Appendix VII
Methodology for the Development of a Reference Timeframe Flow (RTF)

1.0 INTRODUCTION

This appendix outlines the process that was developed to generate reference timeframe flow and/or groundwater-head (head) time-series at groundwater monitoring locations, springs and/or stream gage locations using observed and modeled data and an estimated time series of historic groundwater withdrawals. For this analysis, a reference timeframe head or flow time-series (referred henceforth as RTF) is defined as an estimate of the historic time-series that would have been observed in the absence of any groundwater withdrawals. In other words, the RTF is a time-series from which impacts of groundwater withdrawals are removed. The concept of RTF generation is generally based on studies conducted by University of Idaho in the Snake River basin. Development of reference time series relies on utilizing the modeling results from the North Florida Southeast Georgia Groundwater Model, NFSEG (SJRWMD 2019).

The NFSEG model covers an area of 60,000 square miles, encompassing a large area of the Floridan aquifer system in north Florida, Georgia, and South Carolina. The model was developed in MODFLOW-NWT and is setup as a steady- state model representing detailed groundwater system as well as springs and major rivers. The model was calibrated to 2001 and 2009 hydrologic conditions and validated using 2010 conditions (SJRWMD, 2019). The groundwater system in NFSEG is represented using seven layers with Layer 1 representing the surficial aquifer system, Layer 3 representing the Upper Floridan aquifer, and Layers 5 representing deeper segment of the Florida aquifer system. **Figure 1** shows the spatial extent of the NFSEG model domain which is further discretized as 2500 ft by 2500 ft square cells (752 rows and 704 columns). Layer 3 and Layer 5 of the NFSEG model represent the water bearing units of the groundwater system where the majority of the groundwater withdrawal takes place. The surface water hydrology, providing recharge and maximum saturated evapotranspiration inputs to the MODFLOW-NWT model, was simulated using the Hydrological Simulation Program – FORTRAN (HSPF).

The groundwater withdrawals required for the development of RTF were estimated on a yearly basis for each county in the NFSEG model domain (**Figure 1**) for calendar-years 1933-2015. These estimates were then used to evaluate changes in groundwater levels and flows in response to changes in groundwater use from 1933 through 2015.The estimated annual groundwater impacts (i.e. reduced flow/ head) were added back to an observed hydrograph of groundwater levels or flows at the site of interest to obtain a synthetic hydrograph representing the variation in groundwater levels or flows at the site in the absence of groundwater withdrawals for the period from 1933 to 2015. These adjusted hydrographs are referred to as reference timeframe flow or head time series. Long-term response of the groundwater system to changes in groundwater use over a long period of time was evaluated through application of the steady state NFSEG groundwater model. The following sections provide details of the RTF development process.

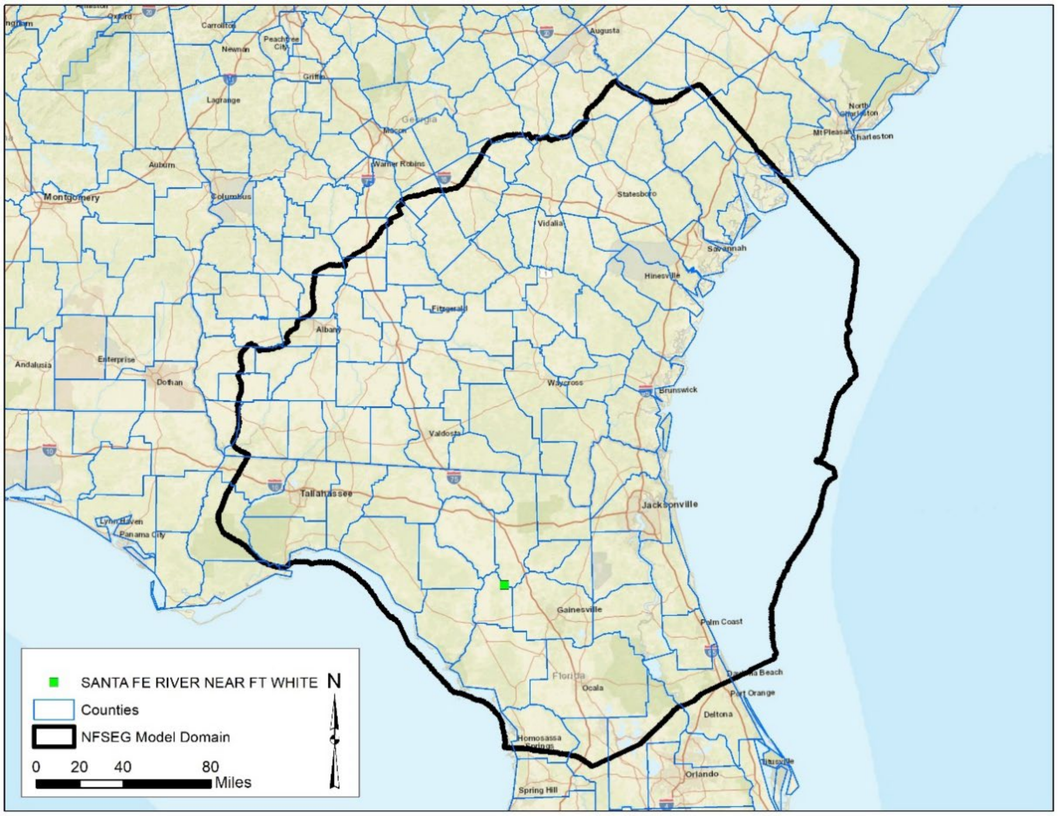

Figure 1. NFSEG Model Domain

2.0 <u>GENERAL APPROACH</u>

The overall process of generating reference timeframe flow or head time-series for a site of interest entails:

- estimating historic impacts from groundwater withdrawals (as described below) at the site, and then,
- adjusting the observed, historic flow or head time-series at the site by removing the estimated groundwater-withdrawal impacts.

Estimation of impacts of groundwater withdrawals is a multi-step process relying on the results from the 2009-condition run of the NFSEG model. The model results were used to develop quantitative unitized estimates (called sensitivities) of the influence of groundwater withdrawals and/or return flow on the observed groundwater level and flow that can be subsequently be used for hindcasting of the impacts (relying on historic groundwater withdrawal conditions).

- The first step involves estimating the influence of ambient groundwater withdrawals on observed values (head and/or flow) (reduction or increase) at a location of interest (monitoring well, stream gage, or spring)
- The second step involves quantifying changes in flow or head values arising due to influence of "return-flows" (e.g., irrigation or other anthropogenic land-surface applications).
- In the final step, the net change in head and/or flow at the location is derived by aggregating the groundwater withdrawal impacts (generally resulting in lowering of flows and head) and return flow impacts (generally resulting in increasing of flow and head) and adding to an observed, historic time series of flows or heads at the location of interest.

A key concept utilized in the development of the reference timeframe flow (or head) is "sensitivity". Sensitivity for a given location of interest (spring/stream gage/groundwater monitoring well) is defined with respect to another place within the watershed (e.g. public supply withdrawal location) and is quantified as the expected change in the observed flow (or head) values at the location of interest due to a 1 MGD change in the groundwater withdrawal or 1 cfs change in the return flow at the given place (i.e., public supply withdrawal location). Within the model domain, the locations of interest are identified by a grid cell location. In simple terms, once sensitivity value maps are generated for each cell the expected change in the observed flow (or head) at a location of interest can be directly computed by multiplying the sensitivity values associated with a withdrawal/return-flow cell location with the actual magnitude of the withdrawal or return flow. The expected change is then summed over the model cells. This process can subsequently be expanded to include historical time-series.

To help illustrate the RTF time-series development process, numerical values from the analysis conducted at the USGS gage on Santa Fe River Near Fort White (USGS Gage ID 02322500, Fort White gage) will be used as an example. The direct groundwater contribution to the river is represented via use of river cells (**Figure 2**) while groundwater contribution from drains and springs are captured via several other model cells (**Figure 3** and **Figure 4**)

