Appendix 4-2. Groundwater Modeling

1.0 Introduction

For the WRWSA's 2014 Water Supply Plan, the SWFWMD, and SJRWMD agreed to work together to update and expand the SWFWMD's Northern District Groundwater Flow Model (Northern District Model Version 4). The expanded boundary included eastern Marion County, with its critical water resources that included the Silver Springs/Silver River system, and parts of Alachua, Levy, Lake, Orange, Polk, Pasco, Pinellas, Putnam, and Hillsborough Counties. Figure 4-2 in the Water Supply Plan shows the domain of the revised model. The Northern District Model Version 4 also included a number of refinements, the most important of which was a more sophisticated representation of the Lower Floridan aquifer that represents the current, albeit limited, understanding of the extent and characteristics of the aquifer.

Following the completion of the 2014 Water Supply Plan, in 2016 the District's updated the Northern District Model to Version 5. The Northern District Model Version 5 (ND Model) was used for the WRWSA 2019 Water Supply Plan. This update includes changes to the hydraulic properties in the Upper Floridan aquifer in northeast Marion County based on recently conducted aquifer performance tests (APT's), removal and addition of springs to the model including updated spring discharge flows and revised recharge in northern Marion County. The addition and removal of springs in the ND Model are not included within the spring analysis provided below. Figure 4-2 shows the domain of the revised model.

2.0 Description of the Northern District Model

The ND Model is a regional groundwater flow model used to simulate transient conditions. The ND Model utilizes MODFLOW-SURFACT groundwater flow and solute transport modeling code. MODFLOW-SURFACT is an updated version of the USGS Modular three-dimensional groundwater flow code. MODFLOW-SURFACT specializes in saturated and unsaturated conditions in unconfined aquifers and has the ability to simulate groundwater-seepage faces and open-borehole wells that penetrate multiple aquifer units.

The regional model finite-difference grid consists of 212 columns and 275 rows with uniform grid spacing of 2,500 feet. The model extent includes the St. Johns River as the eastern boundary. The western boundary extends approximately five miles offshore in the Gulf of Mexico to be used in future iterations to determine regional salt water intrusion. The model was constructed to contain seven layers to represent the major hydro-stratigraphic units.

- Layer 1 – surficial aquifer unit (SAS)
- Layer 2 – intermediate confining unit (ICU)
- Layer 3 – Suwannee Limestone
- Layer 4 – Ocala Limestone
- Layer 5 – Upper Avon Park Formation
- Layer 6 – Middle Confining Unit (MCU) I and II
- Layer 7 – Lower Avon Park Formation or Oldsmar Formation

The Upper Floridan Aquifer System (UFAS) is composed of the Suwannee Limestone, Ocala Limestone and the Upper Avon Park Formation. The Lower Floridan Aquifer System (LFAS) comprises the permeable sections of both Lower Avon Park and the Oldsmar Formation.

In regions where the ICU is missing, layer 2 represents the uppermost portion of the UFAS. The Suwannee Limestone is absent over large sections of the model and in these areas, layers 3 and 4 represent the Ocala Limestone. The Ocala Limestone is absent in localized portions of northern region of the model domain and in this area, model layers 3 to 5 represent the Upper Avon Park Formation. The Oldsmar Formation is assumed to have relatively low permeability similar to the permeability of the overlying MCU II (which includes the Lower Avon Park Formation), except in the eastern portion of the model domain. Therefore, the finite-difference cells representing the LFAS in Layer 7 are active only in this eastern region.

The external boundary conditions used to represent the lateral and lower model boundaries of the model include constant-head, general-head, or no-flow boundary conditions. The SAS (Layer 1) along the southeastern boundary is represented by constant-head boundary conditions of prescribed model heads. The southeastern boundary extends through southwestern Orange, Polk, and Hillsborough Counties. The western boundary of the model was also assigned constant-head boundary conditions to represent the saltwater interface along the gulf coast. Equivalent freshwater heads were assigned for all finite-difference cells located along the Gulf of Mexico for all layers replacing saltwater heads via conversion.

Regional scale modeling results (Sepulveda, 2002) were duplicated to assign general-head boundary conditions along the southeastern section of the model domain in southwestern Orange and northern Polk Counties. The general-head boundary conditions were assigned to the Suwannee Limestone (Layer 3), Ocala Limestone (Layer 4) and the Upper and Lower Avon Park Formations (Layers 5 and 7). The SAS boundary near Keystone Heights was also assigned a general-head boundary condition (HGL, 2013).

