TETRA TECH

MEMO

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Subject:	Transient Region II SEAWAT Model Predictive Simulations (Final)

1.0 INTRODUCTION

The Northwest Florida Water Management District (NWFWMD, or "the District") is updating its groundwater flow and transport models to assess the need to develop and establish minimum aquifer levels to manage saltwater intrusion in the Upper Floridan aquifer along the coastal portion of Water Supply Planning Region II (Santa Rosa, Okaloosa, and Walton Counties). Modeling tasks include the following: (1) perform transient calibration of the Region II MODFLOW ("R2MF") groundwater flow model with updated pumpage and hydrologic data, (2) build and verify a sub-regional, Coastal Region II SEAWAT ("CR2SWT") model from two existing sub-regional DSTRAM models, (3) calibrate the CR2SWT model with updated pumpage, water level, and water quality data, and (4) perform predictive simulations with the CR2SWT model. Tasks 1, 2, and 3 were completed prior to the work documented herein, which addresses the fourth task.

The transient R2MF model (Tetra Tech, 2020a) was developed based on an earlier, steady-state MODFLOW model of the Upper and Lower Floridan aquifers in planning Region II (HydroGeoLogic, 2000). The CR2SWT model domain is contained entirely within the R2MF model boundaries (**Figure 1**), covers an area of approximately 3,680 square miles, and encompasses portions of five Florida counties (Santa Rosa, Okaloosa, Walton, Washington, and Bay; **Figure 2**). The CR2SWT model was calibrated to match observed water level and water quality conditions from 1942 through 2015. The transient calibration of the CR2SWT model is documented in Tetra Tech (2020b).

This technical memorandum describes three (3) applications of the transient CR2SWT model to predict the effects of potential future conditions on variable-density groundwater flow and salt transport from 2016 through 2040. The three applications ("scenarios") simulated the following conditions:

- Scenario 1 – Permitted Average Daily Rate (ADR) groundwater pumping and injection
- Scenario 2 – Projected Water Supply Assessment (WSA) groundwater pumping and injection
- Scenario 3 – Projected Water Supply Assessment (WSA) groundwater pumping and injection (Scenario 2) with projected sea level rise

2.0 PREDICTIVE MODELS

The transient R2MF and CR2SWT calibration models (Tetra Tech, 2020a; 2020b) formed the basis for the predictive simulations. During calibration, the R2MF model was used as an efficient tool to define transient constant head

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boundary conditions for the CR2SWT model. Both calibration models were reconfigured as needed to efficiently execute the predictive simulations.

2.1 EXECUTION

Each predictive simulation was executed by invoking PEST (Doherty, 2019) and a PEST control file in a Command Prompt window (e.g. "*i64pest r2swt_Pred_Scen01.pst*" for Scenario 1). Each scenario simulation was executed once using the final calibrated parameter set by setting PEST's "NOPTMAX" variable to a value of 0. All model input files containing calibration parameters were created directly by PEST or by a modified version of the pre- and post-processing framework developed during calibration of the CR2SWT model (Tetra Tech, 2020b). Utilizing the CR2SWT model processing framework was desirable given its efficiency and because it could also facilitate predictive uncertainty analyses in the future. Model batch files and Name Files unique to each scenario were used to simulate the appropriate pumping/injection rates and sea level boundary conditions of each scenario. All other aspects of the three scenario simulations were identical.

2.2 SPECIFICATIONS

2.2.1 Transport Formulation

The CR2SWT model simulates coupled variable-density groundwater flow and transport using relative seawater concentration (or "relative salinity") as the simulated "species" upon which water density depends. As formulated in the CR2SWT model, seawater has a concentration of 1.0 relative salinity unit (or "RSU"), whereas fresh water without any dissolved solids has a concentration of 0.0 RSU. This formulation was used for its intuitiveness and the ease with which relative salinities can be converted to other species of interest using a single conversion factor (e.g. 1.0 RSU = 35,000 mg/L total dissolved solids, or "TDS").

2.2.2 Simulation Period and Initial Conditions

The R2MF and CR2SWT calibration models were modified to simulate 25 transient annual stress periods immediately following the calibration period. The calibration period ended in 2015 (Tetra Tech, 2020b), thus the predictive simulations end in 2040. The final simulated heads from the R2MF model and the final simulated heads and relative salinity concentrations from the CR2SWT calibration model were used as initial conditions in the predictive simulations.