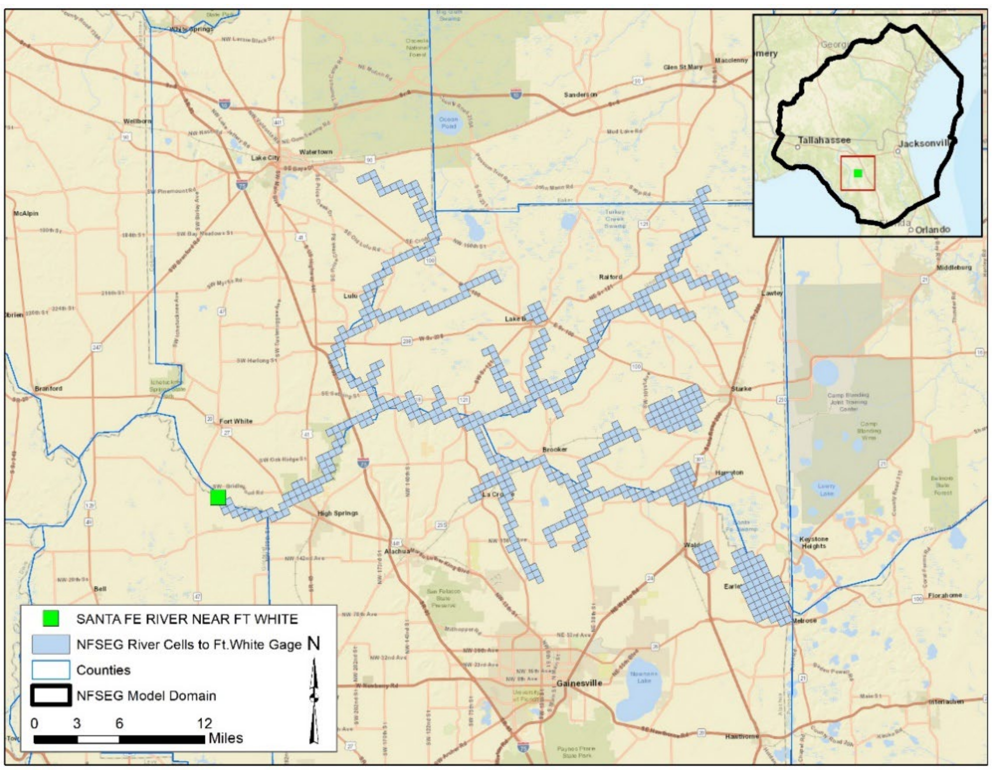

Figure 2. NFSEG River Cells Contributing to Fort White Gage

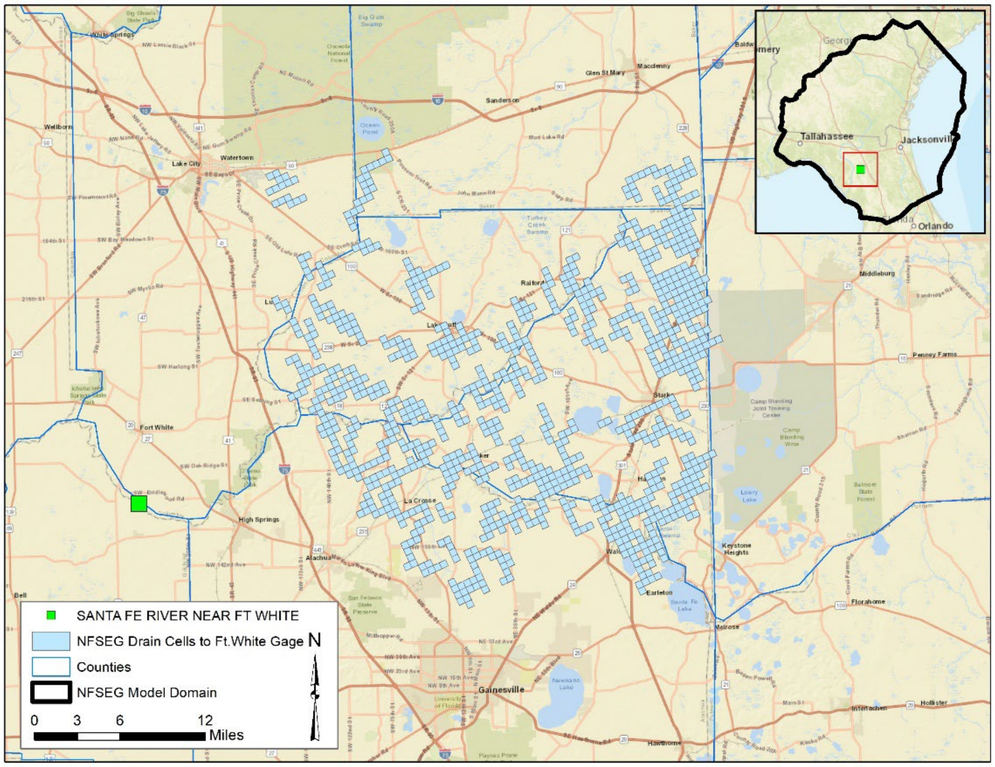

Figure 3. NFSEG Drain Cells Contributing to Fort White Gage

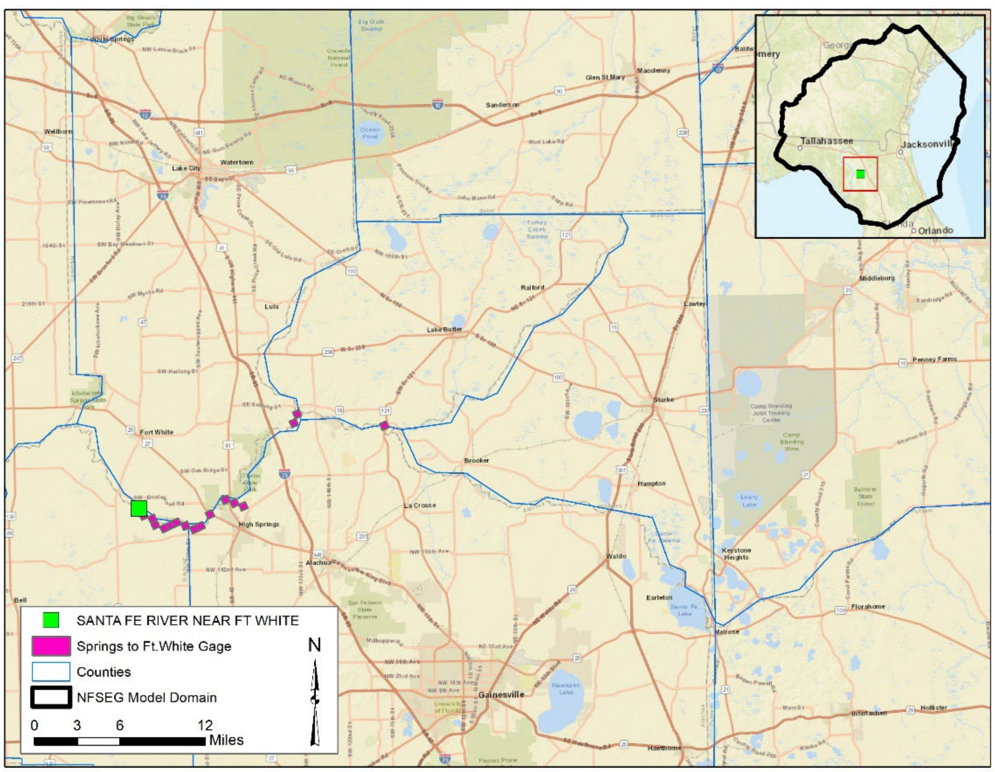

Figure 4. NFSEG Spring Cells Contributing to Fort White Gage

2.1 Estimation of Gross Impacts From Groundwater Withdrawals

For the development of RTF, two different versions of NFSEG model were used: namely NFSEG v1.1 (Case 007h) and NFSEG v1.1(Case 007h1). NFSEG v1.1(Case 007h) refers to the calibrated model submitted for final peer review. NFSEG v1.1(Case 007h1) refers to the version released for public use in which the groundwater recharge specified in the peer review model was updated to reflect the HSPF-derived recharge (NFSEG Addendum, 2019). Refer to **Section 2.2** for additional details for Case 007h1.

NFSEG v1.1 (Case 007h) formed the basis of the quantifying groundwater impacts for the estimation of the sensitivity values. Groundwater withdrawals in NFSEG model are specified using groundwater wells that either extract water from a single hydrogeologic unit (modeling layer), primarily Layer 3 and Layer 5 (regular wells), or in some cases are screened to allow withdrawals from multiple layers (multi-node wells MNW).

For regular wells, the process of developing sensitivity maps involved running the calibrated steady state NFSEG v 1.1 (2009 conditions, Case 007h) model several times. For each model run, the calibrated base NFSEG model was modified by specifying an additional 1 MGD injection flow at a single model cell in Layer 3. The process was repeated for every active cell in Layer 3 of the NFSEG model. The simulated flow (or head) value at a given location of interest for every model run was compared against the base NFSEG model simulated head or flow value and the difference was assigned as the sensitivity value for the corresponding cell with 1 MGD of added injection rate. This process results in determining sensitivity values at all cells within the model domain (for Layer 3) for the given location of interest. A similar process is subsequently repeated for each individual cell in Layer 5 of the NFSEG model. **Figure 5** shows an example from a selected cell (highlighted red) where an additional 1MGD flow was injected in Layer 3 and as indicated in **Figure 5** the simulated flow at the Fort White gage increased from 726.779 cfs to 727.682 cfs. The sensitivity value associated with the highlighted cell with a 1 MGD injection in Layer 3, was thus computed as:

$$S = \frac{727.682 - 726.779}{1} = 0.903\,\frac{cfs}{mgd} = 0.903 \times \frac{86400 \times 7.48052}{1e6} = 0.583 \text{ cfs/cfs} \qquad (1)$$

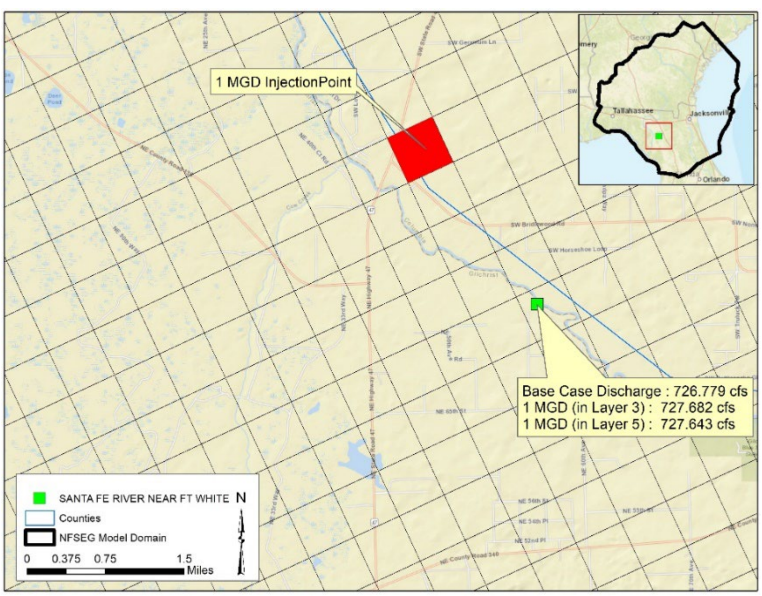

Figure 5. Selected Location of Additional 1 MGD Injection Flow and Corresponding Changes in the Simulated Flow at Fort White Gage

If the same injection of 1 MGD is transferred from Layer 3 to Layer 5 the simulated flow value at the Fort White gage increases to 727.643 cfs (**Figure 5**) resulting in a sensitivity value of 0.558 (using **Equation 1**). **Figure 6** shows results from a second location where a 1 MGD injection flow in Layer 3 and Layer 5 results in flow increases of 726.812 cfs and 727.049 cfs, respectively, resulting in corresponding sensitivity values of 0.022 and 0.170 (**Figure 7**).

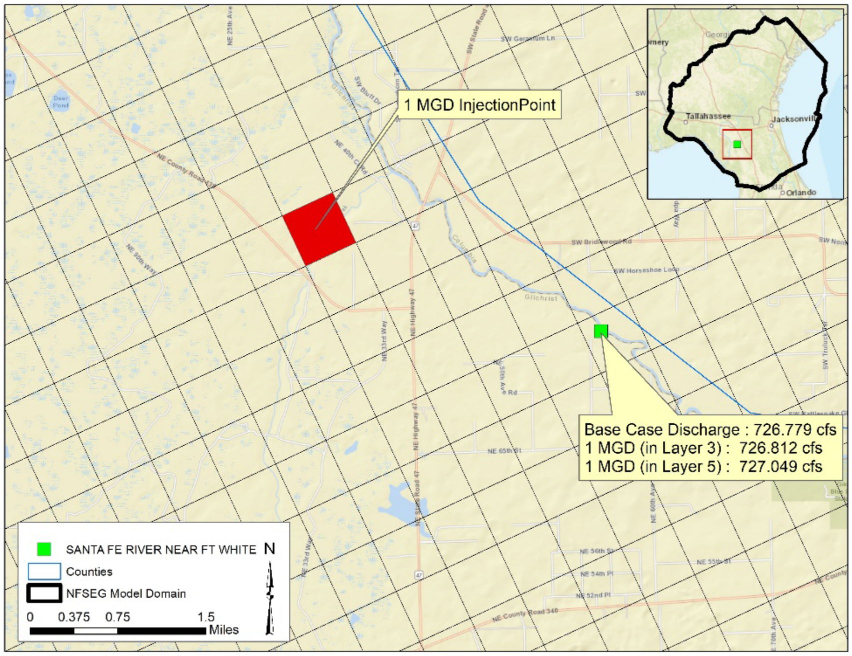

Figure 6. Second Selected Location of Additional 1 MGD Injection Flow and Corresponding Changes in the Simulated Flow at Fort White Gage

This exercise, when conducted for all individual cells in Layer 3 and Layer 5, resulted in spatially distributed sensitivity values that can be mapped to indicate influence (sensitivity) of an individual cell on the Fort White gage (see **Figure 7** and **Figure 8**). Overall, the model wide sensitivity maps for the Fort White gage are shown in **Figure 9** and **Figure 10,** showing the local influence of groundwater impacts (higher sensitivity value areas).

