CENTRAL SPRINGS GROUNDWATER FLOW MODEL (CSM) VERSION 1.1 MODEL REPORT

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List of Acronyms and Abbreviations

APT	aquifer performance test
cfs	cubic feet per second
CHD	constant head (MODFLOW package)
CSM	Central Springs Model
CUP	consumptive use permit
day^{-1}	feet per day per foot
DRN	drain package (MODFLOW)
ECFTX	East-Central Florida Transient Expanded Groundwater Flow Model
ET	Evapotranspiration
ft	foot or feet
ft/day	feet per day
ft^2/day	feet squared per day
GHB	general head boundary (MODFLOW package)
HOB	head observation package (MODFLOW)
HSPF	Hydrological Simulation Program – FORTRAN
ICU	Intermediate Confining Unit
in/yr	inch(es) per year
Kh	horizontal hydraulic conductivity
Kv	vertical hydraulic conductivity
LFA	Lower Floridan Aquifer
MAE	mean absolute error
MCU	Middle Confining Unit
ME	mean error
MFL	minimum flows and levels
MODFLOW	modular three-dimensional finite-difference groundwater flow model
MODFLOW-NWT	Newton formulation for MODFLOW-2005
NAVD88	North American Vertical Datum of 1988
NDM	Northern District Model
NSE	Nash–Sutcliffe efficiency coefficient
PBIAS	percent bias
PEST	Parameter ESTimation code
R^2	coefficient of determination
RMSE	root mean square error
RSR	ratio of root mean square error and standard deviation
SAS	Surficial Aquifer System
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
SWFWMD	Southwest Florida Water Management District
UFA	Upper Floridan Aquifer
USGS	U.S. Geological Survey
WUP	water use permit

1. Introduction

1.1 BACKGROUND

The Central Springs Model (CSM) groundwater flow model was developed through a collaboration between the St. Johns River Water Management District (SJRWMD) and the Southwest Florida Water Management District (SWFWMD). The model was designed to quantify the effects of current and future groundwater withdrawals on aquifer water levels, river baseflows, and spring discharges and provide a modeling tool to support water supply planning, evaluation of minimum flows and levels (MFLs), and consumptive/water use (CUP/WUP) permitting across north-central Florida. The CSM domain includes all of Marion, Volusia, Lake, Seminole, Sumter, Citrus, Hernando, and Pasco counties and parts of Alachua, Bradford, Clay, Putnam, Flagler, Brevard, Orange, Osceola, Polk, Hillsborough, Pinellas, and Levy counties (Figure 1-1).

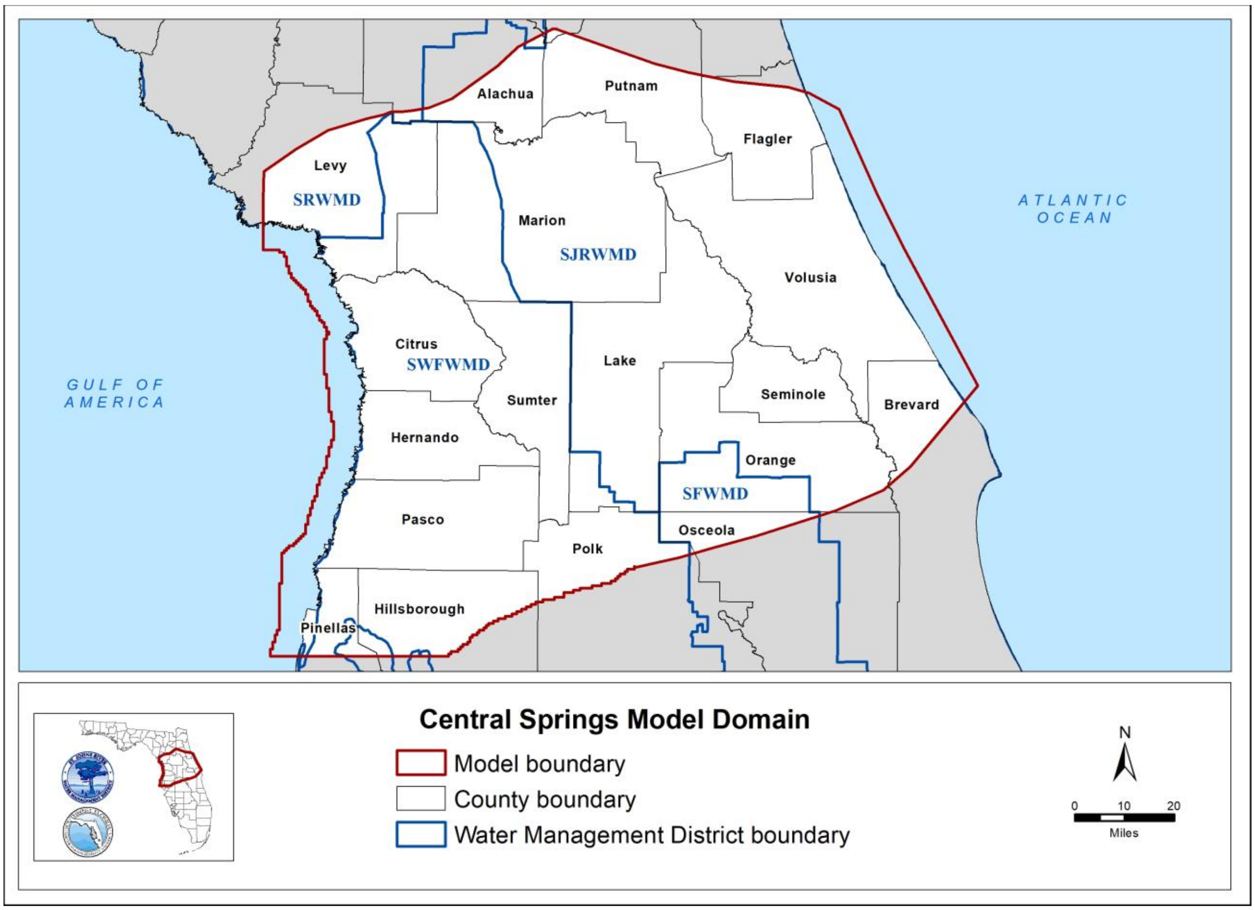


Figure 1-1. Central Springs Model domain.

The CSM is a fully three-dimensional groundwater flow model developed using the MODFLOW-NWT (Niswonger et al. 2011) computer code. The CSM is horizontally discretized into a uniform grid with a cell size of 2,500 ft by 2,500 ft and consists of 275 rows and 332 columns. The model is vertically discretized into seven hydrostratigraphic layers, with each layer representing hydrostratigraphic units of similar hydraulic properties. Figure 1-2 provides a visual representation and description of the model layers. The CSM includes a steady-state model representing average hydrologic conditions from 2005 to 2018 and a transient model representing 2005 annual conditions followed by 2006 to 2018 monthly conditions.

In 2023, the CSM was reviewed by independent modeling experts (peer reviewers) and interested stakeholders with suggested updates incorporated as appropriate. The model files, model report and resolution documents were finalized in the model version referred to as CSM version 1.0 (CSM v1.0).

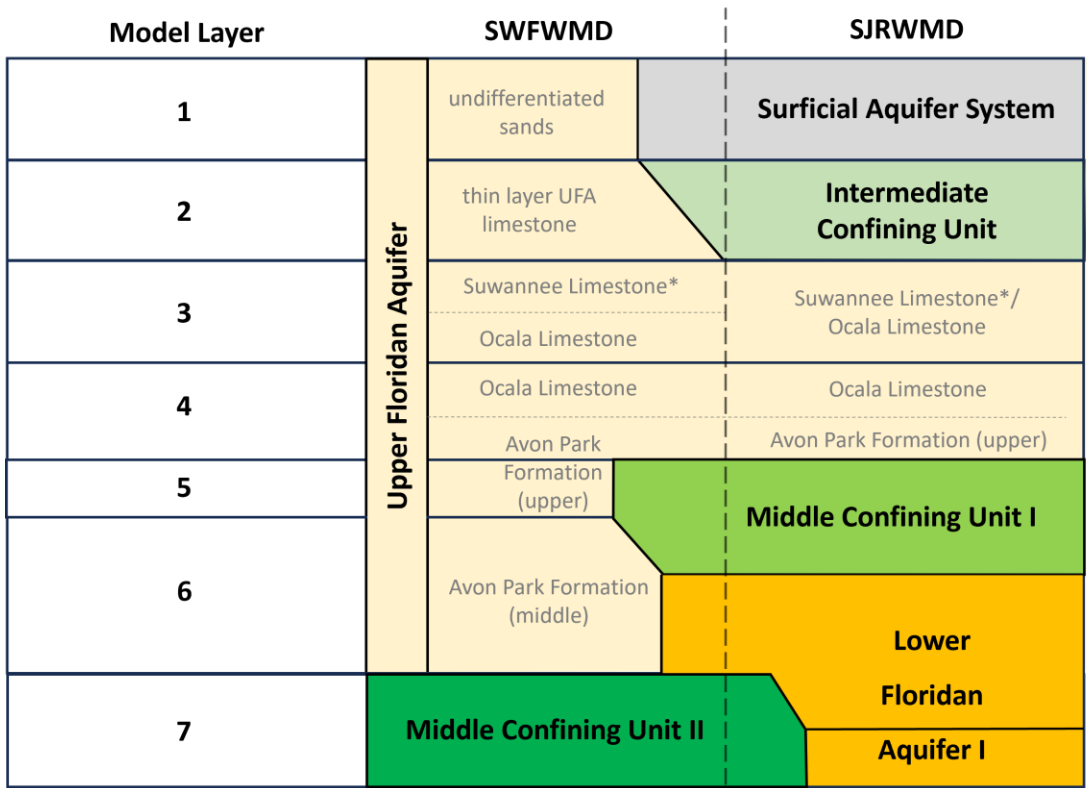


Figure 1-2. Visual representation and description of layers in the Central Springs Model
*Where present

1.2 Objectives

Following the completion of the CSM v1.0, the modeling team determined that additional model refinement was needed to address specific technical review comments, make the model a more suitable tool for regulatory decisions, and improve the model performance in the areas where minimum flows and levels (MFL) water bodies are located. To address these objectives and facilitate the recalibration effort, the modeling team delineated a critical area where the original calibration could be improved. The recalibration area, designated as "CSM v1.1 Recalibration Focus Area" in Figure 1-3, was delineated using the U.S. Geological Survey (USGS) May/June 2010 (Upper Floridan Aquifer) UFA potentiometric surface as a general guide.

As a result of more thorough review of the data in these areas, the team identified refinements to the following:

- Groundwater level targets
- River boundary conditions
- Drain boundary conditions
- Historical water use data and well layering

The recalibration effort was conducted only in the focus area with a goal to improve the model's ability to better match observed water levels and spring flows. In addition to the recalibration performed within the focus region, hydraulic conductivity values in layer 3 through layer 7 in the Northern Sumter County region were modified.

Information from the expanded Northern District Model (NDM) and available Lower Floridan Aquifer (LFA) aquifer performance test (APT) data was incorporated. The area modified for this purpose is shown in Figure 1-4 and documented in Appendix A. This report describes the model updates, recalibration approach, and results of the recalibration effort. The original and recalibrated model are referred to as CSM v1.0 and CSM v1.1, respectively, in this document.

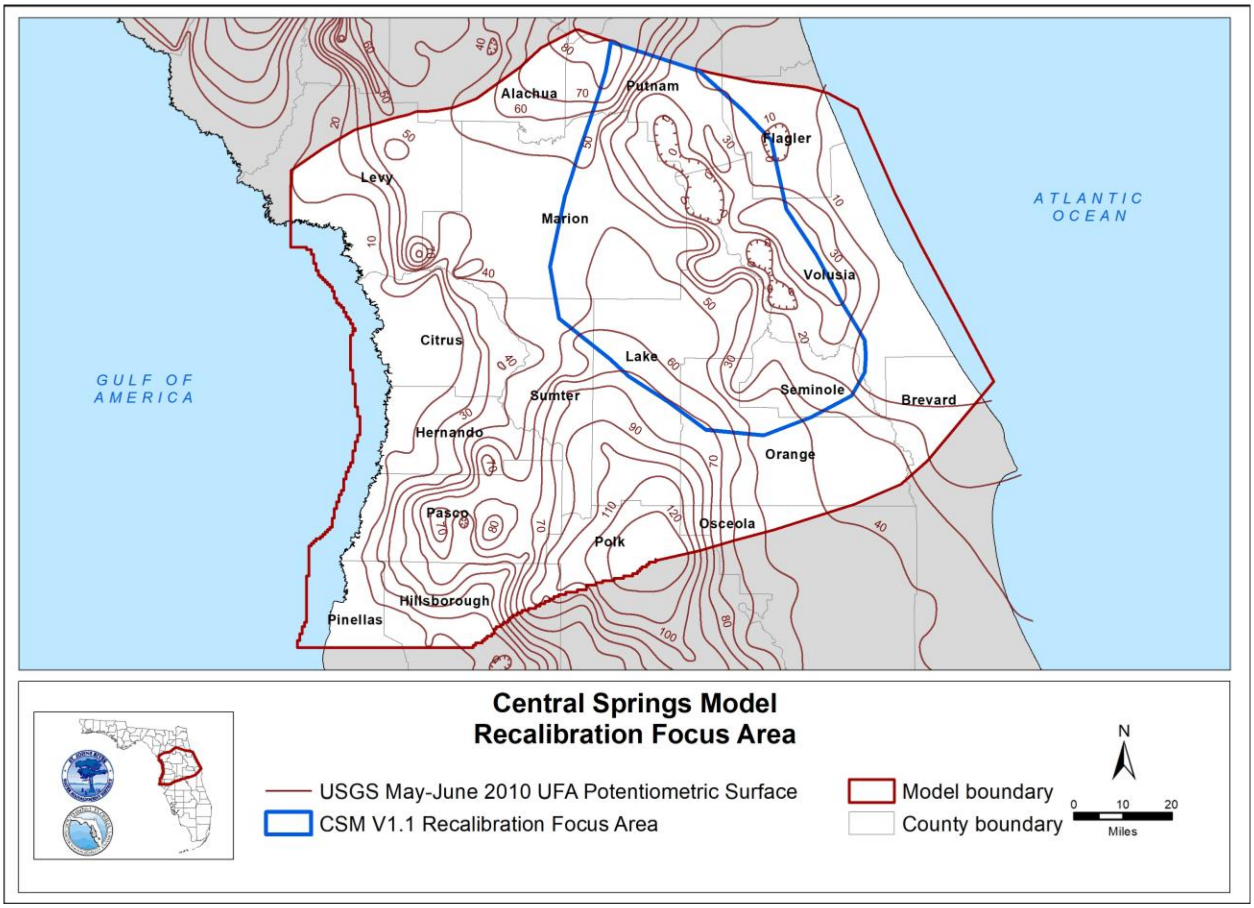


Figure 1-3. Central Springs Model recalibration focus area

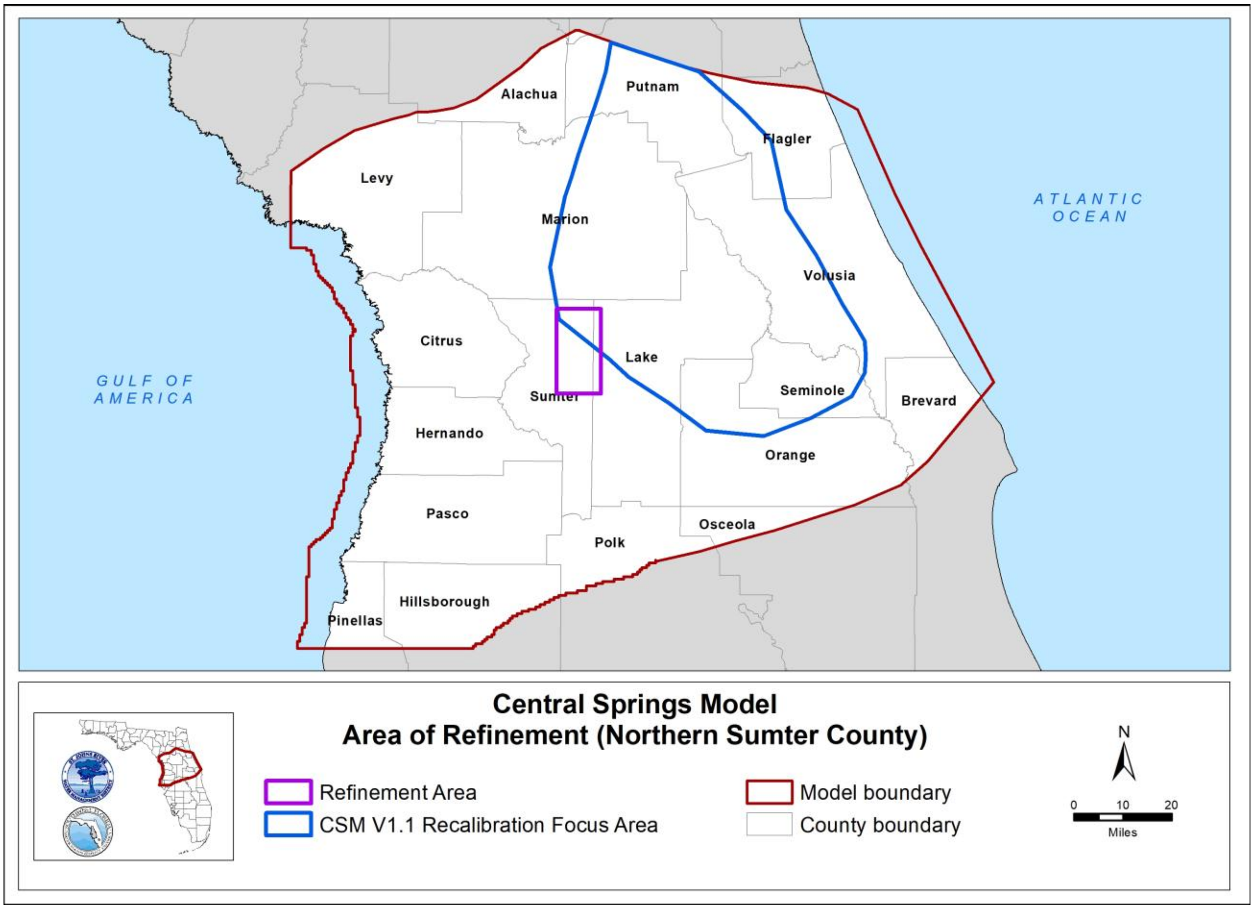


Figure 1-4. The Northern Sumter County refinement area updated in CSM v1.1. See Appendix A for additional information.

2. Model Updates

Updates to the CSM were generally limited to the focus area shown in Figure 1-3, and included modification of historical water use, groundwater level targets, drain boundaries and river boundaries. Changes to the model outside of the focus area included updates to layers 3 through 6 horizontal (Kh) and vertical (Kv) hydraulic conductivity values in the Northern Sumter County area of refinement shown in Figure 1-4 and described in Appendix A.

2.1 Historical Water Use

A review of groundwater withdrawals in the CSM v1.0 revealed that consumptive/water use permits (CUPs/WUPs) associated with The Villages production wells in SJRWMD (CUPs 50279 and 50280) and SWFWMD (WUPs 3206, 12239, 20687, 11404, and 11624) required layer assignment modifications in the MODFLOW well package. Model layers in the well package were adjusted for these permits as described in Table 2-1. Additionally, it was discovered during review that approximately 4 million gallons per day of groundwater withdrawal at Wekiva Falls Resort Spring (CUP 2742) associated with commercial water use was erroneously included in the model well package. Wekiva Falls Resort Spring is a free flowing well that was simulated using a MODFLOW drain boundary condition in the model, therefore accounting for the natural discharge of groundwater at this location during the calibration period. To rectify this, the groundwater withdrawal associated with CUP well SJ_2742_19795 was removed from the well package.

Table 2-1. Summary of permitted well model layer assignment modifications of The Villages production wells.

District	Permit	Station ID	CSM v1.0 Layer	CSM v1.1 Layer
SJR	50279	SJ_50279_454722	3 to 4	4
SJR	50279	SJ_50279_922	3 to 4	4
SJR	50279	SJ_50279_923	3 to 4	4
SJR	50279	SJ_50279_924	3 to 4	4
SJR	50279	SJ_50279_925	6	4, 6
SJR	50279	SJ_50279_926	3 to 4	4
SJR	50279	SJ_50279_927	3 to 4	4
SJR	50279	SJ_50279_928	3 to 4	4
SJR	50280	SJ_50280_23222	3 to 4	4
SJR	50280	SJ_50280_942	3 to 4	4
SJR	50280	SJ_50280_943	3 to 4	4
SWF	3206	SW0032060110025	3 to 4	6
SWF	3206	SW0032060120025	3 to 4	6
SWF	3206	SW0032060130025	3 to 4	6
SWF	3206	SW0032060140025	3 to 4	6
SWF	12339	SW0122390020001	4	6
SWF	12339	SW0122390020002	3 to 4	6
SWF	12339	SW0122390020003	3 to 4	6
SWF	12339	SW0122390020006	3 to 4	6
SWF	12339	SW0122390020013	3 to 4	6
SWF	20687	SW0206870020025	3 to 4	6
SWF	3206	SW0032060120008	4	4, 6
SWF	3206	SW0032060140008	4	4, 6
SWF	3206	SW0032060050008	4	4, 6
SWF	3206	SW0032060060008	4	4, 6
SWF	3206	SW0032060090008	4	4, 6
SWF	3206	SW0032060110008	4	4, 6

Additional review of model layer assignments for all SJRWMD permitted wells in the focus region was performed as a part of this model recalibration effort. For this review, hydrogeologic data, including well construction information, layer thickness, UFA transmissivity, and degree of confinement were considered in evaluating layer assignments used in the CSM v1.0. As a result of this effort, layer modifications were performed for 7,206 stations within the focus area. Approximately 99% (7,164) of the modified station withdrawals were sourced in the UFA and retained the same aquifer designation but shifted pumping to a single layer (model layer 3 or 4) instead of applying the withdrawal to both model layers that comprise the UFA. The remaining stations (42) shifted aquifer designation to the UFA (model layer 3 or 4), LFA (model layer 6), or split pumping across the UFA and LFA.

2.2 Groundwater Level Targets

Groundwater level targets in the focus area were reviewed for location accuracy, model layer assignment, and observation values. For this recalibration effort, there was a primary focus on improving simulation of groundwater levels in the surficial aquifer within the focus area, particularly those with an average residual, expressed as the simulated value minus observed value, greater than ± 5 feet in the CSM v1.0 transient calibration (Figure 2-1).

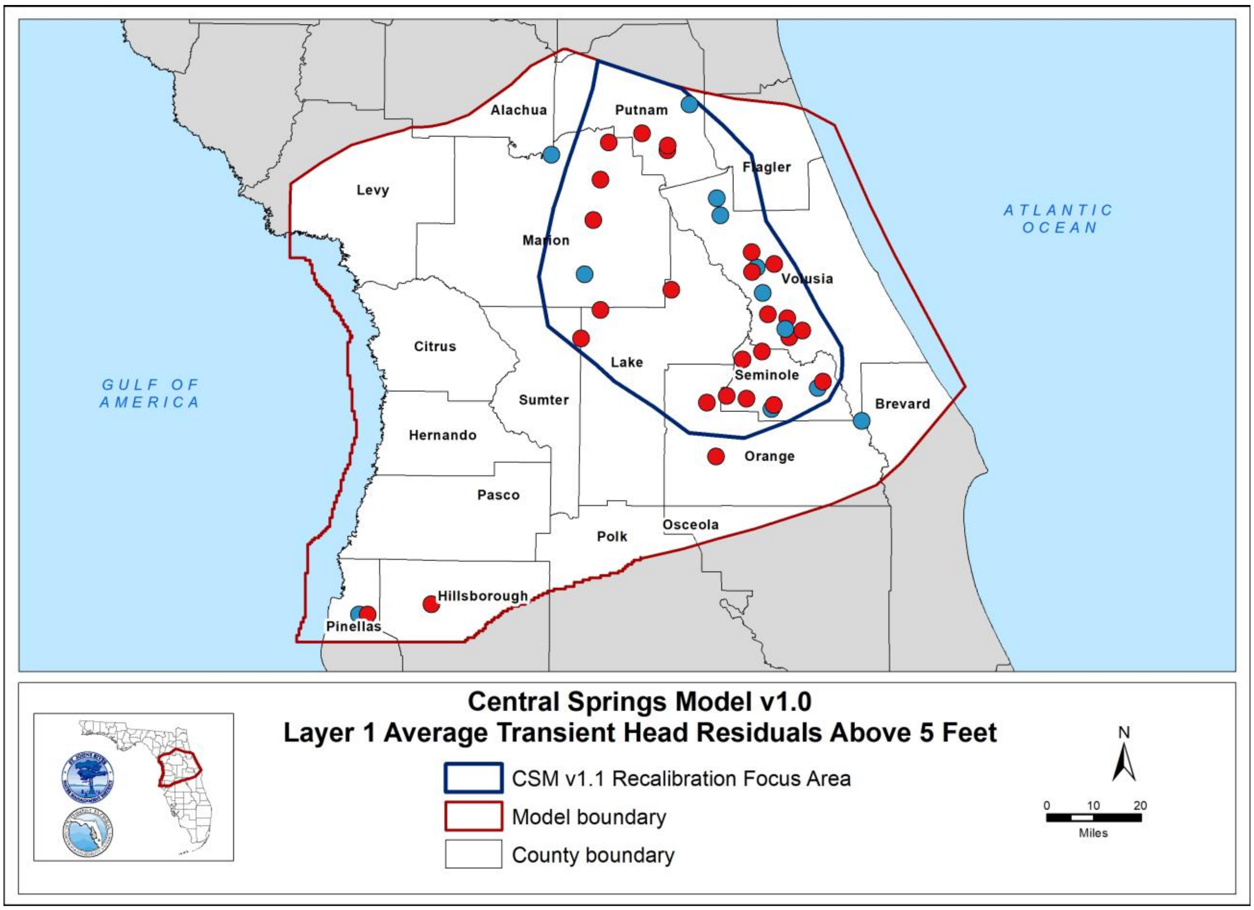


Figure 2-1. CSM v1.0 2005 to 2018 average transient head residuals greater than 5 feet in layer 1. Red circles indicate the model is underestimating the observed head by more than 5 feet. Blue circles indicate the model is overestimating the observed head by more than 5 feet.

A total of 13 wells shown in Figure 2-1 are adjacent to surface water features represented by river or drain boundary conditions in the model. Many of these wells showed a high degree of correlation between the observed stage and nearby groundwater level. In these cases, grid cell locations were moved to adjacent cells in the MODFLOW Head

Observation (HOB) package to correlate with the location of the head dependent boundary condition cell used to represent the surface water feature in the model.

Well construction information was also reviewed to verify accuracy of model layer assignment for groundwater level targets in the focus area. Monitoring well OR0547 is located near Wekiwa Springs. A review of the CSM v1.0 HOB package indicated that OR0547 was assigned to model layer 4, and the CSM v1.0 transient calibration results show that this well is undersimulated by greater than 10 feet. Well construction information indicates that OR0547 is open to the Middle Confining Unit (MCU) I (model layer 5). Due to uncertainty regarding MCU I and MCU II spatial extent and limited groundwater level monitoring data in the MCU I, OR0547 was zero weighted for the CSM v1.1 recalibration. Additionally, monitoring well OR0893 near Prevatt Lake was determined to be open to the upper part of the UFA (model layer 3), instead of model layer 4 as assigned in the CSM v1.0 HOB package.

Two groundwater level targets, P-4045 and M-0628, were added to the steady-state and transient calibration for this recalibration effort. Well P-4045 is a surficial aquifer monitoring well located in the upland area east of Little Lake George. In review of the CSM v1.0 HOB package, surficial well P-4046 is in the same grid cell as P-4045 and was utilized in the CSM v1.0 calibration. In review of the observed data available at these wells, it was determined that observed groundwater levels at P-4045 more accurately represent average conditions in the area represented in the model grid cell. Therefore, well P-4046 was inactivated in the model calibration and well P-4045 was included. It was also determined during review of the MODFLOW HOB package that LFA well M-0628, located in Marion County, was not utilized in the CSM v1.0 steady-state calibration since regular monitoring at this well was not initiated until 2020. Due to the limited amount of data available in the LFA in the focus region and the proximity of this well to Silver Springs, it was decided to include this well in the steady-state calibration. Nearby UFA well M-0419 had groundwater level measurements available through the transient simulation period (2005 to 2018) and linear correlation with LFA groundwater levels at M-0628 show a strong relationship (R^2 = 0.93, Figure 2-2). The linear regression model in Figure 2-2 was used to estimate LFA levels at M-0628 (response variable) using UFA levels at M-0419 (predictor variable) for the period of 2005 to 2018.