The remaining lateral boundaries not defined with constant-head or general-head boundaries were assigned no-flow boundary conditions. This includes the ICU (Layer 2) and MCU I and II (Layer 6) boundaries due to the semi-confining nature of the hydrogeologic units with groundwater flow predominately in the vertical direction. In the western section of the model, no flow-boundaries are assigned to the base of Layer 6 to represent MCU II. This is based on the assumption that the Oldsmar Formation in this area has permeability that is similar to MCU II. In this section of the model, the LFAS is represented by inactive cells and groundwater flow is not simulated (HGL, 2013).

In the ND Model, recharge is calculated through a water-budget methodology that accounts for the major components of the hydrologic cycle: precipitation, evapotranspiration and runoff. Initial Hydraulic parameter values used in the ND Model were taken from previous iterations of the model developed by HGL, LLC. Initial hydraulic parameters for the expanded areas of the model domain were taken from existing models that overlap or are adjacent to the expanded areas. These models include the Volusia County Model, the East Central Model and the North-Central Florida Model (HGL, 2013). Additional transmissivity values for the LFAS in Marion, Sumter, Lake and Orange Counties were collected from other data sources (HGL, 2013)

The ND Model was calibrated to average, steady-state conditions observed in 1995. Once the steady-state ND Model was calibrated, the regional model was calibrated to observed transient conditions from 1996 to 2006. This period encompasses abnormal precipitation conditions including wet (El Nino 1997 to1998) dry (1999 to 2000 drought) and wet (2004) periods (HGL, 2013). As part of the ND Model update a 2010 steady-state model run was developed as a verification for the model calibration period of 1996 to 2006; which included recharge, groundwater withdrawals and boundary heads set at values from 2010.

The SWFWMD provided the 2040 water demand projections for the entire model boundary; which are detailed in Chapter 3 of the Water Supply Plan.

3.0 Modeling Scenarios

3.1 Scenario 1. Pre-development (No-Pumpage)

The ND model was used to simulate a pre-development or no pumpage scenario. The pre-development scenario used the calibrated transient model removing all groundwater withdrawals (domestic self-supply users and permitted withdrawals). The ND model was run for 365 days to allow water levels to simulate pre-development potentiometric surfaces reach equilibrium throughout the model domain. The water levels and spring-flows calculated under the pre-development scenario served as the basis to which all other model scenario results are compared, as described in Chapters 4 and 5 of the Water Supply Plan.

3.2 Scenario 2. 2040 Adjusted Water Use Demand Scenario

The SWFWMD used the ND Model to conduct a comprehensive evaluation of the impacts of projected 2040 groundwater withdrawals from the UFAS and LFAS on MFL waterbodies in the WRWSA region. Groundwater withdrawals were set equal to the projected 2040 demand in the model domain, approximately 410.8 mgd and 75.9 mgd from the UFAS and LFAS, respectively, and distributed throughout the region based on the location of where the demands were projected to occur. The withdrawals were adjusted by the SWFWMD to account for water conservation and use of reclaimed water. The adjustments for water conservation included reductions of 10 percent for public supply, 10 percent for agriculture, and 20 percent for recreational/aesthetic, which were considered to be reasonable targets. The higher percentage allocated to recreation is due to the likely application of reclaimed water to some of the golf courses. The effects of reclaimed water use projected for 2040 were represented in the model as an increase in recharge in the vicinity of reclaimed water facilities (HGL, 2013). The recharge factors chosen were based on those that were published by the Florida Department of Protection (Page 19, FDEP, 2013). The adjusted water demand scenario was simulated for five years to determine the effect of increased recharge on the extent of potential impacts caused by the projected demands.

3.2.1 Aquifer Drawdowns

Aquifer drawdown was predicted by calculating the difference in surficial and UFAS water levels from pre-pumping conditions to adjusted 2040 demand. Drawdowns predicted by the model in the surficial and Upper Floridan aquifer varied across the WRWSA and are shown in Figures 1 through 3. The range-of-drawdowns in each county were as follows: Citrus County, 0.0 to 0.4 feet, Hernando County, 0.0 to 2.9 feet, Sumter County, 0.0 to 5.1 feet and Marion County 0.0 to 4.1 feet. The largest drawdowns were located in the vicinity of concentrated centers of groundwater withdrawals.