Aggregation of Sensitivity Values based on County and Water-Use Type

The individual sensitivity values, though accurate and refined, do not lend themselves to long-term hindcasting since they rely on exact withdrawal locations to compute the impact on the gage (or well) of interest, which for historical withdrawals may not be available. Thus, it was decided to aggregate the computed sensitivity values based on unique combinations of County and water-use categories. The well package simulated in the NFSEG v1.1 model (representing the 2009 condition) was categorized based on County and Use type (see **Table 1** as an example). The sensitivity values (**Figure 9** and **Figure 10**) from individual cells where withdrawal was specified were multiplied by the corresponding withdrawal rate to compute the expected reduction in flow at Fort White due to withdrawals. The computed reduction for each combination of given County and use-type was summed to compute the aggregated flow reduction at the Fort White gage due to a use-type in a County.

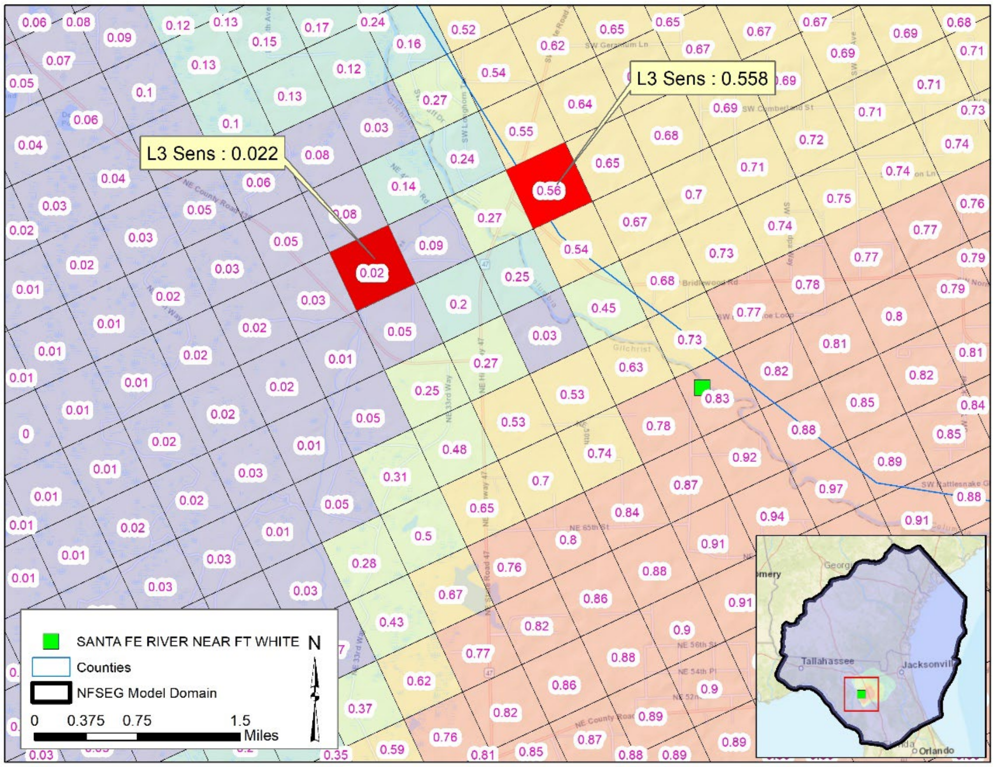

Figure 7. Zoomed-In Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 3 for the Simulated Flow at Fort White Gage

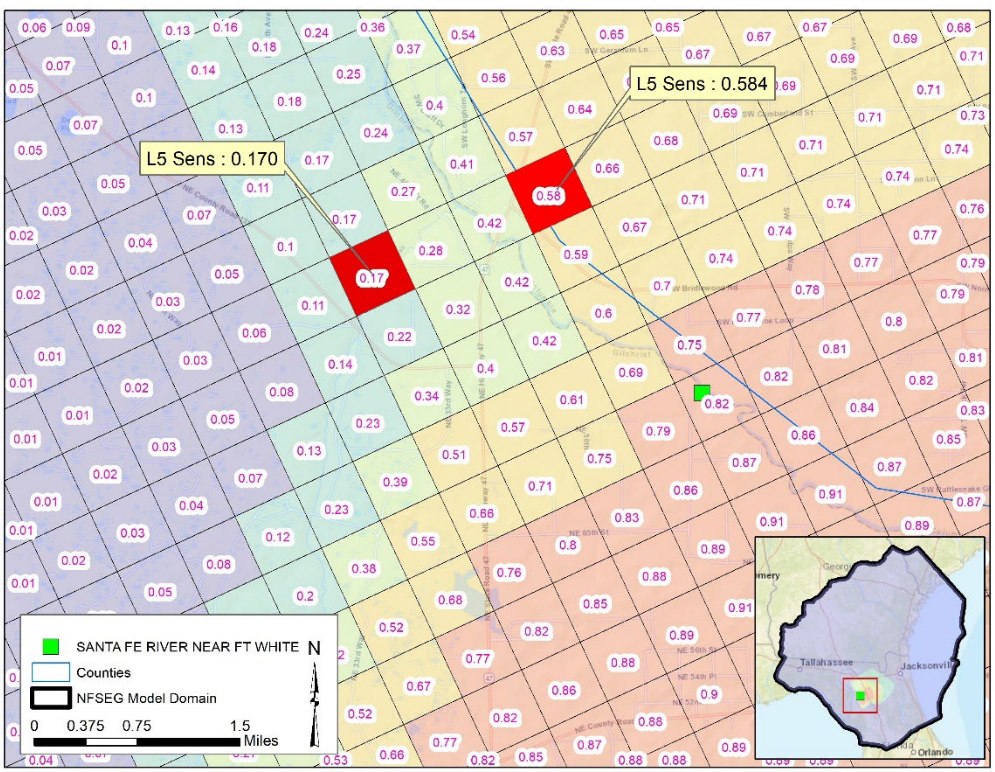

Figure 8. Zoomed-In Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 5 for the Simulated Flow at Fort White Gage

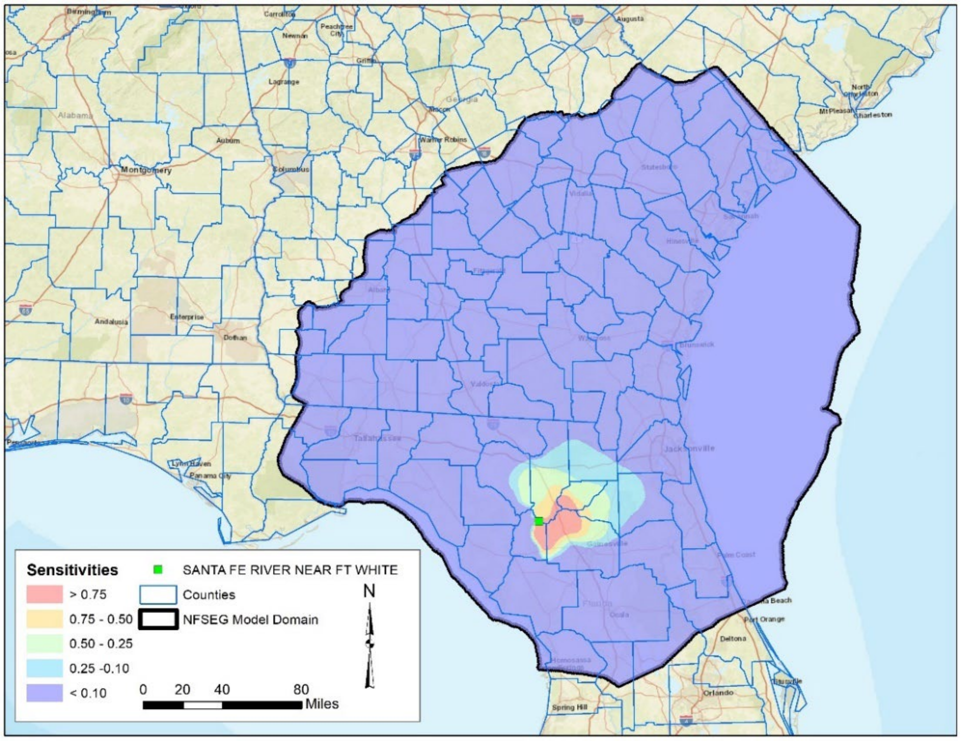

Figure 9. Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 3 for the Simulated Flow at Fort White Gage

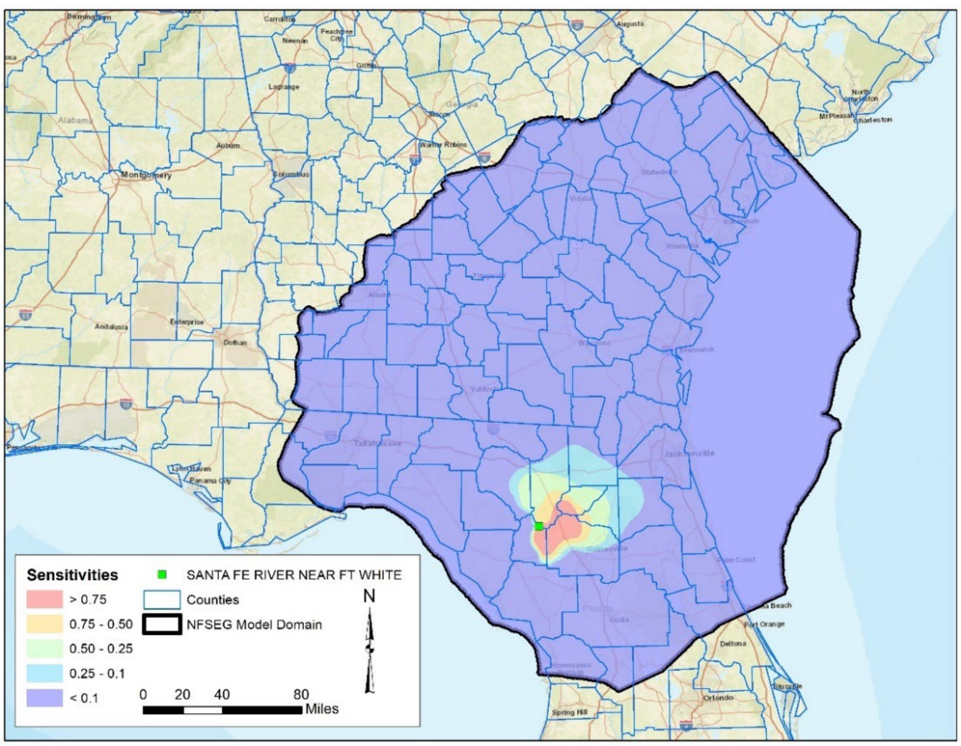

Figure 10. Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 5 for the Simulated Flow at Fort White Gage

