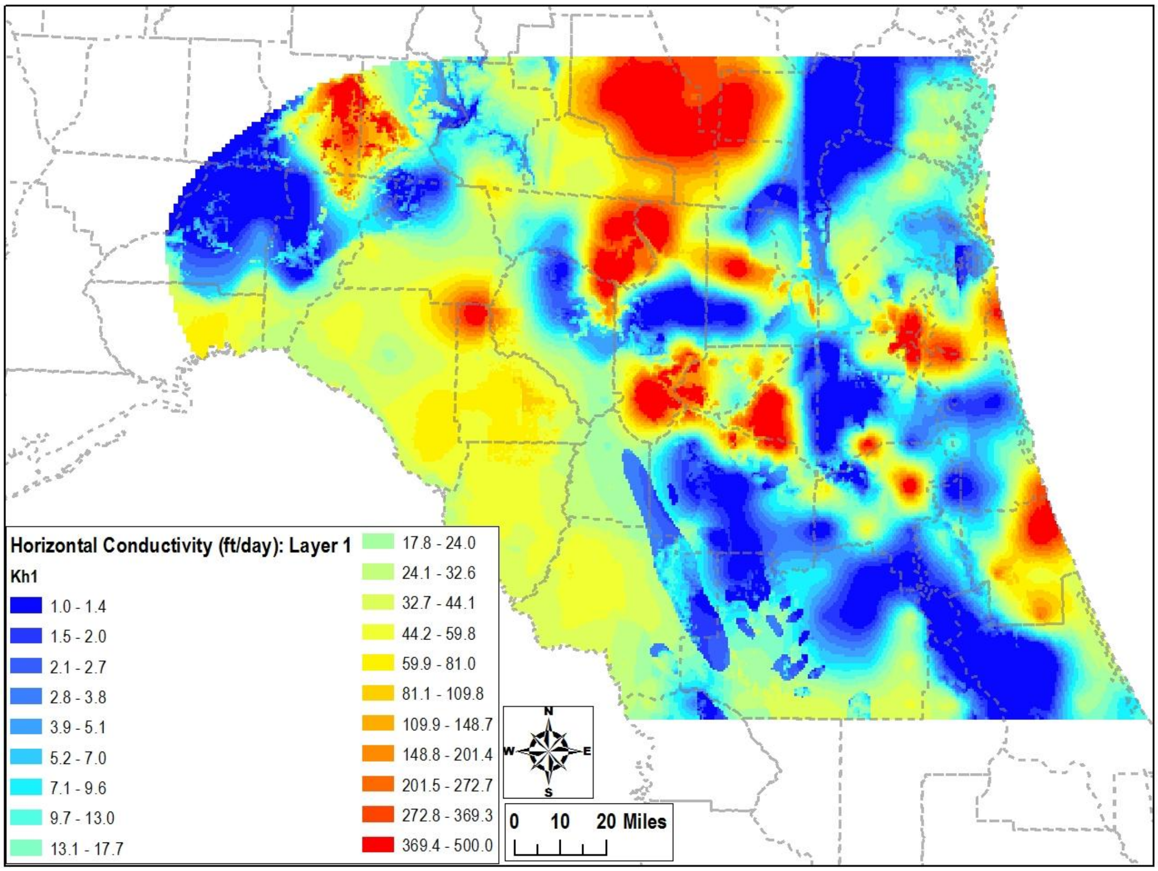

Figure 50. Calibrated Hydraulic Conductivity Array, Layer 1

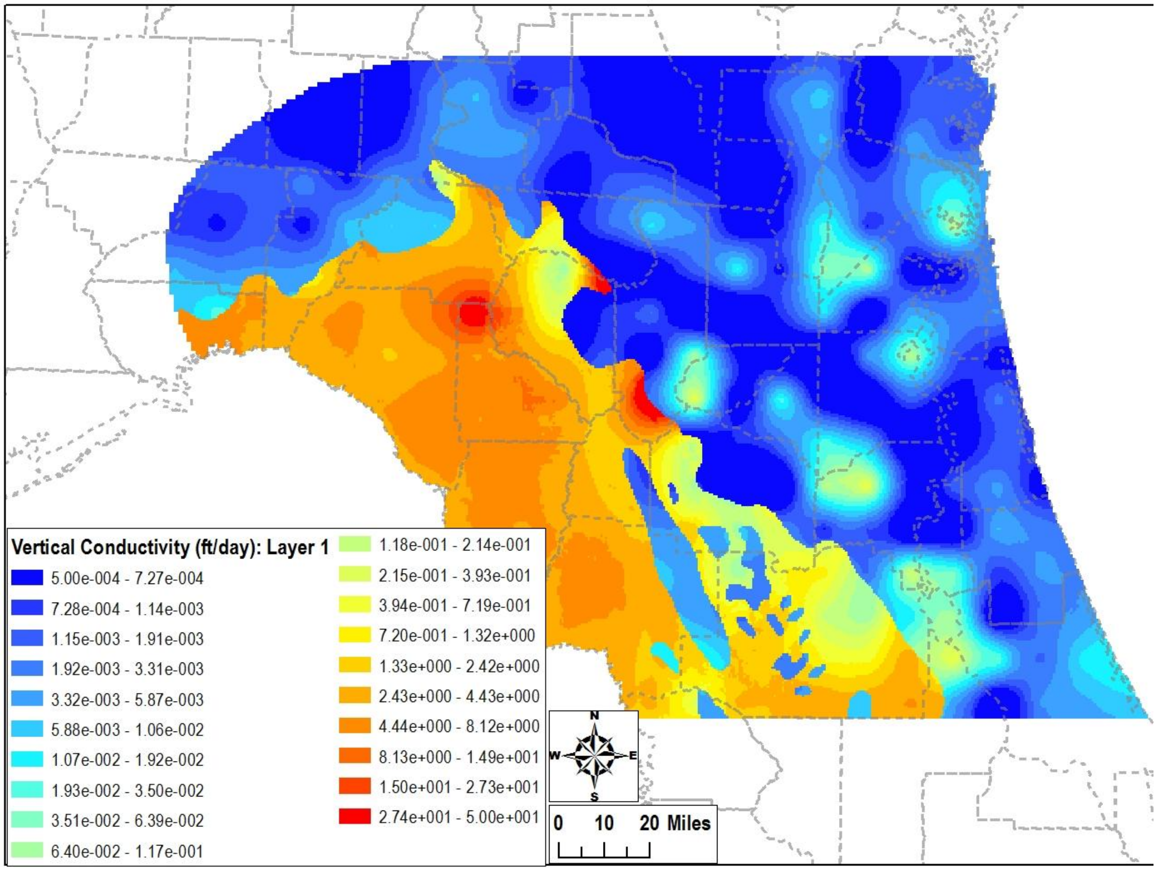

Figure 51. Calibrated Vertical Conductivity Array, Layer 1

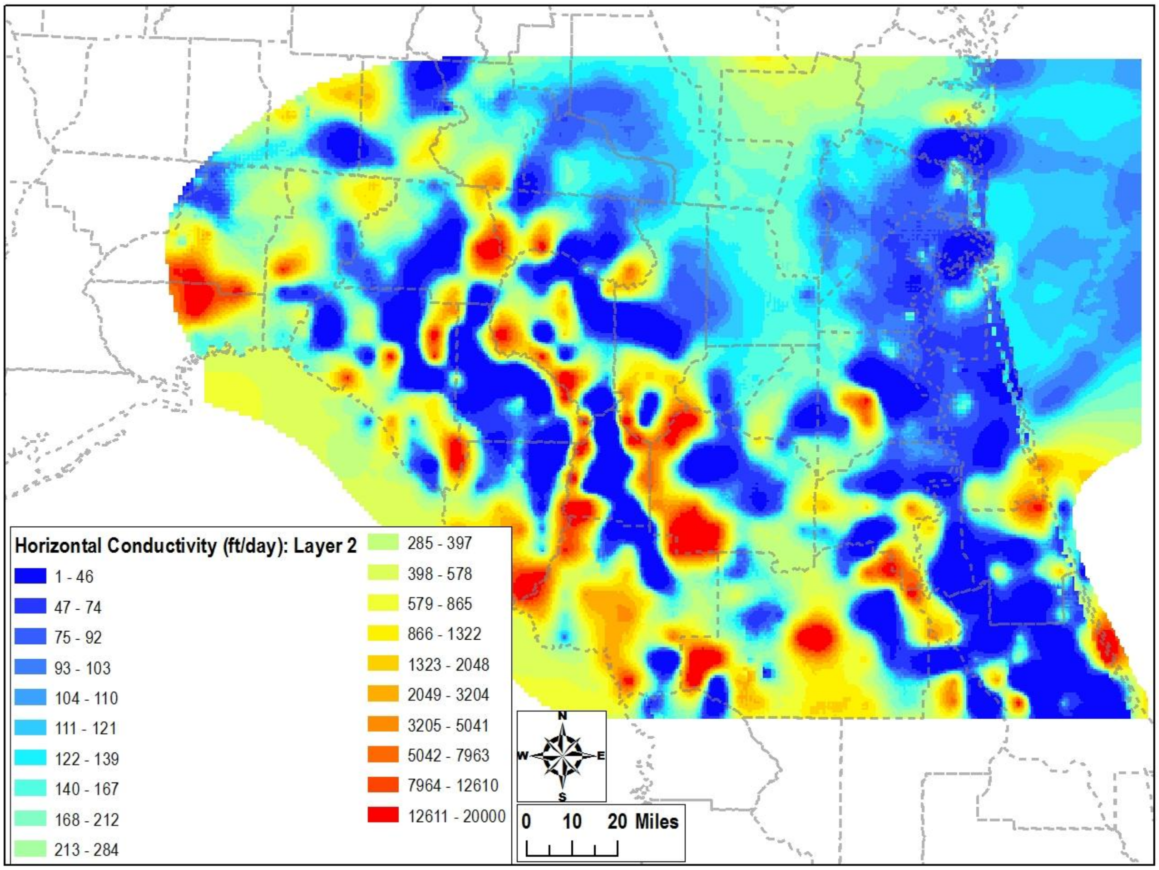

Figure 52. Calibrated Hydraulic Conductivity Array, Layer 2

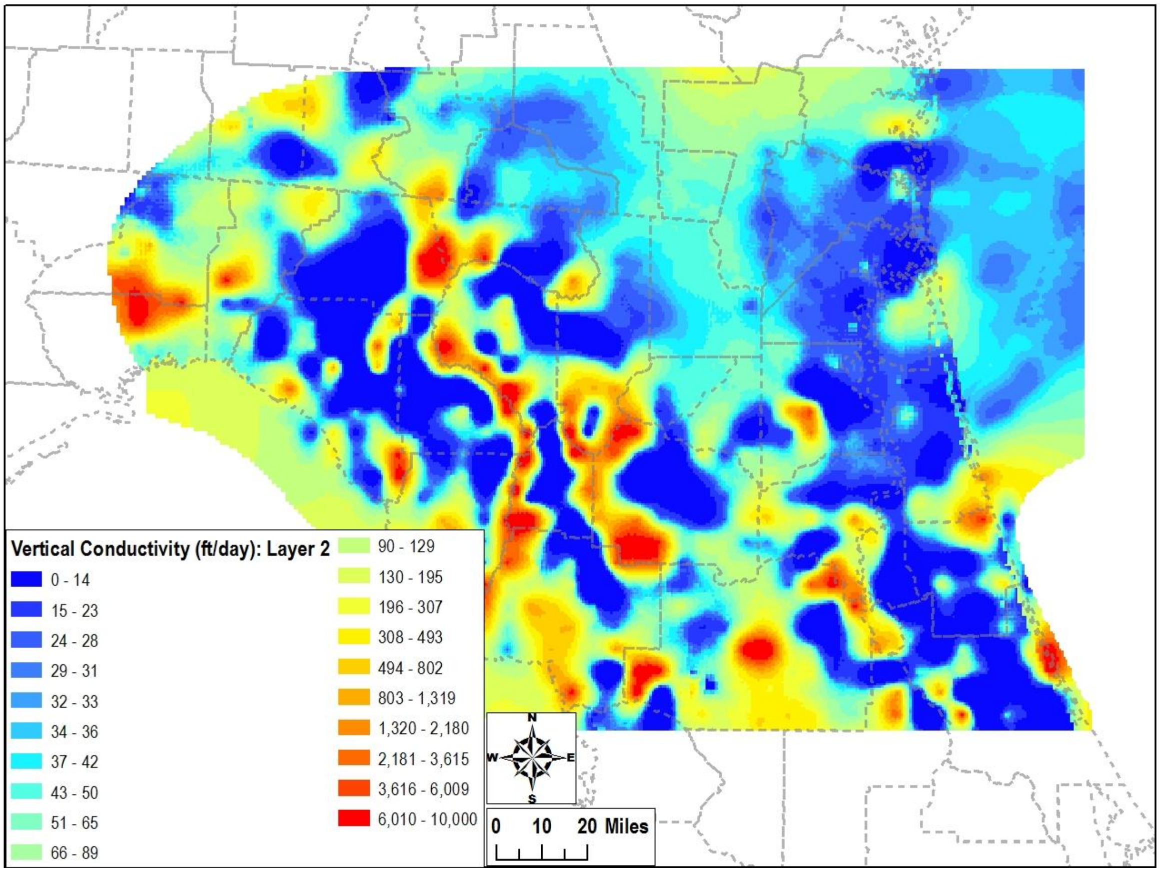

Figure 53. Calibrated Vertical Conductivity Array, Layer 2

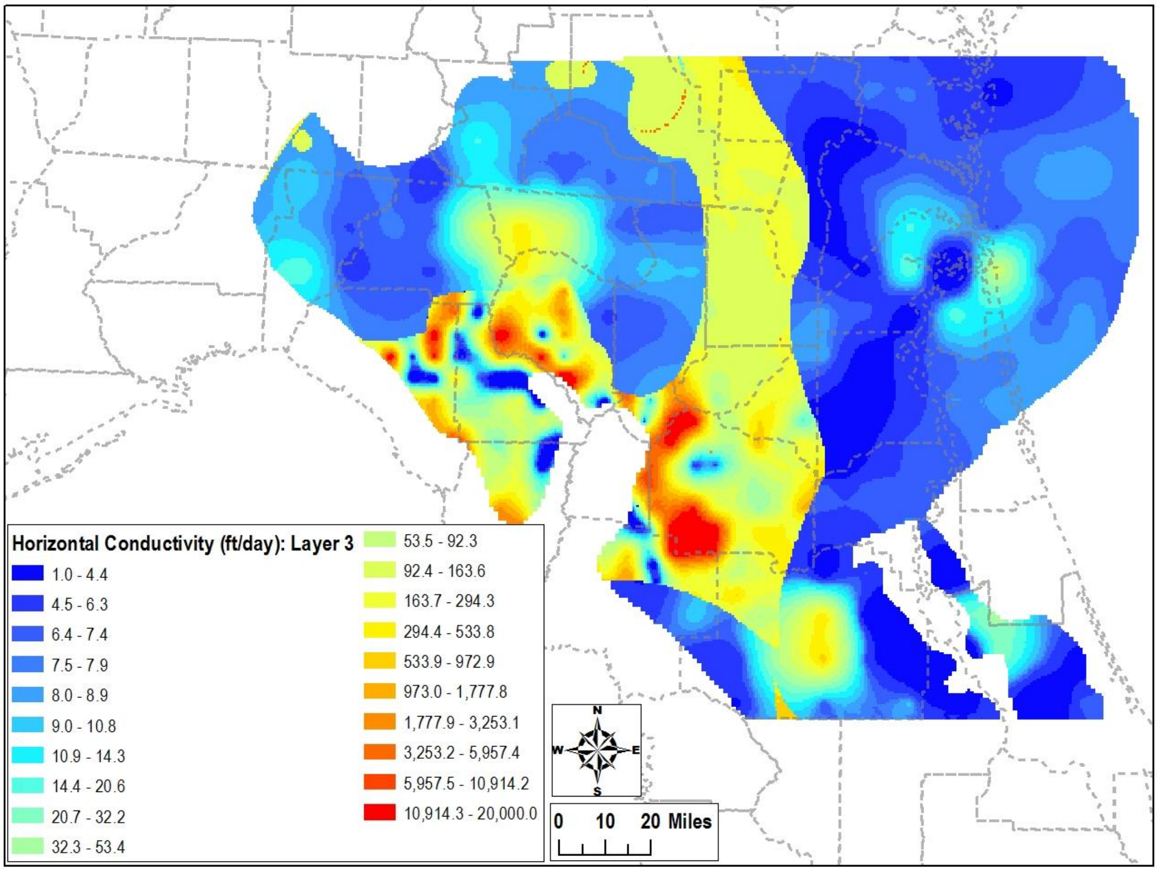

