APPENDIX 6D

Future Conditions Scenario 3

Lower Charlotte Harbor Flatwoods Strategic Hydrologic Restoration Plan

Lower Charlotte Harbor Flatwoods Strategic Hydrologic Restoration Plan

6D – Future Conditions Scenario 3

PREPARED FOR:

Coastal & Heartland National Estuary Partnership
1050 Loveland Boulevard
Port Charlotte, Florida 33980

PREPARED BY:

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Coastal & Heartland National Estuary Partnership

IN CONJUNCTION WITH:

South Florida Water Management District
Florida Fish and Wildlife Conservation Commission
Southwest Florida Water Management District

LOWER CHARLOTTE HARBOR FLATWOODS HYDROLOGIC MODELING AND PLANNING PROJECT

TECHNICAL MEMORANDUM – TASK 6D – SCENARIO 3

To:	Ms. Jennifer Hecker, Ms. Nicole Iadevaia, Ms. Sarina Weiss
From:	Roger Copp and Kirk Martin, P.G. Water Science Associates
Date	October 18, 2022
Re:	Task 6D – Scenario 3

INTRODUCTION

Water Science Associates (Water Science) was contracted by the Coastal & Heartland National Estuary Partnership (CHNEP) to develop a hydrologic restoration plan for the Lower Charlotte Harbor Flatwoods that will promote sheet flow enhancement, restore wetland hydroperiods in the Babcock Webb and the Yucca Pens Wildlife Management Areas (WMA), and improve the timing and magnitude of flows to tidal creeks west of Yucca Pens WMA.

Project tasks include:

1. Compilation of existing hydrologic data,
2. Installation of new surface and groundwater monitoring stations and rain gages,
3. Evaluation of vegetative indicators of wetland health,
4. Maintenance of the monitoring stations and management of manual and electronic data,
5. Development of an existing conditions hydrologic model of the study area,
6. Evaluation of alternative management scenarios, and
7. Development of a Lower Charlotte Harbor Flatwoods Strategic Hydrological Restoration Planning Tool and Report.

Tasks 1 through 5 have been completed. Task 6 includes modeling natural pre-development and three future conditions scenarios. Memoranda for Task 6A Natural Systems Analysis Task 6B Scenario 1, and Task 6C Scenario 2 have been completed.

The three future conditions scenarios include the following assumptions:

1. Scenario 1 includes channel blocks and low water fords in Yucca Pens to minimize excessive drainage caused by eroded all-terrain vehicle (ATV) trails, storage of wet season flows from Babcock Webb in the proposed Bond Farm Hydrologic Enhancement Impoundment (HEI) from which outflows are directed south, and a groundwater seepage barrier at the Gator Slough Canal.
2. Scenario 2 includes Scenario 1 improvements plus additional storage for flooded areas of Babcock Webb and a flow-way from Bond Farm HEI to Yucca Pens for additional hydroperiod restoration in Yucca Pens.
3. Scenario 3 includes Scenario 2 improvements along with evapotranspiration (ET) and sea level rise assumptions associated with climate change.

This TM describes the work associated with Task 6D, the development and results of Scenario 3 of the three planned Scenario evaluations. The Scope of Work stipulates that this memorandum describe the predicted water levels, flows, and hydroperiods for Scenario 3.

CLIMATE CHANGE: SEA LEVEL RISE

A gradual sea level rise has been observed throughout the last century due to climate change, with projections indicating that the rate of sea level rise will increase in the next 50 years (Obeysekera, 2014). The sea level rise projections defined by the National Oceanic and Atmospheric Administration (NOAA) present various scenarios considering the intensity accompanied by the accretion rate as a measure of sea level rise (https://coast.noaa.gov/slr/). For the analysis of Scenario 3, this study assumes the NOAA case of Intermediate/High Sea Level Rise with Low Accretion Rate (of 2 mm/year), as has been used in other recent regional studies (ESA & CHNEP, 2020). In these conditions, NOAA estimates that the sea level will raise about 1.64 ft by year 2050, as shown in **Figure 1**. Thus, the water level time series applied in MIKE11 as the tidal boundary condition is increased by adding an offset of 1.64 ft.

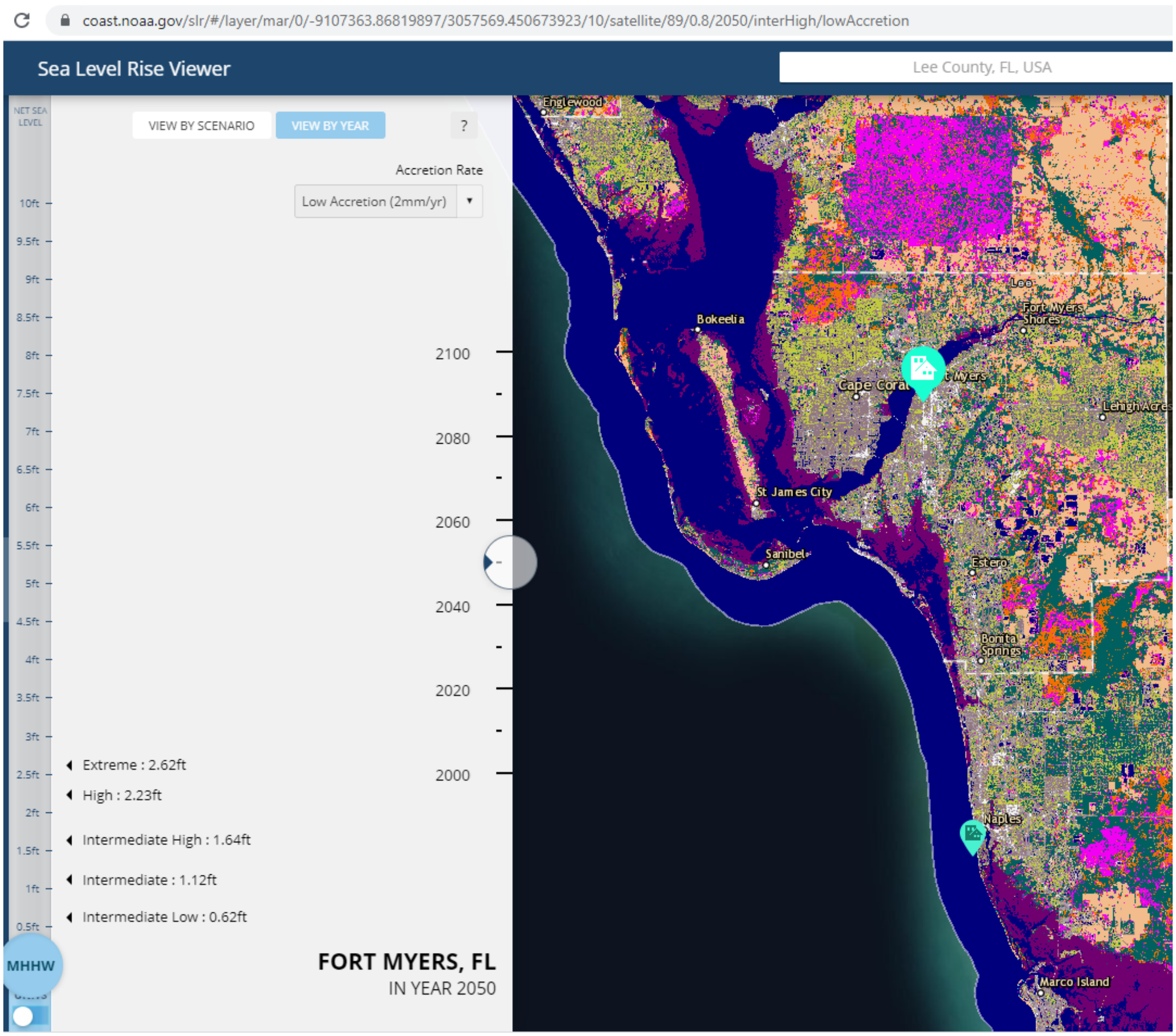

Figure 1. Sea level rise estimated for year 2050 in NOAA's Sea Level Rise Viewer webpage.

CLIMATE CHANGE: RAINFALL AND REFERENCE ET

The Danish Hydraulic Institute (DHI) has implemented a Climate Change Module for many of the DHI modeling software packages, such as MIKE which was used for this analysis. This tool allows the modeler to input information on the location of the study area, the number of Global circulation models to use, the CO emissions scenario, and the future scenario year that is being evaluated. The software then uses that information to change the evapotranspiration and rainfall data according to the user preference (DHI, 2022).