Table 1. Example of Withdrawal Dataset from 2009 Well Package, Indicating County and Use Type [*Shown in Figure 11]

Layer	Row	Column	State	County	Use Type	2009 Withdrawal (MGD)
3	488	162	FL	Taylor	CII	4.255
3	488	162	FL	Taylor	CII	4.255
3	488	164	FL	Taylor	CII	4.255
3	488	164	FL	Taylor	CII	4.255
3	489	166	FL	Taylor	CII	4.255
5	472	257	FL	Hamilton	MD	3.349
3	398	93	FL	Leon	CII	3.206
3	398	93	FL	Leon	CII	3.206
3	398	93	FL	Leon	CII	3.206
3	510	433	FL	Nassau	CII	2.809
5	540	229	FL	Suwannee	AG	0.027*
5	570	213	FL	Gilchrist	AG	0.012*
5	585	268	FL	Alachua	LRA	0.03*
5	617	294	FL	Alachua	LRA	0.01*

Figure 11 shows selected groundwater withdrawals from Layer 5 in the vicinity of the lower Santa Fe River system. For Alachua County, for example, the two wells for Landscape/Recreation/Aesthetics uses are withdrawing 0.03 MGD and 0.01 MGD, respectively (based on the 2009 well package from NFSEG v1.1 model). The single well sensitivity map (**Figure 10**) indicated sensitivity values at the corresponding withdrawal locations are 0.752 and 0.058, respectively, thus the overall influence of LRA withdrawals from Layer 5 in Alachua County on flow at Fort White would be:

$$\Delta Q = \frac{[(0.752 \times 0.03) + (0.058 \times 0.01)]}{86400 * 7.48052} \times 1e6 = 0.036\ cfs \quad (2)$$

Similarly, the 2009 AG use type withdrawals in Suwannee and Gilchrist from Layer 5 would result in a reduction of 0.0006 cfs (using **Equation 2**) and 1E-5 cfs, respectively. **Table 2** shows a clip of reduction in flow values at Fort White gage due to withdrawals associated with a combination of County and use type.

The flow reduction estimates (**Table 2**) associated with the same use type in a given county, but in different layers, were simply summed to create an aggregated flow reduction table (see **Table 3**) based on County and use-type.

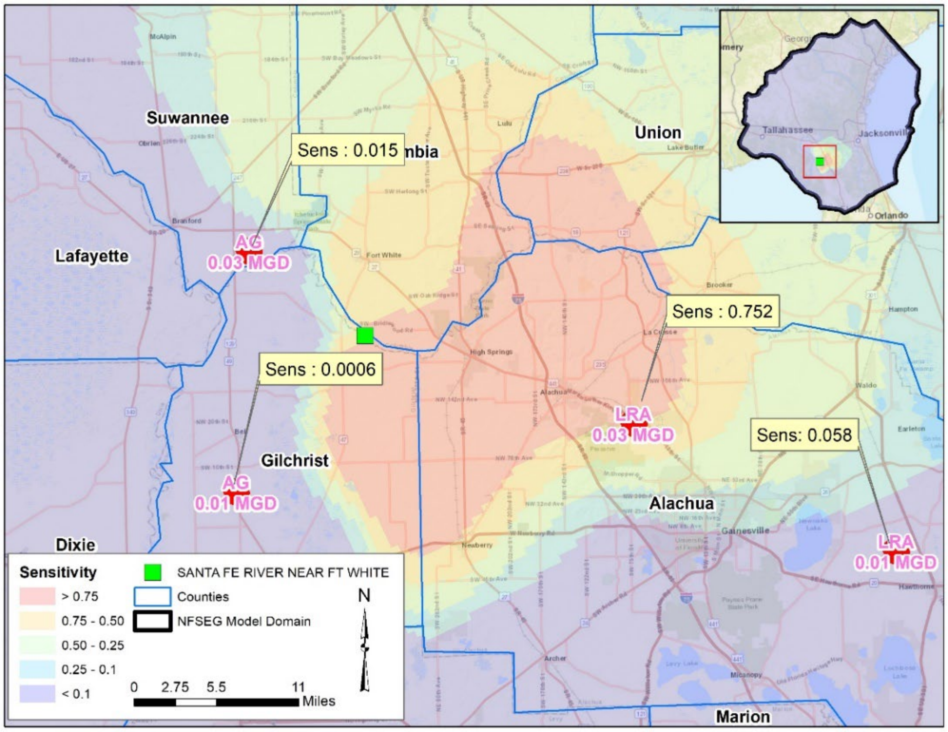

Figure 11. Selected Groundwater Withdrawal Locations (and Use-Type) in Layer 5. The Withdrawal Quantities are based on 2009 NFSEG v1.1 Well Package

Table 2. Selected Flow Reduction Estimates (using 2009 withdrawal data) for Fort White Gage [*Locations are show in Figure 8]

State	County	Use Type	Model Layer	Flow Reduction Estimates(cfs)
FL	Alachua	PS	3	14.9435
FL	Alachua	AG	3	9.0165
FL	Duval	PS	3	3.0295
FL	Nassau	CII	3	2.9802
FL	Alachua	CII	3	2.8905
FL	Alachua	DSS	3	2.8080
FL	Columbia	AG	3	2.6209
FL	Suwannee	AG	3	2.4619
FL	Alachua	LRA	5*	0.0361
FL	Suwannee	AG	5*	0.0006
FL	Gilchrist	AG	5*	1E-5

Table 3. Selected Aggregated Flow Reduction Estimates (using 2009 withdrawal data) for Fort White Gage

State	County	Use Type	Number of Locations	Total Withdrawals (MGD)	Flow Reduction Estimates (cfs)
FL	Baker	CII	9	0.43	0.123
FL	Clay	AG	102	0.36	0.047
FL	Clay	CII	29	0.30	0.032
FL	Clay	LRA	20	0.13	0.013
FL	Clay	CII	29	0.30	0.032
FL	Clay	PS	23	1.74	0.202
FL	Duval	AG	42	0.96	0.097
FL	Duval	CII	71	6.01	0.571
FL	Duval	LRA	59	0.66	0.063
FL	Duval	PS	92	32.15	3.029
FL	Lake	AG	470	5.19	0.010
FL	Lake	CII	43	1.57	0.002
FL	Lake	PS	191	19.64	0.033
FL	Marion	AG	970	10.36	0.226
FL	Nassau	PS	22	4.94	0.471
FL	Putnam	CII	46	2.64	0.145

Table 3 provides a representative table quantifying influence of "regular wells" (a term used for describing wells screened in a single layer) on the flow at Fort White (2009 average conditions). For groundwater wells of interest, the aforementioned process would result in quantification of influence of "regular wells" on the observed head (delta head).

As mentioned earlier, NFSEG v1.1 represents the groundwater withdrawals using regular wells screened in a single layer (simulated using MODFLOW well package) and multi-node wells (MNW, simulated using MODFLOW MNW2 package) that are screened in multiple layers. **Table 4** lists the sixteen MNW wells that were specified in the NFSEG v1.1 model. Calculation of sensitivity values and subsequent determination of impacts due to flow reduction at a gage or observation well of interest was achieved by selectively turning off MNW wells of a given county and use type and noting the resulting increases in simulated flow (or head) at the gage (or observation well) of interest. For instance, in one model run only withdrawals associated with CII wells in Baker county were turned off, leaving all other specified withdrawals as-is. For the second model run, AG withdrawals in Clay County were turned off and the process repeated for the next county until all remaining counties are completed. **Table 4** shows the calibrated simulated base flow at the Fort White gage and the simulated flows associated with turning off the corresponding set of wells. In Clay County, for example, AG MNW withdrawals (2009 conditions) were 0.21 MGD. Switching them off resulted in the flow increase of 0.023 cfs (= 726.802-726.779). Similarly, by switching off the 0.12 MGD withdrawals associated with CII wells in Clay County, the simulated flow at Fort White gage increased by 0.0205 cfs (726.800 – 726.779). **Figure 12** shows the location of Clay County with the example withdrawals and their impacts on the Fort White gage.

Table 4. All MNW Wells Specified in NFSEG v1.1 and Computed Flow Change Reduction at the Fort White Gage when each is turned off in the model.

State	County	Use Type	Total Withdrawals (MGD)	Base Q (cfs)	Scenario Q (cfs)	Del Q (cfs)
FL	Baker	CII	0.29	726.779	726.840	0.061
FL	Clay	AG	0.21	726.779	726.802	0.023
FL	Clay	CII	0.12	726.779	726.800	0.021
FL	Clay	LRA	0.49	726.779	726.834	0.055
FL	Clay	CII	0.44	726.779	726.841	0.062
FL	Clay	PS	12.01	726.779	728.093	1.314
FL	Duval	AG	0.01	726.779	726.779	0.000
FL	Duval	CII	14.05	726.779	728.216	1.437
FL	Duval	LRA	0.76	726.779	726.852	0.073
FL	Duval	PS	84.63	726.779	735.338	8.559
FL	Lake	AG	0.42	726.779	726.782	0.003
FL	Lake	CII	0.13	726.779	726.780	0.001
FL	Lake	PS	3.28	726.779	726.784	0.005
FL	Marion	AG	0.11	726.779	726.780	0.001
FL	Nassau	PS	2.31	726.779	727.000	0.221
FL	Putnam	CII	0.07	726.779	726.784	0.005

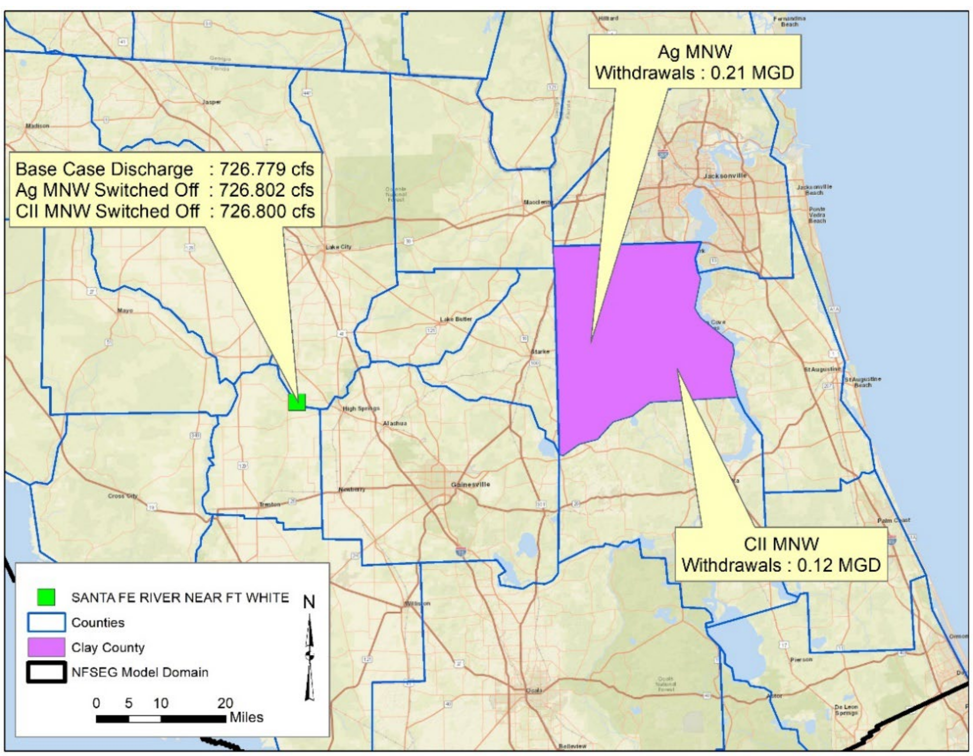

Figure 12. Clay County AG and CII MNW Wells and their impacts on the Fort White gage