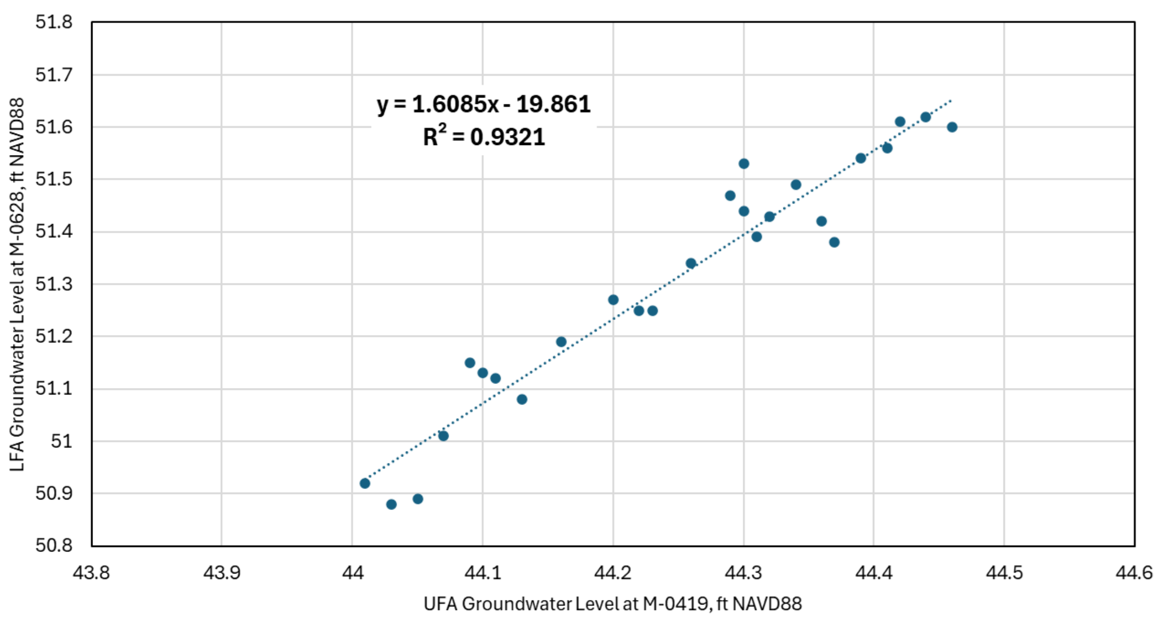


Figure 2-2. Linear regression of LFA level at well M-0628 (response variable) and UFA level at well M-0419 (predictor variable)

A summary of the groundwater level target modifications described above is presented in Table 2-2.

Table 2-2. Summary of groundwater level target modifications and justifications.

Well ID	Layer	Modification	Justification
V-0813	1	Moved to adjacent river cell (103, 221)	High degree of correlation with stage at Lake Daugharty. Updated observed head values based on measured data.
V-0808	3	Moved to adjacent river cell (103, 221)	High degree of correlation with stage at Lake Daugharty
V-0541	1	Moved to adjacent river cell (73, 196)	High degree of correlation with stage at Cowarts Lake
V-0528	1	Moved to adjacent drain cell (82, 197)	Average model top elevation more appropriate in grid cell
V-0531	3	Moved to adjacent drain cell (82, 197)	Same location as V-0528 (nested well)
V-0530	6	Moved to adjacent drain cell (82, 197)	Same location as V-0528 (nested well)
S-0716	1	Moved to adjacent river cell (146, 208)	High degree of correlation with stage at Sylvan Lake
S-0718	3	Moved to adjacent river cell (146, 208)	High degree of correlation with stage at Sylvan Lake
S-1023	1	Moved to adjacent river cell (159, 242)	Reduce influence of river stage
S-0001	3	Moved to adjacent river cell (159, 242)	Reduce influence of river stage
OR0894	1	Moved to adjacent river cell (159, 194)	High degree of correlation with stage at Prevatt Lake
OR0893	3	Moved from layer 4 to layer 3. Moved to adjacent river cell (159, 194)	Well is in upper part of UFA. Same location as OR0894.
OR0547	5	Moved to layer 5. Zero weighted well in calibration	Well in located in MCU I. Model lacks necessary layer discretization to simulate water levels at this location.
P-0197	1	Moved to adjacent drain cell (31, 184)	Reduce influence of river stage
P-0164	1	Moved to adjacent drain cell (31, 184)	Reduce influence of river stage
P-4045	1	Activated well in calibration	Located in well cluster next to P-4046
P-4046	1	Zero weighted well in calibration	Located in well cluster next to P-4045
M-0628	6	Activated well in calibration	Average water level estimated based on linear regression for model calibration period

2.3 Drain Boundary Conditions

The model drain boundary conditions utilized to represent small, intermittent streams, wetlands, and small lakes within the focus area were reviewed for this recalibration effort. Figure 2-3 shows the CSM v1.0 drain cells distributed in layer 1 as well as the location of ridge areas in the focus region. In the focus region, the principal ridges include the Crescent City and DeLand ridges in western Volusia County. These features are characterized by sandy deposits with high topographic elevation, karst development, and an absence of well-developed surface drainage (Williams 1997). Drain boundary condition cells located in layer 1 within the ridge areas identified in Figure 2-3 were reviewed and a majority were removed from the model. Additional drain cells outside of the ridge areas were reviewed and removed if they were deemed to not be conceptually appropriate based on review of surface water drainage and topographic maps of the region. The total number of drain cells in the model was reduced from 22,046 to 20,430. Figure 2-3 includes the revised CSM v1.1 drain cell distribution in layer 1.

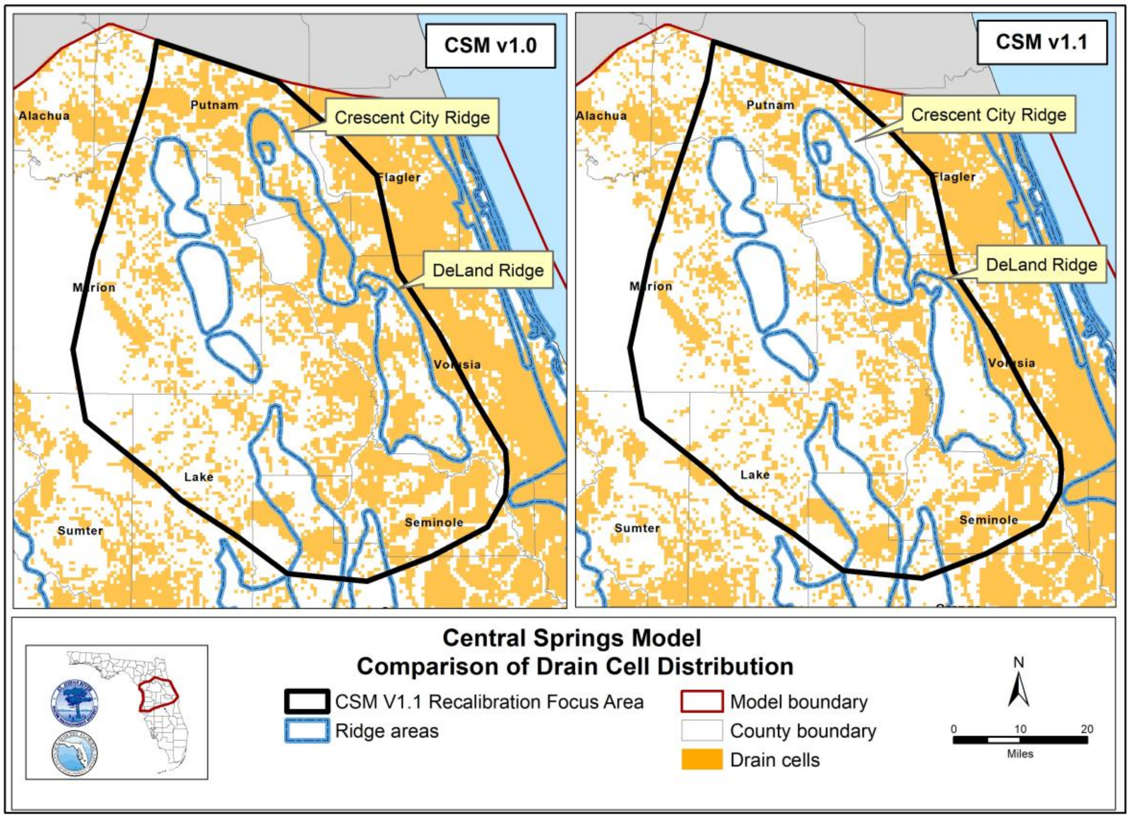


Figure 2-3. Distribution of drain cells in layer 1 in CSM v1.0 (left) and CSM v1.1 (right)

2.4 River Boundary Conditions

River stages assigned to the grid cells representing MFL lakes within the focus area were reviewed for accuracy. River stage at Lake Dias, Lake Daugharty, Lake Monroe, Prevatt Lake, Sylvan Lake, Silver Lake (Marion County), and Silver Lake (Lake County) were updated to be consistent with observed or estimated stage data. In addition to modifications to existing river cells in the model, the hydrography of the focus area was reviewed to determine if additional surface water features lacked representation in CSM v1.0. Table 2-3 lists 23 river boundary condition cells that were added within the focus region to represent surface features, primarily small lakes. Stage information for these features was estimated based on topographic elevation where data was not available. The added river cells are displayed spatially in Figure 2-4.

Table 2-3. Added river boundary condition grid cell location, stage and associated hydrologic feature name.

Layer	Row	Column	Assigned Stage (2005 to 2018 average feet, NAVD88)	Waterbody Name
1	133	227	75	Clearwater Lake
1	126	219	10	Mill Lake
1	116	218	20	No name available
1	116	219	20	No name available
1	133	220	30	Glen Abbey Pond
1	73	196	35	Cowarts Lake
1	132	228	40	McGarity Lake
1	132	227	60	Fieldstone Lake
1	133	228	40	Vivian Lake
1	31	184	20	Long Swamp
1	133	233	22.85	Theresa Lake
1	129	233	24.77	Angela Lake
1	130	233	24.77	Angela Lake
1	130	237	33.54	Deep Creek
1	131	237	33.61	Deep Creek
1	137	227	50	Thormpson Pond
1	136	225	60	Outlook Lake
1	110	220	65	Lake Lindley
1	136	227	65	Broken Arrow Lake
1	135	227	78.58	Randolph Lake
1	135	226	85	Castle Lake
1	116	225	60	No name available
1	133	235	25	No name available

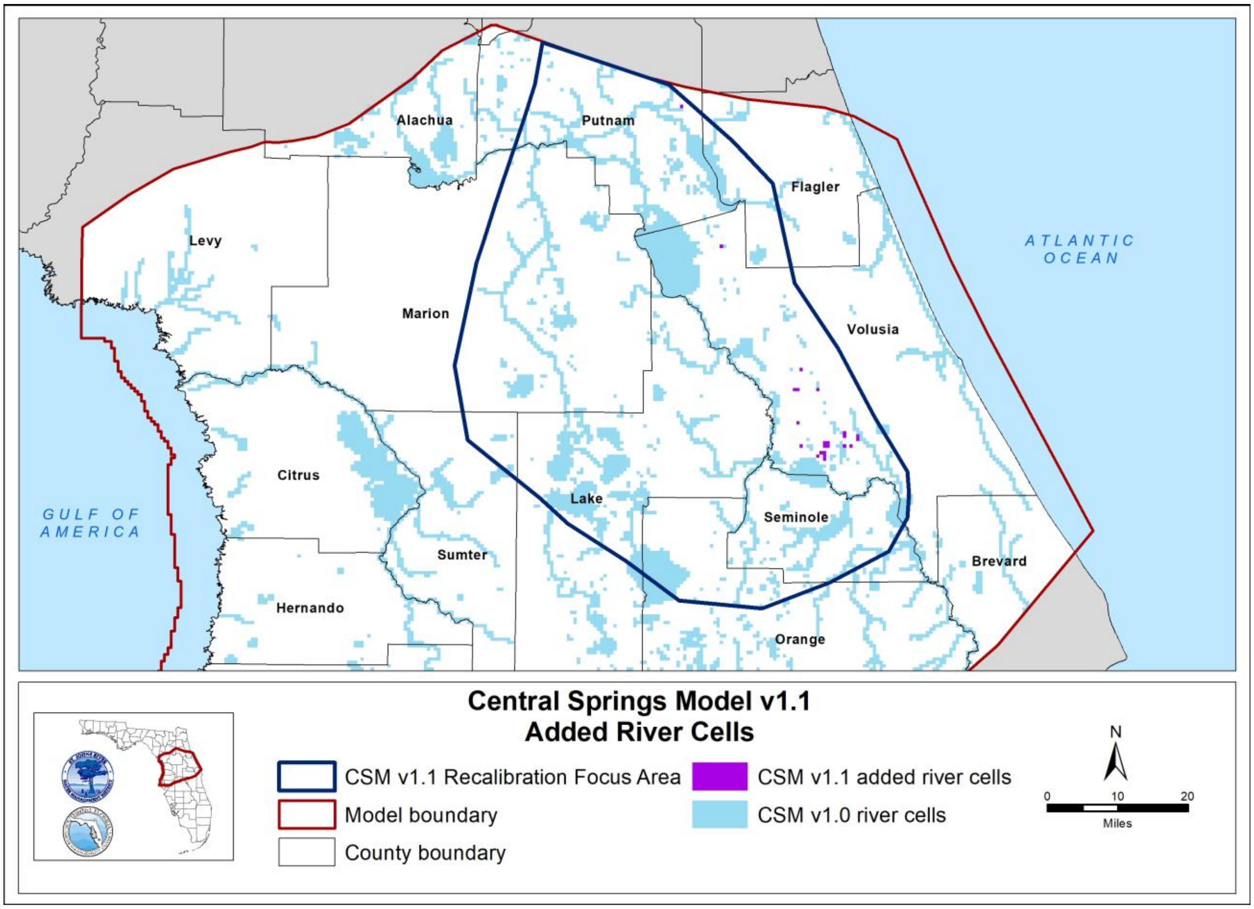


Figure 2-4. CSM v1.1 river cell distribution. Added or converted river boundary cells are shown in purple.

3. Model Recalibration

3.1 Calibration Approach

After the model was updated, model parameters were recalibrated to improve the model performance within the focus area. No changes were made to the parameters outside of the recalibration focus area (Figure 1-3) or the Sumter County refinement area (Figure 1-4) as part of recalibration. Model testing during recalibration indicated that modifications to model parameters within the focus area resulted in minimal changes to simulated groundwater levels and flows outside of the focus area.

Automated parameter estimation software (PEST) (Doherty 2015) was used for recalibration. The following parameters were adjusted using PEST:

- Hydraulic conductivity
- Spring conductance
- River conductance
- Drain conductance

Horizontal hydraulic conductivity (Kh) values for layers 1, 3, 4, 6, and 7 and vertical hydraulic conductivity (Kv) values for layers 2 and 5 were estimated directly at pilot point locations in the PEST calibration process. Pilot points are user specified points at which the values of parameters are adjusted during the PEST calibration process. CSM v1.0 utilized a uniform approach in the distribution of pilot points in each layer, with pilot points located uniformly with 10 grid cells (25,000 ft) between each point. A review of the hydrogeology within the focus region was completed to assess the reasonableness of the pilot point distribution for model calibration of this area. A literature review indicated that the hydrogeology of the area is heterogeneous, with recharge primarily concentrated in ridge areas and localized regions existing where the Intermediate Confining Unit (ICU) is thin or absent (Williams 1997; Tibballs 1990). Due to the heterogeneity of the system prevalent in the focus area, the pilot point locations were revised for model layers 1 (Surficial Aquifer System; SAS) through 5 (MCU I) to produce a denser network of points for parameter estimation. Additionally, pilot points were added to the Northern Sumter County Refinement Area (Figure 1-4) for model layers 3 (UFA) through 7 (LFA) to ensure a smooth hydraulic conductivity field that reasonably represented the local hydrogeology, as described in Appendix A. The revised pilot point distribution maps for layers 1 through 7 are included in Appendix B. Vertical anisotropy ratios remained the same as CSM v1.0.

Initial parameter values were obtained from the CSM v1.0 model. The upper and lower bounds of the pilot points, utilized for adjustment of hydraulic conductivities, were set so that the UFA and LFA transmissivities and ICU and MCU leakance values were maintained within the values consistent with the known hydrogeology of the area. All observations in the model were utilized for PEST calibration. Target weights assigned for the CSM v1.0 steady-state calibration were reviewed and revised, if needed, based on review of data. Spring flow target weights were reduced by an order of magnitude in PEST to enable greater emphasis on groundwater levels within the focus region. The following observations were employed for calibration:

- Groundwater levels for all layers
- Groundwater level differences between UFA and SAS and between LFA and UFA
- Spring flows
- Baseflows (qualitative)
- Vertical lake leakages (qualitative)

The model was recalibrated using a four-step approach as follows. The process is illustrated in Figure 3-1.

1. PEST optimization was first conducted on a steady-state model representing the average 2005-2018 condition.
2. Once a steady-state calibration was satisfactory, a transient model was run with the updated hydraulic properties.
3. Storage coefficients were adjusted as needed.
4. Steps 1 through 3 were repeated until a satisfactory transient calibration was achieved.

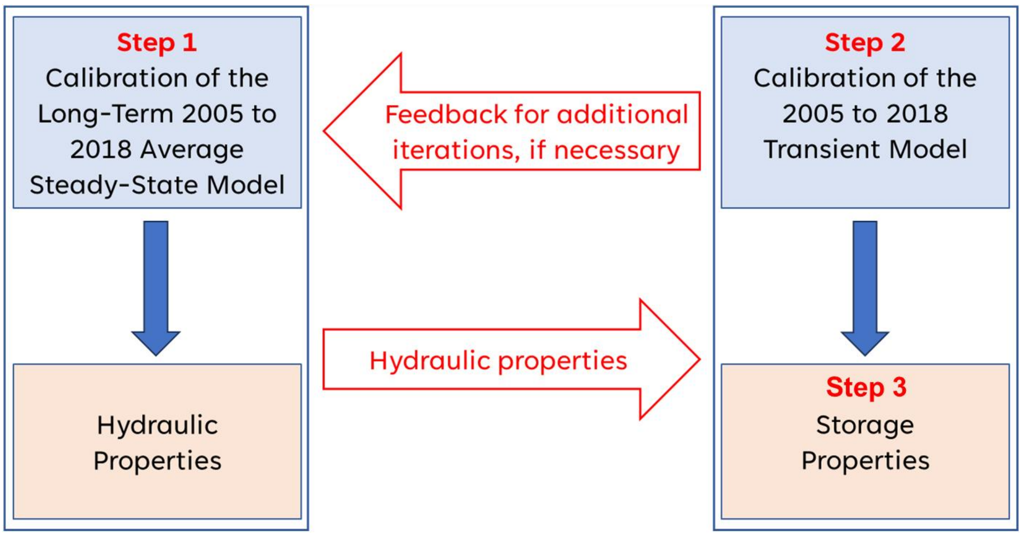


Figure 3-1. Central Springs Model calibration approach (Sun et al. 2024)

The transient calibration criteria set for CSM v1.0 were used to evaluate model performance. The recalibration was performed to ensure that the modeled groundwater levels and spring flows matched observed values closely within the focus area. Baseflows were reviewed qualitatively to ensure that the CSM v1.1 performed in a similar manner as CSM v1.0. Additional information on how baseflows were estimated and qualitatively assessed can be viewed in Chapter 6 of the CSM v1.0 model report (Sun et al. 2024). Simulated groundwater level contours were compared with potentiometric surface maps to further assess the model's ability to adequately match the configuration of the UFA flow field and groundwater flow direction. Aquifer performance test (APT) and literature data were utilized qualitatively to evaluate the reasonableness of the aquifer parameters.

No adjustments were made to recharge, maximum saturated evapotranspiration (ET) rates, general head boundary (GHB) conductance values, or the Kv multiplier in layer 2 underneath lakes in the CSM v1.0 model. The exception to this is Lake Weir, where the layer 2 Kv values underneath the lake area were manually adjusted during calibration to produce simulated lake leakage rates closer to the estimated value from water budget studies (Deevey 1988). After the recalibration was finalized, model-wide calibration statistics were also reviewed to ensure there was no degradation in model performance outside of the focus area.

3.2 Transient Model Calibration Results

Monthly average aquifer water levels and springflows, developed for the calibration of CSM v1.0, were utilized in this recalibration effort as calibration targets to assess model calibration metrics. These included average monthly water levels from observation wells of the SAS (layer 1), UFA (layers 3–4), and the LFA (layers 6–7). Additionally, vertical head differences (VHDs) between the SAS and UFA and between the UFA and LFA were evaluated quantitatively. Model-simulated river baseflows and lake leakages were compared with estimated values to ensure that the simulated fluxes were within a reasonable range. Flooded and dry cells were also examined during model calibration. Additional information regarding the observation data utilized to calibrate the transient model can be found in Chapter 6 of the CSM v1.0 documentation (Sun et al. 2024).

The CSM v1.0 calibration criteria were also used in this recalibration effort and included: 1) a mean error of less than ± 0.5 feet for SAS, UFA, and LFA heads from all wells, 2) 50% of the mean absolute simulated head residuals for all wells in the SAS, UFA, and LFA had to be within 2.5 feet of observed, and 3) 80% of the mean absolute simulated head residuals for all wells in the SAS, UFA, and LFA were required to be within 5 feet of observed values. Mean simulated spring discharge had to be within 5% of the estimated/measured flows for first magnitude springs and within 10% for second magnitude springs with reliable observed data.

Model calibration statistics for observation wells are presented in this section for two geographic areas: 1) CSM domain and 2) the recalibration focus area shown in Figure 1-3. For assessing improvement in model prediction performance, model statistics were compared to CSM v1.0.

3.2.1 Groundwater Levels

Transient groundwater level targets were analyzed and are presented in the following section. Transient model calibration statistics were computed for the target wells in the SAS, UFA, and LFA within the focus area (Table 3-1) and CSM domain (Table 3-2). Calculated statistics including ME, MAE, and R^2 are presented for each major aquifer. The spatial distributions of average head residual, expressed as the simulated minus observed water level, for the target wells in the SAS, UFA, and LFA in the focus area are shown in Figure 3-2 through Figure 3-4, respectively. The mean simulated versus observed water levels for the SAS, UFA, and LFA targets in the focus area are compared between version 1.0 and 1.1 of the models in Figure 3-5 through Figure 3-7. Figure 3-8 through Figure 3-13 show individual simulated versus observed water level hydrographs at selected wells within the focus area. The complete set of simulated and observed hydrographs for calibration target wells is provided in Appendix C (SAS), Appendix D (UFA), and Appendix E (LFA). The spatial distribution of transient average simulated versus observed vertical head differences in the recalibration focus area are compared between version 1.0 and 1.1 of the models in Figure 3-14 and Figure 3-15 across the ICU and MCU I, respectively. Scatterplots comparing the simulated to observed vertical head differences across the ICU and MCU I are compared between version 1.0 and 1.1 in Figure 3-16 and Figure 3-17, respectively. The distribution of 2005 to 2018 average flooded cells in layer 1 (defined as the head in layer 1 greater than 5 feet above land surface) and dry cells in layer 1 are compared in Figure 3-18 and Figure 3-19, respectively.

Table 3-1. Transient model calibration statistics of target monitoring wells in the focus area.

Statistic	Target	Focus Area – V1.0			Focus Area – V1.1		
		SAS	UFA	LFA	SAS	UFA	LFA
Mean error	< ± 0.5 ft	1.3	0.2	0.1	0.6	0.2	0.4
RSR	≤ 0.5 (UFA/LFA) ≤ 0.7 (SAS)	0.1	0.1	0.2	0.1	0.1	0.1
Mean absolute error (MAE)	-	3.5	1.9	1.6	2.1	1.4	1.4
PBIAS	< ± 10 (UFA/LFA) < ± 15 (SAS)	3.2%	0.6%	0.3%	1.5%	0.6%	1.1%
RMSE	-	5.1	2.3	2.0	2.2	1.4	1.7
Minimum Residual	-	-12.1	-6.7	-3.5	-6.1	-4.4	-2.7
Maximum Residual	-	24.5	13.1	6.4	5.6	3.6	5.8
Number of wells	-	159	168	20	159	168	20
% MAE < 2.5 ft	50%	56%	80%	85%	73%	91%	90%
% MAE < 5.0 ft	80%	80%	96%	95%	97%	100%	95%
R^2 > 0.4	> 0.85 (UFA/LFA) > 0.75 (SAS)	55%	89%	100%	56%	88%	100%

Note: Mean error expressed as simulated minus observed.
SAS = Surficial Aquifer System; UFA = Upper Floridan Aquifer ; LFA = Lower Floridan Aquifer; RSR = ratio of root mean square error and standard deviation; PBIAS = Percent bias; RMSE = root mean square error; R^2 = coefficient of determination.

Table 3-2. Transient model calibration statistics of target monitoring wells in the model domain.

Statistic	Target	Model Domain – V1.0			Model Domain – V1.1		
		SAS	UFA	LFA	SAS	UFA	LFA
Mean error	< ± 0.5 ft	0.5	0.3	-0.3	0.2	0.2	-0.2
RSR	≤ 0.5 (UFA/LFA) ≤ 0.7 (SAS)	0.1	0.1	0.1	0.1	0.1	0.1
Mean absolute error (MAE)	-	2.6	1.8	1.7	2.0	1.7	1.6
PBIAS	< ± 10 (UFA/LFA) < ± 15 (SAS)	0.9%	0.7%	-0.6%	0.4%	0.6%	-0.4%
RMSE	-	3.6	2.2	2.2	2.2	1.9	2.1
Minimum Residual	-	-12.1	-12.4	-8.4	-10.4	-11.0	-8.6
Maximum Residual	-	24.5	13.1	6.4	8.9	9.7	5.8
Number of wells	-	403	601	38	403	600	38
% MAE < 2.5 ft	50%	72%	81%	89%	78%	85%	89%
% MAE < 5.0 ft	80%	91%	97%	95%	98%	97%	95%
R2 > 0.4	> 0.85 (UFA/LFA) > 0.75 (SAS)	61%	88%	95%	61%	88%	92%

Note: Mean error expressed as simulated minus observed.
SAS = Surficial Aquifer System; UFA = Upper Floridan Aquifer ; LFA = Lower Floridan Aquifer; RSR = ratio of root mean square error and standard deviation; PBIAS = Percent bias; RMSE = root mean square error; R^2 = coefficient of determination.

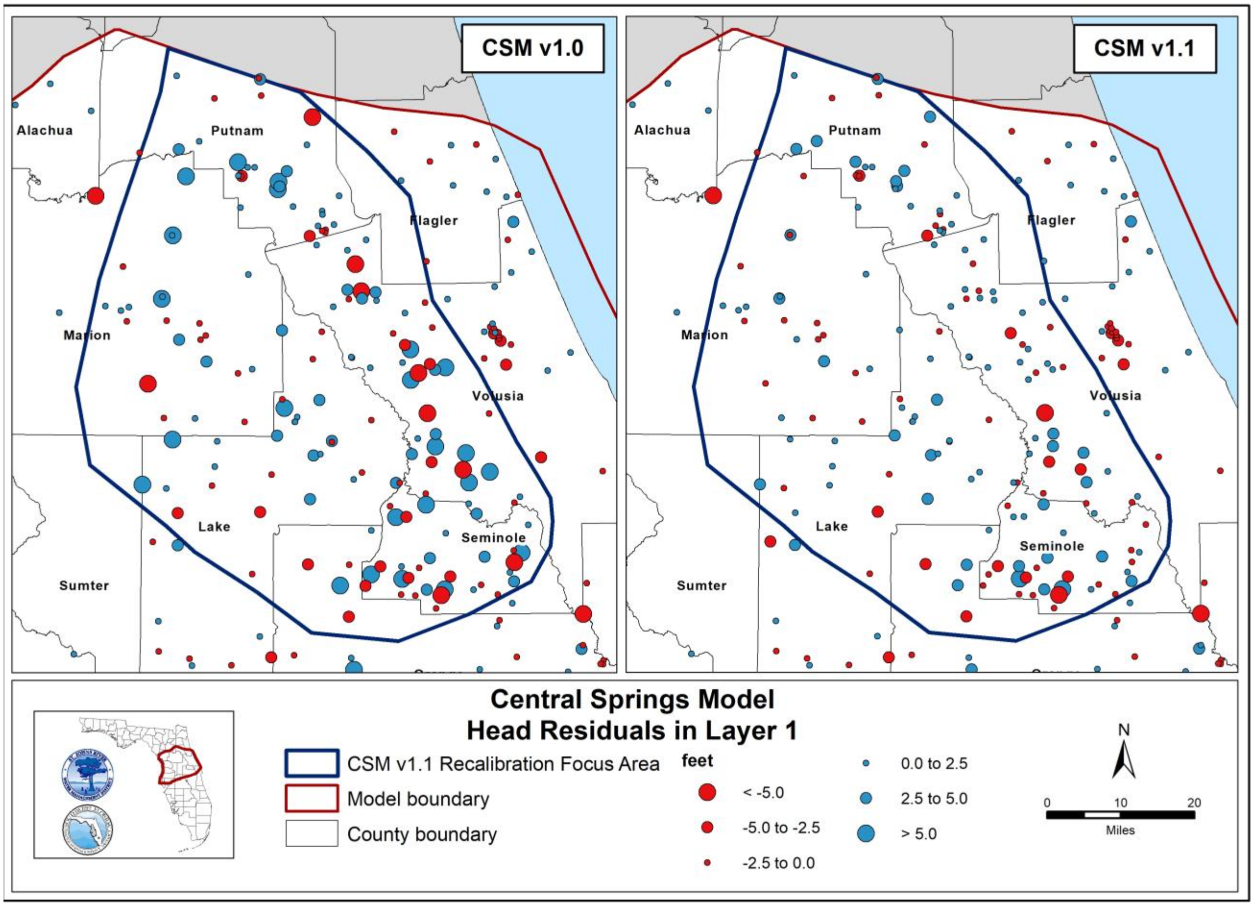


Figure 3-2. Spatial distribution of average transient head residuals in model layer 1 in CSM v1.0 (left) and CSM v1.1 (right). Residual is calculated as the simulated value minus observed value.