The Climate Change Tool in the DHI software enables the user to calculate monthly factors that can be applied to Rainfall and Reference ET (RET) time series to convert them to a future date (DHI, 2022). The DHI tool produced the monthly rainfall and evapotranspiration increments by using the following parameters:

- Location (Latitude, Longitude) = (26.8, -81.94) degrees, which is the model domain center
- Global Circulations Models = All
- CO_2 emission scenario = SRA1B (balanced scenario between fossil and non-fossil fuel)
- Scenarios Year = 2050

The historic 2012-2022 daily rainfall and RET time series used in the calibration model (see TM 5c) were spatially averaged inside the model domain to obtain the monthly, quarterly, and annual average amounts presented in ***Table 1***. These amounts together with the increments obtained from the DHI tool were used to calculate the future rainfall and RET amounts included in ***Table 2***.

The mean annual increase in temperature of 3.1^{o} F predicted from the DHI Tool (see ***Table 2***) is consistent with the 1.5^{o} C (i.e., 2.7^{o} F) projected increase in Florida by year 2060 [Kirtman et al., 2017]. The average increase in evaporation of 6.3% by 2050 from the DHI Tool (see ***Table 2***) is also in line with the 7% increase by 2060 used in a recent study in the non-tidal Caloosahatchee River Watershed [ESA & CHNEP, 2020].

While the DHI tool produces reasonable predictions for the increase in temperature and evaporation; the predicted decrease in annual precipitation by 10% (see ***Table 2***) is more extreme than a range of projections and conflicts with other studies. For example, [Obeysekera et al., 2014] used a range of ±10 % to evaluate changes in precipitation by year 2060. [Dessalegne et al., 2016] found variations from -2.6 to 20.2 % in rainfall [Kirtman, B. P. al. 2017]. A more recent study by [Infanti et al. 2020] concluded that there is a likely increase in the annual mean precipitation in south Florida by 2045. Finally, the recent Caloosahatchee study assumed a slight positive increase of 2% in precipitation by year 2060 [ESA & CHNEP, 2020].

The decrease in precipitation of 10% was tested by the South Florida Water Management District (SFWMD) in the past [Obeysekera et al., 2014], however the more recent study by [Infanti et al. 2020] concluded that an increase in the annual precipitation is more likely. During the development of this model there were too many uncertainties to confidently assume how rainfall will change either in quantity or distribution. Therefore, rainfall will remain unchanged in the model and results should be interpreted carefully before being used for decision making and planning.

These assumption should be revisited in future climate change scenario analyses when scientific investigations are able to reduce the uncertainty in predicting how rainfall will change due to climate change as it is near certain that future rainfall will be different. This approach of excluding potential changes in the 2050-year rainfall was used recently in a future condition modeling evaluation for nearby areas in South Lee County [Lago & CHNEP, 2021]. However, it is known that climate change will impact the frequency and intensity of rainfall, and therefore it is recommended that future projects model a theoretical spectrum of changes that could occur with increased or decreased rainfall amounts and/or patterns to understand the relative role of rainfall and evapotranspiration (ET) in changes to hydroperiods and wetland water depths. This tool can be used now effectively to quantify hypothetical changes in rainfall; for example, a 5 or 10% increase in rainfall, a 5% decrease in rainfall, or a different rainfall distribution (increased rainfall in wet season and less rainfall in dry season).

As there is more certainty around rainfall changes in Florida in the future, it is recommended that Scenario 3 input files be updated to use the latest available scientific information on rainfall and climate change predictions. Due to the significant ecological impacts of reduced hydroperiod to wetlands in the Charlotte Harbor Flatwoods area, the findings could be used to form specific guidance on measures that can be taken in advance (in management, engineering, and/or policy) to buffer climate change impacts (e.g., options for water storage and additional restoration measures)

Table 1. Rainfall and RET from 10-year data 2012-2022, spatial averages inside model domain

	Monthly												Quarterly				Annual
Parameter	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	DJF	MAM	JJA	SON	
Precipitation (in)	1.72	2.25	2.00	1.39	2.15	4.60	9.53	9.52	10.20	8.87	3.17	2.10	5.97	8.13	29.25	14.14	57.49
Reference ET (in)	2.90	3.07	3.59	5.00	5.82	6.40	5.71	5.73	5.52	4.89	4.55	3.40	9.57	17.22	16.96	12.84	56.58

Table 2. Future Rainfall, RET, and temperature as obtained from the DHI Tool by year 2050.

	Monthly												Quarterly				Annual
Parameter	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	DJF	MAM	JJA	SON	
	Future increments																
Precipitation (%)	4.3	-4.1	-13.9	-15.3	-15.1	-17.0	-14.7	-14.8	-10.8	-2.0	12.0	3.2	-4.9	-16.2	-13.4	1.9	-9.2
Evaporation (%)	7.0	5.9	6.4	7.1	6.7	6.4	6.2	6.1	6.1	5.6	6.0	6.7	6.4	6.7	6.1	6.0	6.3
Temperature (ºF)	3.0	2.4	2.6	3.1	3.2	3.4	3.5	3.5	3.5	3.1	3.1	3.2	2.7	3.2	3.5	3.2	3.1
	Future rainfall and RET																
Precipitation (in)	1.79	2.16	1.72	1.17	1.82	3.82	8.13	8.10	9.10	8.69	3.55	2.17	5.67	6.82	25.33	14.41	52.23
Reference ET (in)	3.11	3.25	3.82	5.35	6.21	6.81	6.07	6.08	5.85	5.17	4.82	3.63	10.19	18.38	18.00	13.61	60.18

Note: DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November
Quarterly groupings are based on wet and dry season.

SCENARIO 3 ASSUMPTIONS

Scenario 3 includes Scenario 2 improvements along with rainfall, ET and sea level rise assumptions associated with climate change. A summary of these assumptions is provided below:

1. All proposed features associated with Scenario 2 are included in Scenario 3. For details on the assumptions for Scenario 2, refer to the Task 6C Scenario 2 Memorandum.
2. During the development of this model there were too many uncertainties to confidently assume how rainfall will change either in quantity or distribution. Therefore, rainfall will remain unchanged in the model and results should be interpreted carefully before being used for decision making and planning. These assumption should be revisited in future climate change scenario analyses when scientific investigations are able to reduce the uncertainty in predicting how rainfall will change due to climate change as it is near certain that future rainfall will be different.
3. Sea levels will rise 1.64 feet by 2050, based on the NOAA case of Intermediate/High Sea Level Rise with Low Accretion Rate (ESA & CHNEP, 2020). This assumption is similar to other recent regional studies.
4. ET will increase by 6.3% by 2050. This assumption is similar to other regional studies (ESA & CHNEP, 2020).

SCENARIO 3 HYDROPERIODS AND WET SEASON WATER DEPTHS

Scenario 3 and baseline existing conditions simulations were run for 2012 – 2021, and the simulation results were analyzed to determine the hydrologic response of the Scenario 3 climate change assumptions. ***Figure 2*** presents the difference in wetland hydroperiods for 2012 - 2021 between Scenario 3 and the Baseline existing conditions scenario.