2.2.3 Groundwater Extraction and Injection Rates

The District developed R2MF model Well Packages for two future pumping and injection scenarios (ADR and WSA) that included all projected groundwater pumping and injection rates for the 2016-2040 period. These Well Packages were used directly in the three predictive R2MF model runs. R2MF model pumping rates from 2015 (i.e. the end of the calibration period) are shown in **Figure 3**. Changes from these 2015 rates to the 2040 ADR and WSA pumping rates are shown in **Figures 4 and 5**, respectively. The 2015 and 2040 pumping rates are summarized by use in **Table 1**.

Hydrostratigraphic units (HSUs) in the R2MF model are each represented as a single layer, whereas the CR2SWT model uses multiple layers to represent each HSU. The HSUs represented within the CR2SWT model domain are the surficial aquifer system (SAS), the intermediate system (IS), the Upper Floridan aquifer (UFA), Bucatunna Clay formation (BUC), Lower Floridan aquifer (LFA), and Sub-Floridan confining unit (SUB). Pumping and injection rates from the R2MF model Well Packages were distributed amongst the layers representing each HSU using the same proportions used to vertically distribute pumping and injection in the CR2SWT calibration model (Tetra Tech, 2020b). For example, if 20% of all UFA (R2MF layer 3) pumping from a given well was allocated to CR2SWT model layer 7 during the calibration period, then 20% of all projected pumping rates for that well were assigned to CR2SWT model layer 7 in the predictive simulations. CR2SWT model pumping rates are summarized by use in **Table 2**.

2.2.4 Sea Level Rise

The effects of projected sea level rise were simulated in Scenario 3. Increases in sea level were represented in the R2MF model as increases in layer 1 constant heads representing the Gulf of Mexico and adjoining bays. The processing procedures executed by PEST following R2MF model execution (Tetra Tech, 2020b; see also below) automatically propagated the effects of these changes to the CR2SWT model, therefore no modifications to the CR2SWT model were necessary.

The rate of sea level rise simulated in Scenario 3 was 8.22 mm/yr, which was the average rate of increase observed from 2000-2020 at two stations (Panama City and Pensacola) in Region II (NOAA, 2020; **Figure 6**). As in the R2MF calibration model (Tetra Tech, 2020a), layer 1 specified heads in the Gulf of Mexico and adjoining bays were assigned based on the equivalent freshwater head[1] (h_f), which was calculated as in SEAWAT (Langevin et al., 2003) using the densities of seawater (ρ_s) and fresh water (ρ_f), point-water heads[2] (h), and the cell-specific bottom elevations of layer 1 (Z):

$$h_f = \frac{\rho_s}{\rho_f} h - \frac{(\rho_s - \rho_f)}{\rho_f} Z$$

For Scenario 3, the point-water constant heads in the Gulf of Mexico and adjoining bays were assumed to begin increasing at the start of the predictive period (2016). Annual average point-water constant heads for 2016-2040 were calculated (**Figure 7**) and used in the equation above to develop the Scenario 3 R2MF Constant Head (CHD) Package.

2.3 AUTOMATED PROCESSING

The automated processing framework developed to execute all necessary pre- and post-processing steps during the calibration process is described in detail in Tetra Tech (2020b). An overview of this framework is provided below, including all modifications that were made for the predictive simulations.

2.3.1 Pre-Processing

Existing pre-processing utilities were utilized to create all model input files reliant upon parameters modified during calibration.

2.3.1.1 Transient R2MF Model Simulation

The processing and execution framework developed specifically for the R2MF model—which was used during calibration of both the R2MF and CR2SWT models (Tetra Tech, 2020a; 2020b)—was also used to execute the R2MF model during the predictive period (**Figure 8**). For each predictive scenario, the R2MF model was executed

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[1] Density is assumed to be temperature-independent and a function of only one dissolved species ("relative salinity"). Therefore, the reference heads used in the solution of the variable-density flow equations are "equivalent freshwater heads" (the height of a hypothetical column of freshwater) and represent the potential for horizontal flow. When two points at the same elevation but different horizontal locations in the groundwater flow system have identical equivalent freshwater heads, no horizontal flow between these two points will occur.