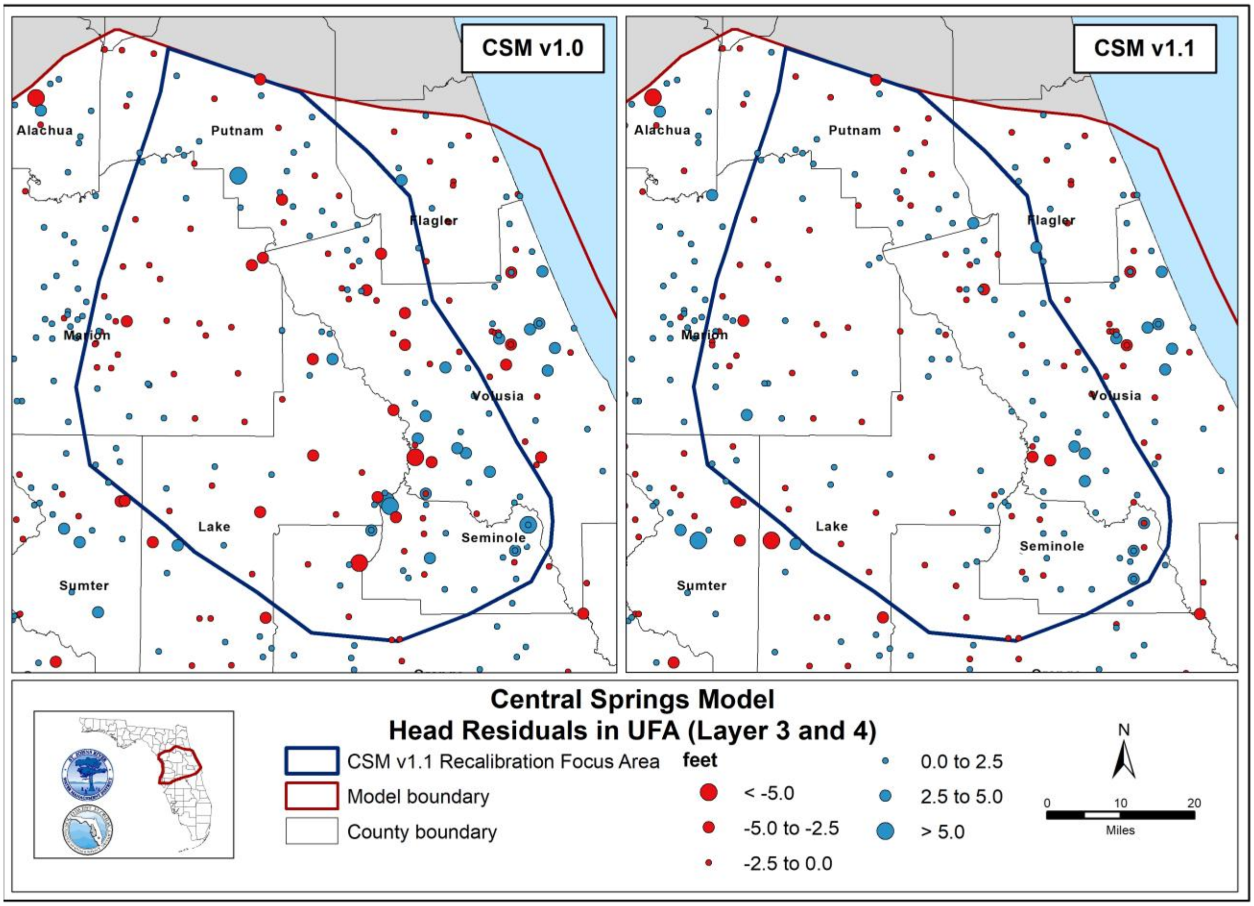


Figure 3-3. Spatial distribution of average transient head residuals in model layer 3 and 4 in CSM v1.0 (left) and CSM v1.1 (right). Residual is calculated as the simulated value minus observed value.

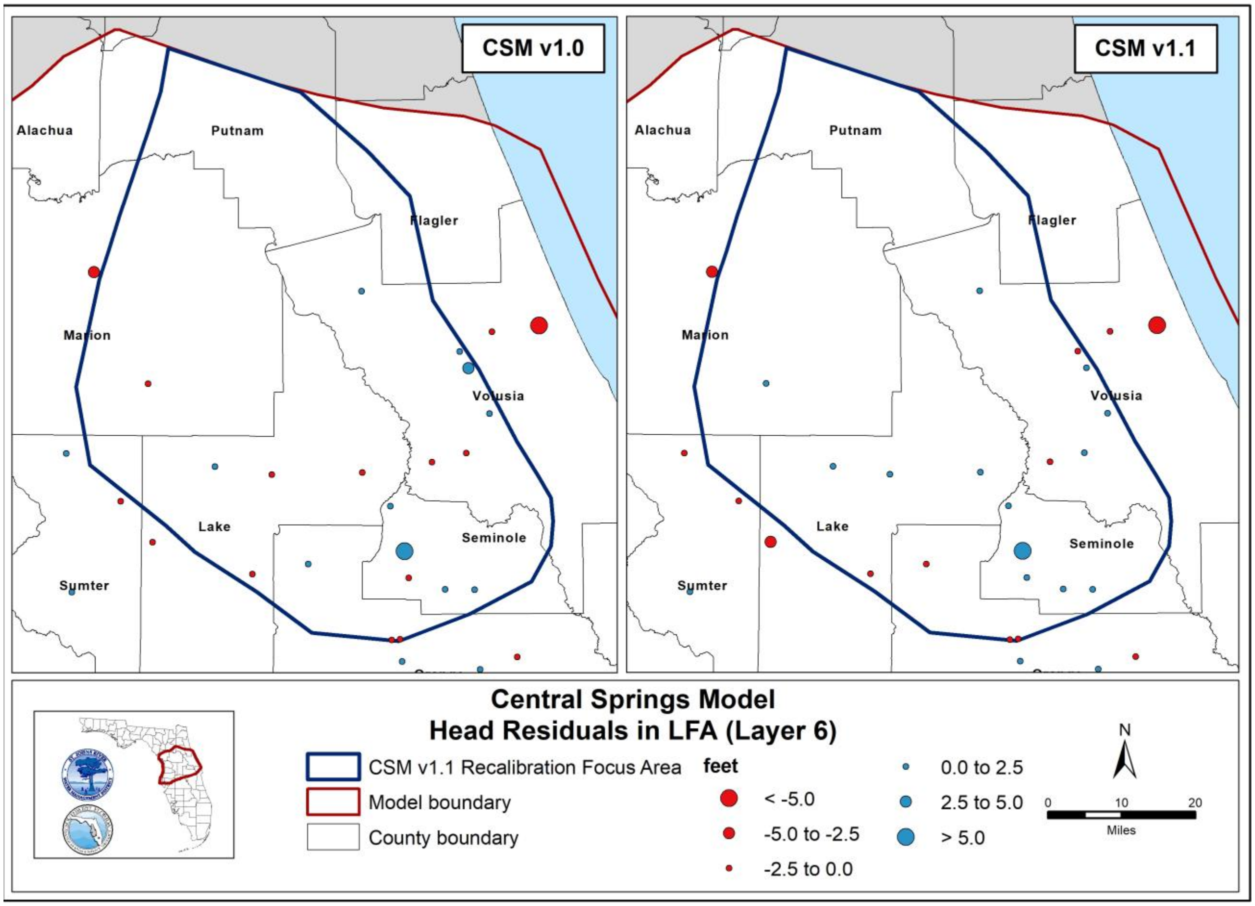


Figure 3-4. Spatial distribution of average transient head residuals in model layer 6 in CSM v1.0 (left) and CSM v1.1 (right). Residual is calculated as the simulated value minus observed value.

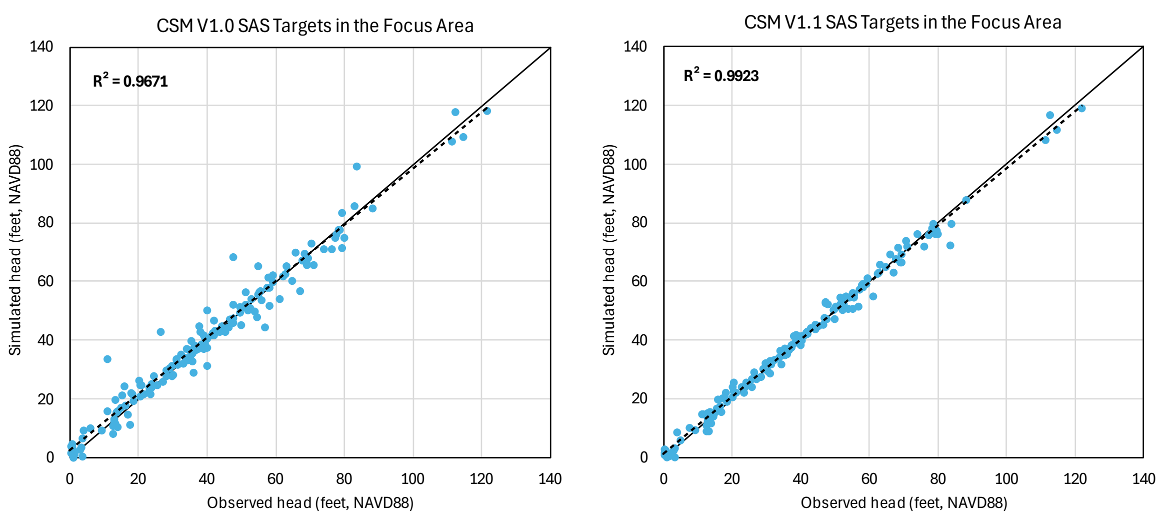


Figure 3-5. Mean simulated versus observed water levels for the SAS within the focus area in the CSM transient model for v1.0 (left) and v1.1 (right). (Note: Solid line is 1:1 relation between simulated and observed water levels; dashed line is linear regression of simulated versus observed water levels from target wells).

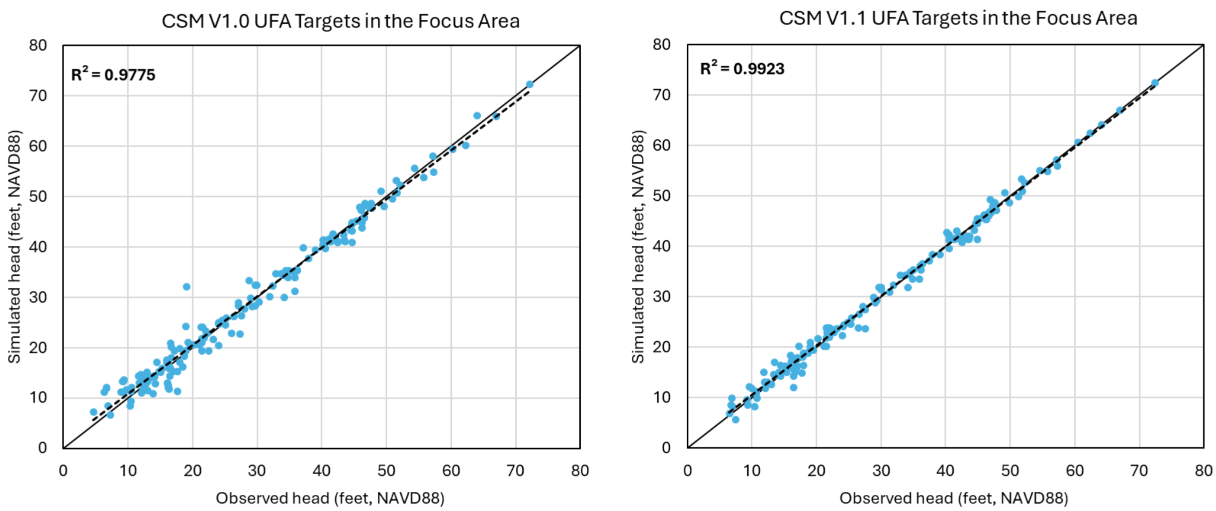


Figure 3-6. Mean simulated versus observed water levels for the UFA within the focus area in the CSM transient model for v1.0 (left) and v1.1 (right). (Note: Solid line is 1:1 relation between simulated and observed water levels; dashed line is linear regression of simulated versus observed water levels from target wells).

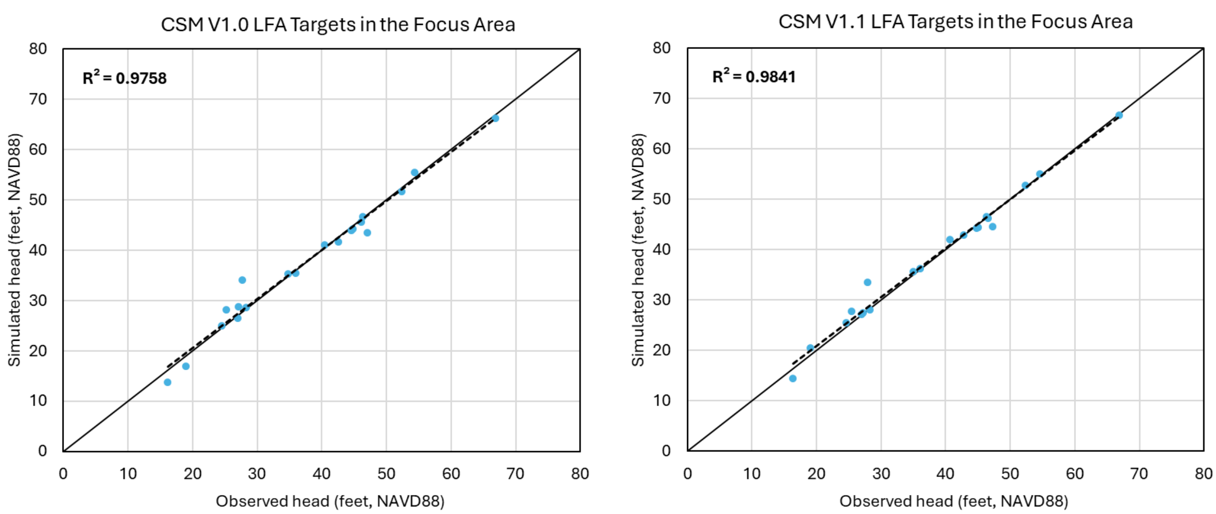


Figure 3-7. Mean simulated versus observed water levels for the LFA within the focus area in the CSM transient model for v1.0 (left) and v1.1 (right). (Note: Solid line is 1:1 relation between simulated and observed water levels; dashed line is linear regression of simulated versus observed water levels from target wells).

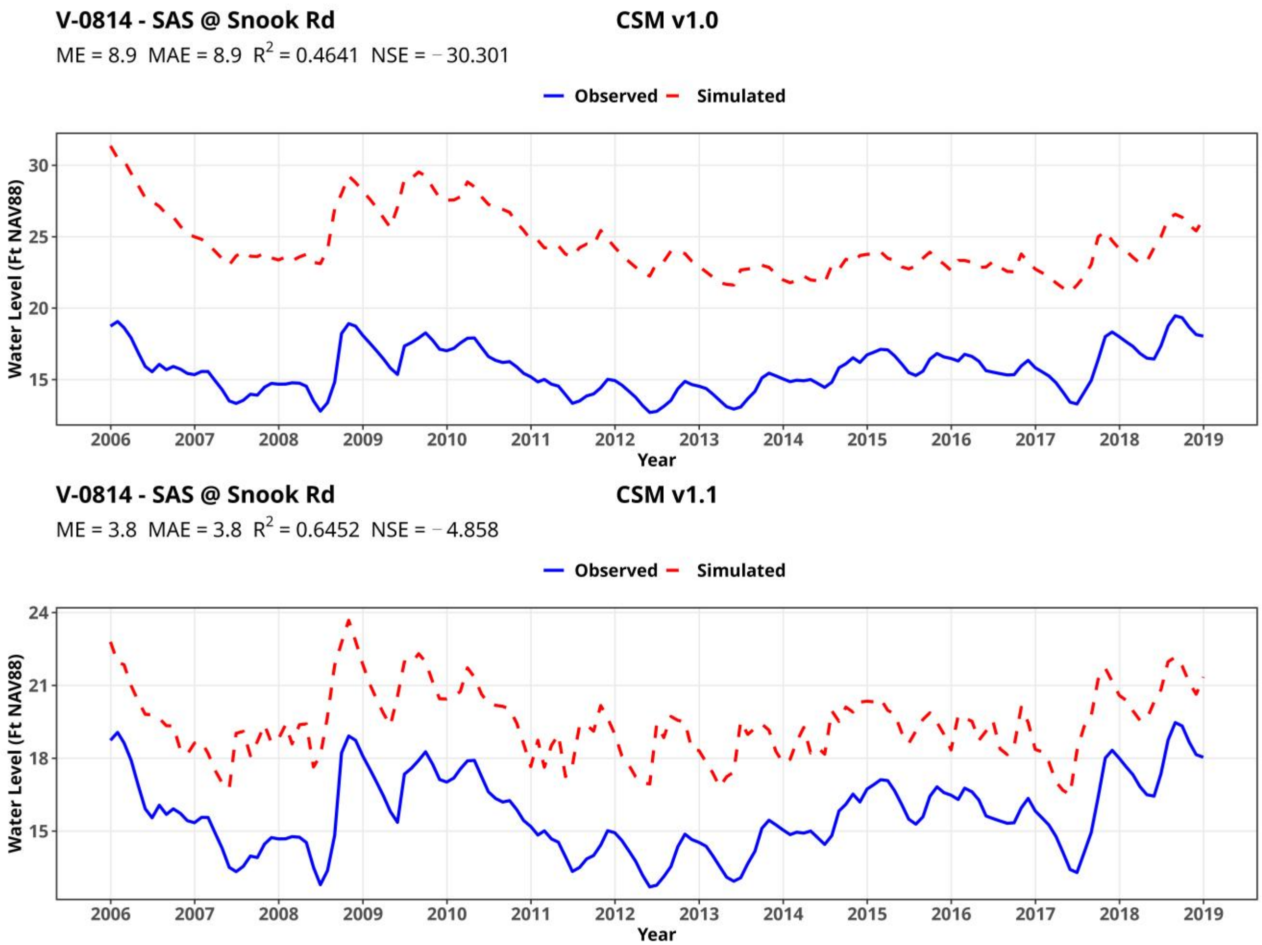


Figure 3-8. Comparison of model simulated hydrographs to monthly observed groundwater levels at surficial aquifer well V-0814 in layer 1. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

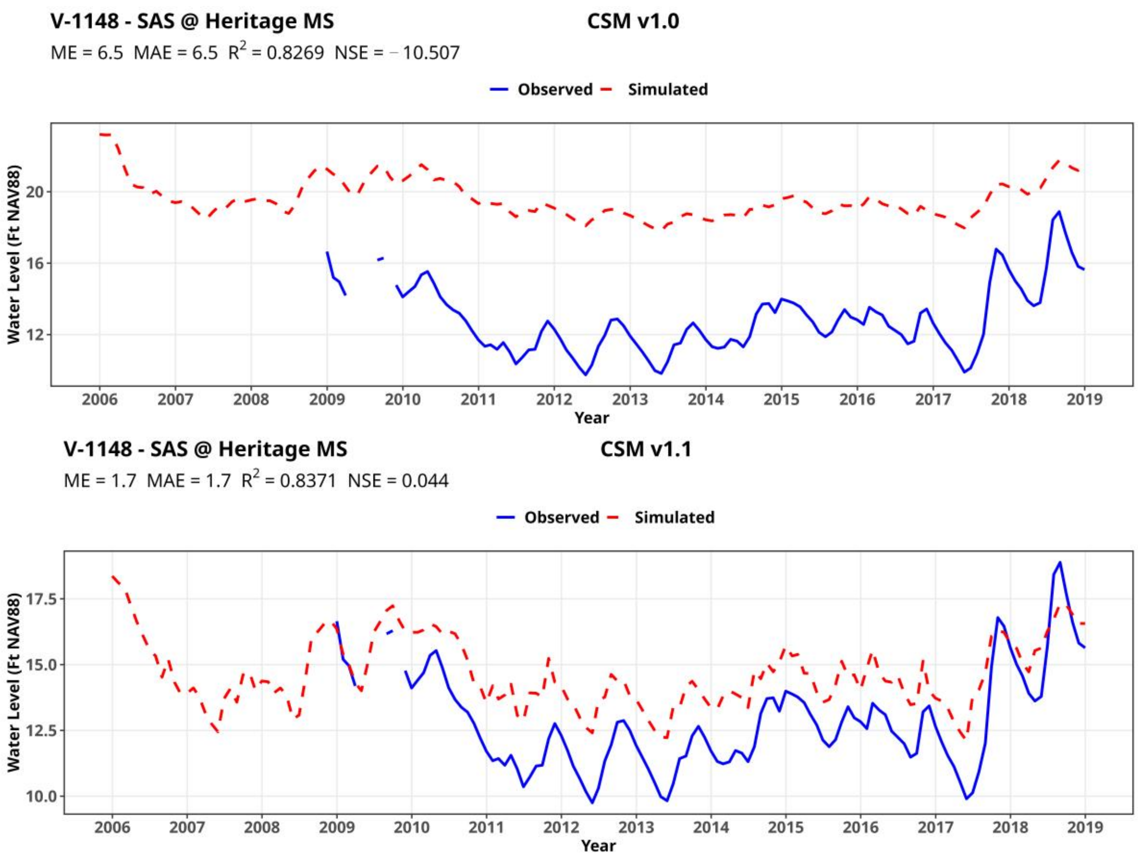


Figure 3-9. Comparison of model simulated hydrographs to monthly observed groundwater levels at surficial aquifer well V-1148 in layer 1. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

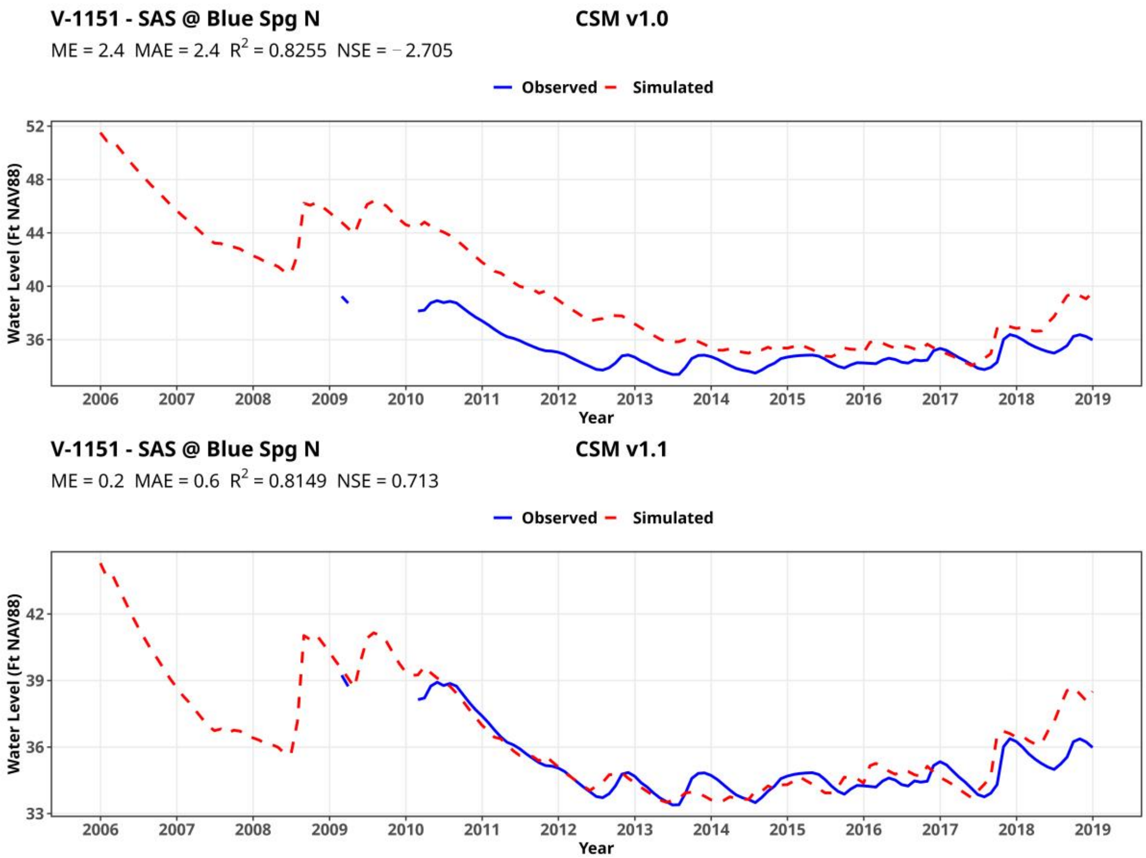


Figure 3-10. Comparison of model simulated hydrographs to monthly observed groundwater levels at surficial aquifer well V-1151 in layer 1. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

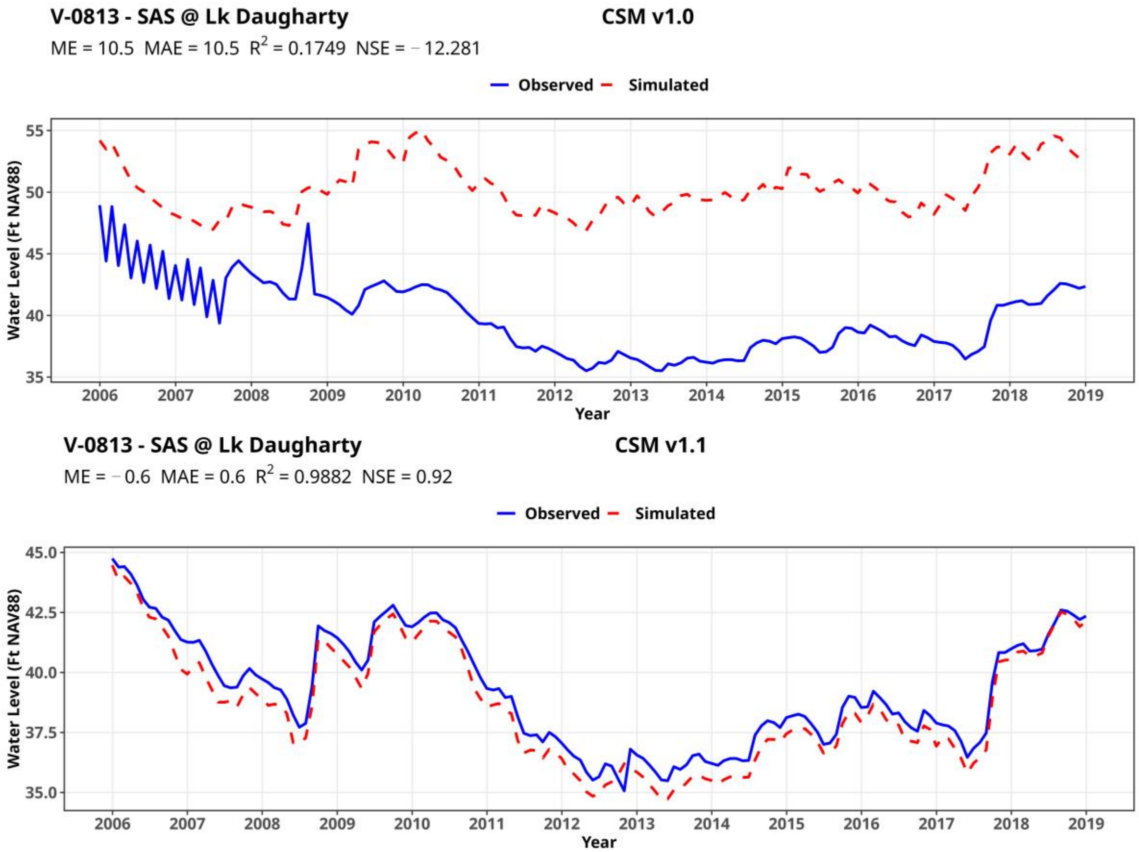


Figure 3-11. Comparison of model simulated hydrographs to monthly observed groundwater levels at surficial aquifer well V-0813 in layer 1. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

