Development and Calibration of Surface Water Models to Support the North Florida/Southeast Georgia (NFSEG v1.1) Groundwater Model

by

Tim Cera, P.E.
David Clapp
Yanbing Jia, PhD., P.E.

St. Johns River Water Management District

Palatka, Florida

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Joseph Amoah, PhD., P.E.
Louis Donnangelo
Gustavo Suarez-Narvaez, P.E.

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LIST OF HYDROLOGICAL SIMULATION PROGRAM – FORTRAN (HSPF) SPECIFIC ACRONYMS

AGWET	Active Groundwater ET
AGWI	Active Groundwater Inflow
AGWO	Active Groundwater Outflow
AGWS	Active Groundwater Storage
BASET	Baseflow ET
CEPE	Interception Evaporation
CEPS	Interception Storage
IGWI	Inactive Ground Water Inflow
IMPLND	Impervious Land Element
IGWO	Inactive Ground Water Outflow (interpretation of model feature added to represent springs in several of the models)
IFWO	Interflow Outflow
IFWI	Interflow Input
LZET	Lower Zone Evapotranspiration
LZS	Lower Zone Storage
PERLND	Pervious Land Element
RCHRES	Reach Module
SUPY	Water supply to land element (if not modeling ice/snow equal to precipitation)
SURO	Surface Outflow
SURS	Surface Detention Storage
UZET	Upper Zone Evapotranspiration
UZS	Upper Zone Storage

INTRODUCTION

The North Florida Southeast Georgia (NFSEG) Regional Groundwater Flow Model was developed in a cooperative process that involved several stakeholders, including the St. Johns River Water Management District (SJRWMD), the Suwannee River Water Management District (SRWMD), the Georgia Department of Natural Resources / Environmental Protection Division (EPD), other governmental institutions, water utilities, private industry, and environmental groups. The goal of this cooperative effort was to construct a groundwater flow model that enabled the assessment of climatic and anthropogenic effects on the historical, current, and future groundwater resources of North Florida and Southeast Georgia.

To improve estimates of recharge and maximum saturated evapotranspiration (MSET) for groundwater model input, surface water hydrology for all the surface water basins within the groundwater model boundary were simulated using the Hydrological Simulation Program—FORTRAN (HSPF) software (Bicknell et al. 2001). HSPF is a comprehensive, rainfall-runoff-water-quality model. Calibration of HPSF models to observed surface water flows represents a significant improvement in estimation of recharge and MSET over the previous Soil Conservation Service (SCS) curve number model and approach. The SCS model does not track evaporation and infiltration which are important components of the surface water balance.

The model conceptualization, input datasets, calibration approach, and calibration results for the 55 HSPF models used in the NFSEG V1.1 are described in the following report.

HYDROLOGICAL SIMULATION PROGRAM – FORTRAN (HSPF)

The Hydrological Simulation Program – FORTRAN (HSPF) is a comprehensive hydrology and water quality modeling system. Currently HSPF is part of the USEPA Better Assessment Science Integrating point & Non-point Sources (BASINS) modeling environment. HSPF is highly regarded as a complete and defensible watershed model for the simulation of hydrology and water quality. The HSPF model has been applied in climatic regimes around the world. HSPF continues to undergo refinement and enhancement of its component simulation capabilities along with user support and code.

The watershed is conceptually represented in HSPF by a series of storage compartments (e.g. surface depression, soil zone, ground water zone, river segment). Based on the principal of mass conservation, HSPF performs continuous budget analysis of water quantity and quality for these storage compartments. Given the inputs of meteorological time series and the parameter values related to watershed characteristics, HSPF generates time series of runoff, stream flow, loading rates, and concentrations of various instream water quality constituents.

While most parameters of HSPF can be specified by watershed spatial and physical data, such as land use, topography, stream characteristics, and soil property; a few parameters, such as those related to infiltration, evaporation, and instream kinetics, need to be determined through the calibration process. Model calibration is the process of adjusting values of model parameters to accurately reproduce the observed flow and water quality data. Once calibrated, the HSPF model is considered able to accurately represent the hydrologic and water quality processes in the watershed and can be utilized for scenario analysis.

A watershed and its stream network are characterized in HSPF by various pervious land segments (PERLND), impervious land segments (IMPLND), and reach segments (RCHRES) based on sub-watershed delineation, land uses, and the ratio of perviousness and imperviousness for each land use. The pervious portion of a land use in a sub-watershed is represented as a PERLND, and the impervious portion of a land use in a sub-watershed is represented as an IMPLND. For modeling purposes, the stream network in a sub-watershed is grouped together and represented as a RCHRES. The geometric and hydraulic properties of a RCHRES are represented in HSPF by a FTABLE, which describes the relationships between stage, surface area, volume, and discharge for the reach segment. Detailed description of these sub-modules can be found in Bicknell et al. (2001).

MAJOR WATER BUDGET COMPONENTS OF HSPF

Some understanding of how HSPF views the world is necessary to establish where MODFLOW and HSPF overlap in the overall water balance. Figure 2 and Figure 3 illustrate the water storages and flows through the HSPF system for PERLND and IMPLND. The legend for the model simulation graphics in Figure 2, Figure 3, and Figure 4 is provided in Figure 1. The simulated hydrologic processes for a PERLND include interception, infiltration, evapotranspiration, runoff, and deep percolation. The simulated processes for an IMPLND are like those for a PERLND, except there are no infiltration and subsequent subsurface processes.

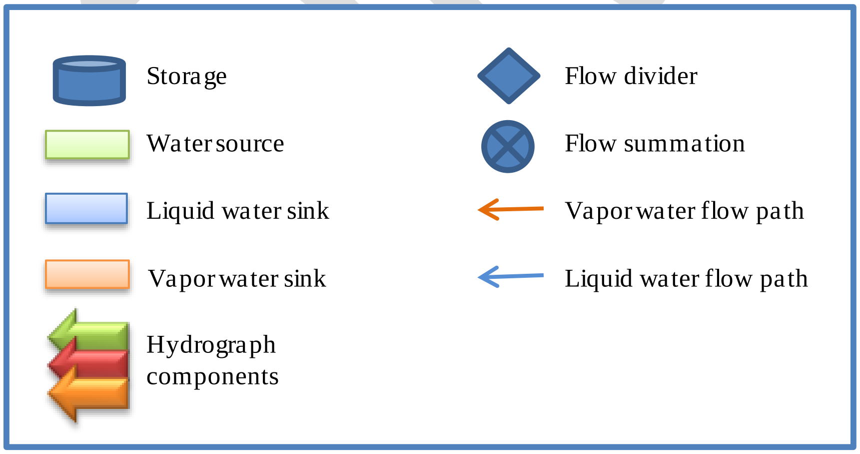

Figure 1. Legend for HSPF model simulation graphics in Figure 2 and Figure 3.

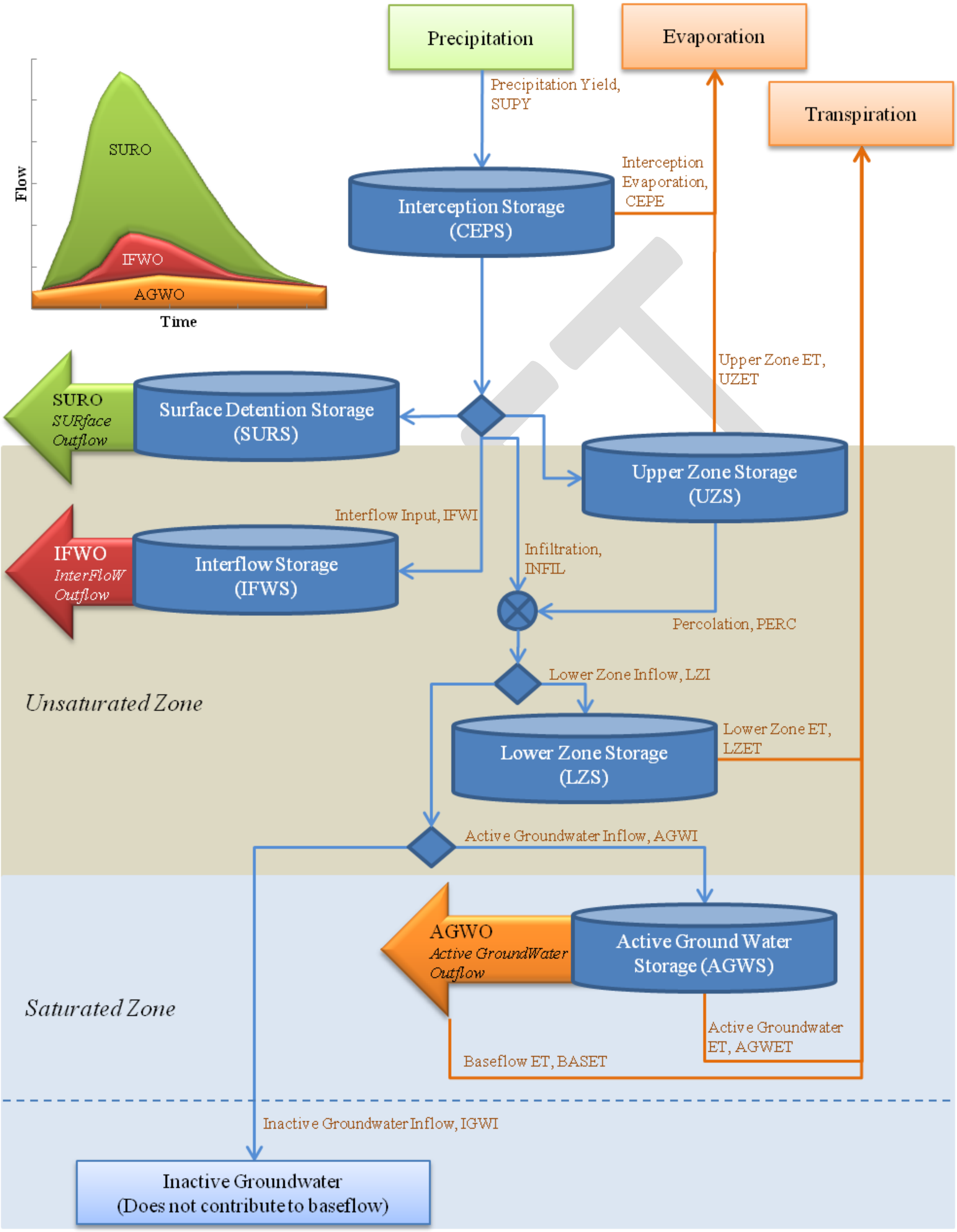

Figure 2. Illustration of water storage and movement in HSPF PERvious LaND (PERLND).

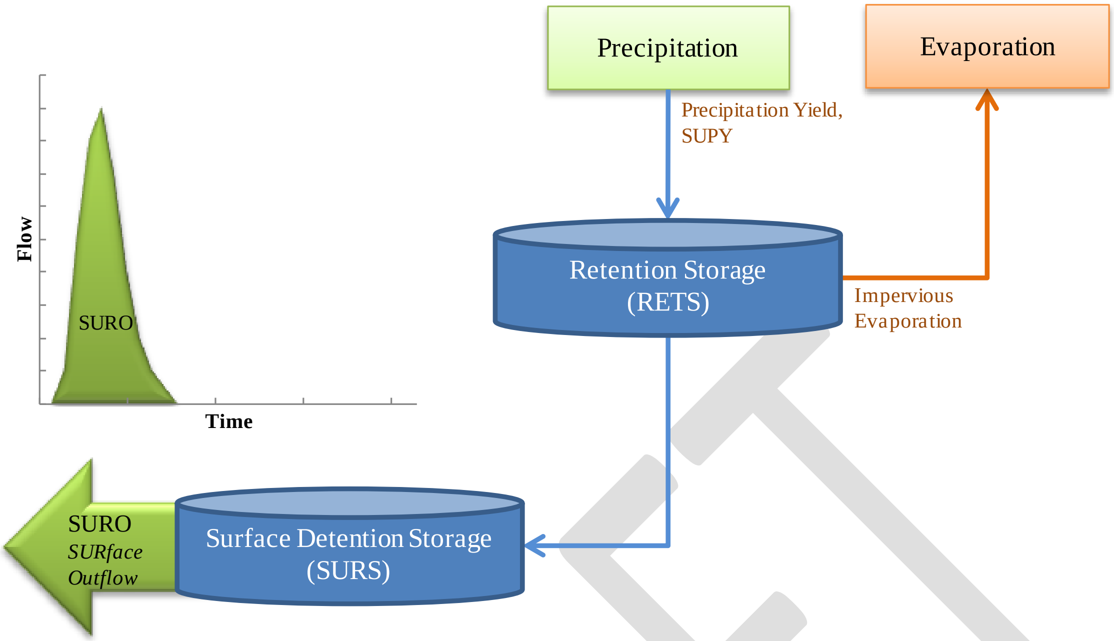

Figure 3. Illustration of water storage and movement in the HSPF model impervious land element (IMPLND).

The RCHRES is the HSPF representation of storage and flow within the local stream reach. In the models, the RCHRES is also the source for water use that comes from surface water. A diagram of a RCHRES is presented as Figure 4.

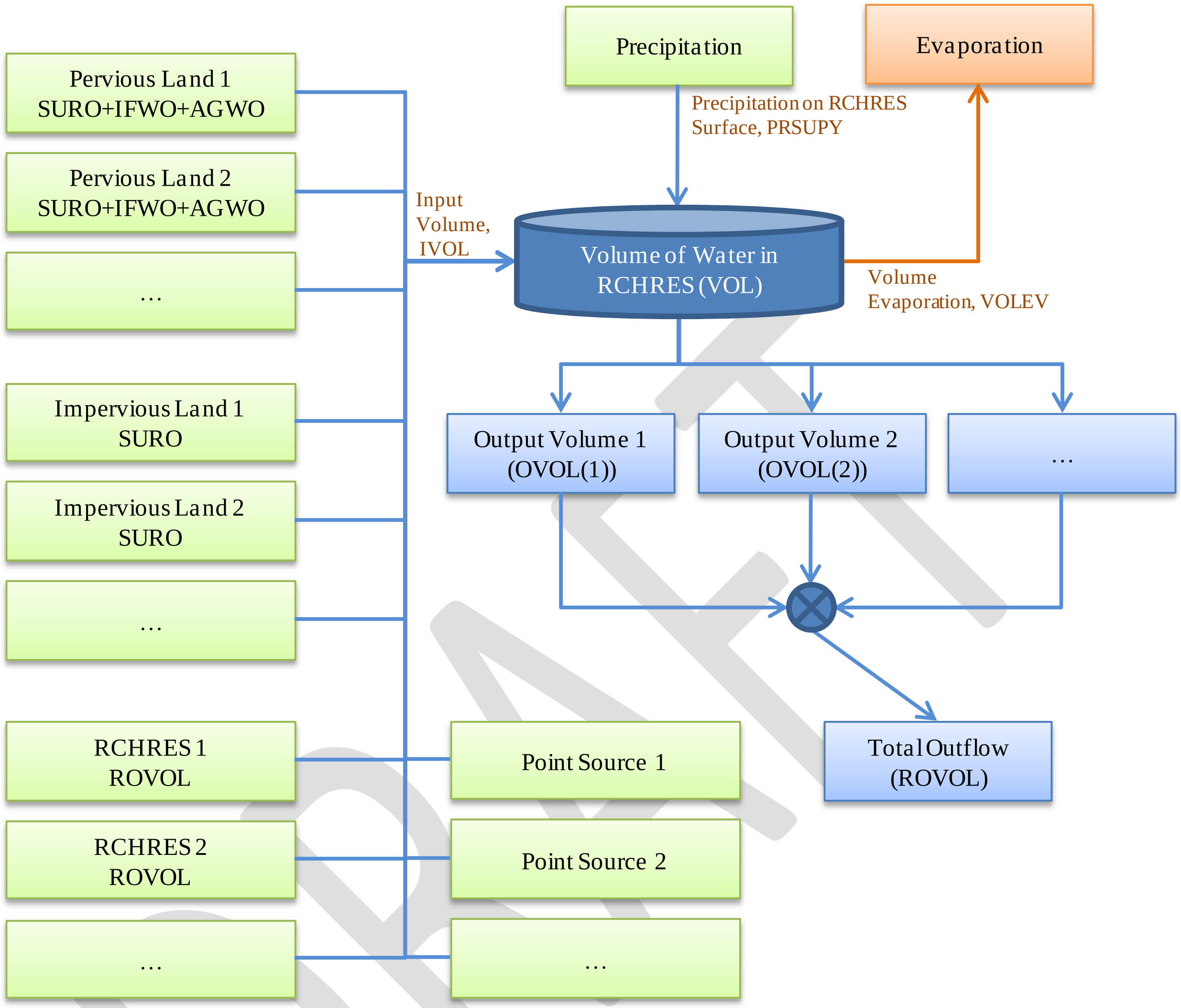

Figure 4. Water collection and movement in a HSPF reach/reservoir element (RCHRES).

HSPF and MODFLOW approach water balance and sometimes even definitions of terms from different perspectives. Coordination between the two models and the derivation of the recharge and maximum saturated ET equations are presented in Appendix A. Table 1 lists the overlapping parts of the MODFLOW and HSPF water balances and the uses within each.

Table 1. Overlapping water balance components between MODFLOW and HSPF.

MODFLOW	HSPF Variables (variable definitions are in Figure 2)	Purpose
Recharge to water table	IGWI + AGWI + SURET	MODFLOW input
Recharge from surficial to next lower confined aquifer. If MODFLOW or data indicate discharge to surficial, then IGWI should be near zero.	IGWI	Comparison/calibration
Baseflow	AGWO	Comparison/calibration
Maximum Saturated ET	Potential ET – CEPE – UZET – LZET	MOFGLOW/ET package input
Saturated ET	AGWET + BASET	Comparison/calibration

Inactive Groundwater Inflow (IGWI) is defined in the HSPF environment as the saturated groundwater component of the water balance that does not contribute to baseflow. It is always a loss out of the ‘bottom’ of the HSPF water balance. IGWI in terms of a representation in MODFLOW would be analogous to recharge from the surficial to the next lower aquifer through a confining layer.

INPUT DATA

The input data for the model are collected from various sources and reformatted to form a consistent framework for the model to use. The input data can be split into three categories; meteorology (Table 2), consumptive use (Table 3) and the input data the defined the watershed (Table 4).

Table 2. HSPF meteorological boundary conditions.

Data	Data Source
Precipitation	National Land Data Assimilation System (NLDAS)
Evaporation	National Land Data Assimilation System (NLDAS)and USGS Evapotranspiration project in Florida

Table 3. Water use data for HSPF.

Data	Data Source
Agricultural irrigation time series	External time-series and polygon layer based on FSAID 1 and tensioned to practice using agricultural use data from SJRWMD, SRWMD, SWFWMD, NWFWMD and USGS
Agricultural surface water withdrawals	
Agricultural groundwater withdrawals	
Agricultural irrigated acreage	Irrigated acreage in Florida based on FSAID 1 for Florida, and USGS outside Florida
Urban irrigation demand	SJRWMD Water Supply Planning and Georgia EPD

Table 4. Spatial data.

Data	Data Source
Watershed and sub-watershed boundaries **HUC8 watershed boundaries: used to establish spatial extent of the models** **HUC12 sub-watershed boundaries (used for establishing closed, flat, and frontal basins to improve sub-watershed delineation)**	NHDPlus version 2
Elevation (for delineation)	1/8 arcsecond gridded dataset from the 3 Digital Elevation Program (3DEP)
Location of USGS flow observation stations (for delineation)	USGS
Land cover	National Land Cover Database, 2001

METEOROLOGY

The precipitation and potential evaporation time-series define the primary hydrologic drivers for HSPF. For HSPF, potential evaporation is defined as the evaporation from a shallow body of water subject to full exposure to sun and wind.

Both precipitation and the core evaporation datasets came from the National Land Data Assimilation Systems (NLDAS). The NLDAS is a quality controlled, meteorological dataset developed to be spatially and temporarily consistent across the contiguous United States (Xia, et al., 2012).

NLDAS has core project support from the NOAA Climate Program Office's Modeling, Analysis, Predictions, and Projections (MAPP) program. It is a collaboration project among the following groups:

- NOAA/NCEP's Environmental Modeling Center (EMC),
- NASA's Goddard Space Flight Center (GSFC),

- Princeton University,
- University of Washington,
- NOAA/NWS Office of Hydrological Development (OHD)
- NOAA/NCEP Climate Prediction Center (CPC)

The NLDAS project also includes four different hydrology models, with the precipitation data as part of the forcing dataset. Table 5 lists all the variables in the forcing dataset.

Table 5. NLDAS parameters in forcing file "A".

NLDAS Parameter	Units	Notes
U wind component	m/s	at 10 meters height
V wind component	m/s	at 10 meters height
air temperature	K	at 2 meters height
specific humidity	kg/kg	at 2 meters height
surface pressure	Pa	
surface downward longwave radiation	W/m^2	
surface downward shortwave radiation	W/m^2	bias corrected using GOES observations
precipitation hourly total	kg/m^2 equates to mm	
precipitation fraction that is convective	unitless	NARR weather model
CAPE: Convective Available Potential Energy	J/kg	NARR weather model
potential evaporation	kg/m^2 equates to mm	NARR weather model

Precipitation

NLDAS combines daily and hourly rain gauge data, NEXRAD Stage II, satellite estimates, and model estimates of precipitation. The data is combined spatially, and disaggregated or filled as needed to create a consistent dataset. There are several quality control checks throughout the process. See Table 6 for the datasets used and for what purpose.

Table 6. List of datasets used to develop the NLDAS precipitation dataset.