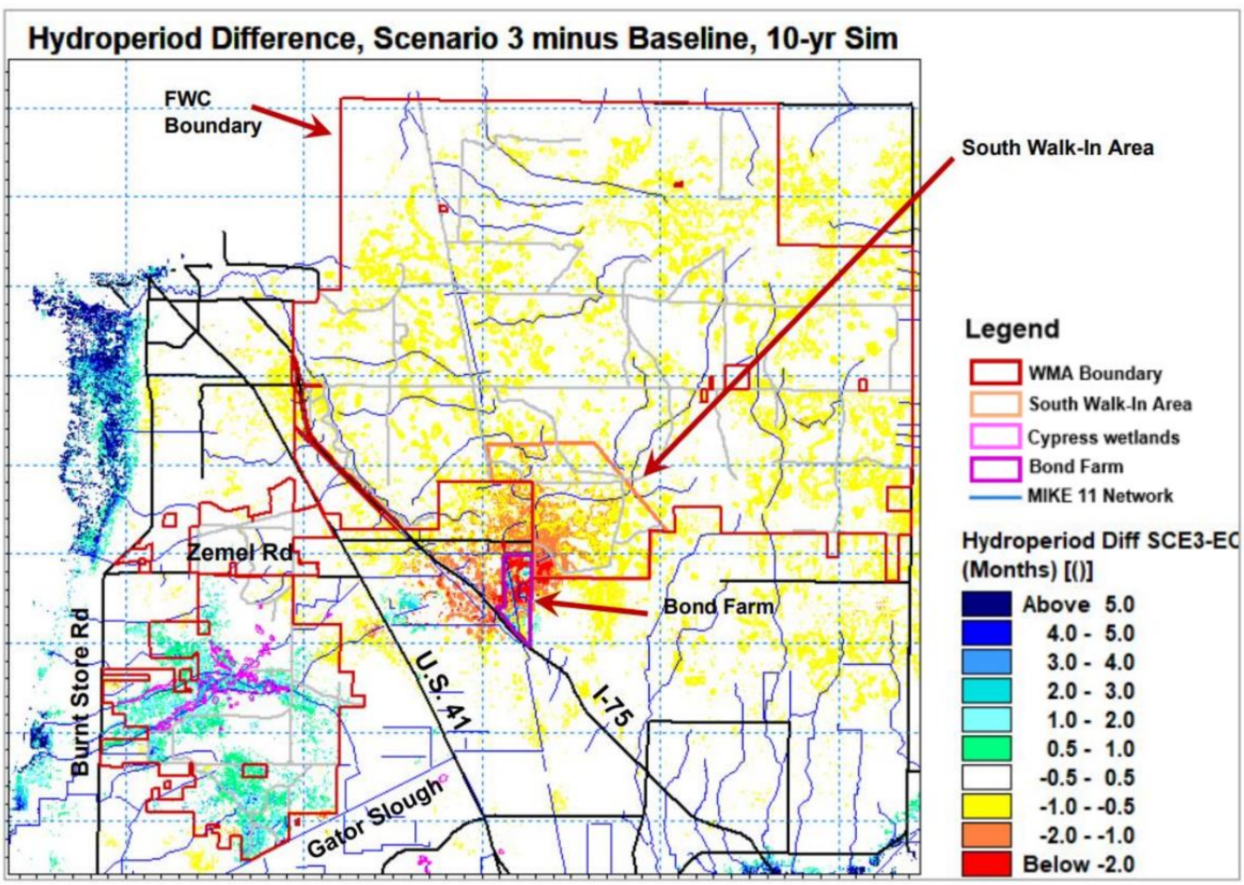

Figure 2. Scenario 3 minus Baseline average hydroperiod difference during the period 2012-2021, at a 50-ft resolution

Scenario 3 simulated hydroperiods are predicted to decrease slightly across much of Babcock Webb, and hydroperiod changes in the Babcock Webb South Walk-In Area are more prominent than for either Scenario 1 or 2 due to the increased ET associated with climate change. The difference between Scenarios 2 and 3 was evaluated as well, and are presented in ***Figure 3***. Overall, hydroperiods are reduced in both Babcock Webb and Yucca Pens by 0.5 -1 month in Scenario 3 due to projected changes in ET. Scenario 3 simulated hydroperiods are increased in tidally influenced areas west of Burnt Store Road and adjacent to the Caloosahatchee Estuary as compared to both Baseline existing conditions and Scenario 2 simulations (this change is due primarily to the sea level rise assumption).

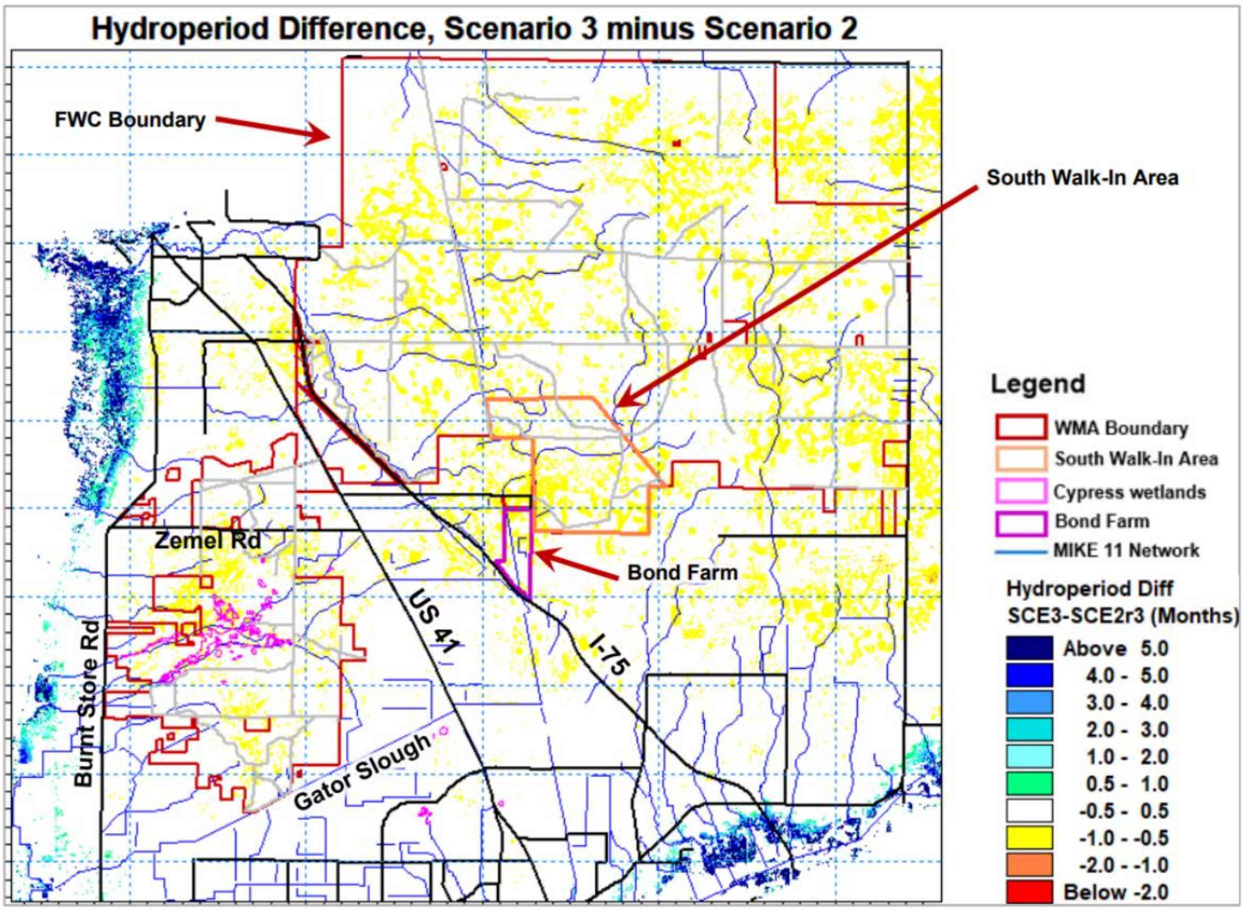

Figure 3. Scenario 3 minus Scenario 2 average hydroperiod difference during the period 2012-2021, at a 50-ft resolution

Wet season water depth differences associated with Scenario 3 relative to Baseline existing conditions are presented in ***Figure 4***. The restoration goals of reduced water depths in the South Walk-In Area of Babcock Webb and increased water depths in Yucca Pens that were achieved in Scenario 2 were still maintained in Scenario 3 with slight differences. The most significant difference between Scenario 2 and Scenario 3 is the increased water depths predicted in tidally influenced lands west of Burnt Store Road, as shown in ***Figure 5****.* Minor decreases in water depths are predicted for the South Walk-In Area of Babcock Webb. Wet season water depth differences between Scenarios 2 and 3 are minor, with reductions less than 0.1 ft in Yucca Pens Cypress and the most southern area of Yucca Pens. These results suggest that increased ET associated with climate change are not significant during wet season conditions.