For long-term hindcasting it would be impractical to differentiate between an MNW and a regular well, hence composite groundwater withdrawal effective sensitivity estimates based on County and Use-type were developed. Estimated reductions in flow (or head) from regular and MNW wells for a given County and Use-type combination can be added and then divided by the total MNW and regular flow withdrawal values to develop effective sensitivity values for groundwater withdrawal for the combination of County and use-type. For Fort White gage, **Table 5** aggregates results from regular wells (**Table 3**) and MNW wells (**Table 4)** and computes total flow reduction and effective sensitivity to groundwater withdrawals associated with a combination of county and use-type. As an example, for Baker County CII wells, the total withdrawal (2009 condition) from regular wells was 0.43 MGD and the corresponding flow reduction at Fort White gage was 0.12 cfs. For the same county and Use-type combination of MNW wells the total withdrawal was 0.29 MGD and the corresponding reduction at Fort White gage was 0.061 cfs. Combining them results in a total flow reduction of 0.181 cfs for a total withdrawal of 0.72 MGD (= 1.114 cfs). Thus, the effective sensitivity value would be 0.164 cfs/cfs (=0.181/1.114). The other effective sensitivity values can be calculated in a similar way. It should be noted that for counties and use-types that did not have MNW wells the effective sensitivity could simply be computed by assuming MNW withdrawals and associated flow reduction to be zero. **Figure 13** shows the effective sensitivity map for Public Supply Wells. Similar effective sensitivity datasets were developed for all possible combinations of county and use-type.

Table 5. Aggregated Withdrawals and Flow-Reduction Estimates for Regular and MNW wells

County	Use Type	Reg. Wells Withdrawals (MGD)	Delta Q (cfs, Reg. Wells)	MNW Wells Withdrawals (MGD)	Delta Q (cfs, MNW Wells)	Total Withdrawals (MGD)	Effective Sensitivity (cfs/cfs)
Baker	CII	0.43	0.12	0.29	0.061	0.72	0.164
Clay	AG	0.36	0.05	0.21	0.023	0.57	0.080
Clay	CII	0.30	0.03	0.12	0.021	0.43	0.080
Clay	LRA	0.13	0.01	0.49	0.055	0.62	0.071
Clay	CII	0.30	0.03	0.44	0.062	0.74	0.082
Clay	PS	1.74	0.20	12.01	1.314	13.75	0.071
Duval	AG	0.96	0.10	0.01	-0.001	0.96	0.064
Duval	CII	6.01	0.57	14.05	1.437	20.06	0.065
Duval	LRA	0.66	0.06	0.76	0.073	1.42	0.062
Duval	PS	32.15	3.03	84.63	8.559	116.79	0.064
Lake	AG	5.19	0.01	0.42	0.003	5.61	0.002
Lake	CII	1.57	0.00	0.13	0.001	1.70	0.001
Lake	PS	19.64	0.03	3.28	0.005	22.91	0.001
Marion	AG	10.36	0.23	0.11	0.001	10.47	0.014

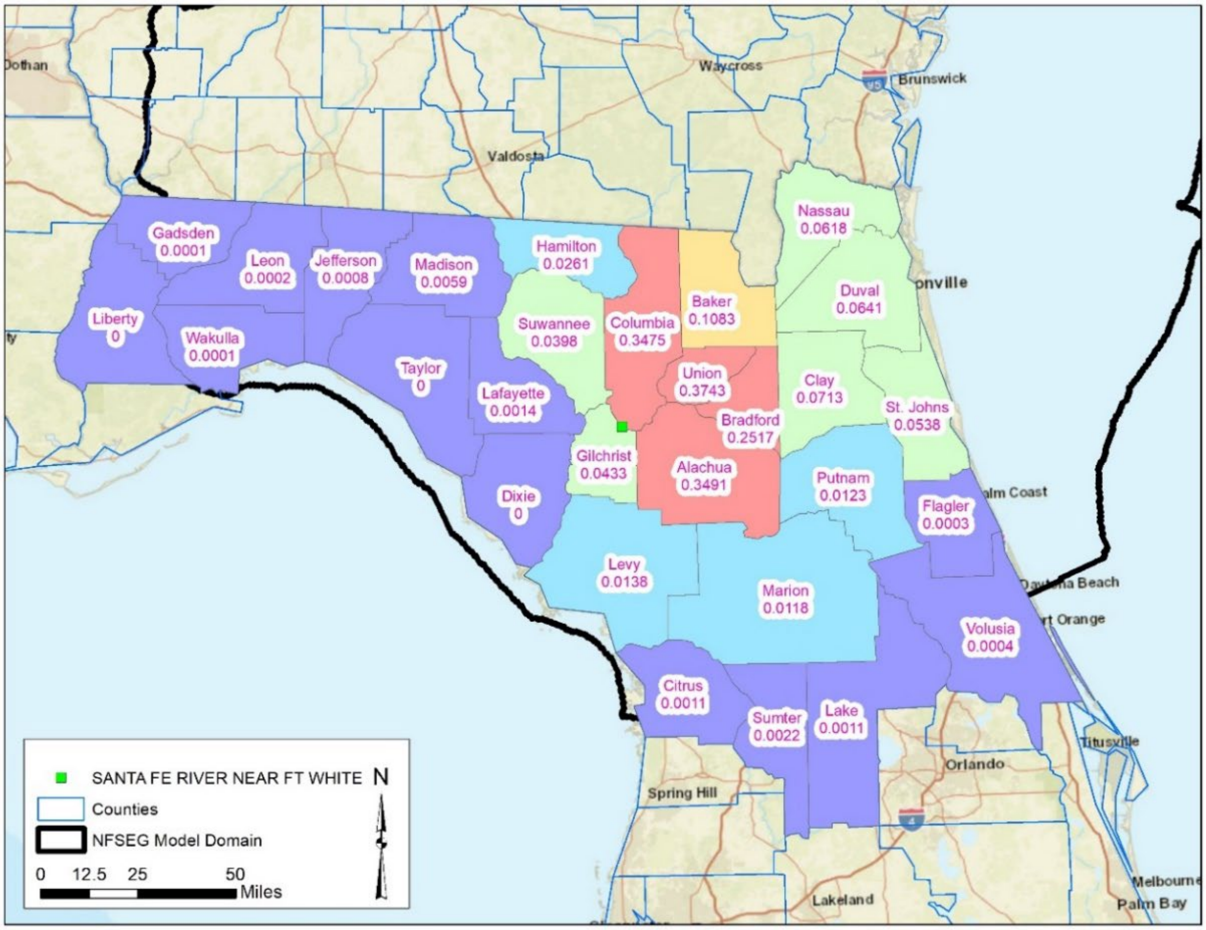

Figure 13. Effective Sensitivities at the Fort White Gage for PS Withdrawals for Different Florida Counties

Historic changes in flow or head were estimated by repeating the following two operations for each year in the historic period. In the first operation, the incremental impact from groundwater withdrawals associated with a given combination of county and use-type was first estimated by multiplying the total groundwater withdrawals in that year for that combination of county and use-type by the effective sensitivity values (ratio of flow or head change per unit change in groundwater withdrawal) associated with that combination of county and use-type. In the second operation, an estimate of the total impact of groundwater withdrawals during that year was computed by adding together the incremental impacts estimated for that year for all of the county and use-type combinations computed in the previous step. The effective sensitivity values were obtained using the methodology described above, while the county-level and use-type specific historic time series development is described in a separate water use hindcasting **Appendix**. An assumption underlying the application of the water use hindcasting process to the generation of RTF is that the well location distribution in 2009 and individual well withdrawals relative to the county total for that use type, are representative for a given use type, through time, in that county. For example, the number of agricultural wells since 1900 are assumed to be in the same locations as the present day (2009). The total water use, by year, estimated for each county and water use-type combination was distributed within each county to the same use-type wells represented in the 2009 well package, but scaled based on the proportional within-county use-type withdrawals

From a physical standpoint, impacts due to changes in the groundwater withdrawals are not instantaneous, but rather take time to manifest (as a flow or head change) at a given gage of interest. To account for this delay in the responses observed at a gage, the historic withdrawal time-series was smoothed using a 5-year antecedent rolling mean. The smoothed withdrawal time-series was subsequently used to convert the effective sensitivity values into changes in flow (or head). **Figure 14** shows the cumulative groundwater withdrawals estimated for the NFSEG model domain

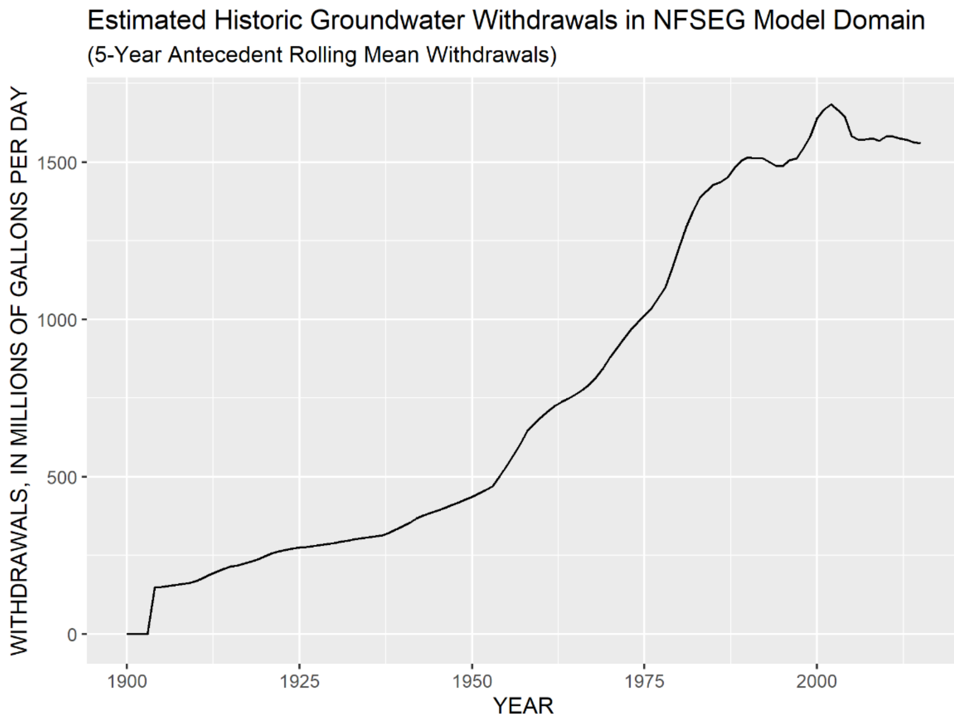

Figure 14. Estimated Historic Groundwater Withdrawals shown as 5-Year Antecedent Rolling Average Values

