Withlacoochee River Watershed Initiative (H066)

Model Scenario Report

Prepared by

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Executive Summary

The Withlacoochee is a unique riverine system, winding 160 miles northward through eight Central Florida counties before eventually discharging into the Gulf of Mexico. The river's origins lie in the Green Swamp, a major source of water not only to the Withlacoochee but also the Hillsborough, Peace and Ocklawaha rivers. For centuries, the Withlacoochee has experienced extreme high and low conditions due to natural fluctuations in rainfall and groundwater levels. In addition, portions of the Withlacoochee River and its surrounding watershed have been altered in efforts to transform its natural function into one that benefited commercial navigation, industry and private needs.

In recent decades, there have been numerous public concerns regarding water levels and flow along the Withlacoochee River. Public meetings and workshops involving stakeholders, special interest groups and residents identified several critical issues and ideas to either restore or further alter portions of the system. To comprehensively address those concerns, a computer model of the entire Withlacoochee River and its surrounding watershed was developed. This included an unprecedented effort to map the entire bottom of the Withlacoochee River from the Green Swamp to the Gulf of Mexico. In addition, portions of the surrounding watershed that contribute flows to the Withlacoochee River were identified.

Using this model, 19 specific scenarios were evaluated to determine the effects of historical or future changes to the river system.

- Five scenarios in the Green Swamp related to removing berms, bridge pilings and constrictions, as well as adding rocks.
- Six scenarios in the Tsala Apopka Chain-of-Lakes related to flooding, low water levels, structure operations and pre-settlement conditions.
- Two scenarios in the Lake Rousseau area related to conveyance of water through the Bypass Spillway to the lower Withlacoochee River.
- Six scenarios at various locations along the river related to flooding, low water levels, and structure operations.

Several of the scenarios had significant local impacts, affecting water levels and flows at specific locations along the river. Their regional effects were minimal, however, and did not necessarily substantiate the original concerns. In general, model results indicate that changing rainfall patterns and the region's natural topography have the greatest impact on water levels and flow along the

Withlacoochee River. The District's management strategies of this unique riverine system have been enhanced through a better understanding of the dynamics of the river and watershed. This tool can also be used to address future public concerns from stakeholders, special interest groups and residents throughout the watershed. Full results of these scenarios are provided as chapters in this report while quick summaries of each are provided as Appendix A.

Introduction

Authorization

As part of the Withlacoochee River Watershed Initiative (H066) agreement number 06CC0000017, the Southwest Florida Water Management District (SWFWMD) authorized Atkins North America Inc. to develop a verified model to simulate hydrologic and hydraulic conditions for design event simulations along the Withlacoochee River, the Green Swamp and the Tsala Apopka chain-of-lakes, which included inflow models to the river covering over 1,500 square miles. Utilizing the verified model, 19 specific scenarios were simulated in an effort to gain a better understanding of the river and its dynamic response to historical or future changes.

Acknowledgements

This project could not have been successfully completed without key contributions from technical staff and project funding partners including:

Florida Fish and Wildlife Conservation Commission (FFWCC) whose contributions enabled the evaluation of selected alternatives related to the Flying Eagle Wildlife Management Area.

Citrus County, whose co-funding of the East Citrus Withlacoochee River Watershed (N090) project allowed for enhancements to the 2D overland flow model within the Tsala Apopka chain-of-lakes.

The Southwest Florida Water Management District (District) Governing Board for endorsements of the project approach and supporting the vision to create a comprehensive watershed management tool capable of simulating surface water conditions in the Green Swamp and Withlacoochee River watershed.

SWFWMD Project Manager – Mark Fulkerson, Ph.D., P.E. for providing local expertise and guiding the data collection efforts necessary to identify and help integrate key river conditions into the model development process. Dr. Fulkerson also provided a valuable link between the project development process and the interests of watershed stakeholders.

SWFWMD Technical Staff – Harry Downing, P.E. for technical contributions to the application of two dimensional modeling of the Withlacoochee River System and Gene Altman, P.E. for

recognizing that the only true way to understand the Withlacoochee River was through the development of a single comprehensive watershed level model.

Streamline Technologies – Pete Singhofen, P.E. for providing technical support of the modelling software and insights into two-dimensional (2D) model development processes.

Background / Purpose

From its origins in the Green Swamp to its terminus in the Gulf of Mexico, the Withlacoochee River winds 160 miles northward through west central Florida. The river's contributing area or watershed, as shown in **Figure 1**, is approximately 2,100 square miles and includes portions of Citrus, Hernando, Lake, Levy, Marion, Pasco, Polk and Sumter counties. The Green Swamp primarily discharges to the Withlacoochee River, but also serves as the headwaters of three other major river systems in Florida including the Hillsborough, Peace and Ocklawaha rivers. In addition to the Green Swamp, the Withlacoochee River also receives water from several major tributaries, including the Little Withlacoochee River, Gum Slough, Jumper Creek, Outlet River, Gum Springs Run and the Rainbow River. The river also interacts with numerous wetlands and lakes including Tsala Apopka, Lake Panasoffkee and Lake Rousseau.