Dataset	Years	CONUS	Advantages	Disadvantages
CPC daily rain gauge analysis (unified) (Daly et al. 1994) (Higgins et al. 2000)	1979 - 2011	1/8th-degree PRISM-adjusted analysis	less bias than radar estimates; improved station density; improved QC checks; least squares distance analysis	coarse temporal resolution; overly smooth spatial analysis scheme
CPC daily rain gauge analysis (operational) Chen et al. (2008)	2012 - present	1/8th-degree PRISM-adjusted analysis	less bias than radar estimates; optimal interpolation method	coarse temporal resolution
Stage II Doppler hourly 4-km radar data	1996 - present	1st choice to temporally disaggregate	hourly, 4 km	errors in radar-based magnitude; gaps from equipment downtime and topography
CMORPH satellite-retrieved half-hourly 8-km analysis	2002 - present	2nd choice to temporally disaggregate		
CPC HPD 2x2.5-degree hourly gauge analysis	1979 - present	3rd choice to temporally disaggregate		
NARR/R-CDAS 3-hourly 32-km model-simulated precipitation	1979 - present	4th choice to temporally disaggregate	Able to fill in all spatial and temporal gaps	

NLDAS Data Integration and Availability

NLDAS data is available through two platforms and several Internet applications. NLDAS data available through:

- Platform
  - BASINS: Seamless integration into Better Assessment Science Integrating Nonpoint Sources (BASINS) as a meteorological data source for development of HSPF models.
  - HydroDesktop: NLDAS is one of the datasets included in the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) HydroDesktop application.
- Internet
  - The "tsgettoolbox" tool available for installation within any modern, scientific Python distribution supplies command line and Python library access to NLDAS and other time-series data.
  - The main web site to download NLDAS data is http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings

- ftp://ydro1.sci.gsfc.nasa.gov/data/s4pa/NLDAS/NLDAS_FORA0125_H.002/
- Mirador is an earth science data search tool. It has a drastically simplified, clean interface and employs the Google mini appliance for metadata keyword searches. Other features include quick response, spatial and parameter sub-setting, data file hit estimator, Gazetteer (geographic search by feature name capability), and an interactive shopping cart. http://mirador.gsfc.nasa.gov/
- Giovanni is a Web-based application developed by the GES DISC NASA that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data without having to download the data. http://disc.sci.gsfc.nasa.gov/giovanni.
- SSW is a Simple Subset Wizard that provides a simple interface for parameter and spatial sub-setting, and format conversion.
- USGS has adopted the NLDAS datasets and made them available through the USGS Geo Data Portal (GDP). The GDP has the ability to process data in various ways for you and when finished sends you a link to download the results. http://cida.usgs.gov/gdp/
- With the USGS Geo Data Portal you can also write a Python program using the pyGDP library to pull data directly from GDP into your Python program.

Comparison Against NEXRAD and Rain Gauges

Raw NEXRAD rainfall estimates are very poor at capturing accurate volumes, though they can represent the spatial characteristics of rainfall. Rain gauges are very good at getting good volumes but have poor spatial representation. The District NEXRAD vendors combined these datasets by adjusting the NEXRAD surface so that the average volumes calculated by NEXRAD would match the average volume from the rain gauges. Over long periods of time you would expect close agreement. Table 7 compares the processing and available data from the three systems.

Table 7. Comparison of available data from NLDAS, NEXRAD, and rain gauges.

	NLDAS	**SJRWMD NEXRAD Precipitation**	**SJRWMD Rain Gauges**
Spatial Type	Gridded	Gridded	Irregularly spaced
Spatial Aggregation	Average over grid cell	Average over grid cell	Sample from 8 inch diameter rain gauge
Spatial Domain	Continental United States	SJRWMD plus buffer[1]	SJRWMD
Spatial Interval	⅛ degree x ⅛ degree approx. 12x12 km	2x2 km	if have approx. 100 gauges then would average 20 km between gauges
Time Domain	1979-continuing	2007-continuing[2]	early 1970s-continuing
Time Interval	1 hour	1 hour	time stamp for each 0.01 inch tip, typically aggregated to an hour

1. What is currently available to SJRWMD staff, though all of Florida is processed by the current contractor (Vieux and Associates).
2. Hourly data is no longer available before 2007 because of problems with the data.

A map of the average annual differences (NEXRAD - NLDAS) is shown in Figure 1. Figure 1 is created by first developing a NEXRAD dataset that can be compared to the NLDAS by calculating an area-weighted average of the NEXRAD grids that lie within each NLDAS grid cell. Included in Figure 1 is an indication of the influence of each of the main NEXRAD radar installations that cover the SJRWMD. The figure shows that most of the precipitation estimates are within plus or minus 10% (approx. plus or minus 5 inches) of each other.

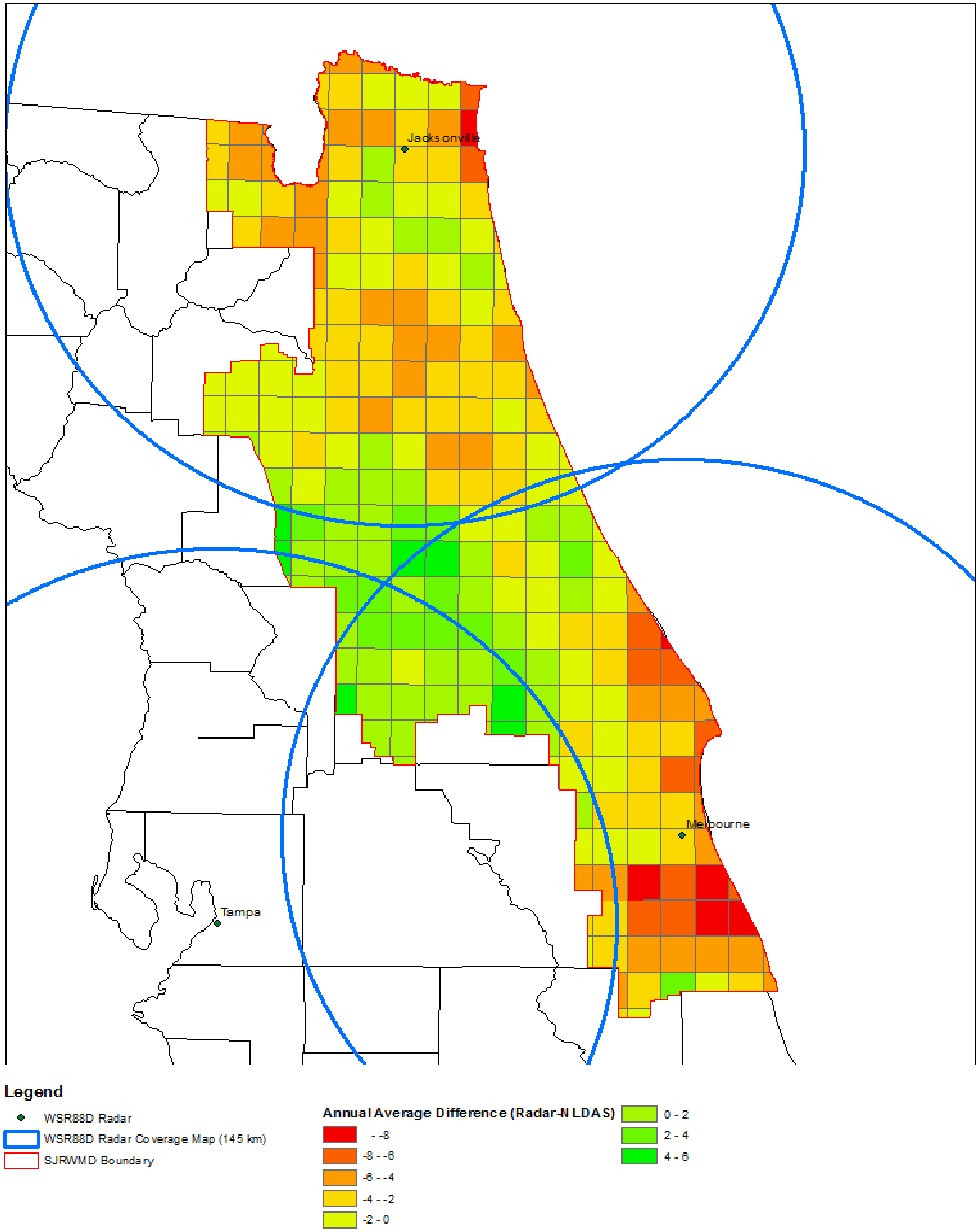

Figure 5. Average annual difference between NEXRAD and NLDAS precipitation.

NLDAS was chosen since it covered Georgia, South Carolina, and Alabama, and it supplied the hourly intervals needed by HSPF. The NLDAS precipitation dataset has been very nice to work with in the calibration of the HSPF models.

Nigro et al. (2010) compared the performance of NLDAS, Stage IV NEXRAD (4x4 km), and rain gauges in HSPF models of the Chesapeake Bay watershed. They found significant improvements of using the NLDAS or NEXRAD precipitation compared to point rain gauges. They saw little difference in the performance between NLDAS and Stage IV NEXRAD precipitation; “There is no demonstrable advantage for using the Stage IV data over the NLDAS 1/8th degree data based on our results.”

NLDAS annual precipitation is mapped in Figure 6, Figure 7, and Figure 8, for years 2001, 2009, and 2010, respectively.

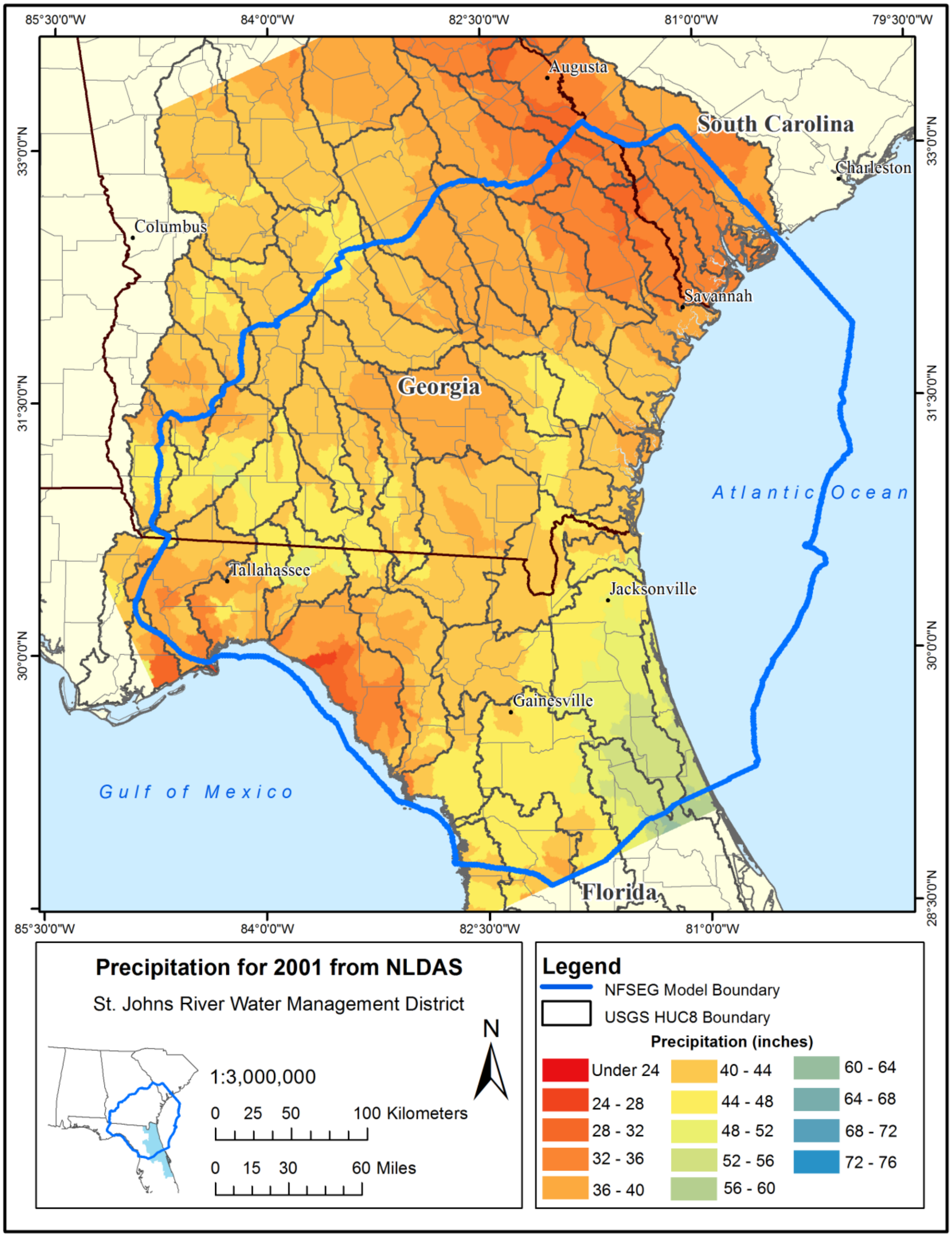

Figure 6. NLDAS annual precipitation for 2001 in inches.

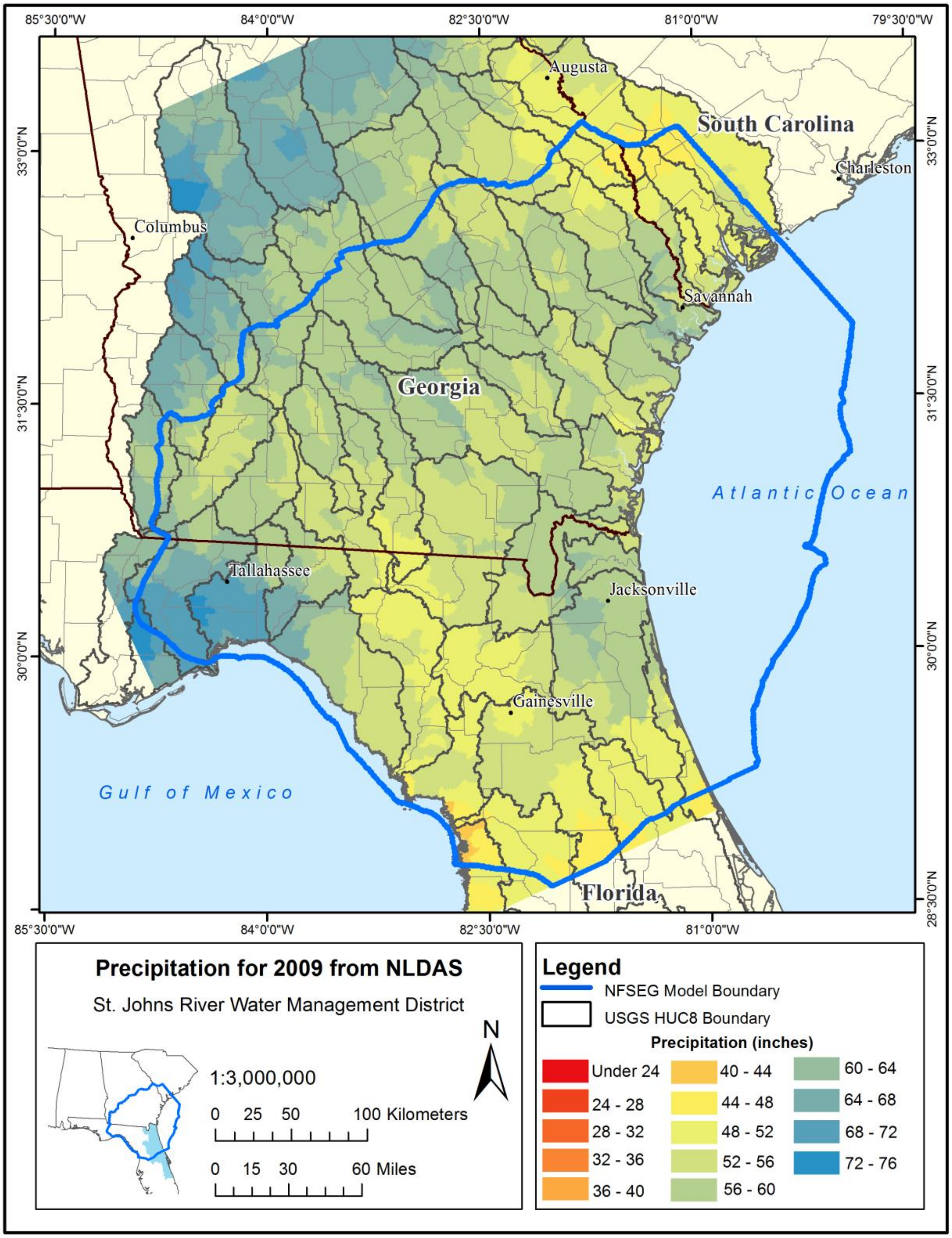

Figure 7. NLDAS annual precipitation for 2009 in inches.

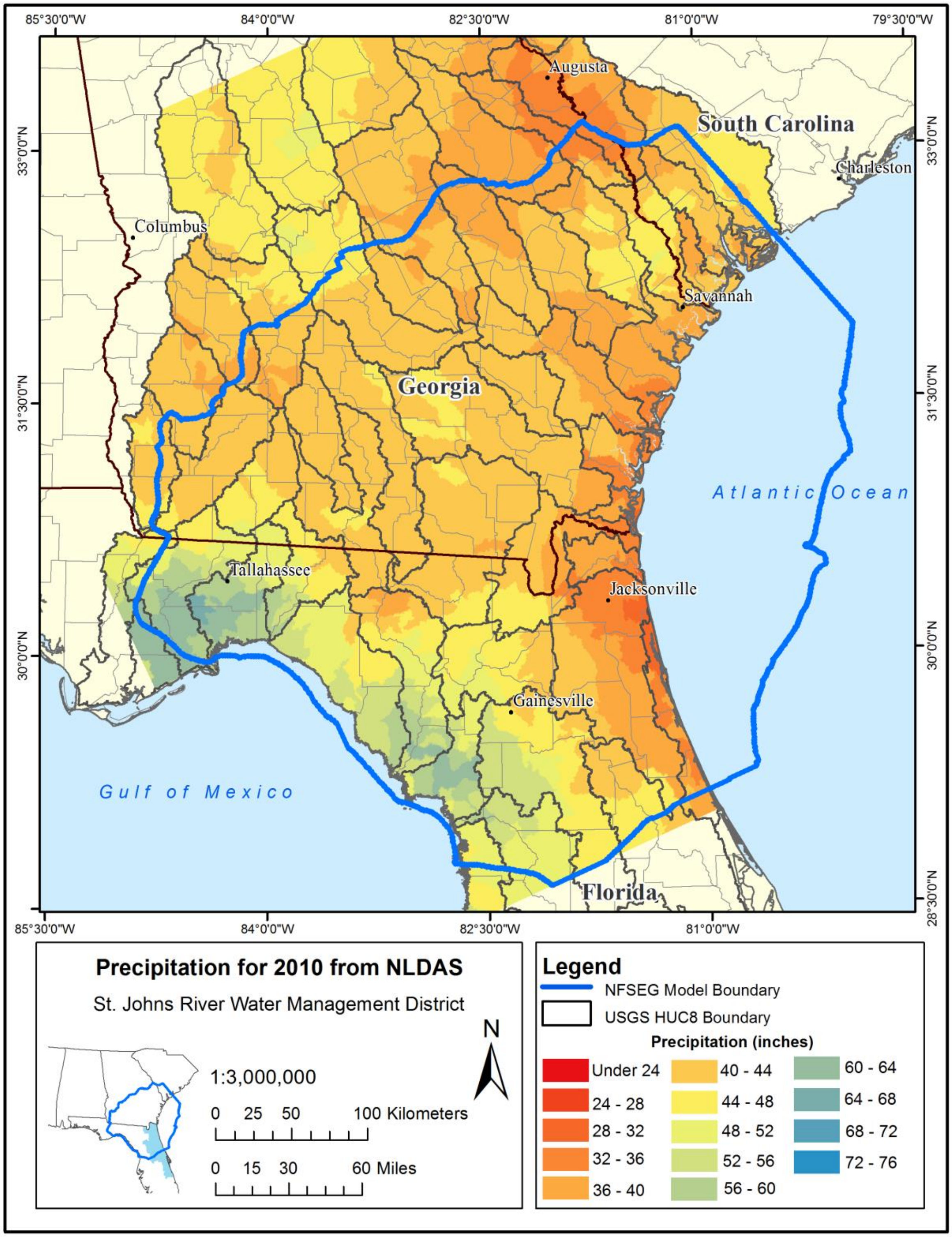

Figure 8. NLDAS annual precipitation for 2010 in inches.

Potential Evaporation

The NLDAS potential evaporation, instead of being a data assimilation product like precipitation (there are very few evaporation data sources available to assimilate), is taken unchanged from the North American Regional Reanalysis weather model without any corrections or modifications. After an initial evaluation of the utility, it was shown to too high to be used directly. We developed a monthly correction factor comparing the NLDAS potential evaporation to data from the USGS Florida Evaporation project (http://fl.water.usgs.gov/et/).

The monthly factors shown in Figure 9 represent a spatial coherence at the locations scattered throughout the SJRWMD.