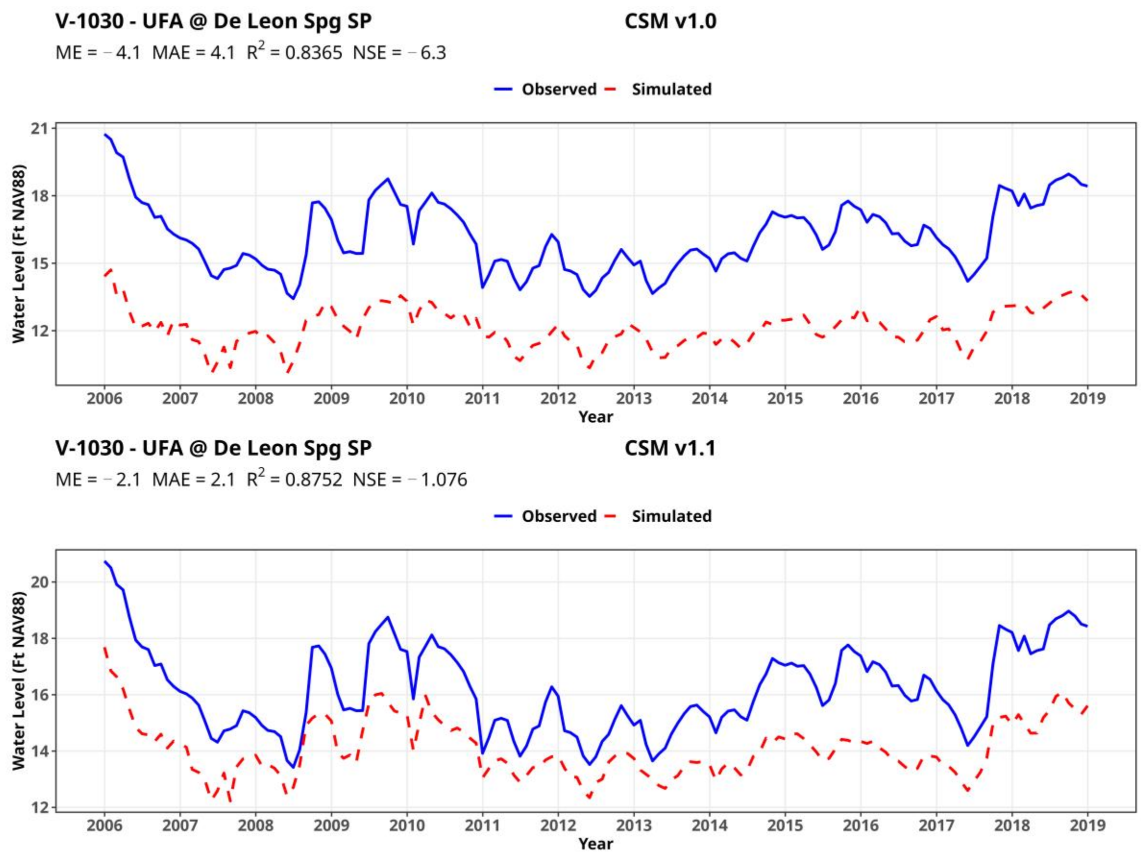


Figure 3-12. Comparison of model simulated hydrographs to monthly observed groundwater levels at Upper Floridan Aquifer well V-1030 in layer 3. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

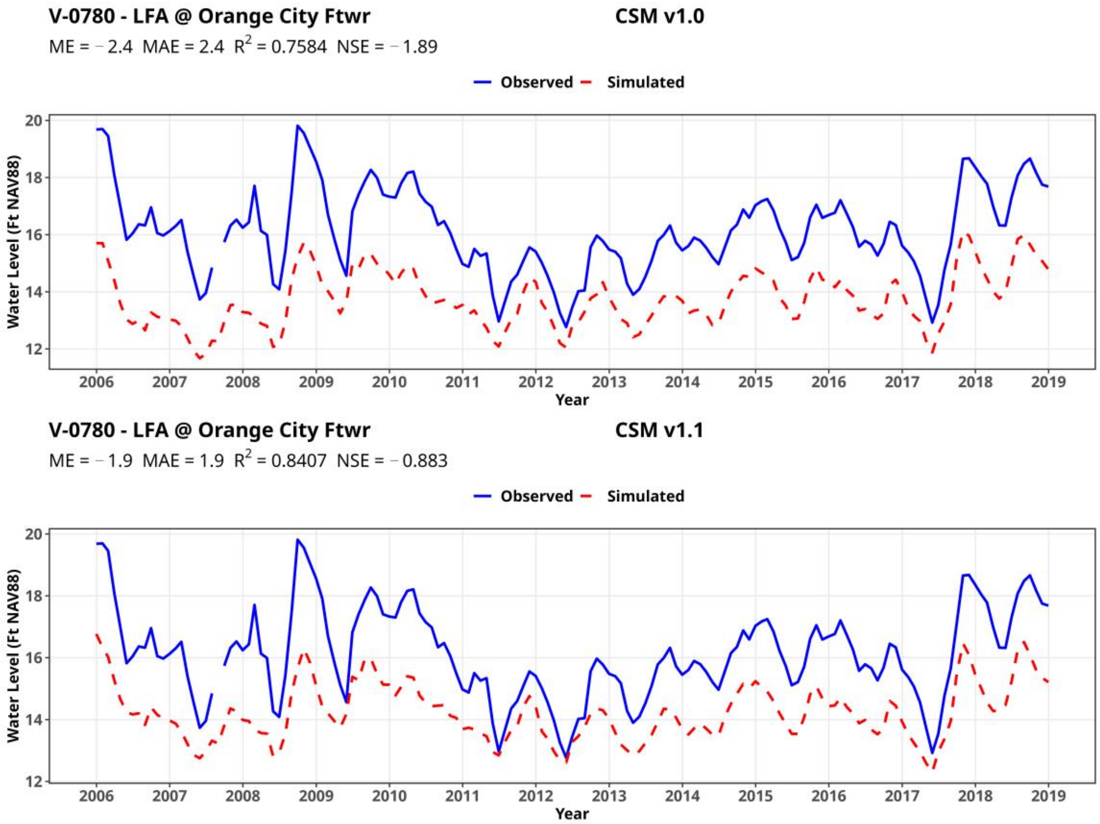


Figure 3-13. Comparison of model simulated hydrographs to monthly observed groundwater levels at Lower Floridan Aquifer well V-0780 in layer 6. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

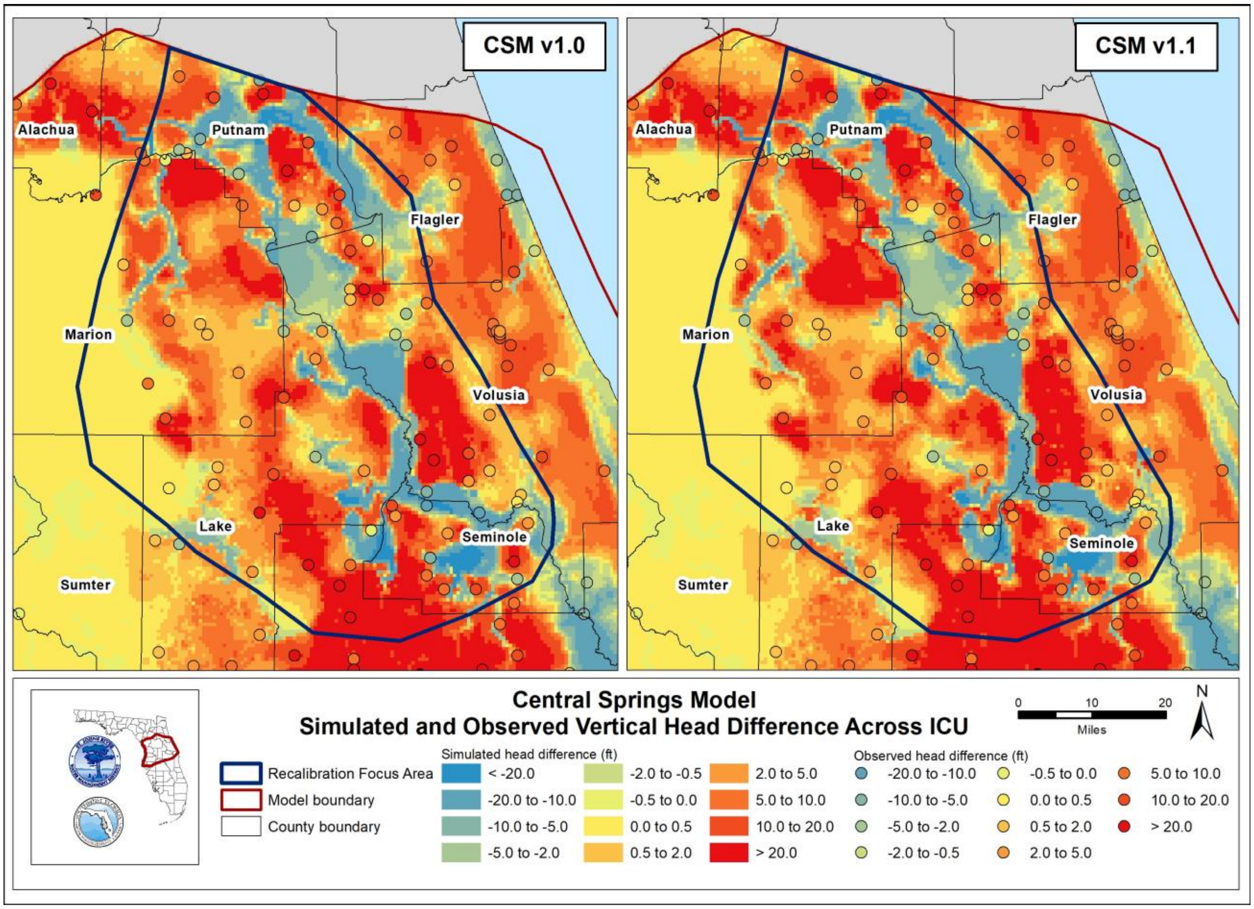


Figure 3-14. Comparison of simulated 2005 to 2018 average vertical head differences across the Intermediate Confining Unit (ICU) with observed values at well pairs

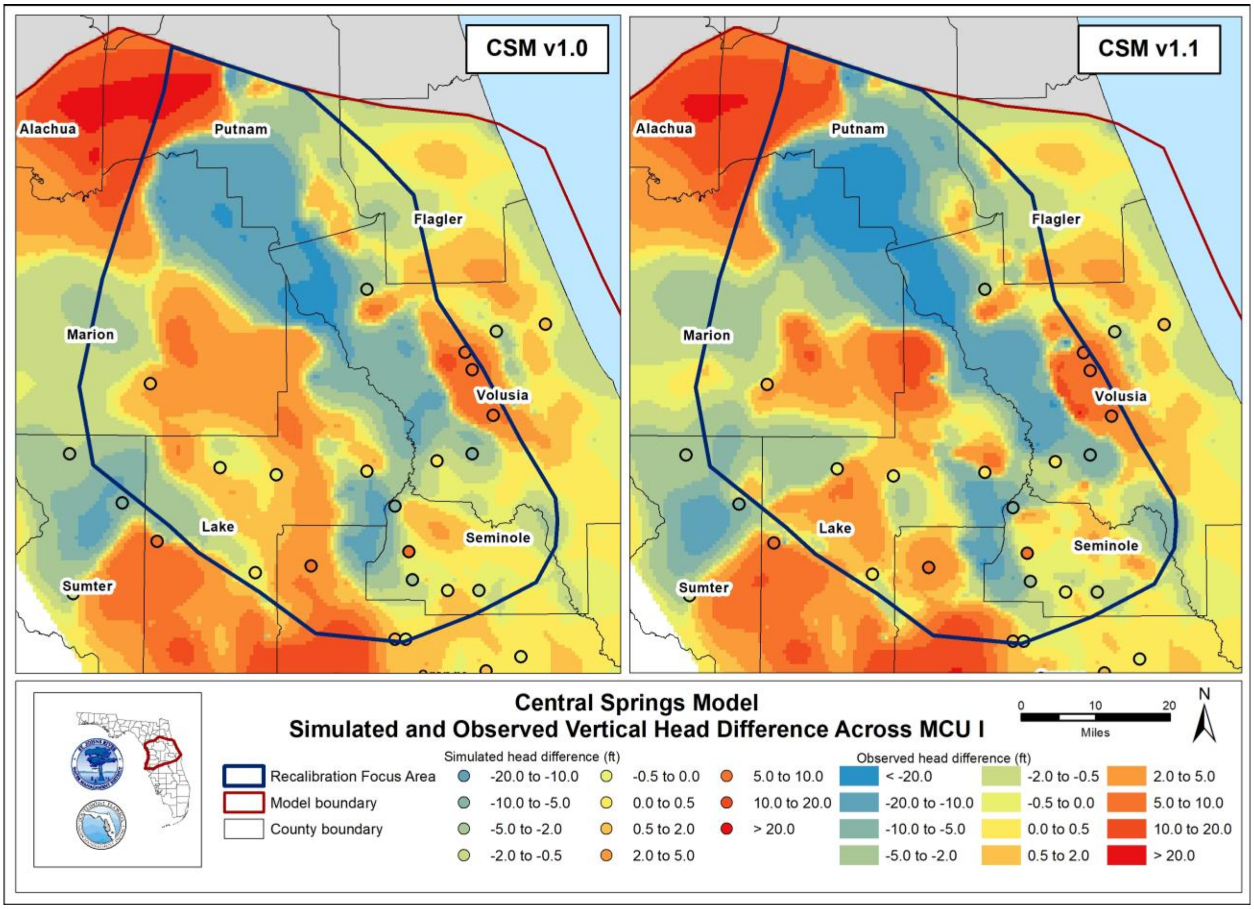
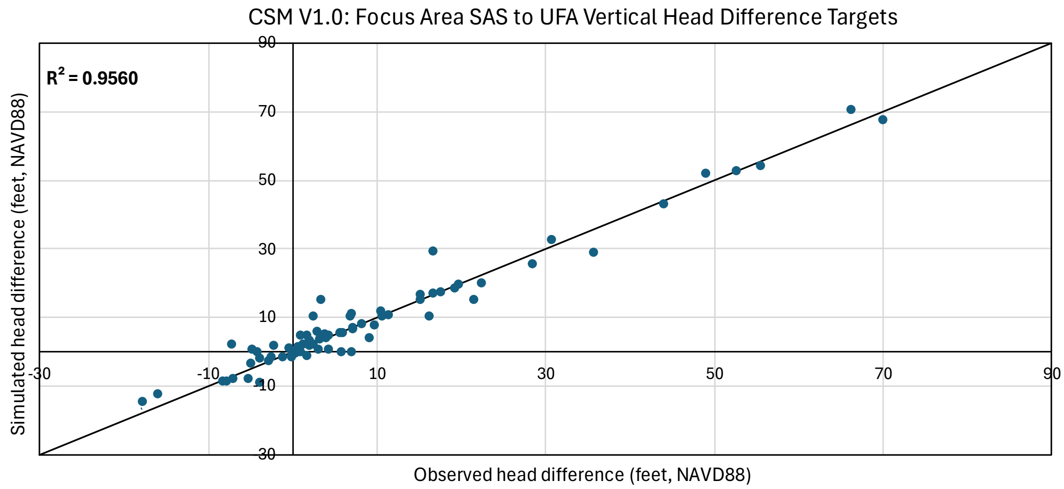


Figure 3-15. Comparison of simulated 2005 to 2018 average vertical head differences across the Middle Confining Unit I (MCU I) with observed values at well pairs



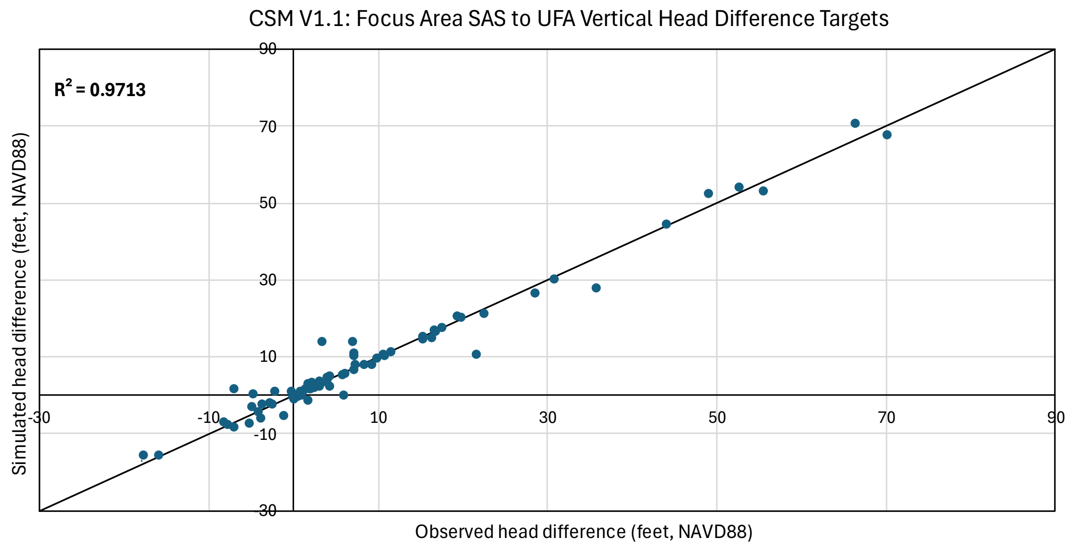
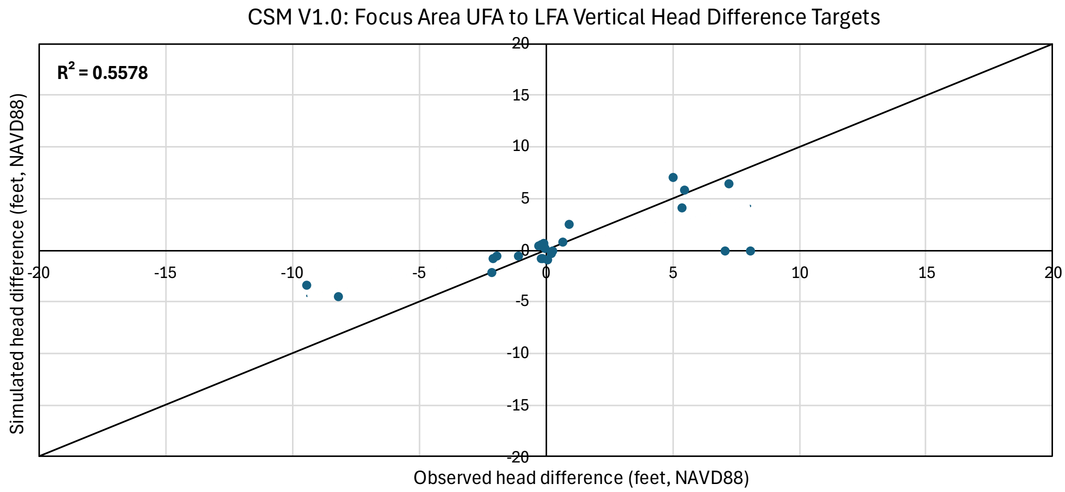


Figure 3-16. Mean simulated versus observed vertical head difference between the SAS and UFA at targets within the recalibration focus area for CSM v1.0 (top) and CSM v1.1 (bottom). (Note: Solid line is 1:1 relation between simulated and observed head differences; dashed line is linear regression of simulated versus observed head differences).



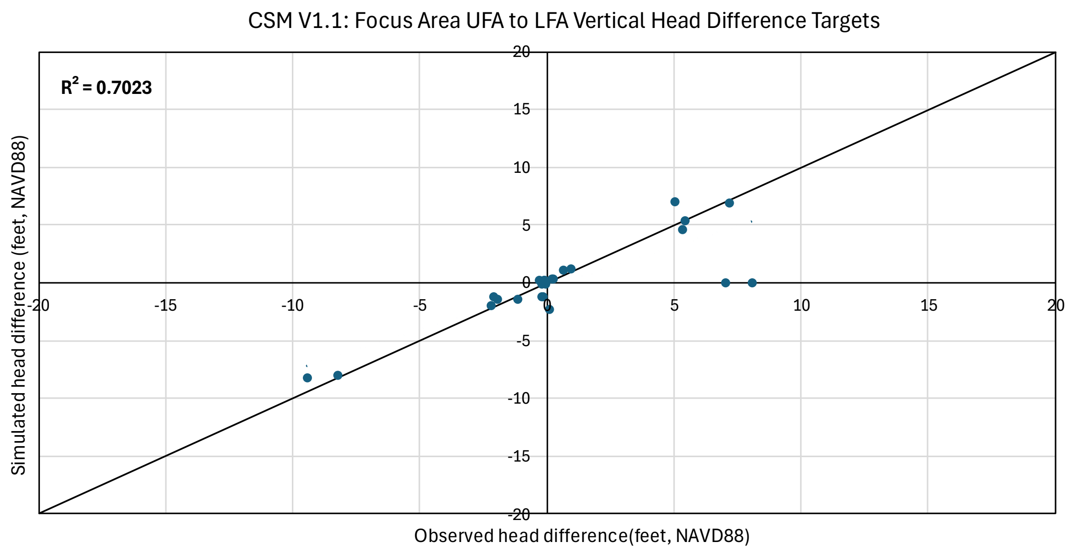


Figure 3-17. Mean simulated versus observed vertical head difference between the UFA and LFA at targets within the recalibration focus area for CSM v1.0 (top) and CSM v1.1 (bottom). (Note: Solid line is 1:1 relation between simulated and observed head differences.

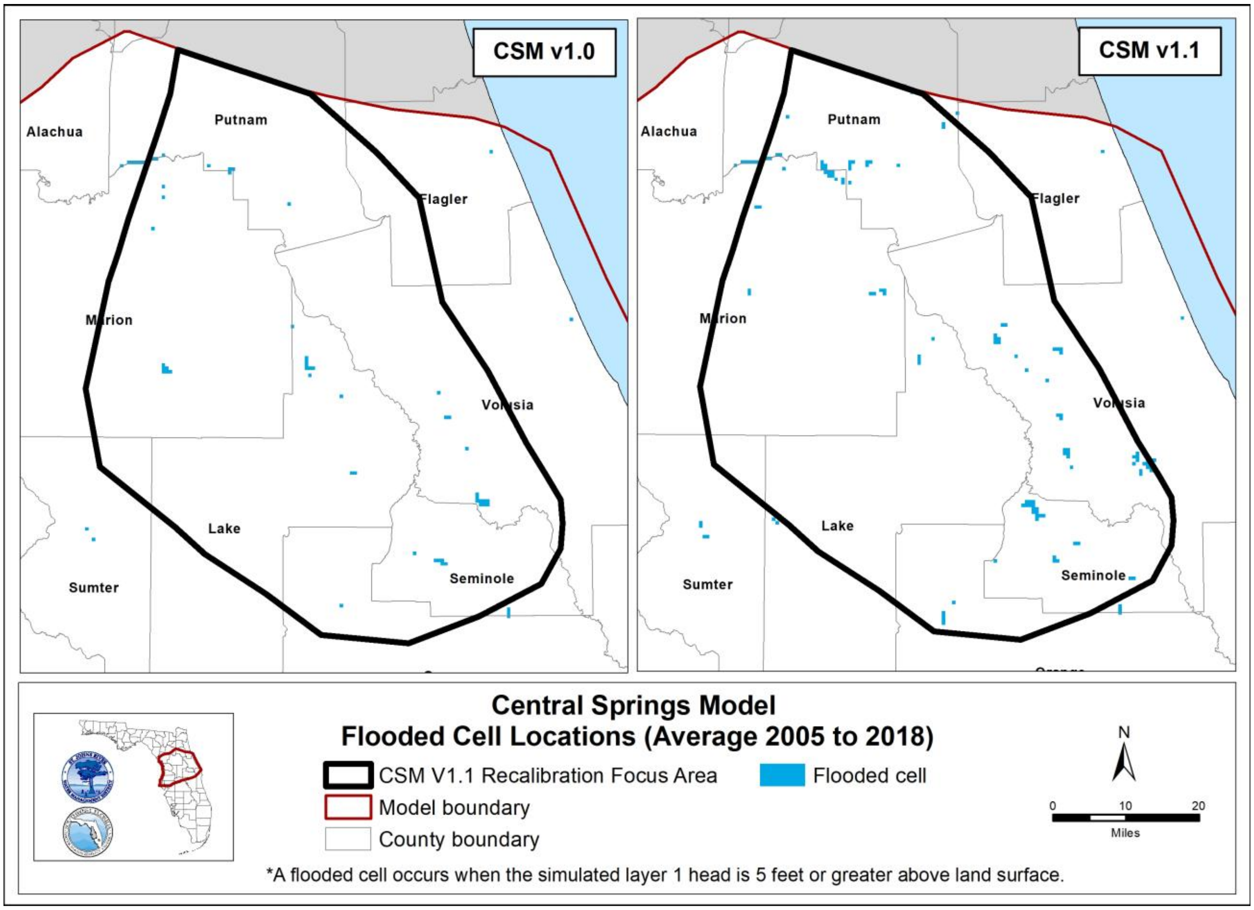


Figure 3-18. Location of flooded cells in layer 1. Flooded cells were identified by subtracting the average 2005 to 2018 simulated head in layer 1 from the top elevation of layer 1.

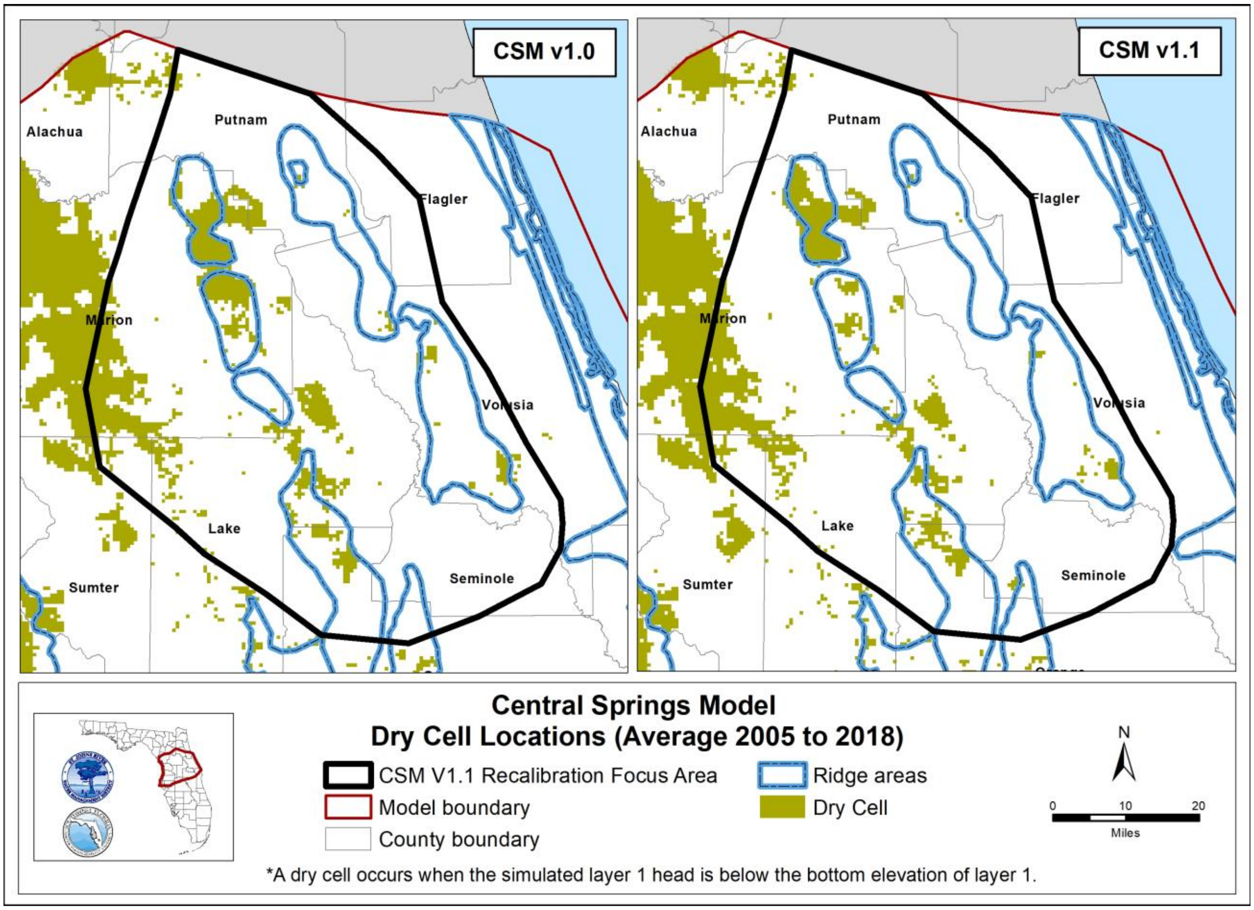


Figure 3-19. Location of dry cells in layer 1. Dry cells were identified by subtracting the average 2005 to 2018 simulated head in layer 1 from the bottom elevation of layer 1. Physiographic ridge areas are also identified within the focus area.