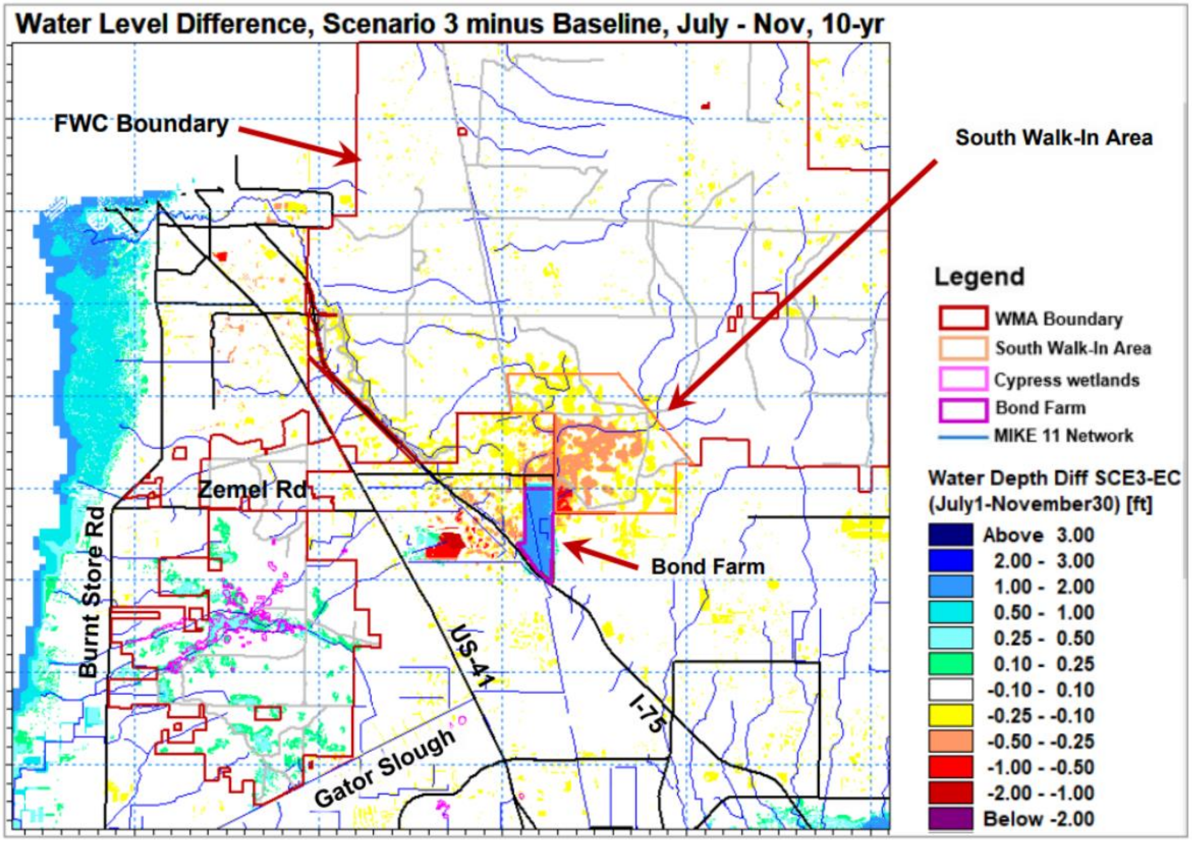

Figure 4. Scenario 3 minus baseline existing conditions average surface water depth differences for July 1 – November 30 during the period 2012-2021

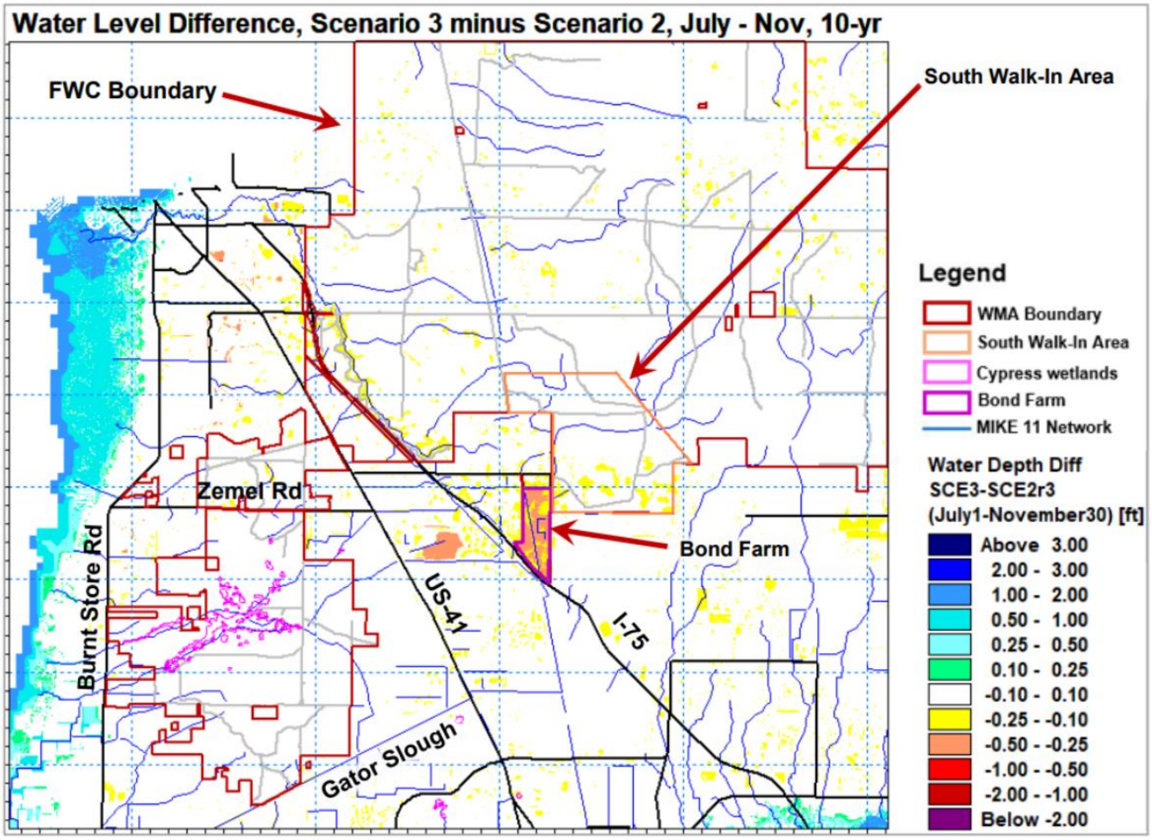

Figure 5. Scenario 3 minus Scenario 2 average surface water depth difference for July 1 – November 30 during the period 2012 - 2021

Dry season groundwater level differences between Scenario 3 and Baseline existing conditions are presented in ***Figure 6***. Groundwater levels are predicted to increase in the tidally influenced lands west of Burnt Store Road and adjacent to the Caloosahatchee Estuary due to the higher tidal water level boundary included in the climate change simulation. Dry season decreases in water levels are predicted in the most of Babcock Webb in Scenario 3, with groundwater levels decreasing by an average of 0.25 – 0.5 ft during the dry season months of March and April. Scenario 3 Yucca Pens dry season groundwater levels are still predicted to be higher than Baseline existing conditions in the southern portion and in the Durden and Yucca Pens Creek watersheds. Yucca Pens Scenario 3 groundwater levels are predicted to decrease between 0.1 and 0.25 ft in the vicinity of Zemel Road and along the eastern border of Yucca Pens.

Dry season groundwater level differences between Scenarios 3 and 2 are presented in ***Figure 7***. Scenario 3 groundwater levels are predicted to be lower than Scenario 2 levels throughout Babcock Webb and Yucca Pens. The smallest changes in groundwater levels (-0.1 to -0.25 ft) were predicted in the vicinity of the Babcock Webb South Walk-In Area and the watersheds of Durden and Yucca Pens Creeks. Therefore, Scenario 3 groundwater levels are 0.25 – 0.5 ft lower than Scenario 2 levels in most of Babcock Webb, the Zemel Road area of Yucca Pens, and the southern portion of Yucca Pens.