Table 6 shows records of smoothed groundwater withdrawals for selected County and use-type (to match **Table 5**) for an example year of 2001. Additionally, **Table 6** also lists the computed effective sensitives with respect to Fort White gage (see **Table 5**) for the listed combination of counties and use-type. From **Table 6** it can be noted that by multiplying (and keeping the units consistent) smoothed withdrawal for 2001 with effective sensitivity, net impact on the flow at Fort White can be computed. As an example, for Baker County the CII wells had a total withdrawal of 0.83 MGD which (using an effective sensitivity of 0.164 cfs/cfs) would result in a net 0.21 cfs reduction in the observed flow. Addition of all such "Delta Q" for all combination of County and use-type would result in the total impact of groundwater withdrawals at the Fort White gage for 2001. Repeating this process for all the years would develop a flow reduction time-series which would indicate the impacts of groundwater withdrawals on the Fort White gage. **Figure 15** shows the time estimated flow reduction time-series at Fort White gage.

Table 6. Sample Estimate of Flow Impacts on Fort White Gage due to Groundwater Withdrawals associated with Different Combination of County and Use -Type

State	County	Use Type	2001 Smoothed Withdrawals (MGD)	Effective Sensitivity (cfs/cfs)	Delta Q (cfs)
FL	Baker	CII	0.83	0.164	0.21
FL	Clay	AG	0.94	0.080	0.12
FL	Clay	CII	3.83	0.080	0.47
FL	Clay	LRA	0.06	0.071	0.01
FL	Clay	CII	3.83	0.082	0.48
FL	Clay	PS	13.42	0.071	1.48
FL	Duval	AG	0.99	0.064	0.10
FL	Duval	CII	21.40	0.065	2.14
FL	Duval	LRA	0.71	0.062	0.07
FL	Duval	PS	105.94	0.064	10.51
FL	Lake	AG	8.23	0.002	0.02
FL	Lake	CII	2.93	0.001	0.00
FL	Lake	PS	15.15	0.001	0.03
FL	Marion	AG	7.60	0.014	0.16

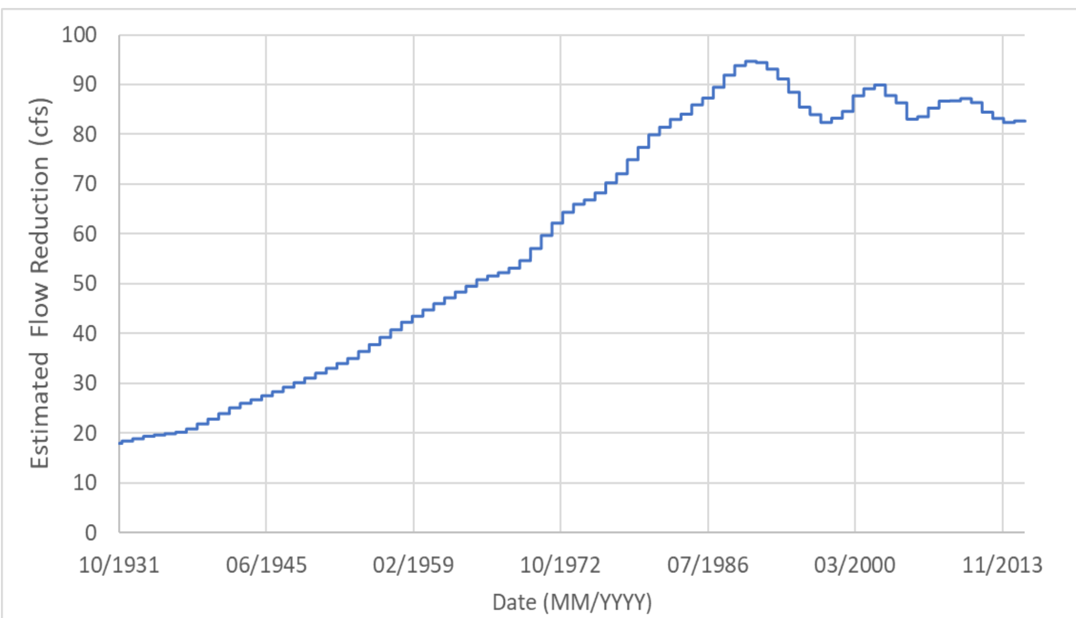

Figure 15. Estimated Flow Reductions over time at Fort White Gage due to groundwater withdrawals

2.2 Estimate of Flow and Head Changes due to Return Flows

To estimate mitigating impacts of the return flows from irrigation or other anthropogenic applications of water at or near the land surface, a series of model runs (one for each county within the NFSEG model domain) using NFSEG v1.1(Case 007h1) was executed. Each of these model runs were set up by creating a new MODFLOW recharge file in which the return flow component of recharge for calendar-year 2009 was removed for the given county. County-level sensitivities to return flows, with respect to a gage (or well) of interest, were then calculated by (1) subtracting the simulated head or flow from the base calibrated model at the location of interest from the corresponding simulated head or flow from the model run in which the return flow was removed for that county, and (2) dividing this head or flow difference by the magnitude of the return flow for that county. **Figure 16** shows the results from the simulations conducted to estimate return flow sensitivities.

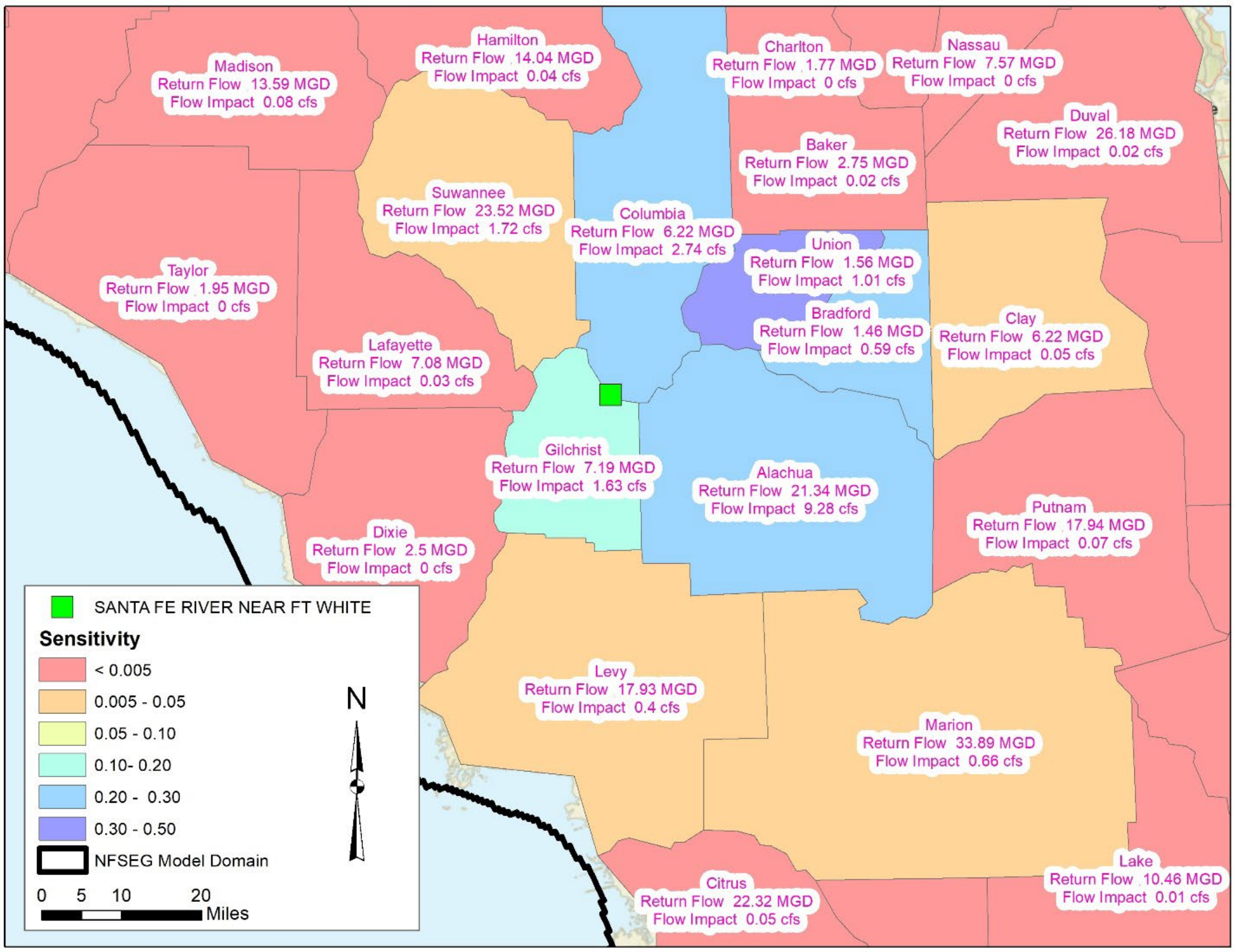

Figure 16. Model Results from Return Flow Sensitivity runs for Fort White Gage

From **Figure 16** for Gilchrist county, as an example, the computed return flow was 7.19 MGD and turning that flow off resulted in a flow decrease of 1.63 cfs at the Fort White Gage. Using **Equation 1** the return flow sensitivity for Gilchrist county would be 0.146. Similarly, for Columbia county the return flow was 6.22 MGD, which when switched off resulted in a flow decrease of 2.74 cfs at the Fort White gage, and a sensitivity value of 0.285. **Figure 17** shows the estimated sensitivity values for Fort White gage with respect to return flow for all counties within the NFSEG model domain.

An important aspect to note is that the groundwater sensitivities were computed using NFSEG v1.1(Case 007h) model, while return flow sensitivities were computed using NFSEG v1.1 (Case 007h1) model. From the application of the NFSEG model for the purpose of computing sensitivity values, and eventually developing a reference timeframe flow (or head) time-series, this is not expected to influence the results of the analysis. The NFSEG base model results comparison for groundwater withdrawal sensitivity calculations use the Case 007h base calibrated model while the return flow sensitivity calculations use the Case 007h1 base calibrated model. Since the methodology relies on the differences in the simulated flows (or heads) which are further unitized (per MGD or per cfs), the absolute values of flows and stages are no longer relevant.

