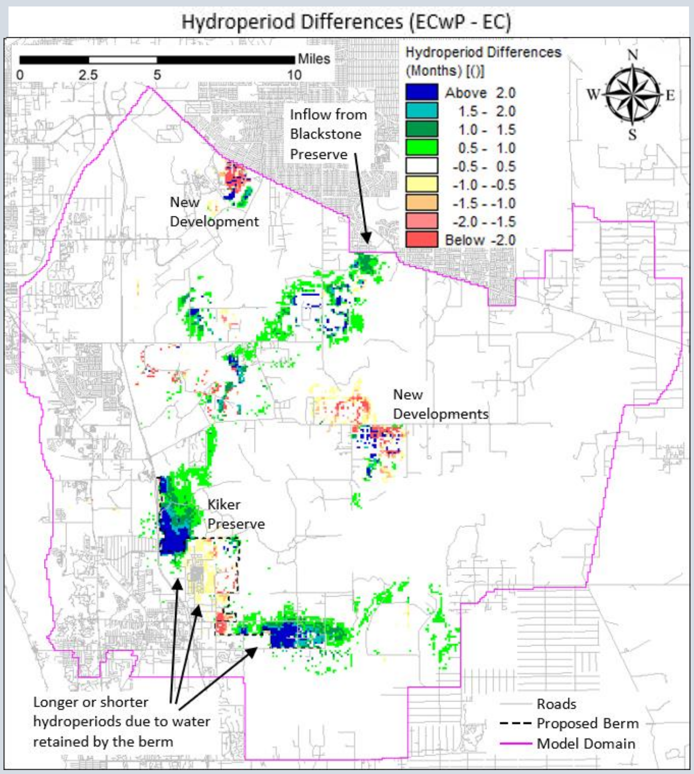
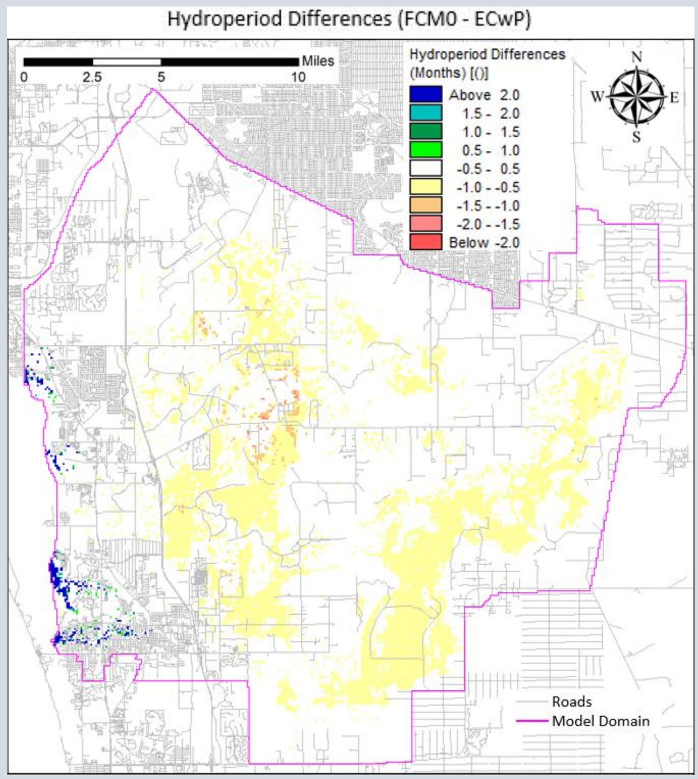
South Lee County Watershed Initiative Hydrological Modeling Project

Final Report





Prepared by:

COASTAL & HEARTLAND NATIONAL ESTUARY PARTNERSHIP

LAGO Consulting and Services

December 2021

Table of Contents

Introduction

Project Origins

The South Lee County Watershed (SLCW) is comprised of the Estero River, Spring Creek, and Imperial River watersheds, all of which flow into the Estero Bay Aquatic Preserve. These riverine and tidal creek systems are primary nursery areas for fisheries, providing food and habitat to numerous species of fish and shellfish including snook, redfish, tarpon and oysters. Over the past 100 years, these wetland ecosystems have been heavily impacted by man-made changes in hydrology. The conversion of native wetland habitats to agriculture or development, installation of drainage canals, surface mining, and construction of major roadways such as Corkscrew Road, SR. 82, US 41 and I-75, have significantly altered the historic sheet flow from the southern region of Lehigh Acres south to the Corkscrew Sanctuary and southwest to Estero Bay. As a result, the vast wetland ecosystems within the SLCW are susceptible to over-drainage, flooding, habitat changes, water quality degradation, and climate change stressors. In some instances, the rivers and creeks in this area experience too much flow during the wet season and too little flow during the dry season to support associated wetlands and downstream waterbodies.

To address these concerns, stakeholders in the region came together to form the South Lee County Watershed Initiative (SLCWI), which aims to restore more natural water flows, improve water quality and environmental conditions, and increase natural water storage while improving moderation of flooding events. Stakeholders include the Coastal and Heartland National Estuary Partnership (CHNEP), South Florida Water Management District (SFWMD), Lee County, Collier County, City of Bonita Springs, Village of Estero, Conservancy of Southwest Florida, Water Science Associates, Lago Consulting, Bonita Springs Utilities, Florida Department of Transportation, Audubon Society, ECCL, ADA Engineering, Southwest Florida Regional Planning Council, AIM Engineering, Stantec, Waldrop Engineering, JR Evans Engineering, Audubon – Corkscrew Swamp Sanctuary, Hole Montes, Lehigh Acres MSLD, University of Florida Institute of Food and Agricultural Sciences (UF/IFAS), Calusa Waterkeeper, WSP, Estero Council of Community Leaders, Florida Gulf Coast University (FGCU), and Charlotte Soil & Water Conservation.

The SLCWI stakeholders identified the need for a Strategic Hydrological Modeling and Planning project as the highest joint priority at their April 5, 2017 meeting, drafting the following mission statement: “To ‘get the water right’ in identifying what needs to happen to restore and maintain our water supply, flood protection, water quality and water-dependent resources in the face of existing degradation and depletion, sea level rise, and continued regional growth”.

Project Purpose

The overarching purpose of this project was to identify opportunities to restore more natural hydrology and water quality to improve environmental conditions, in a way that complemented efforts to also increase storage and moderate high flow events to provide greater flood protection in the region. The anticipated results would be restored wetland levels and hydroperiods (duration of inundation), improved water quality, improved habitat for wetland-dependent wildlife species, as well as protection of public freshwater drinking water supplies.

The project involved developing a science-based, data-driven, strategic hydrological planning tool to provide guidance to resource management agencies related to the appropriate restoration and management of surface waters currently flowing from the SLCW and discharging into the Estero Bay

Aquatic Preserve. The Strategic Hydrological Planning Tool provides SLCWI project partners and stakeholders with the needed information to determine the timing, distribution, quantity, and quality of the water needed to improve the historic surface water flows of the Estero River, Spring Creek, and Imperial River to Estero Bay.

The project is intended to be additive to other local efforts in order to fill gaps and bridge various modeling efforts to create a regional watershed-scaled picture. The modeling effort in this project has been coordinated and designed to complement other models recently completed for the Village of Estero, Lee County, and the Corkscrew Swamp Watershed Initiative Hydrological Modeling Project, as well as integrates existing appropriate ecological data from the Density Reduction/Groundwater Resource (DRGR) studies in Lee County and Bonita Springs. This project generated an up-to-date integrated surface/groundwater hydrological model that is capable of simulating both dry and wet season water levels and flows in the Estero and Imperial River watersheds and is sufficient for evaluating wetland hydroperiods and depth ranges in the wetlands in the basin.

Project Team

The project team consists of staff from the Coastal & Heartland National Estuary Partnership (CHNEP), including Jennifer Hecker, Nicole Iadevaia, Sarina Weiss and Andrew Webb; Lago Consulting, including Marcelo Lago and Maria C. Bravo; Water Science Associates (WSA), including Roger Copp and Kirk Martin; Church Environmental, including Church Roberts; and Southwest Engineering & Design (SED), including Gary Bayne. CHNEP served as the project manager and assisted in the drafting of this final report. Lago Consulting and WSA were the leads on data collection and modeling and assisted in the drafting of this final report. They also led the drafting of all Technical Memoranda that serve as appendices to this report. SED and Church Environmental assisted in field data collection and verification.

Data Collection and Model Building

This modeling effort is intended to be additive to existing regional flood mitigation and hydrological restoration efforts underway in this basin. This includes the Southern Lee County Flood Mitigation Plan to address serious flooding that has occurred periodically in portions of South Lee County. Additionally, the City of Bonita Springs has conducted a number of studies in response to flooding during Hurricane Irma. To complement these efforts and assist in optimizing proposed projects to maintain the desired level of flood reduction while improving natural resource protection, as well as to identify other potential hydrological restoration projects, this hydrological modeling effort was undertaken.

The initial steps were taken to gather and improve existing data sets, collect limited additional new data, and to conduct field verifications. Once the data was sufficient, the model was refined and calibrated to be more sophisticated than its predecessors in this region, allowing for more accurate modeling analysis to be conducted. The updated model was then used to simulate existing conditions, predevelopment conditions of what natural systems need in terms of water levels and flows, as well as five future condition scenarios to consider recent and proposed future projects, climate change, and three future landuse scenarios (maximum restoration, maximum development, and intermediate restoration/development). From looking at these modeling results, recommendations were formulated for proposed future modeling and proposed hydrological restoration projects. This section summarizes the aspects of the project involving the data collection and model-building activities.

Collection of Prior Model Information

Recent prior models in the South Lee County watersheds were reviewed and used as starting point to develop the new existing conditions MIKE SHE model, referred herein as SLCWI Model (details available in **Appendix A**: Gather Existing Data and Models Technical Memorandum).

The prior models utilized (see **Figure 1** showing some of the various model boundaries/domains) include:

- The Corkscrew Swamp Sanctuary (CSS) MIKE SHE Model [WSA, 2020b]. Derived from the Big Cypress Basin (BCB) model [LAGO and Stanley, 2020] and the Edison Farm models.
- The Lehigh Acres Municipal Improvement District (LA-MSID) MIKE SHE Model [WSA, 2020a].
- Edison Farm MIKE SHE Model. Derived from the Village of Estero Model [WSA, 2018], which was based on the Density Reduction Groundwater Recharge (DRGR) Model of the South Lee County region [DHI, 2009].
- The Southern Lee County Flood Mitigation Plan (see SLCR in map below) MIKE SHE Model [AIM, 2020]. Derived from the Village of Estero and the LA-MSID models.
- The City of Bonita Springs ICPR Model [LAGO, 2019], domain not shown in map below.

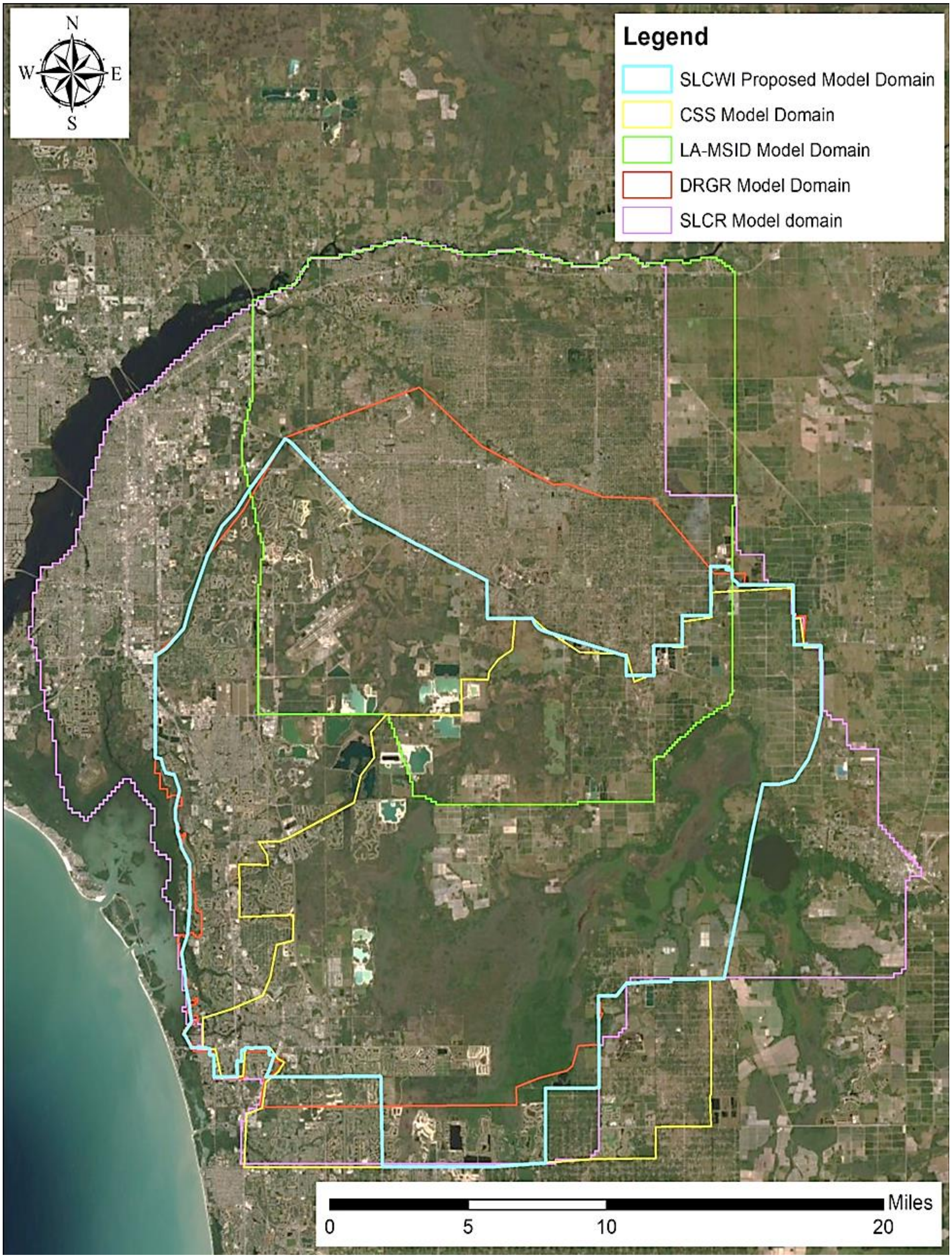


Figure 1. Model Domains for Models of South Lee County

A preliminary SLCWI Model for this project (outlined in blue in Figure 1) was built after merging information from those models. The new model domain covers an area of 363 square miles, south of the SR-82 and north of the Cocohatchee Canal (located just north of Immokalee Road).