3.2.2 Spring Discharges

First magnitude (greater than 100 cubic feet per second [cfs]) and second magnitude (10 to 100 cfs) springs in the recalibration focus area (Figure 3-20) with flow measurement data during the calibration period served as calibration targets for the transient model. Comparison of simulated and observed spring fluxes averaged through the transient simulation period are provided in Table 3-3 for the 17 target springs within the focus area. Comparisons between the simulated and observed hydrographs for selected first and second magnitude springs in the focus area are shown on Figure 3-21 through Figure 3-26. A complete set of simulated and observed hydrographs for transient target springs in the model domain is provided in Appendix F. For the transient simulation, the cumulative average discharge of the 17 calibration target springs within the focus area was 1,294 cfs, which is less than 0.3% higher than the total estimated flow of 1,259 cfs.

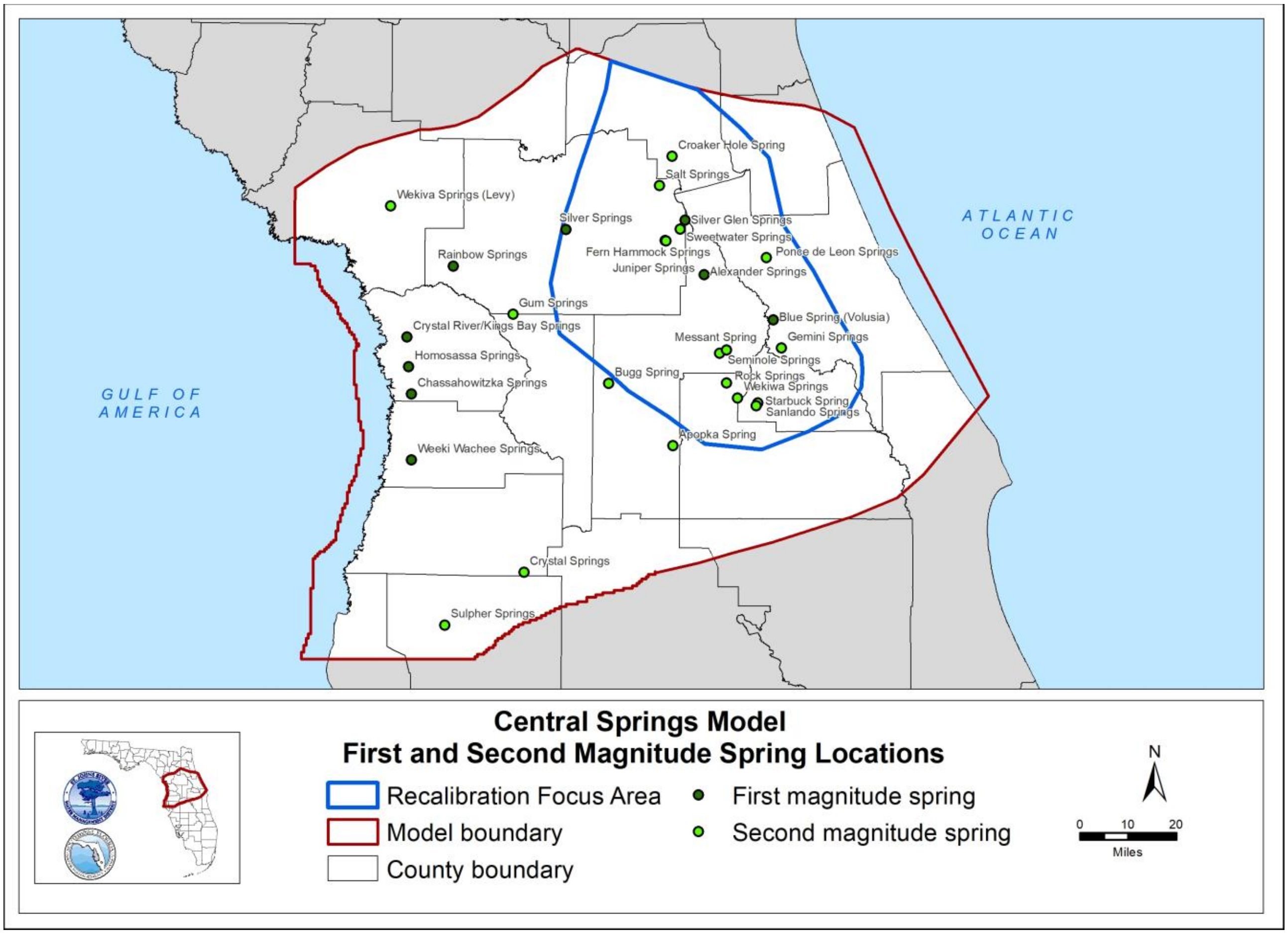


Figure 3-20. Location of first and second magnitude springs within the recalibration focus area

Table 3-3. Comparison of average 2005 to 2018 simulated and observed flux at target springs in the focus area.

Name	Observed Flux[1] (cfs)	Simulated Flux[2] (cfs)		% Difference	
		CSM v1.0	CSM v1.1	CSM v1.0	CSM v1.1
Silver Springs	542.6	531.8	530.6	-2.0%	-2.2%
Blue Spring (Orange City)	140.6	142.3	141.5	1.2%	0.7%
Alexander Springs	97.1	99.6	99.3	2.6%	2.3%
Silver Glen Springs	85.7	87.4	89.5	2.0%	4.4%
Salt Springs	76.4	78.5	79.3	2.8%	3.8%
Croaker Hole Spring	69.3	69.9	70.6	0.8%	1.8%
Ponce De Leon Springs	22.7	22.9	23.1	0.9%	1.8%
Blue Spring (Marion)	20.7	21.8	21.9	5.5%	6.0%
Sweetwater Springs	12.9	13.3	13.5	2.7%	5.0%
Fern Hammock Springs	11.3	11.7	11.9	3.4%	5.4%
Juniper Springs	11.1	11.4	11.8	2.8%	6.0%
Gemini Springs	9.6	9.7	10.0	1.4%	3.9%
Rock Springs	55.0	55.3	55.2	0.5%	0.4%
Sanlando Spring	19.8	20.0	20.2	0.8%	2.1%
Starbuck Spring	11.8	11.8	11.9	0.5%	1.4%
Wekiva Falls Resort Spring[3]	11.6	10.2	10.3	-11.6%	-10.9%
Wekiwa Springs	61.1	61.4	62.0	0.5%	1.6%

[1] Observed flux is the average of the observed flux for the period of 2005 to 2018.
[2] Simulated flux is the average of the simulated flux for stress periods where observations exist.
[3] Target represents a free-flowing well and is not a natural spring.
Note: cfs = cubic feet per second
% Difference = (simulated – observed)/observed
Rounding of flows accounts for nominal discrepancies

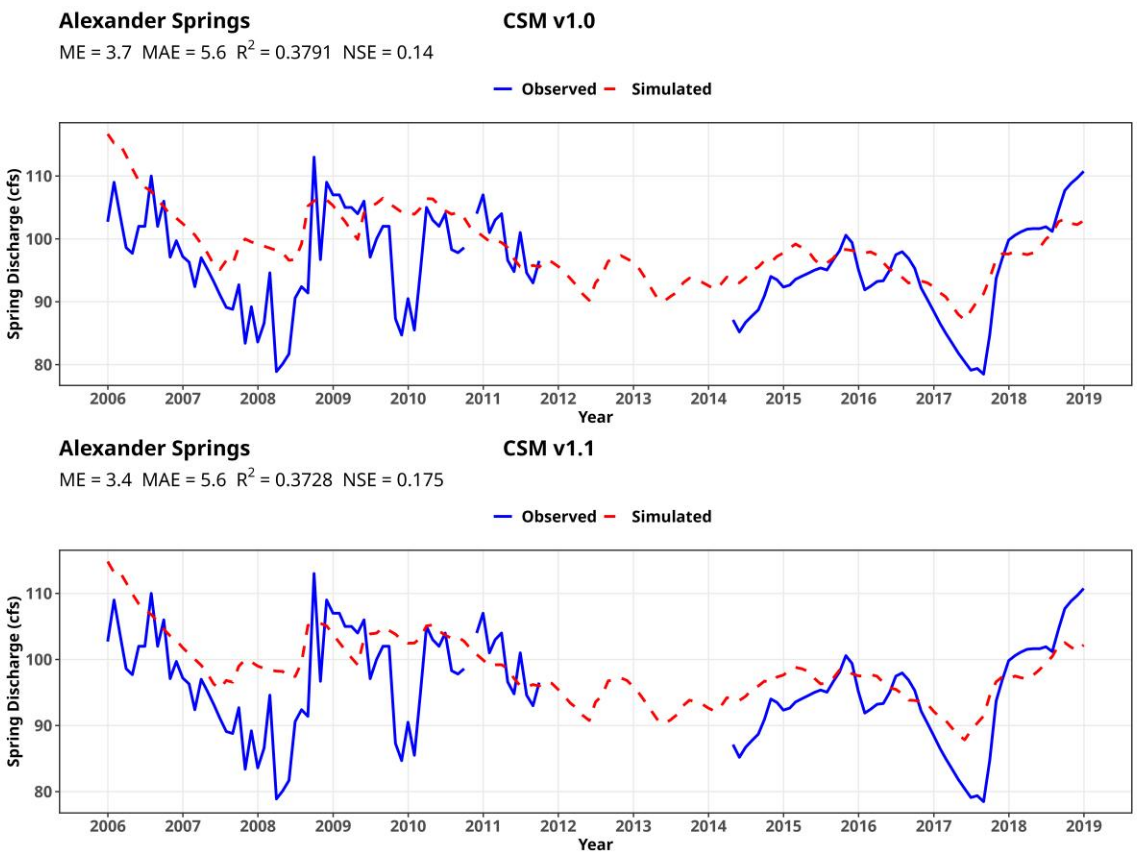


Figure 3-21. Comparison of model simulated to observed spring discharge at Alexander Springs. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

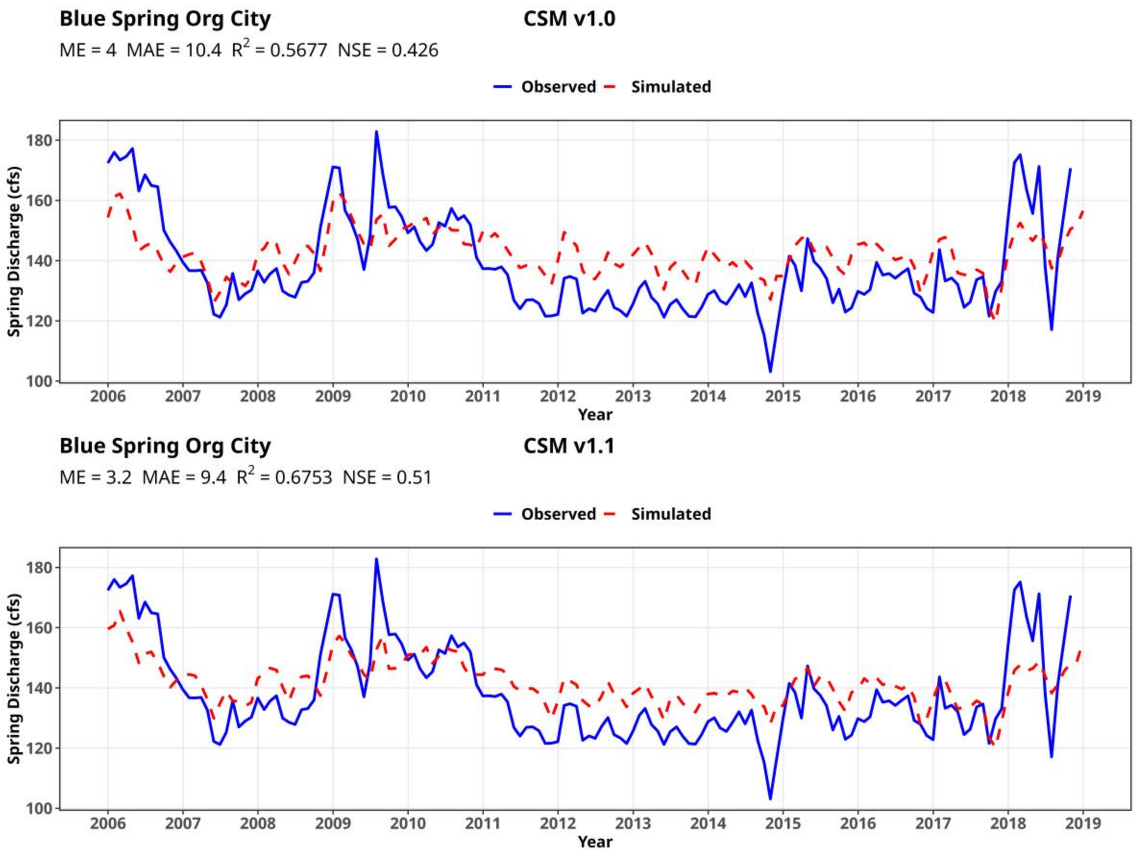


Figure 3-22. Comparison of model simulated to observed spring discharge at Blue Spring (Orange City). CSM v1.0 (top) is compared to CSM v1.1 (bottom).

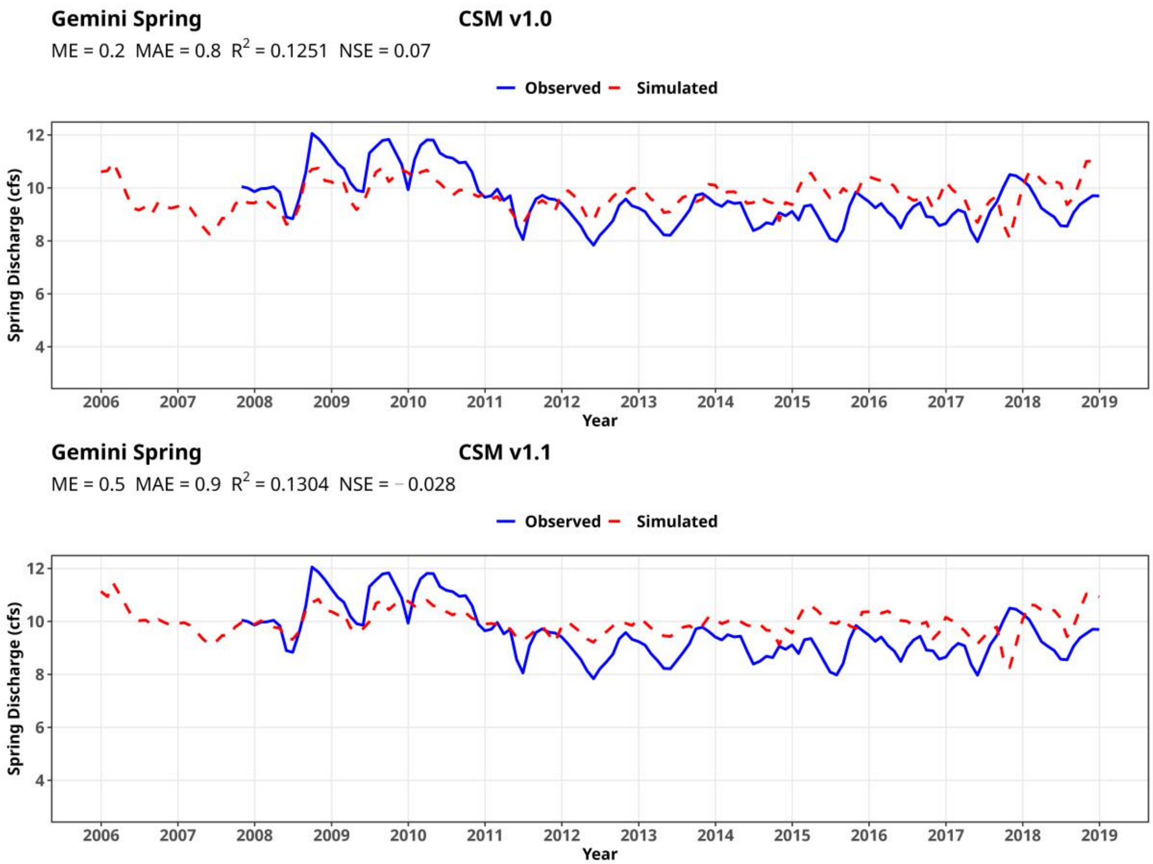


Figure 3-23. Comparison of model simulated to observed spring discharge at Gemini Springs. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

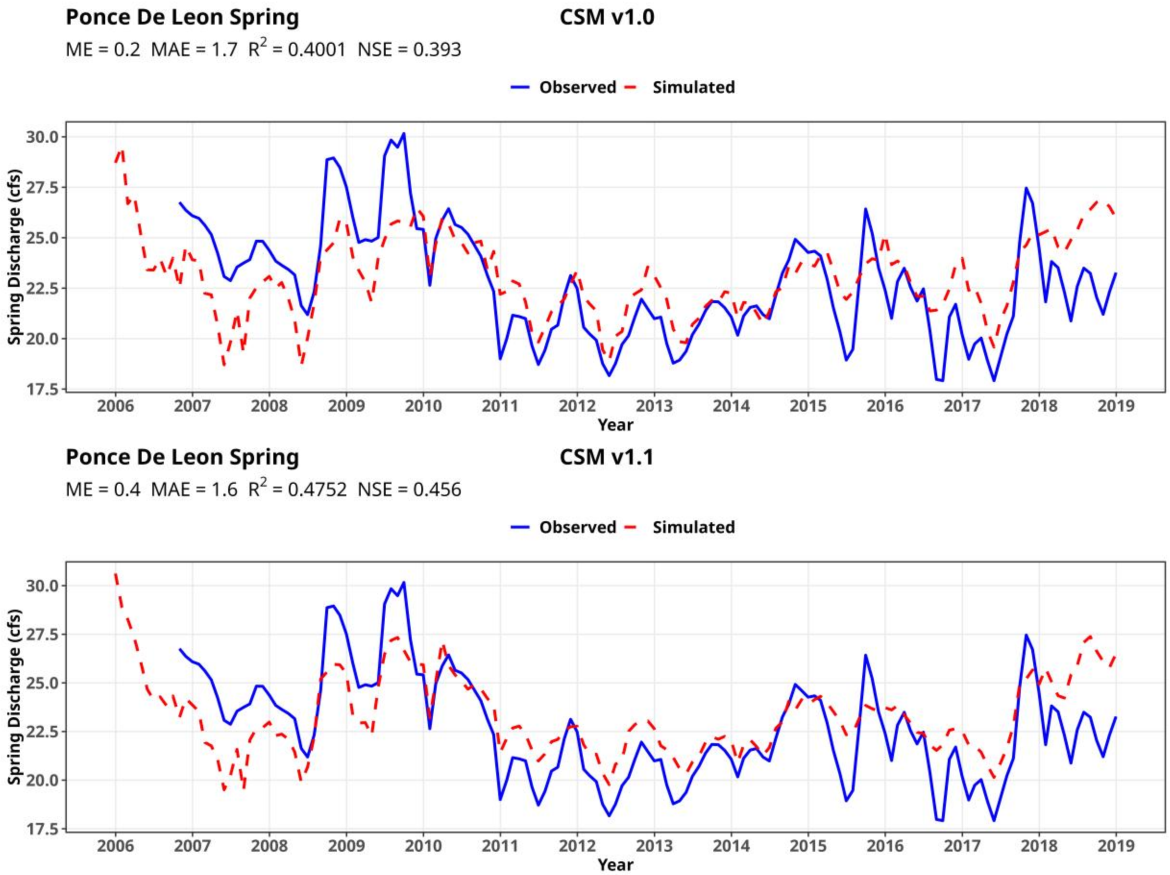


Figure 3-24. Comparison of model simulated to observed spring discharge at Ponce De Leon Springs. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

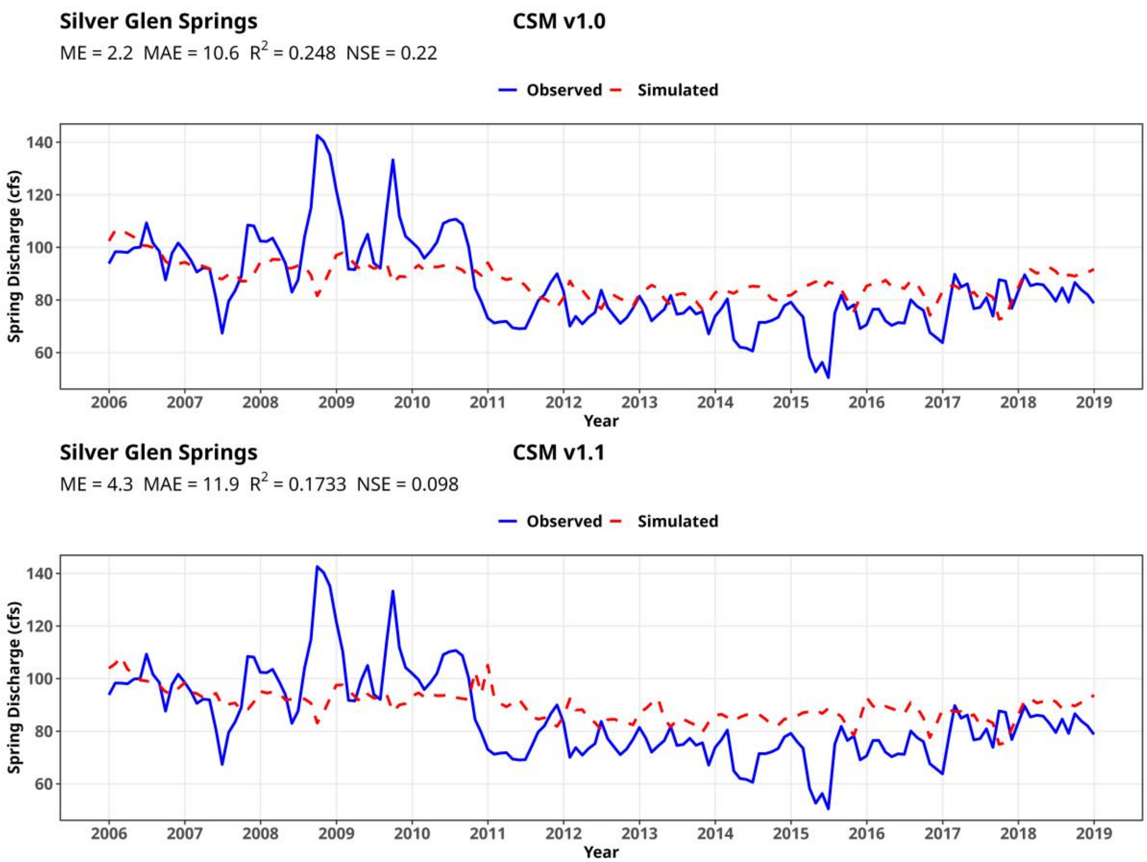


Figure 3-25. Comparison of model simulated to observed spring discharge at Silver Glen Springs. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

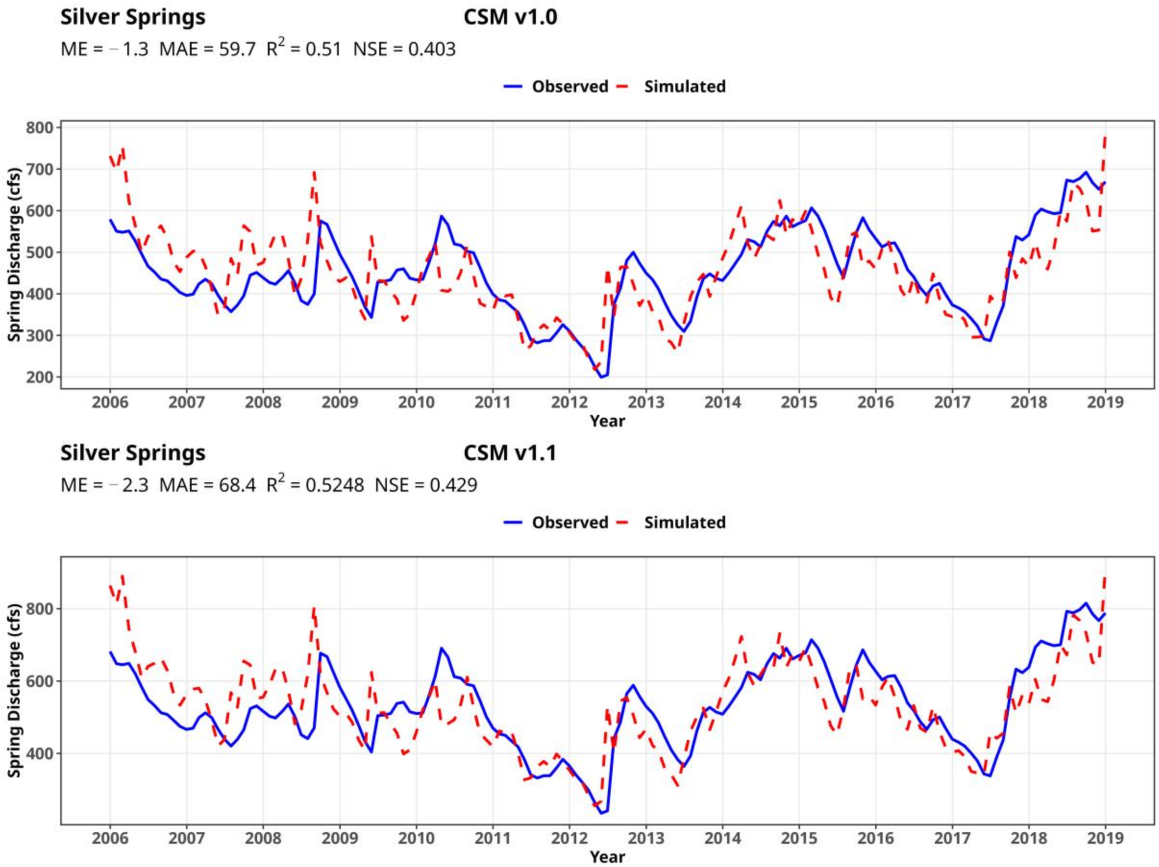


Figure 3-26. Comparison of model simulated to observed spring discharge at Silver Springs. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

3.2.3 River Baseflows

River baseflows were used as qualitative calibration targets in the transient model calibration and were estimated using techniques from the USGS GW Toolbox (Barlow et al. 2014) and the Perry method (Perry 1995). Additional documentation on baseflow estimation can be found in Chapter 6 of the CSM v1.0 model report (Sun et al. 2024). The simulated baseflow was compared to estimated cumulative baseflow and segmental baseflow (or pickup baseflow) at all gages within the model domain (locations shown in Figure 3-27) in Appendix G and H, respectively. Simulated cumulative baseflow is compared to the range of estimated baseflow at 16 USGS gages within the recalibration focus area in Table 3-4. For the calibration period, from 2005 to 2018, the mean simulated total baseflow at the 16 USGS gauges was 3,473 cfs, while the range of estimated flows varied between 1,894 and 5,639 cfs. This is an increase from 3,236 cfs simulated with the CSM v1.0 transient model. A total of 11 out of 16 USGS gages were within the range of estimated baseflows by baseflow separation methods, a reduction from 12 out of 16 in the CSM v1.0 model. Selected hydrographs of simulated versus estimated baseflow discharge at the two major rivers in the focus area (St. Johns River and Ocklawaha River) are shown on Figure 3-28 through Figure 3-31.