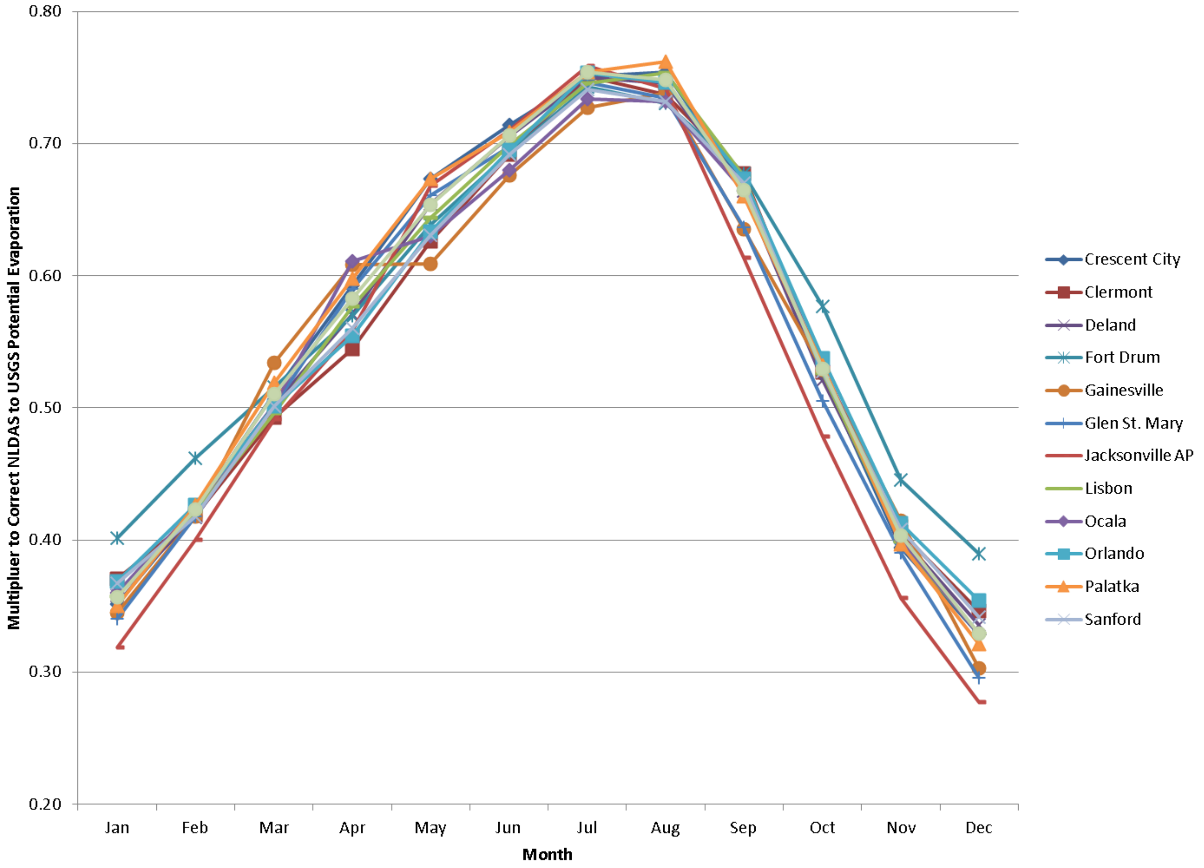

Figure 9. Comparison of NLDAS potential evaporation to USGS potential evaporation at several locations.

From this analysis to tension the NLDAS data to the USGS data, the monthly factors in Table 8 were applied to the NLDAS potential evaporation data.

Table 8. Monthly tensioning factors for NLDAS potential evaporation

Month	Factor
January	0.36
February	0.42
March	0.51
April	0.58
May	0.65
June	0.71
July	0.75
August	0.75
September	0.66
October	0.53
November	0.40
December	0.33

The annual potential evaporation, tensioned to USGS potential evaporation, for 2001, 2009, and 2010 are shown in Figure 10, Figure 11, and Figure 12, respectively.

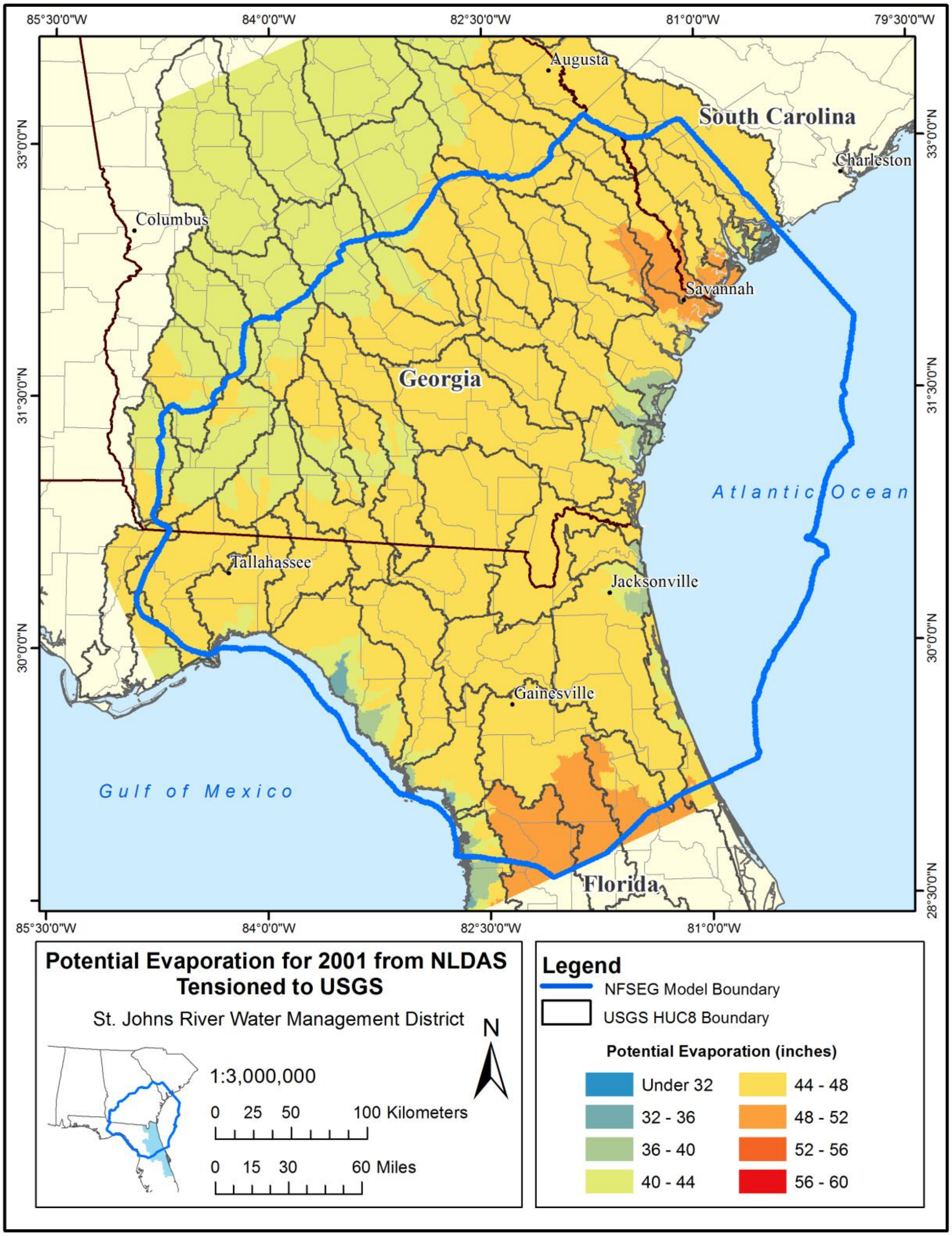

Figure 10. Potential evaporation for 2001 from NLDAS tensioned to USGS.

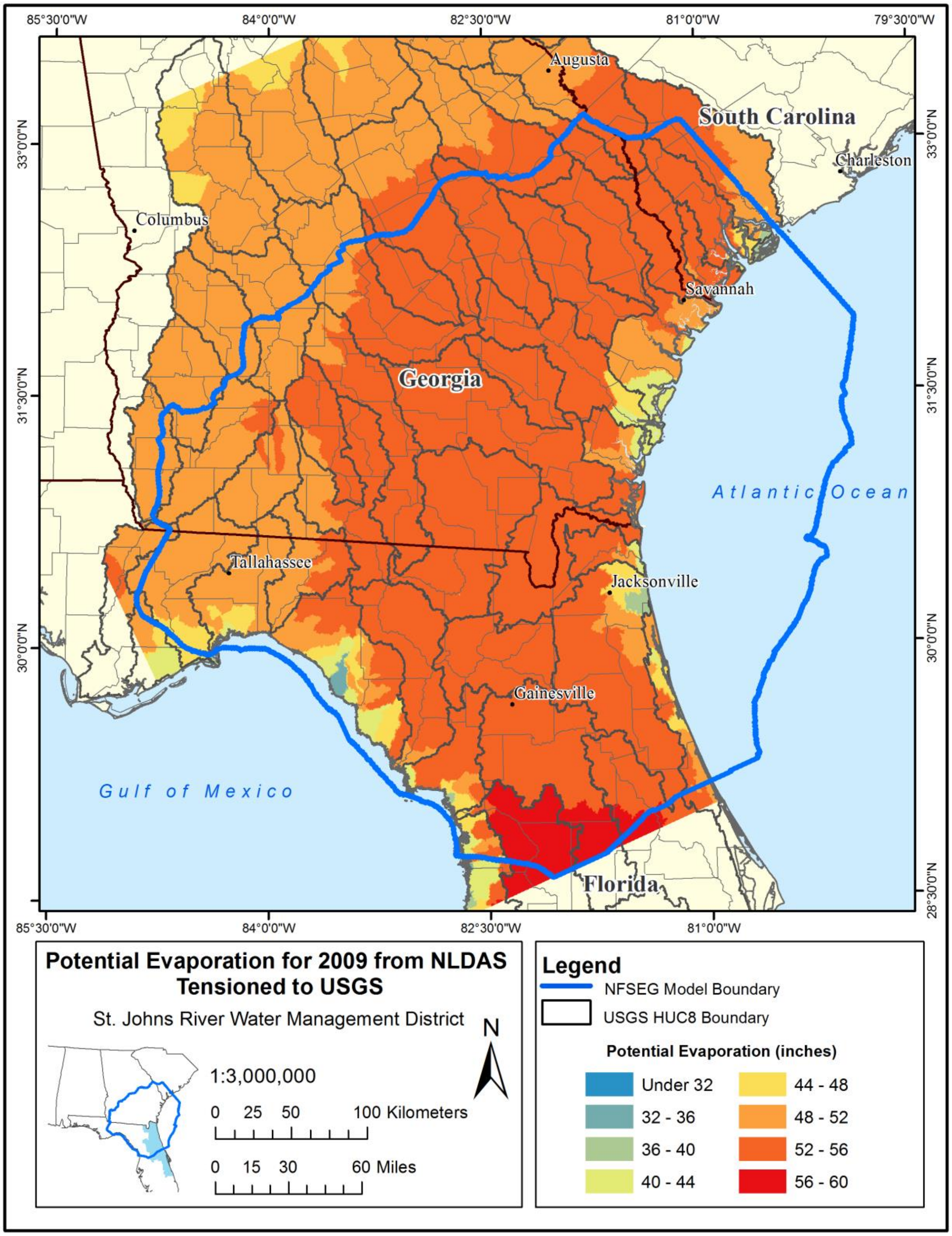

Figure 11. Potential evaporation for 2009 from NLDAS tensioned to USGS.

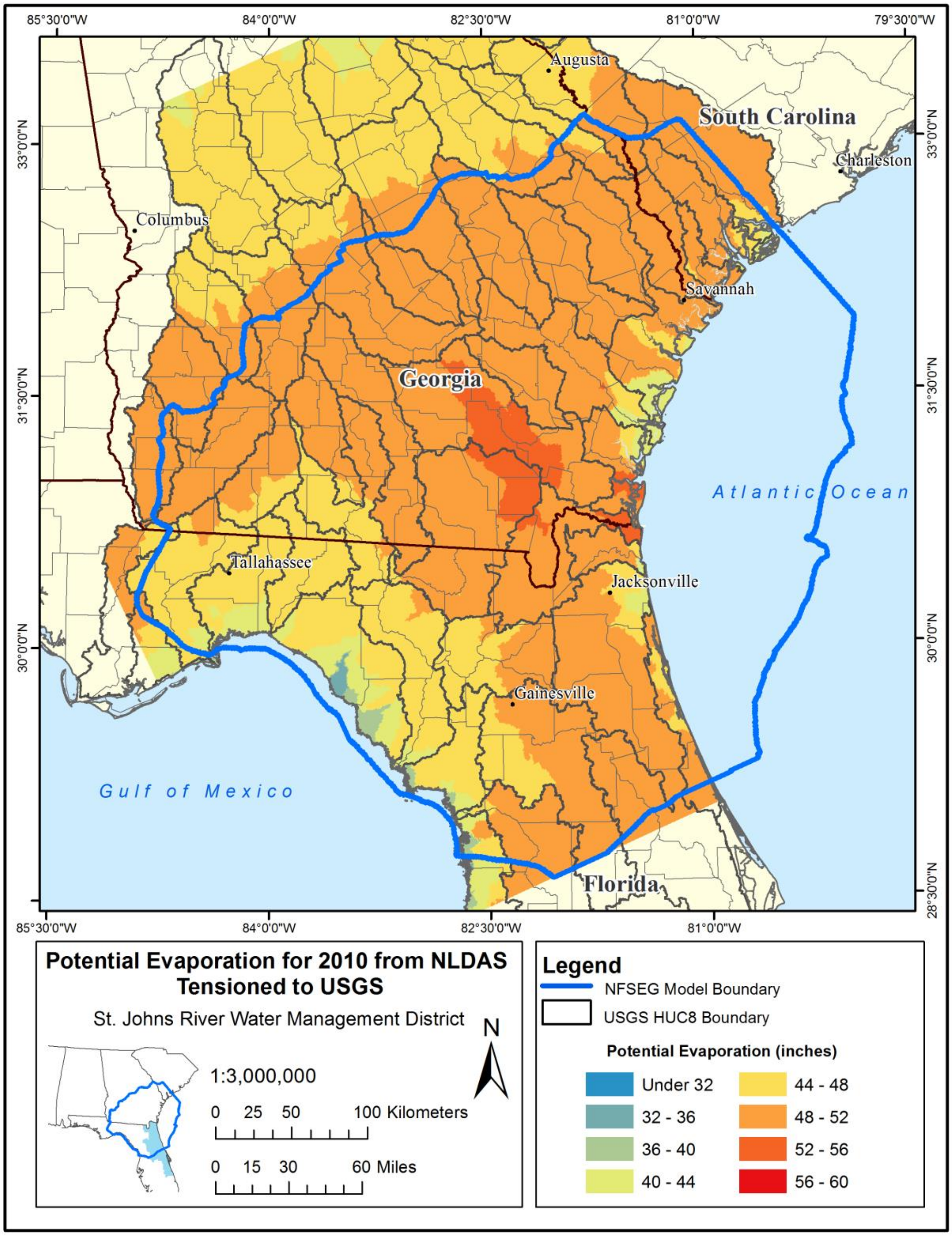

Figure 12. Potential evaporation for 2010 from NLDAS tensioned to USGS.

WATER USE

The consumptive water use throughout the NFSEG domain is documented in detail by others that have worked on the development of the datasets. The description in this document addresses only how the dataset was included in the HSPF models.

Agricultural Irrigation

The agricultural irrigation time-series were developed as part of FSAID 1. The overall process was to run the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) model to establish demand based irrigation requirements and then tension those volumes to match actual practice. The AFSIRS model used the same NLDAS precipitation as the HSPF models and a reference evapotranspiration dataset derived from the other meteorological data in the NLDAS suite. The reference evapotranspiration development was performed by Intera under contract to the SJRWMD.

Irrigation in HSPF can be included in two ways, imposed as an external time-series (analogous to adding additional precipitation), or using a crop demand algorithm based on the AFSIRS model. The irrigation demand time-series was established by the SJRWMD Water Supply Planning group based on a separate run of AFSIRS, then tensioned to practice. Since the tensioning to practice could not be done easily within HSPF, a time-series of irrigation per polygon was developed that is imposed as an external source into HSPF.

Which dataset was used for tensioning to practice was based on availability of data. For SJRWMD and SWFWMD, actual metered data was used and for SRWMD, Georgia, Alabama, and South Carolina the USGS county wide estimates were used.

The daily time-series was disaggregated to hourly and applied between the hours of 6 and 10 in the morning.

The irrigation types were used to put the water into the correct part of the HSPF water balance as shown in Table 9.

Table 9. Irrigation type matched to appropriate part of HSPF water balance.

Irrigation System	Application to HSPF Water Balance
Pipeline Seepage	LZLI: Lower Zone Lateral Inflow
Micro Drip	SURLI: Surface Storage Lateral Inflow
Container Nursery	SURLI: Surface Storage Lateral Inflow
Crown Flooding	LZLI: Lower Zone Lateral Inflow
Linear Pipeline Seepage	LZLI: Lower Zone Lateral Inflow
Low Volume	SURLI: Surface Storage Lateral Inflow
Micro Spray	SURLI: Surface Storage Lateral Inflow
Overhead Frip	SURLI: Surface Storage Lateral Inflow
Pipeline Seepage	LZLI: Lower Zone Lateral Inflow
Seepage	LZLI: Lower Zone Lateral Inflow
All other types	Applied as precipitation (PREC)

Two time-series were developed for each irrigated polygon, one for irrigation supplied by groundwater and the other for irrigation supplied by surface water. The time-series that represented the irrigation supplied by surface water was also used to take the same amount of water from the local reach.

Additional detail about the development of the tensioned FSAID 1 project is provided in the documentation of the water use component of the NFSEG project.

Urban Irrigation and Septic Fields

A monthly time-series for indoor, outdoor, and indoor that would go to septic was developed for each sub-watershed. This effort started with utility records, compared to parcel records, then extended to account for domestic self-supply and areas in Florida and Georgia where we had no utility records. Additional detail about the development of this dataset is provided in the documentation of the urban water use component of the NFSEG project.

The irrigation and septic volumes were applied uniformly within each month, and uniformly across all urban land uses. Since this uniformity implies a low application rate, the irrigation was applied as Surface Lateral Inflow (SURLI) to avoid interception losses that would occur if applied as precipitation. Volume from septic fields was applied to Lower Zone Lateral Inflow (LZLI). All water for urban irrigation and septic field contribution was considered to come from groundwater.

Golf Courses

Golf course irrigation use was established based on the best available data for the region. Where available, permitted or measured values were used, otherwise used USGS estimates. Additional detail is available in other NFSEG documentation.

Monthly time-series of golf course volumes were established per irrigated area. The volumes were imposed into HSPF as SURLI and from an evaluation of sourcing data in SJRWMD, an estimated split of 50/50 was established between surface water and groundwater. The volume to supply the surface water component is taken from the local reach within HSPF.

Reuse

Reuse data came from FDEP as part of the WAFR database. Since sourcing and volumes for agricultural irrigation, urban irrigation and septic, and golf course irrigation were already established in other ways, the inclusion of those reuse components would double count the reuse volumes. The WAFR database does not include the actual polygon area for spray fields or other aerial applications, there is only a point. All aerial discharges therefore were applied to developed open space within the sub-watershed. The point discharges were sent to the local reach. Additional detail is available in other documentation of the development of NFSEG water use datasets.

SPATIAL DATA

Most of the framework describing the sub-watersheds within the HSPF models is developed from spatial data.

Watershed and Sub-Watershed Boundaries

The model boundaries were set to the USGS HUC8 watershed boundaries (Figure 13). There are 55 models within or contributing to the NFSEG groundwater model. Watershed boundaries are established by the USGS at several levels identifies by a series of digits as part of the Watershed Boundary Dataset (WBD). The HUC4 boundaries form very large watersheds, with the HUC8 boundaries as sub-watersheds of HUC4, and HUC12 are sub-watersheds of the HUC8 boundaries. There are some regions that also have HUC16 sub-watersheds, but these are outside of the southeast. The HUC4 is labeled with 4 digits, the HUC8 with 8 digits, and the HUC12 with 12 digits. All of the HUC8 sub-watersheds in a HUC4 have the same 4 digits at the beginning and all HUC12 sub-watersheds in a HUC8 share the same 8 digits at the beginning.

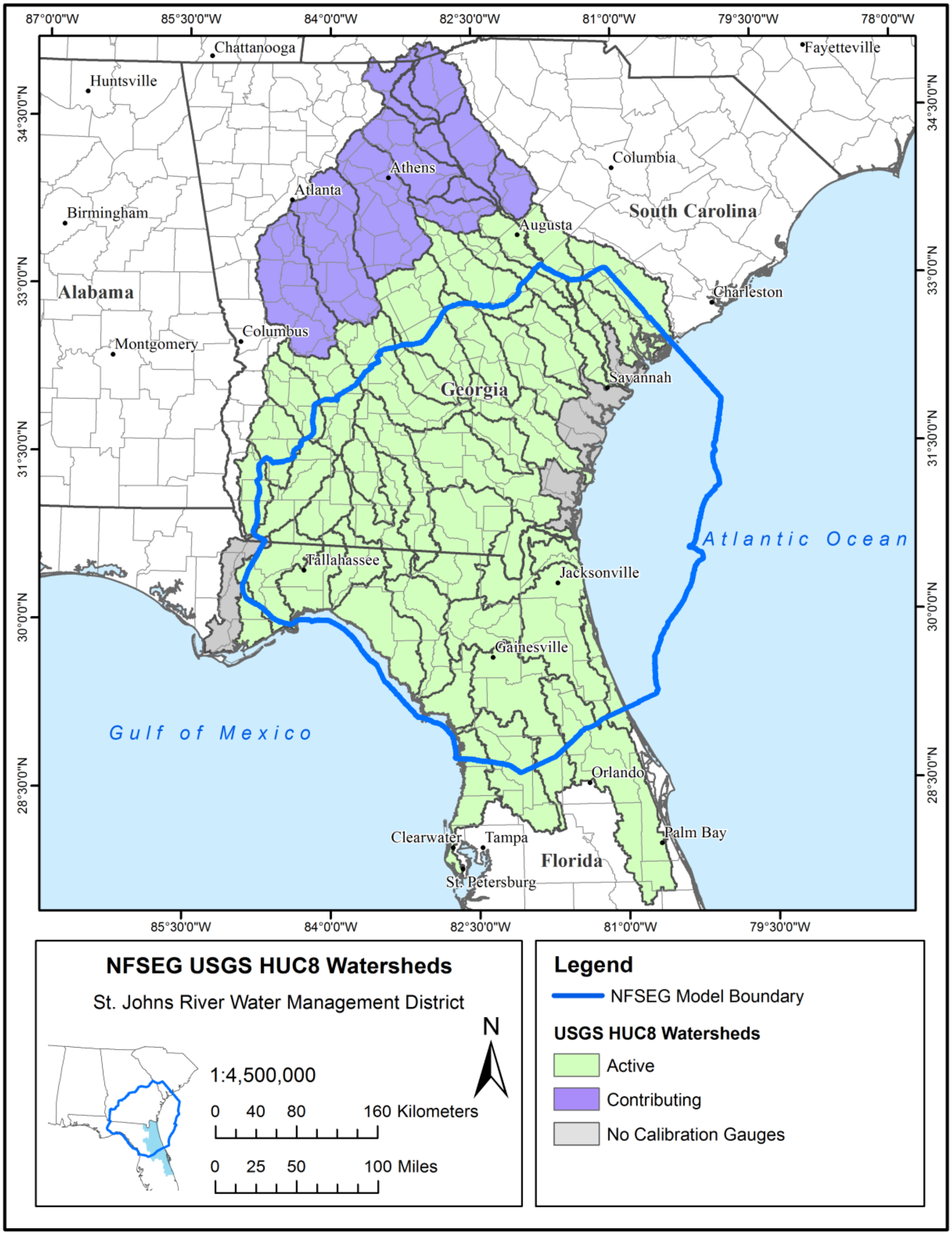

Figure 13. USGS HUC8 watersheds.