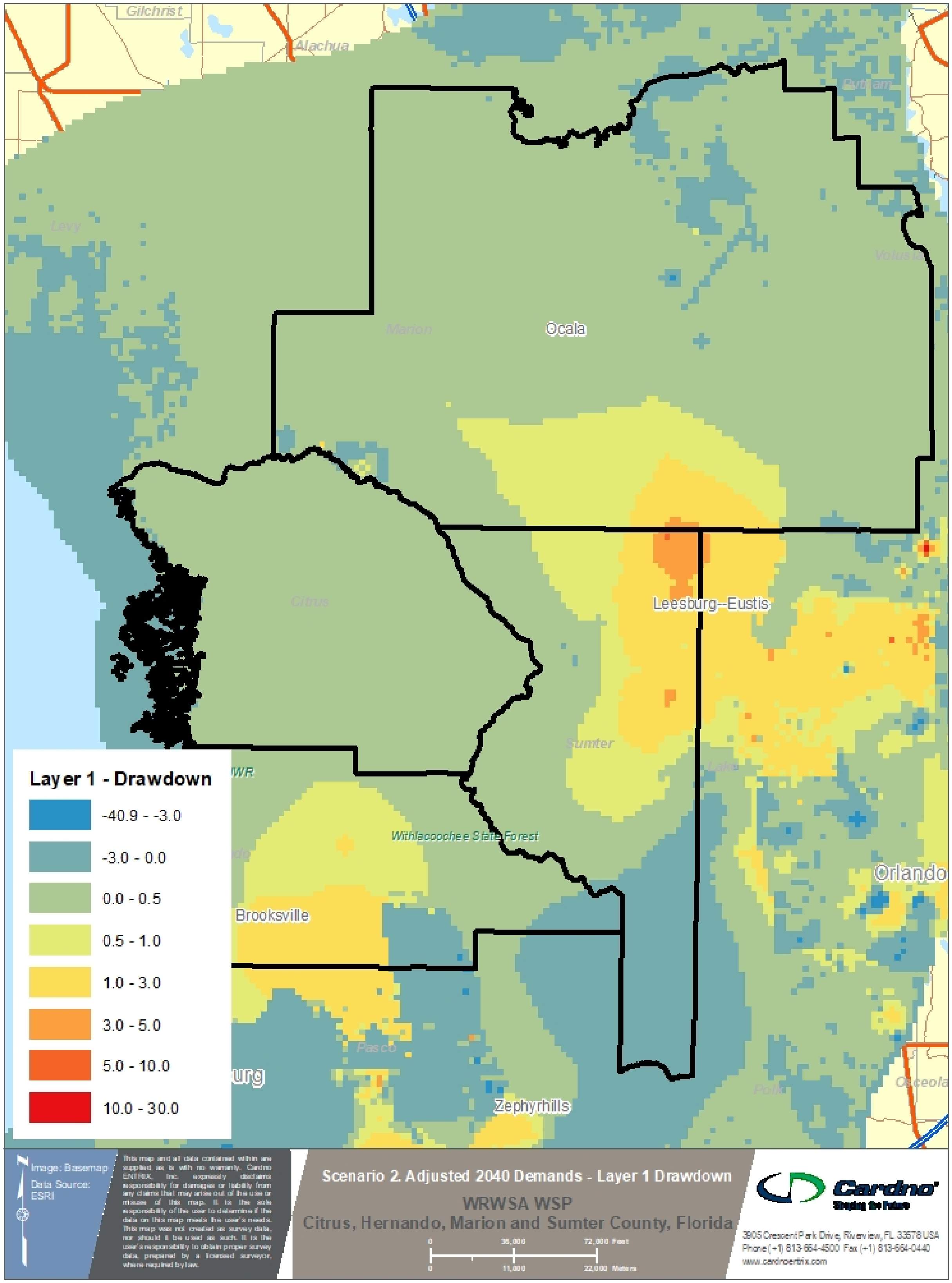

Figure 1. Scenario 2 Predicted 2040 Drawdown in Layer 1.