Collection and Verification of Existing Field Data

This project collected and utilized data from a variety of existing sources. Once existing data sources were identified, efforts ensued to improve and expand existing data sets as well as to collect some limited additional data needed for the project modeling phase. All of this is outlined in detail in **Appendix B**: Monitoring Planning and Field Verifications Technical Memorandum, **Appendix C**: Field Investigations Technical Memorandum, **Appendix D**: Vegetation Coverage Data Compilation and Processing Technical Memorandum, **Appendix E**: Irrigation Data Compilation and Processing Technical Memorandum, and **Appendix F**: Time Series Update Technical Memorandum.

In summary, the project activities related to data collection and improvement of existing data included:

- Barometric pressure data from 10 wells at Kiker Preserve to improve accuracy of observed water levels
- Observed stages from 5 stations at Halfway Creek from private engineering firm
- Bonita Springs Utilities observation water level data from 8 wells
- Daniels Parkway monitoring well data at 2 deep wells from Lee County
- Wild Blue observation water levels at 6 stations from a private engineering firm
- Green Meadows observation water levels at 10 stations from Lee County Utilities
- Panther Island Mitigation Bank observation water levels from 10 stations from Corkscrew Swamp Sanctuary
- Lee County Port Authority Mitigation Bank observation water levels at 10 stations from Lee County Port Authority
- Florida Gulf Coast University water level data at one station, as well as photographic records of water levels immediately preceding and following Hurricane Irma, from Florida Gulf Coast University
- Corkscrew Swamp Sanctuary monitoring well and staff gage data, from the Sanctuary and as collected by the project consultant team
- Irrigation and reuse water application rates from Lee County and Bonita Springs Utilities
- NEXRAD rainfall and rain gauge data from DBHYDRO and Lee County
- Reference Evapotranspiration rates from the USGS
- Potable Water Supply extraction well data from the SFWMD
- Accurate ground elevations from four survey transects (total length 4.3 miles) in Corkscrew Swamp Sanctuary and Bird Rookery Swamp

Conversion of Existing Land Use Data

The SLCWI Florida Land Use Cover Classification System (FLUCCS) codes were converted to a smaller set of MIKE SHE codes for use in the SLCWI Model. Their polygon shape files were resampled to a 375-ft grid resolution as well as adjusted to reflect known recent land use changes not reflected in the original FLUCCS coding. For pre-development conditions, the mapped land cover types established in the Southwest Florida Feasibility Study were utilized.

Figure 2 reflects the existing conditions MIKE SHE vegetation codes used in the SLCWI Model.

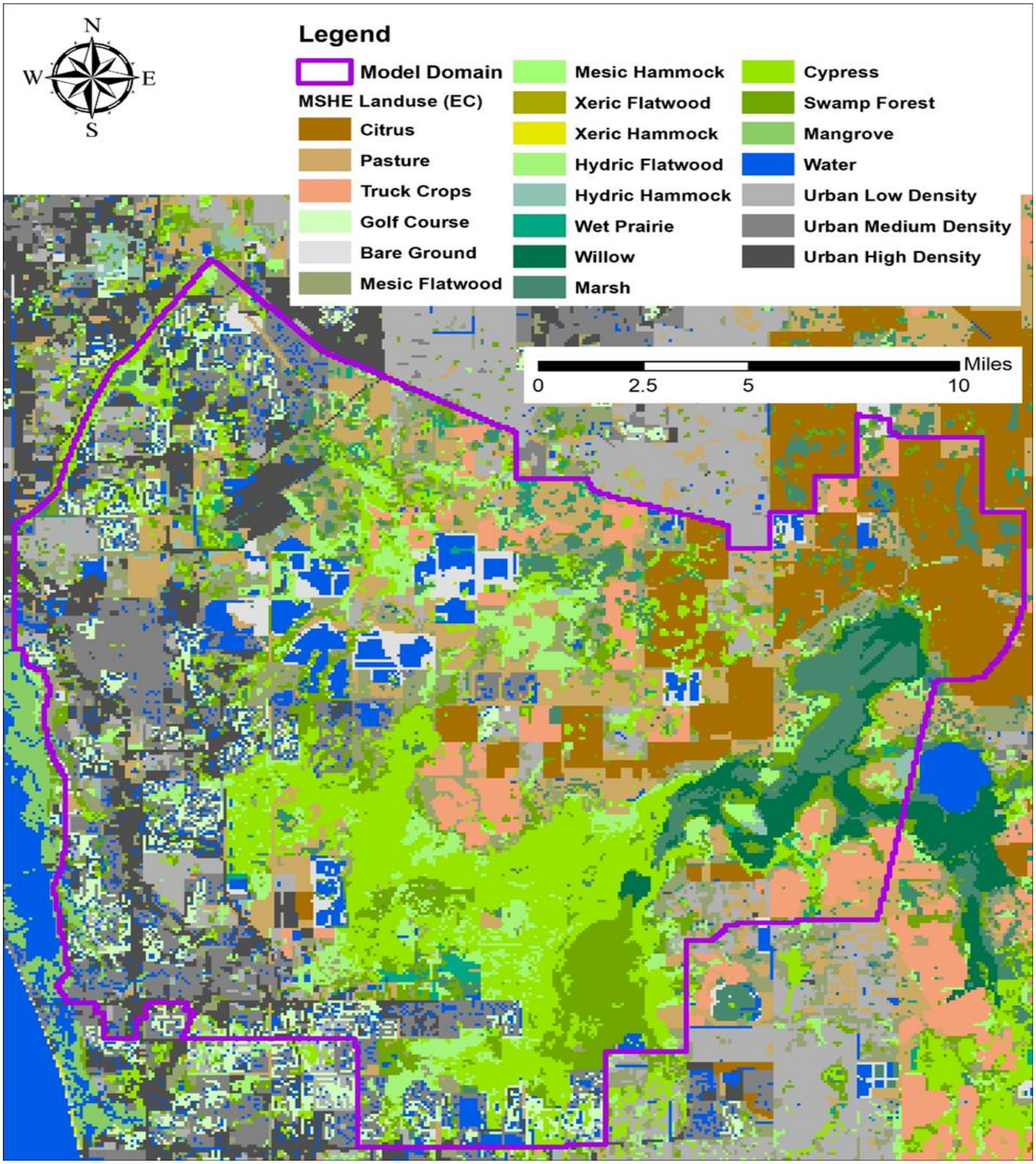


Figure 2. Existing Condition Land Use in the MIKE SHE Model

Collection of Additional Data

The project also involved some limited efforts to gather additional data, including:

- A number of ground elevation points were surveyed with a global navigation satellite system (GNSS) receiver (see ground elevations survey points outlined as symbols in **Figure 3**).

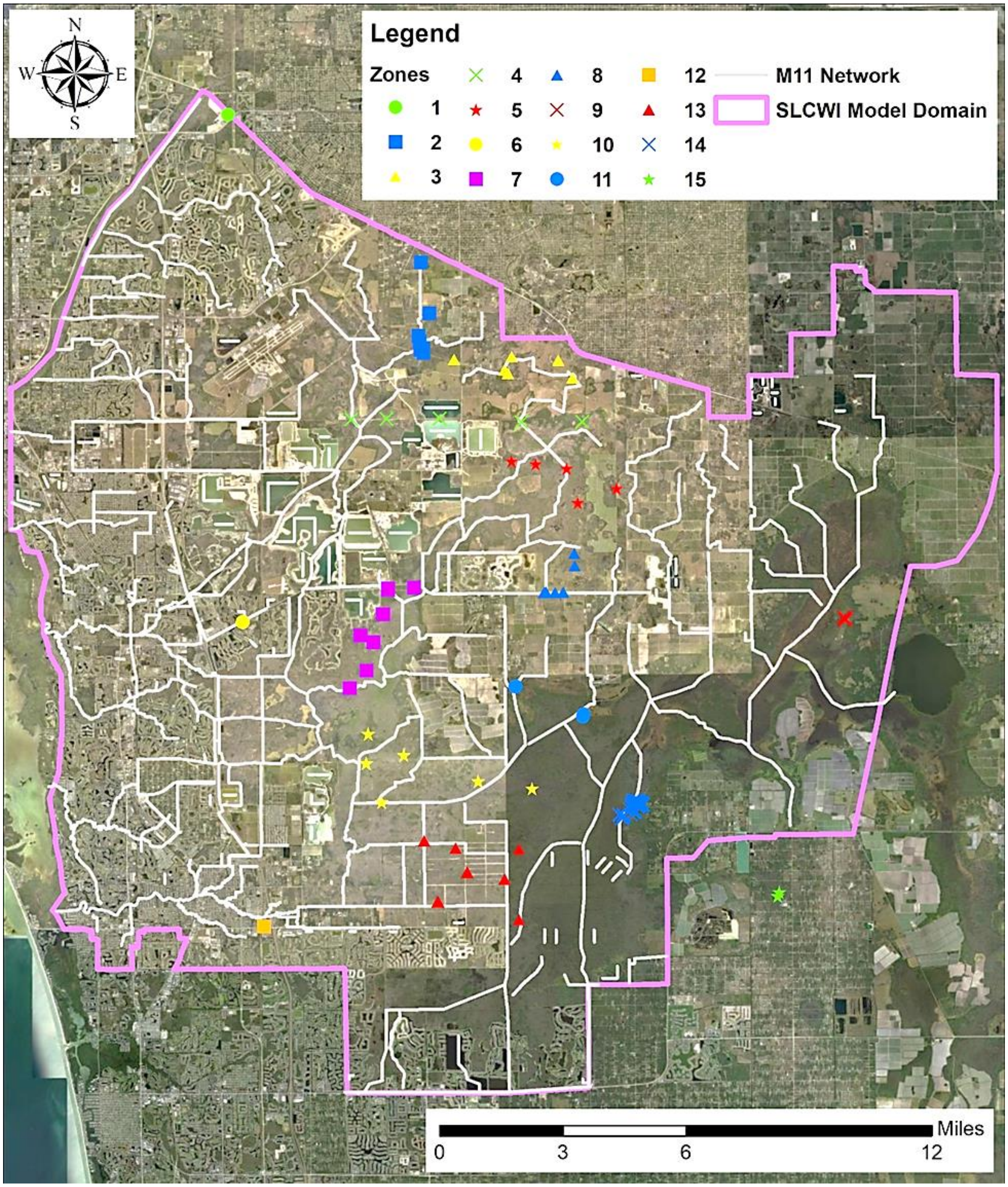


Figure 3. Locations of Surveyed Elevations of Vegetation Evaluation Sites

- A number of field visits were conducted to verify the presence, dimension, and invert elevation of hydraulic structures (hydraulic structure sites visited outlined as green stars in **Figure 4**).