Elevation

Elevation data is used to delineate the sub-watersheds so that boundaries are set to calibration points. The elevation dataset chosen for this work it the National Elevation Dataset (NED). This dataset is a gridded 1/3 by 1/3 arc-second (approximately 10x10 meter) Digital Elevation Model (DEM). All elevation data managed by the USGS has been collected under the umbrella of a new program called 3D Elevation Program (3DEP). The 3DEP has adopted the NED as the gridded dataset component of their suite of datasets. The NED elevation data for the NFSEG domain is mapped in Figure 14.

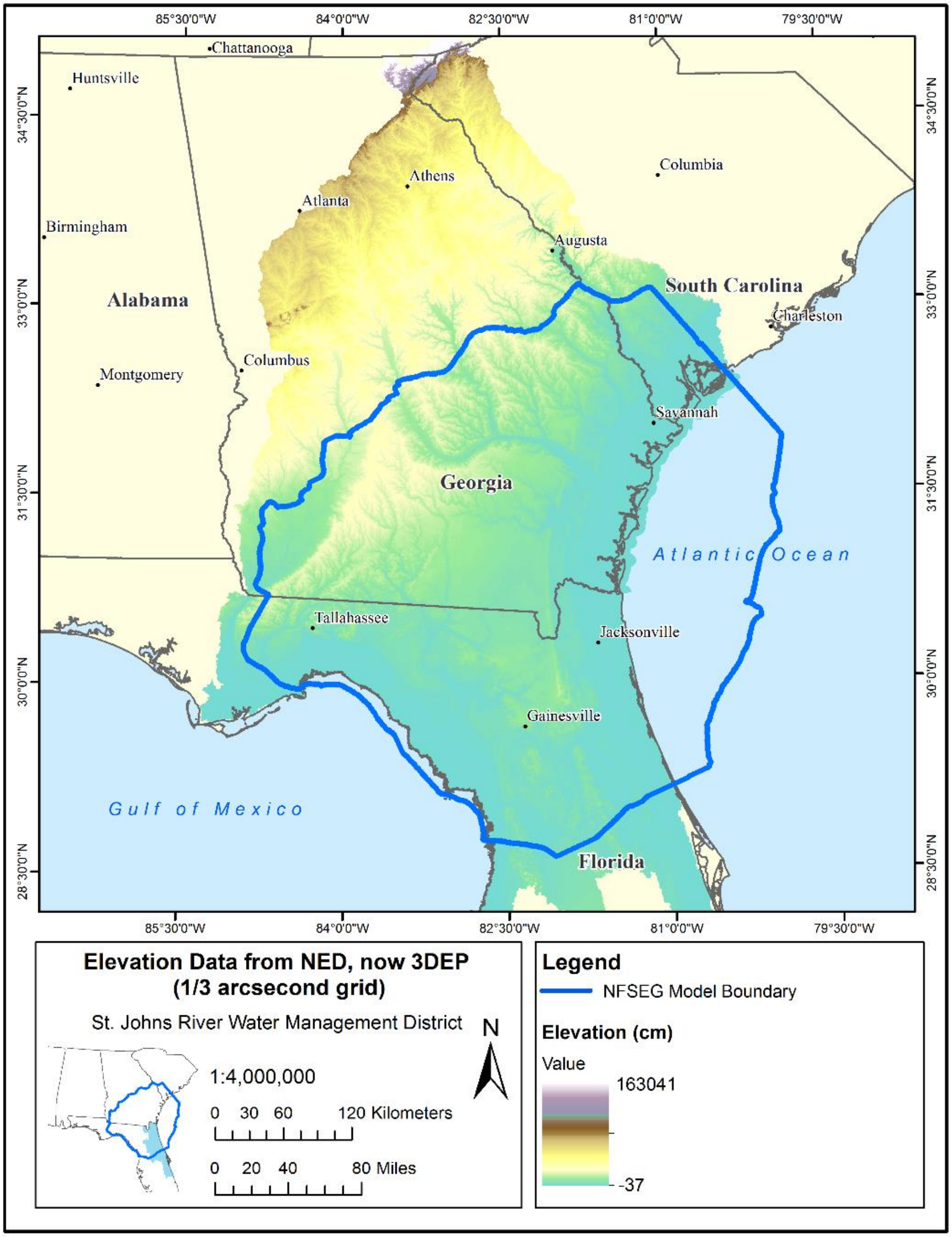

Figure 14. Elevation from the National Elevation Dataset (NED), now 3DEP

USGS Flow Observation Stations

All the stream flow observation stations that have any data between 1990 and 2015 are shown in Figure 15. Figure 15 also identifies those observation stations that were used for calibration. There are several reasons why a station may not be used for calibration, including short period of record, wrong location to be included in the delineation process, tidally influenced, or indications that the data is of poor quality.

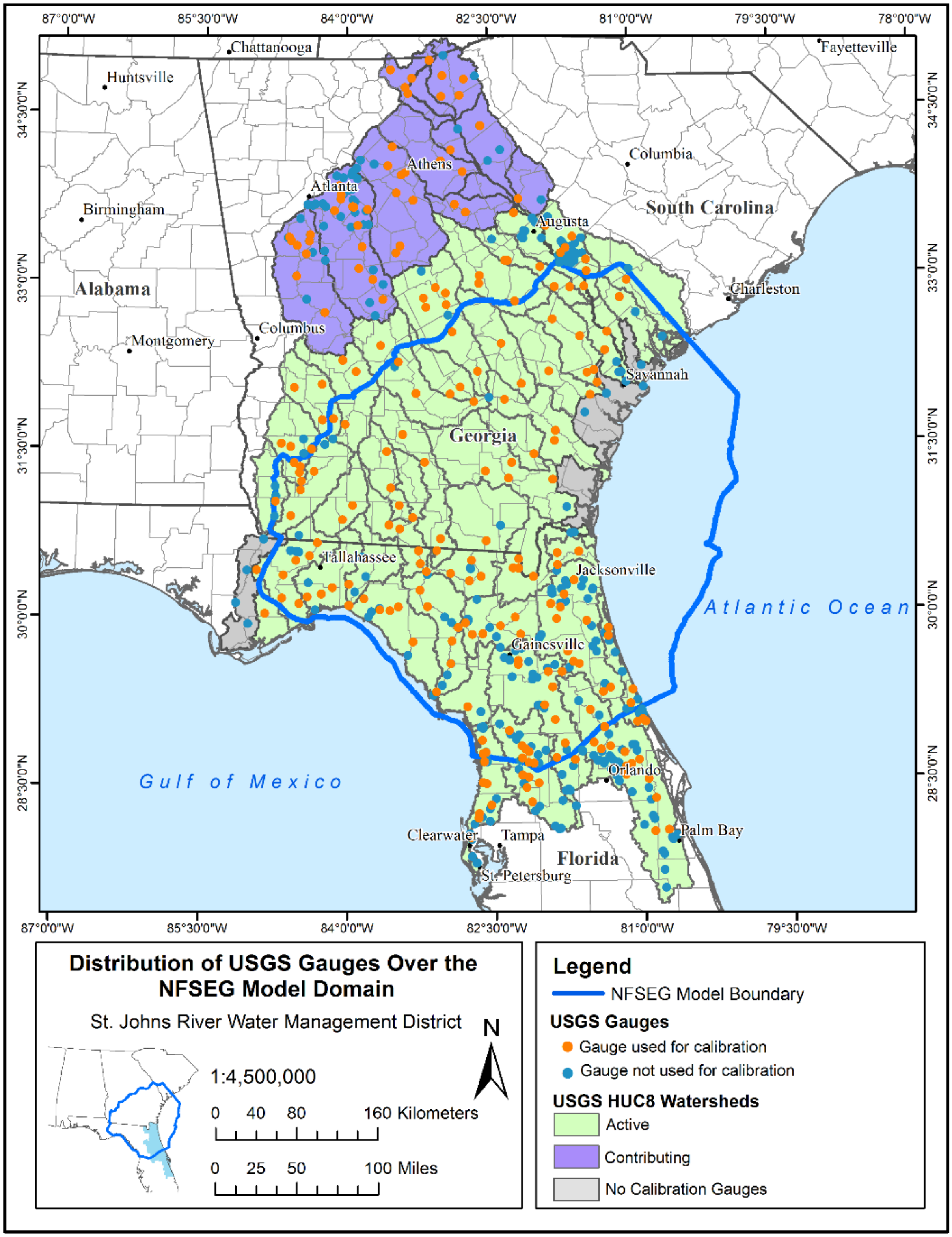

Figure 15. USGS Flow Observation Gauges.

Land Cover

The National Land Cover Database (NLCD) land use coverage is a convenient, consistent, nationwide land use coverage. It consists of the groups identified in the first column of Table 10. The initial parameter ranges used in the first cut model will be taken from previous models developed by the SJRWMD.

Table 10. NLCD and HSPF land cover classifications.

NLCD Land Use	NLCD Code	HSPF Land Cover Group Assignment	Approximate Percentage of NFSEG Domain
Water			
Water-Open	11: areas of open water, generally with less than 25% cover of vegetation or soil.	1: Water	3.3
Ice/Snow-Perennial	12: areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.	(not applicable)	
Developed			
Developed-Open Space	21: areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	2: Developed Open Space	5.8
Developed-Low Intensity	22: areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.	3: Developed Low Intensity	2.3
Developed-Medium Intensity	23: areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	4: Developed Medium Intensity	0.6
Developed-High Intensity	24: areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.	5: Developed High Intensity	0.2
Barren			
Barren Land	31: areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.	6: Open and barren land	0.4
Forest			
Forest-Deciduous	41: areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	7: Forest	8.9
Forest-Evergreen	42: areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.	7: Forest	24.9

NLCD Land Use	NLCD Code	HSPF Land Cover Group Assignment	Approximate Percentage of NFSEG Domain
Forest-Mixed	43: areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.	7: Forest	2.6
Shrubland			
Scrub-Dwarf	51: Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.	(not applicable)	
Scrub-Scrub	52: areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.	8: Shrub	5.9
Herbaceous			
Grassland	71: areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	9: Rangeland	5.6
Sedge	72: Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.	(not applicable)	
Lichens	73: Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.	(not applicable)	
Moss	74: Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.	(not applicable)	
Cultivated			
Agriculture-Pasture	81: areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	10: Pasture	8.1
Agriculture-Cultivated Crops	82: areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	11: Agricultural general	8.4

NLCD Land Use	**NLCD Code**	**HSPF Land Cover Group Assignment**	**Approximate Percentage of NFSEG Domain**
Wetlands			
Wetlands-Woody	90: areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	12: Wetlands	18.9
Wetlands-Emergent Herbaceous	95: Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	12: Wetlands	4.0

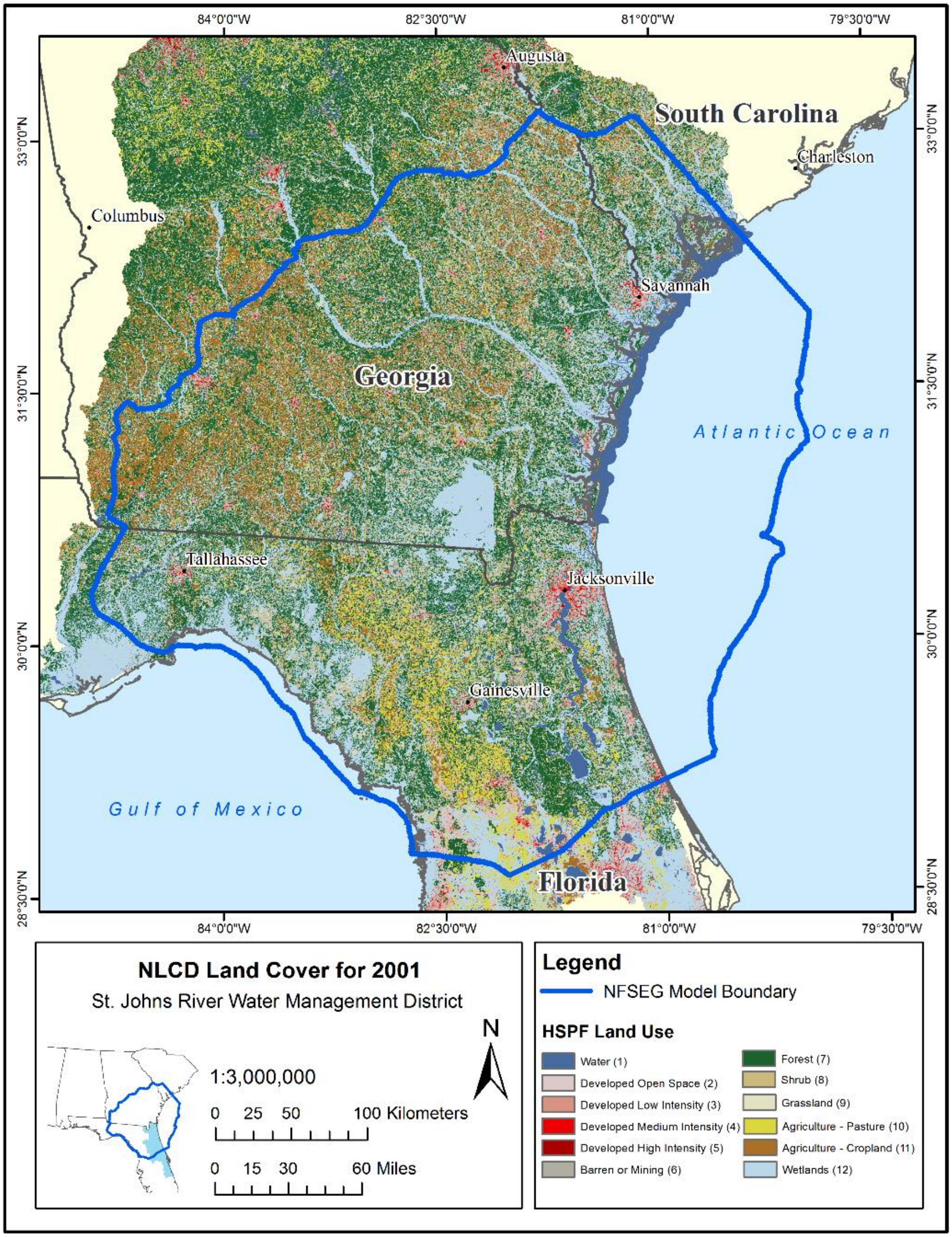

Figure 16. National Land Cover Database, land cover for 2001.

CALIBRATION DATA

Two main dataset were used for calibration. The flow observations from USGS stations and estimates of total evapotranspiration from literature.

USGS FLOW OBSERVATION

All available daily flow data from all USGS flow observation stations within the NFSEG domain was downloaded from USGS. There was a series of statistics that were developed and used as part of the calibration process. These statistics are as follows:

- Daily average data
- Monthly minimum, maximum, average
- Yearly minimum, maximum, average
- Period of record minimum, maximum, average, standard deviation, median
- Frequency distribution curve
- Average of all Januaries, Februaries, …etc
- A 5-day baseflow statistic
- Rise rate
- Fall rate
- Fixed interval, sliding interval, local minimum baseflow, 31 day window

LITERATURE TOTAL EVAPOTRANSPIRATION ESTIMATES

Evapotranspiration in HSPF is calculated for each of the land cover segments in each sub-watershed. A literature review was performed to estimate the range of values for evapotranspiration for the land covers classes included in the HSPF model.

Evapotranspiration values found in the literature review were used as references values in the HSPF calibration process using PEST. This was performed in order to have adequate estimation for evapotranspiration in the model water budget. Table 11 presents the evapotranspiration values and their reference source.

Table 11. Literature total evapotranspiration by land cover

Land Use Code	Land Cover	Min mm/d (winter)	Max mm/d (summer)	Annually Averaged mm/d	Area	Reference
1	Water	2.8	5.3	4.18	Reedy Lake, FL	Douglas et al. (2009)
		3.5	5.2	4.45	Indian River Lagoon, FL	

Land Use Code	Land Cover	Min mm/d (winter)	Max mm/d (summer)	Annually Averaged mm/d	Area	Reference
2	Developed Open Space			2.13	Oklahoma	Liu et al. (2010)
3	Developed Low Intensity			1.96	Oklahoma	Liu et al. (2010)
4	Developed Medium Intensity			1.88	Oklahoma	Liu et al. (2010)
5	Developed High Intensity			1.79	Oklahoma	Liu et al. (2010)
6	Barren or Mining					
7	Forest			2.82	Havana, FL	Lu et al. (2003)
				2.78	Bradford, FL	
				2.51 to 2.93	Volusia County, FL	Sumner (2001)
		1.3	4.2	3.08	Alachua County, FL	Douglas et al. (2009)
				3.2	Blue spring Tract, FL	
				2.35	Oklahoma	Liu et al. (2010)
8	Shrub	0.2	5	1.86	Orange County, FL	Sumner (1996)
				2.21	Oklahoma	Liu et al. (2010)
9	Grass Land			2.2	Oklahoma	Liu et al. (2010)
10	Agriculture - Pasture	0.8	2.9	1.58	Ferris Farm, FL	Douglas et al. (2009)
		1.8	4.3	3.06	Duda Farm, FL	
		0.67	4.72	2.16	Floral City, FL	Sumner and Jacobs (2005)
11	Agriculture - Cropland			2.18	Oklahoma	Liu et al. (2010)
	Citrus	1.4	4.1	3.03	Belle View Farm, FL	Douglas et al. (2009)
		1.9	4.8	3.48	Carlton Ranch Farm, FL	

Land Use Code	**Land Cover**	**Min mm/d (winter)**	**Max mm/d (summer)**	**Annually Averaged mm/d**	**Area**	**Reference**
12	Wetlands			2.36	Withlacoochee State Forest, FL	Ewel and Smith (1992)
		2.04	6.18	-	Alachua County, FL	Jacobs et al. (2002)
		1.42	4.72	3.25	Indian River County, FL	Mao et al. (2002)
		2.13	4.95	3.66		
		1.5	6.4	3.53		
		2.4	4.8	3.98	Blue Cypress, FL	Douglas et al. (2009)
		2.9	4.4	3.86	Everglades, FL	
				2.39	Oklahoma	Liu et al. (2010)

HSPF MODEL DEVELOPMENT

The first step in development of a surface water model is to delineate the sub-watersheds so that the calibration points represent outflow from a sub-watershed. The delineation process at the same time establishes the stream network. The next step is to establish the areas of all the land cover PERLNDs, and IMPLNDs within each sub-watershed.

SUB-WATERSHED DELINEATION

To calibrate against data at the USGS gauge stations, the sub-watersheds need to be created to have their exits correspond with the location of the gauges. This process is called delineation and the TauDEM software was used for this project. The TauDEM software is a suite of programs used to analyze Digital Elevation Models (DEM) to determined sub-watersheds and corresponding stream reaches.

Conventional TauDEM processing would entail use of the following TauDEM commands:

1. pitremove: The DEM grid is used to create the pit filled DEM grid. Filling of pits is required for the remaining steps to function reliably. A pit is considered a mistake in the DEM and the elevation in pits is increased until there is a continuous downslope to the stream.
2. d8flowdir: The pit filled DEM grid is used to calculate a flow direction grid. The flow direction for each elevation grid point is determined as the direction that has the greatest difference in elevation.

3. aread8: The flow direction grid is used to calculate the flow accumulation grid. An accumulation count is developed for each grid which is the count of all grid cells that flow into that grid.
4. threshold: The flow accumulation grid is used to calculate the stream network. A value is set to establish the accumulation count where a stream would develop.
5. streamnet: The pit remove grid, the flow direction grid, the accumulation grid, the threshold grid, and location of USGS gauges are used by "streamnet" to create the delineated sub-watersheds and stream network.

Closed, Flat, and Frontal Sub-Watersheds

The project area has several unique features that affect surface water hydrology and the delineation process. One of these is “closed” basins which are surface watersheds that have no observable stream flow. The precipitation that falls on a closed basin either must infiltrate or evaporate. The USGS has identified closed basins at the HUC12 level of detail throughout the United States. Of the 100591 HUC12 sub-watersheds in the United States, there are 1189 closed basins for an overall percentage of 1.2%. The typical approach in surface water models is that closed basins are ignored since there is no surface flow. For establishing recharge estimates for a groundwater model, an approach needed to be developed. Within the NFSEG domain there are 35 closed basins identified by the USGS and an additional 32 HUC12 sub-watersheds that are known to be closed though not identified as such by the USGS.