Figure 54. Calibrated Horizontal Conductivity Array, Layer 3

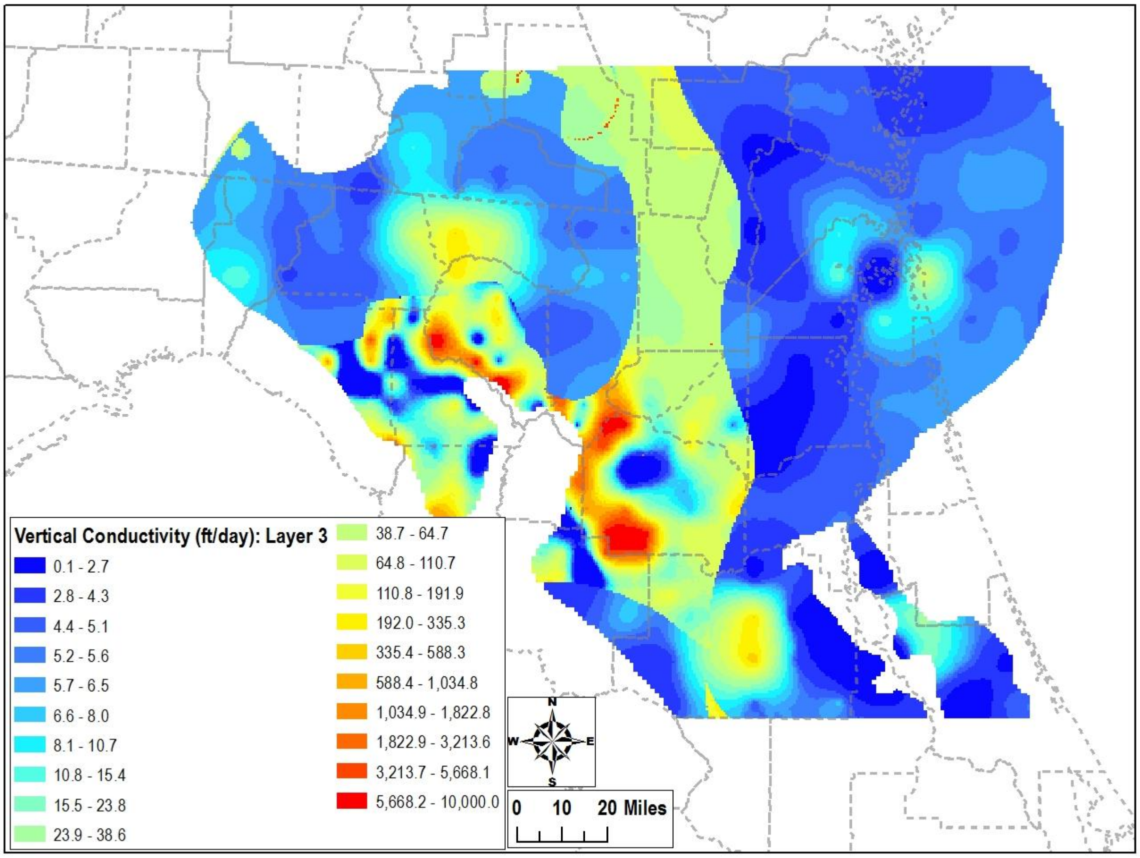

Figure 55. Calibrated Vertical Conductivity Array, Layer 3

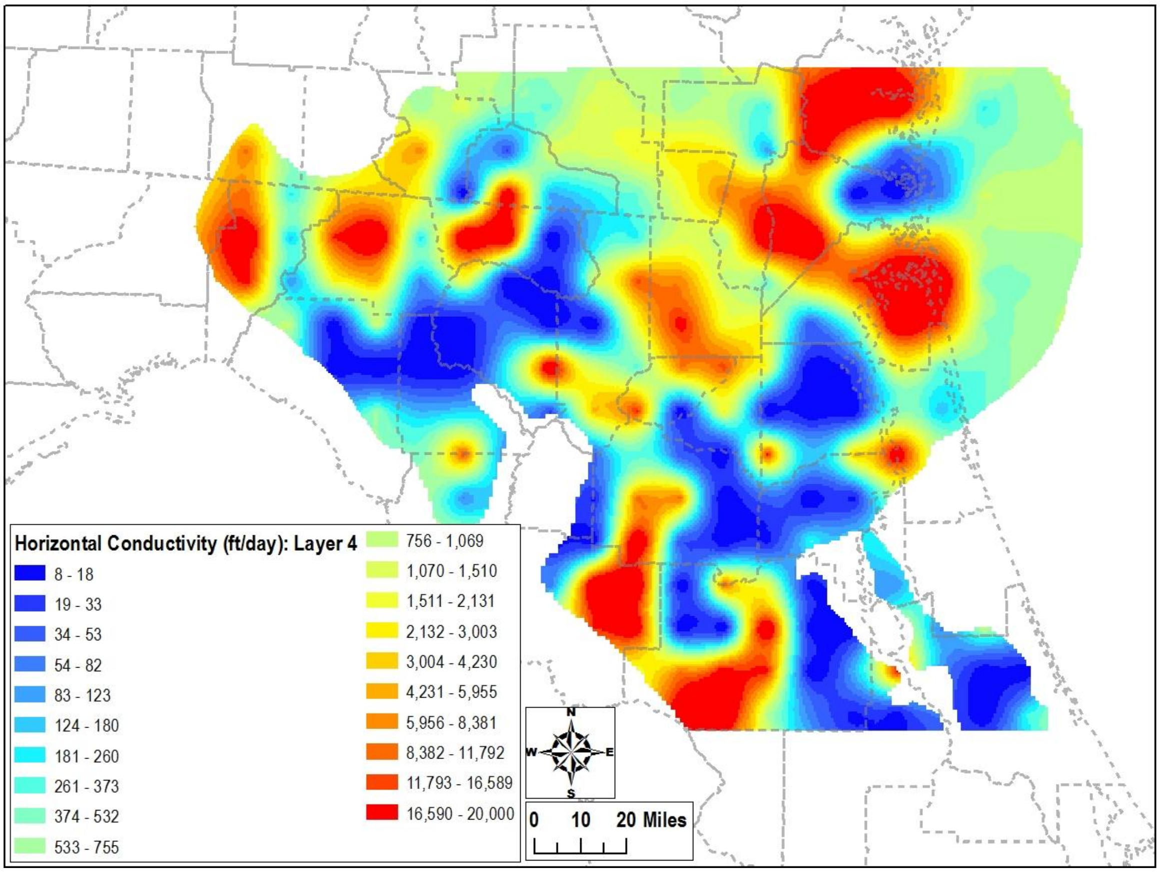

Figure 56. Calibrated Horizontal Conductivity Array, Layer 4

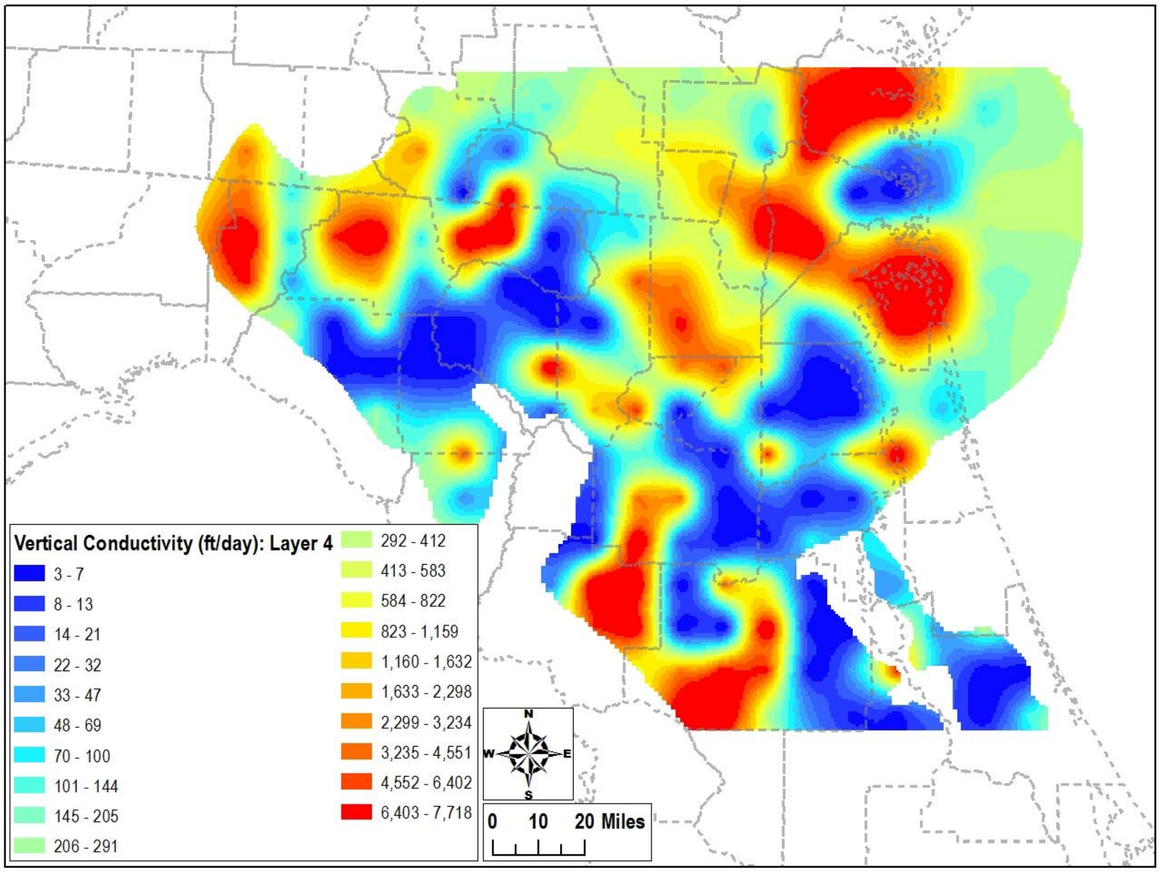

Figure 57. Calibrated Vertical Conductivity Array, Layer 4

Calibrated Recharge and ET Arrays

The calibrated recharge array for 1995 is shown in Figure 58. As previously described, recharge was calibrated by PEST using the pilot points shown in Figure 28. In addition to the pilot points, overall multipliers were applied to the recharge array. Figure 59 depicts the simulated spatial distribution of actual groundwater ET (ET that is leaving the groundwater system). Figure 60 shows the net recharge array accounting for the actual groundwater ET. Negative net recharge and net recharge as percent of precipitation are shown in Figures 61 and 62, respectively.