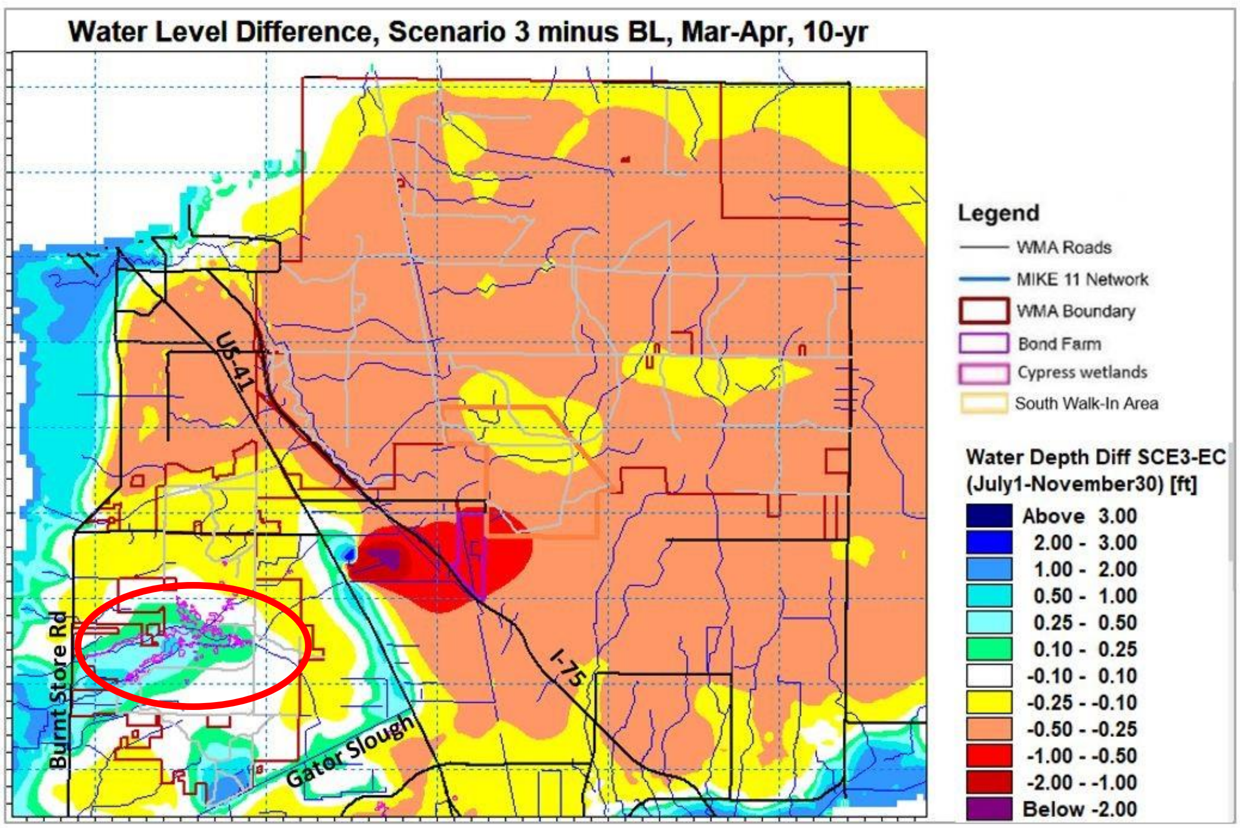

Figure 6. Scenario 3 minus Baseline Existing Conditions groundwater level difference in March – April during the period 2012 – 2021 (red ellipse indicates Yucca Pens Creek and Durden Creek watersheds)

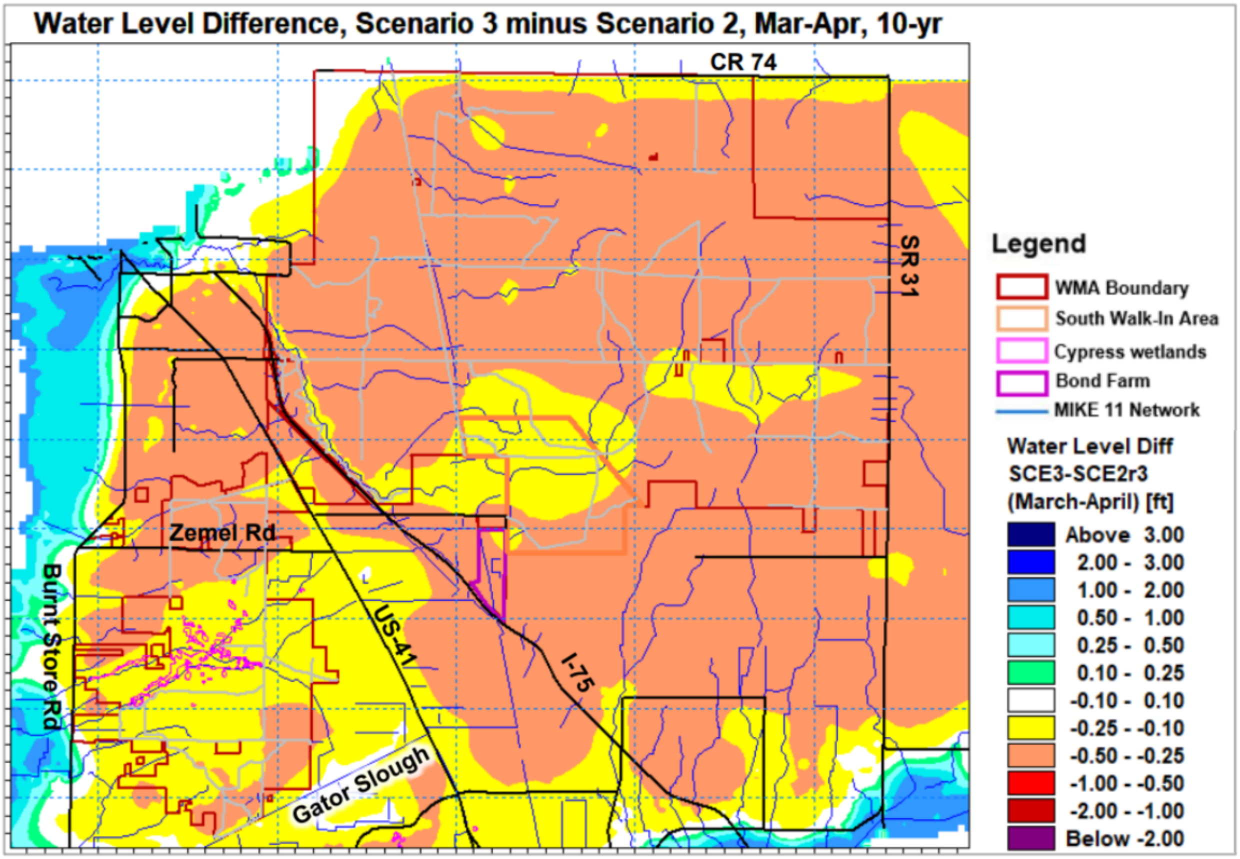

Figure 7. Scenario 3 minus Scenario 2 groundwater level difference in March – April during the period 2012 – 2021

Quantitative summaries of the changes in Yucca Pens in Scenario 3 are presented below in ***Table 3***. In Yucca Pens 2,163 acres experienced hydroperiod improvements greater than one month, compared to 3,465 acres that were improved for Scenario 1. This is a 38% **decrease** in area improved in Yucca Pens. When comparing Scenario 3 to Baseline existing conditions, water levels in the late dry season of March and April are still predicted to improve by greater than 1 foot for 304 acres. Thus, the proposed weirs and/or low water fords in Yucca Pens provide hydrologic benefits in spite of the climate change assumptions.