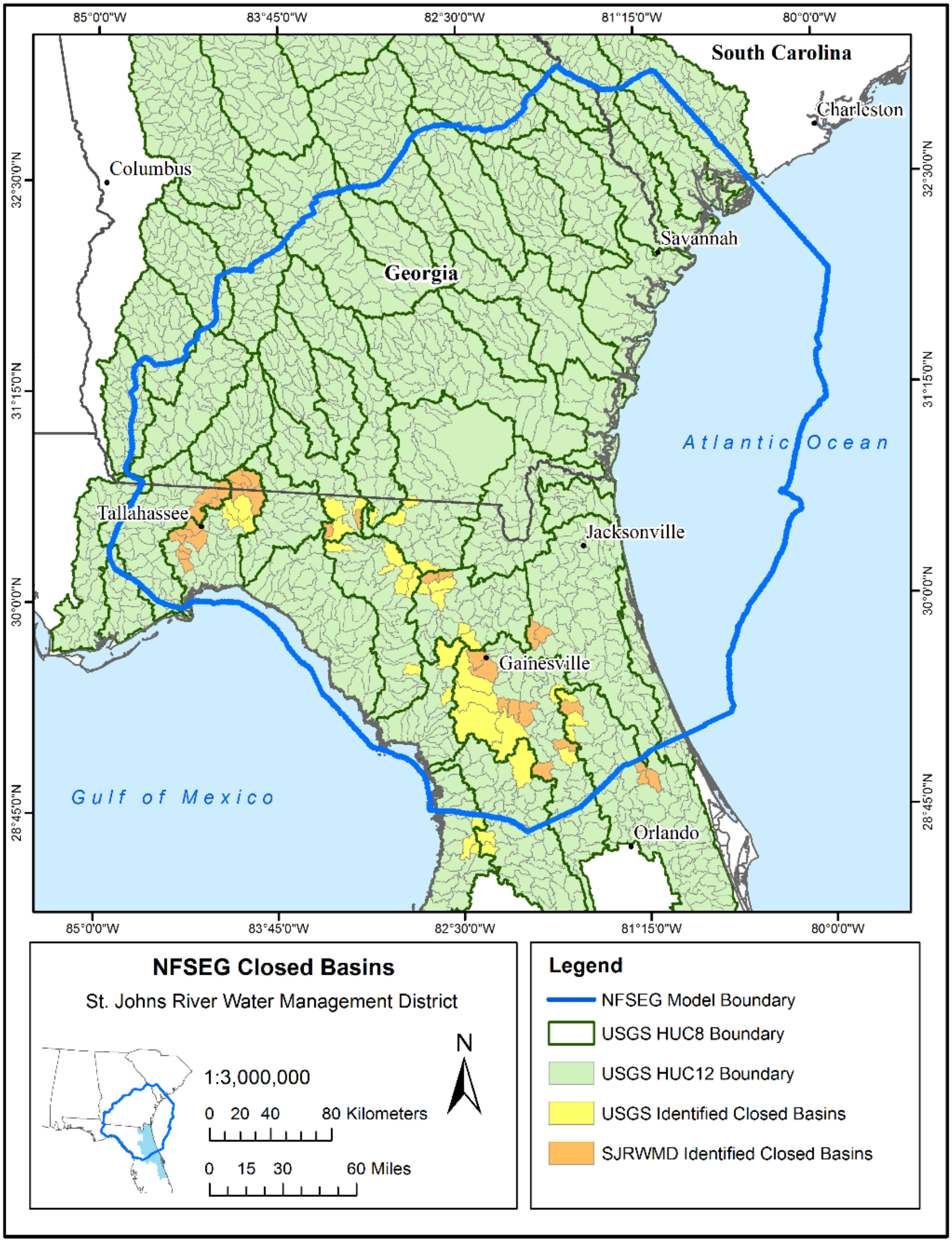

Figure 17. Map of closed basins within the NFSEG model.

TauDEM processing had to be adapted to handle the special situations that occur in this project. From the conventional TauDEM approach, each closed basin is a pit in the DEM that needs to be filled. Also, TauDEM does a poor job with flat areas. For this project, we handled the closed and flat areas separately from the tributary areas so that known sub-watershed boundaries were honored by TauDEM.

CLOSED BASIN REPRESENTATION

Figure 18 illustrates a conventional tributary sub-watershed in HSPF where the flow out of the reach to downstream is greater than 0.

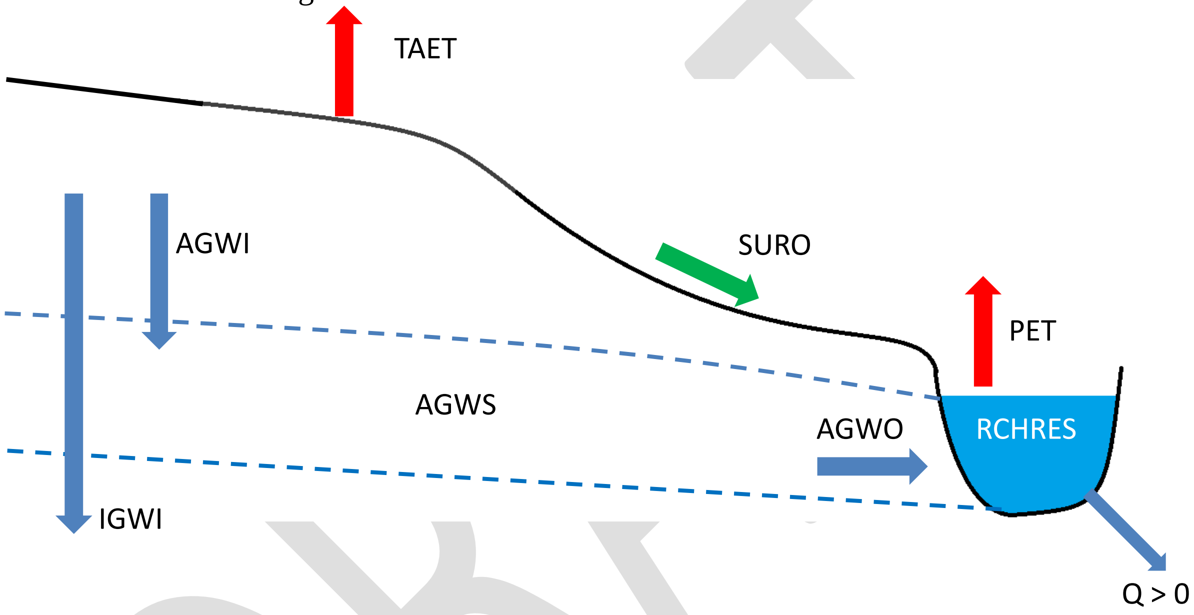

Figure 18. Conventional representation of a sub-watershed for a tributary basin.

Figure 19 illustrates the approach taken to represent closed basins for this project. The simple approach would be to simply increase IGWI until there is no flow out of the reach. This would distort all the other model parameters, flows, and storages. Also, the parameter adjusted to increase IGWI is called DEEPFR and has a recommended maximum of 0.5 in EPA Technical Note 6, but to have zero flow from the reach DEEPFR needs to be set at 0.9 or greater.

It was noted that the closed basins had at least one sink that accepted surface water flows (Figure 20). To keep the parameters all in line for a closed basin, the parameters are taken from a nearby tributary basin, and a feature was added to the reach where high flows would be directed to a virtual sink, representing all sinks within the basin. This is a significant improvement because the parameters that affect evaporation and recharge are from a calibrated system and aren't distorted by unusual changes to adapt to the closed basin. This virtual sink was parameterized with an invert, a maximum flow, and a depth above the invert when maximum flow starts. The virtual sink flows for each sub-watershed were then divided among the known sink or drainage well features within the sub-watershed.

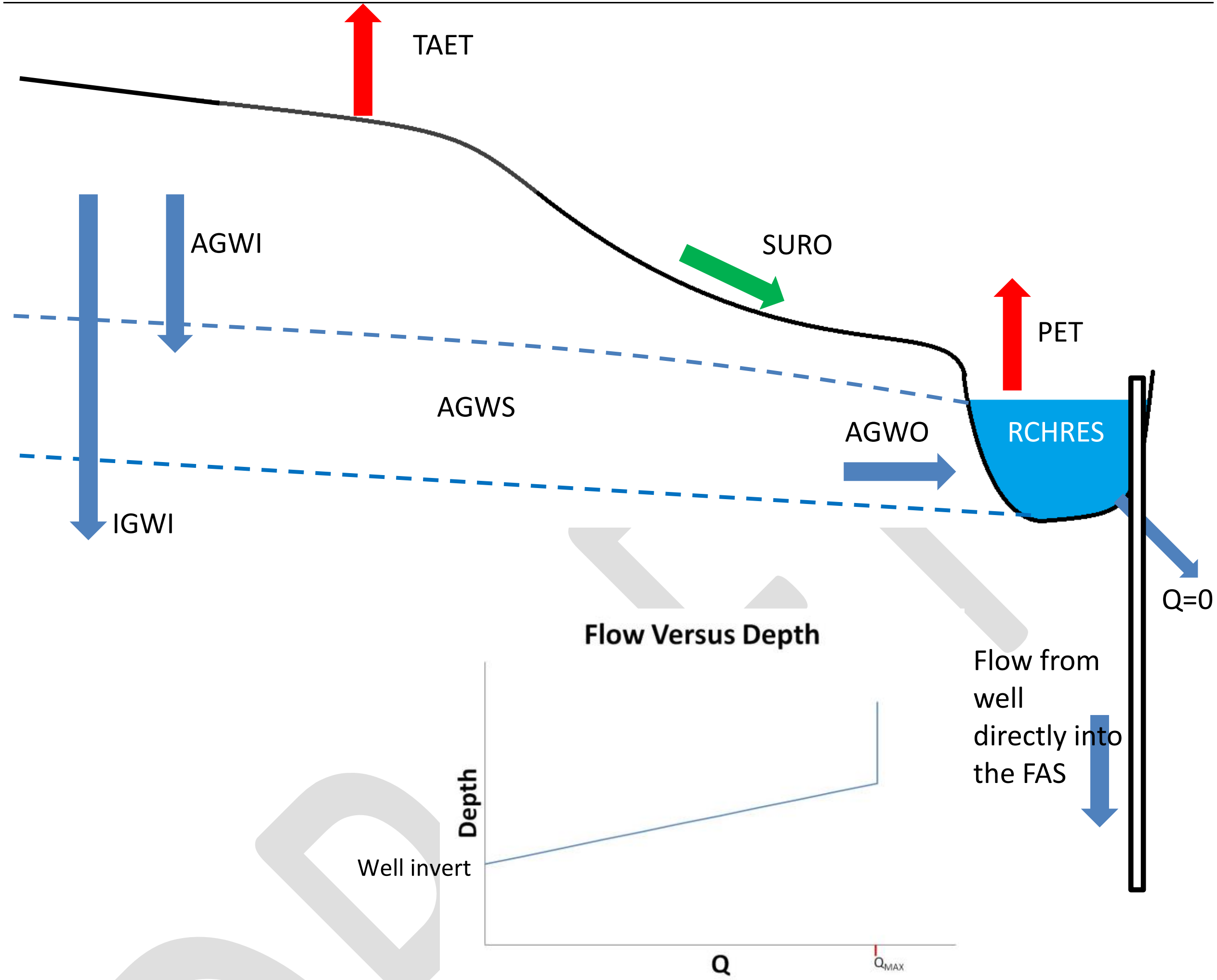

Figure 19. Closed basin representation of a sink to replace outflow, where surface flow Q = 0.

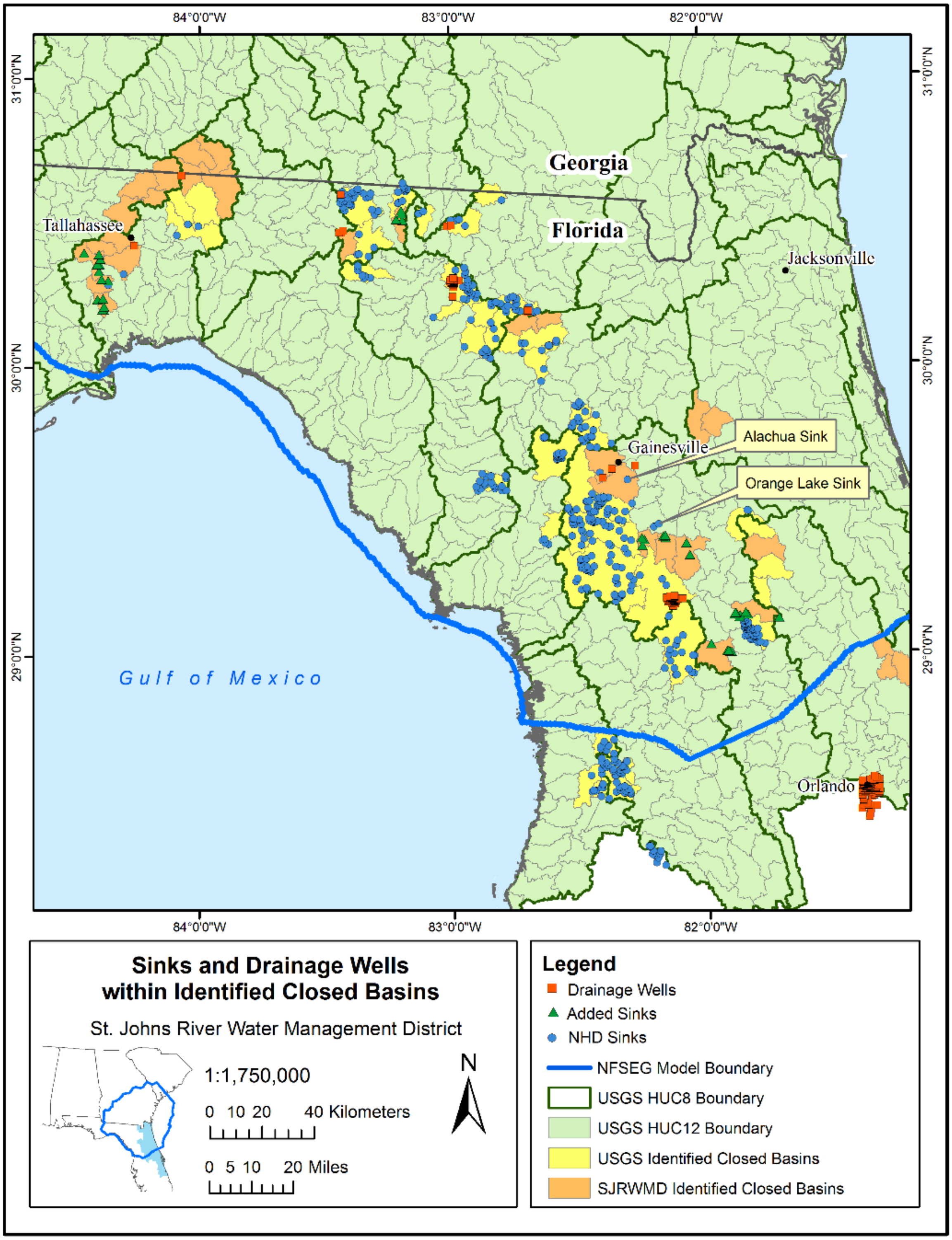

Figure 20. Sink and drainage wells within NFSEG domain.

REPRESENTATION OF SPRINGS TO IMPROVE HSPF CALIBRATION

Hydrological Simulation Program - FORTRAN (HSPF) is a surface water model. A component of the surface water balance in HSPF is Inactive Ground Water Inflow (IGWI). Typically, IGWI is a loss term that moves out of the surface water balance simulated by HSPF to deep groundwater and springs are represented as new water imposed directly into the surface water reach. The time-series of imposed spring flow is developed based upon observed data.

We established a simple underground reservoir in HSPF to collect IGWI within a springshed. This underground reservoir is then used as a source for spring flow. This approach is illustrated in Figure 21.

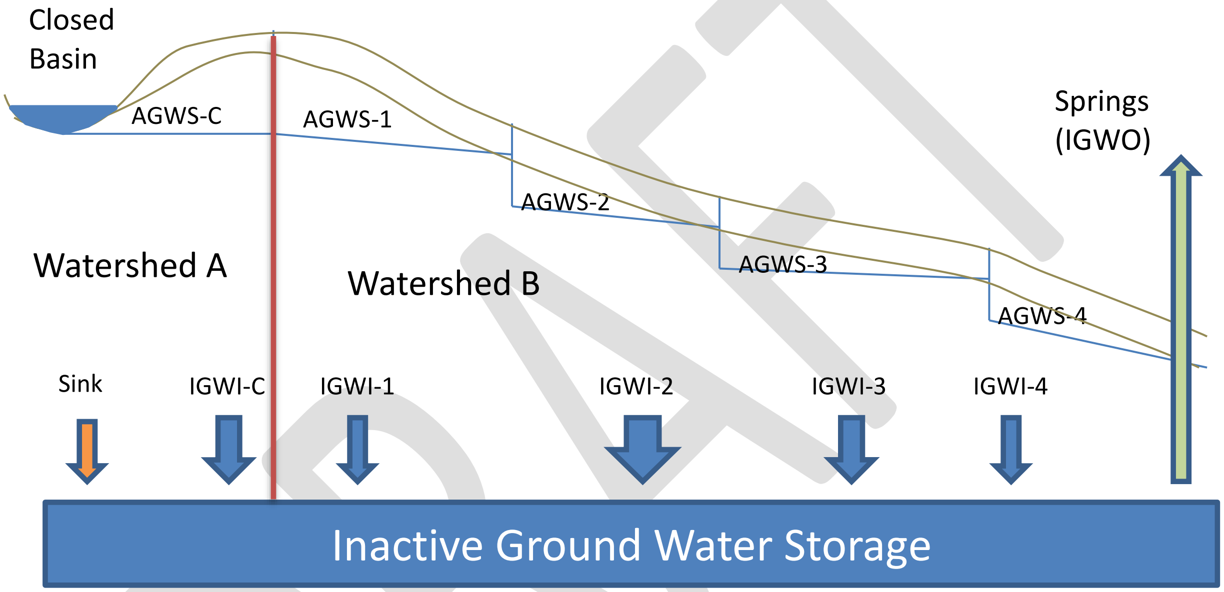

Figure 21. Conceptual framework for the IGWO representation of springs.

The springsheds were delineated by referencing the Upper Floridan Aquifer (UFA) potentiometric surface map as illustrated in Figure 22.

Of course, the surface sub-watershed boundaries did not match the springshed boundaries. The decision about which sub-watershed belonged to which springshed was done manually based on which springshed contained the most area of the sub-watershed. The assignment of sub-watershed to springshed is shown in Figure 23. Also, shown in Figure 23 is the target reach that receives the accumulated IGWO flow.

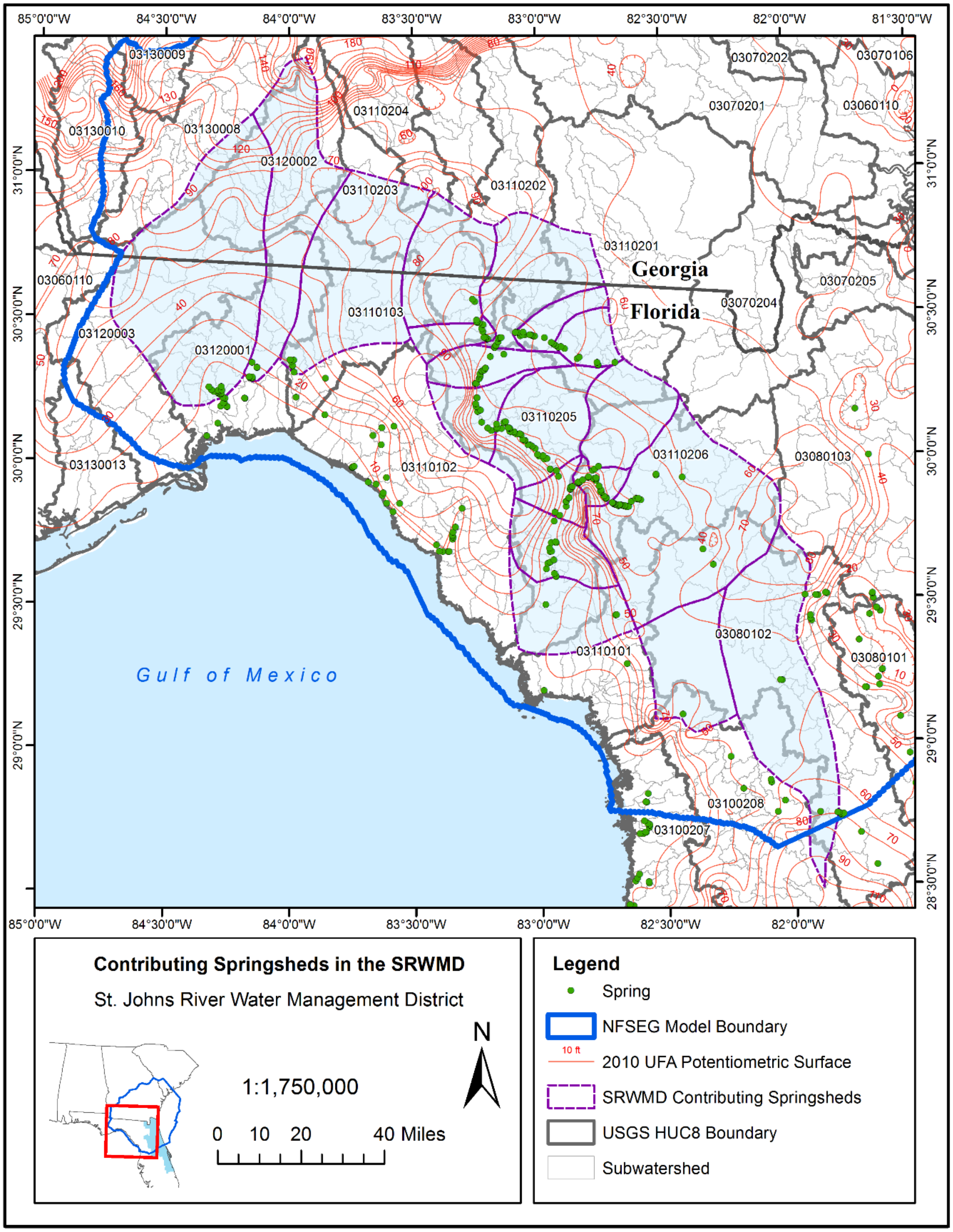

Figure 22. UFA Potentiometric surface and springsheds in the Suwannee River Basin.