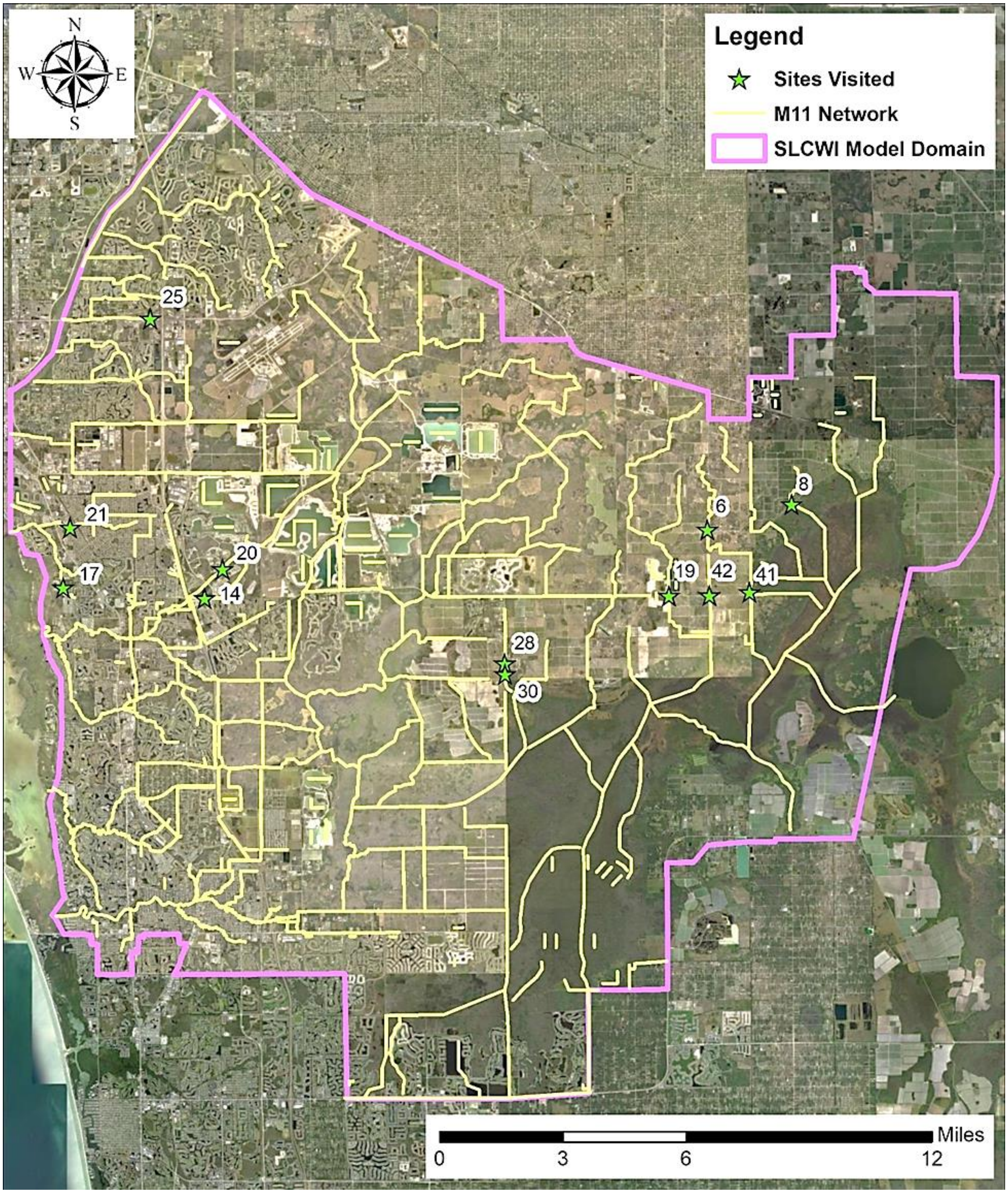


Figure 4. Field Surveyed Elevation Locations

- A number of field visits by the consulting team ecologist and survey crew were conducted to assess a variety of vegetative indicators for estimation of average wet season water depths (wet season water depth assessment sites outlined as yellow and peach stars in **Figure 5**).

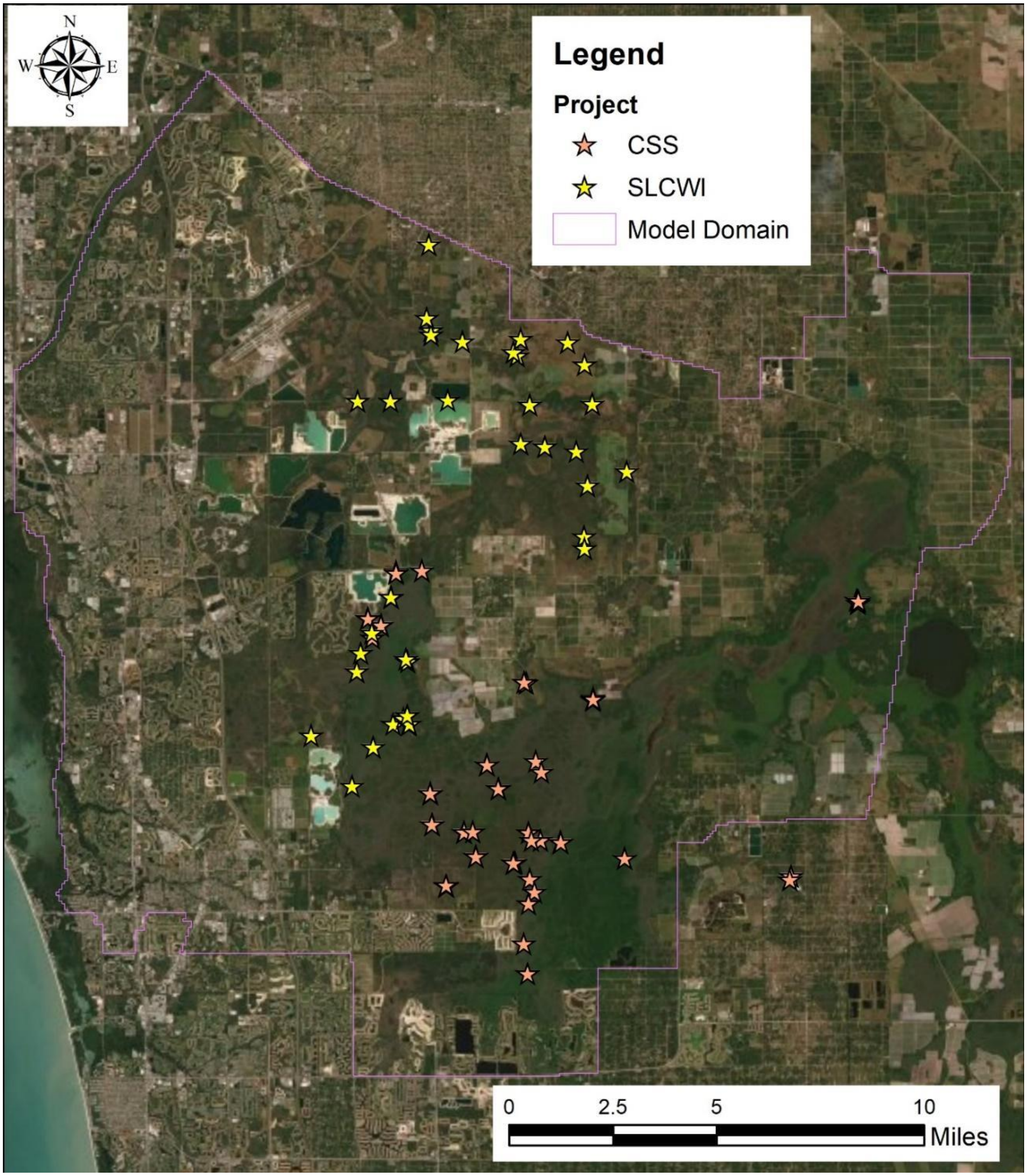


Figure 5. Locations Visited to Estimate Average Wet Season Water Depth from Vegetation Indicators.

The improved and collected data sets were later used in the integrated surface/groundwater SLCWI Model.

Model Calibration

A preliminary version of the SLCWI Model was built using the MIKE SHE input files from recent models and conducting a number of necessary updates (details available in **Appendix G**: Preliminary Model Performance Technical Memorandum). The calibrated model was developed from the preliminary model with input from the SFWMD review team and the additional calibration effort.

Model calibration focused on improving the model input data and better representing the existing surface water movement in the watershed during the simulation period 2013-2019 (details available in **Appendix H**: Model Calibration Technical Memorandum). The calibration was further refined by adjusting model parameters to better match the observation data.

In summary, the project activities related to model calibration included:

- Obtaining corrected LiDAR-based topographic maps at 50-ft and 375-ft spatial resolutions
- Redrawing surface water (MIKE11 branch) paths and introducing new branches to better represent the channelized flow network
- Adding or revising hydraulic structures based on surface water management permit information and field visits
- Re-cutting cross-sections from the latest Light Imaging and Detection and Ranging (LiDAR)-based Digital Elevation Model (DEM)
- Defining short branches to represent storage and outfall structures within urban developments and to represent pump-driven drainage in some of the agricultural areas.
- Modifying Separated Overland Flow Area (SOLFA), flood, and drain code maps accordingly
- Enhancing the vertical distribution of the specific yield (S_y) by dividing the Water Table Aquifer in two computational layers
- Adjusting the crop coefficient (Kc) and moisture deficit start/stop values to improve predicted flow at observation stations and predicted irrigation amounts at some large water use permits
- Adjusting the maximum allowable irrigation application rate
- Adjusting saturated zone (SZ) hydraulic conductivities
- Adjusting overland and river Manning's coefficient M

Sensitivity tests were conducted on several model input parameters during the second part of the calibration task. The model sensitivity was evaluated using statistical measures at observation stations. The tests concluded that model results were most sensitive to saturated zone (SZ) hydraulic conductivities, vegetation crop coefficient (Kc), irrigation maximum application rate, and overland and river Manning's coefficient M. Accordingly, hydraulic conductivities in the SZ component were adjusted consistently within the range of variations from previous models and other literature sources. The iterative procedure generated conductivity maps for each geologic layer that produced lower overall mean absolute error (MAE) at water level observation stations. In terms of vegetation-related parameters, the crop coefficient (Kc) and the moisture deficit start/stop values were adjusted to improve predicted flow at observation stations and predicted irrigation amounts at some large water use permits with reported irrigation data. The maximum allowable irrigation application rate was also adjusted for the same purpose. Finally, the bed roughness coefficient Manning's M (i.e., reciprocal of Manning's n) was increased by 20% in order to increase the predicted surface water flows at observation flow stations.

Comparisons of preliminary and calibrated model results at observation stations showed an overall improvement in the model performance after the calibration. There were visible improvements in the hydroperiod and water depth maps from the preliminary to the calibrated models.

Topographic data for this project was available from regional topographic data sets created from LiDAR technology. LiDAR data is collected from airplanes that uses lasers to measure the distance (range) from the airplane to the ground. These measurements are combined with position and orientation data to generate a database of elevations that can be converted into a Digital Elevation Model (DEM). Lowering the LiDAR-based DEM in wetlands areas according to recent survey elevation data produced longer hydroperiods and higher water depths in those areas. Moreover, implementing a pump-driven drainage in some of the agricultural areas corrected many of the unrealistic ponded water as predicted in the preliminary model. The average wet season water depths estimated from vegetative indicators at field investigation sites were originally found to be underestimated (in average by around 0.5 ft.) from the water depth estimations in the calibrated model or from observation station data. An underestimation of 0.2 ft. was obtained later from the calibrated model with the subset of points within areas with LiDAR-based DEM corrections. Lowering of the LiDAR-based DEM in those wetland areas produced a significant improvement in the wet season water depth model predictions.

The model performance was evaluated by comparing the observation station data for 146 monitoring stations with the model results by using statistical measures, with the final calibrated model having 88% with okay to good calibration (above industry standard). Overall, the calibrated model was more accurate than predecessor models and appropriate to conduct scenario evaluations.

Hydroperiod and wet season water depth maps were generated from the model results. Average annual hydroperiod duration as predicted from the SLCWI Model is presented in **Figure 6**.

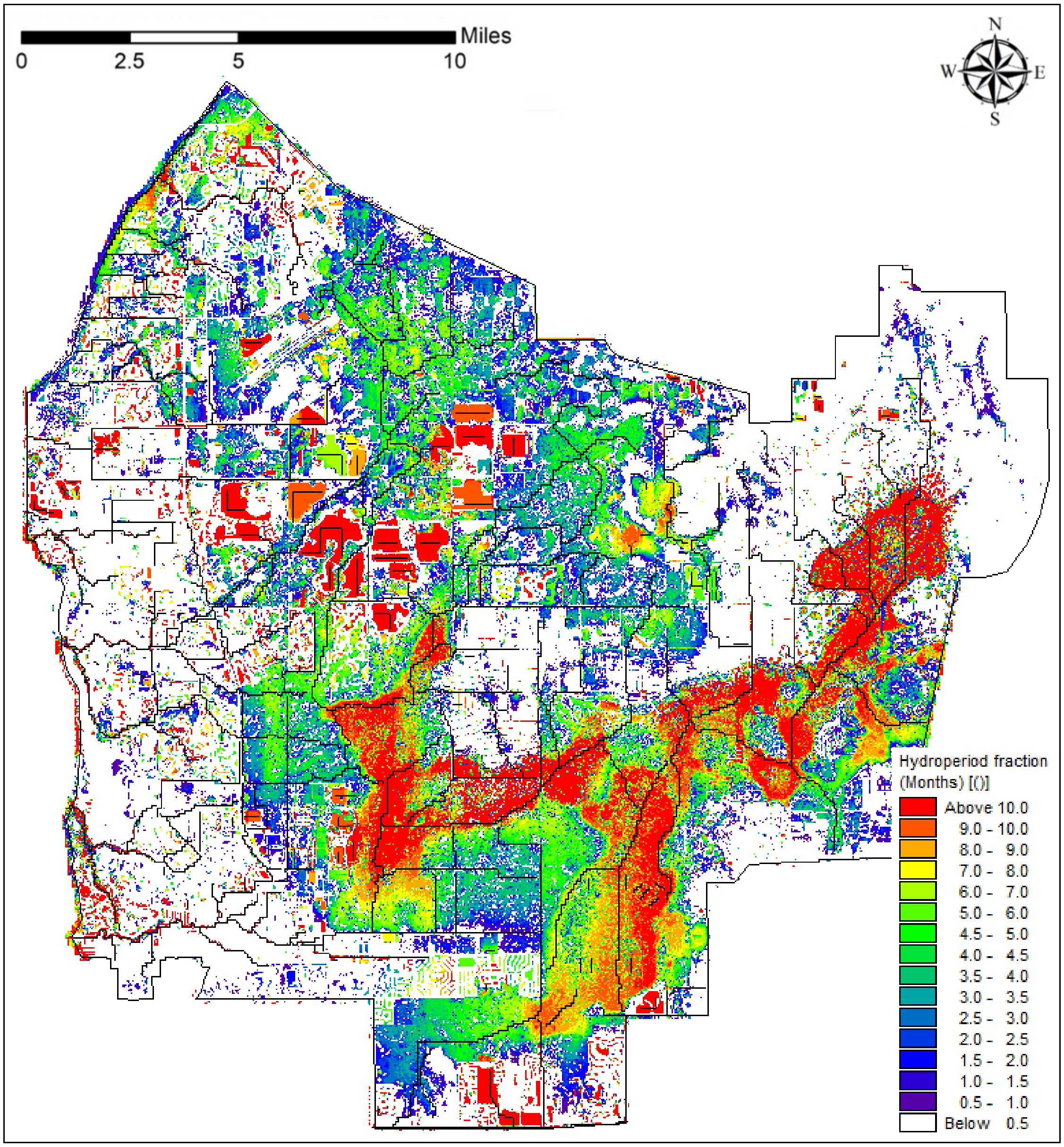


Figure 6. Average Annual Hydroperiod Duration from the Calibrated Model at a 50-ft resolution

After the calibration was completed, the final calibrated model was converted to a baseline existing-conditions model version, producing a useful tool to conduct scenario evaluations.