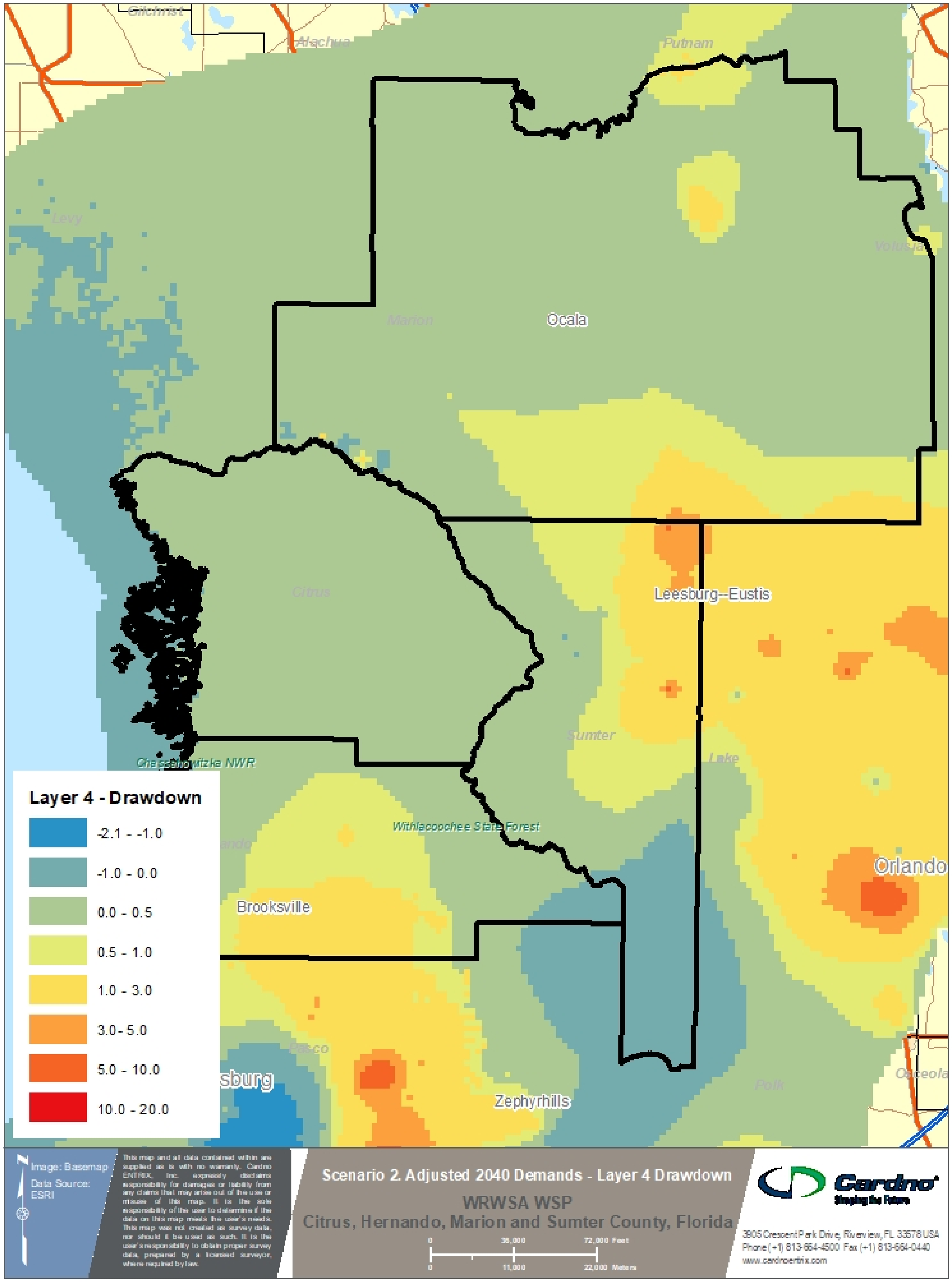

Figure 2. Scenario 2 Predicted 2035 Drawdown in Layer 4.