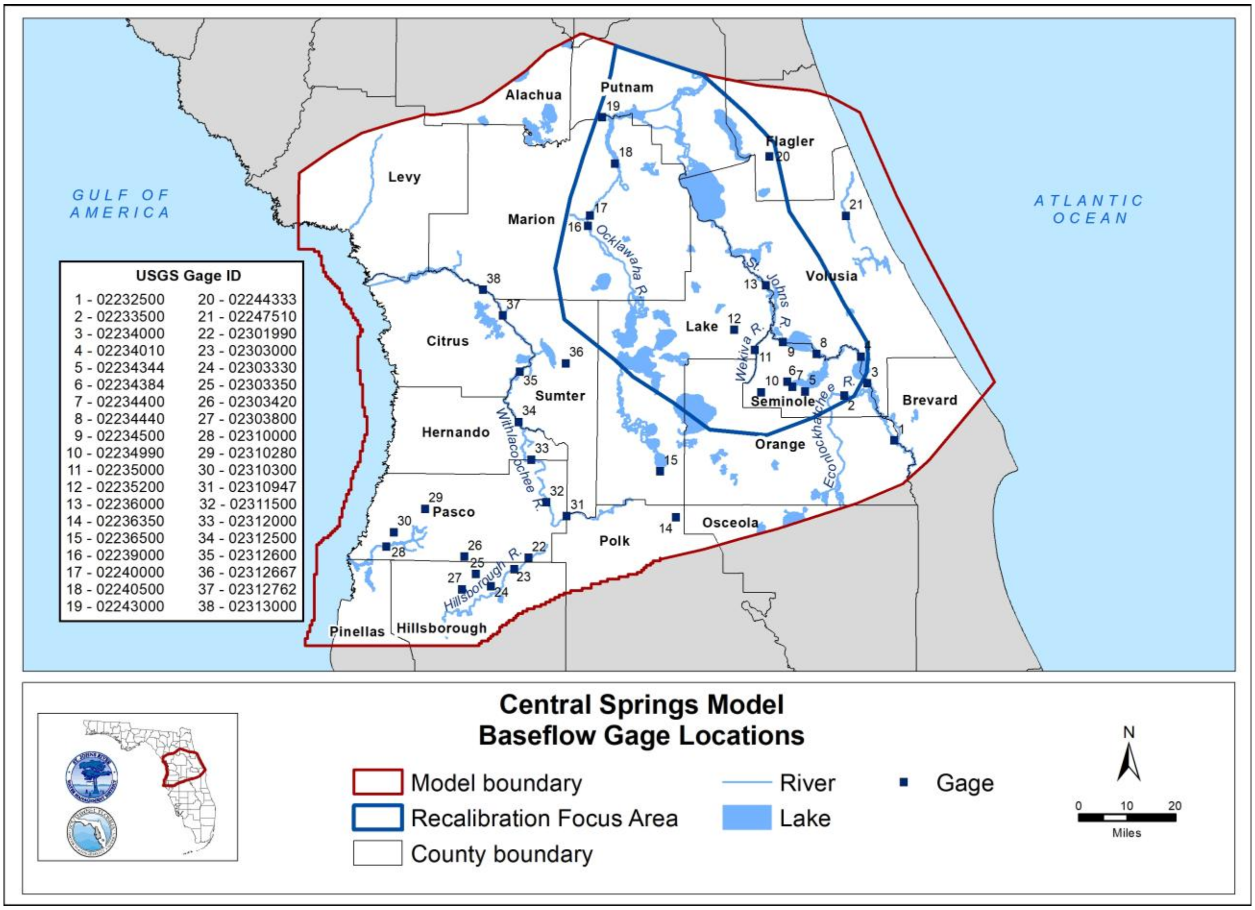


Figure 3-27. Location of cumulative baseflow gages within the recalibration focus area

Table 3-4. Comparison of average 2005 to 2018 simulated with minimum and maximum estimated baseflow at streamflow gages in the focus area.

USGS ID	Station Name	Watershed	Simulated Baseflow (cfs)[1]		Estimated Baseflow (cfs)[2]	
			V1.0	V1.1	Min	Max
02233500	Econlockhatchee River near Chuluota, FL	Upper St. Johns	8.8	15.5	67.2	240.0
02234010	St. Johns River at Osceola, FL	Upper St. Johns	246	273.2	88.9	456.0
02234344	Howell Creek at State Hwy 434 near Oviedo, FL	Upper St. Johns	3.9	4.9	16.3	51.8
02234384	Soldier Creek near Longwood, FL	Upper St. Johns	2.5	2.0	1.7	9.7
02234400	Gee Creek near Longwood, FL	Upper St. Johns	2.4	3.3	1.9	12.6
02234440	St. Johns River at State Hwy 415 near Sanford, FL	Upper St. Johns	309	356.5	104	708.0
02234500	St. Johns River near Sanford, FL	Upper St. Johns	379	388.8	122	894.0
02234990	Little Wekiva River near Altamonte Springs, FL	Upper St. Johns	22.5	26.1	4.6	24.2
02235000	Wekiva River near Sanford, FL	Upper St. Johns	197	200.3	175	248.0
02235200	Blackwater Creek near Cassia, FL	Upper St. Johns	20.4	11.9	12.7	43.2
02236000	St. Johns River near De Land, FL	Upper St. Johns	832	824.0	232	1342.0
02239000	Ocklawaha River near Ocala, FL	Ocklawaha	-3.9	33.7	19	101.0
02240000	Ocklawaha River near Conner, FL	Ocklawaha	559	615.8	490	651.0
02240500	Ocklawaha River at Eureka, FL	Ocklawaha	604	657.8	538	724.0
02243000	Orange Creek at Orange Springs, FL	Ocklawaha	10.5	11.6	16.8	55.5
02244333	Haw Creek above Russells Landing near St Johns Park, FL	Lower St. Johns	43	47.3	4.2	77.6

[1] Simulated baseflow is the average of the simulated flux for all stress periods.
[2] Estimated baseflow represents the minimum and maximum flux estimated from all baseflow estimation methods.
Note: cfs = cubic feet per second

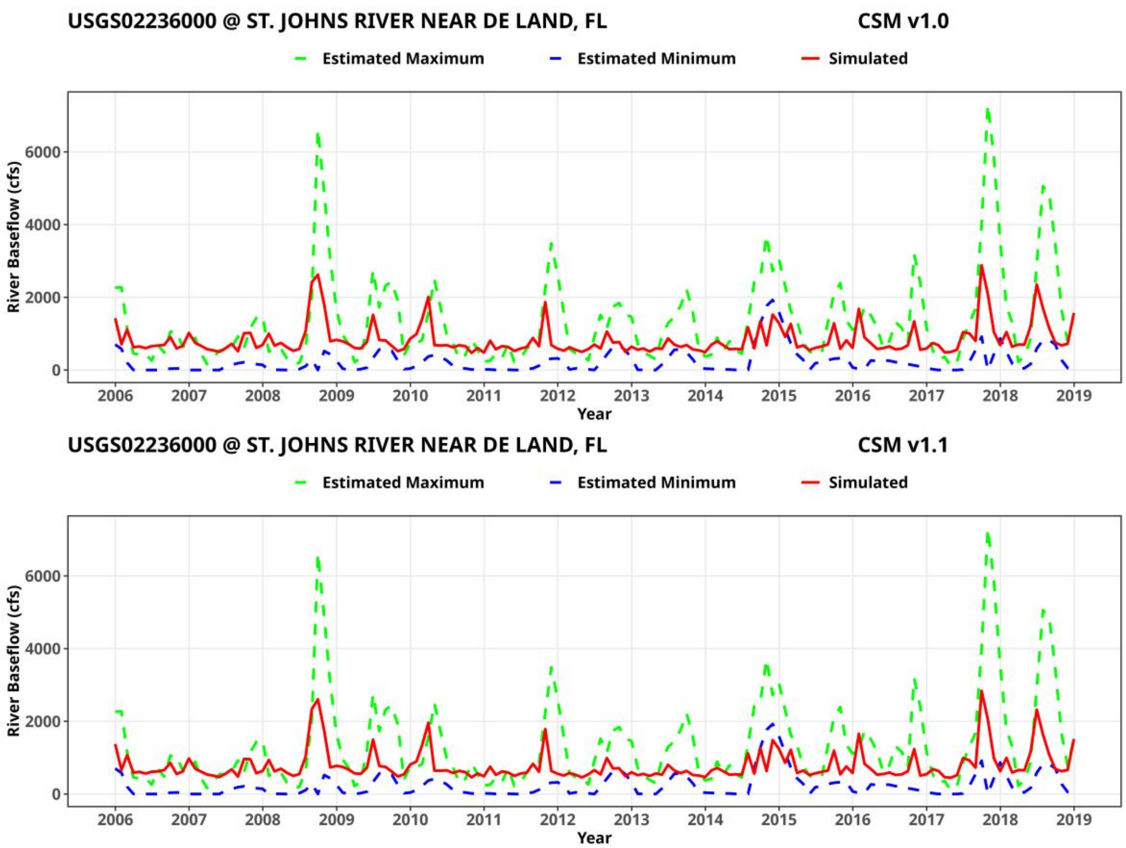


Figure 3-28. Comparison of model simulated to estimated cumulative baseflow at USGS gage 02236000 (St. Johns River Near DeLand, FL). CSM v1.0 (top) is compared to CSM v1.1 (bottom).

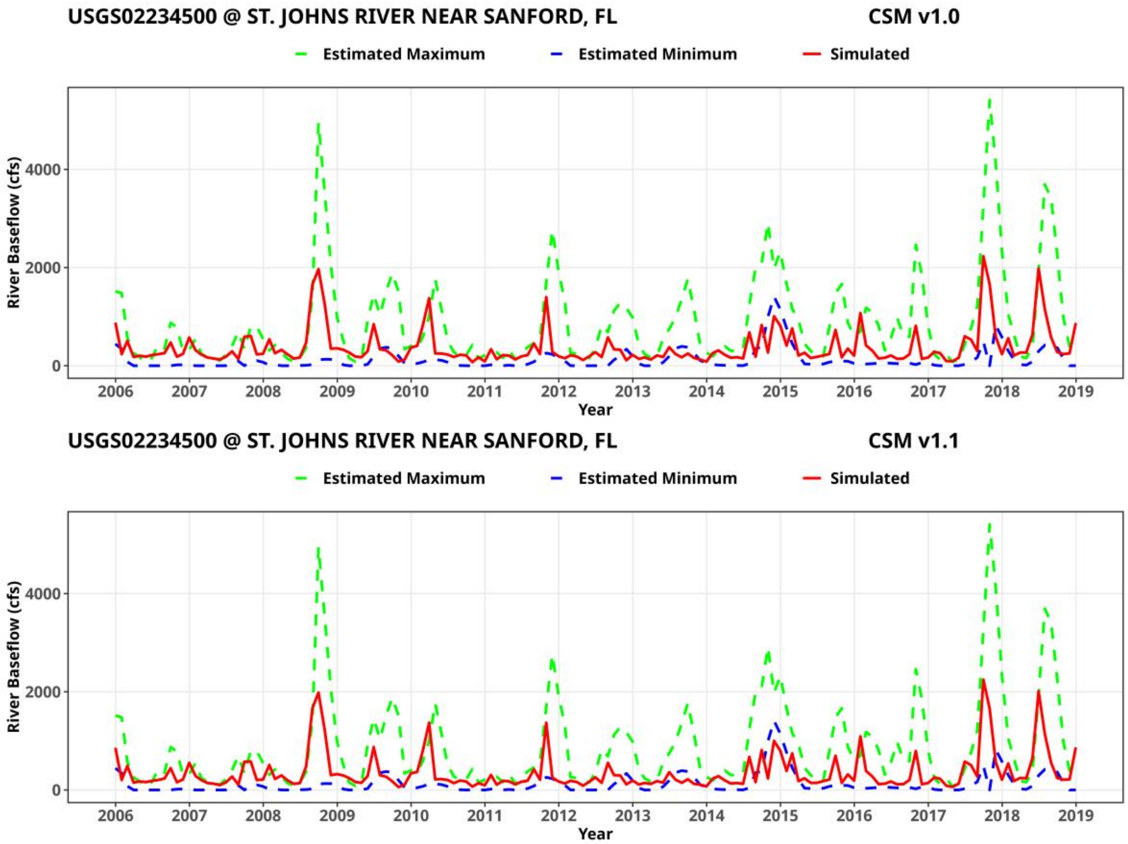


Figure 3-29. Comparison of model simulated to estimated cumulative baseflow at USGS gage 02234500 (St. Johns River Near Sanford, FL). CSM v1.0 (top) is compared to CSM v1.1 (bottom).

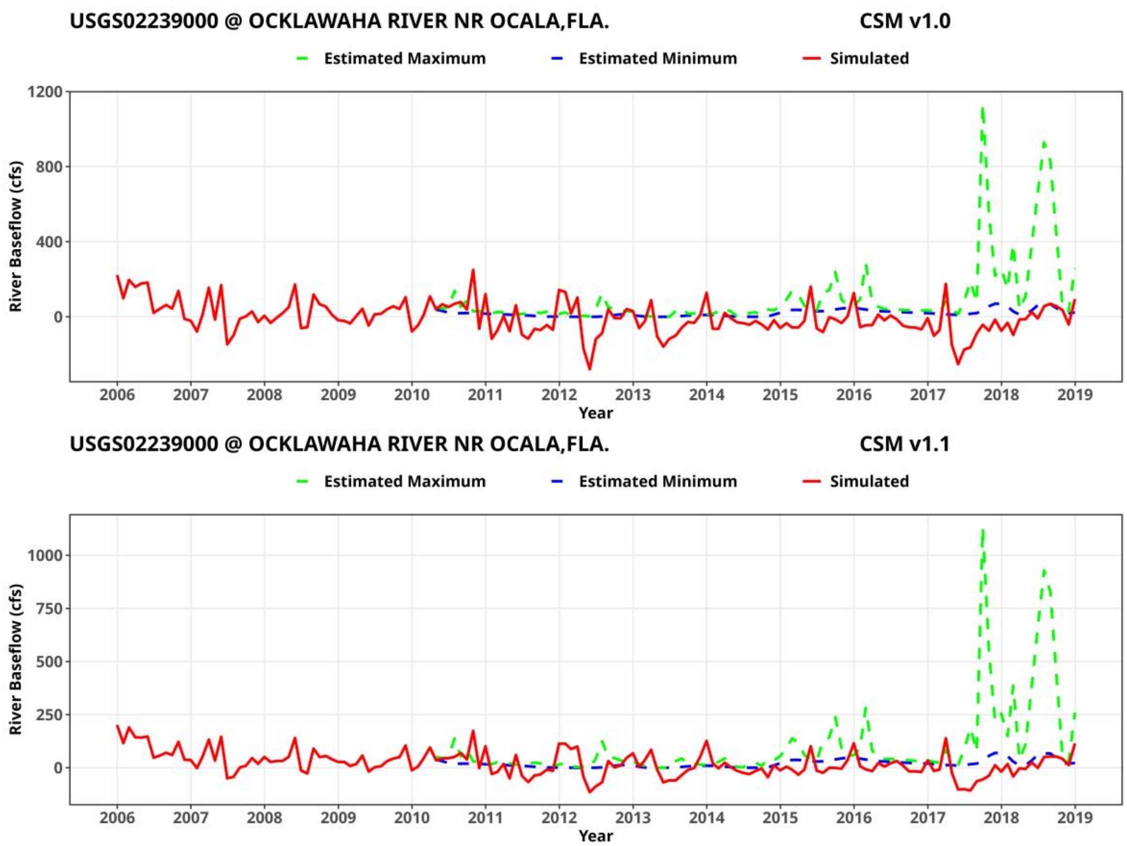


Figure 3-30. Comparison of model simulated to estimated cumulative baseflow at USGS gage 02239000 (Ocklawaha River Near Ocala, FL). CSM v1.0 (top) is compared to CSM v1.1 (bottom).

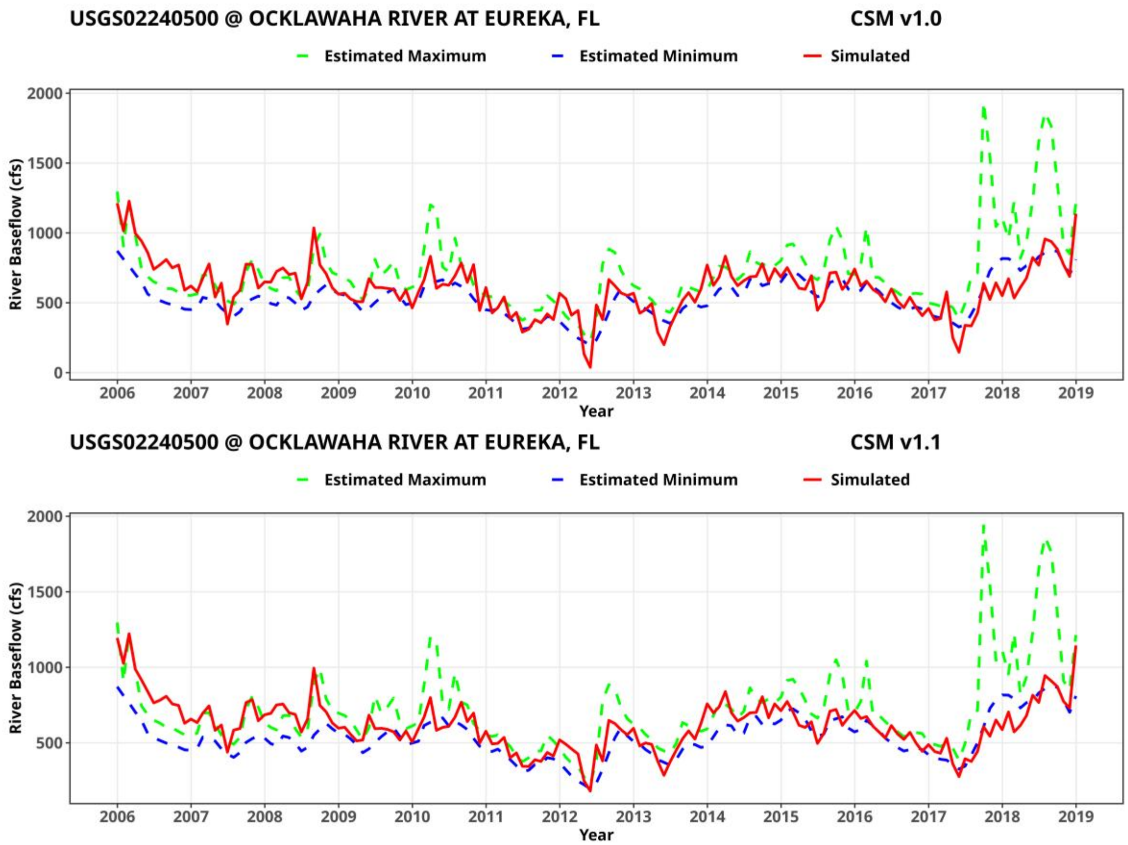


Figure 3-31. Comparison of model simulated to estimated cumulative baseflow at USGS gage 02240500 (Ocklawaha River at Eureka, FL). CSM v1.0 (top) is compared to CSM v1.1 (bottom).

3.2.4 Lake Leakage Rates

The spatial distribution of average leakage values for the simulated lakes are shown in Figure 3-32. The only lake in the focus area with a reported leakage value from water budget studies is Lake Weir, which was estimated to be -13.5 inches per year, on average, for the period of 1954 to 1986 (Deevey 1988), indicating net outflow from the lake to the aquifer for this period. The average simulated lake leakage rate at Lake Weir is -17.6 inches per year, an increase in magnitude from -3.5 inches per year simulated with CSM v1.0. The lake leakage hydrograph at Lake Weir is compared for both versions of the model in Figure 3-33. A complete set of simulated hydrographs of lake leakage is provided in Appendix I. Among the 508 lakes simulated in the CSM v1.0, 442 (87%) lakes had average simulated leakage values within ± 20 in/yr.

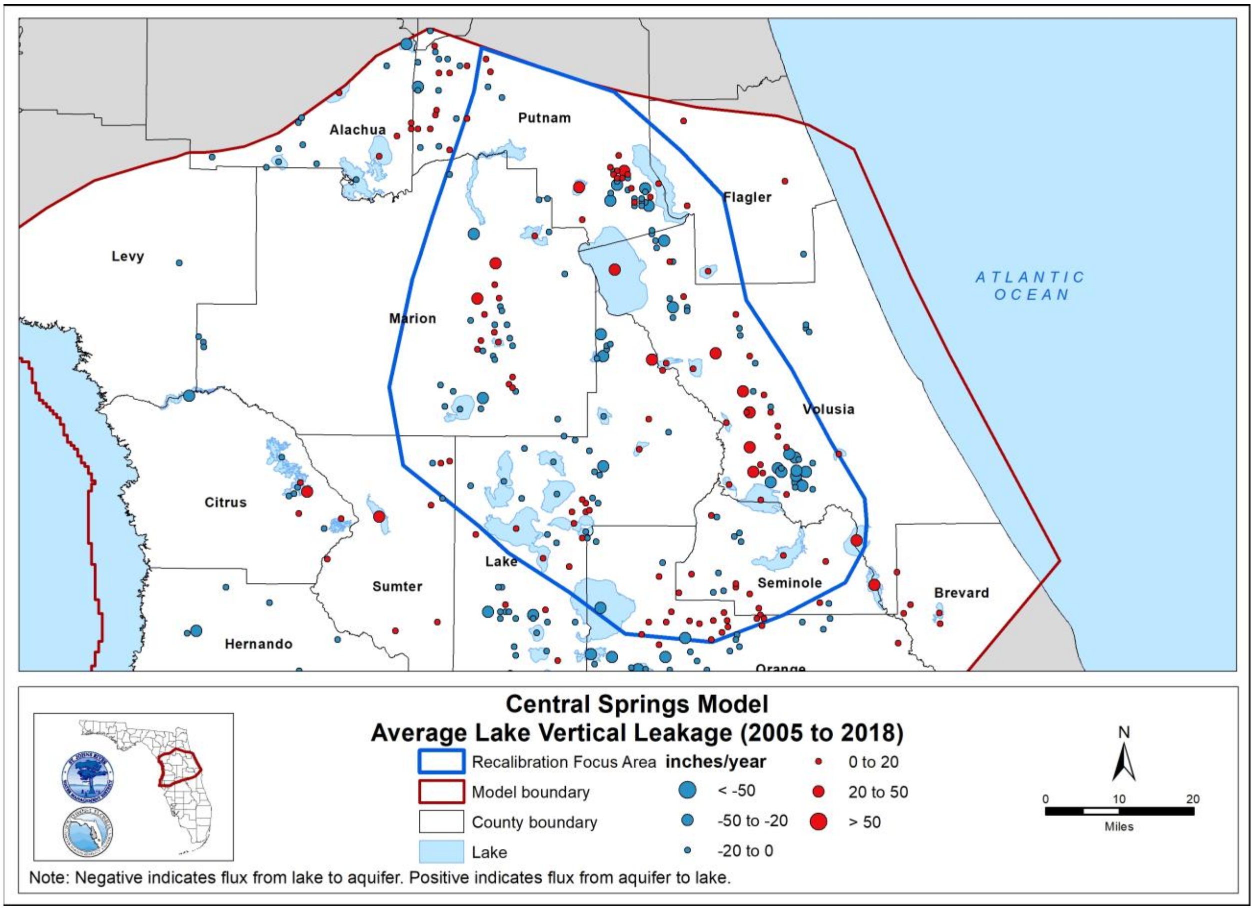


Figure 3-32. Transient simulated 2005 to 2018 average lake vertical leakage within the recalibration focus area (inches per year). Negative values indicate flux from the lake to the aquifer and positive values indicate flux from the aquifer to the lake.

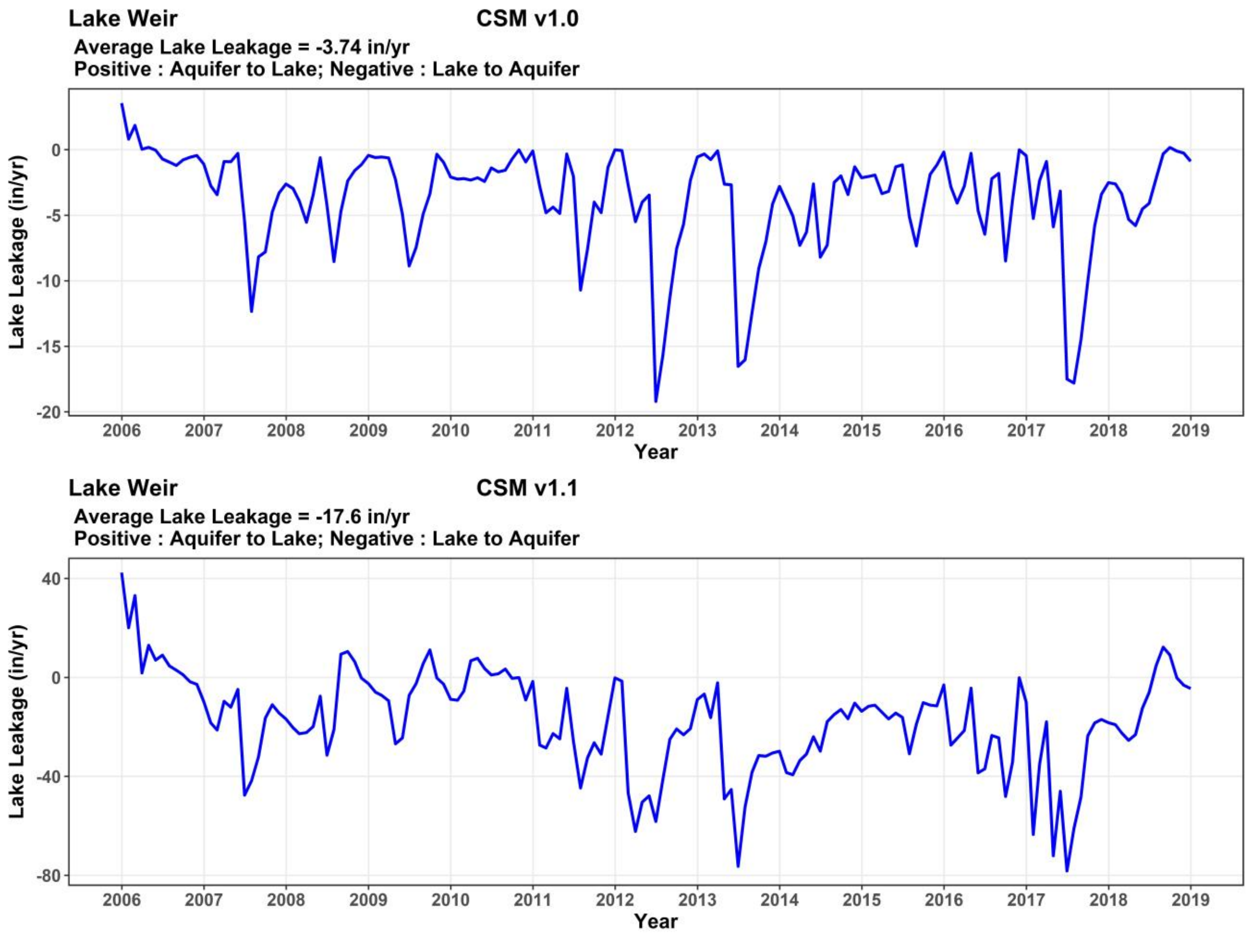


Figure 3-33. Simulated hydrograph of vertical lake leakage at Lake Weir, located in Marion County. CSM v1.0 (top) is compared to CSM v1.1 (bottom).

3.2.5 Water Budget

Simulated water budgets of boundary condition inflow and outflow, inter-layer vertical flux, and storage calculated from the transient simulation are summarized for each layer in the model domain in Table 3-5 and Table 3-6. The net flow, calculated as inflow minus outflow, is listed in Table 3-7. Net fluxes for each major component of the water budget during the calibration period included recharge of 14.2 in/yr, groundwater ET of -5.1 in/yr, net discharge to river, lake, and wetlands of -2.2 in/yr (summation of -1.3 in/yr of River/Lake and -0.9 in/yr of Drain net discharge), and spring discharge of -4.1 in/yr. The overall groundwater withdrawal is -1.5 in/yr and groundwater recharge through drainage wells and RIBs is 0.3 in/yr, resulting in a net groundwater withdrawal of -1.3 in/yr. A total net storage change of 0.2 in/yr in layer 1 (SAS) and a total of 0.1 in/yr in the remaining model layers occurred over the model simulation period.

Table 3-5. Boundary condition influx in the CSM transient model (2005-2018) by layer (inches/year).

Layer	CHD in/yr	GHB in/yr	Well in/yr	River in/yr	Recharge in/yr	Vertical in/yr	Storage in/yr
1	0.0	-	0.1	0.9	14.2	4.5	3.3
2	0.1	-	-	-	-	5.9	0.5
3	0.1	0.0	0.2	-	-	6.0	0.2
4	0.2	0.1	-	-	-	2.4	0.2
5	0.1	-	-	-	-	2.3	0.0
6	0.3	0.2	-	-	-	0.2	0.0
7	0.1	-	-	-	-	-	0.0
Total	0.8	0.3	0.3	0.9	14.2	-	4.2

Note: – = not applicable
CHD = constant head boundaries (coastal)
GHB = general head boundaries (non-coastal)
Rounding of fluxes accounts for nominal discrepancies.

Table 3-6. Boundary condition outflux in the CSM transient model (2005-2018) by layer (inches/year).

Layer	CHD in/yr	GHB in/yr	Well in/yr	River in/yr	Drain in/yr	Spring in/yr	ET in/yr	Vertical in/yr	Storage in/yr
1	-2.0	-	0.0	-2.2	-0.9	-	-5.1	-9.6	-3.0
2	0.0	-	-	-	-	-	-	-11.2	-0.4
3	-0.1	-0.3	-0.4	-	-	-	-	-10.8	-0.2
4	0.0	-0.3	-0.8	-	-	-4.1	-	-2.4	-0.2
5	0.0	-	-0.1	-	-	-	-	-2.3	0.0
6	-	-0.2	-0.3	-	-	-	-	-0.1	0.0
7	-	-	0.0	-	-	-	-	-	0.0
Total	-2.1	-0.8	-1.5	-2.2	-0.9	-4.1	-5.1	-	-3.9

Note: – = not applicable
CHD = constant head boundaries (coastal)
ET = evapotranspiration
GHB = general head boundaries (non-coastal)
Rounding of fluxes accounts for nominal discrepancies.

Table 3-7. Boundary condition net flux in the CSM transient model (2005-2018) by layer (inches/year).