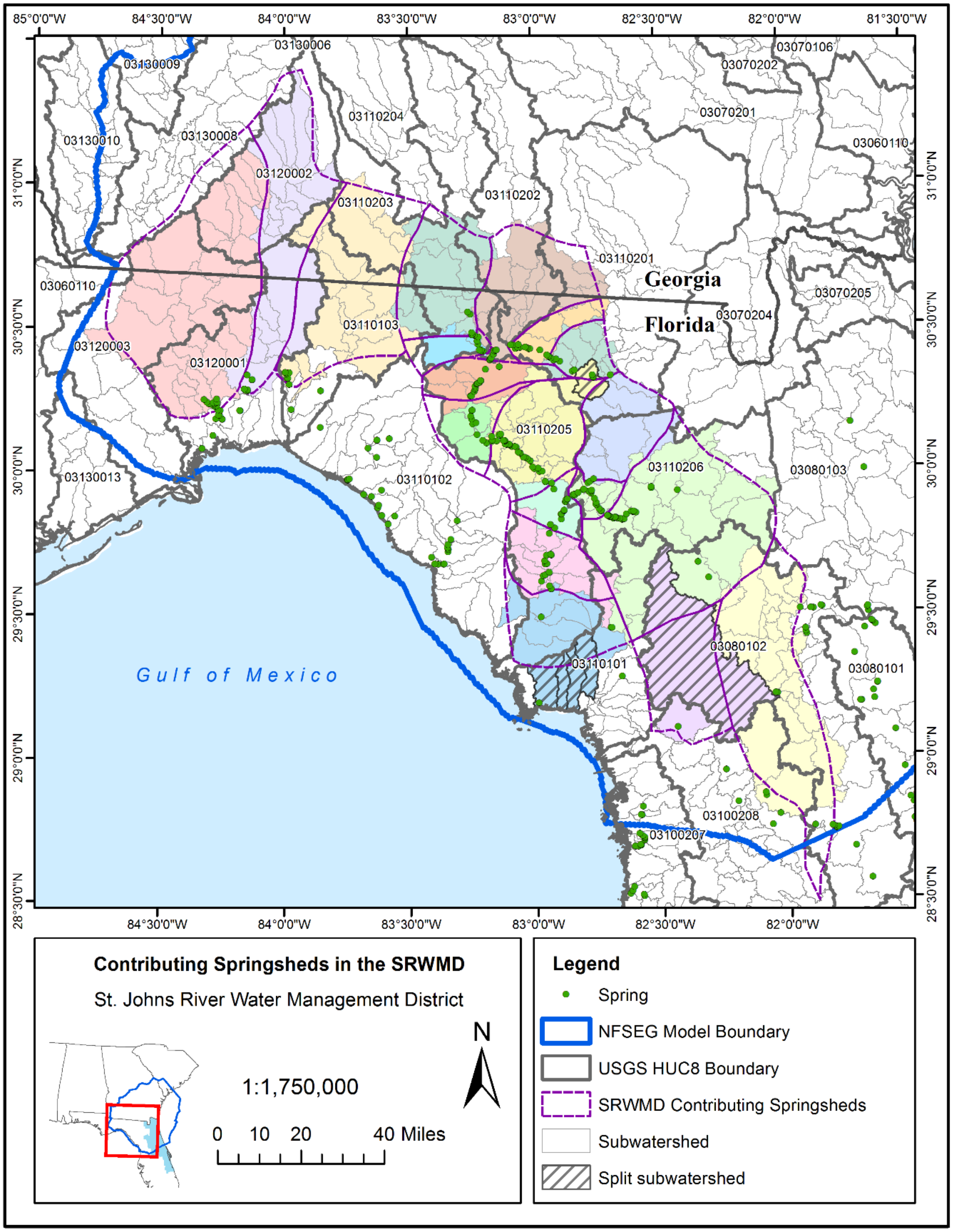

Figure 23. Identified sub-watersheds that were used as springshed outlets.

CALIBRATION PROCESS

The modeled time-period is dependent on the question that needs to be answered. Flood control analysis will calibrate using a single storm event or a design storm or multiple storm events. Water supply, MFLs and certain environmental analysis require long-term continuous modeling simulations. The land use/cover is set for a point in time and historical rainfall records are selected, which will match the length of rain needed for the simulation. Using the historic rainfall record, it is assumed that the rain in the future will approximate the amount and patterns of the past. These are pseudo-random events and if the period of record used is long enough, there should not be a discernable bias in the data.

The calibration period selected for these hydrologic models is from 1992 to 2015. This period was selected for three reasons.

1. The overall project of the HSPF models were intended to be used for other transient, groundwater models that began in 1995.
2. The longer time period that is available for calibration, the less chance of bias in the model due to calibration against a short period of record.
3. It encompasses the planned time frame of 2000-2012 for the transient groundwater model.

The actual time-period of meteorological data and land and stream gage data is used as input data for the HSPF models. The calibration period of the individual models is within the 1992 to 2015 time-period, depending length of data available for calibration. The calibration performance of the models is described in detail in the Calibration Results section and **Error! Reference source not found.**.

The calibration process is illustrated in Figure 24. Something to note is that neither the input data to the model or the calibration data is the “Real World”, but instead a small part of what we imperfectly observe.

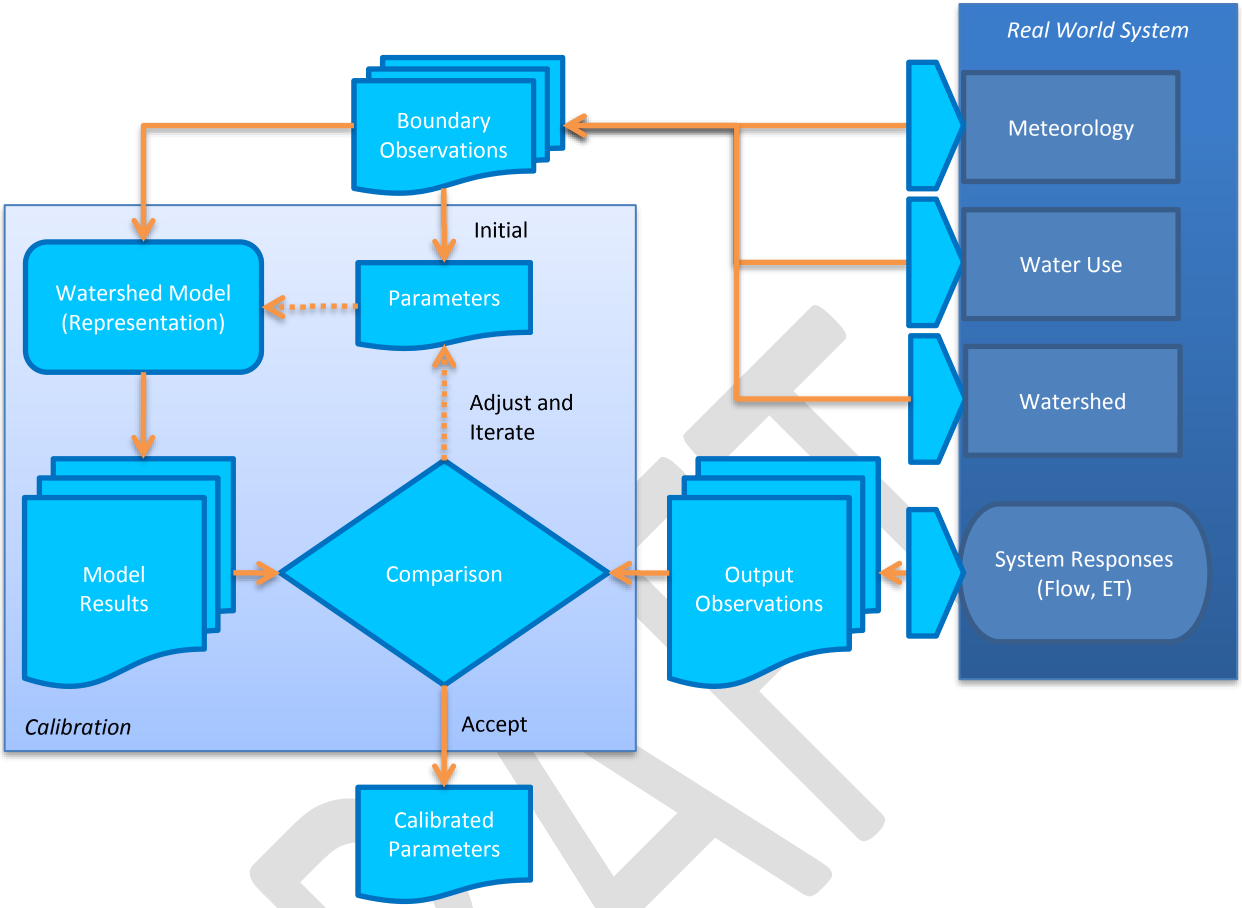

Figure 24. Overview of calibration process.

MODEL INPUT PARAMETERS – COMMON LOGIC

The changes to the model concerning land-use, precipitation, and evaporation require a complete examination of the model parameters. Originally, different modelers at the District modeled watersheds with HSPF for various purposes, and developed model parameters that were characteristic of the individual watersheds. The District has developed a common logic (Appendix A – SJRWMD HSPF Common Logic) setting reasonable parameter value ranges for all HSPF models in the District. This common logic was an evaluation of the possible range of model parameters given the unique hydrology of Florida, extensive District HSPF experience, and the ranges common in other parts of the world (USEPA 2000).

LAND USE AND DIRECTLY CONNECTED IMPERVIOUS AREA

The HSPF model has many parameters used to define storages and interactions and many are defined for each land use. The NLCD has land use grouped into 12 categories for hydrologic modeling (See Table 10).

Impervious areas include all surface areas that prevent water from infiltrating into the ground. Typical impervious areas are roofs, roads, and parking lots. These impervious areas can be classified into two categories: directly connected impervious area (DCIA) and non directly connected impervious area (NDCIA). DCIAs are the impervious areas that directly connect to the drainage network with no opportunity for infiltration. NDCIAs are the impervious areas that drain to pervious areas. In this study, only DCIAs are modeled as IMPLND, and NDCIAs are lumped to PERLND.

Among 12 consolidated land uses, 4 urban land groups consisting of the Low, Medium, and High Density Residential, and Industrial, which also includes commercial, (LDR, MDR, HDR, IND respectively) are assumed to have DCIA. The remaining land uses are taken as consisting only of pervious land elements. Estimation of the percent DCIA focus on matching the observed flows during small storm events because most runoff during small storms is generated from DCIA. Impacts of changing imperviousness percentages on total mass balance and seasonal flow distribution are also considered. Table 12 lists the percentages of DCIA determined from this analysis and used in this study.

Table 12. Percentages of directly connected impervious area

Land Uses	% Imperviousness
Low Density Residential (LDR)	5
Medium Density Residential (MDR)	15
High Density Residential (HDR)	35
Industrial and Commercial (IND)	50

DEVELOPMENT OF FTABLE FOR STREAM NETWORK

In HSPF, the stream network in a sub-watershed is grouped together and represented as a reach segment, which could be either a free-flowing stream or a mixed lake. The FTABLEs for stream reaches are developed based on the Manning's equation. Channel cross-section characteristics are based on survey data, field visits, USGS quad maps, etc. For example, the stream reaches in the urbanized Lake Jesup watershed are modeled as streams with uniform trapezoidal cross-sections. Stream length, slope, and elevation are estimated based on the stream network and digital elevation map available at the SJRWMD. Manning's "n" coefficients for these streams are estimated by comparing the calculated stage-discharge relationships with the measured relationships at several USGS flow gauge sites.

For the Ocklawaha basin (03080102), FTABLEs were taken from earlier very detailed models used for the Water Supply Impact Study (Lowe et al. 2012) and the development of Upper Ocklawaha MFLs. For the Suwanee River (03110201 and 03110205), a HEC-RAS model was used to develop FTABLEs. For all other sub-watersheds the regional approach in BASINS was used.

PARAMETER ESTIMATION WITH PEST

Calibration of HSPF is an iterative process of changing parameters, running simulations, checking results, and repeating until a calibrated model is achieved. When manually performed, this can be a time-consuming endeavor. In addition, it can be difficult to maintain a consistent approach of parameter adjustments to produce calibrated models among a group of HSPF modelers with various levels of experience and expertise. For this reason, PEST (which is an acronym for Parameter ESTimation) is used to assist in model calibration.

PEST is a nonlinear parameter estimator that will adjust model parameters to minimize the discrepancies between the pertinent model-generated numbers and the corresponding measurements. It does this by running the model as many times as is necessary to optimize a least-squares objective function. The objective function (represented by the Greek letter, "phi" Φ) is the summation of the weighted, squared, model-to-measurement differences. PEST evaluates parameter changes based on the minimizing the objective function and decides whether to undertake another optimization until no more improvement in the objective function is achieved.

$$\Phi = \sum_{i=1}^{n} (w_i(o_i - s_i))^2$$

Where: Φ is the objective function
n is the number of observations
w_i is the assigned weight for the i'th observation
o_i is the i'th observation
s_i is the i'th simulated value corresponding with the i'th observation

The modeler must define the observations that are included in the objective function. The objective function takes the form of matching as best as possible simulated to gauge values for the observations and statistics shown in .

Table 13 and Table 14.

Since Φ is a function of the number of observations and the overall magnitude of the values, the assigned weight is an important part of using PEST since it can make observations more or less visible in the calibration process. Because the assignment of weights can be so tedious, there is a utility in the PEST suite to help with this called "PWTADJ1". The initial weighting was established using "PWTADJ1". This utility equalizes the contribution to Φ from each observation group. After the contribution to Φ is equalized, the weighting was increased for a couple observations groups by multiplying by a weight factor as shown in .

Table 13 and Table 14.

Table 13. Observations and statistics used in the PEST objective function for each USGS station used in the calibration.

	Number of Observations Within Group	**Weight Factor After Equalizing Contribution to Φ**
Daily mean	*8767	1
Monthly minimum, maximum, and mean	*288	1
Yearly minimum, maximum, and mean	*24	1
Differences between successive daily terms	*8766	1
Daily flow duration table	59	1.5
Daily time exceedance table	84	1.5
Monthly time exceedance table	84	2
Period of record minimum, maximum, mean, standard deviation, and median	5	1
Baseflow using USGS fixed window with a window of 31 days	*8736	1
Monthly mean of fixed window baseflow	*287	1
Yearly mean of fixed window baseflow	*24	1
Baseflow using USGS sliding window with a window of 31 days	*8736	1
Monthly mean of sliding window baseflow	*287	1
Yearly mean of sliding window baseflow	*24	1
Baseflow using USGS local minima with a window of 31 days	8736	1
Monthly mean of local minima baseflow	*287	1
Yearly mean of local minimum baseflow	*24	1
CV, all daily flows CV, log of all daily flows Mean daily flow / median daily flow Ratio, Q10 / Q90 for all daily flows Ratio, Q20 / Q80 for all daily flows Ratio, Q25 / Q75 for all daily flows (Q10 - Q90) / median daily flow (Q20 - Q80) / median daily flow (Q25 - Q75) / median daily flow Mean monthly flow, January…December	21	3

	Number of Observations Within Group	**Weight Factor After Equalizing Contribution to Φ**
Mean minimum monthly flow, January…December CV of minimum monthly flows Mean minimum daily flow / mean median annual flow Mean minimum annual flow / mean annual flow Median minimum annual flow / median annual flow Ratio of baseflow volume to total flow volume CV of annual minimum flows Mean annual minimum flow divided by catchment area	19	3
Mean of positive changes from one day to next (rise rate) CV, mean of positive changes from one day to next (rise rate) Mean of negative changes from one day to next (fall rate) CV, mean of negative changes from one day to next (fall rate) Ratio of days that are higher than previous day Median of difference in log of flows over two consecutive days of rising Median of difference in log of flows over two consecutive days of falling Number of flow reversals from one day to the next CV, number of flow reversals from one day to the next	8	3

*Actual number depends on period of record.

Table 14. Total Actual ET (TAET) observation groups in the objective function.

Observation Group	Number of Observations Within Group	Weight Factor After Equalizing Contribution to Φ
Yearly average total ET for water	24	2
Yearly average total ET for developed open space	24	2
Yearly average total ET for developed low intensity	24	2
Yearly average total ET for developed medium intensity	24	2
Yearly average total ET for developed high intensity	24	2
Yearly average total ET for barren or mining	24	2
Yearly average total ET for forest	24	2
Yearly average total ET for shrub	24	2
Yearly average total ET for grass land	24	2
Yearly average total ET for pasture	24	2
Yearly average total ET for crops	24	2
Yearly average total ET for wetlands	24	2
Yearly maximum total ET for water	24	2
Yearly maximum total ET for forest	24	2
Yearly maximum total ET for shrub	24	2
Yearly maximum total ET for pasture	24	2
Yearly maximum total ET for wetlands	24	2

PEST was used to optimize the parameters LZSN, LZEPT, INFILT, UZSN, AGWRC, INTFW, IRC, DEEPFR, and the water/wetland surface runoff FTABLE storage-runoff relationship. Relative values of parameters were established by the modelers between land uses to produce expected relative runoff amounts. Urban land, including impervious area, produces the most runoff, agriculture produces the next largest runoff, open land and rangeland produce less, and forest and wetland produce the least runoff. PEST allows parameters to be “tied” to a “parent” parameter. In this way, all the tied parameters are adjusted equally among the various land uses. In general, LZSN, LZEPT, INFILT, and UZSN parameters are tied together between land uses. The exception to this is wetland. Wetland parameters give emphasis to larger upper zone storage and lower infiltration rate. For this reason, wetland parameter sets are not comparable to other land uses and are adjusted independent of the other land uses. The parameters AGWRC and DEEPFR are applied to the entire watershed. In addition, PEST allows parameters to be “fixed” and not adjusted. For example, in many cases of INTFW and IRC (see the Common Logic for INTFW in Appendix A – SJRWMD HSPF Common Logic), if these parameters are not given a restricted range close to zero, the parameters are fixed to zero or a very small number.

Regularization of parameters between models using PEST is not planned, but a manual review and adjustment of parameter ranges was made to ensure that adjacent watersheds have similar parameter values.

HSPF SPECIAL ACTIONS

HSPF permits the user to perform certain "Special Actions" during a run. A special action instruction specifies the following:

- The operation on which the action is to be performed (e.g., PERLND 10)
- The date/time or condition at which the action is to be taken.
- The variable name and element (if the variable is an array) to be updated.
- The action to be performed. The most common actions are to reset the variable to a specified value and to increment the variable by a specified value, but a variety of mathematical functions are available.

The special action facility is used to accommodate unique characteristics of a watershed, such as:

- Human intervention in a watershed. Events such as plowing, cultivation, fertilizer and pesticide application, and harvesting are simulated in this way.
- Changes to parameters. For example, a user may wish to alter the value of a parameter for which 12 monthly values cannot be supplied. This can be done by specifying a special action for that variable. The parameter could be reset to its original value by specifying another special action, to be taken later.

For this project, special actions were used to create the virtual sink/drainage well in closed basins and basins that have drainage wells.

SURFACE FTABLES

Water and wetlands tend to allow limited downward movement of water. Instead, water is stored at or near the surface. One result of this is that water and wetland areas have a larger potential for evapotranspiration. HSPF provides the option to use FTABLES block to define surface outflow as a function of surface detention depth. This feature allows improved representation of the surface storage and attenuated surface runoff typical of wetlands.

A surface FTABLE was developed for each water and wetland PERLND. Development of the storage-outflow relationship begins with the general function:

$$Q = ay^{\mathrm{m}}$$

Where

Q = fraction of storage that runs off per hour

y = normalized depth above the invert

a, m = general coefficient and exponent

PEST is used to optimize the water and wetland storage-outflow relation by adjusting the depth of incipient flow and equation parameters.

CALIBRATION RESULTS

An important and underappreciated aspect of almost all published stream flow data is that stream flow data are not measured directly, but calculated from a rating curve, which serves essentially as a model. Water stages are measured, and flow rates corresponding to these stage readings are found using rating curves. When developing rating curves, results of individual flow measurements are plotted with their corresponding stages, and stage-discharge relation curves are then developed. From these curves, rating tables are prepared that indicate the approximate discharge for any stage within the range of the measurements. For flows outside the range of the flow measurements, the curves are extended using (1) logarithmic plotting; (2) velocity-area studies; and (3) results of indirect measurements or peak discharge, such as slope-area or contracted-opening measurements. If the stage-discharge relationship is subject to change because of changes in the physical features that affect the gauge site, discharge is determined by the shifting-control method, in which correction factors that are based on individual discharge measurements and notes of personnel making the measurements are used when applying gage heights to the rating tables. This shifting-control method also is used if the stage-discharge relationship is changed temporarily because of aquatic growth or debris on the control. Downstream flow obstructions may produce backwater effects that reach the gage. Upstream obstructions may change the cross-sectional area.