Figure 1 Withlacoochee Watershed Boundary

The Withlacoochee River was called by its earliest inhabitants, “We-Thalko-Chee” or “Little-Big-Water,” characterizing the great fluctuations between drought and flood that are commonly exhibited by the river due to naturally changing hydrologic conditions. In addition, portions of the Withlacoochee River and its surrounding watershed have been altered over the past 130 years in efforts to transform its natural function into one that benefited commercial navigation, industry and private needs.

In recent decades, public meetings and workshops involving stakeholders, special interest groups and residents identified several critical issues and ideas to either restore or further alter portions of the system. To comprehensively address those concerns, a computer model of the entire Withlacoochee River and its surrounding watershed was developed. This included an unprecedented effort to map the entire bottom of the Withlacoochee River from the Green Swamp to the Gulf of Mexico. In addition, portions of the surrounding watershed that contribute flows to the Withlacoochee River were identified. This model is being used to simulate several scenarios designed to specifically address these concerns.

Scenario Locations

District staff worked closely with stakeholders throughout the watershed, documenting both past and present concerns, ultimately identifying 19 scenarios as shown in **Figure 2**. These scenarios are designed to determine what effect historical or future changes might have on water levels and flows throughout the entire river and watershed. It is important to note that many of these model scenarios directly compete for the finite amount of water available, which means changes in one part of the river may affect other areas. The chapters of this report provide a description of each scenario, how the model was used to evaluate them, and a summary of specific results for each.

Figure 2 Location of Withlacoochee River Model Scenarios

Model Simulations

To address the unique characteristics of the river and watershed, a comprehensive model was developed using the Interconnected Channel and Pond Routing software version 4 (ICPRv4). This computer model has the ability to simulate one-dimensional flow in channels as well as two-dimensional flow in wetlands and marsh areas, both of which are prevalent throughout the Withlacoochee River watershed. Additionally, the model accounts for the volume and timing of contributing inflows from the surrounding watershed using dynamic rainfall inputs and varying initial water levels. This is critical since water levels and flow along the river are a direct result of rainfall and the watershed's antecedent conditions. **Figures 3** and **4** depict the wide range of initial water levels the river might experience prior to a rainfall event. In the low condition, water is contained within the main channel and rainfall on the surrounding land will infiltrate prior to contributing flows to the river. In the high condition, water levels are higher and the surrounding land is inundated. Subsequently, when rainfall occurs, runoff immediately causes river levels to rise and flows to increase, since the watershed's soils are already saturated.