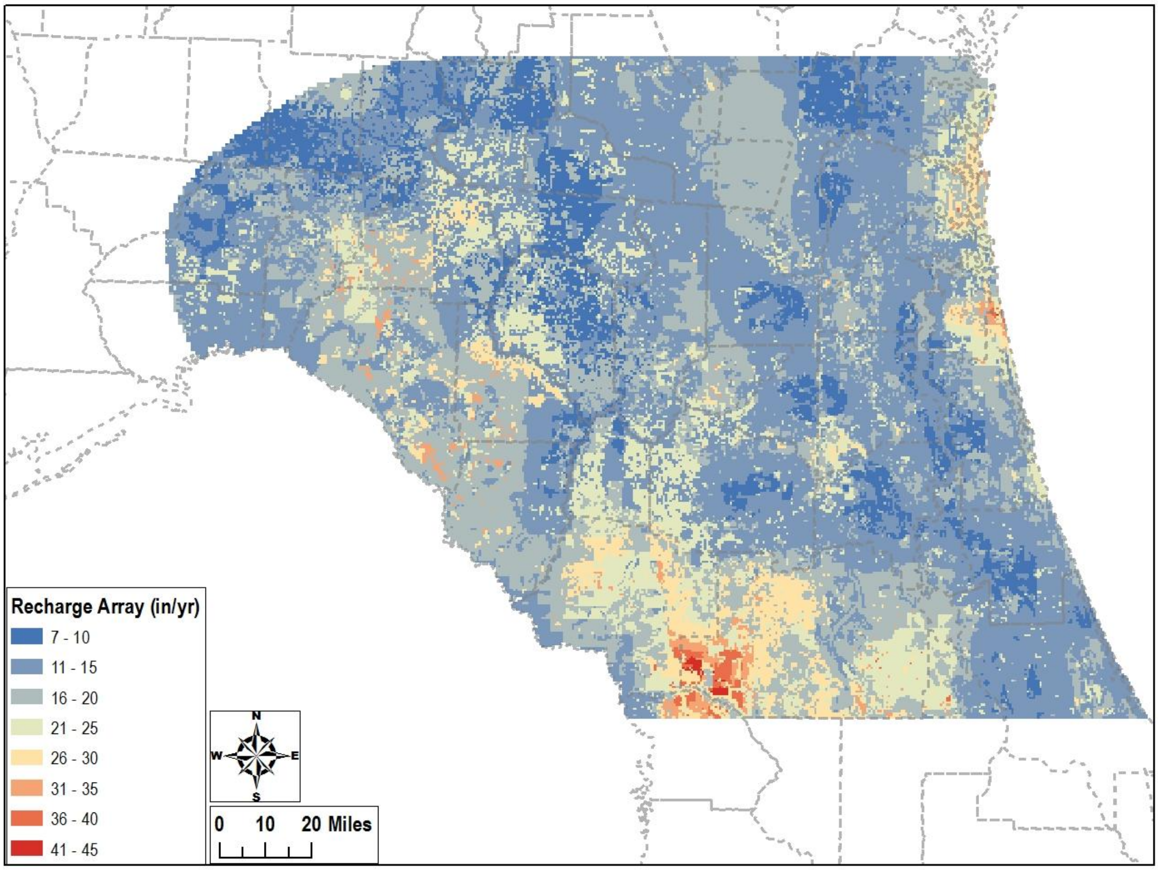

Figure 58. Calibrated Recharge Array (in/yr)

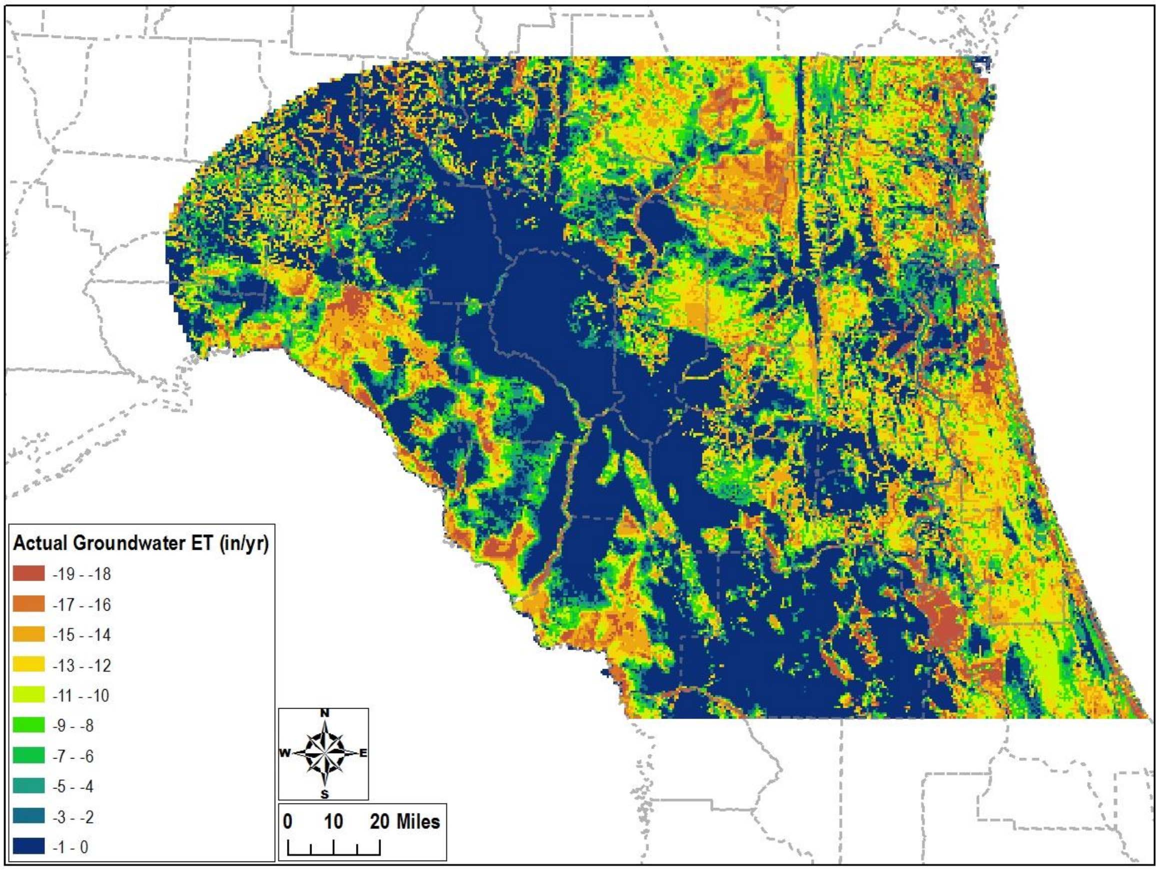

Figure 59. Actual Groundwater ET (in/yr)

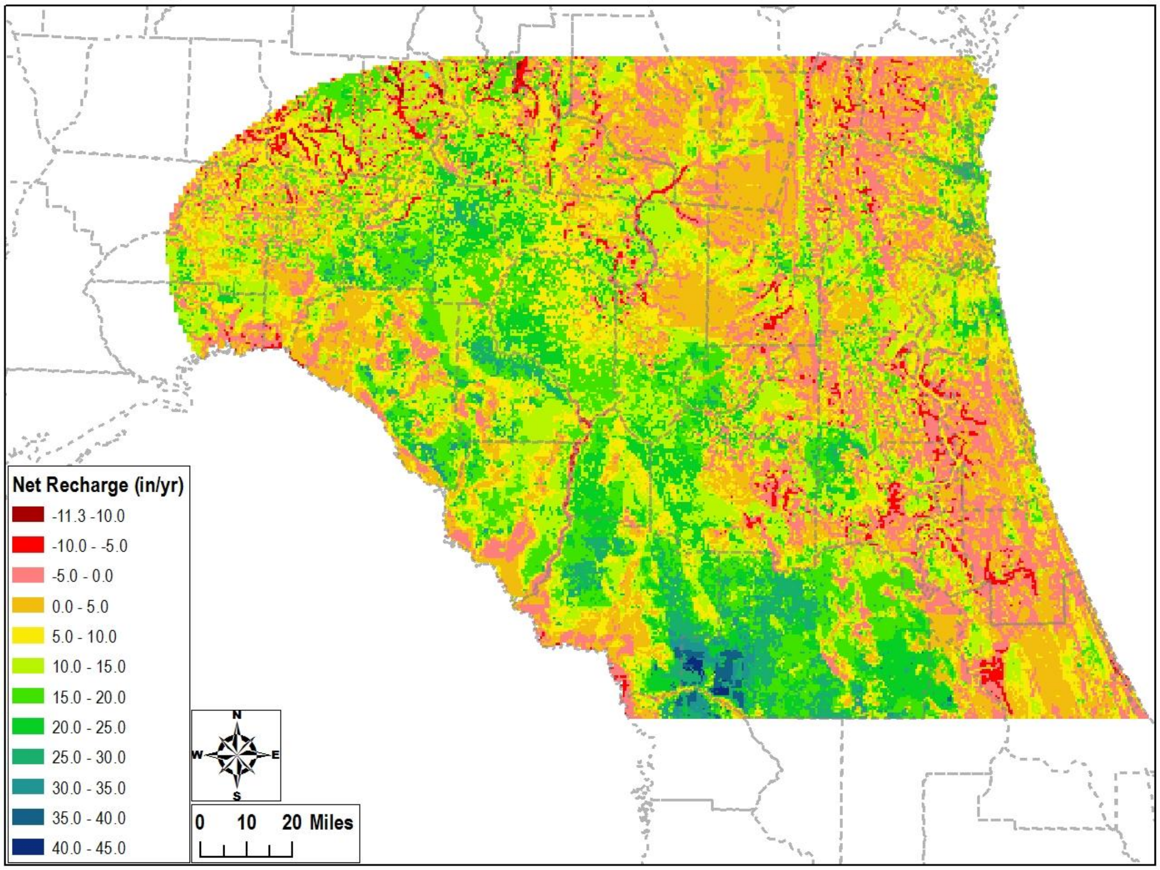

Figure 60. Net Recharge Array (in/yr)