Natural Systems Model

The Natural Systems Model (NSM) was designed to simulate predevelopment conditions to determine changes to natural systems in the South Lee County Watershed (detailed explanation of methodology and results are contained in **Appendix I**: Natural Systems Model Technical Memorandum).

The procedure used to build the Natural Systems Model from the baseline existing conditions model consisted of removing all anthropogenic alterations made in the watershed. This included man-made changes in the topography, vegetation, soil, and SOLFA maps; as well as in the MIKE11 hydraulic network. Irrigation, drainage, and pumping well components were turned off.

- **Figure 7** presents maps of existing and the pre-development conditions vegetation coverage maps at 375-ft spatial resolution. This comparison shows the vegetative community changes that have occurred in different areas throughout this basin.

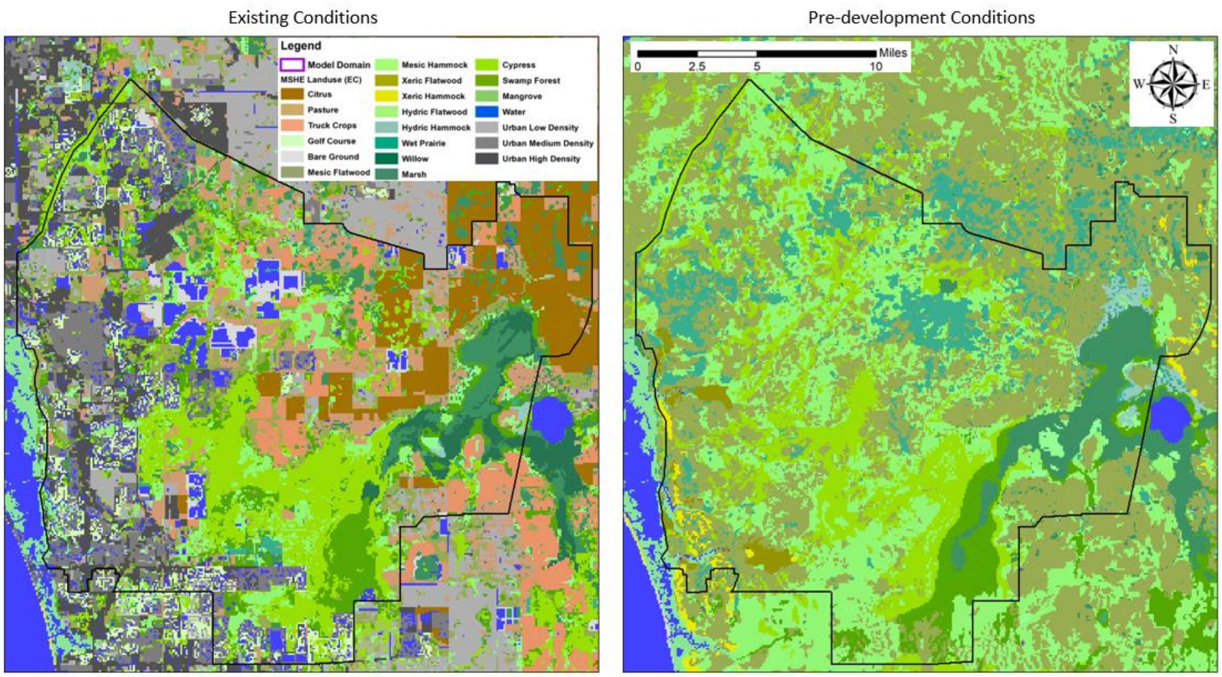


Figure 7. Existing and the pre-development land use maps

Existing conditions and pre-development conditions hydroperiod maps are presented in **Figure 8**. In general, the results comparing pre-development and existing conditions show extensive drainage that resulted in lowering water levels and shortening hydroperiods throughout all the developed portions of the watershed. This reduction in water storage has negatively affected some remaining natural areas that are needed to recharge groundwater drinking water supplies, provide freshwater flows to downstream rivers and estuaries, as well as to support habitats (particularly wetlands) needed by area wildlife. Understanding where and how exactly these changes have affected remaining natural areas allows for understanding of what natural system restoration needs exist in guiding potential restoration activities.

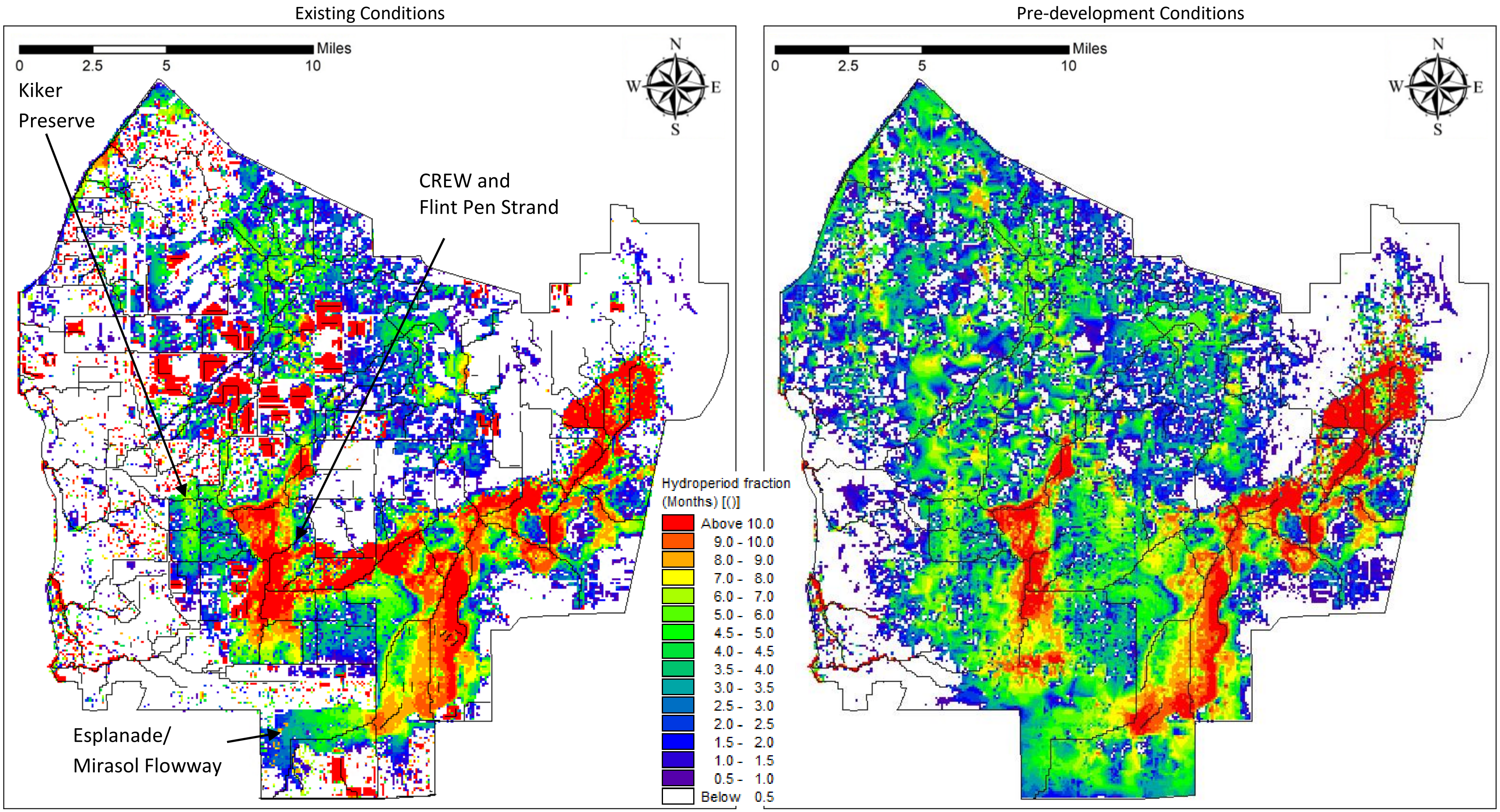


Figure 8. Existing and the pre-development hydroperiod at 375-ft resolution as predicted during the period 2010-2019

Future Conditions Scenarios

The Future Conditions model was built in phases as shown in the diagram in **Figure 9** (methodology and results of which are detailed in **Appendix J**: Future Condition Scenarios Technical Memorandum). Starting with the baseline existing condition model, existing known development projects that were permitted and/or underway, projects anticipated to be implemented from the Southern Lee County Flood Mitigation Plan and other recent and future known projects (ex. permitted mines) were included to create an Existing Conditions with Projects Model (ECwP). Note that the projects from the Southern Lee County Flood Mitigation Plan used in this analysis were the identified as higher priority projects that are being evaluated in greater detail by Lee County. Other projects mentioned in the Southern Lee County Flood Mitigation Plan are not being included in this analysis because they are lower priority or because information is not yet available at the detail needed to be included. Then, anticipated near-term climate change (such as increased evapotranspiration and sea level rise), as well as future potable water supply demands, were included to create the baseline Future Conditions Model (FCM0).

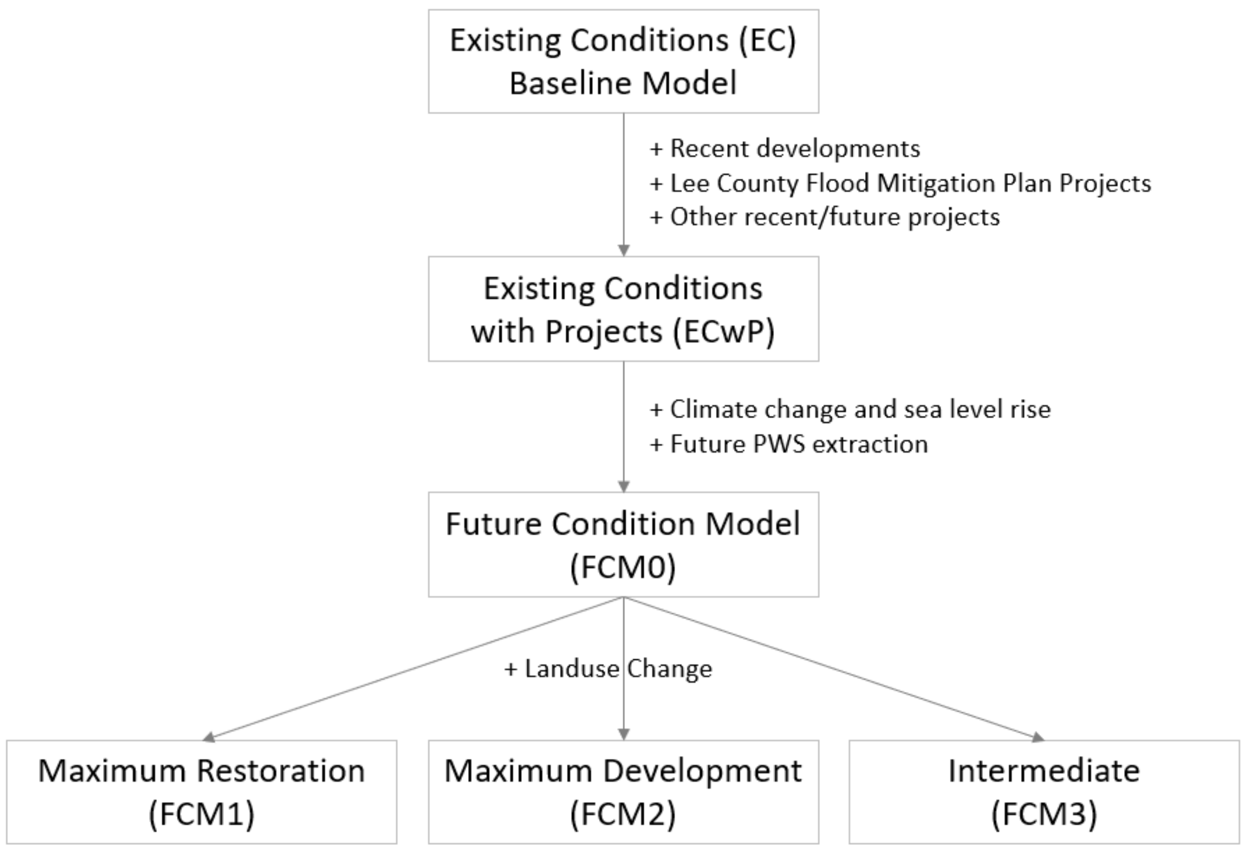


Figure 9. Model Development for Future Condition Scenario Evaluations

The baseline Future Conditions Model served as the basis for modeling three landuse future conditions scenarios: maximized development, maximized restoration and an intermediate development restoration scenario. The maximized development scenario assumed that all highest land use intensities allowed in local land development code occurred, and that the only preservation/conservation opportunities outlined in the CHNEP Habitat Restoration Needs (HRN) Plan being preserved would be those outside of where further development was allowed, in addition to existing conservation properties. The maximized restoration scenario assumed all CHNEP HRN preservation/conservation opportunities lands were conserved, with natural lands being fully publicly protected and the non-natural lands being in a public conservation easement that allowed their current land use to continue. Finally, the intermediate scenario assumed that all non-natural preservation/conservation opportunity lands were developed to highest allowed land use intensity, as well as all lands not designated preservation/conservation opportunities, with only natural preservation/conservation opportunity lands being conserved in addition to existing conservation lands. Further explanations of these different modeling scenarios are presented in next sections.