[2] Point-water head are based on the density at the point where head is measured, or "head in terms of the native aquifer water" (Langevin et al., 2003).

prior to running the CR2SWT model and both models were run using the same values for shared calibration parameters. The same pre-processing steps and utilities used to execute the R2MF in the calibration period (Tetra Tech, 2020a) were used to perform identical functions in the predictive model framework.

2.3.1.2 8CR2SWT Model Constant Heads

Following R2MF model execution, the MOD2OBS1 utility (Doherty, 2019) was used to spatially interpolate simulated groundwater heads from R2MF model cell centers to CR2SWT cell center locations. The resulting MOD2OBS1 output files were used to generate the CR2SWT model's CHD Packages (**Figure 8**).

The Python script used to invoke FloPy (Bakker et al. 2016) in the CR2SWT calibration model processing framework (Tetra Tech, 2020b) was modified to generate CHD Packages for the shorter-duration predictive scenario simulations. As in the calibration model (Tetra Tech, 2020b), simulated layer 1 heads from the R2MF model were assigned to the CHD boundaries in layer 1 of the CR2SWT model. Any layer 1 R2MF model cells with simulated heads below the bottom of layer 1 ("dry cells") were assigned CHD boundary heads equal to the cells' bottom elevations plus 0.1 ft. Lateral CHD boundaries in CRSWT layers 5-9 and 13-18 (the UFA and LFA, respectively) were assigned R2MF model-based heads from corresponding cells around the perimeter of the R2MF's UFA and LFA layers (3 and 5, respectively). The CR2SWT model CHD boundaries in layer 21 were assigned the same "zero flow heads" used during calibration.

For consistency, the same SEAWAT (Langevin et al., 2003) "CHDDENSOPT" options used in the pre- and post-development calibration models were also used in the predictive simulations. All layer 1 CHD boundaries were assigned a CHDDENSOPT value of 1, for which the user must assign cell-specific densities that are used to convert the specified (point-water) CHD heads to the reference (in this case, equivalent freshwater) heads used internally by SEAWAT. Densities of layer 1 constant heads were assigned based on location: onshore cells were prescribed densities of 62.442 (lb/ft^3) to represent freshwater, and cells in the Gulf of Mexico and adjoining bays were assigned densities of 64.001 (lb/ft^3) to represent saline water.

CHD boundaries along the lateral and bottom boundaries were not assigned CHDDENSOPT values of 1, and thus did not require specified densities. Lateral boundaries were assigned a CHDDENSOPT value of 3, which instructs SEAWAT to interpret the specified heads as reference (equivalent freshwater) heads. To be consistent with the "zero flow heads" used during the calibration period, the layer 21 CHD boundaries were assigned a CHDDENSOPT value of 2, in which SEAWAT interprets the specified heads as environmental heads[3].

2.3.1.3 Specified Concentration Boundaries

Concentrations for all sources of water were specified in the Source-Sink Mixing (SSM) Package created during model pre-processing. Layer 1 constant head boundaries were specified as constant concentration cells (ITYPE = -1). As with the constant heads, layer 1 constant concentrations were based on location: cells onshore were assigned a groundwater concentration of 0.001 RSU (35 mg/L TDS) and cells representing the Gulf of Mexico and adjoining bays were assigned concentrations of 1.0 RSU (35,000 mg/L TDS)[4]. Sub-Floridan (layer 21) CHD cells

[3] Environmental head is the water level of a hypothetical well filled with water that has a vertical concentration distribution of salinity identical to that of the surrounding column of groundwater. Environmental head represents the potential for vertical flow. Where two vertically separated (but horizontally coincident) points in the groundwater flow system have identical environmental heads, then there should be no vertical flow between these two points.

[4] A pre-calibration sensitivity analysis was conducted to determine the impact of assuming seawater salinity in bays and estuaries (Tetra Tech, 2020b). This analysis showed that the assumed boundary concentrations had negligible effects on model results during the 74-year calibration period.

were also assumed to be constant concentration cells, and the concentrations assigned throughout the entire predictive simulation period were equal to those used throughout the calibration period.

Lateral CHD boundaries were not treated as constant concentration cells but were rather specified as CHD boundaries in the SSM Package (i.e. ITYPE = 1), which allowed the simulated concentrations to vary around the edges of the Upper and Lower Floridan Aquifers. Concentrations for the lateral UFA and LFA CHD boundaries were assigned based on the initial concentrations developed prior to calibration (i.e. using the ELEV2CONC1 utility; Doherty, 2019) and the 100 (50 UFA and 50 LFA) lateral boundary concentration scaling (LBCS) parameters used to modify these concentrations during calibration (Tetra Tech, 2020b).