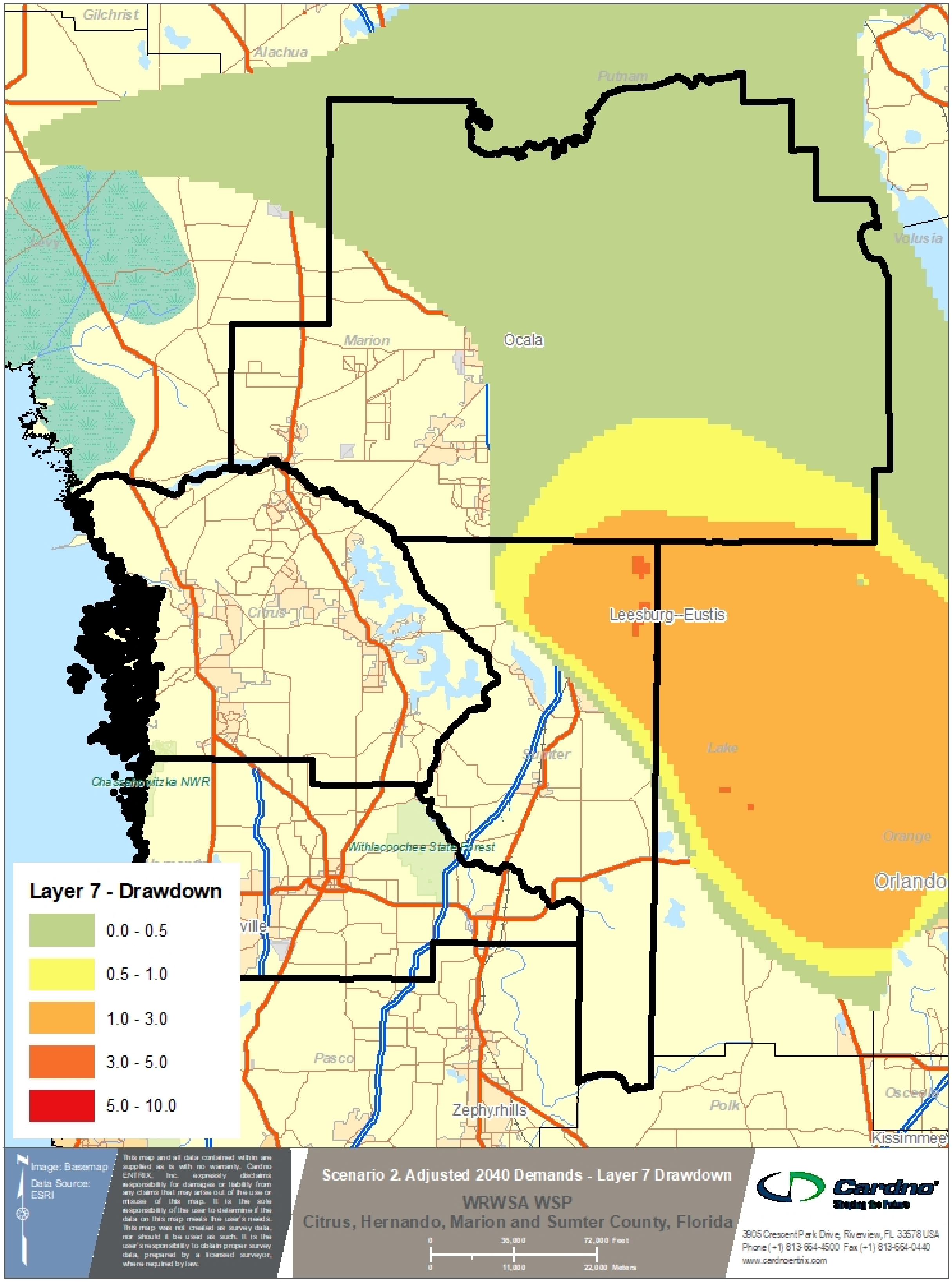

Figure 3. Scenario 2 Predicted 2035 Drawdown in Layer 7.

3.2.2 Spring Flow

Reductions in the flow of springs from pre-pumping conditions to the adjusted 2040 demand that would result from projected groundwater withdrawals are shown in the following tables.

Weeki Wachee Spring System - The minimum flow adopted for the Weeki Wachee Springs System allows for a 10 percent reduction in flow. The table shows that the predicted decline for the system of 6.1 percent, resulting from projected 2040 groundwater withdrawals, does not exceed the allowable 10 percent reduction.

Weeki Wachee Springs System.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flows (cfs)	2040 Percent Change
Weeki Wachee Spring	160.3	149.4	6.8
Jenkins Creek Spring	18.3	17.7	3.6
Mud Spring	9.1	8.4	8.0
Salt Spring	22.8	22.2	2.9
Hospital Hole	5.4	5.2	3.6
Weeki Wachee River and Spring System	**215.9**	**202.8**	**6.1**

[1] Based on 2040 adjusted demand

Chassahowitzka Springs System - The minimum flow adopted for the Chassahowitzka Springs System allows for a 8 percent reduction in flow. The table shows that the predicted decline for the system of 1.7 percent, resulting from projected 2040 groundwater withdrawals, does not exceed the allowable 8 percent reduction.