Table 3. Summary of Scenario 3 hydroperiod and March – April water level improvements in Yucca Pens relative to baseline existing conditions

Hydroperiod Difference	Area, ac. (S3-Baseline)	+/- from S2, ac.	Avg Hydroperiod Change, months
> 2 months	+754	-327	+2.87
1 - 2 months	+1,409	-975	+1.39
0.5 - 1 months	+1,850	-949	+0.73
0.25 - 0.5 months	+1,508	-928	+0.36
Total (> 0.25 months)	**+5,463**	**-3,237**	**+1.07**
Water Elevation Difference, March - April	**Area, ac. (S3-Baseline)**	**+/- from S2, ac.**	**Avg Elevation Change, ft**
> 2 ft	0	-2	0.00
1 - 2 ft	+304	-124	+1.24
0.5 - 1 ft	+963	-1,248	+0.66
0.25 - 0.5 ft	+2,285	-3,155	+0.36
0.1 - 0.25 ft	+2,761	-4,789	+0.17
Total (> 0.1 ft)	**+6,313**	**-9,318**	**+0.36**

Quantitative summaries of the changes in Babcock Webb in Scenario 3 are presented in ***Table 4***. Scenario 2 improvements in hydroperiods and water levels were maintained and slightly increase overall in Scenario 3. Hydroperiod and water depth increases in Yucca Pens for Scenario 3 are still better than for the baseline existing condition scenario, however the improvements are less significant than for Scenarios 1 and 2. This is because Scenario 3 evapotranspiration rates are higher than for either Scenarios 1 or 2 (due to the climate change assumptions). Improvements gained from Scenario 2 projects in Yucca Pens continue to provide restoration benefits in Scenario 3. Hydroperiod and water depth decreases in the SWIA of Babcock Webb are more pronounced for Scenario 3 than for Scenario 2, again due to the increased evapotranspiration associated with climate change. This is a benefit for the SWIA, but is a negative impact in the remainder of Babcock Webb where reductions in hydroperiods and water depths are not desired. In Scenario 3, wetland hydroperiods and water depths were reduced throughout most of Babcock Webb. Hydroperiods in Scenario 3 will be 1 - 2 months shorter than Baseline existing conditions in 692 acres. Hydroperiods in Scenario 3 will be 0.5 - 1 month shorter than Baseline existing conditions for 14,155 acres. Water depths in Scenario 3 will decrease by 0.25 - 0.5 feet for 56,364 acres in Babcock Webb as compared to Baseline existing conditions. This change is primarily due to increased ET.

Table 4. Summary of Scenario 3 hydroperiod and March – April water level improvements in Babcock Webb relative to baseline existing conditions

Hydroperiod Difference	Area, ac. (S3-Baseline)	+/- from S2, ac.	Avg Hydroperiod Change, months
< -2 months	+94	+5	-2.65
-2 to -1 months	+692	+484	-1.23
-1 to -0.5 months	+14,155	+13,715	-0.63
Water Elevation Difference, March - April	**Area, ac. (S3-Baseline)**	**+/- from S2, ac.**	**Avg Elevation Change, ft**
-1 to -0.5 ft	+319	+279	-0.62
-0.5 to -0.25 ft	+56,364	+56,241	-0.29
-0.25 to -0.1 ft	+10,839	+9,165	-0.22

Simulated combined flows at Burnt Store Road for Greenwell Branch, Durden Creek, Yucca Pens Creek, and Hog Branch are presented in ***Figure 8***. In Scenario 3, peak flows are reduced for most rainfall or storm events, demonstrating a slight decrease in benefits gained in Scenario 1. The peak flow reduction is due to the extra water retained by the proposed 26 water control structures in Yucca Pens. However, the recession limb of each rain or storm event has been extended due to the restoration measures from Scenarios 1 and 2 and this overall benefit appears to continue for Scenario 3. Continued pursuit of extension of the recession limb in tidal creeks will provide the most benefits to downstream habitats and sportfish. Despite climate change impacts on the hydrology of both Babcock Webb and Yucca Pens, restoration measures continue to provide additional hydrologic benefits in Yucca Pens in extending the duration of positive discharges to tide during the early dry season. A statistical comparison of the changes in peak flows for both Scenarios 1, 2 and 3 is presented in ***Table 5***. Locations of the Burnt Store Road stations are presented in ***Figure 9***.

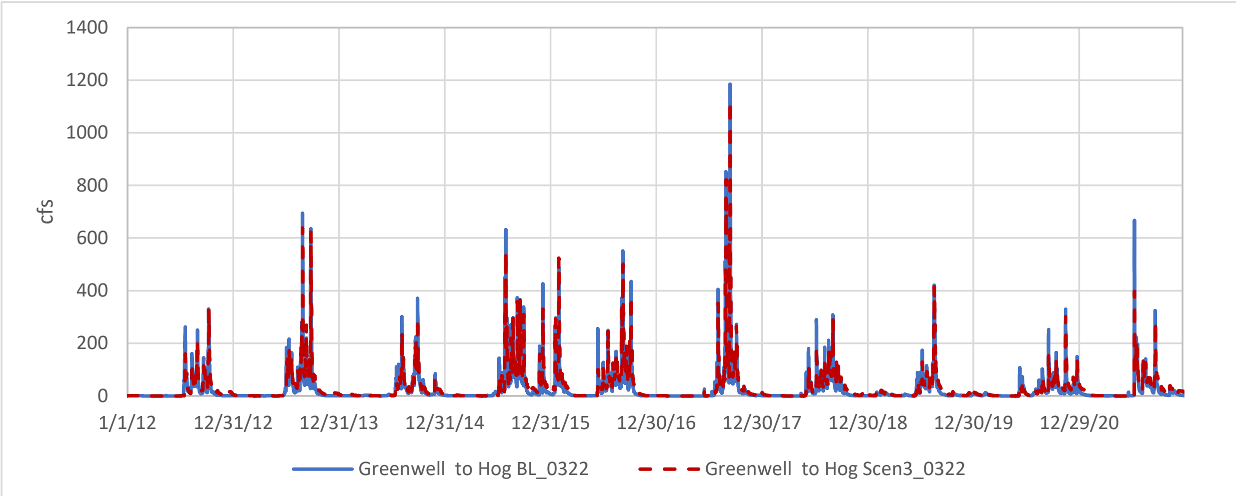

Figure 8. Simulated flows under Burnt Store Road for Greenwell Branch, Durden Creek, Yucca Pens Creek, and Hog Branch for Scenario 3 and Baseline Existing Conditions

Table 5. Comparison of changes in peak flows for 74 rain or storm events as compared to baseline, 2012 – 2021

Statistic	Scenario 1	Scenario 2	Scenario 3
Median Change in Peak Flow, %	-16%	-1%	-13%
25th Percentile Change in Peak Flow, %	-8%	+8%	-2%
75th Percentile Change in Peak Flow, %	-22%	-10%	-20%

Note: Changes were relative to the baseline existing condition scenario.

A detailed evaluation of simulated flows during the late wet/early dry seasons was conducted to highlight the differences between Scenarios 1, 2 and 3. Flows for November 1 through January 31 for each simulation year under Burnt Store Road from Greenwell Branch, Durden Creek, Yucca Pens Creek, and Hog Branch for Scenarios 1, 2 and 3 are compared in ***Table 6***. Scenario 3 maintains benefits from Scenarios 1 and 2. Despite climate change impacts on the hydrology of both Babcock Webb and Yucca Pens, restoration measures continue to provide additional hydrologic benefits in Yucca Pens in extending the duration of positive discharges to tide during the early dry season. Scenario 3 provides, on average, 65% more flow to tidal creeks during the late wet season and early dry season than Scenario 1.

Table 6. Simulated flows under Burnt Store Road for Scenarios 1, 2 and 3, Greenwell Branch to Hog Branch

Flows November 1 to January 31, acre ft			
Year	Scenario 1	Scenario 2	Scenario 3
2012	199	1,538	1,187
2013	138	1,041	877
2014	1,450	2,905	2,158
2015	10,018	13,590	12,763
2016	84	678	537
2017	563	2,155	1,918
2018	173	1,373	1,045
2019	469	1,552	1,193
2020	4,947	8,925	8,061
Averages	2,005	3,751	3,304

Note: The flow period that is being evaluated in this table is 11/1 through 1/31. The 2021 flow period would therefore be 11/1/21 through 1/31/22. Our simulation period ended on 12/31/21, therefore the amount for that period would only represent half of the evaluation period for that year. No flows are provided for 2021 since the simulation period ended 12/31/21, and the 2021 evaluation period would include January 2022, which was beyond the end of the simulation period.

Mitigation Efforts to Address Climate Change. The most significant dry season water level reductions occur in Babcock Webb. There are several corrugated metal pipe (CMP) risers and two gated weirs in Babcock Webb that are not actively managed, and changes to those structures could be implemented to adopt different control elevations during the wet and dry seasons. In order to mitigate climate change impacts, it is recommended that the structures remain in open or partially open positions during the wet season and gate elevations be raised at the end of the wet season to hold water on the landscape for the coming dry season. Additionally, there is potential to retrofit leaking riser structures with metal lift gates that can be installed on the upstream side of existing CMP risers (Halliday Products, Orlando, FL). Suggested specifications for these modifications are further explored in the recommendations section of the final report. Structures SR-2, SP-4, SP-5, SP-6, SP-7, SP-9, SP-9, and SP-10 are candidates for this type of operation. The location of these structures is shown in **Figure 10** below.