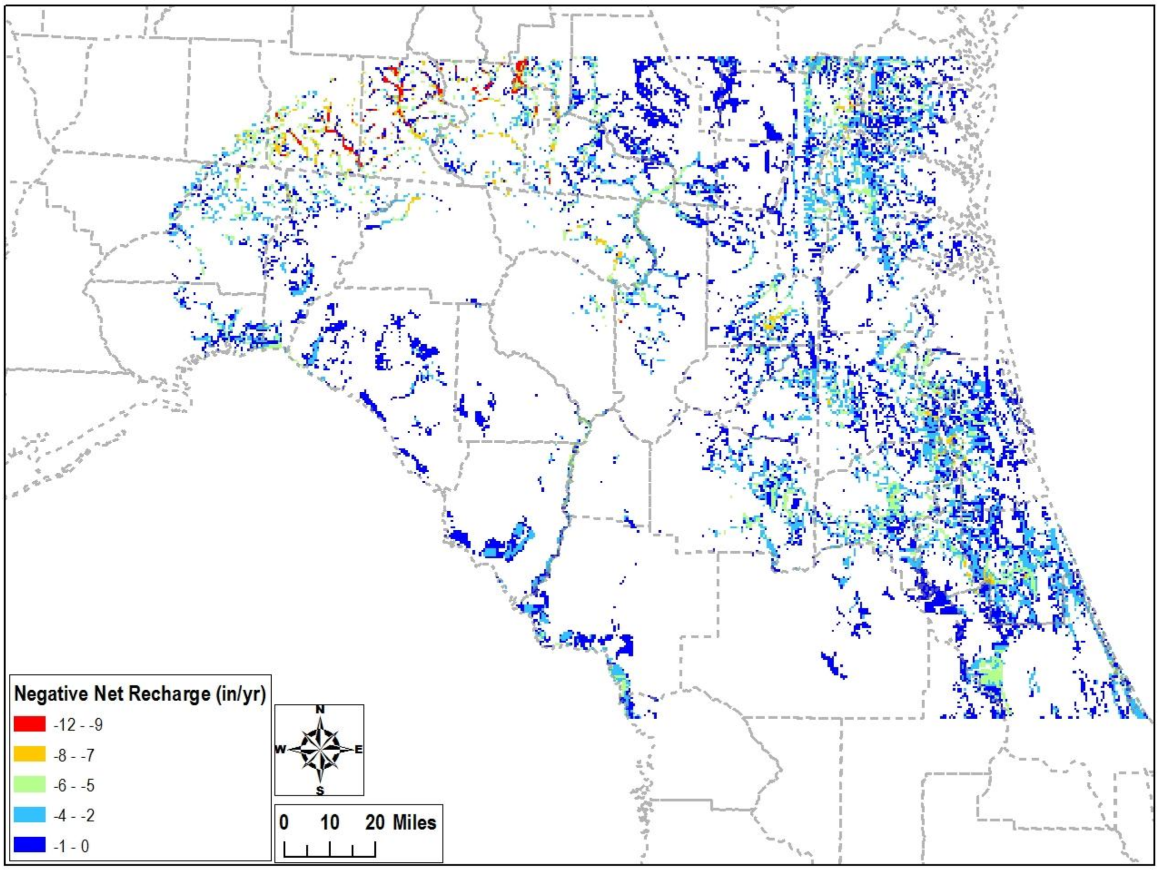

Figure 61. Negative Net Recharge

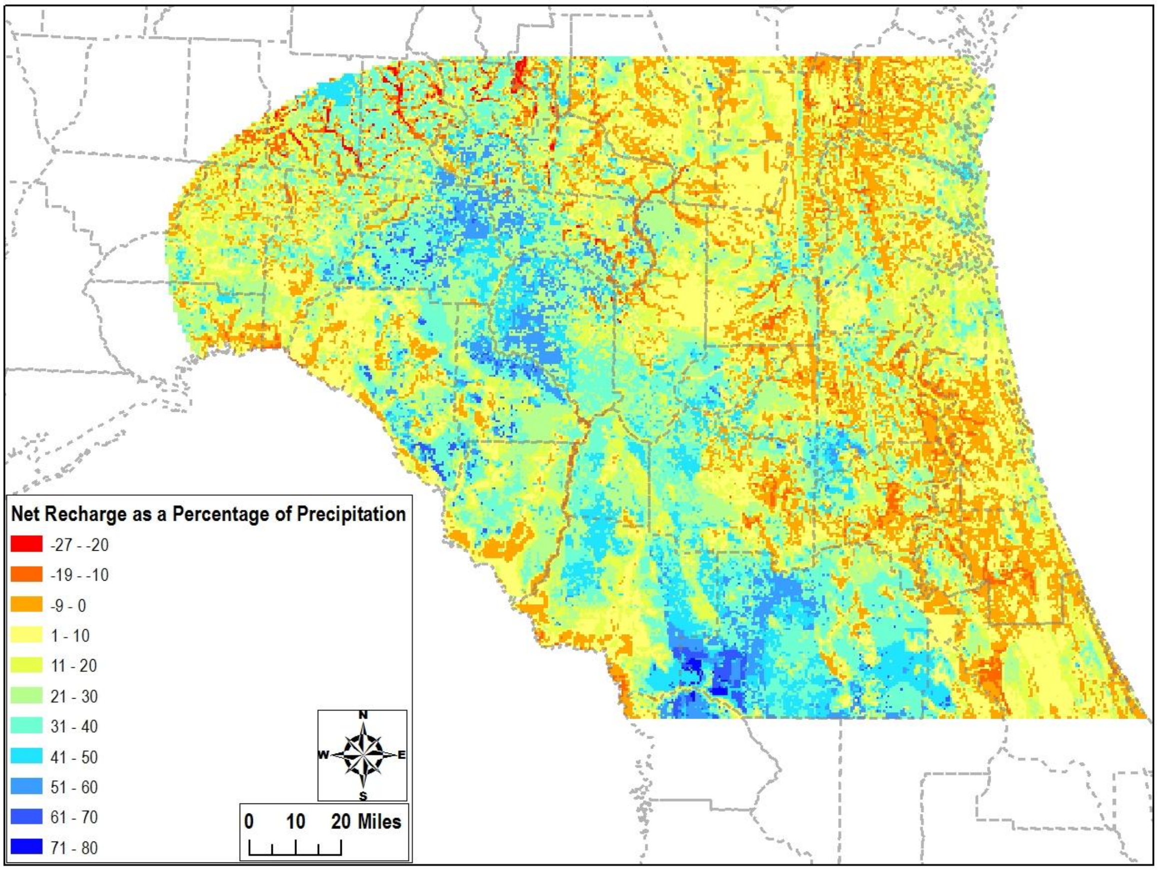

Figure 62. Net Recharge as a Percentage of Precipitation

Recommendations and Conclusions

Although the modeling effort began as a recalibration of the Version 1 model (SDII, 2008), all packages in the final model were updated with the best available data. Key modifications to the NF model include systematic representation of river hydrography through a river package and improved representation and calibration of springs. Surface topography and layer thicknesses were also modified using best-available datasets from the U.S. Geological Survey (USGS). During model calibration, changes were made to the Version 1 conceptualization by modeling the surficial and thin underlying intermediate aquifer systems as one layer in order to mitigate drying and rewetting problems caused by thin surficial and intermediate aquifers in the model domain. The original model domain was expanded to the southeast for better alignment with hydrologic boundaries. Additional modifications included changes to the distribution of groundwater recharge and evapotranspiration (ET) via ET and recharge packages.

PEST software (Watermark Numerical Computing, 2010) was used to automate calibration of the revised North Florida Model parameters including recharge, ET, hydraulic conductivity, river characteristics and springs characteristics. The calibration efforts focused on the surficial, intermediate, and Floridan aquifer systems, mainly in the Suwannee River and Santa Fe River basins.

Like the previous version of the NF model, the current version is a single stress period, steady state application. The current modeling effort represents average 1995 conditions. As with all steady state models, care should be taken when applying this model for predictive scenarios. Although this model can be utilized to simulate future pumping scenarios, caution should be taken if this model is utilized for zero pumping (or pumps off) simulations. Zero pumping simulations require updates to many of the model boundary conditions, and the data needed for these updates are scarce.

Although the updated NF model better represents the Floridan aquifer system in the model domain than the previous model version, more can be learned from moving from a steady-state application to a transient application. Thus, it is highly recommended that future updates to the model incorporate transient simulations in order to simulate the aquifer system in several states. Nevertheless, the updated North Florida Model provides the District with and improved tool for consumptive use permit evaluation that is based on an improved conceptual understanding of regional groundwater flow interactions of the Floridan aquifer system.