Chassahowitzka Springs System.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flows (cfs)	2040 Percent Change
Chassahowitzka Main Spring	66.2	64.8	2.1
Crab Spring	34.2	33.3	2.6
Potter Creek Spring	14.9	14.6	1.9
Blind Spring	42.9	42.7	0.4
Salt Creek Springs	0.4	0.4	2.0
Baird Spring	3.4	3.3	2.1
Betee Jay Spring	7.4	7.3	1.3
Ryle Creek Spring	8.3	8.2	1.4
Blue Run Spring	5.3	5.2	1.7
Hernando Unnamed Spring 10	20.1	19.8	1.8
Hernando Unnamed Spring 08	5.0	5.0	0.0
Chassahowitzka River and Spring System	**208.0**	**204.5**	**1.7**

[1] Based on 2040 adjusted demand

Homosassa Springs System - The minimum flow adopted for the Homosassa Springs System allows for a 5 percent reduction in flow. The table shows that the predicted decline for the system of 2.1 percent, resulting from projected 2040 groundwater withdrawals, does not exceed the allowable 5 percent reduction.

Homosassa Springs System.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flows (cfs)	2040 Percent Change
Homosassa 1 Spring	86.9	85.3	1.9
SE Fork Homosassa Spring	37.5	36.8	1.9
Halls River Head Main Spring	100.2	98.2	2.0
Halls River 1 Spring	6.3	6.2	1.8
Hidden River Head Spring	5.9	5.4	9.1
Trotter Spring	4.9	4.8	1.9
Belcher Spring	4.9	4.6	4.9
Abdoney Spring	5.6	5.5	1.9
McClain Spring	5.6	5.5	1.9
Pumphouse Spring	4.2	4.2	1.9
Homosassa River and Spring System	**261.9**	**256.3**	**2.1**

[1] Based on 2040 adjusted demand

Gum Slough and Springs System - The minimum flow proposed for the Gum Slough Springs System allows for a 6 percent reduction in flow. The table shows that the predicted decline for the group of 4.2 percent, resulting from projected 2040 groundwater withdrawals, does not exceed the allowable 6 percent reduction.

Gum Slough and Spring System.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flows (cfs)	2040 Percent Change
Gum Springs 1	98.8	94.7	4.2
Gum Slough and Spring System	**98.8**	**94.7**	**4.2**

[1] Based on 2040 adjusted demand

King's Bay Springs System - The minimum flow proposed for the Kings Bay System allows for a 11 percent reduction in flow. The table shows that the predicted decline for the group of 1.6 percent, resulting from projected 2040 groundwater withdrawals, does not exceed the allowable 11 percent reduction.

Kings Bay Springs System.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flows (cfs)	2040 Percent Change
House Spring	2.5	2.4	4.3
Manatee Sanctuary Spring	99.2	97.6	1.6
Crystal Spring	347.3	341.8	1.6
Kings Bay	**449.0**	**441.8**	**1.6**

[1] Based on 2040 adjusted demand

Rainbow Springs System – The minimum flow proposed for the Rainbow Springs and River System allows for a 5.0 percent reduction in flow. The table shows that the predicted decline for the group of 1.6 percent, resulting from projected 2040 groundwater withdrawals, does not exceed the allowable 5.0 percent reduction.

Rainbow Springs System.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flows (cfs)	2040 Percent Change
Rainbow 1 Spring	659.7	649.0	1.6
Bubbling Spring	1.8	1.7	1.5
Rainbow Springs System	**661.4**	**650.7**	**1.6**

[1] Based on 2040 adjusted demand

Silver Springs System – The table shows that the predicted decline in flow for the springs resulting from adjusted 2040 groundwater withdrawals is 4.6 percent. The SJRWMD has set minimum flows for Silver Springs that incorporate 3 tiers.

The purpose of the tiered system is to prevent the occurrence of minimum average or frequent low flows from occurring more often and prevent frequent high flows from occurring less often. The frequent high flow of the spring is set at 828 cfs for a duration of 30 days with a return interval of 5 years. The average flow is set at 638 cfs for a duration of 180 days with a return interval of 1.7 years and the frequent low flow is set at 572 cfs with a duration of 120 days with a return interval of 3 years.

The SJRWMD has determined that all the adopted minimum flows and levels for Silver Springs are currently being achieved. However, by 2025, the adopted frequent low flow for Silver Springs will not be met based on current demand projections and permitted groundwater withdrawals from the Upper Floridan aquifer in the SJRWMD portion of Marion County (SJRWMD, 2017). The SJRWMD has developed a prevention strategy to ensure that minimum flows for the springs continue to be met through the planning horizon. The prevention strategy requires that any additional UFA withdrawal impacts to Silver Spring beyond which is projected at 2024, must be offset. The SJRWMD will complete a strategy five-year assessment in 2022 and provide adjustments as necessary to ensure MFL achievement at the planning horizon.