Lift Gates, https://www.hallidayproducts.com/

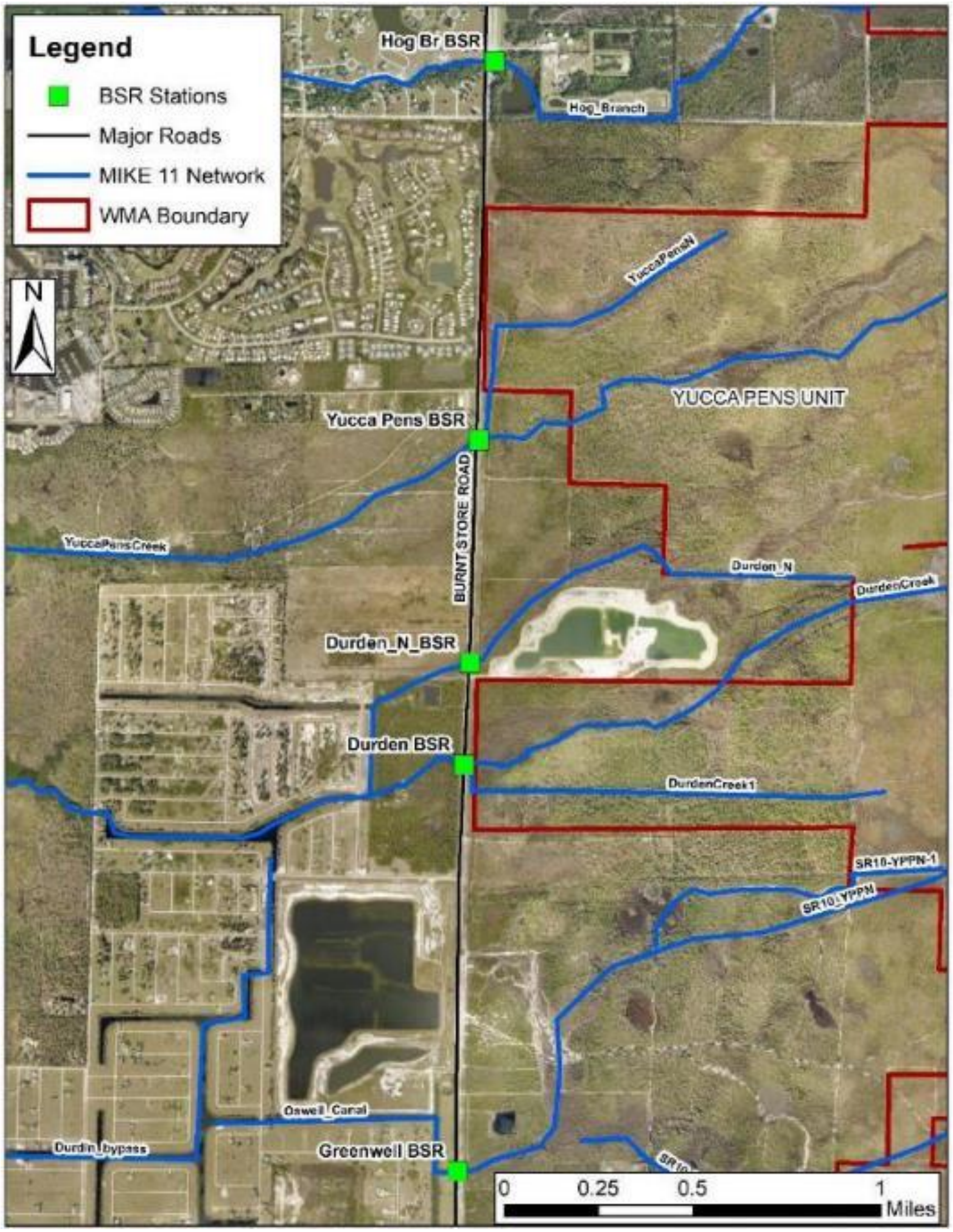

Figure 9. Locations of stations referenced in Figure 8

SIMULATED PERFORMANCE FOR THE BOND FARM HEI AND THE SOUTHWEST AGGREGATES RESERVOIR

Bond Farm HEI and Southwest Aggregates Reservoir operations for Scenario 3 are unchanged from Scenario 2. The Scenario 3 simulated inflows and outflows for Bond Farm HEI during the period of 2012 – 2021 are summarized below in ***Table 7***. Outflows are less than 50% of inflows for the final calibrated model (assumed lower water table hydraulic conductivity in Bond Farm HEI only). The depth range modeled was 15.0 to 25.0 ft-NAVD. The modeled inflow rate to the Southwest Aggregates Reservoir was limited to 35 cfs between June and November, and the outflow rate between March and May was limited to 26 cfs. Inflow rate was determined by iteratively testing inflow rates in the model to maximize storage in both Bond Farm HEI and the Southwest Aggregates Reservoir (by running pumps simultaneously it allows water to continuously be removed from Babcock Webb during the wet season to achieve desired restoration goals). The outflow rate was selected based upon prior water deliveries from Southwest Aggregates Reservoir to

US-41 ditches during 2017, 2020, 2021, and 2022. The majority of the difference between inflows and outflows is due to groundwater seepage (72%), with a small percentage due to evaporation (28%). ***Table 8*** presents results for a sensitivity analysis with hydraulic conductivities capped at 297 ft/day (see Scenario 1 Technical Memorandum for more information, WSA & CHNEP, 2022a).

Table 7. Simulated inflows and outflows for Bond Farm HEI and Southwest Aggregates Reservoir, Final Calibration (units in acre-ft)

Year	Bond In	Bond Out		SW Agg In	SW Agg Out
Storage Capacity	***2,400 acre-ft***			***4,744 acre-ft***	
2012	2,088	759		4,796	See note
2013	3,693	839		8,292	4,744
2014	455	429		3,164	4,744
2015	3,186	1,808		5,984	4,744
2016	4,589	819		9,091	4,744
2017	2,418	947		4,941	4,744
2018	3,982	634		7,523	4,744
2019	2,936	453		5,620	4,744
2020	3,494	1,798		4,953	4,744
2021	3,315	See note		6,697	4,744
Averages:	3,066	943		6,016	4,744
Avg Scen2	3,299	1,042		6,800	4,744

Note: Outflows not calculated in 2012 for SW Agg and 2021 for Bond.

Table 8. Simulated inflows and outflows for Bond Farm HEI and Southwest Aggregates Reservoir, Lower Hydraulic Conductivity (units in acre-ft)

Year	Bond In	Bond Out		SW Agg In	SW Agg Out
2012	2,006	1,286		4,157	See note
2013	2,659	1,329		8,005	4,744
2014	500	660		2,915	4,744
2015	2,475	2,293		5,588	4,744
2016	2,951	1,288		8,751	4,744
2017	1,864	1,408		4,665	4,744
2018	3,007	1,228		6,970	4,744
2019	2,424	1,147		4,960	4,744
2020	2,763	2,126		5,000	4,744
2021	2,885	See note		6,179	4,744
Averages	2,353	1,418		5,719	4,744
Avg Scen2	2,448	1,524		6,413	4,744

Note: Outflows not calculated in 2012 for SW Agg and 2021 for Bond. Final calibration model is described in TM 5c (WSA & CHNEP, 2022b). Reduced hydraulic conductivity sensitivity analysis is described in WSA & CHNEP, 2022a

The sensitivity analysis with capped conductivities indicates lower overall losses to groundwater. On average, simulated Bond Farm HEI outflows were 62% of simulated inflows for the reduced hydraulic conductivity sensitivity analysis simulation. Scenario 3 assumptions result in a 10% decrease in the volume of water stored in Bond Farm HEI and the Southwest Aggregates Reservoir as shown below:

Total Stored Bond Farm HEI plus SW Agg Scenario 2: 10,099 acre-ft (final calibration)

Total Stored Bond Farm HEI plus SW Agg Scenario 3: 9,082 acre-ft (final calibration)

Tables 7 and **8** both show that Bond Farm HEI would not fill during 2014, a year with low wet season rainfall. Recommended refinements are included in the final report for the operating protocols for the Bond Farm HEI and Southwest Aggregates Reservoir inflow pumps so that the priorities for turning on both pumps may be varied through a series of sensitivity tests to obtain simulation results where Bond Farm HEI is filled to full capacity before the Southwest Aggregates Reservoir is filled during all simulation years. One possible approach is to have different operating rules for dry years where the Southwest Aggregates Reservoir inflow pump turns on at a higher trigger elevation, which will maximize inflows to the Bond Farm HEI.