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Appendix A. Springflow Residuals

PEST Name	STATID	Spring Name	Simulated Springflow (cfs)	Target Springflow (cfs)	Residual (Observed - Simulated)
ala112971	ALA112971	UN-NAMED SPRING	190.83	200.75	9.92
ala930971	ALA930971	UN-NAMED SPRING	11.73	21.31	9.58
ala930972	ALA930972	UN-NAMED SPRING	64.99	74.57	9.58
alr010c1	ALR010C1	ALAPAHA RISE NEAR FORT UNION	648.83	649.13	0.30
amp010c1	AMP010C1	ALLEN MILL POND	19.52	20.24	0.72
ans010c1	ANS010C1	ANDERSON SPRING IN SUWANNEE RIVER	18.81	18.79	-0.02
bel010c1	BEL010C1	BELL SPRINGS IN GILCHRIST CO	0.98	10.10	9.12
bes010c1	BES010C1	BELL SPRINGS NEAR WHITE SPRINGS	0.00	1.60	1.60
bet010c1	BET010C1	BETTY SPRINGS	1.02	2.32	1.30
blm010c1	BLM010C1	BLUE SPRING NR MADISON	150.56	150.83	0.27
blu010c1	BLU010C1	BLUE SPRING IN GILCHRIST COUNTY	41.68	51.39	9.71
bon010c1	BON010C1	BONNET SPRINGS	29.88	30.73	0.85
bra010c1	BRA010C1	BRANFORD SPRINGS	22.87	23.07	0.20
bsk010c1	BSK010C1	BLUE SINK	74.79	70.24	-4.55
bts010c1	BTS010C1	BATH TUB SPRINGS	6.38	7.45	1.07
chs010c1	CHS010C1	CHARLES SPRINGS	12.03	15.95	3.92
col010c1	COL010C1	COLUMBIA SPRINGS	109.02	118.65	9.63
col1012971	COL1012971	UN-NAMED SPRING	5.48	17.49	12.01
col1012972	COL1012972	UN-NAMED SPRING	3.19	11.98	8.79
col101971	COL101971	UN-NAMED SPRING	0.18	2.80	2.62
col101972	COL101972	UN-NAMED SPRING	0.20	6.63	6.43
col101974	COL101974	UN-NAMED SPRING	0.90	10.93	10.03
col101975	COL101975	UN-NAMED SPRING	0.07	0.60	0.53
col428981	COL428981	UN-NAMED SPRING	2.24	1.53	-0.71
col428982	COL428982	UN-NAMED SPRING	6.72	15.99	9.27
col522981	COL522981	UN-NAMED SPRING	1.62	3.44	1.82
col522982	COL522982	UN-NAMED SPRING	2.43	4.80	2.37
col61981	COL61981	UN-NAMED SPRING	57.55	67.12	9.57
col61982	COL61982	UN-NAMED SPRING	0.81	0.71	-0.10
col917971	COL917971	UN-NAMED SPRING	0.47	11.06	10.59
col928971	COL928971	UN-NAMED SPRING	0.36	5.62	5.26
col928972	COL928972	UN-NAMED SPRING	8.00	19.97	11.97
col930971	COL930971	UN-NAMED SPRING	5.01	14.21	9.20
con010c1	CON010C1	CONVICT SPRING	4.89	6.07	1.18
cop010c1	COP010C1	COPPER SPRINGS	18.25	30.18	11.93

PEST Name	STATID	Spring Name	Simulated Springflow (cfs)	Target Springflow (cfs)	Residual (Observed - Simulated)
dar010c1	DAR010C1	DARBY SPRINGS	2.34	10.70	8.36
dee010c1	DEE010C1	DEER SPRINGS	8.48	5.38	-3.10
der010c1	DER010C1	DEVILS EAR	118.97	129.29	10.32
dix625991	DIX625991	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	10.48	10.78	0.30
dix625992	DIX625992	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	1.78	1.60	-0.18
dix625993	DIX625993	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	56.35	56.56	0.21
dix625994	DIX625994	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	10.32	10.70	0.38
dix95971	DIX95971	UN NAMED SPRING	0.46	3.85	3.39
dog010c1	DOG010C1	DOGWOOD SPRINGS	9.39	14.42	5.03
dye010c1	DYE010C1	DEVIL EYE	34.68	44.69	10.01
ell010c1	ELL010C1	ELLAVILLE SPRINGS	43.49	43.76	0.27
eva010c1	EVA010C1	EVA SPRING ON THE STEINHATCHEE RIVER	2.23	2.75	0.52
fan010c1	FAN010C1	FANNING SPRINGS	107.45	105.48	-1.97
fls010c1	FLS010C1	FLETCHER SPRING	7.06	13.23	6.17
fps010c1	FPS010C1	FOLSON PARK SPRING IN PERRY	2.12	2.29	0.17
gil1012971	GIL1012971	UN-NAMED SPRING	10.77	23.31	12.54
gil1012972	GIL1012972	UN-NAMED SPRING	3.19	9.41	6.22
gil1012973	GIL1012973	UN-NAMED SPRING	318.90	332.00	13.10
gil1012974	GIL1012974	UN-NAMED SPRING	69.26	81.60	12.34
gil101971	GIL101971	UN-NAMED SPRING	0.47	9.01	8.54
gil107971	GIL107971	UN-NAMED SPRING	28.03	34.97	6.94
gil107972	GIL107972	UN-NAMED SPRING	28.87	34.97	6.10
gil729971	GIL729971	UN-NAMED SPRING	2.62	9.76	7.14
gil729972	GIL729972	UN-NAMED SPRING	0.29	0.22	-0.07
gil729973	GIL729973	UN-NAMED SPRING	0.29	0.49	0.20
gil84971	GIL84971	UN-NAMED SPRING	9.40	15.31	5.91
gil917971	GIL917971	UN-NAMED SPRING	0.73	1.12	0.39
gil917972	GIL917972	UN-NAMED SPRING	0.55	5.73	5.18
gil917973	GIL917973	UN-NAMED SPRING	0.29	1.15	0.86
gil928971	GIL928971	UN-NAMED SPRING	0.26	1.26	1.00
gil928972	GIL928972	UN-NAMED SPRING	0.20	0.86	0.66
gil94972	GIL94972	UN-NAMED SPRING	16.60	32.49	15.89
gil99971	GIL99971	UN-NAMED SPRING	0.35	1.15	0.80
gil99972	GIL99972	UN-NAMED SPRING	1.90	8.19	6.29
gil99974	GIL99974	UN-NAMED SPRING	0.69	9.10	8.41
gin010c1	GIN010C1	GINNIE SPRINGS	42.59	51.80	9.21
gua010c1	GUA010C1	GUARANTO SPRINGS	3.15	10.29	7.14

PEST Name	STATID	Spring Name	Simulated Springflow (cfs)	Target Springflow (cfs)	Residual (Observed - Simulated)
ham010c1	HAM010C1	HAMPTON SPRING	0.83	0.22	-0.61
ham1017971	HAM1017971	UN-NAMED SPRING	1.78	2.17	0.39
ham1017972	HAM1017972	UN-NAMED SPRING	0.92	0.44	-0.48
ham1017973	HAM1017973	UN-NAMED SPRING	0.34	0.44	0.10
ham1017974	HAM1017974	UN-NAMED SPRING	5.03	7.28	2.25
ham1019971	HAM1019971	UN-NAMED SPRING	2.71	0.80	-1.91
ham1019972	HAM1019972	UN-NAMED SPRING	1.05	0.44	-0.61
ham1023971	HAM1023971	UN-NAMED SPRING	24.43	24.00	-0.43
ham522981	HAM522981	UN-NAMED SPRING	4.67	2.42	-2.25
ham54011	HAM54011	HARDEE SPRING	28.50	29.48	0.98
ham54012	HAM54012	UN-NAMED SPRING	7.70	8.00	0.30
ham610981	HAM610981	UN NAMED SPRING	32.13	41.14	9.01
ham610982	HAM610982	UN NAMED SPRING	28.91	30.86	1.95
ham610983	HAM610983	UN NAMED SPRING	30.41	30.86	0.45
ham610984	HAM610984	UN NAMED SPRING	20.30	20.57	0.27
ham612981	HAM612981	TANNER	94.94	95.14	0.20
ham612982	HAM612982	UN NAMED SPRING	7.27	6.18	-1.09
ham923971	HAM923971	UN-NAMED SPRING	13.54	13.72	0.18
ham923972	HAM923972	UN-NAMED SPRING	1.09	0.14	-0.95
ham923973	HAM923973	UN-NAMED SPRING	9.27	9.42	0.15
har010c1	HAR010C1	HART SPRINGS	71.48	81.63	10.15
hol010c1	HOL010C1	HOLTON CREEK RISE	137.77	137.96	0.19
hor010c1	HOR010C1	HORNSBY SPRING NR HIGH SPRINGS	56.76	66.47	9.71
ich001c1	ICH001C1	ICHETUCKNEE HEAD SPRING	36.53	37.04	0.51
ich002c1	ICH002C1	BLUE HOLE SPRING VENT	91.96	92.73	0.77
ich003c1	ICH003C1	MISSION SPRING VENT	68.06	68.63	0.57
ich004c1	ICH004C1	DEVILS EYE SPRING VENT	35.74	36.25	0.51
ich005c1	ICH005C1	MILL POND SPRING VENT	20.15	20.53	0.38
ich006c1	ICH006C1	CEDAR HEAD SPRING	4.89	5.53	0.64
ich007c1	ICH007C1	GRASSY HOLE	2.08	2.17	0.09
ich008c1	ICH008C1	COFFEE SPRINGS	1.56	1.26	-0.30
iro010c1	IRO010C1	IRON SPRINGS	0.61	7.48	6.87
jam010c1	JAM010C1	JAMISON SPRINGS	0.55	3.56	3.01
jul010c1	JUL010C1	JULY SPRING	67.62	77.66	10.04
laf1024001	LAF1024001	UN-NAMED SPRING	1.37	0.80	-0.57
laf57981	LAF57981	UN NAMED SPRING	1.95	3.05	1.10
laf57982	LAF57982	UN NAMED SPRING	2.95	3.98	1.03