Silver Springs.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flows (cfs)	2040 Percent Change
Silver Springs	**733.7**	**700.0**	**4.6**

[1] Based on 2040 adjusted demand

Silver Glen Springs - The SJRWMD minimum flow for Silver Glen Springs is based on an allowable 2.5 percent, or 2.6 cfs, reduction in flow from a no-pumping condition. The minimum mean flow for Silver Glen Springs is 99.6 cfs. The table shows that the predicted decline in flow rate for the spring resulting from adjusted 2040 groundwater withdrawals is 2.4 cfs which is below the allowable decline set by the SJRWMD.

Silver Glen Springs.

Spring Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flow (cfs)	2040 Change (cfs)
Silver Glen Springs	108.8	106.4	2.4

[1] Based on 2040 adjusted demand

3.2.3 River Flow

River systems in the WRWSA four-county region include the Withlacoochee and Ocklawaha Rivers. Draft minimum flows have been developed for the Withlacoochee River by the SWFWMD. The Ocklawaha River is currently on the SJRWMD's Priority Water Body List and is scheduled for MFLs completion in 2021. The following is a discussion of the predicted changes in the baseflow of the rivers resulting from adjusted 2040 groundwater withdrawals.

Withlacoochee River – The table below shows that the predicted decline in baseflow for the Withlacoochee River at Croom and Holder, resulting from projected 2040 groundwater withdrawals, is 1.3 percent and 5.5 percent, respectively.

Predicted Reduction in Baseflow in 2040 for the Withlacoochee River at Croom and Holder.

River Segment	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flow (cfs)	Percent Flow Reduction
Withlacoochee at Croom	78.3	79.3	+1.3
Withlacoochee near Holder	322.7	305.0	5.5

[1] Based on 2040 adjusted demand

The following procedure was used to determine whether the predicted reductions in baseflow of the Withlacoochee River resulted in exceedances of the draft minimum flows at Holder. This analysis was not completed for Croom based on the ND Model predicted flows that show an increase in predicted flows based on 2040 groundwater withdrawals and implemented conservation measures. Figures 4 shows the historic median daily flow (blue line) and the draft minimum flow (black line), which is the historic median daily flow reduced by the allowable reductions for each seasonal flow block at the Holder gauge station.