Existing Conditions with Projects (ECwP) Model

The Existing Conditions (ECwP) Model included urban developments that have been permitted and have started construction, as well as some of the higher-priority projects from the Southern Lee County's Flood Mitigation Plan. Lower-priority projects from the Lee County Flood Mitigation Plan were not included because implementation for the lower priority projects is uncertain. The higher-priority Flood Mitigation Plan projects included in the ECwP model are summarized below:

- **1.3.4: Alico Mine Lake Interconnects (West)**. The proposed conceptual project 1.3.4 consists of connection of an existing stormwater pond on the Southwest Florida International Airport to a number of mining pits north and south of Alico Road. This proposed conceptual project is intended to reduce flooding by capturing stormwater in the pond and mining pits.
- **1.3.7: Blackstone Drive to Alico Mine Lakes Drainageway**. The proposed conceptual project 1.3.7 conveys excess stormwater drainage flow from Blackstone Drive area in Lehigh Acres lying south of SR 82 to the existing Alico Mine Lakes. The originally proposed project is conceived with a control structure that would allow gravity-driven flows. There is not always a positive hydraulic gradient for the surface water to flow south, so for this study, the original proposed structure has been replaced by a 10-cfs pump as a refinement modification to the proposed project in order to protect wetland hydroperiods on Lee County Port Authority (LCPA) mitigation properties. As a result of this modification, no adverse changes to hydrology are anticipated within the LCPA property boundary.
- **1.3.8: Alico Mine Lake to Halfway Creek Drainageway**. The proposed conceptual project 1.3.8 utilizes the existing mine lakes in the WildBlue development currently under construction lying north of Corkscrew Road for storage, conveys water into the Flint Pen Strand preservation area, and directs excess flow towards the Halfway Creek bridge under the I-75. The replacement of some culverts under Corkscrew Roads is proposed as part of this project.
- **1.3.11: East I-75 Overland Flow Collection Drainageway**. The proposed conceptual project 1.3.11 connects existing borrow pit lakes (also referred to here as ponds) east of I-75 to the conveyance structures under I-75. The project consists of creating a collector drainageway that would direct overland flow and equalize water levels at each I-75 crossing to fully utilize each structure. Control structures with overflow elevations ranging from 18 to 19 ft.-NAVD would be installed at the berm.
- **1.3.13 CREW-Flint Pen Strand Hydrological Restoration**. The proposed conceptual project 1.3.13 would develop a water storage area located within the boundaries of Kiker Preserve, Flint Pen Strand, and the Southern Corkscrew Regional Ecosystem Watershed (Southern CREW). The project objective is to hold excess stormwater upstream of the proposed berm until downstream developed areas have drained following a large storm event. This area would be contained within a perimeter berm and will have remotely operated control outflow gated structures to maintain the water level within desirable ranges. The berm configuration used in this modeling effort was obtained from a second berm alignment proposed as part of additional flood mitigation studies conducted for Lee County and was the latest information available at the time of the scenario analysis.

Figure 10 illustrates the location of the projects listed above. Note that the proposed projects listed above were modified to reflect recent development, and the conceptual Lee County Flood Mitigation Plan components may have different dimensions after the completion of more detailed investigations of those concepts. In addition, some hydraulic structures were modified, removed, or added in this study to maintain and/or enhance hydrologic restoration of natural areas, including wetlands, while not diminishing the level of added flood protection. Finally, two other future projects (namely the new Corkscrew Crossing conveyance and hydroperiod restoration at the south end of Corkscrew Swamp Sanctuary) were added in the ECwP model.

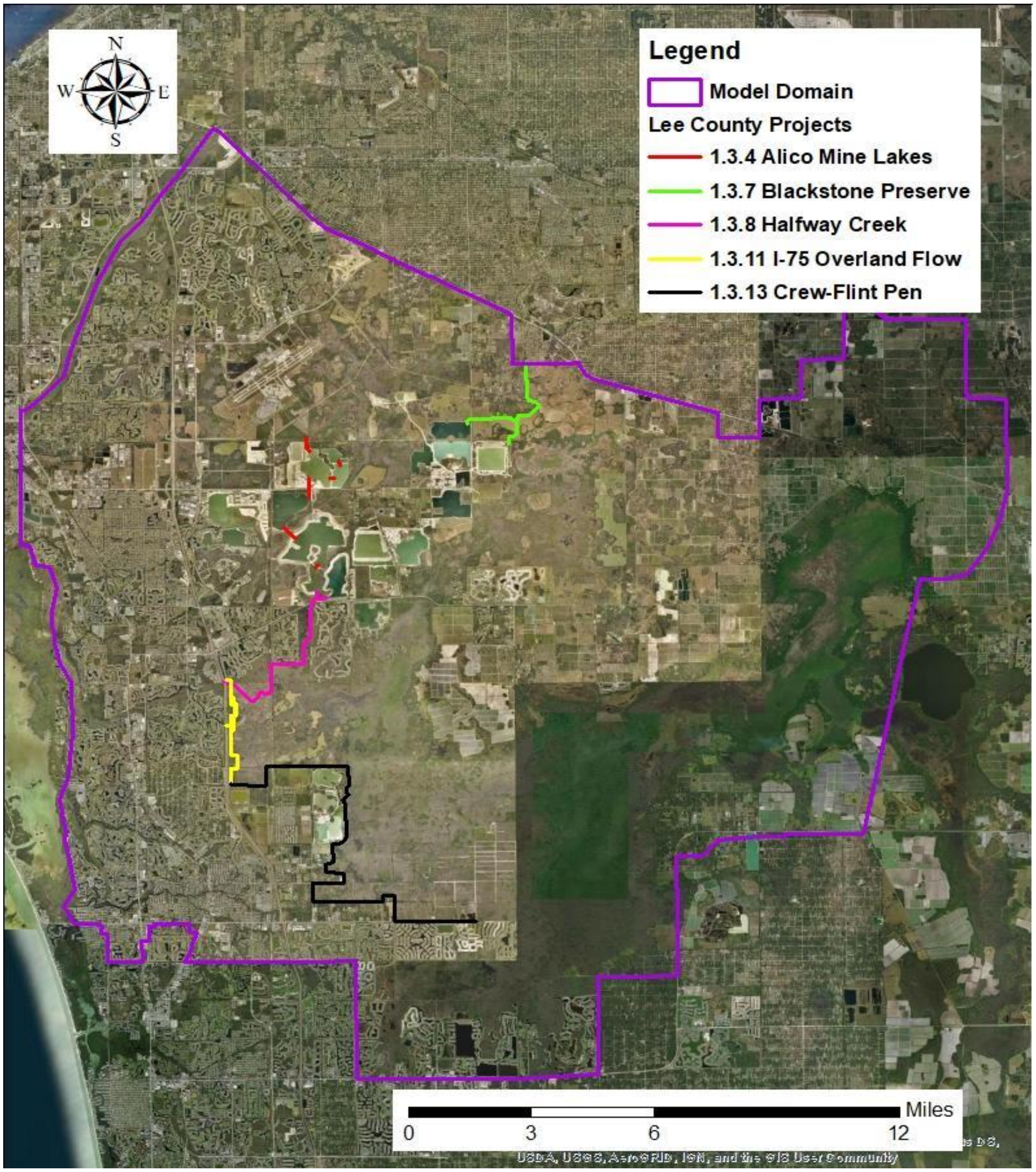


Figure 10. Lee County Flood Mitigation Projects Included in the ECwP Model

The model predicted hydroperiod differences between existing conditions with projects (ECwP) and existing conditions (EC, without projects) are presented in **Figure 11**. The comparison between the EC baseline and the ECwP models indicates altered hydroperiods and wet season water depths resulting from the projects introduced in the model. Hydroperiods were typically shorter in the urban developed areas (see New Development call-out in Figure 11) and higher in receiving waters outside of the developed lands. The shorter hydroperiods in developed area are due to a combination of increased land elevations in the developed areas as well as drainage of those lands to adjacent stormwater management facilities. Hydroperiods adjacent to the developed areas are therefore longer due to the routing of water from the developed lands and subsequent outflows from the stormwater management areas. Longer hydroperiods on the northern portion of the study area were predicted due to inflows from the Blackstone Preserve. Longer hydroperiods were also seen typically at upstream areas of the proposed berm (see Kiker Preserve area in map). As a result, longer hydroperiods are seen along a northeast-southwest linear alignment from the Blackstone inflow to Kiker Preserve and the east-west section of the proposed berm. Hydroperiod differences are shown in greater detail in Appendix J. Hydroperiod and wet season water depth maps from the existing condition model with projects (ECwP) are presented in Appendix J.

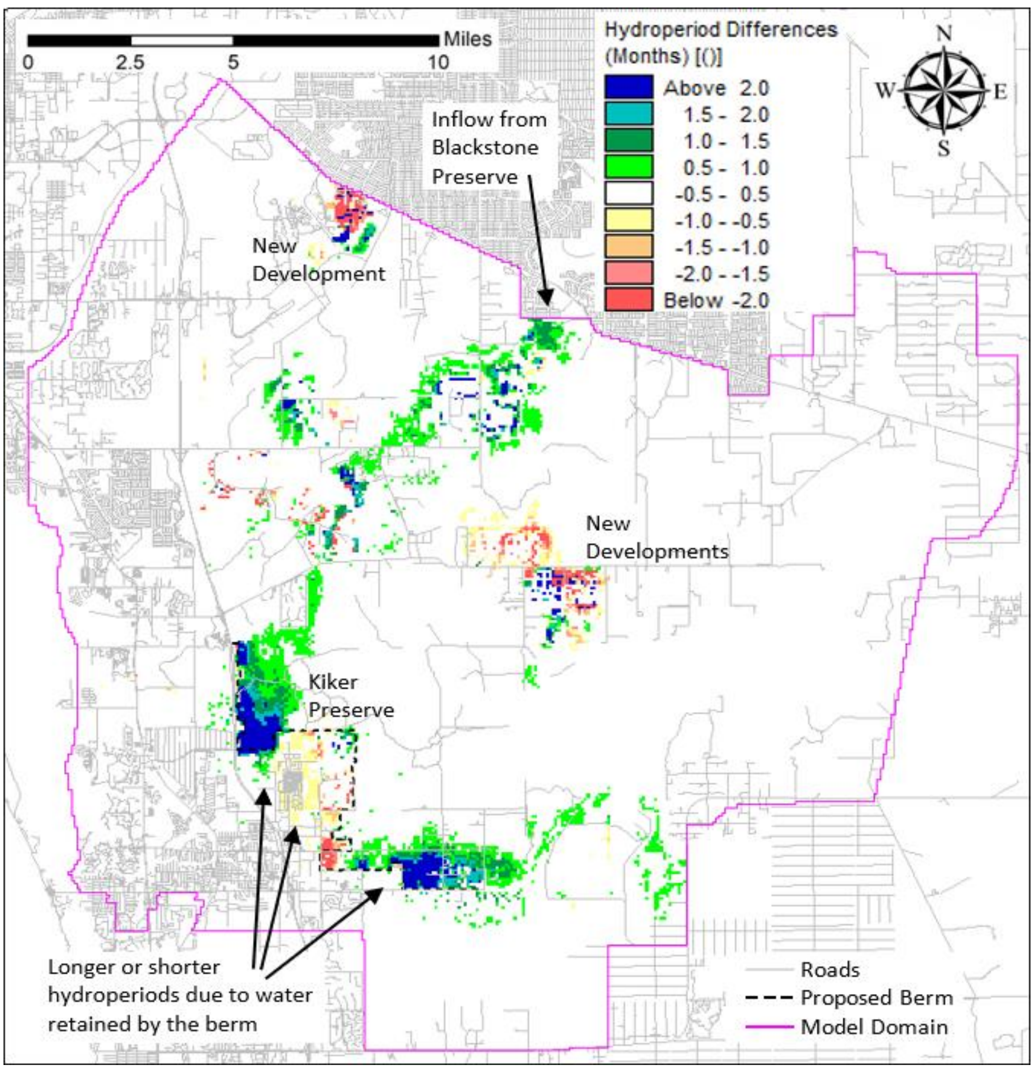


Figure 11. Hydroperiod Difference for EC minus ECwP

Future Condition Model without Land Use Change Scenarios (FCM0)

The anticipated near-term climate change factors such as increased evapotranspiration and sea level rise, as well as future potable water supply demands, were included to create the baseline Future Conditions Model (FCM0). Sea level rise was based on sea level rise projections by NOAA for year 2050, assuming Intermediate/High Sea Level Rise with Low Accretion Rate (of 2 mm/year). Monthly reference evapotranspiration (ET) rate factors (of around 6 % increase) were obtained from the DHI climate change tool. Since there is no scientific consensus in the literature on anticipated future changes in rainfall, the rainfall input time series were not modified. In addition to the climate factors, an increase in public water supply (PWS) pumping was included using the maximum extraction rates as specified in the water use permits, which represents an increase of 34% above the existing condition baseline model (i.e., period 2010-2019).