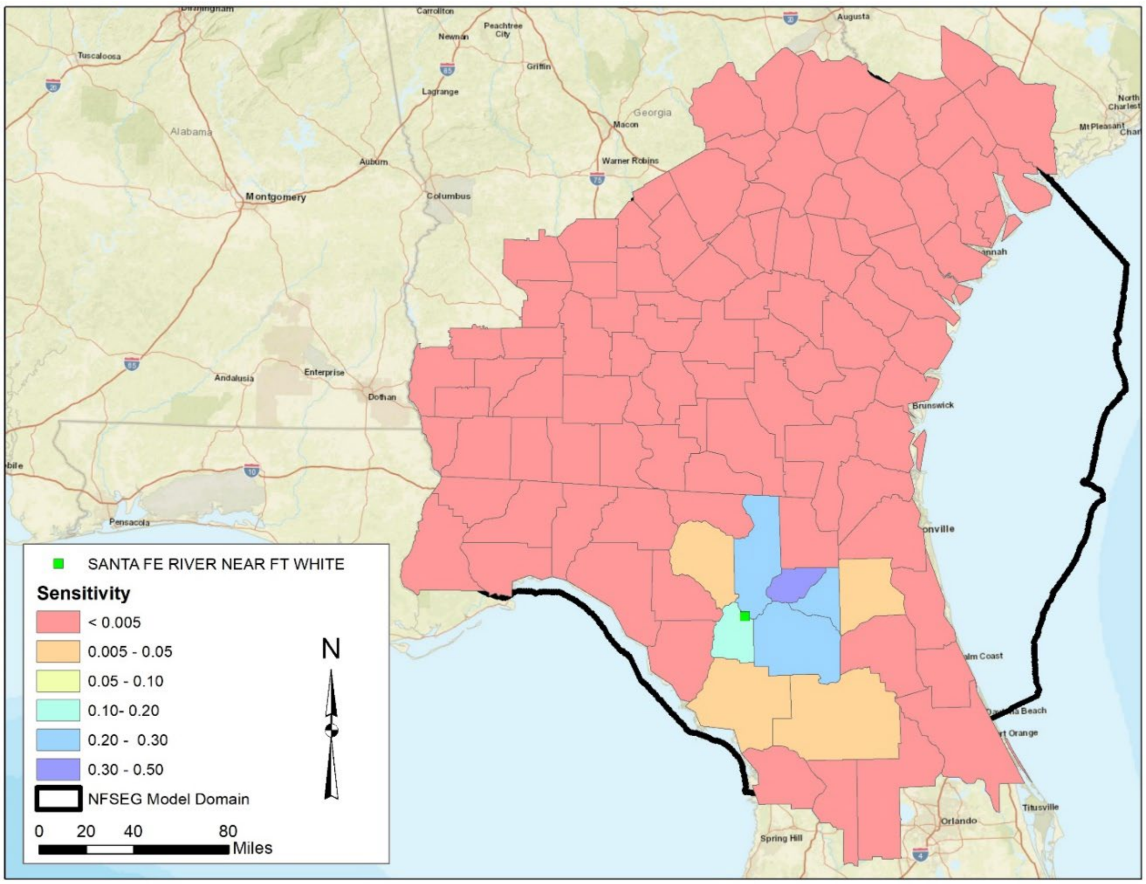

Figure 17. County-Level Return Flow Sensitivity for Fort White Gage

To develop historic return flow time-series that can be subsequently used to estimate the mitigating impact of return-flow on the gage (or well) of interest a two-step process was followed. In the first step, the ratio of calendar-year 2009 total return flow to calendar-year 2009 total withdrawals for agricultural, commercial-industrial-institutional, domestic self-supplied, landscape and recreation, and public supply uses was computed for each county assumed to contribute to return flow impacts. In the second step, the change in return flow in each year of the historic period was estimated for each of these counties by multiplying the ratio computed in the first step by the total withdrawals in that year and in that county for the uses described in the first step.

Table 7 shows an example for the estimate of groundwater withdrawals from CII, DSS, AG, and LRA for selected counties of interest (see **Figure 16**) and corresponding return flow values for 2009. The ratio of return flow values and groundwater withdrawals is computed by simply dividing the two terms. For example, for Taylor County the groundwater withdrawal for 2009 was 43.5 MGD which the return flow was 1.95 resulting in a ratio of 0.045 (=1.95/43.5). Also listed in **Table 7** is the return flow sensitivity values computed previously (**Figure 16**).

Table 7. Groundwater Withdrawals and Return Flow Estimates for Selected Counties for 2009

County	2009 GW Withdrawals (MGD)	2009 Return Flow (MGD)	Ratio	Return Flow Sensitivity
Madison	17.850	13.600	0.762	0.0040
Taylor	43.525	1.947	0.045	0.0000
Lafayette	9.031	7.081	0.784	0.0026
Dixie	2.731	2.503	0.916	0.0001
Levy	23.289	17.946	0.771	0.0143
Gilchrist	9.929	7.198	0.725	0.1466
Citrus	28.518	22.331	0.783	0.0013
Marion	60.103	33.913	0.564	0.0127
Lake	34.879	10.470	0.300	0.0004
Putnam	29.290	17.953	0.613	0.0026
Clay	20.084	6.221	0.310	0.0056
Duval	151.888	26.198	0.172	0.0005
Nassau	47.139	7.573	0.161	0.0001
Columbia	11.539	6.228	0.540	0.2850
Alachua	49.062	21.354	0.435	0.2810
Union	2.349	1.559	0.663	0.4191
Bradford	6.097	1.462	0.240	0.2593
Suwannee	36.615	23.534	0.643	0.0473
Hamilton	40.748	14.053	0.345	0.0018

Table 8 shows application of return flow ratio and sensitivity values utilizing the historical smoothed groundwater withdrawal data (for 2001 as an example). The ratio for individual counties computed in **Table 7** can be used to convert the smoothed groundwater withdrawal values to return flow values for corresponding counties (only selected counties shown in **Table 8**). For example, for Lafayette county the 2001 smoothed groundwater withdrawal is 8.51 MGD and the ratio of return flow to groundwater withdrawal is 0.784 resulting in the 2001 estimate of return flow to be 6.67 MGD (=0.784 x 8.51). Using the previously computed return flow sensitivity of 0.0026 the increase in flow at Fort White gage would be 0.027 cfs due to return flow from Lafayette County for 2001. Similarly, return flow impacts from all counties can be added up to determine the return flow impacts at Fort White gage for 2001. Similar exercises can be conducted for all historical years to develop a return flow impact time-series for the gage (or well) of interest. **Figure 18** shows the time-series of estimate flow increase as Fort White gage due to return flow impacts.

Table 8. Sample Estimate of Flow Impacts (positive) on Fort White Gage due to Return Flows associated with Selected Counties

County	2001 Smoothed GW Withdrawals (MGD)	Ratio	2001 Return Flow (MGD)	Return Flow Sensitivity	Delta Q (cfs)
Madison	16.089	0.762	12.258	0.0040	0.075
Taylor	49.274	0.045	2.204	0.0000	0.000
Lafayette	8.511	0.784	6.674	0.0026	0.027
Dixie	3.788	0.916	3.471	0.0001	0.001
Levy	27.774	0.771	21.402	0.0143	0.474
Gilchrist	10.113	0.725	7.332	0.1466	1.662
Citrus	24.272	0.783	19.006	0.0013	0.039
Marion	59.960	0.564	33.833	0.0127	0.663
Lake	27.883	0.300	8.370	0.0004	0.006
Putnam	45.159	0.613	27.679	0.0026	0.112
Clay	22.014	0.310	6.819	0.0056	0.059
Duval	141.236	0.172	24.361	0.0005	0.020
Nassau	45.230	0.161	7.266	0.0001	0.001
Columbia	11.568	0.540	6.243	0.2850	2.753
Alachua	45.857	0.435	19.959	0.2810	8.678
Union	2.474	0.663	1.641	0.4191	1.064
Bradford	6.796	0.240	1.629	0.2593	0.654
Suwannee	33.143	0.643	21.302	0.0473	1.560
Hamilton	43.094	0.345	14.862	0.0018	0.041

NFSEG v1.1 has multiple sources of groundwater inflow that have a potential to positively impact a given gage or well of interest. These sources include deep injection wells, as well as drainage wells and natural sink features that receive treated wastewater discharges. To estimate the impact of these features on flow (or head), the point groundwater sensitivity values for a "regular well" with respect to a given gage of interest for Layer 3 and Layer 5 are manually queried from the previously developed sensitivity maps (see example **Figure 9** and **Figure 10**). The queried sensitivity value is multiplied by the historic flow injection time-series for each of the features to estimate their positive influence (i.e. increase in flow or stages) on the gage (or well) of interest.

Note that the historic time series of annual injection rates for these features are based on data from reported values of treated wastewater discharges, when available. Estimation of missing historic treated wastewater discharged to Alachua Sink and injection wells at Lake Alice in Gainesville, Florida was required for some periods, and was accomplished by calculating ratios of reported wastewater discharges and reported or estimated concurrent withdrawals at the Murphree Wellfield in Gainesville. These ratios were then multiplied by reported or estimated historic withdrawals from the Murphree Wellfield for periods when reported wastewater discharge data were not available. (See Injection Wells Hindcasting Appendix for more information)

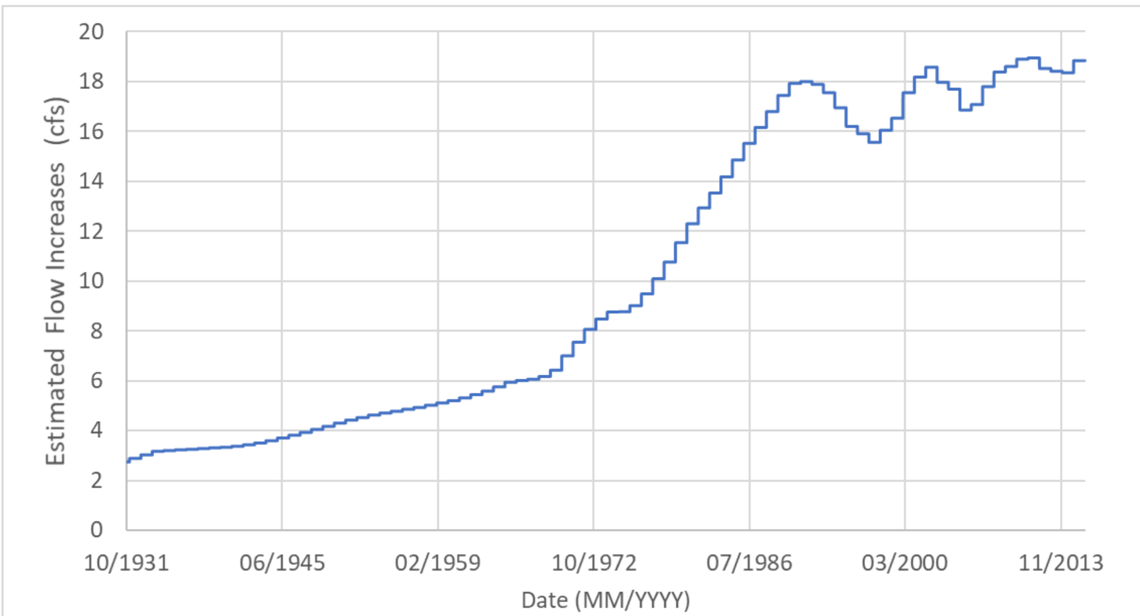

Figure 18. Estimated Flow Increases at Fort White Gage due to Return Flows

Figure 19 shows an example figure for Fort White gage indicating different injection wells and their corresponding "regular" well sensitivity values based on the model layer that the injection wells are screened in. For instance, Kanapaha well is screened in Layer 5 and its point sensitivity value is 0.046. Multiplication of 0.046 with the historic injection time-series for Kanapaha well results in the impact time-series for Fort White gage. When results from all injection wells are added, the resultant time-series represents overall impact of the injection wells on a given gage of interest. **Figure 20** shows historic combined time-series of the influence of all four injection wells on the Fort White gage.