PEST Name	STATID	Spring Name	Simulated Springflow (cfs)	Target Springflow (cfs)	Residual (Observed - Simulated)
laf710981	LAF710981	UN-NAMED SPRING	1.12	0.75	-0.37
laf718971	LAF718971	UN-NAMED SPRING	14.17	13.78	-0.39
laf718972	LAF718972	UN-NAMED SPRING	17.80	17.81	0.01
laf919971	LAF919971	UN-NAMED SPRING	0.33	0.18	-0.15
laf919972	LAF919972	UN-NAMED SPRING	1.40	2.08	0.68
laf922975	LAF922975	UN-NAMED SPRING	1.89	3.87	1.98
laf922976	LAF922976	UN-NAMED SPRING	0.71	1.18	0.47
laf922977	LAF922977	UN-NAMED SPRING	1.69	0.54	-1.15
laf924971	LAF924971	UN-NAMED SPRING	12.92	13.72	0.80
laf924972	LAF924972	UN-NAMED SPRING	0.45	0.11	-0.34
laf929971	LAF929971	UN-NAMED SPRING	8.37	8.75	0.38
laf929972	LAF929972	UN-NAMED SPRING	0.34	2.21	1.87
laf929973	LAF929973	UN-NAMED SPRING	10.03	10.81	0.78
laf93971	LAF93971	UN-NAMED SPRING	2.82	2.46	-0.36
lbs010c1	LBS010C1	BLUE SPRINGS NR MAYO	83.61	84.29	0.68
lcp010c1	LCP010C1	LITTLE COPPER (DIX94971)	3.19	14.40	11.21
lds010c1	LDS010C1	LITTLE DEVILS	1.19	2.22	1.03
lfn010c1	LFN010C1	LITTLE FANNING SPRINGS	11.38	9.61	-1.77
lil010c1	LIL010C1	LILLY SPRINGS	27.07	36.67	9.60
lim010c1	LIM010C1	LIME SPRINGS	24.58	24.77	0.19
lou010c1	LOU010C1	LOUISE SPRINGS	0.94	0.46	-0.48
lrs010c1	LRS010C1	LITTLE RIVER SPRINGS	76.06	76.58	0.52
lsr010c1	LSR010C1	LIME RUN SINK	98.27	99.26	0.99
lur010c1	LUR010C1	LURAVILLE SPRINGS	4.50	5.37	0.87
mad610981	MAD610981	UN NAMED SPRING	5.26	6.01	0.75
mad610982	MAD610982	UN NAMED SPRING	32.13	41.14	9.01
mad612981	MAD612981	UN NAMED SPRING	15.20	15.43	0.23
mad612982	MAD612982	UN NAMED SPRING	15.22	15.43	0.22
mad922971	MAD922971	UN-NAMED SPRING	0.84	0.21	-0.63
mad922972	MAD922972	UN-NAMED SPRING	0.88	0.11	-0.77
mad922973	MAD922973	UN-NAMED SPRING	0.79	0.13	-0.66
mad922974	MAD922974	UN-NAMED SPRING	0.81	0.28	-0.53
mad922975	MAD922975	UN-NAMED SPRING	0.76	0.32	-0.44
mad922976	MAD922976	UN-NAMED SPRING	0.50	0.32	-0.18
mad922977	MAD922977	FARA SPRINGS	10.43	11.28	0.85
man010c1	MAN010C1	MANATEE SPRINGS	233.81	232.23	-1.58
mat010c1	MAT010C1	MATTAIR SPRINGS	23.01	24.30	1.29

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mcc010c1	MCC010C1	McCRABB SPRINGS (DIX95971)	10.33	19.29	8.96
mea010c1	MEA010C1	MEARSON SPRINGS	61.60	64.09	2.49
mor010c1	MOR010C1	MORGAN SPRING	17.64	18.09	0.45
oas010c1	OAS010C1	OASIS SPRINGS	0.17	1.17	1.00
org010c1	ORG010C1	ORANGE GROVE SPRING	21.99	22.85	0.86
ott010c1	OTT010C1	OTTER SPRINGS CAMPGROUND	6.43	17.68	11.25
own010c1	OWN010C1	OWENS SPRINGS	36.85	37.83	0.98
pea010c1	PEA010C1	PEACOCK SPRING	51.45	52.51	1.06
per010c1	PER010C1	PERRY SPRINGS	7.30	8.00	0.70
pic010c1	PIC010C1	PICKARD SPRINGS	3.31	12.59	9.28
poe010c1	POE010C1	POE SPRINGS IN ALACHUA COUNTY	50.94	60.51	9.57
pot010c1	POT010C1	POTHOLE SPRING	22.48	28.29	5.81
pts010c1	PTS010C1	POT SPRING	39.11	39.28	0.17
rkb010c1	RKB010C1	ROCK BLUFF SPRING	29.46	35.46	6.00
rls010c1	RLS010C1	RUTH/LITTLE SULFUR SPRINGS	9.39	9.12	-0.27
roy010c1	ROY010C1	ROYAL SPRINGS	7.59	8.82	1.23
rum010c1	RUM010C1	RUM ISLAND SPRING	27.38	37.14	9.76
run010c1	RUN010C1	RUNNING SPRING - WEST	26.74	28.04	1.30
run011c1	RUN011C1	RUNNING SPRINGS - EAST	36.43	38.28	1.85
saw010c1	SAW010C1	SAWDUST SPRING	9.39	7.46	-1.93
sbl010c1	SBL010C1	SUWANNEE BLUE SPRINGS	10.32	18.92	8.60
scs010c1	SCS010C1	SUWANACOOCHEE SPRINGS	37.43	37.72	0.29
sfr045c1	SFR045C1	SANTA FE RISE	350.99	361.23	10.24
shn010c1	SHN010C1	SHINGLE SPRINGS	4.18	12.77	8.59
shy010c1	SHY010C1	SHIRLEY SPRINGS	1.02	1.81	0.79
sis010c1	SIS010C1	IRON SPRING ON THE STEINHATCHEE RIVER	1.63	1.60	-0.03
sss010c1	SSS010C1	SUWANNEE SPRINGS	13.84	20.95	7.11
str010c1	STR010C1	STEINHATCHEE RISE	561.70	560.00	-1.70
sub010c1	SUB010C1	SUNBEAM SPRINGS	54.84	70.59	15.75
sun010c1	SUN010C1	SUN SPRINGS	31.35	39.78	8.43
suw1017971	SUW1017971	UN-NAMED SPRING	5.48	5.82	0.34
suw1017972	SUW1017972	UN-NAMED SPRING	17.13	19.62	2.49
suw1019971	SUW1019971	UN-NAMED SPRING	3.67	0.48	-3.19
suw1023971	SUW1023971	UN-NAMED SPRING	1.18	0.15	-1.03
suw106971	SUW106971	UN-NAMED SPRING	0.53	0.47	-0.06
suw107971	SUW107971	UN-NAMED SPRING	17.63	23.31	5.68
suw718971	SUW718971	UN-NAMED SPRING	5.17	6.20	1.03

PEST Name	STATID	Spring Name	Simulated Springflow (cfs)	Target Springflow (cfs)	Residual (Observed - Simulated)
suw725971	SUW725971	UN-NAMED SPRING	7.05	8.04	0.99
suw917971	SUW917971	UN-NAMED SPRING	0.39	3.44	3.05
suw917972	SUW917972	UN-NAMED SPRING	0.36	0.11	-0.25
suw919971	SUW919971	UN-NAMED SPRING	3.16	4.57	1.41
suw919972	SUW919972	UN-NAMED SPRING	0.82	0.75	-0.07
suw919973	SUW919973	UN-NAMED SPRING	1.46	2.33	0.87
suw919974	SUW919974	UN-NAMED SPRING	0.29	1.01	0.72
suw922971	SUW922971	UN-NAMED SPRING	1.62	1.08	-0.54
suw922972	SUW922972	UN-NAMED SPRING	0.92	0.54	-0.38
suw922973	SUW922973	UN-NAMED SPRING	1.95	1.29	-0.66
suw922974	SUW922974	UN-NAMED SPRING	0.93	0.54	-0.39
suw923971	SUW923971	UN-NAMED SPRING	37.77	37.96	0.19
suw923972	SUW923972	UN-NAMED SPRING	4.73	0.14	-4.59
suw923973	SUW923973	UN-NAMED SPRING	132.30	132.53	0.23
suw925971	SUW925971	UN-NAMED SPRING	37.29	37.33	0.04
suw925972	SUW925972	UN-NAMED SPRING	14.31	14.28	-0.03
suw925973	SUW925973	UN-NAMED SPRING	7.40	7.64	0.24
suw925974	SUW925974	UN-NAMED SPRING	1.72	1.81	0.09
suw925975	SUW925975	UN-NAMED SPRING	6.49	0.14	-6.35
tay625991	TAY625991	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	2.04	2.13	0.09
tay625993	TAY625993	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	23.70	24.00	0.30
tay625995	TAY625995	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	0.91	0.32	-0.59
tay730991	TAY730991	UN-NAMED SPRING ON THE ECONFINA RIVER	16.49	7.55	-8.94
tay76991	TAY76991	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	5.66	6.40	0.74
tay76992	TAY76992	UN-NAMED SPRING ON THE STEINHATCHEE RIVER	119.41	119.97	0.56
tay924991	TAY924991	UN-NAMED SPRING ON SPRING CREEK	1.79	1.14	-0.65
tay924993	TAY924993	UN-NAMED SPRING ON SPRING CREEK	3.55	3.43	-0.12
tel010c1	TEL010C1	TELFORD SPRINGS	40.86	41.58	0.72
tra010c1	TRA010C1	TRAIL SPRING GROUP	2.38	10.85	8.47
try010c1	TRY010C1	TROY SPRINGS	138.88	140.15	1.27
tur010c1	TUR010C1	TURTLE SPRINGS	24.72	31.28	6.56
twn010c1	TWN010C1	TWIN SPRINGS	12.39	21.06	8.67
wal010c1	WAL010C1	WALDO SPRING	3.62	3.38	-0.24
wcr010c1	WCR010C1	WOODS CK RISE	18.78	18.48	-0.30
wil010c1	WIL010C1	WILSON SPRINGS	32.20	44.66	12.46
wth010c1	WTH010C1	WORTHINGTON SPRING	0.00	0.23	0.23
rainbspr	FDEP	RAINBOW SPRING	653.03	652.09	-0.94