The concentration of any water entering from the layer 5 River Package boundaries (**Figure 2**) was assumed to be 0.001 RSU (35 mg/L TDS). The concentration of injected water from the only active LFA injection well during the predictive simulation period (NWF_7911) was specified to be equal to the 2015 concentration specified in this injection well in the calibration model (249 mg/L TDS, or 0.0007 RSU).

2.3.1.4 Hydraulic Properties

Pilot points used to represent the model's various hydraulic properties were selected during calibration of the R2MF model (Tetra Tech, 2020a). Kv pilot points in layers 10-12 were spaced irregularly to allow for greater refinement of the transition from the Bucatunna clay-confined portion of the LFA to the undifferentiated Floridan Aquifer System (FAS). Pilot point locations were spaced regularly for all other properties represented using pilot points. The PLPROC utility (Doherty, 2016) was used to interpolate smooth parameter fields for all pilot point-based properties:

1. Kv of the IS and SUB;
2. Kh of the UFA and LFA; and
3. Kv, Kh/Kv, and specific storage of the BUC/undifferentiated FAS layers.

The PAR2PAR utility (Doherty, 2019) was used to perform the following functions:

1. Scale riverbed conductance values using the riverbed conductance multiplier and write River Packages;
2. Convert undifferentiated FAS Kh pilot point values to Kv pilot point values (using the undifferentiated FAS Kh/Kv); and
3. Populate the layer 10-12 storage pilot point file with Bucatunna clay or UFA storage values[5].

The TWOARRAY utility (Doherty, 2019) was used to calculate the necessary Kh arrays for three HSUs (IS, SUB, and BUC/undifferentiated FAS layers) from the vertical hydraulic conductivity arrays written by PLPROC and each HSU's respective horizontal-to-vertical hydraulic conductivity anisotropy (Kh/Kv).

2.3.2 Post-Processing

The post-processing procedures used during calibration (Tetra Tech, 2020b) were not needed for—and were therefore eliminated from—the predictive scenario simulations. Instead, the ZONEBUDGET utility (Harbaugh, 1990) was used to tabulate vertical seepage rates at 27 CR2SWT row/column combinations specified by the District (**Figure 9**). Vertical seepage rates for multiple HSUs were desired at some of the 27 locations shown in **Figure 9** for a total of 40 seepage rate locations. The zones used by ZONEBUDGET generally corresponded to individual HSUs and were assigned as follows:

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[5] Properties at pilot points where the Bucatunna clay is absent in the eastern portion of layers 10-12 were assigned the same values as the LFA (layers 13-18).

Zone 1: Layer 1 (Surficial aquifer system, the Gulf of Mexico and bays);

Zone 2: Layers 2-4 (Intermediate System, IS)[6];

Zone 3: Layers 5-9 (UFA)[7];

Zone 4: Layers 10-12 where the Bucatunna clay is present;

Zone 5: Layers 13-18 (LFA) and the portions of layers 10-12 where the Bucatunna clay is absent[8];

Zone 6: Layers 19-21 (Sub-Floridan aquifer system); and

Zones 7 to 46: Forty (40) District-specified row/column/HSU combinations.

The vertical seepage fluxes for each scenario determined by ZONEBUDGET were treated as PEST "observations"; PEST was instructed to compare these fluxes to dummy (zero) values specified in the PEST control files. These observations were assigned to the only PEST observation group ("seepage"). Each observation was assigned a unique name using the following format:

r **R** *c* **C_YrFT**

where:

R = row index

C = column index

Yr = two-digit calendar year (e.g. Yr = "40" for 2040)

F = HSU index FROM which seepage occurs[9]

T = HSU index TO which flow occurs

For example, observation "*r69c167_1723*" is the seepage rate (in ft^3/d) at row 69 column 167 during 2017 from the IS (HSU 2) to the UFA (HSU 3). Conversely, observation "*r69c167_1732*" is the seepage rate from the UFA to the IS during 2017 in the same row and column[10].

3.0 RESULTS & DISCUSSION

3.1 INITIAL CONDITIONS

Simulated results from the end of the CR2SWT calibration model simulation period (2015) were reprocessed to illustrate differences between the predictive simulations' initial and final conditions. The point-water heads and relative salinities simulated in the UFA and LFA at the end of 2015 were used to calculate equivalent freshwater heads in the UFA (**Figure 10**) and LFA (**Figure 11**) for year 2015. The point-water to equivalent freshwater head (EFH) conversion was performed using the formula shown in Section 2.2.