The FCM0 results showed a decrease in hydroperiods (as shown in **Figure 12**) and wet season water depths with respect to the ECwP model in the regional scale. Hydroperiods are predicted to decrease by up to 1 month and the wet season water depths will decrease by up to 0.4' due to increases in temperatures and ET. Water budget calculations showed that the increase in actual ET by 5% will create drier conditions and will reduce river outflows.

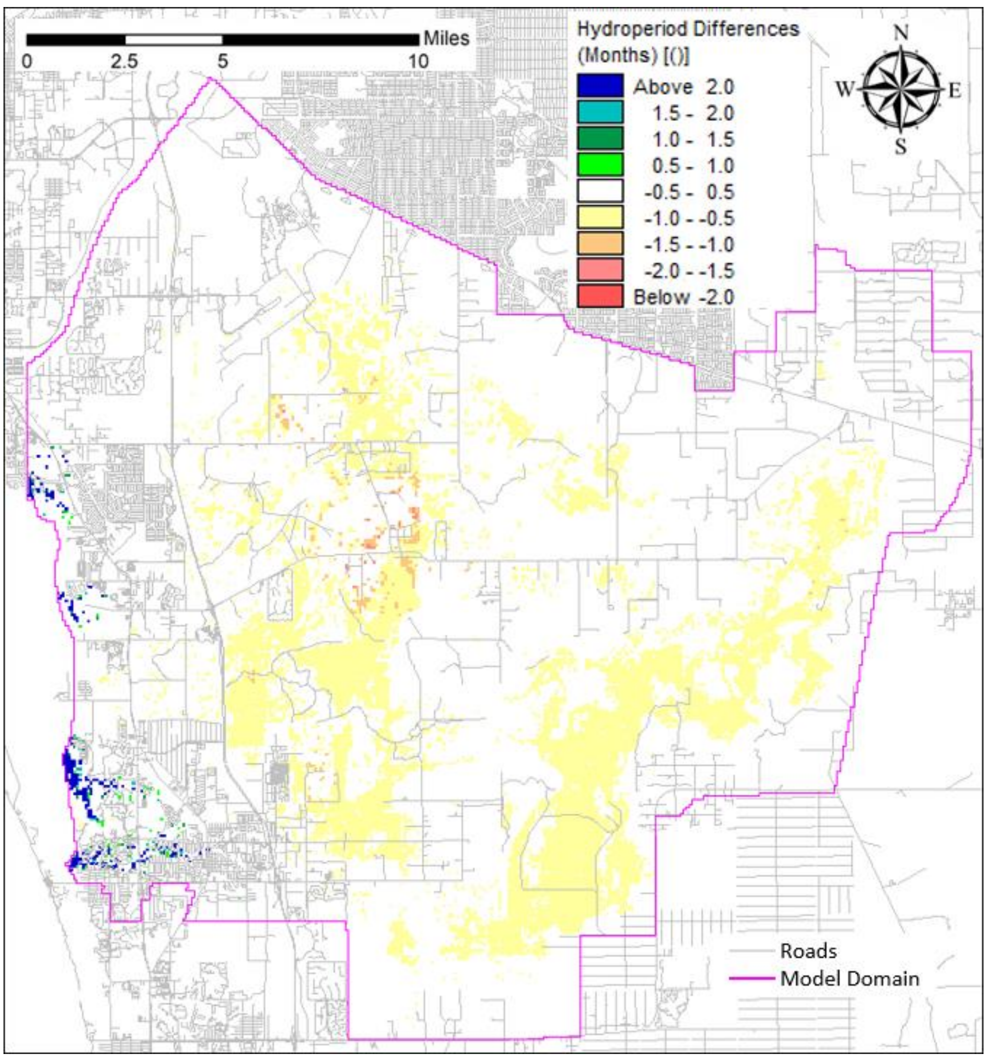


Figure 12. Hydroperiod Difference for FCM0 minus ECwP after including climate change and groundwater pumping

The FCM0 results showed an increase in hydroperiod and water depth along the tidal portions of all rivers in the model (i.e., Imperial River, Spring Creek, Estero River, and Mullock Creek) as a consequence of the sea level rise. This is shown in Figure 12 and also in greater detail in Appendix J. The model predicted an increase in the water depth by about 7 inches along mangrove areas, which will likely result in changes in vegetation along the coastal boundary. This landward migration of brackish tidal water along the rivers (due to higher tidal levels and reduced river outflows) may have negative impacts on the freshwater resources near the coast.

Future Condition Models with Land Use Change Scenarios (FCM1, FCM2, and FCM3)

Three future condition scenarios were evaluated in this study with different land use/vegetation coverages, which were built based on the CHNEP Habitat Restoration Needs mapped preservation and conservation opportunities (PCO) and the Lee County simplified future land use map. The first scenario (FCM1) represented maximum restoration, the second scenario (FCM2) represented maximum development, and the third scenario (FCM3) incorporated land use changes intermediate between the maximum restoration and development scenarios. Changes in the land use maps were propagated to the topography and ICA maps, as well as to the other correlated input maps in the model obtained from the land use.

Developed areas showed typically shorter hydroperiods due to increased land elevations and increased drainage from those developed lands. In addition, the adjacent natural areas receiving runoff from developed lands showed typically longer hydroperiods.

FCM1, Maximum Restoration. Hydroperiod increases for FCM1 were predicted for agricultural lands such as 6Ls and Troyer Brothers as shown in **Figure 13** that were assumed to be restored in the 2020 CHNEP Habitat Restoration Needs study. Both areas have subsequently been approved for development either for residential development or mining, and therefore, most of these areas will not experience hydroperiod increases.

FCM2, Maximum Development. **Figure 14** indicates that hydroperiods are predicted to decrease in lands assumed to be converted to development with hydroperiod changes ranging from -1 to -2 months. Undeveloped lands adjacent to the developed lands receiving runoff from the newly developed lands are predicted to have hydroperiod increases, ranging from 0.5 to 2.5 months. These increases are predicted to occur both north and south of Corkscrew Road east of Alico Road as well as in the Lee County Port Authority (LCPA) mitigation lands.

FCM3, Intermediate Restoration. **Figure 15** presents the predicted hydroperiod changes associated with this scenario. The spatial extent of the hydroperiod changes was less than for FCM2 since less land was assumed to be developed. Hydroperiod increases are predicted to increase for undeveloped lands adjacent to developed lands that will receive additional runoff from those developed areas (such as 6Ls and Troyer Brothers).

Predicted hydroperiod and wet-season water depth maps for the different future condition scenarios, as well as other difference maps, are presented in Appendix J. Groundwater level difference maps during wet and dry season periods are also included also in Appendix J. Water table changes during the peak of the dry season are also important since they may influence the occurrence of fires in natural area systems in the dry season. To understand full spectrum of change please view Figures 88 - 95 in Appendix J. Two areas of focus for stakeholders are captured in the hydrographs presented in **Figure 16** and **Figure 17**.

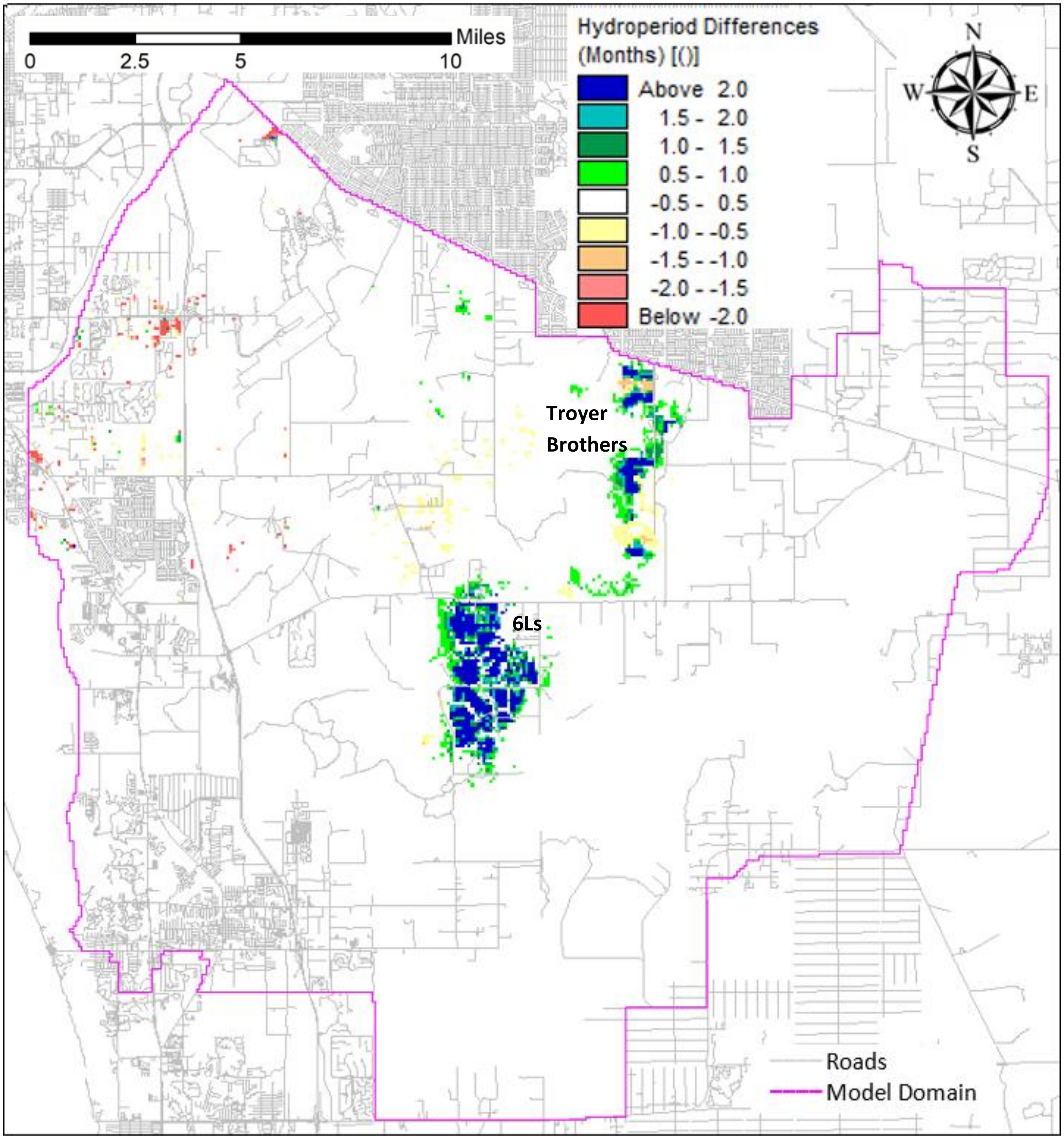


Figure 13. Future condition hydroperiod differences after the land use changes in the scenarios: Max. Restoration (FCM1) – Future Condition Baseline (FCM0)

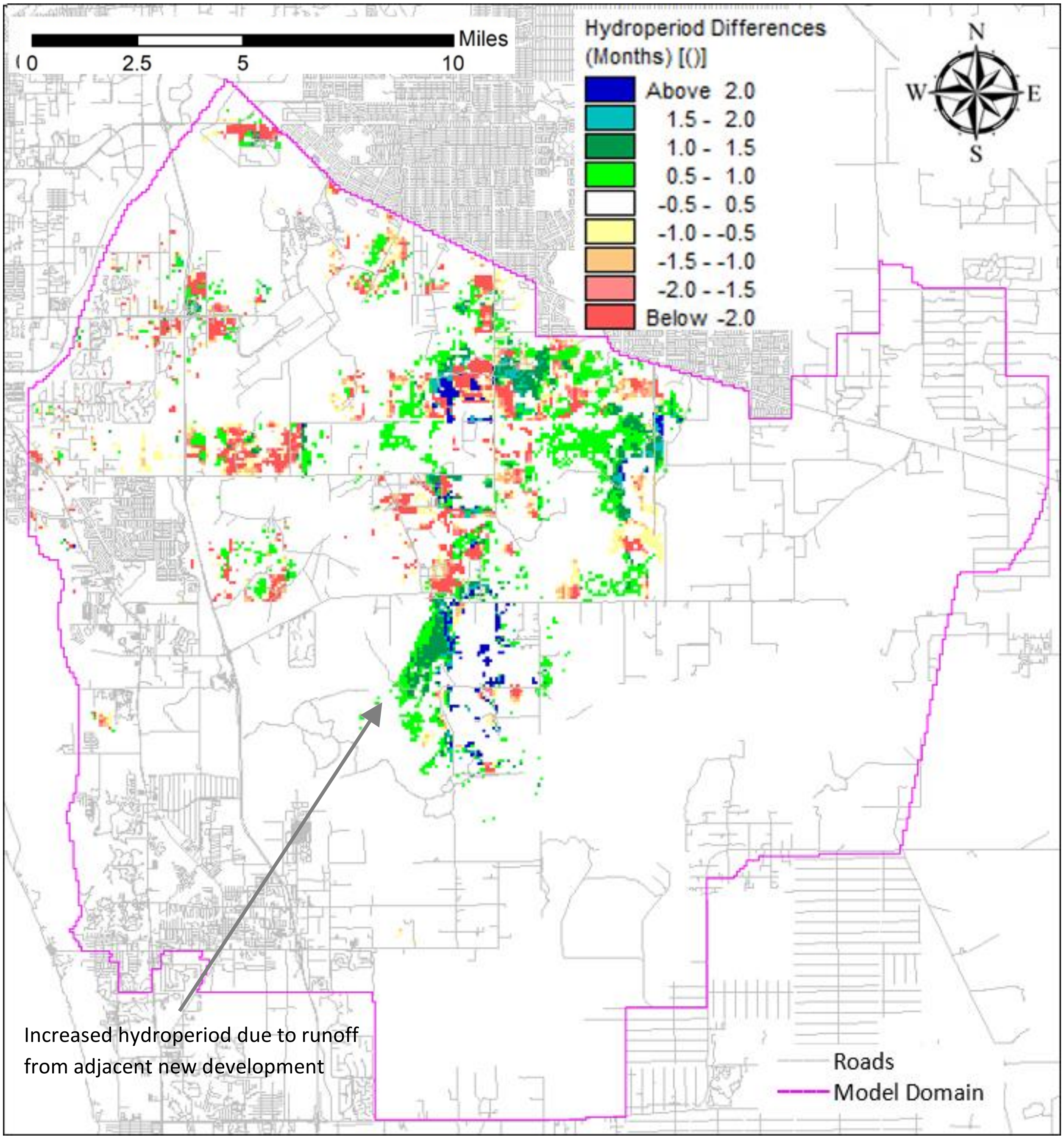


Figure 14. Future condition hydroperiod differences after the land use changes in the scenarios: Max. Development (FCM2) – Future Condition Baseline (FCM0)