PEST Name	STATID	Spring Name	Simulated Springflow (cfs)	Target Springflow (cfs)	Residual (Observed - Simulated)
silvespr	FDEP	SILVER SPRING MAIN	705.40	707.53	2.13
wakulspr	FDEP	WAKULLA SPRING	668.57	669.29	0.72
auc100c1	FDEP	NUTALL RISE	358.52	360.00	1.48
big010c1	FDEP	BIG SPRINGS	14.24	18.42	4.18
bks010c1	FDEP	BLUE CREEK SPRING NR KEATON BEACH	10.49	10.00	-0.49
brs010c1	FDEP	BRADLEY SPRINGS	0.17	5.47	5.30
bsb010c1	FDEP	BLUE SPRING NEAR BRONSON	11.26	17.03	5.77
cis010c1	FDEP	CEDAR ISLAND SPRING	8.82	15.00	6.18
jcs010c1	FDEP	JABO CAMP SPRING	0.00	10.50	10.50
jef312991	FDEP	UN-NAMED SPRING ON THE WASSICA RIVER	0.66	4.65	3.99
jef63991	FDEP	UN-NAMED SPRING ON THE WASSICA RIVER	9.21	10.00	0.79
jef63992	FDEP	UN-NAMED SPRING	9.21	10.00	0.79
jef63993	FDEP	UN-NAMED SPRING ON THE WASSICA RIVER	23.22	25.00	1.78
jef64991	FDEP	UN-NAMED SPRING ON THE WASSICA RIVER	39.25	40.00	0.75
lev719991	FDEP	UN-NAMED SPRING ON THE WACCASSASA RIVER	0.00	15.00	15.00
lev97991	FDEP	UN-NAMED SPRING	3.46	5.00	1.54
sws010c1	FDEP	SPRING WARRIOR SPRING	23.22	23.16	-0.06
tay616991	FDEP	UN-NAMED SPRING	9.81	15.00	5.19
tay616992	FDEP	UN-NAMED SPRING	35.27	33.36	-1.91
tay622991	FDEP	UN-NAMED SPRING	50.20	50.00	-0.20
tay69991	FDEP	UN-NAMED SPRING	5.15	5.00	-0.15
tay69992	FDEP	UN-NAMED SPRING	3.84	3.64	-0.20
tay77041	FDEP	UN-NAMED SPRING ON SPRING CREEK	1.41	0.50	-0.91
tay77042	FDEP	UN-NAMED SPRING ON SPRING CREEK	1.20	0.10	-1.10
tay77043	FDEP	UN-NAMED SPRING ON SPRING CREEK	8.23	8.00	-0.23
tay77044	FDEP	UN-NAMES SPRING ON SPRING CREEK	1.41	0.50	-0.91
tay819991	FDEP	UN-NAMED SPRING	29.18	28.95	-0.23
was100c1	FDEP	WACISSA HEADSPRING	199.35	200.00	0.66
was101c1	FDEP	BIG SPRING ON THE WACISSA RIVER	49.83	50.58	0.75
was102c1	FDEP	BLUE SPRINGS ON THE WACISSA RIVER	45.81	46.64	0.83
was103c1	FDEP	BUZZER LOG SPRINGS ON THE WACISSA RIVER	14.23	15.00	0.77
was104c1	FDEP	CASSIDA SPRINGS ON THE WACISSA RIVER	43.54	44.36	0.82
was105c1	FDEP	GARNER SPRINGS ON THE WACISSA RIVER	9.41	10.00	0.59
was106c1	FDEP	HORSEHEAD SPRINGS ON THE WACISSA RIVER	13.81	15.00	1.19
was107c1	FDEP	LOG SPRING ON THE WACISSA RIVER	49.31	50.00	0.69
was108c1	FDEP	MINNOW SPRINGS ON THE WACISSA RIVER	14.23	15.00	0.77
was109c1	FDEP	THOMAS SPRING ON THE WACISSA RIVER	29.35	30.00	0.65

PEST Name	STATID	Spring Name	Simulated Springflow (cfs)	Target Springflow (cfs)	Residual (Observed - Simulated)
was110c1	FDEP	AUCILLA SPRING ON THE WACISSA RIVER	8.54	8.81	0.27
wek010c1	FDEP	WEKIVA SPRINGS NEAR GULF HAMMOCK	62.85	62.58	-0.27
wlk010c1	FDEP	WALKER SPRING	2.04	1.35	-0.69
citrublspr	FDEP	CITRUS BLUE SPRING	15.52	15.96	0.44
alexaspr	FDEP	ALEXANDER SPRING	114.06	118.19	4.13
deleovospr	FDEP	DELEON SPRING (VOLUSIA)	5.19	22.98	17.79
fernhaspr	FDEP	FERN HAMMOCK SPRINGS	11.07	13.00	1.93
sweetspr	FDEP	CITRUS BLUE SPRING	9.38	12.70	3.32
silveglspr	FDEP	SILVER GLEN SPRINGS	106.84	110.00	3.16
saltmaspr	FDEP	SALT SPRINGS (MARION)	77.61	80.00	2.39
wellslaspr	FDEP	WELLS LANDING SPRING	10.01	9.09	-0.92
tobacpaspr	FDEP	TOBACCO PATCH LANDING SPRING	9.89	2.80	-7.09
croakhospr	FDEP	CROAKER HOLE SPRING	73.91	76.00	2.09
beechspr	FDEP	BEECHER SPRING	3.90	9.04	5.14
mudpuspr	FDEP	MUD SPRING (PUTNAM)	1.72	0.75	-0.97
welakspr	FDEP	WELAKA SPRING	7.37	7.91	0.54
campsespr	FDEP	CAMP SEMINOLE SPRINGS	1.74	0.79	-0.95
orangmaspr	FDEP	ORANGE SPRING (MARION)	4.06	2.40	-1.66
marioblspr	FDEP	MARION BLUE SPRING	1.16	5.00	3.84
greencospr	FDEP	GREEN COVE SPRINGS	5.66	2.86	-2.80
shephspr	FDEP	SHEPHERD SPRING	1.23	4.99	3.76
newpospr	FDEP	NEWPORT SPRING	0.00	8.30	8.30
stmarriris	FDEP	ST MARKS RIVER RISE (LEON)	200.42	200.00	-0.42
naturbrspr	FDEP	NATURAL BRIDGE SPRING (LEON)	151.77	152.00	0.23
rhodespr	FDEP	RHODES SPRINGS #2A	0.00	60.00	60.00
hornspr	FDEP	HORN SPRING	0.00	30.00	30.00
chickbrspr	FDEP	CHICKEN BRANCH SPRING	0.00	50.00	50.00
ala1029101	FDEP	UN-NAMED SPRING	0.86	5.50	4.64
car010c1	FDEP	CARLTON SPRING	0.66	0.05	-0.61
cgs010c1	FDEP	CAMP GROUND SPRING	0.84	0.05	-0.79
col1105041	FDEP	UN-NAMED SPRING	3.20	5.50	2.30
col728101	FDEP	UN-NAMED SPRING	0.08	5.50	5.42
cow010c1	FDEP	COW SPRINGS	1.19	0.05	-1.14
ews010c1	FDEP	EWING SPRINGS	0.94	0.05	-0.89
fsp010c1	FDEP	FENHOLLOWAY SPRING	0.94	0.05	-0.89
hlb010c1	FDEP	HEILBRONN SPRING IN BRADFORD COUNTY	0.00	0.05	0.05
rks010c1	FDEP	ROCK SINK SPRING	14.70	55.00	40.30

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stn015c1	FDEP	STEINHATCHEE SPRING	0.58	0.05	-0.53
suw616101	FDEP	UN-NAMED SPRING	6.49	0.05	-6.44
gandespr	FDEP	GANDER SPRING	0.80	55.00	54.20