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[6] Excluding IS row/column combinations specified by the District.
[7] Excluding UFA row/column combinations specified by the District.
[8] Excluding LFA row/column combinations specified by the District.
[9] HSU indices correspond to zone indices for Zones 1-6; see Section 2.3.2.
[10] Two separate observations for each HSU pairing are needed because of ZONEBUDGET's convention of reporting flow rates: when outflow is simulated inflows are reported as zero, and vice versa.

Groundwater velocity vectors were also generated for 2015 for the UFA (layer 7; **Figure 12**) and LFA (layer 15; **Figure 13**) using Groundwater Vistas (Version 8; Rumbaugh and Rumbaugh, 2020) and the calibrated, HSU-specific porosities. The ZONEBUDGET-based vertical seepage velocities at the District's pre-specified locations are summarized in **Table 3** for 2015 and for 2040 in all three predictive scenarios.

3.2 SCENARIO 1

3.2.1 Heads

The effects of Upper Floridan aquifer pumping at current, permitted average daily rates and Lower Floridan deep well injections were simulated in Scenario 1. In this scenario, groundwater extraction/injection inside the CR2SWT model domain increases by approximately 70% from 2016 to 2020 and the elevated 2020 pumping rates are maintained for the remainder of the predictive period. This fairly abrupt and sustained increase in pumping is intended to simulate the maximum effect of pumping at currently permitted rates on water levels and rates of saltwater intrusion.

Simulated 2040 UFA equivalent freshwater heads (**Figure 14**) were subtracted from the 2015 UFA equivalent freshwater heads (**Figure 10**) to determine the drawdown in equivalent freshwater head between 2015 and 2040 (**Figure 15**). The two centers of greatest UFA drawdown—near Fort Walton Beach and Niceville (**Figure 2**)—have much lower simulated heads in 2040 (less than -200 ft and -120 ft NAVD88, respectively; **Figure 14**) than in 2015. The additional drawdown during the predictive period at the pumping center near Fort Walton Beach is predicted to be greater than 100 ft. Greater pumping outside the CR2SWT model domain during the predictive period than in 2015 also impacted 2040 UFA heads and drawdowns; the specified heads along the northern boundary (based on R2MF simulated heads) were substantially lower in 2040 than 2015, particularly in Okaloosa County. In fact, pumping north of the CR2SWT domain in Okaloosa County (**Figure 4**) induced northward flow out of the model domain, which is apparent from the equivalent freshwater head contours (**Figure 14**) and flow velocity vectors (**Figure 16**). A potentiometric high in UFA heads (relative to surrounding simulated heads) is predicted to develop in Okaloosa County (**Figure 14**) to the west and northwest of Niceville (see **Figure 2** for location). This relative potentiometric high was not present in 2015 (**Figure 10**); in 2040, it results in divergent northward flow across the northern boundary and southward flow toward the Fort Walton Beach pumping center (**Figure 14**). Groundwater flow velocities in 2040 are predicted to be highest near the center of the cone of depression and in the northeast, undifferentiated portion of the model domain (**Figure 16**) where horizontal hydraulic conductivities are highest (Tetra Tech, 2020b).

LFA equivalent freshwater heads in 2040 (**Figure 17**) are also considerably lower than in 2015 (**Figure 8**). Onshore equivalent freshwater head drawdowns range from -5 ft in southern Bay County to more than 120 ft in Okaloosa County (**Figure 18**). Predicted drawdowns are highest along the north-central portion of the domain due to the high simulated pumping rates north of the model boundary (**Figure 4**). Onshore LFA flow generally converges from the south, east, and west toward Okaloosa County where—as in the UFA—northward flow across the model's northern boundary not simulated in 2015 (**Figure 13**) is simulated in 2040 (**Figure 19**).