The primary calibration targets come from the United States Geological Survey (USGS) stream flow data. The USGS rating curve model has errors associated with the estimated flow. Even though there are several ways to estimate the rating curve error (Dymond and Christian 1982), the USGS has established a subjective estimate of annual flow data quality established by a review of measured data, datum shifts, and other characteristics of the flow measurement station. Table 15 describes the USGS system of data quality estimation (Kennedy 1983). The USGS system provides a general site-specific estimate of error, and there may be significantly more error where there are few flow measurements in the rating curve, for example at high and low flows. However, the USGS gives a single quality category for each water year of record.

Table 15. USGS flow data quality categories (Kennedy 1983)

Quality Category	Description
Excellent	95% of daily discharges within 5% of ‘true’
Good	95% of daily discharges within 10% of ‘true’
Fair	95% of daily discharges within 15% of ‘true’
Poor	Daily discharges have less than ‘fair’ accuracy

There are inherent difficulties in flow measurement in Florida due to the factors such as shallow slope, poorly defined cross sections, and tidal influences. Most USGS flow measurement stations in Florida are rated ‘Fair’. An ‘Excellent’ rating for a station in Florida is very rare. A map illustrating the USGS assigned data quality for flow observations in water year 2009 is presented in Figure 25. For 2009 there isn’t an ‘Excellent’ rated gauge in any of the HSPF models.

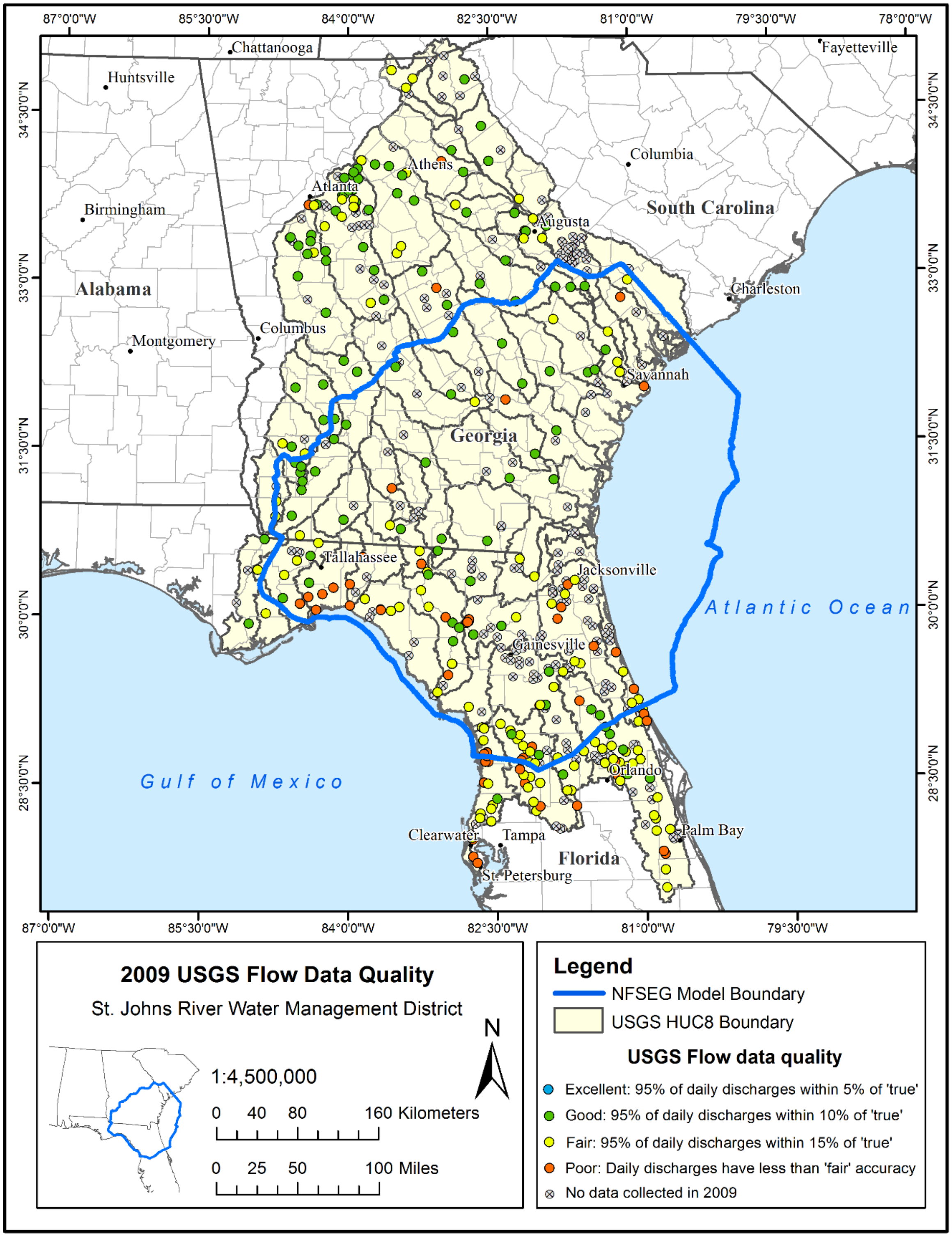

Figure 25. USGS quality assessment of flow data for water year 2009.

A very common measure of the performance of a hydrologic model is the Nash-Sutcliffe statistic (Moriasi et al. 2007). A Nash-Sutcliffe statistic equal to one is a perfect match between simulated and observed, where a zero would mean that the average of the observations is a better model. Negative Nash-Sutcliffe values are possible, though they do not have a meaning. The Nash-Sutcliffe model categories are listed in Table 16.

Table 16. Grading model calibration performance. Adapted from Moriasi et al. (2007)

Performance Rating	Percent Bias (Monthly)	Nash-Sutcliffe (Monthly)
Very good	< ±10	0.75 < NSE < 1.00
Good	±10 < PEM < ±15	0.65 < NSE < 0.75
Satisfactory	±15 < PEM < ±25	0.50 < NSE < 0.65
Unsatisfactory	> ±25	< 0.50

The calibration performance results for of the watersheds are presented in Table 17. A total of 243 gauges within 50 HUC8 watersheds were used for calibration. Five HUC8 watersheds were ungauged and parameters were used from adjacent models to run them.

Table 17. Observed and simulated mean monthly flows, percent differences in flows, and Nash-Sutcliffe coefficients for monthly data. All flow values are cfs. Contributing basins that are not in the active cells of the NFSEG MODFLOW model domain are indicated by an asterisk.

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
03050207	10	02175500	fair	280	282	-1	0.74
03050208	7	02176500	poor	123	109	11	0.76
03060101	23	02185200		171	179	-5	0.83
	3	02186000	good	174	166	5	0.85
	7	02186645		115	114	1	0.92
	5	02186699	good	55	52	5	0.84
03060102	1	02176930		208	161	22	0.75
	22	02177000	good	637	576	10	0.85
	18	02178400	good	178	142	20	0.70
	24	02181580	fair	58	293	-403	-25.55
	9	02182000		52	68	-30	0.68
03060103	16	02187910	good	121	125	-3	0.82
	8	02188600	good	73	55	25	0.73
03060104	16	02191300	fair	825	828	0	0.89
	5	02191743		163	177	-9	0.85
	21	02192000	good	1571	1506	4	0.92
03060105	4	02193340	good	24	25	-1	0.82
	20	02193500	good	209	218	-4	0.85
03060106	18	00219730B		134	126	6	0.11
	17	02195320	good	58	53	8	0.86
	20	02196690	good	167	151	9	0.68
	7	02197300		101	109	-7	-1.06
	23	02197310		218	215	2	0.54
	24	02197315		235	236	-1	0.47

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
	13	02197400		70	64	8	0.37
	22	02197415		115	148	-29	0.78
	38	02197500	fair	9289	3210	65	-0.45
03060107	15	02196000	good	305	322	-5	0.86
03060108	8	02197598	good	12	14	-23	0.24
	10	02197600		25	25	0	0.68
	19	02197830		422	382	10	0.87
	20	02198000	good	509	476	6	0.90
	9	02198100	good	25	18	28	0.52
03060109	10	02198500	good	10327	4116	60	-0.18
	8	02198690	good	112	108	4	0.79
03060201	35	02200120		323	320	1	0.67
	24	02201000	good	100	99	1	0.89
	40	02201230	good	920	920	0	0.92
03060202	14	02202040	good	1303	1303	0	0.89
	21	02202190		1306	1430	-9	0.90
	23	02202500	good	2020	1950	3	0.90
	15	02202600	good	166	150	10	0.81
	25	02202680		1714	1873	-9	0.91
03060203	25	02203000	good	439	460	-5	0.93
	30	02203518		765	758	1	0.93
03070101	19	02217475	good	429	410	4	0.94
	21	02217500	good	470	481	-2	0.93
	1	02217615		114	114	-1	0.94

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
	27	02217770	good	287	288	0	0.94
	35	02218300	good	1193	1097	8	0.94
	5	02219000	good	226	226	0	0.90
	22	02220900	fair	229	161	29	0.75
	15	02221525	good	149	116	22	0.76
03070102	18	02223056	fair	2206	2482	-13	0.86
	14	02223110		268	272	-1	0.92
	5	02223190		159	68	57	0.45
	22	02223248	good	3478	3487	0	0.96
	7	02223360		103	78	24	0.82
	25	02223500	good	3973	3801	4	0.92
	28	02224500		4238	3804	10	0.90
03070103	38	02204070	good	315	276	12	0.86
	1	02206500		256	230	10	0.85
	16	02207120	good	265	236	11	0.84
	19	02207220	good	345	316	8	0.81
	20	02207335	good	403	357	12	0.82
	2	02207448	fair	92	99	-7	0.83
	22	02208000		507	509	0	0.97
	39	02208450	good	232	200	14	0.89
	27	02210500	fair	1885	1655	12	0.89
	7	02211800		258	278	-8	0.90
	31	02212735		2042	2006	2	0.96
	33	02213000	good	2602	2371	9	0.89

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
03070104	6	02214590		127	151	-19	0.80
	19	02215000		3259	3122	4	0.92
	24	02215260		4377	4207	4	0.90
	28	02215500	good	5085	4896	4	0.86
03070105	1	02215900		221	215	3	0.90
	5	02216180	good	45	45	1	0.82
03070106	3	02225000	good	10756	10024	7	0.89
	16	02226000	good	12439	11877	5	0.89
	11	02226100		166	166	0	0.83
03070107	7	02225270		481	370	23	0.82
	12	02225500	good	988	998	-1	0.93
03070201	13	02226362		402	402	0	0.91
	15	02226500	good	931	880	5	0.91
	10	02227270		208	120	42	0.65
	21	02228000	good	2009	1980	1	0.86
03070202	12	02227500	good	473	478	-1	0.83
03070204	4	02228500		112	114	-2	0.79
	6	02229000		95	63	34	0.58
	10	02229250		119	79	34	0.69
	14	02231000	good	534	484	9	0.86
03070205	4	02231268		15	18	-21	0.80
	7	02231280		38	35	7	0.78
	13	02231289		1087	306	72	-0.30
03080101	21	02231600	fair	189	250	-32	0.63

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
03080102	25	02232000	good	726	632	13	0.70
	29	02232400	fair	1087	958	12	0.71
	31	02232500	good	1314	1220	7	0.72
	11	02233104		103	90	13	0.58
	17	02233484	fair	298	235	21	0.74
	24	02233500	fair	329	256	22	0.69
	35	02234000	fair	1940	1705	12	0.77
	9	02234435	fair	167	180	-8	-0.27
	39	02234500	fair	2214	2136	4	0.69
	7	02235000	fair	289	291	-1	0.66
	3	02235200	poor	57	80	-40	0.36
	42	02236000	good	2931	2924	0	0.67
	45	02236125	fair	3169	3323	-5	0.63
	25	02237293	fair	31	47	-51	0.61
	27	02237700	fair	53	56	-7	0.40
	28	02238000	fair	142	133	6	0.66
	7	02238500	fair	152	153	-1	0.64
	25	02239501		591	612	-4	0.30
	10	02240000	good	812	797	2	0.76
	13	02240500	fair	885	851	4	0.80
	31	02240902		51	29	43	0.59
	32	02241000		23	30	-31	0.51
	41	02243000	fair	46	52	-14	0.80
	47	02243960	fair	1051	1005	4	0.78

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
03080103	13	02244040	fair	4652	4638	0	0.59
	40	02244320		75	71	6	0.65
	41	02244420		81	108	-33	0.46
	46	02244440	fair	494	582	-18	0.36
	12	02244473		43	45	-5	0.70
	11	02245050		70	149	-114	-4.23
	9	02245140		56	43	22	0.67
	7	02245328		157	73	53	0.39
	19	02245500	good	128	130	-1	0.54
	21	02246000	good	174	176	-1	0.84
	25	02246025	fair	456	449	2	0.63
	2	02246318	fair	51	54	-7	0.71
	33	02246500	fair	7969	6909	13	0.16
03080201	23	02246895		319	20	94	-2.62
	26	02247015		34	34	2	0.39
	5	02247510	fair	50	55	-10	0.66
	15	02247598	poor	129	125	3	0.27
	9	02248000	fair	29	11	62	0.21
	12	02248053	poor	85	85	0	0.61
	8	02248060	poor	38	19	51	0.24
03100207	29	02309421	fair	9	3	67	-0.35
	32	02309425	good	16	20	-24	0.24
	27	02310000	fair	58	53	9	0.65
	40	02310280	fair	5	14	-211	-4.76

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
	41	02310300	fair	21	38	-86	0.23
	18	02310525	fair	156	161	-3	0.52
	19	02310545	fair	173	170	2	0.55
	12	02310663	fair	100	150	-50	0.02
	7	02310688		59	61	-2	0.72
	9	02310700	poor	202	88	57	-2.70
	3	02310747	fair	463	34	93	-4.13
03100208	22	02311500	fair	154	152	1	0.57
	26	02312000	fair	238	214	10	0.63
	9	02312180	fair	39	22	43	0.45
	19	02312200	fair	61	46	24	0.59
	28	02312500	fair	300	282	6	0.68
	32	02312600	fair	300	312	-4	0.56
	6	02312640	fair	11	10	12	0.38
	14	02312645		9	13	-45	-4.49
	23	02312700	fair	127	113	11	0.45
	36	02312720	fair	455	488	-7	0.57
	37	02312722	poor	260	372	-43	-1.05
	41	02313000	fair	646	659	-2	0.65
	22	02313100	fair	622	688	-11	-3.61
03110101	15	02313700	poor	183	207	-13	0.58
03110102	7	02324000		245	211	14	0.71
	18	02324400	fair	35	64	-82	0.05
	19	02324500		117	109	7	0.38

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
	20	02325000	fair	165	115	30	0.33
	11	02326000	good	129	130	-1	0.76
03110103	9	02326526		437	468	-7	-0.87
	20	02326550	poor	938	1045	-11	0.20
03110201	44	00231427S		136	135	1	0.72
	45	02314500	fair	784	625	20	0.83
	24	02315000		1201	1163	3	0.90
	13	02315200		70	63	9	0.76
	31	02315500	fair	1469	1422	3	0.90
	34	02315550		1982	1997	-1	0.88
	0	02319500	good	5560	5143	8	0.88
03110202	27	02315920		294	290	1	0.85
	30	02316000	good	450	453	-1	0.87
	34	02317500	good	1072	1002	6	0.88
	36	02317620		975	903	7	0.84
03110203	15	00231774A		458	270	41	0.65
	16	02317755		241	173	28	0.76
	18	02318500	good	1237	1086	12	0.83
	13	02318700	poor	233	161	31	0.73
	21	02319000	fair	1758	1546	12	0.82
	22	02319300	fair	1457	1487	-2	0.78
	23	02319394	fair	1982	1777	10	0.79
	44	02319500	good	5560	5131	8	0.88
03110204	1	02317797		101	84	16	0.87

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
	11	02318000	fair	492	470	5	0.90
	13	02318380		570	545	4	0.91
03110205	14	02319800	good	4803	4832	-1	0.87
	16	02320000	good	5115	4960	3	0.86
	21	02320500	good	6319	6185	2	0.82
	22	02323000	good	6930	7039	-2	0.75
	26	02323500	fair	8157	8485	-4	0.76
	29	02323592	fair	7407	7568	-2	0.74
03110206	7	02320700		32	32	-1	0.32
	11	02321000	fair	136	115	15	0.73
	15	02321500	good	325	299	8	0.79
	17	02321975		772	784	-1	0.74
	18	02322500	fair	1170	1138	3	0.75
	5	02322700	poor	298	297	1	0.60
	21	02322800	fair	1510	1681	-11	0.69
03120001	5	02326900	poor	698	684	2	0.68
	26	02327022	poor	635	588	7	0.06
	8	02327033		117	66	44	0.25
03120002	23	02327355		186	180	3	0.94
	27	02327500	fair	525	519	1	0.91
03120003	4	02327100	fair	174	108	38	0.34
	15	02328522	fair	826	842	-2	0.87
	16	02329000	good	1002	1112	-11	0.82
	6	02329600	fair	353	333	6	0.82

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
	8	02330000	fair	1573	1704	-8	0.83
	3	02330100	good	194	152	22	0.73
	10	02330150	fair	1797	1854	-3	0.80
03130005	24	02344350	good	181	164	10	0.87
	27	02344396	good	181	174	4	0.94
	33	02344500	good	306	310	-1	0.85
	4	02344605		42	33	21	0.81
	22	02344630		40	43	-6	0.71
	23	02344700	good	121	107	11	0.77
	36	02344872	good	738	762	-3	0.92
	44	02347500	good	1925	1877	3	0.86
03130006	29	02349500		3306	2932	11	0.72
	31	02349605	good	3069	2864	7	0.77
	7	02349900	good	41	43	-6	0.78
	43	02350512	good	4114	3782	8	0.81
03130007	17	02350600	good	193	174	10	0.80
	26	02350900	good	522	508	3	0.84
	18	02351500	good	132	135	-2	0.78
	25	02351890	good	382	371	3	0.77
03130008	23	02353000	good	5815	5704	2	0.81
	24	02355662	good	6375	6717	-5	0.86
	29	02356000	good	6577	7186	-9	0.84
03130009	27	02353265	good	278	281	-1	0.90
	22	02353400	good	220	180	18	0.67

Model (HUC8)	HSPF Model Reach	Calibration Gauge	USGS Data Quality Water Year 2009*	Observed Mean Monthly (cfs)	Simulated Mean Monthly (cfs)	Monthly Percent Bias (%)	Monthly Nash-Sutcliffe Coefficient
	32	02353500	good	664	646	3	0.85
	10	02354440		67	71	-7	0.83
	28	02354500	good	254	290	-14	0.85
	34	02354800	good	890	940	-6	0.92
	35	02355350	good	856	898	-5	0.88
03130010	18	02357000	good	491	489	0	0.87
03130013	6	02330400	fair	260	222	15	0.63

* Blank cells do not have any data collected in water year 2009.

The spatial distribution of Nash-Sutcliffe values is show in Figure 26.

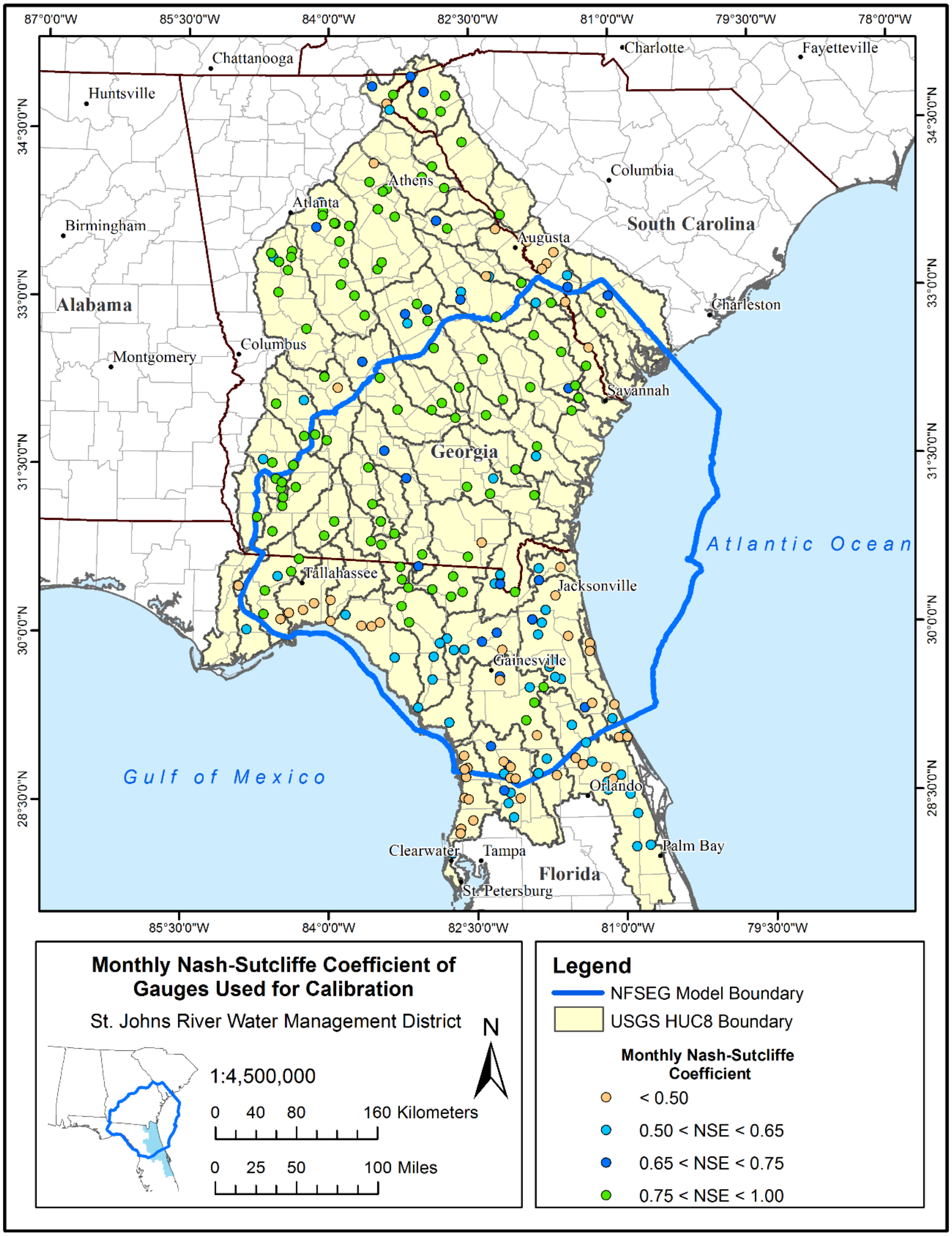

Figure 26. Map showing Nash-Sutcliffe values for model calibrations at individual gauges over the NFSEG model domain.

