1. INTRODUCTION

This appendix outlines the process used to develop a reference timeframe flow and/or groundwater-head (head) time-series at groundwater monitoring locations, springs and/or stream gage locations using modeled data and an estimated time series of historic groundwater withdrawals. This reference time series process incorporated data from two versions of the North Florida Southeast Georgia Groundwater Model, NFSEG v1.1(007h) and NFSEG v1.1(007h1). NFSEG 1.1(007h) refers to the calibrated model submitted for final peer review. NFSEG 1.1(007h1) refers to the version released for use, for which updates to the HSPF-derived recharge have been implemented using the same calibrated model (NFSEG Addendum, 2019).

For the purpose of this analysis, a reference timeframe head or flow time-series is defined as an estimate of the historic time-series that would have been observed in absence of any groundwater withdrawals. In other words, the reference timeframe flow (or head) time-series is an estimate of the historic flow (or head) time-series from which any impacts of groundwater withdrawals are removed. Groundwater pumping was estimated on a yearly basis for each county in the NFSEG v1.1 model domain 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 response of the groundwater system to changes in groundwater use was evaluated through application of the NFSEG v1.1 groundwater model in a manner that did not require development of a transient version of the model.

2. GENERAL APPROACH

The overall process of generating reference timeframe flow or head time-series for a site of interest entails first 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. Changes in groundwater levels or flows at an MFL site of interest in response to changes in groundwater withdrawals were estimated on a yearly basis from 1933 through 2015. The resulting estimates were added to an observed hydrograph of groundwater levels or flows at the site of interest to obtain a hypothetical 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.

Estimation of impacts of groundwater withdrawals is a multi-step process. The first step involves estimating the gross change (reduction or increase) in observed values (head and/or flow) at a location of interest (monitoring well, stream gage, or spring) in response to a change in groundwater withdrawals. In the second step, changes in flow or head values arising from any “return-flows” (e.g. irrigation or other anthropogenic land-surface applications) at the location are estimated. In the final step, the net change in head and/or flow at the location is estimated by subtracting the return flow impacts from an observed, historic time series of flows or heads at the location.

2.1 Estimation of Gross Impacts from Groundwater Withdrawals

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 water-use category was first estimated by multiplying the total groundwater withdrawals in that year for that combination of county and water-use category by an estimate of the flow or head sensitivity (ratio of flow or head change per unit change in groundwater withdrawal) associated with that combination of county and water-use category. 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 water-use category combinations computed in the previous step.

The flow and head sensitivities described in the previous paragraph were estimated using NFSEG v1.1(007h), and details of this process are described below. Implementing the process described in the previous paragraph also required that estimates of county-level, historic time series of annual groundwater withdrawals be developed for a standard set of water-use categories (Appendix B).

The process of computing sensitivities necessary to estimate gross impacts[1] from groundwater withdrawals consists of several steps. In the first step, the gross impact from wells withdrawing water from a single model layer during NFSEG v1.1(007h) calibration-year 2009 for a given combination of county and use type are estimated. Note that, for the purposes of this report, wells withdrawing water from a single model layer are referred to as 'regular' wells[2]. Included in this step is the development of 'sensitivity' maps for each model layer and waterbody of interest. In the second step, the gross impact of calendar-year 2009 pumping from wells withdrawing water from multiple model layers (multinode wells, also referred to as MNW) is estimated for combinations of county and water-use categories. For each combination of county and water-use category, the estimated impacts of regular well and MNW withdrawals for that combination of county and water-use category are added together, and this sum is then divided by the sum of the withdrawals from regular well and MNW wells in 2009 for wells associated with that combination of county and water-use category. This last step results in an estimate of the sensitivity of head or flows to regular well and MNW well withdrawals for a given county and water-use category combination.

The set of sensitivity maps (one map for each model layer and waterbody of interest) described in the previous paragraph were developed by first running the calibrated steady state NFSEG v1.1(007h) model of calendar-year 2009 conditions many times - once for each active model grid cell in a given model layer. For each model run, the calibrated, base model was modified by adding a well injecting 1 mgd of additional water to a single model cell in a given model layer. The process was repeated for every active cell in that layer of the model. The simulated head and flow value at a given location of interest for every model run was compared against the base model flow or head values and the flow or head sensitivity associated with a regular well withdrawal or injection in that model grid cell for the gage, spring, or groundwater monitoring location of interest was calculated as the change in simulated head or flow value from the base condition (arising from the additional 1 mgd injection), divided by the 1 mgd added injection rate. This process results in a set of sensitivity values at all active cells within the layer for the given location of interest. Note that this process was implemented for layers 3 and 5 of the NFSEG model. Once a sensitivity map has been created, the impacts of a withdrawal from a given model grid cell can be estimated as the product of that withdrawal and the sensitivity associated with that cell.