3.2.2 Concentrations

Simulated salinity differences from 2015 to 2040 were relatively minor. TDS equivalent concentrations in the UFA (**Figure 20**) reveal that between 2015 and 2040 (1) the area in Okaloosa County with simulated TDS greater than 500 mg/L in 2015 expanded slightly, and (2) concentrations increased from less than to greater than 500 mg/L TDS equivalent in several small areas in Okaloosa County. Relatively low concentration areas (e.g. below 100 mg/L TDS equivalent) in the vicinity of the Choctawhatchee River (i.e. layer 5 River Boundaries in **Figure 2**, where the leakance of the IS is high) were larger in 2040 than 2015, suggesting increased flow of fresher groundwater from above due to increased pumping. The increased downward flow from the IS to the UFA from 2015 to 2040 at point "A" nearby (**Table 3**) supports this conclusion. A comparison of 2015 and 2040 TDS equivalent concentrations in the LFA (**Figure 21**) reveals relatively small migrations of the 500 and 1000 mg/L TDS contours in the vicinity of the potentiometric low near Niceville (**Figure 21**).

Vertical cross-sections through the UFA cone of depression (**Figures 22 and 23**) show little vertical movement of the various TDS equivalent contours from 2015 to 2040, except for in the area immediately north of Fort Walton Beach (**Figure 23**). In this area, simulated concentrations in the deepest UFA layers (layers 8-9) increased due to increased pumping and thinning of the Bucatunna Clay confining unit, such that the 500 and 1000 mg/L TDS equivalent contours were shifted upward. The (interpolated) 500 mg/L TDS contour exhibited the greatest apparent upward migration, which exceeded more than 25 (vertical) ft along a north-south distance of approximately two miles. This simulated effect indicates the potential for greater upward migration of higher TDS water from the LFA in this area under conditions of greater UFA extraction and aquifer drawdown.

3.2.3 Seepage and Flow Directions at Select Locations

The predicted net seepage to the Choctawhatchee River from groundwater in 2040 is approximately 112 ft^3/s, which is a reduction in flow of more than 16 ft^3/s from the simulated net discharge in 2015 (128.5 ft^3/s). Horizontal seepage velocity vectors at select locations in the UFA (**Figure 24**) and LFA (**Figure 25**) and Scenario 1 vertical seepage rates at the same locations (**Table 3**) reveal several noteworthy patterns. Based on **Figure 24**, pumping-induced flow offshore in the UFA (points "W" through "AA"; see **Figure 9**) has a downward component in layer 7 in 2040 (**Figure 24**). Although there is inflow from the HSUs both above and below the UFA at these locations, the vertical migration of offshore water is primarily from the IS (i.e. the HSU above; **Table 3**). The offshore horizontal velocities in 2040 in the UFA are generally of lower magnitude than the onshore velocities (locations A, B, C, G, H, K, N, Q, R, and V) which generally have an upward component (**Figure 24**). Velocity vectors in layer 15—which are predominantly onshore—have an upward component in 2040 with only one exception (**Figure 25**). Overall, the localized horizontal velocities in areas of interest are much greater in magnitude—in both the UFA and LFA—than the coinciding vertical velocities (**Table 3**); horizontal velocities are generally on the order of tens to hundreds of inches per year, whereas only 20% (16 of 80) of the Scenario 1 vertical velocities have magnitudes greater than one inch per year.

The increase in Scenario 1 pumping rates from 2015 to 2040 influenced the magnitudes of vertical seepage rates at all selected locations but only resulted in the reversal of vertical flow at two locations ("I" and "M"), both of which are in the LFA (**Table 3**). At these locations, which are at the western end of Choctawhatchee Bay (**Figure 2**), flow was from the LFA to the BUC/undifferentiated FAS in 2015, whereas in 2040 the flow direction was reversed. This reversal from upward to downward flow is attributable to the substantial increase in pumping near Fort Walton Beach (**Figure 4**) that produces greater drawdown in the UFA (**Figure 15**) than in the LFA (**Figure 18**) and, consequently, reverses the vertical hydraulic gradient. The reversal of the vertical gradient near Fort Walton Beach—where concentrations in the LFA exceed 1000 mg/L TDS (**Figure 21**)—explains the appearance of the localized area in layer 7 where simulated concentrations increase from below to above 500 mg/L TDS between 2015 and 2040 (**Figure 20**). The vertical gradient reversal and increased concentrations in this area suggest that pumping at ADR rates (as simulated in Scenario 1) would lead to a degradation in water quality at the UFA wells in this area that might eventually lead to exceedance of the 500 mg/L TDS secondary drinking water standard.