Layer	CHD in/yr	GHB in/yr	Well in/yr	River in/yr	Drain in/yr	Spring in/yr	Recharge in/yr	ET in/yr	Vertical in/yr	Storage in/yr
1	-2.0	-	0.1	-1.3	-0.9	-	14.2	-5.1	-5.2	0.2
2	0.1	-	-	-	-	-	-	-	-5.3	0.0
3	0.0	-0.2	-0.2	-	-	-	-	-	-4.9	0.0
4	0.2	-0.3	-0.8	-	-	-4.1	-	-	0.1	0.0
5	0.1	-	-0.1	-	-	-	-	-	0.1	0.0
6	0.3	-0.1	-0.3	-	-	-	-	-	0.1	0.0
7	0.1	-	-	-	-	-	-	-	-	0.0
Total	-1.2	-0.5	-1.3	-1.3	-0.9	-4.1	14.2	-5.1	-	0.3

Note: – = not applicable
CHD = constant head boundaries (coastal)
ET = evapotranspiration
GHB = general head boundaries (non-coastal)
Rounding of fluxes accounts for nominal discrepancies.
Positive value = influx; negative value = outflux

3.2.5 Aquifer and Confining Unit Properties

Hydraulic properties within the CSM include hydraulic conductivity (both vertical and horizontal) and specific storage properties. During the calibration process, the initial estimates of hydraulic conductivity were adjusted within reasonable limits to improve the agreement between simulated and observed conditions while maintaining parameterization consistent with the conceptual model of the system. After reviewing storage properties in CSM v1.0 and local hydrogeologic information, the specific yield in layer 1 was reduced from a value of 0.2 to 0.1 in four model grid cells located in the focus area (Figure 3-34). Outside of this modification, the storage properties remain the same as applied in CSM v1.0. The horizontal hydraulic conductivity distribution in model layer 1 is shown in Figure 3-35 and hydraulic conductivity maps for all model layers are included in Appendix J. Transmissivity, the product of the aquifer horizontal hydraulic conductivity and the saturated thickness expressed in feet squared per day (ft^2/d), was computed for the UFA (layer 3 and 4) and the LFA (layer 6 and 7). UFA transmissivity is spatially compared with normalized APT results in Figure 3-36 and graphically in Figure 3-37. The leakance coefficient, computed as the vertical hydraulic conductivity divided by the confining unit thickness and expressed in units of ft/d/ft (d^{-1}), was computed for layers 2 (ICU) and 5 (MCU I) (Appendix J).

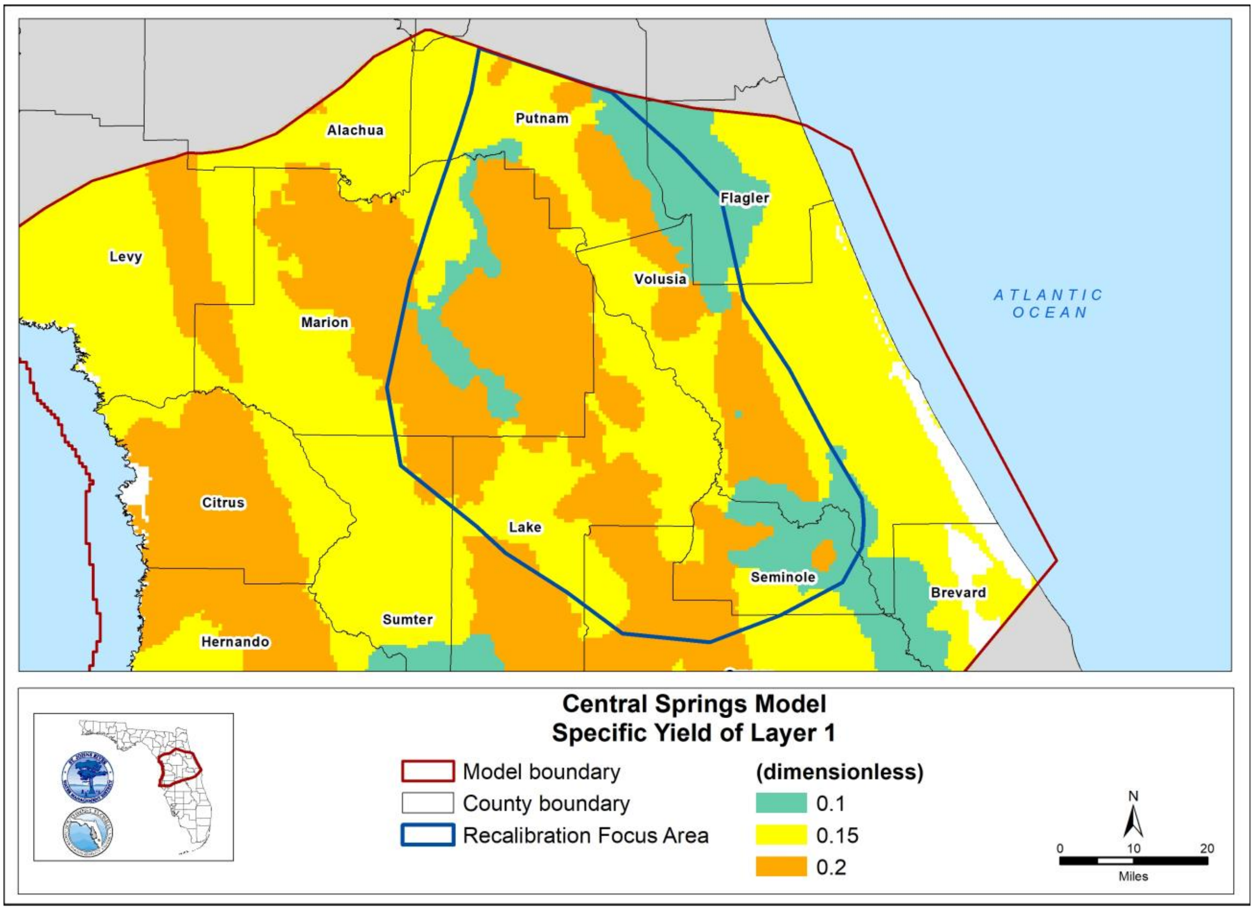


Figure 3-34. Specific yield of layer 1 within the Central Springs Model focus area.

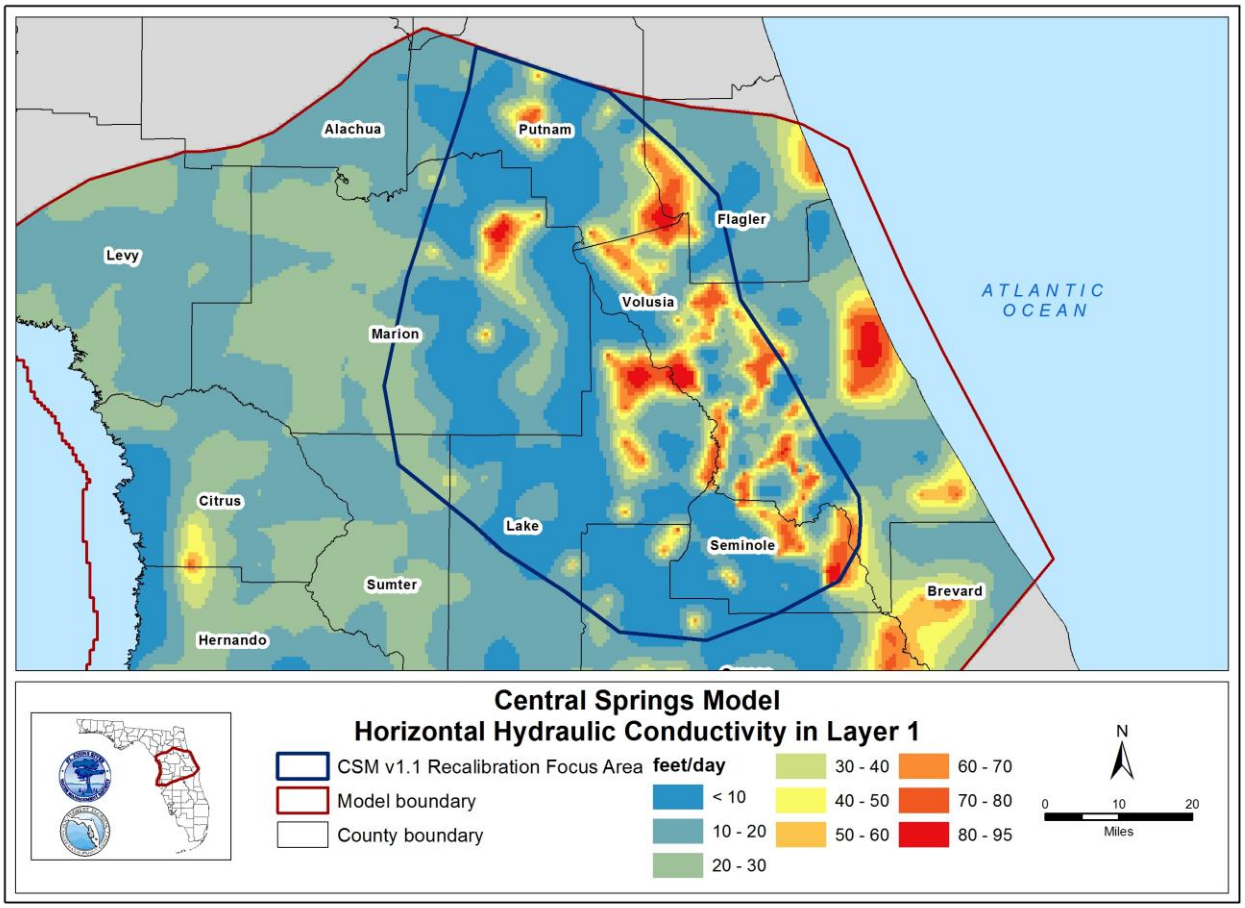


Figure 3-35. Horizontal hydraulic conductivity values in layer 1 in the focus area

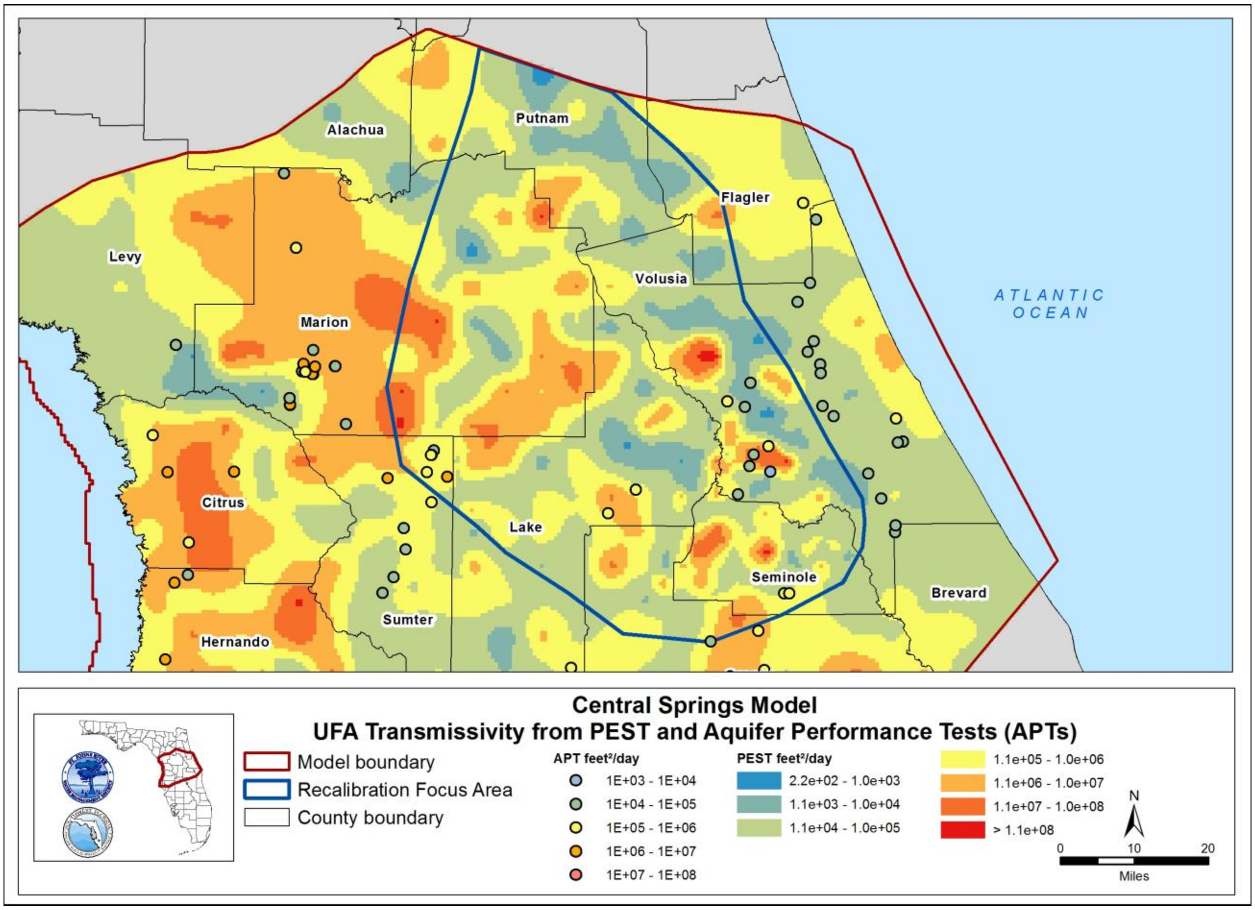


Figure 3-36. Upper Floridan Aquifer (UFA) transmissivity from the calibrated model and normalized UFA transmissivity from aquifer performance tests (APTs) within the focus area

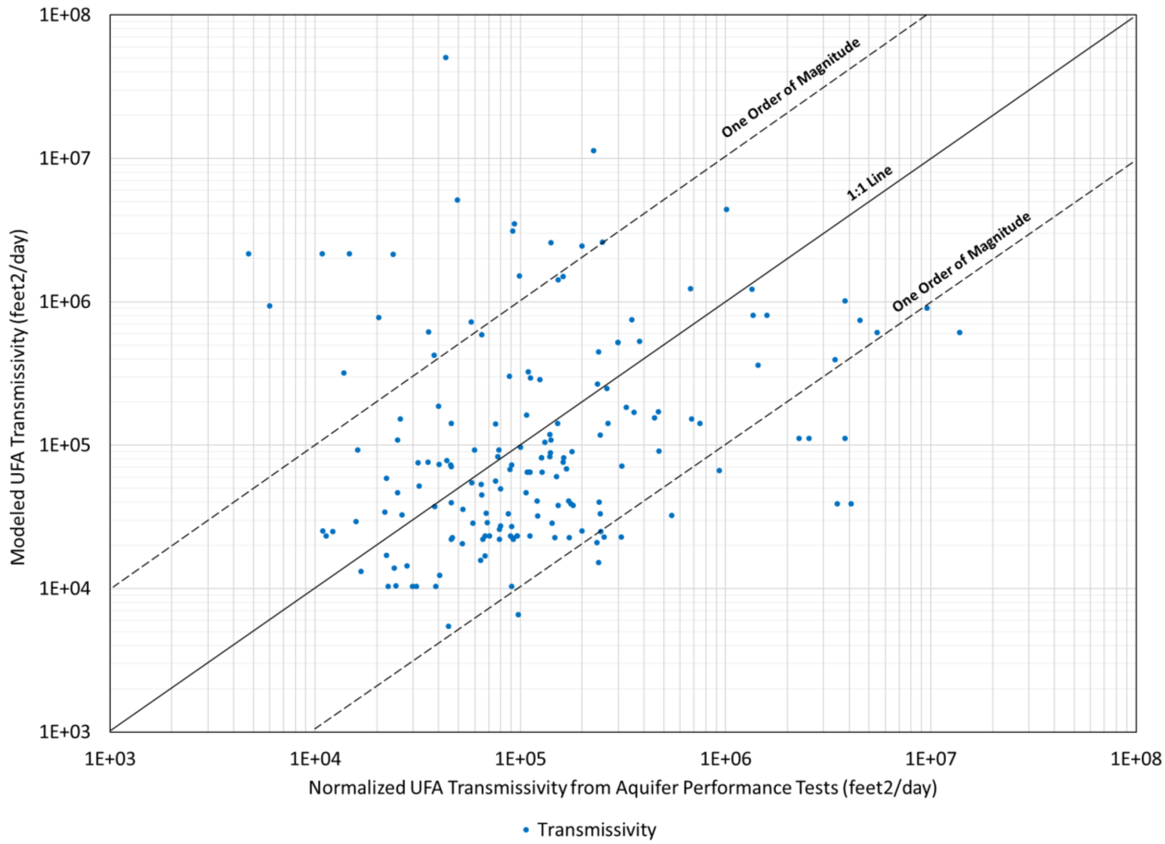


Figure 3-37. Scatterplot of modeled Upper Floridan Aquifer (UFA) transmissivity versus normalized transmissivities from aquifer performance tests within the Central Springs Model domain

4. Discussion

The recalibration of the CSM significantly improved the model prediction performance of groundwater levels in the focus area, particularly in the SAS, which was a major objective of the model recalibration. Average RMS error (RMSE) in the focus area reduced from 5.1 to 2.2 feet in the SAS, from 2.3 feet to 1.4 feet in the UFA, and from 2.0 to 1.7 feet in the LFA (Table 3-1). In addition, the residual mean decreased from 1.3 feet to 0.6 feet in the SAS, relative to CSM v1.0 model performance. The magnitude of the minimum and maximum residual in the SAS within the focus area was also reduced from -12.1 to -6.1 feet and from 24.5 to 5.6 feet, respectively. The percentage of wells with a MAE less than 2.5 and 5.0 feet increased within all major aquifers within the focus area, with the most significant increase occurring in the SAS, where 73% and 97% of wells had a MAE value of less than 2.5 and 5.0 feet, respectively. This is a significant improvement from CSM v1.0 in this area, where 56% and 80% of SAS wells were simulated with a MAE below 2.5 and 5.0 feet, respectively. The percentage of wells with a R^2 value of greater than 0.4, generated by regressing all simulated versus observed water levels, were generally similar to CSM v1.0 within the focus area and across all aquifers. Model-wide statistics also indicate there was general improvement in the groundwater level calibration statistics from CSM v1.0 to CSM v1.1, with minor degradation occurring in the LFA, where the minimum residual increased from -8.4 to -8.6 feet and the percentage of wells with an R-squared value above 0.4 decreased from 95% to 92% after recalibration (Table 3-2). However, the maximum increase in MAE at any individual LFA well outside of the focus area was only noted to be 0.8 feet (L-1049 – Leesburg WWTF), which is minimal compared to the average observed head at the well of 72 feet.

Vertical head differences are one of the primary indicators of the degree of confinement between two aquifers and improve the model's ability to simulate degree of confinement in the region. The spatial distribution of simulated and observed vertical head differences across the ICU (Figure 3-14) and MCU I (Figure 3-15) generally show good agreement within the focus area, with some improvements from CSM v1.0 noted in Marion and Volusia County. Furthermore, the recalibration resulted in no significant changes in model performance outside of the focus area. A regression between mean simulated and observed vertical head differences across the SAS and UFA (Figure 3-16) and the UFA to LFA (Figure 3-17) was performed and shows a higher R^2 value, indicating improvement in correlation between observed and simulated vertical head differences across both confining units. This is important for accurately predicting the propagation of impacts from groundwater pumping in the UFA and LFA to lakes, rivers, and wetlands.

Review of average flooded cells in layer 1 in the focus area indicates flooding is generally minimal in magnitude (within 5 to 10 feet) and isolated in spatial distribution (Figure 3-18). There was an increase in the number of flooded cells in Volusia County, on average, compared to CSM v1.0, however this additional flooding occurs over isolated areas.

The occurrence of dry cells in layer 1 was reduced within the focus area, primarily in western Volusia County, relative to the CSM v1.0 (Figure 3-19). In Volusia County, dry cells in layer 1 are located within ridge areas, namely the Crescent City and DeLand ridges, characterized by sandy deposits with high topographic elevation, karst development, and lack of well-developed surface drainage (Williams 1997). These hydrogeologic characteristics result in a relatively deep water table and thick unsaturated zone in these areas, conducive to the simulation of dry cells in a regional groundwater flow model.

The simulation of major springs in the focus area were generally similar to CSM v1.0 model performance, with some minimal degradation likely due to reduced weighting of spring flow calibration targets in the PEST calibration procedure. The recalibrated model resulted in a decrease in the magnitude of average model error at Volusia Blue Springs (reduced from 1.2% to 0.7%) and Alexander Springs (reduced from 2.6% to 2.3%). The average model error slightly increased at Silver Springs (increased from 2.0% to 2.2%) and Silver Glen Springs (increased from 2.0% to 4.4%). However, the transient calibration criteria established for spring discharges was still maintained, with all first magnitude springs in the focus area maintaining a model error of ± 5% and second magnitude springs with reliable data within ± 10%.

Simulated lake leakage rates were generally similar in direction and magnitude to CSM v1.0, in which both models resulted in approximately 87 to 88% of lakes with an average leakage rate of ± 20 inches per year. A considerable improvement was made at Lake Weir, in which the simulated average leakage rate (-17.6 inches per year) matches more closely with the estimated leakage rate (-13.5 inches per year). This can be attributed to recalibration of river conductance and lake leakance terms and improved simulation of surficial groundwater levels in the vicinity of the lake.

Model simulated cumulative baseflows were within range of estimated baseflows at major streamflow gages along the St. Johns River and Ocklawaha River within the focus area (Table 3-4). Additionally, the Ocklawaha River near Ocala gage (USGS 02239000), which simulated negative baseflow on average from 2005 to 2018 of -3.7 cfs in CSM v1.0 (indicative of discharge from the river to the aquifer), simulated a net average positive baseflow of 33.7 cfs (indicate of discharge from the aquifer to the river) in CSM v1.1 which is within range of estimates from baseflow separation methods (Table 3-4). This is an improvement from the previous version of the model and more accurately represents the groundwater flow system in this region.

To assess the MODFLOW simulated water budget, HSPF-calculated baseflow (AGWO) was compared to the cumulative baseflow calculated in the DRN and RIV packages of MODFLOW and HSPF-simulated saturated ET (AGWET+ BASET) was compared to groundwater ET for the major river basins in the focus area (Upper St. Johns, Lower St. Johns, and Ocklawaha). The comparison of baseflow shows that the two models are in general agreement for the major river basins (Figure 4-1 to Figure 4-3). The groundwater ET is comparable in the Upper and Lower St. Johns River, however, is undersimulated in the Ocklawaha River, as was the case in CSM v1.0 (Figure 4-4 to Figure 4-6). Further investigation of the water balance in the Ocklawaha River watershed is needed to improve the model performance.

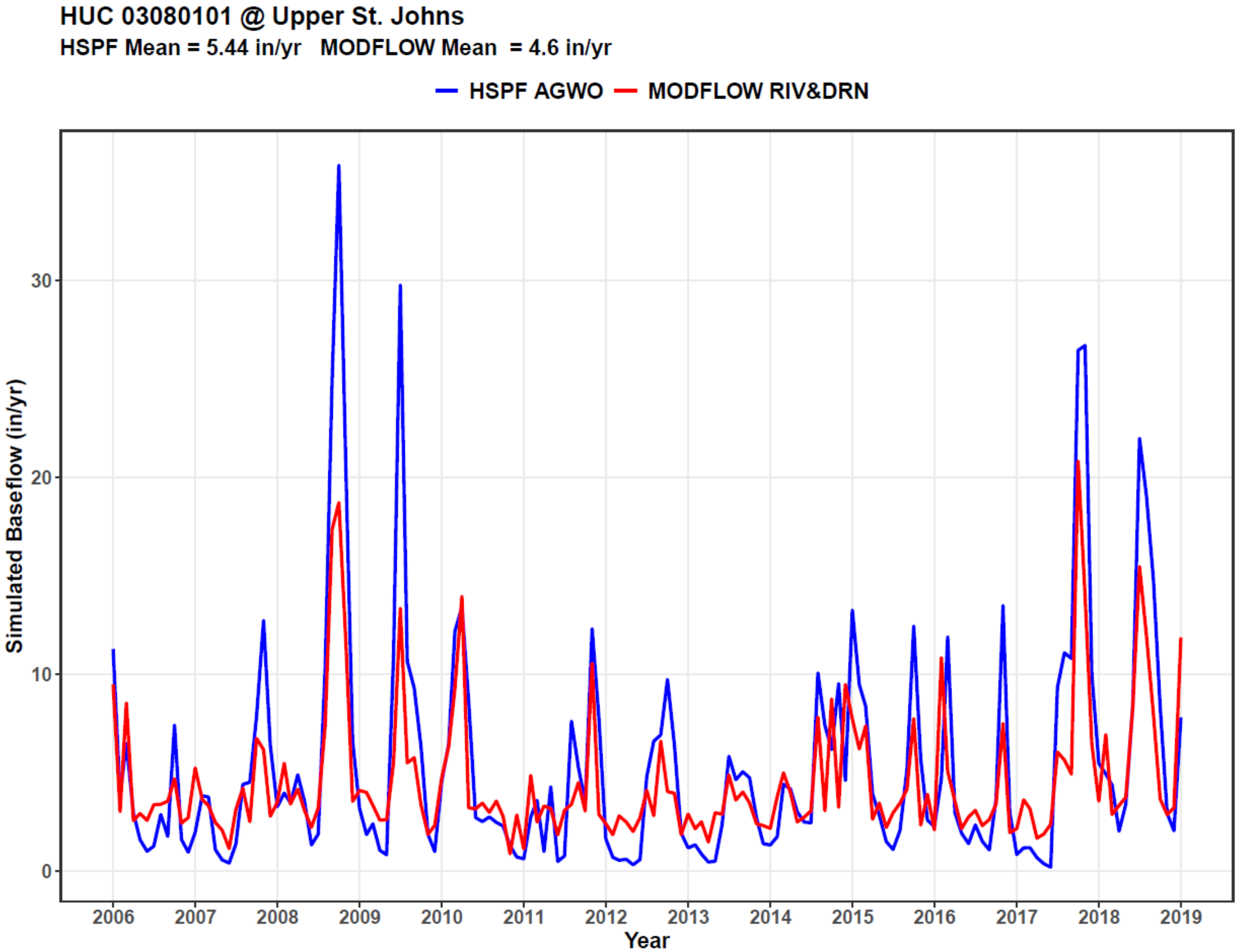


Figure 4-1. Simulated HSPF-calculated baseflow (AGWO) and cumulative baseflow calculated in the DRN and RIV packages of MODFLOW for the Upper St. Johns River.

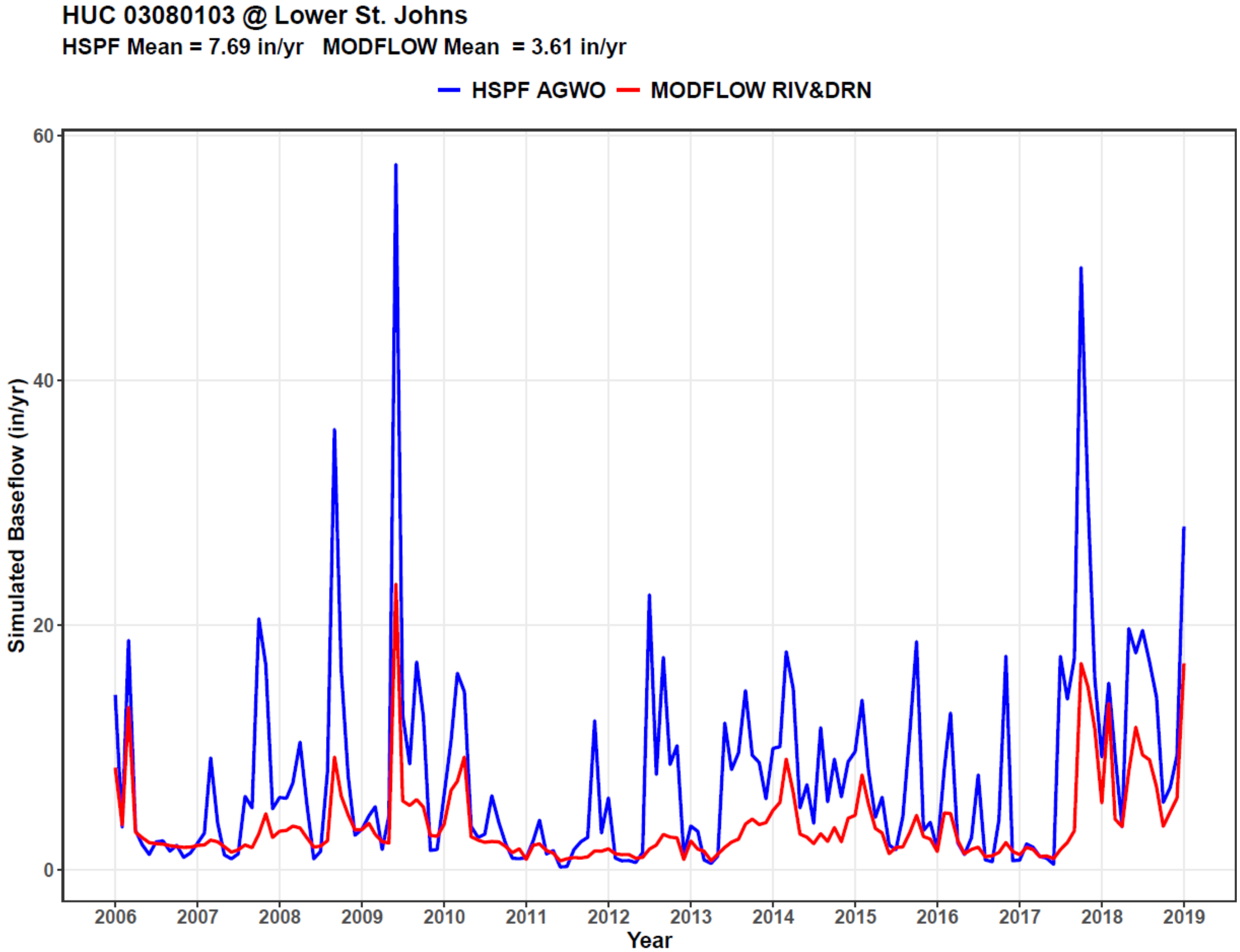


Figure 4-2. Simulated HSPF-calculated baseflow (AGWO) and cumulative baseflow calculated in the DRN and RIV packages of MODFLOW for the Lower St. Johns River.