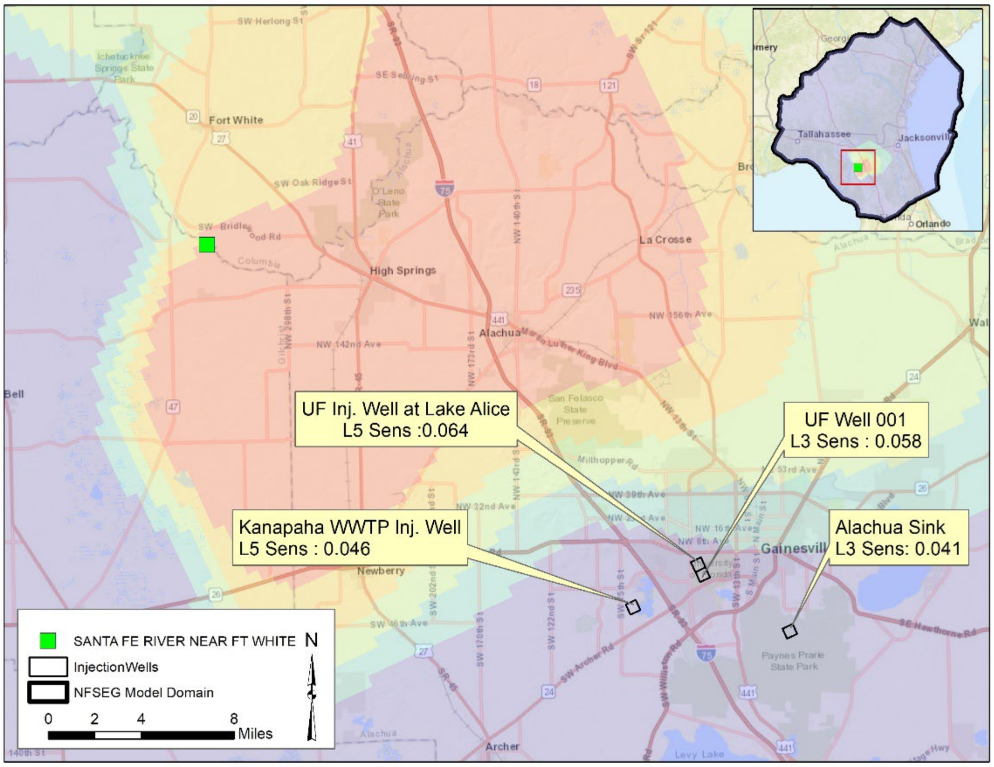

Figure 19. Deep Injections Wells and Corresponding Sensitivity Values

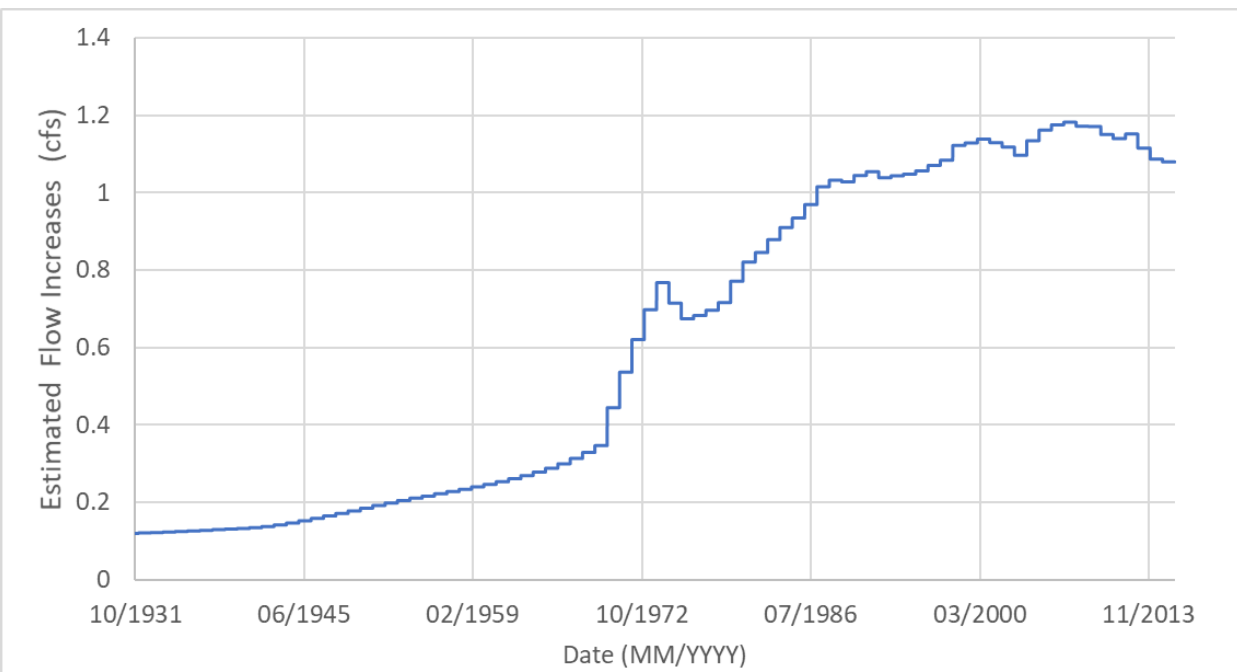

Figure 20. Flow Impact Time Series due to Deep Injection Wells at Fort White Gage

2.3 Estimating Net Flow and Head Changes

Net impacts are defined in this report as the difference between the estimated impacts from groundwater withdrawals (associated with a given time step) on flows or head at a location of interest, after accounting for the offsetting impacts of near surface applications and deep injection returns from groundwater withdrawals. These net impacts were calculated for each time step by subtracting the total offsetting impacts of near surface and deep injection returns at that time step from the previously estimated gross groundwater withdrawal impacts. Recall that the latter is computed as the sum of estimated total gross impacts from regular well and MNW withdrawals. This resulted in a time series of estimated historic net impacts on flows or head at the given location of interest.

For Fort White gage this essentially translates into subtracting the time-series shown in **Figure 18** and **Figure 20** from the groundwater withdrawal time-series show in **Figure 15**. **Figure 21** shows the adjusted flow reduction time-series for Fort White gage. These are the overall flow adjustments that indicate the influence of anthropogenic groundwater withdrawals and injections.

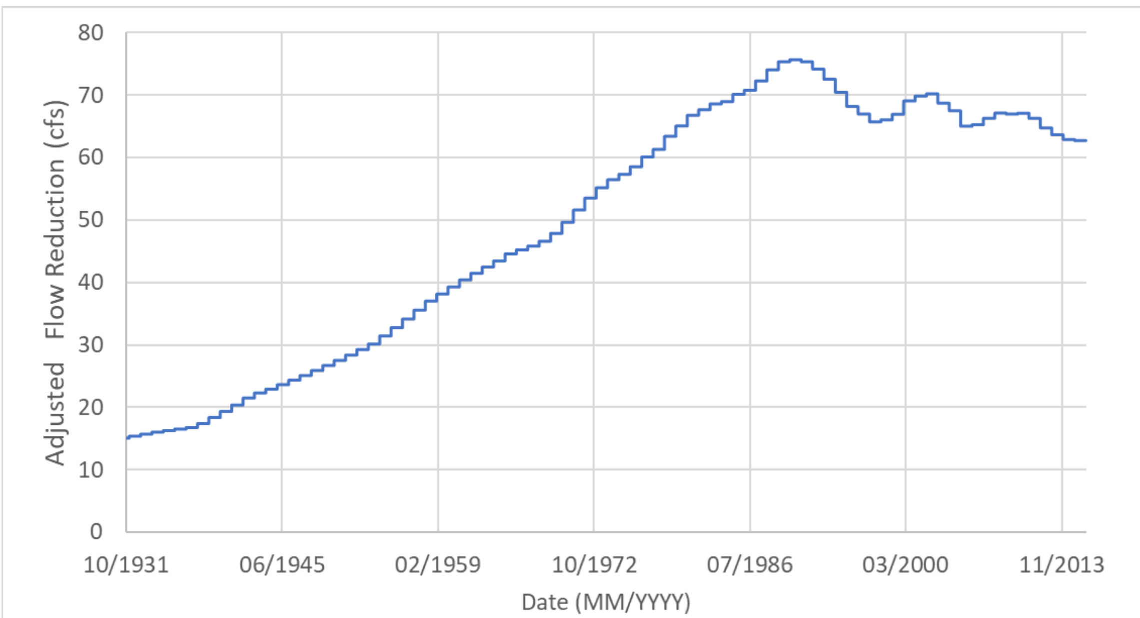

Figure 21. Adjusted Flow Reductions for Fort White Gage

2.4 Development of Reference Timeframe Flow or Head Time-Series

Once the adjusted flow reduction time-series is generated (e.g., **Figure 21**) the reference timeframe flow or Head time-series can be simply developed by adding the adjusted flow reduction values from the observed time series. An important factor to note is that the adjusted flow reduction time-series developed above is not dependent on the period of record for the actual observed data. For instance, if the available flow data at a given gage starts from 1/1/1960, then the adjusted flow reduction factors computed from 1/1/1960 can be used to adjust observed flow (or head) time-series to the reference timeframe flow or head time-series. The values from 1930s through 1950s can be ignored.

3.0 REFERENCES

Durden, D., F. Gordu, D. Hearn, T. Cera, T. Desmarais, L. Meridith, A. Angel, et al. 2019. "North Florida Southeast Georgia Groundwater Model (NFSEG v1.1). ." *St. Johns River Water Management District Technical Publication SJ2019-01*