3.3 SCENARIO 2

3.3.1 Heads

The effects of WSA-projected rates of pumping and injection were simulated in Scenario 2. The pumping rates simulated in Scenario 2 (and 3) increased linearly during the predictive period for a total increase of approximately 31% by 2040. This projected increase over a 20-year planning period is due mainly to increase in pumping for public supply. Pumping, therefore, increased more gradually and was generally lower throughout the simulation period than the Scenario 1 pumping rates.

As in Scenario 1, the simulated UFA equivalent freshwater heads in 2040 (**Figure 26**) and 2015 (**Figure 10**) reveal greater drawdown in 2040 due to pumping than in 2015 (**Figure 27**). However, unlike Scenario 1, the two aforementioned centers of UFA drawdown have similar simulated heads in 2040 and 2015: drawdown from 2015 to 2040 is approximately 5 ft near Fort Walton Beach and 10 ft near Niceville (**Figure 27**). The R2MF-simulated heads along the CR2SWT model's northern boundary were substantially higher in 2040 in Scenario 2 relative to Scenario 1 (**Figures 14 and 26**) and the relative UFA potentiometric high in southern Okaloosa County simulated in Scenario 1 is absent from the Scenario 2 results. The Scenario 2 UFA cone of depression in 2040 is similar in shape to that in 2015 (**Figure 10**) than in Scenario 1 (**Figure 14**), with the notable exception of an area of simulated equivalent freshwater head below 0 ft in south-central Walton County (**Figure 26**) that was not present in 2015. The Scenario 2 UFA flow directions and velocities in 2040 (**Figure 28**) are also similar to those from 2015 (**Figure 12**). As in 2015 and Scenario 1, horizontal UFA groundwater flow velocities are (1) greatest near the centers of the UFA cone of depression and in the northeast portion of the model domain, and (2) substantially higher than vertical velocities (**Table 3**).

The simulated 2040 LFA head distribution (**Figure 29**) also has a similar shape as the 2015 heads (**Figure 11**). The additional pumping-induced drawdowns simulated in layer 15 between 2015 and 2040 (**Figure 30**) are similar to the layer 7 drawdowns (**Figure 27**) where the FAS is undifferentiated. As was the case with the UFA heads (**Figure 26**), the 2040 LFA heads exhibit an area of simulated heads below 0 ft in south-central Walton County that was not present in 2015 (**Figure 11**). Drawdown in this area in 2040 is greater than 10 ft (**Figure 30**). LFA groundwater flow in 2040 is generally toward southern Okaloosa County from all four cardinal directions, with no northward flow out of the model domain (**Figure 31**).

3.3.2 Concentrations

Like the Scenario 1 results, simulated salinity differences from 2015 to 2040 in Scenario 2 were minor. Results from 2040 in the UFA (**Figure 32**) show that TDS equivalent concentrations are generally greater than 2015 concentrations in Okaloosa County. Concentrations increased from below to above 500 mg/L TDS equivalent in the same (albeit smaller) areas between Fort Walton Beach and Niceville where this change was noted in Scenario 1. The rate of expansion of low concentration areas in the northeastern portion of the model domain was also less than in Scenario 1. The 500 and 1000 mg/L TDS contours near the LFA potentiometric low near Niceville migrated relatively short distances (**Figure 33**) and resulted in small, localized concentration increases.

As was the case with the higher pumping rate (Scenario 1) results, cross-sections through the UFA cone of depression show little movement of individual TDS equivalent contours from 2015 to 2040 (**Figures 34 and 35**). The notable exception to this in Scenario 2—as in Scenario 1—is in the area north of Fort Walton Beach, where simulated concentrations in the lower portion of the UFA increased and the resulting 500 and 1000 mg/L TDS contours moved upward between 2015 and 2040 (**Figure 35**).