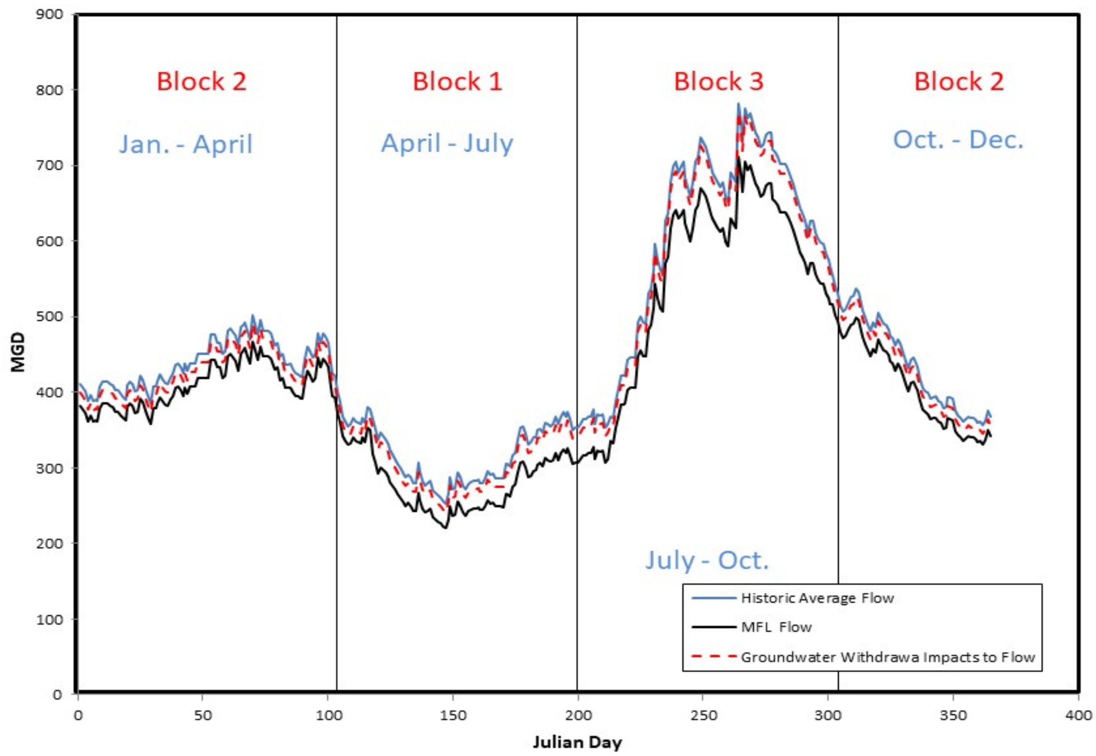

Figure 4. Predicted Reduction in Baseflow for the Withlacoochee River at Holder Resulting from Projected 2040 Groundwater Withdrawals, Relative to the Historic Median Daily Flow and the Draft Minimum Flow.

The predicted baseflow reductions were subtracted from the historic median daily flows at Holder and the resulting flow was plotted on the graph (dashed red line). If the line representing the predicted baseflow reduction was above the draft minimum flow line, the minimum flow was not exceeded. The figure shows that this was always the case and therefore, the predicted reduction in groundwater baseflow resulting from the projected 2040 groundwater withdrawals, does not cause the Withlacoochee River to exceed the draft minimum flows at Holder.

Ocklawaha River – The table below shows the predicted percent reduction in baseflow for the Ocklawaha River at Moss Bluff, Conner, and Eureka.

Predicted Reduction in Baseflow in 2040 for the Ocklawaha and Silver Rivers.

River Segment Name	Pre-Pumpage Flow (cfs)	Predicted 2040[1] Flow (cfs)	Percent Reduction
Ocklawaha River near Moss Bluff	51.0	42.4	16.8
Ocklawaha River at Conner	858.2	814.7	5.1
Ocklawaha River at Eureka	868.6	824.9	5.0

[1] Based on 2040 adjusted demand

As mentioned previously, MFLs for the Ocklawaha River are scheduled for completion in 2021. As part of final MFLs adoption, the SJRWMD will conduct a current and future MFLs compliance assessment to determine the corresponding MFL status. This information will be included in subsequent updates of this plan.

3.2.4 Lakes and Wetlands

The impacts on lakes and wetlands from predicted declines in aquifer levels resulting from the 2040 projected groundwater withdrawals were not included in this analysis. This is because the ND Model could not accurately assess impacts to relatively small-scale features such as lakes and wetlands. The SWFWMD undertakes a separate analysis of lakes to determine compliance each year. The MFL lakes in the SWFWMD portion of the WRWSA Region are currently meeting their levels.

SJRWMD uses regional groundwater models in conjunction with surface water models to predict drawdown impacts to lakes and wetlands that have significant connection to the Floridan aquifer. There are eight MFL lakes and wetlands within the SJR portion of Marion County. According to the SJRWMD draft Central Springs/East Coast Regional Water Supply Plan, six lakes are predicted to meet their MFLs based on 2040 projected demand, one has no significant Floridan aquifer connection, and the other is being reevaluated.

3.2.5 Scenario 2 Summary

The results of the modeling investigation discussed above demonstrate that in the SWFWMD portion of the WRWSA region, 2040 demands for all use categories can be met with groundwater with no exceedances to springs and rivers for which MFLs have been proposed or adopted. However, this result was achieved by reducing demand through water conservation and mitigating aquifer drawdowns to some degree by recharge from the use of reclaimed water. The implication of this is that groundwater from the Upper Floridan aquifer may be limited in certain areas by 2040.

In the SJRWMD portion of the WRWSA region, the SJRWMD has determined that all the adopted minimum flows and levels for Silver Springs are currently being achieved. However, by 2025, the adopted frequent low flow for Silver Springs will not be met based on current demand projections and permitted groundwater withdrawals from the UFA in the SJRWMD portion of Marion County (SJRWMD, 2017). The SJRWMD has developed a prevention strategy to ensure that minimum flows for the springs will continue to be met through the planning horizon. The prevention strategy requires that any additional UFA withdrawal impacts to Silver Springs beyond which is projected at 2024, be offset. This may limit users in central and eastern Marion County from obtaining additional groundwater quantities from the Upper Floridan aquifer.