Figure 27 and Figure 28 compare measures of model performance against data quality. Note from the figures that the USGS has not identified any gauge as "Excellent" for 2009. The figures show that measures of model performance like the Nash-Sutcliffe or percent bias should not be the only way model performance is evaluated, since these measures are also dependent on data quality.

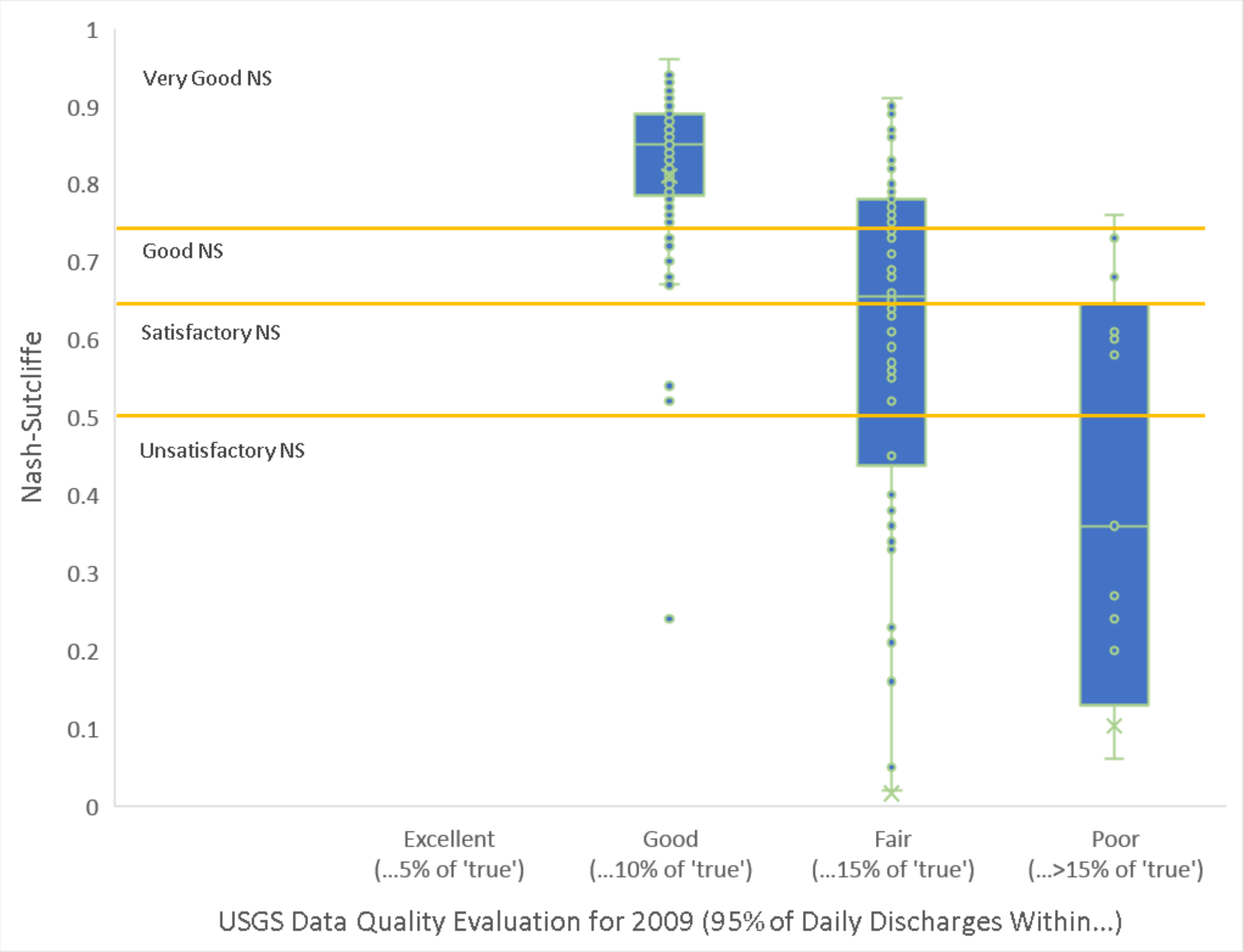

Figure 27. Comparison between model performance and data quality.

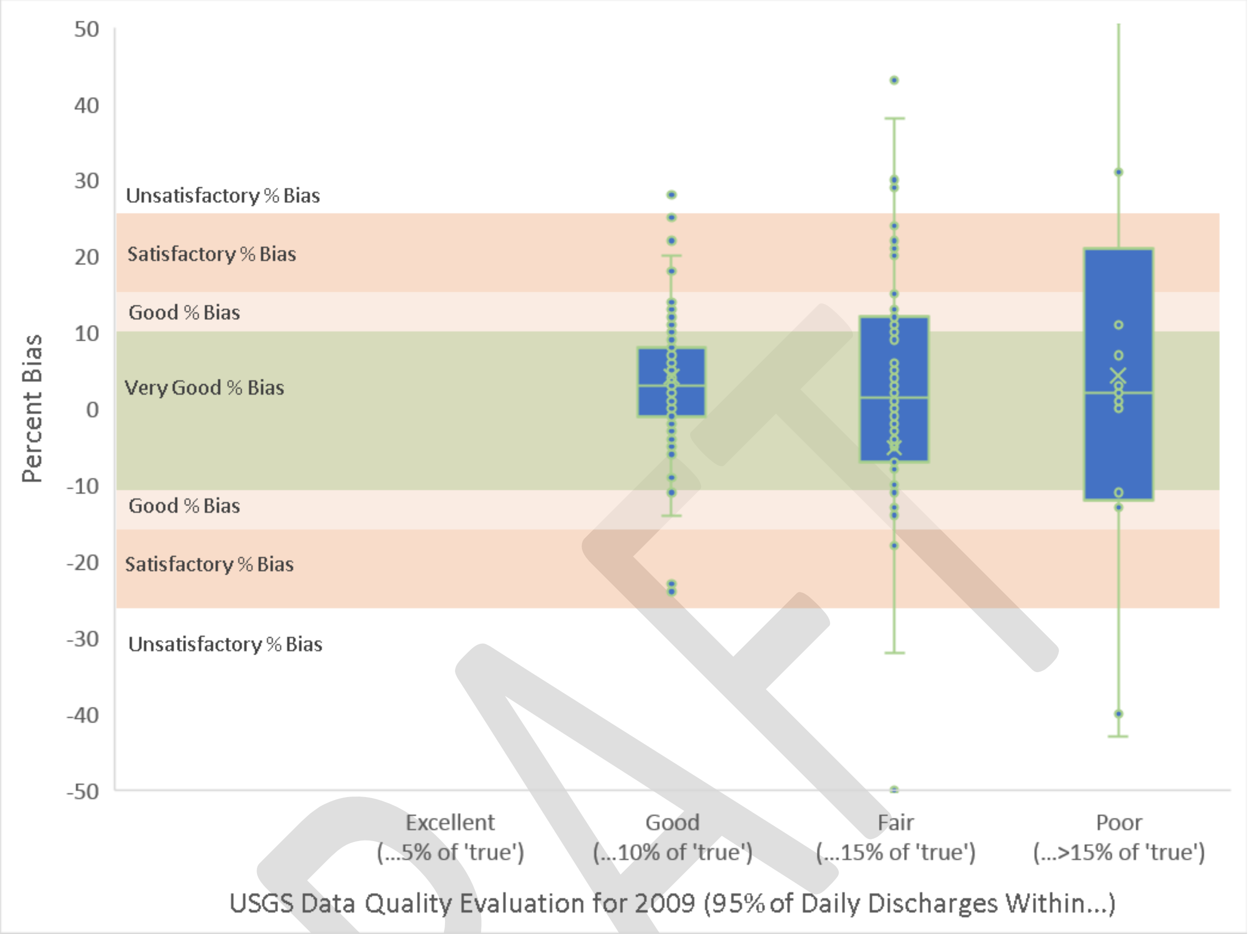

Figure 28. Percent bias chart plotted against USGS data quality evaluation.

Calibration plots and statistics are provided as appendices for all 243 gauges organized. These appendices are organized by model and named “Appendix XXXXXXXX” where “XXXXXXXX” is the HUC8 number of the model.

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APPENDIX A – SJRWMD HSPF COMMON LOGIC

Parameter	Description	Units	District	USEPA (2000)	Notes
			Min/Max	Min/Max	
AGWRC	Base groundwater recession	none	0.9/0.999	0.85/0.999	
BASETP	Fraction of remaining ET from baseflow	none	0.0/0.1 a little higher is OK	0.0/0.2	
CEPSC	Interception storage capacity	inches	0.03/0.20	0.01/0.40	
DEEPFR	Fraction of groundwater inflow to deep recharge	none	0.0/0.6 1.0 is OK if ephemeral stream	0.0/0.5	DEEPFR is the fraction of infiltrating water, which is lost to deep aquifers (i.e. inactive groundwater), with the remaining fraction (i.e. 1-DEEPFR) assigned to active groundwater storage that contributes base flow to the stream. It is also used to represent any other losses that may not be measured at the flow gage used for calibration. The District has planning level recharge values that should be used as initial values. DEEPFR > 0 (rare exceptions) Adjust DEEPFR so that IGWI approximately matches recharge numbers from Boniol
FOREST	Fraction forest cover	none	0/0	0/0.95	Fraction of land that can transpire when there is snow pack
INFEXP	Exponent in infiltration equation	none	2.0/2.0	1.0/3.0	
INFILD	Ration of max/mean infiltration capacities	none	2.0/2.0	1.0/3.0	

Parameter	Description	Units	District	USEPA (2000)	Notes
			Min/Max	Min/Max	
INFILT	Index to infiltration capacity	inches/hr	0.01/1.0 See table in notes	0.001/0.5	INFILT is the parameter that effectively controls the overall division of the available moisture from precipitation (after interception) into surface and subsurface flow and storage components. Thus, high values of INFILT will produce more water in the lower zone and groundwater, and result in higher base flow to the stream; low values of INFILT will produce more upper zone and interflow storage water, and thus result in greater direct overland flow and interflow. INFILT is primarily a function of soil characteristics (soil type and land treatment); therefore land use should be used to adjust this parameter providing a range of values, i.e. forest, open, pasture and ag should have a greater values than urban, and wetland. A soils: 0.40-1.00 in/hr: low runoff potential B soils: 0.10-0.40 in/hr: moderate runoff potential C soils: 0.05-0.10 in/hr: moderate to high runoff potential D soils: 0.01-0.05 in/hr: high runoff potential
INTFW	Interflow inflow parameter	none	0.0/3.0	1.0/10.0	INTFW determines the amount of water, which enters the ground from surface detention storage and becomes interflow, as opposed to direct overland flow and upper zone storage. Interflow can have an important influence on storm hydrographs; particularly when vertical a shallow, less permeable soil layer has retarded percolation. For most watersheds in the District interflow should be zero due to flat land slopes and shallow depth to water do not allow much lateral flow in the vadose zone. Determined from A,B soils plus slope. Higher slope -> higher INTFW, more A,B soils -> higher INTFW
IRC	Interflow recession parameter	none	0.50/0.70	0.30/0.85	

Parameter	**Description**	**Units**	**District**	**USEPA (2000)**	**Notes**
			Min/Max	**Min/Max**	
KVARY	Variable groundwater recession	1/inches	0.0/3.0	0.0/5.0	
LSUR	Length of overland flow	ft	200/500	100/700	WinHSPF has a table of values for LSUR based on slope. That table is the preferred set of values.
LZETP	Lower zone ET parameter	none	0.20/0.70	0.10/0.90	LZETP is a coefficient to define the ET opportunity; it affects evapotranspiration from the lower zone, which represents the primary soil moisture storage and root zone of the soil profile. LZETP behaves much like a 'crop coefficient' with values mostly in the range of 0.2 to 0.7; as such it is primarily a function of vegetation. The following ranges for different vegetation are expected for the 'maximum' value during the year: Forest: 0.6-0.85 Grassland: 0.4-0.6 Row crops: 0.5-0.7 Barren: 0.1-0.4 Wetlands: 0.8-0.95
LZSN	Lower zone nominal soil moisture storage	inches	2.0/10.0	2.0/15.0	LZSN is related to both precipitation patterns and soil characteristics in the region. Initial estimates for LZSN in the Stanford Watershed Model (SWM-IV, predecessor model to HSPF) can determined by using one-eighth annual mean rainfall plus 4 inches for coastal, humid, or sub humid climates. Deep-rooted plants extract water from this zone; therefore land use should be used to modify this parameter providing a range of values for various PERLNDs, i.e. wetlands, forest and ag. should have a greater value than urban, open and pasture. Could base on (field capacity - wilting point) * minimum (depth to water table, root zone depth).
NSUR	Manning's 'n' for overland flow	none	0.15/0.35	0.05/0.50	

Parameter	**Description**	**Units**	**District**	**USEPA (2000)**	**Notes**
			Min/Max	**Min/Max**	
PETMAX	Temperature below which ET is reduced	deg. F.	35.0/45.0	32.0/48.0	
PETMIN	Temperature below which ET is zero	deg. F.	30.0/35.0	30.0/40.0	
SLSUR	Slope of overland flow plane	ft/ft/	0.001/0.15	0.001/0.30	
UZSN	Upper zone nominal soil moisture	inches	0.10/1.0 4.0 for wetlands	0.05/2.0	UZSN is related to land surface characteristics, topography, and LZSN. For agricultural conditions, tillage and other practices, UZSN may change over the course of the growing season. Increasing UZSN value increases the amount of water retained in the upper zone and available for ET, and thereby decreases the dynamic behavior of the surface and reduces direct overland flow; decreasing UZSN has the opposite effect. The model generally maintains a convention of using 10% of the value for LZSN. However, for wetlands this value does not need to follow this convention, and indeed a high value for UZSN is a key way to represent standing water, as the overland flow plane does not allow for this. The upper zone is defined as surface depression storage plus shallow soil moisture –essentially the water that is available for direct evaporation as opposed to transpiration by plants. It is acceptable for wetlands to have values of UZSN up to 1 to 4 inches.

APPENDIX C—DEVELOPMENT OF RECHARGE AND MAXIMUM SATURATED EVAPOTRANSPIRATION EQUATIONS

DEVELOPMENT OF RECHARGE EQUATION

HSPF Pervious Land Elements (PERLND)

Using the control volume in Figure 29 establish a mass balance on PERLND land elements:

$$In = Out + (Change\ in\ storage) \tag{1}$$

Take that:

$$In = Precipitation \tag{2}$$

$$Out = SURO + IFWO + LZET + UZET + CEPE + AGWI + IGWI + SURET \tag{3}$$

$$(Change\ in\ storage) = 0 \tag{4}$$

Then:

$$Precipitation = SURO + IFWO + LZET + LZET + UZET + CEPE + AGWI + IGWI + SURET \tag{5}$$

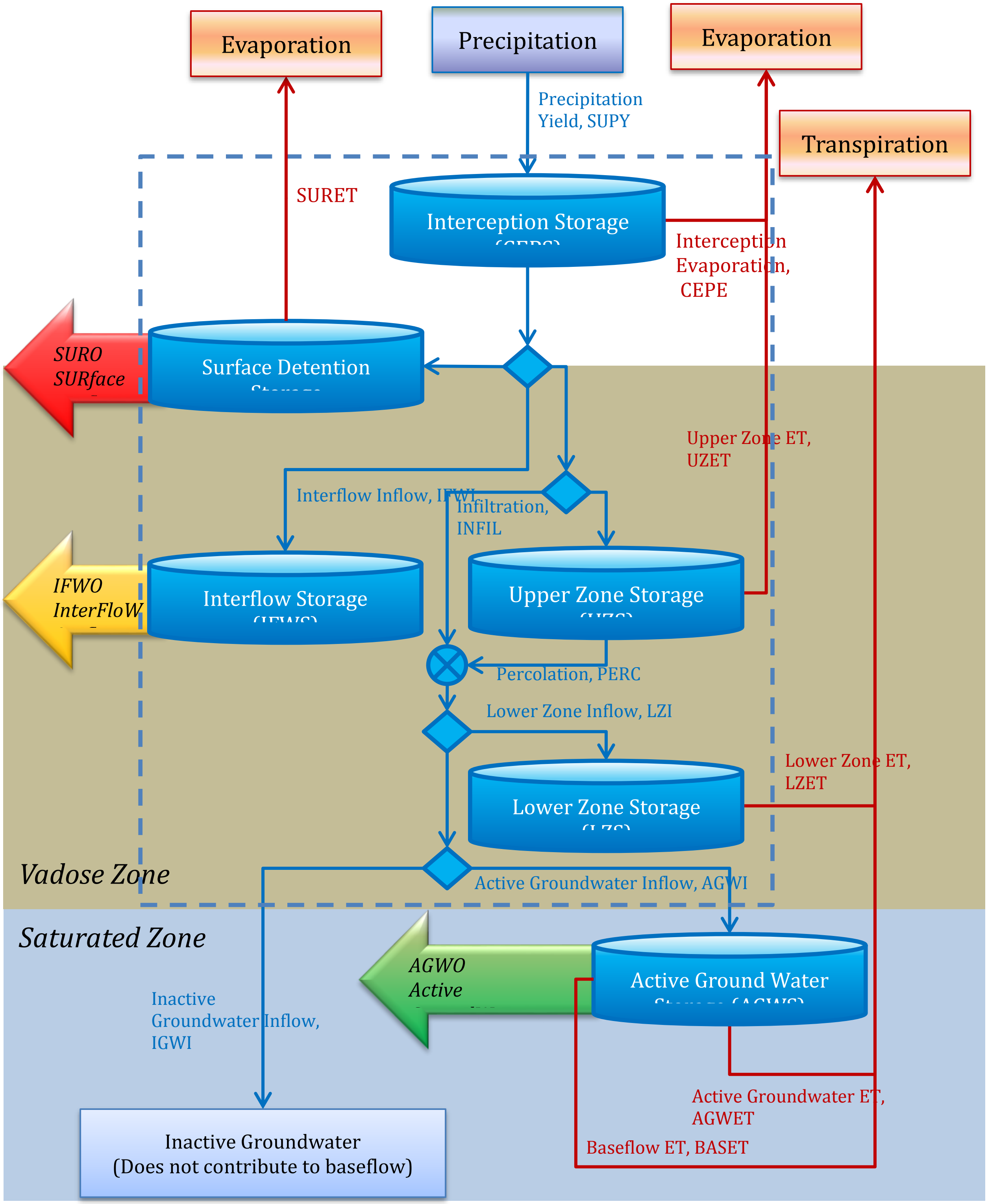
Evaporation
Precipitation
Evaporation
Transpiration
Precipitation Yield, SUPY
SURET
Interception Storage
Interception Evaporation, CEPE
SURO
SURface
Surface Detention
Upper Zone ET, UZET
Interflow Inflow, IFWI
Infiltration, INFIL
IFWO
InterFloW
Interflow Storage
Upper Zone Storage
Percolation, PERC
Lower Zone Inflow, LZI
Lower Zone ET, LZET
Lower Zone Storage
Vadose Zone
Active Groundwater Inflow, AGWI
Saturated Zone
AGWO
Active
Active Ground Water
Inactive Groundwater Inflow, IGWI
Active Groundwater ET, AGWET
Baseflow ET, BASET
Inactive Groundwater
(Does not contribute to baseflow)

Figure 29. Illustration of vadose zone control volume. Control volume is inside the blue, dashed line.

MODFLOW Recharge

What MODFLOW expects as recharge:

$$MODFLOW\ Recharge = Precipitation - interceptionET - directrunoff - unsaturatedET \tag{6}$$

Replace using HPSF water balance terms:

$$interceptionET = CEPE \tag{7}$$

$$directrunoff = SURO + IFWO \tag{8}$$

$$unsaturateET = LZET + UZET \tag{9}$$

MODFLOW recharge equation in HSPF terms:

$$MODFLOW\ Recharge = Precipitation - CEPE - SURO - IFWO - LZET - UZET \tag{10}$$

Rearrange Equation 5:

$$Precipitation - CEPE - SURO - IFWO - LZET - UZET = AGWI + IGWI + SURET \tag{11}$$

Combine Equation 5 and Equation 11:

$$MODFLOW\ recharge = AGWI + IGWI + SURET \tag{12}$$

DEVELOPMENT OF MAXIMUM SATURATED EVAPOTRANSPIRATION EQUATION

In the steady-state version of the NFSEG groundwater flow model, the rate of evapotranspiration (ET) from the saturated zone was estimated through use of the MODFLOW ET package. In the MODFLOW ET package, the rate of saturated ET varies linearly with the depth to the water table between a maximum saturate ET value input into the model that occurs at the “ET surface” typically assumed to be land surface, and 0 feet/day (ft/day), which occurs at the “extinction depth.” If the estimated water table is above the extinction depth then evaporation occurs. If the water table is above the "ET surface" then evaporation occurs at the maximum saturated ET rate. The maximum saturated ET is potential ET subtracting away the unsaturated ET terms. In HSPF terms shown in Figure 29 the equation used is:

$$Maximum\ Saturated\ ET = Potential\ ET - CEPE - UZET - LZET \tag{13}$$