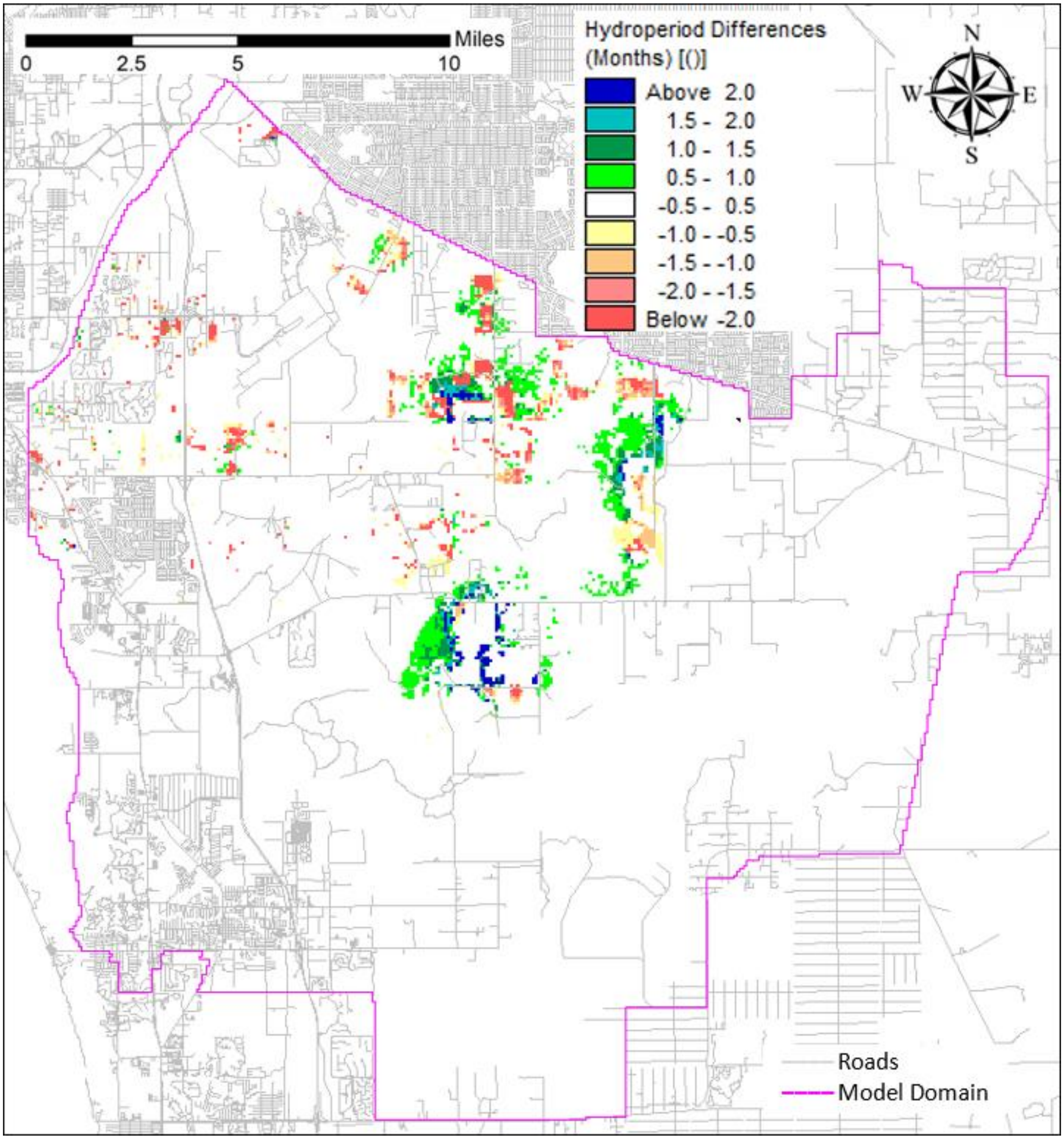


Figure 15. Future condition hydroperiod differences after the land use changes in the scenarios: Intermediate Restoration/Development (FCM3) – Future Condition Baseline (FCM0)

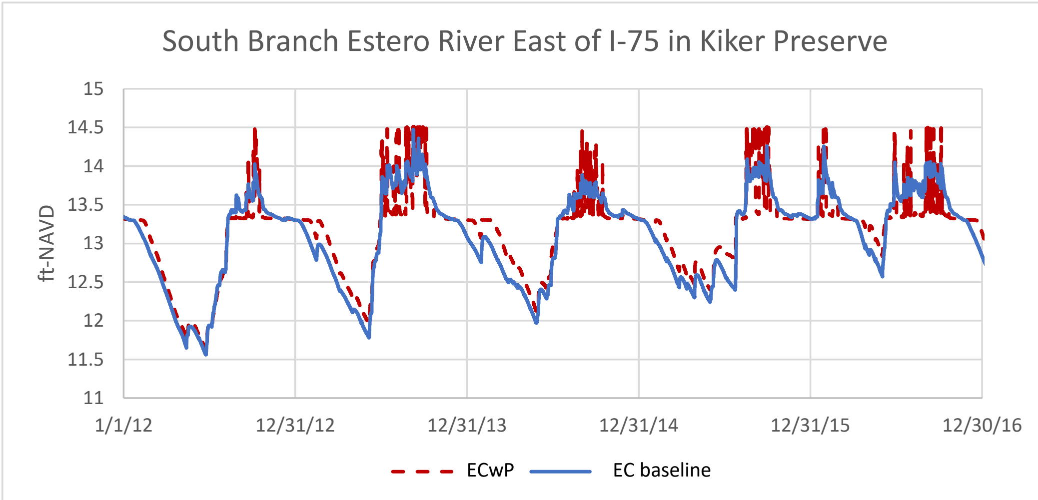


Figure 16. Comparison of Water Level Hydrographs at Kiker Preserve

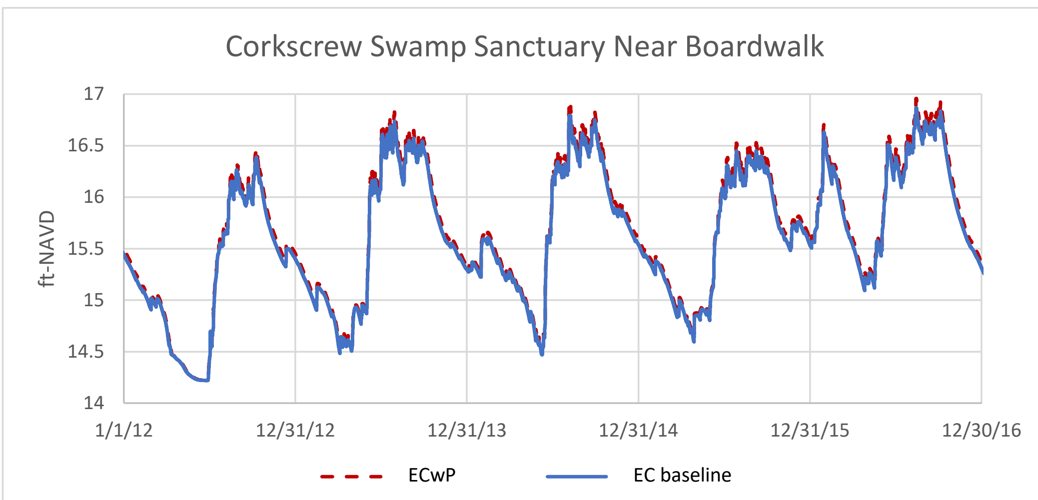


Figure 17. Comparison of Water Level Hydrographs at Corkscrew Swamp Sanctuary near Boardwalk

Results

Hydrological Model Development and Calibration

The integrated surface/ground water MIKE SHE model developed for this project is a robust modeling tool that is appropriate for evaluation of a range of alternative water management strategies to address existing and future water management challenges. The model is based on the best available information and is suitable for both wet and dry season conditions.

Hydrological Restoration and Flood Mitigation

This modeling study affirms that flood mitigation can be achieved while preserving water resources and wetland hydroperiods, with enhanced water management that optimizes projects to achieve multiple objectives. Flooding events occur typically during the wet season when the water table levels are higher and there is less storage inside and above the ground. The project proposed in the Southern Lee County Flood Mitigation Plan are intended to mitigate flooding by increasing conveyance and storage. During Hurricane Irma, it was also apparent that there is a need to improve channel maintenance to remove debris and other unnatural flow restrictions.

The berm proposed in the Lee County Flood Mitigation project east of the I-75 and north from Kehl Canal (projects 1.3.11 and 1.3.13 described above) is a good example of surface water management features that can be used for both purposes: flood control and water resources preservation. During the wet season, the controlling gates can be operated to minimize water levels upstream of the berm for flood control. In the case of a heavy forecasted storm, water levels could be lowered even more in advance. However, by the end of the wet season, the gates can be operated differently to keep the upstream water level higher to increase water stored within the watershed. This approach of using seasonal rules and emergency operation protocols is not new and has been used by the SFWMD at gated structures for many years. This type of water level control could become more important in the future to reduce the impact of climate change.

Future Scenarios that meet Project Goals

Maximum Restoration (FCM1) and Intermediate Restoration (FCM3) future conditions scenarios both provide opportunities to increase wetland hydroperiods in existing conservation lands and increase water storage for aquifer recharge, which the Maximum Development scenario would not provide. Therefore, pursuing Intermediate to Maximum Restoration is advisable to support natural system needs and public water supplies.

Climate Change

This modeling study evaluated the impact of climate change on watershed hydrology. This study suggests that reduced wetland hydroperiods, reduced water depths, reduced stream flows, and higher tidal water levels may be experienced by 2050. This study assumed higher rates of evapotranspiration resulting from a warming climate. A range of rainfall forecasts were reviewed during the development of the climate change scenario. Because forecasts of future annual rainfall range from +/- 10% of existing rainfall, no changes were made to the rainfall input data set. This surface and ground water integrated modeling study has shown that the predicted increase in temperatures and the sea level rise due to climate change could have adverse impacts to freshwater resources in areas of South Lee County and Corkscrew Swamp by year 2050. Throughout CREW (and other inland marshes and prairies), reducing hydroperiod can encourage the spread of Carolina willow, which may increase evapotranspiration even further.

Hydroperiod reductions throughout CREW will have significant impacts on fire (both land managers' ability to conduct prescribed fire and risk of catastrophic wildfire). These changes in vegetation/land cover and their potential impacts (including exacerbating hydroperiod reduction), as well as the uncertainty of rainfall overall, emphasize the need for hydrological preservation and restoration.

Recommendations

As a result of this project and the modeling results, a number of proposed projects and additional modeling activities are recommended that would advance the work of the South Lee County Watershed Initiative. The objective of the recommendations presented below is to restore more natural hydrology to natural systems while mitigating future flooding, as well as to provide additional water storage to offset possible future hydroperiod changes that may result from climate change. Stored water from man-made storage areas and from enhancement of natural areas would be designed to increase wetland hydroperiods and water depths to match, but not exceed, optimum conditions. Restoration strategies and projects below are needed presently in order to address near-term climatic conditions. It should be noted, that additional analysis on long-term climate predications are recommended to help identify appropriate actions, projects, or adaptive management strategies needed to address long-term climatic changes.