3.3.3 Seepage and Flow Directions at Select Locations

Net seepage to the Choctawhatchee River from groundwater in 2040 is predicted to decrease from 128.5 ft^3/s in 2015 to 118.6 ft^3/s in 2040—a reduction in flow of nearly 10 ft^3/s—due to increased pumping. Scenario 2 vertical seepage rates at the District-selected locations (**Table 3**) and horizontal groundwater flow vectors at the subset of these locations in the UFA (**Figure 36**) and LFA (**Figure 37**) reveal similar patterns to those from Scenario 1. Offshore flow in 2040 in the UFA is toward the coast and has a downward component in layer 7 (**Figure 36**) and there is greater inflow to the UFA at these locations from the IS than from the BUC/undifferentiated FAS. One notable difference between the Scenario 2 results and those from Scenario 1 is that the rates of (1) downward seepage from the IS and (2) upward seepage from the BUC/undifferentiated FAS are lower in 2040 than in 2015 for offshore points "W" through "AA." That is, the magnitudes of both sets of seepage velocities for these points are all smaller in 2040 than 2015, thus indicating less pumping-induced vertical flow offshore. Horizontal velocities at these points in 2040 are also lower in Scenario 2 (**Figure 36**) than Scenario 1 (**Figure 24**). The lower 2040 horizontal velocities in Scenario 2 are due to lower pumping rates (versus Scenario 1) and, as a result, lower drawdown-induced horizontal gradients in the UFA. Lower offshore vertical seepage velocities in 2040 (versus 2015) are likely due to after-effects of the reductions in groundwater pumping between approximately 2000 and 2015 during the calibration period. Leakage fluxes (and, therefore, also leakage velocities) to the UFA from the IS decreased from 2000 to 2015 (Tetra Tech, 2020b). Minimal additional UFA drawdown offshore between 2015 and 2040 (i.e. less than 5 ft; **Figure 27**) combined with the continued propagation of pumping effects from pre-2015 UFA pumping into the overlying and underlying confining units (i.e. depressurization) likely resulted in the reduction in vertical gradients from layers 4 (IS) and 10 (BUC) toward the UFA in 2040.

Horizontal LFA groundwater flow patterns in Scenario 2 (**Figure 37**) are similar to those in Scenario 1 (**Figure 25**). Flow near the coast is northward and has an upward component (as in Scenario 1), however the Scenario 2 velocity magnitudes are lower than in Scenario 1. As was the case in Scenario 1, the simulated Scenario 2 horizontal velocities at locations of interest are much greater than the coincident vertical velocities (**Table 3**).

3.4 SCENARIO 3

The combined effects of sea level rise and WSA pumping projections were simulated in Scenario 3. Adding sea level rise to Scenario 2 does not produce any notable differences in results for Scenario 3. Equivalent freshwater heads and drawdowns for the UFA (**Figures 38 and 39**) and LFA (**Figures 40 and 41**) in Scenario 3 are nearly identical to those for Scenario 2. The Scenario 3 simulated concentrations in 2040 (**Figures 42-45**) are also nearly identical to the Scenario 2 concentrations (**Figures 32-35**). Sea level rise does affect vertical seepage velocities; however, the greatest absolute effect is approximately 0.03 in/yr, which corresponds to a small reduction in outflow from the IS to Choctawhatchee Bay at point “H” (**Table 3**).

The lack of any substantial effects of sea level rise is reasonable given other model results. The vertical leakance of the IS is low (Tetra Tech, 2020b), which results in a large hydraulic gradient between layer 1 and the UFA; in 2000, the simulated differences in equivalent freshwater heads between the UFA and layer 1 exceeded 100 ft along portions of the coast near Fort Walton Beach[11]. The change in equivalent freshwater head imposed in layer 1 over the predictive period in Scenario 3—approximately 200 mm, or less than 8 inches—is small by comparison. Groundwater concentrations were generally stable during the calibration period despite the much greater, pumping-induced changes to UFA-layer 1 head differences (Tetra Tech, 2020b). Therefore, it is reasonable that a small incremental change in the UFA-layer 1 head difference due to rising sea levels would have a minimal impact on simulated heads, seepage rates, and concentrations during the shorter predictive period.

4.0 CONCLUSIONS

The transient, calibrated CR2SWT model (Tetra Tech, 2020b) was used to perform three (3) 25-year predictive simulations of the 2016-2040 period. The effects of two very different pumping scenarios were assessed, as were the compounded effects of one pumping scenario with rising sea levels. Differences in pumping rates had substantial impacts on aquifer heads and flow directions, with the first (ADR) pumping scenario simulating the greatest impacts. The WSA pumping scenario was characterized by relatively smaller drawdown-induced effects, which were nearly identical to the results from a third scenario with both WSA pumping and sea level rise simulated.

[11] Simulated layer 7 equivalent freshwater heads in 2000 were less than -100 ft (Tetra Tech, 2020b; **Figure 29**) and specified equivalent freshwater heads in layer 1 were 0 ft.

5.0 REFERENCES

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