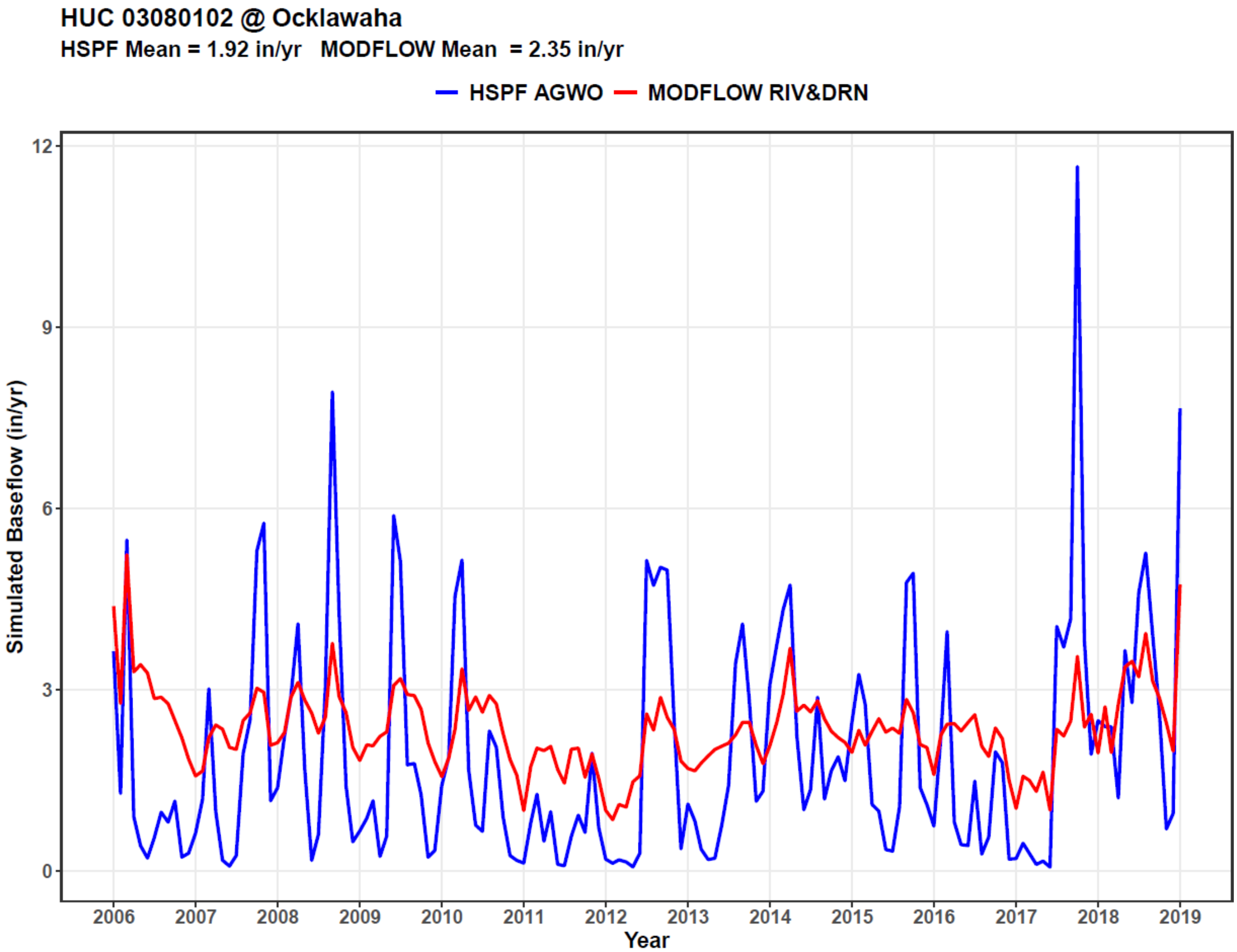


Figure 4-3. Simulated HSPF-calculated baseflow (AGWO) and cumulative baseflow calculated in the DRN and RIV packages of MODFLOW for the Ocklawaha River.

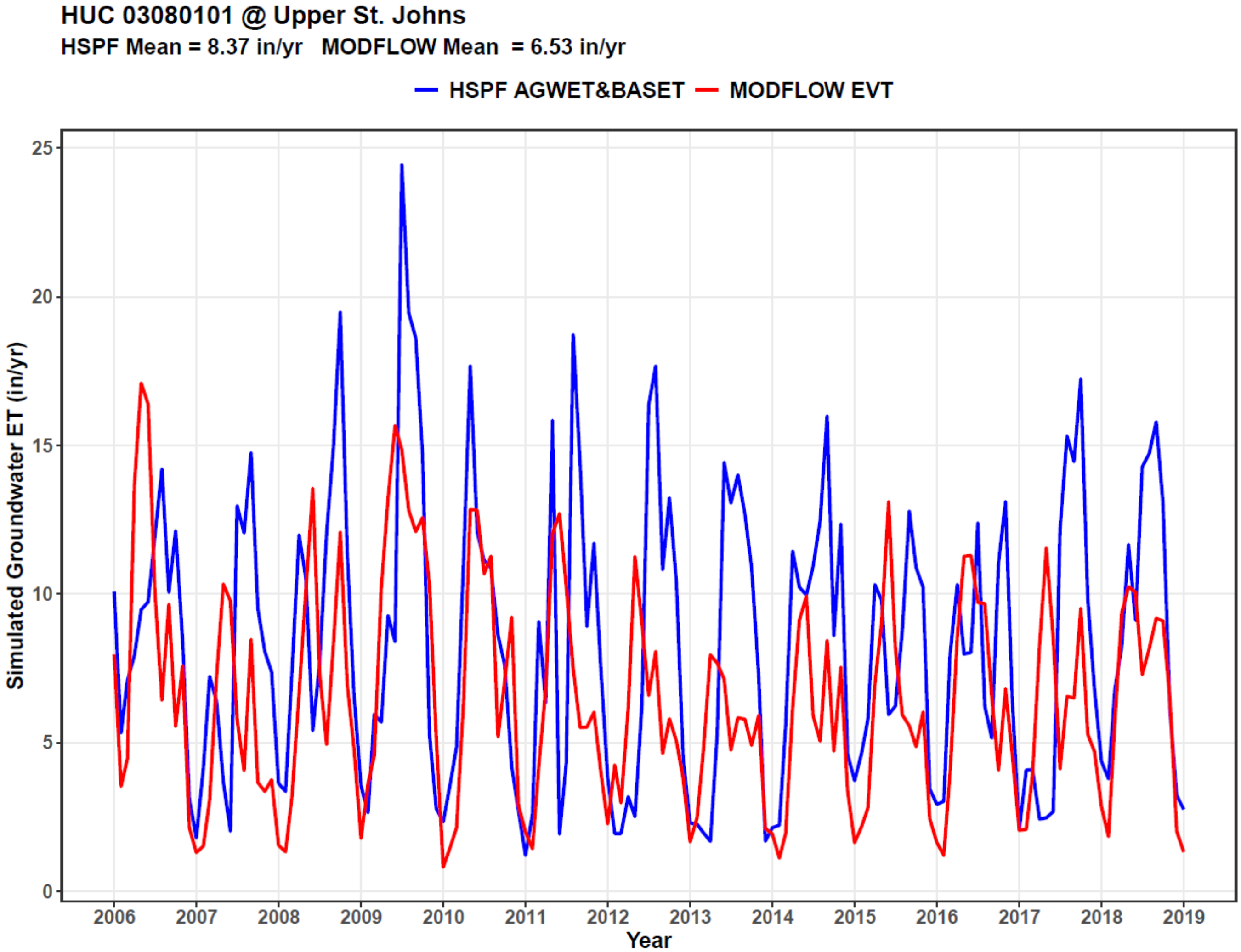


Figure 4-4. Simulated HSPF Saturated ET and MODFLOW ET for the Upper St. Johns River.

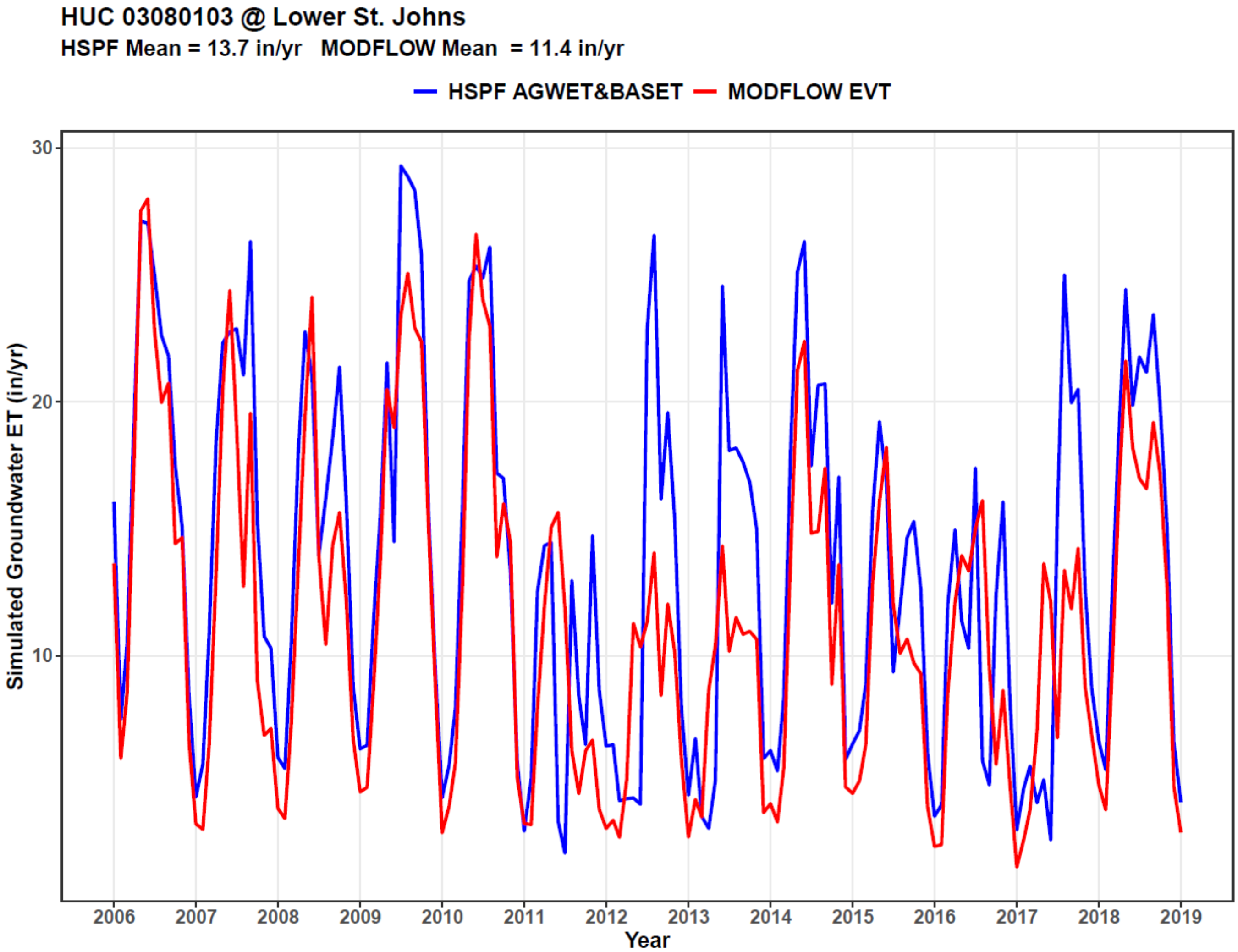


Figure 4-5. Simulated HSPF Saturated ET and MODFLOW ET for the Lower St. Johns River.

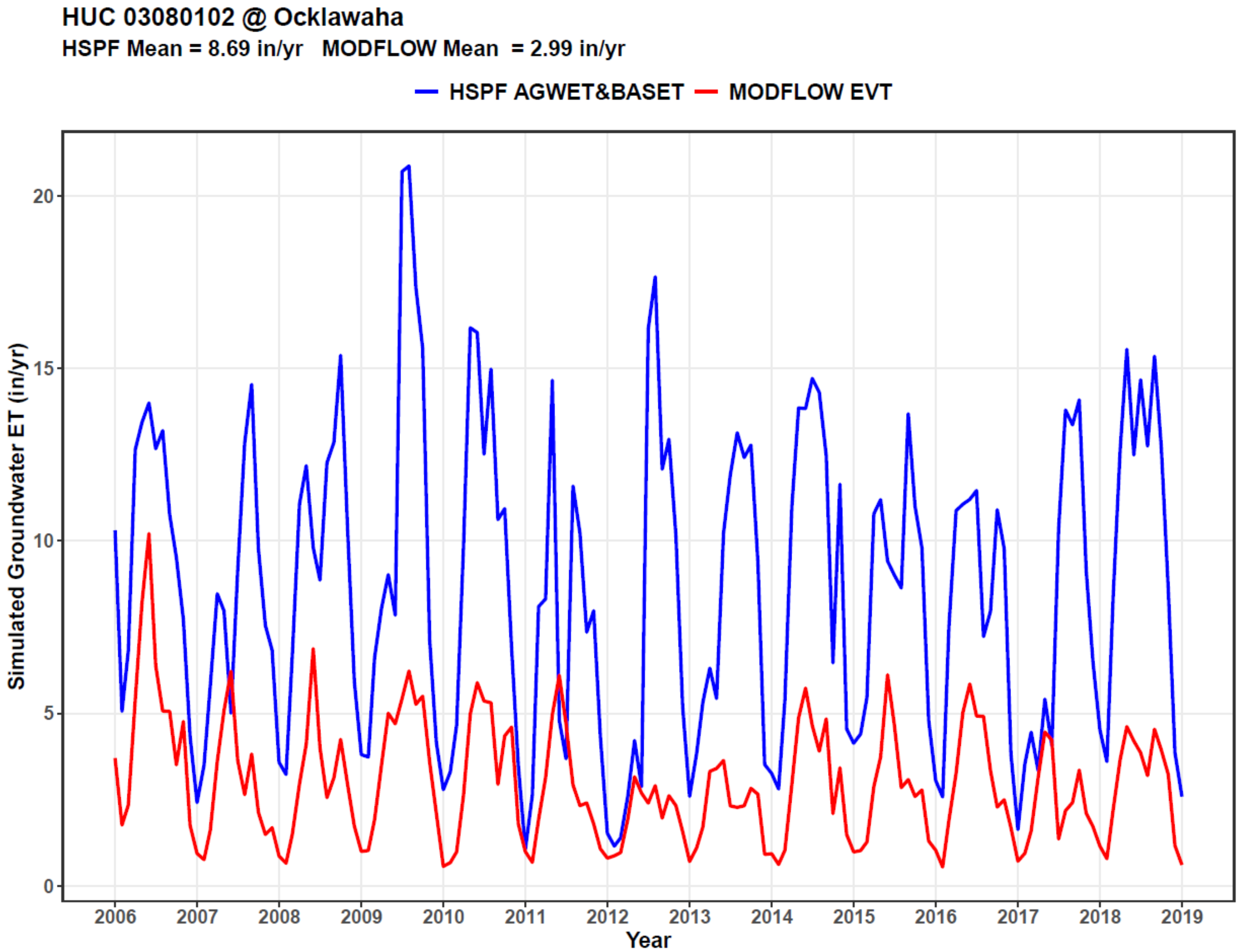


Figure 4-6. Simulated HSPF Saturated ET and MODFLOW ET for the Ocklawaha River.

The reasonableness of the updated simulated hydraulic conductivities was assessed by reviewing the transmissivity values of the UFA with APT data, spring locations (karst-dominated geology), and potentiometric surface contour gradients. The leakance values of the ICU were compared against observed vertical head differences and literature information to infer degree of confinement. Figure 4-7 shows the updated UFA transmissivity values with September 2014 potentiometric surface contours and spring locations. Small and large spacings between two contours of potentiometric surface are usually indications of low and high aquifer transmissivities, respectively. As shown in Figure 4-7, the recalibrated parameter distribution is generally consistent with contour spacing as high transmissivity areas usually coincide with the contours with large spacing (flat gradients) whereas low transmissivity areas usually coincide with contours with tight spacing (steep gradients). In addition, very high transmissivity values were assigned to the areas of springs and their vicinities, which is consistent with the fact that aquifers are expected to be highly transmissive in the vicinity of springs due to presence of conduits and fractures. Although the recalibrated transmissivity values are generally within one order of magnitude of the APT-derived values in most of the focus area, the transmissivity values in the model are higher than the APT-derived values in southern Volusia County, however, this zone of high transmissivity is in proximity to Blue Spring, a first magnitude spring. APT values should be used cautiously when comparing model parameters as they are usually derived from field tests using analytical solutions with limitations. The quality of the field tests and data collection can significantly affect the transmissivity values derived from the APTs. In addition, the APTs (mostly lasting less than 72 hours) usually do not sufficiently stress the aquifer more than a few miles, and therefore, the derived transmissivity values may not represent large areas. Moreover, some of the APTs are based on only one pumping well (with no monitoring well nearby) and can produce questionable transmissivity estimates due to frictional effects and water level changes in the pumping well. Figure 4-8 shows the recalibrated leakance values in the ICU with vertical head differences between the SAS and UFA. As expected, low leakance values are generally in the areas of large vertical head differences and high leakance values are generally in the areas of small vertical head distances, indicating the reasonableness of the leakance values in the ICU.

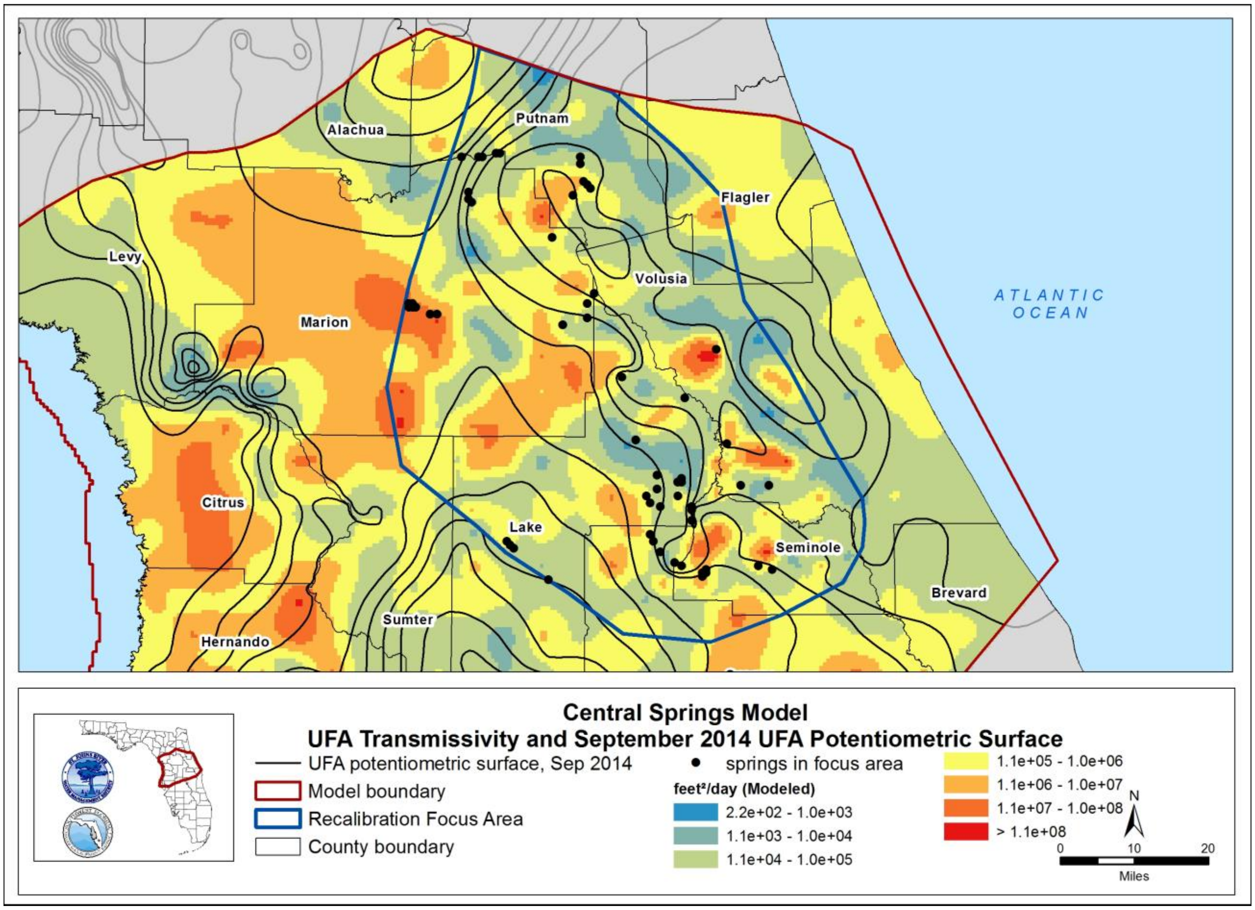


Figure 4-7. Simulated UFA transmissivity plotted with the September 2014 UFA potentiometric surface contours and spring locations.

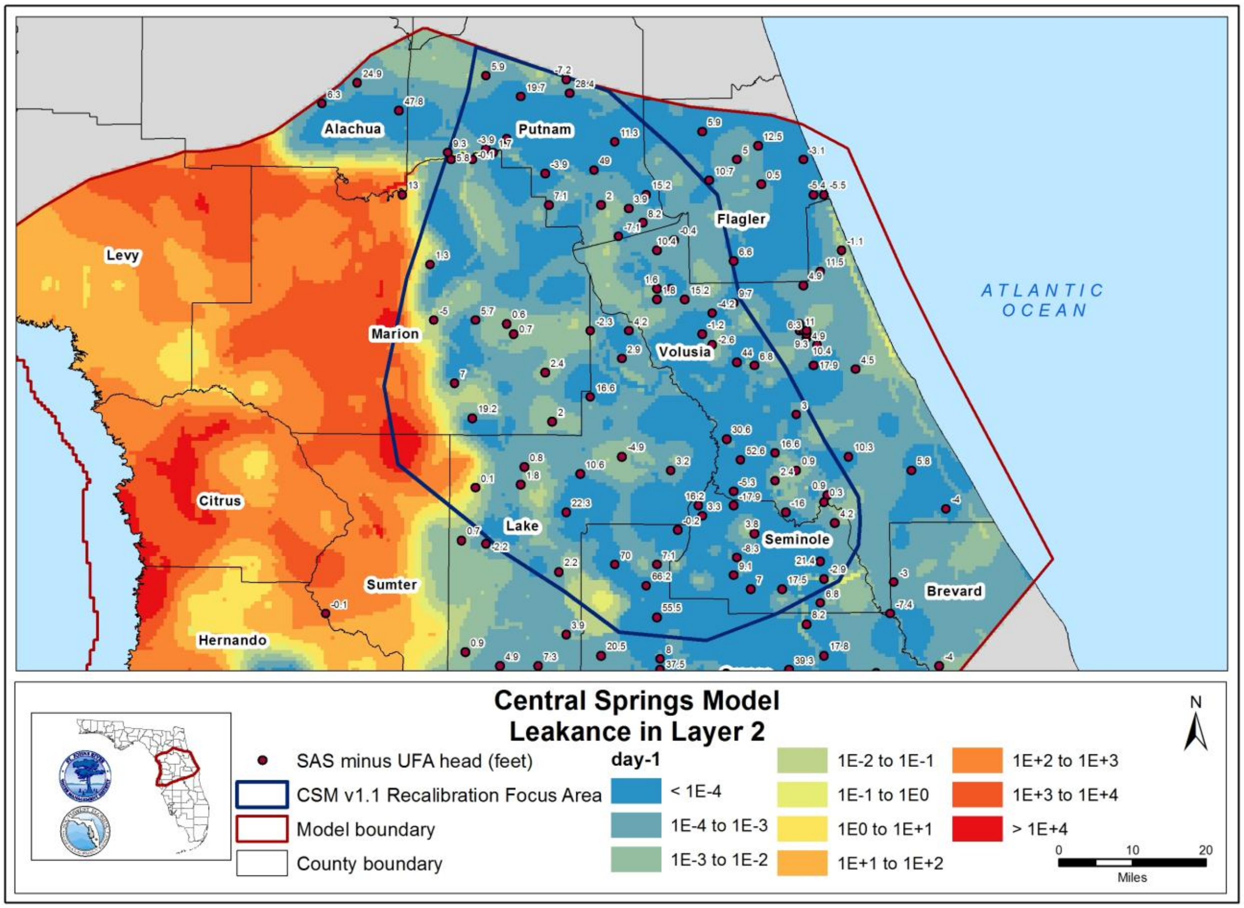


Figure 4-8. Simulated ICU (layer 2) leakance and observed vertical head differences between the SAS and UFA.

5. Conclusions

The CSM v1.0 was updated and recalibrated to make the model a more suitable tool for regulatory decisions and to improve model performance in areas where critical minimum flows and levels (MFL) water bodies are located. To accomplish this, a focus area was delineated where the calibration of the CSM v1.0 could be improved (Figure 1-3). Refinements in the focus area included updates to groundwater level targets used for calibration, river boundary conditions, drain boundary conditions, and groundwater use data. After the model was updated, PEST optimization was performed on the steady-state model to estimate hydraulic properties within the focus area. Aquifer parameters within the focus area were adjusted within a range consistent with the known hydrogeology in the region. The steady-state model hydraulic properties and storage properties were incorporated into a transient simulation for the period of 2005 to 2018 that was used to evaluate model performance.

The CSM v1.1 transient model performance in simulating groundwater levels was considerably improved within the focus area. The model-wide groundwater level calibration statistics were also improved as a result of the improvements in the focus area. Furthermore, the CSM v1.1 reliably estimated spring flows at first magnitude and second magnitude springs with observed data and simulated baseflows within a reasonable range of estimates flows. Overall, this provides greater confidence that CSM v1.1 should be considered an appropriate tool for assisting regulatory decisions, MFL evaluations, and future water supply planning efforts.

6. References

Barlow, P.M., W.L. Cunningham, T. Zhai, and M. Gray. 2014. *U.S. Geological Survey groundwater toolbox, a graphical and mapping interface for analysis of hydrologic data (version 1.0): user guide for estimation of base flow, runoff, and groundwater recharge from streamflow data*. Technical Report 3-B10. Reston, Va.: U. S. Geological Survey.

Deevey, E.S. 1988. *Estimation of Downward Leakage from Florida Lakes*. Limnology and Oceanography, vol. 33, no.6., pp. 1308-1320.

Doherty, J. 2015. *PEST – The Book: Calibration and Uncertainty Analysis for Complex Environmental Models*. Brisbane, Australia.: Watermark Numerical Computing.

Gordu, F., L. Sisco, R. Basso, H. Zhang, J. Patterson, P. Kwiatkowski, and A. Obeysekera. 2022. *East-Central Florida Transient Expanded (ECFTX) V2.0 Model Report.* March 2022.

Niswonger, R.G., P., Sorab, and I., Motomu. 2011. *MODFLOW-NWT, A Newton formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6-A37*. https://doi.org/10.3133/tm6A37.

Perry, R.G. 1995. *Regional Assessment of Land Use Nitrogen Loading of Unconfined Aquifers*. Ph.D. Dissertation, University of South Florida, Tampa, Florida.

Sun, Q., W. Jin, A. Nur, F. Gordu, J. Kokjohn, H. Zhang, and C. Joseph. 2024. *Central Springs Groundwater Flow Model (CSM) Version 1.0*. St. Johns River Water Management District, Palatka, Florida.

Tibbals, C.H. 1990. *Hydrology of the Floridan aquifer system in east-central Florida*. Professional Paper 1403-E. Washington, D.C.: U.S. Geological Survey.

Williams, S. 1997. *A Regional Flow Model of the Volusia Ground Water Basin*. St. Johns River Water Management District, Palatka, Florida.

7. List of Appendices