Recommended Future Projects

1. Green Infrastructure – Restoring Wetland Hydroperiods in Existing Wetlands

Where existing natural areas have wetland hydroperiods less than optimum, green infrastructure of created berms and filter marshes could be added to enhance natural wetland hydroperiods and to minimize fire risk. **Figure 18** presents possible locations of cross berms that could be constructed across natural wetlands within the South Lee County area that could be used to restore wetland hydroperiods and attenuate peak flows. The proposed cross berms would have gated weir structures to manage water levels upstream of the berms to achieve both flood mitigation and hydroperiod restoration. Cross berms in locations where wetland hydroperiods are most severely impacted would have the highest priority, and the details associated with the design should be closely coordinated between wetlands scientists, hydrologists, and design engineers. Potential alignments for these berms could be along existing ATV trails that have lower elevations than surrounding lands. These berms could also be used to enhance recreational access to these existing natural public lands that currently have poor access. If passive water control structures cannot achieve the desired water flows, levels and hydroperiods alone, then operable grey infrastructure may also be necessary.

2. Grey Infrastructure - Additional Man-made Water Storage

The predicted changes in wetland hydroperiods across the model domain suggest that future water management planning should consider additional storage within disturbed or developed areas. Water can be routed to storage areas during the wet season with subsequent release during the latter part of the wet season to offset the predicted hydroperiod changes. The proposed water storage area in the Southern Lee County Flood Mitigation Plan may help to offset flooding impacts since extreme wet weather events are predicted to be more frequent resulting from climate change. Should additional storage beyond the levels described in the Southern Lee County Flood Mitigation Plan be considered, the impact of the additional storage will need to be evaluated to assure that wetlands are not adversely affected in terms of hydroperiods and average wet season depths.

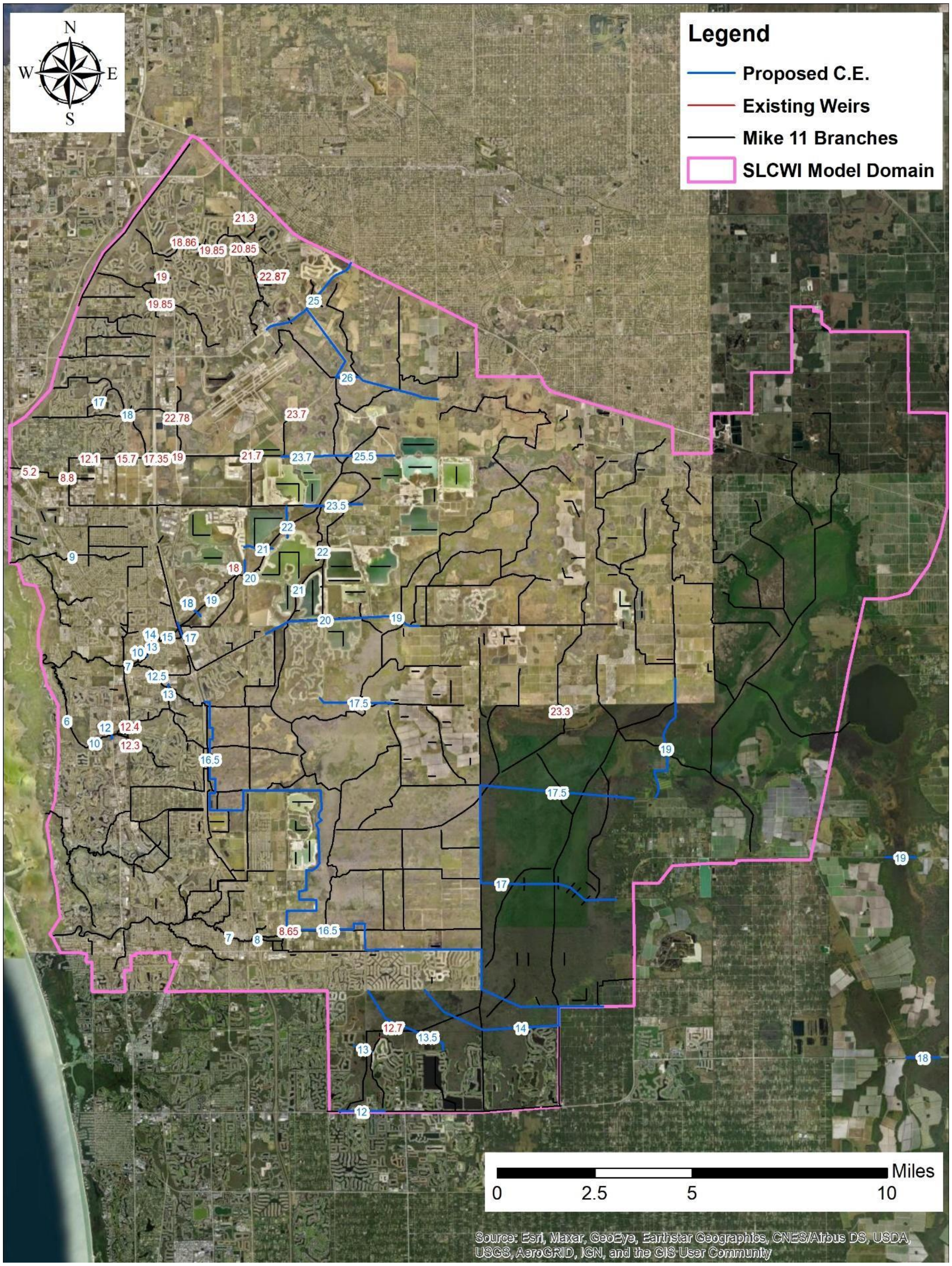


Figure 18. Potential Locations of Cross Berms to Restore Wetland Hydroperiods and Attenuate Peak Flood Flows

Existing mining pits are also feasible locations for the suggested additional storage areas. Possible locations include the Bonita Springs mine, mining pits north and east of Alico Road, and the mining pits that are currently being mined north of Corkscrew Road such as the Troyer Brothers property. Since these mining pits are privately owned, it is expected that this recommendation will depend greatly on having sufficient funds to lease or purchase those mining pits and further investigations into their suitability for these purposes. Further investigations to evaluate buried shell layer conduits is currently being evaluated in greater detail by Audubon and SFWMD.

Another potential water management solution is to work collaboratively with private developers to create storage beyond the volumes currently required to meet regulatory water management requirements. These private-public partnerships have the potential to achieve restoration goals at significant savings.

Maximizing storage within the purview of hydroperiod and depth ranges that are protective of natural areas can be achieved with future proposed projects such as those in the Southern Lee County Flood Mitigation Plan by incorporating operable gates and other surface water management control features. The additional storage should be designed to augment flows to natural areas with the objective of maintaining hydroperiods in those natural areas.

3. Grey Infrastructure - Operational Water Control Structures

Having water control structures that can be remotely operated to hold more water back in dry season to raise water levels in natural areas while opening to allow more flow in flooding conditions during wet season would allow for more precise water management that better balances these two objectives. There are already examples of this such as the Corkscrew Mitigation Bank north of Corkscrew Road (4 miles east of Alico Road intersection with Corkscrew Road). The outflow gates at this location shown in **Figure 19** could be modified to have automatic gate operations and additional outflow structures could be added to increase conveyance to lower water levels in advance of major flooding events and then operate the gates to maximize attenuation of peak flows during the flood. Gate operation of this type is common in Lehigh Acres by LA-MSID and could be implemented within the South Lee County area.

Figure 19. Corkscrew Mitigation Bank Outfall, August 8, 2019

4. Grey Infrastructure - Strategic Enhanced or Added Culverting

Having updated or added culverts to allow for additional sheet flow or flow volume to areas which need added flow, or to relieve areas that need more flood protection would allow for enhanced water management that better protects populated and natural areas. There are existing roads that currently cross large wetland systems where flows are routed under the roads via open culverts. Gated culverts with upstream risers should be considered for those roads where the upstream wetlands are below optimum hydroperiod. The road along the Green Meadows wellfield alignment is one example of where this approach might be feasible. Another location is the north section of the Bird Rookery hiking trail that is adjacent to the southern end of Corkscrew Swamp Sanctuary (CSS). Prior studies have documented reduced wetland hydroperiods in CSS, and improvements to these structures have already been recommended and studies are underway to further evaluate the benefits of hydrological improvements at the south end of CSS.

Recommended Future Modeling

A comprehensive surface and ground water integrated model of the South Lee County Watershed has been developed in this study by incorporating updated available information with spatial resolution higher than the earlier models of the watershed formulated in MIKE SHE platform during the last two decades. The model is now robust enough to be applied as a useful tool for evaluating water and land management measures to enhance flood protection and natural resource functions of the region. However, this developed model will need to be treated as a living model with frequent periodic updates and verifications to be consistent with changes in land and water use features of the watershed. Therefore, the following are recommended future modeling-related activities:

1. Update Future Conditions Model with Future Land Use and Hydrological Changes

The future conditions model produced by this project should be updated periodically with future development and land preservation changes incorporated.

2. Conduct Additional Field Surveys and Update Model with the Additional Field Data

The model would benefit from being updated with data from added field surveys, including incorporating the results and recalibrating the model with topographic information from an in-depth survey of land elevations in the Corkscrew Swamp region.

3. Use Model to Refine Proposed Flood Mitigation Projects

This model could be used in parallel with more detailed studies of the higher-priority conceptual projects in the Lee County Flood Mitigation Plan to further refine them in the design process. Evaluation of wetland hydroperiod impacts of proposed projects will aid in the final design of the proposed flood mitigation projects, and this type of evaluation can be used to facilitate the project review during the environmental permitting process. Then once stormwater project details are beyond the conceptual phase, it would be beneficial to update the future conditions model and rerun the future conditions scenarios accordingly.

4. Update Future Conditions with Updated New Climate Data to Run Added Simulations

Additional climate change simulations would be beneficial. First, additional modeling to separate the impacts of climate change (increased ET) versus increased PWS pumping would be helpful. Also, it would be useful to run more scenarios to evaluate rainfall changes with climate change given the widespread implications of hydroperiod change within the model domain. Given the uncertainty of rainfall predictions with climate change, it would be helpful to understand the relative role of rainfall and ET, when there is more certainty around rainfall changes known, or modeling theoretical spectrum of changes that could occur with increased or decreased rainfall. For example, is +10% rainfall enough to reverse the drying seen due to increased ET? Or, what would be the additive impact of -10% rainfall and increased ET? Understanding these extremes would help to frame predictions. Due to the significant ecological impacts of reduced hydroperiod to wetlands such as the Corkscrew Swamp, 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).

The model was calibrated in this study to perform well for multi-year seasonal evaluations. However, due to the evolving climate conditions and increased storms continually contributing to increased flooding, the model should continue to be updated to incorporate new storm event data, including recorded high water marks during and after such events. Thus, it is recommended to further verify the model performance during extreme rainfall events, to include available high water marks in the evaluation, and to perform model recalibration to those extreme conditions as needed without diminishing the model performance for multi-year seasonal evaluations.

5. Create Comparison Hydrograph Plots

For hydrograph plots of proposed vs existing conditions, it would be advantageous to break the existing 10-year simulation period into 1-yr increments to provide added information showing model performance (surface water flows and stages, and groundwater elevations). A programming script (Matlab, Python, R, etc.) can be put together to take model results (ex. in spreadsheet or other formats) for many years and generate plots of individual years. This effort to produce additional plots would provide an important added outcome to the overall modeling effort.

6. Conduct Additional Simulations to Isolate Effects from each Scenario Change

Additional simulations are recommended to compare the effect of individual scenario changes with respect to the preceding scenario model (example comparing existing conditions with projects scenario with only one factor such as public water supply without climate change against the baseline scenario) instead of applying more than one changes in a scenario. This is more relevant in cases where the effect of the changes can overlap, and it is difficult to isolate the effect from each scenario change.

Conclusion

The outcomes of this modeling effort and report support objectives set forth by Coastal & Heartland National Estuary Partnership (CHNEP) and members of the South Lee County Watershed Initiative (SLCWI) to identify possible measures to restore appropriate freshwater flow across the landscape to sustain healthy wetlands, rivers, and estuaries and to provide adequate aquifer recharge and freshwater volume and timing of flow to support healthy natural systems as well as to moderate flooding events. The modeling tool examined both dry and wet season water levels, flows, and needs in order to fill data gaps and bridge the various modeling efforts in the area to build a regional watershed-scale picture.

Results from this study will be useful to resource management agencies in the area to guide appropriate restoration and management of surface waters currently flowing from the South Lee County Watershed. Our strategy was to create a data-driven integrated surface/groundwater model and watershed planning tool to better understand the hydrology in the system and to help identify restoration projects that would protect and restore natural flow regimes and provide sufficient fresh surface water and groundwater to natural systems. This project also accounts for factors that would inform likely future conditions in the region such as anticipated infrastructure projects, additional development, and climate change.

Special thanks to the South Florida Water Management District and the other members of the South Lee County Watershed Initiative (SLCWI) for their invaluable contributions to the project and production of this report. SLCWI members include: Coastal and Heartland National Estuary Partnership (CHNEP), South Florida Water Management District (SFWMD), Lee County, Collier County, City of Bonita Springs, Village of Estero, Conservancy of Southwest Florida, Water Science Associates, Lago Consulting, Bonita Springs Utilities, Florida Department of Transportation, Audubon Society, ECCL, ADA Engineering, Southwest Florida Regional Planning Council, AIM Engineering, Stantec, Waldrop Engineering, JR Evans Engineering, Audubon – Corkscrew Swamp Sanctuary, Hole Montes, Lehigh Acres Municipal Services Improvement District, University of Florida Institute of Food and Agricultural Sciences (UF/IFAS), Calusa Waterkeeper, WSP, Estero Council of Community Leaders, Florida Gulf Coast University (FGCU), and Charlotte Soil & Water Conservation.

To view an electronic full copy of this report with all its associated appendices, go to
https://www.chnep.org/south-lee-co-watershed-initiative