[1] Gross impacts are defined here as groundwater withdrawal impacts that do not include any offsetting impacts from 'return flows' from withdrawals that result in additional groundwater recharge.

[2] This same approach was also used to estimate the (offsetting) impacts of direct injections of waste-water to the Floridan aquifer system in Gainesville, Florida. This is discussed in a subsequent section describing the estimation of return flow impacts.

Some of the groundwater withdrawal wells within the model domain are constructed such that they withdraw water from multiple model layers (primarily Layer 3 and Layer 5). As stated above, these types of wells are referred to as multinode wells (MNW). To quantify impacts of MNW on flow and head values, additional runs of NFSEG v1.1(007h) were carried out. During each of the model runs, MNW wells corresponding to a unique combination of state, county, and use-type were removed from the model and the changes in the simulated head and streamflow values from the base, calibrated 2009 condition at the specific location of interest were computed. This process was repeated for all combinations of counties (containing MNW wells) and use-types.

As stated previously, estimates of the gross impact of groundwater withdrawals for a given time step are calculated by (1) estimating the incremental impacts of groundwater withdrawals for a given combination of county and use category at that time step by multiplying the total withdrawal for that combination of county and use category at that time step by the corresponding sensitivity of heads or flows to regular well and MNW withdrawals for that combination of county and use type, and (2) adding all of the incremental impacts calculated in the previous step across all of the combinations of county and use categories. This calculation is repeated for all time steps in the historic period of interest, resulting in a time series of estimated gross impacts from a corresponding time series of regular well and MNW withdrawals.

2.2 Estimate of Flow and Head Changes due to Return Flows

To estimate any 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 using NFSEG v1.1(007h1) was executed. Each of these model runs were set up by creating a new recharge file in which the return flow component of recharge for calendar-year 2009 was removed for a given county. County-level sensitivities to return flows were then calculated for each county of interest, by (1) subtracting the simulated head or flow from the 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. Estimates of the offsetting impact of return flows for a given time step were then estimated by multiplying each of the county-level sensitivities by an estimate of the respective change in return flow for that county associated with that time step. An estimate of the total mitigating impact from return flows applied at or near the land surface was then calculated by adding together the estimated return flow impacts from each of the counties, and repeating this calculation for each time step. This results in a time series of (offsetting) aggregate flow impacts associated with time series of county-level return flows.

Note that the process described in the previous paragraph was implemented using a set of historic time series (one for each county for which county-level sensitivities were computed) of changes in near-surface return flows that were estimated using a two-step process. 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.

The impacts of return flows that are injected into deeper model layers were estimated for each time step as the product of the injection rate and the 'regular well' sensitivity for the cell associated with the injection (see previous description of the calculation of sensitivities of withdrawals for regular wells). An estimate of the total offsetting impact from deep injections of return flows associated with a given time step was then calculated as the sum of these products (injection rate multiplied by corresponding sensitivity) for all injection wells that are active during that time step. Note that the historic time series of annual injection rates for these wells are based on data from reported values of treated waste water discharges, when available. Estimation of historic treated waste water discharged to Alachua Sink and injections wells at Lake Alice in Gainesville, Florida was required for some periods, and was accomplished by calculating ratios of reported waste water 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 (SRWMD, Injection Wells Hindcasting ReadMe, 2018).

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.

2.4 Development of Reference Timeframe Flow or Head Time-Series

Since the sensitivity values are derived from a steady state model, it is not practical to estimate the 'travel-time' and 'dispersion' of the impacts from the withdrawal location to the location of interest. Thus, the historic groundwater withdrawals time-series used to develop the reference timeframe time-series was smoothed using a five-year rolling average window. This dataset was used to estimate the time-varying impacts of each of the impact components described previously (regular well and MNW withdrawals, and near-surface and deep injection return flows. The time series of estimated historic net impacts is added to the observed historic time series to develop the reference timeframe flow or head time-series for the location of interest.