SUMMARY OF SCENARIO 3

Scenario 3 maintained hydrologic improvements from Scenario 2. The only differences between the two scenarios were the higher tidal boundaries and higher evapotranspiration rates that were assumed for Scenario 3. The hydrologic improvements maintained from Scenario 2 were:

- Bond Farm HEI would be used to store water up to a depth of 4 ft with water discharged west to Yucca Pens during the dry season.
- Additional storage is provided in the Southwest Aggregates mine property.
- Weirs in Yucca Pens will be constructed that will increase on-site detention in the historic wetlands of Yucca Pens. The weirs will consist of structures ranging from ditch blocks in eroded ATV trails, low water fords, and concrete weirs.
- A partial seepage barrier along the southern portion of Yucca Pens just north of Gator Slough. At this point, it is anticipated that this seepage barrier will not be a complete barrier to groundwater flow but will reduce seepage rates to the degree that hydroperiods are increased in Yucca Pens wetlands north of Gator Slough.

The Scenario 3 simulation results suggest that:

- Improved wet season water depths from Scenario 2 will not change substantially in either Babcock Webb or Yucca Pens due to Scenario 3 climate change assumptions.
- Dry season water levels will decrease by 0.25 to 0.50 feet in most of Babcock Webb due to Scenario 3 climate change assumptions.
- Scenario 3 dry season water levels will still be higher than baseline existing conditions in most of Yucca Pens south of Zemel Road, however the water level improvements will be lower than for Scenario 2.
- Scenario 3 discharges under Burnt Store Road are 12% less than Scenario 2 between November 1 and January 31. However, discharges under Burnt Store Road during this period are still 65% higher than baseline existing conditions.
- Scenario 3 assumptions result in a 10% decrease (relative to Scenario 2) in the combined volume of water stored in Bond Farm HEI and the Southwest Aggregates Reservoir.

Based on the analysis described herein, while restoration benefits will be maintained, climate change assumptions will present additional challenges to future restoration planning and design efforts. Significant uncertainties exist when attempting to predict the changes in rainfall due to climate change. Climate change assumptions should be reviewed throughout the preliminary and final design of proposed restoration projects and effects of climate change on restoration measures should be evaluated using the best available information on future changes in tidal fluctuations, rainfall, and evapotranspiration (ET).

Dry season control elevations at existing water control structures are recommended for further consideration to mitigate the potential changes associated with climate change. There are several corrugated metal pipe (CMP) risers and two gated weirs in Babcock Webb that are not actively managed, and changes to those structures could be implemented to adopt different control elevations during the wet and dry seasons. In order to mitigate climate change impacts, it is recommended that the structures remain in open or partially open positions during the wet season and gate elevations be raised at the end of the wet season to hold water on the landscape for the coming dry season. Additionally, there is potential to retrofit leaking riser structures with metal lift gates that can be installed on the upstream side of existing CMP risers (Halliday Products, Orlando, FL). Structures SR-2, SP-4, SP-5, SP-6, SP-7, SP-9, SP-9, and SP-10 as well as a number of other risers that are not actively managed are candidates for this type of operation. Locations for potential structures recommended for modification are shown in **Figure 10**.

As with recommendations for Scenario 2, further model refinements are recommended during subsequent restoration planning and design efforts. Simulation refinement is suggested for more optimal results in peak flows to tide during the wet season. Scenarios 2 and 3 include a flow-way to send water from Bond Farm HEI west to Yucca Pens only during the dry season (Dec-Jan), and thus, the flow-way is blocked at the east side of US-41 so that water cannot pass throughout the remainder of the year. However, there is potential for high water levels in US-41 ditches to route water west into Yucca Pens during the wet season, minimizing the improvements to hydroperiods in Yucca Pens. Therefore, it is recommended that modeled design plans include a gated structure in US-41 ditches in order to maintain hydroperiod benefits in Yucca Pens and reduce peak flows during the wet season. Additional calibration is recommended to decrease uncertainties regarding groundwater hydraulic conductivities, and this effort may indicate that greater restoration can be achieved by the hydrologic improvements assumed for Scenarios 2 and 3. Recalibration may indicate more substantial Yucca Pens peak flow reductions at Burnt Store Road. In addition, refinements are recommended for the operating protocols for the Bond Farm HEI and Southwest Aggregates Reservoir inflow pumps so that filling of either may have dynamic priorities.

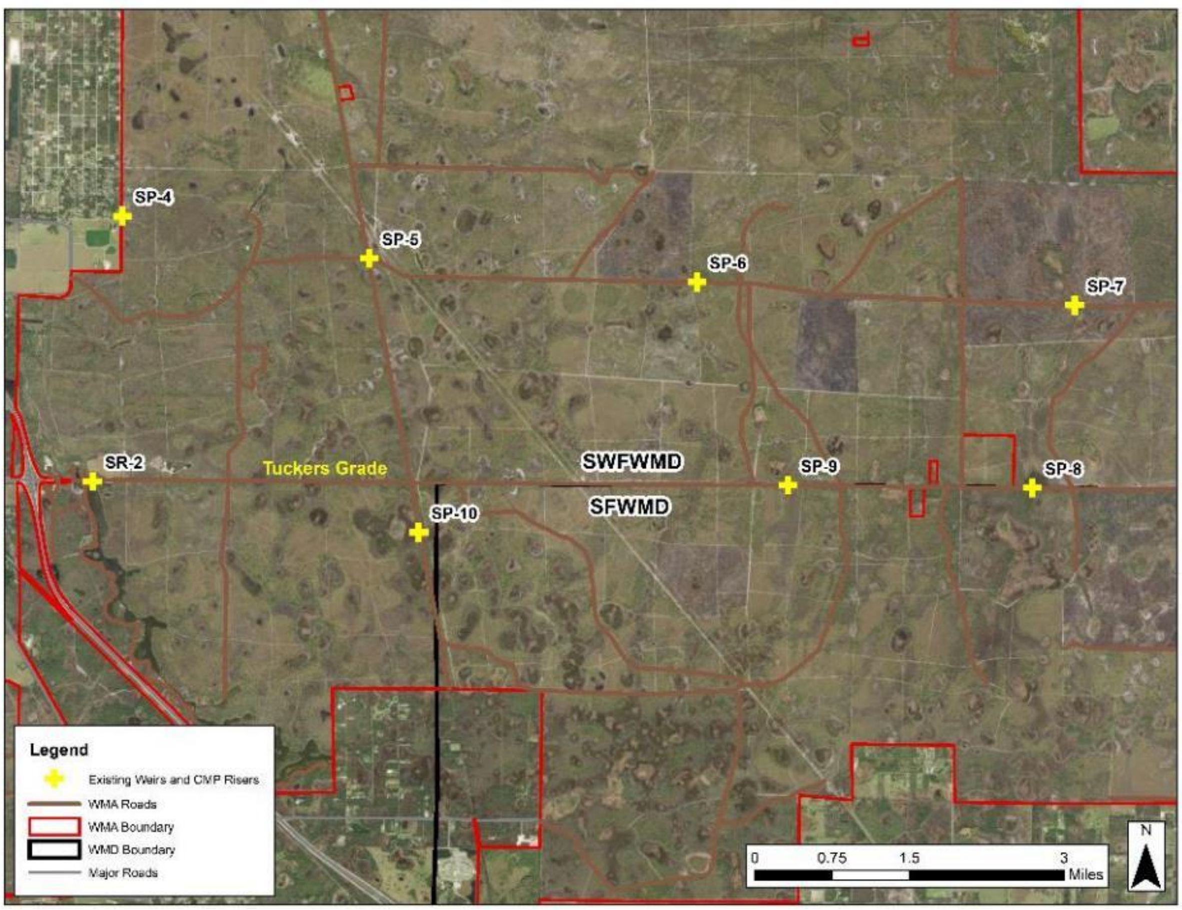

Figure 10. Locations of Existing Water Control Structures on Babcock Webb to be considered for Retrofits

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