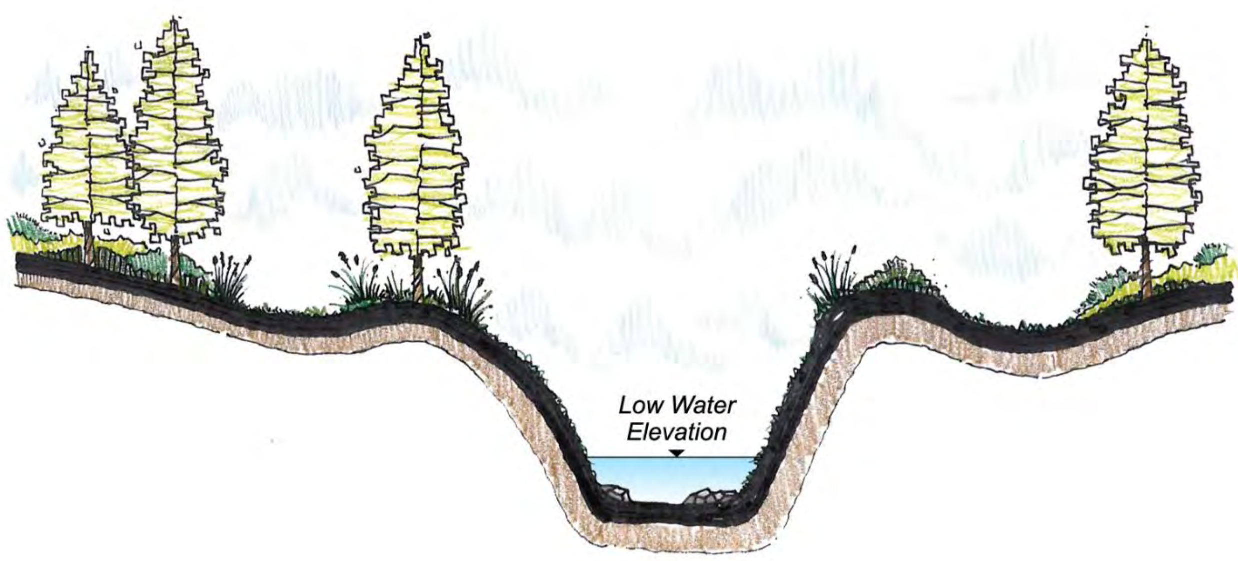

Figure 3 Low Initial Water Level

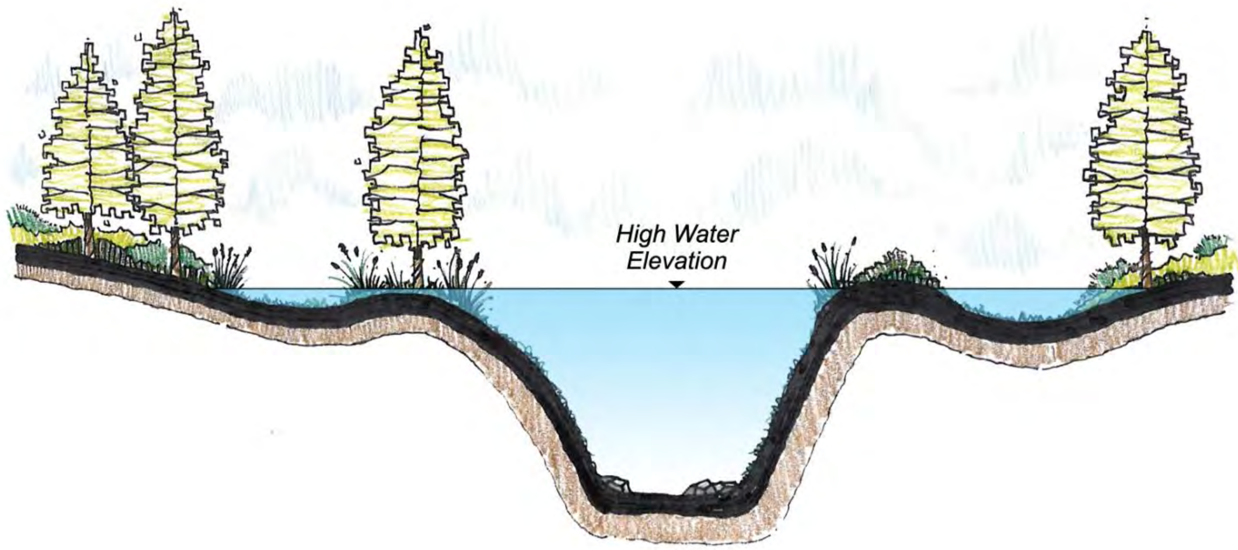

Figure 4 High Initial Water Level

To provide a basis of comparison for the scenario results, several storm events simulated existing conditions across the entire watershed. **Table 1** lists the simulated storms with their associated rainfall amounts and durations. Refer to the Verification Report (SWFWMD 2014) and Design Storms Memo (SWFWMD 2014) associated with this project for more information related to the specific storm events.

Table 1 Storm Events Simulated Rainfall Amounts

Storm Event Simulation	Verification Event	Design Events[2]			
	2004 Hurricanes	Mean Annual	10-Year	25-Year	100-Year
Rainfall Amount	13 to 28 inches[1]	6.9 inches	10.8 inches	12.3 inches	16.3 inches
Rainfall Duration	-	5 days	5 days	5 days	5 days
Simulation Duration	119 days	40 days	40 days	40 days	40 days

[1] varied throughout the watershed
[2] simulated for both high and low initial water levels

The first of these was the model's verification event, which simulated actual river stages and rainfall distributions during the 2004 hurricanes (August 4 through November 24). This event was the most recent flood to occur along the entire Withlacoochee River and was the result of intense rainfall on a previously saturated watershed. This event underlines the importance of initial water levels in this system. In addition to the verification event, several design level rainfall events including the mean annual, 10-year, 25-year and 100-year storms were simulated. These events applied constant rainfall amounts over the entire watershed and were evaluated using both high and low initial water levels, providing a range of comparison for the model scenario results. Overall nine events were simulated for the existing conditions, including the verification event and the four design storms with both high and low initial water levels.

Each of the 19 model scenarios were simulated using some or all of the nine storm events. For example, scenarios related to flooding were simulated with high initial water levels, while scenarios focused on the potential to increase waters levels were simulated with the low initial water levels. Overall 103 model simulations were performed for the 19 scenarios. All elevations provided in this report reference the North American Vertical Datum of 1988 (NAVD88).

Scenario 1: Green Swamp Railroad Berms

1.1. Description

From the 1920s through the 1950s, large-scale logging operations were active throughout much of Florida, including the headwaters of the Withlacoochee River in the Green Swamp. As a result of this booming industry, railroads were built within the Green Swamp to access centuries old cypress trees and transport the timber to a large mill in the nearby town of Lacoochee. Where these rails crossed swamps or other lowlands, ditches and holes were dug to raise them above the surrounding landscape. Today, these bermed roads are used to access the Green Swamp for land management, hunting and recreation. The General James A. Van Fleet State Trail, for example, was once a major railroad line that is now a popular multi-use trail. While culverts have been installed at many locations, the direction and magnitude of the natural flows may have been altered. As a result, the amount of water being stored in the Green Swamp and allowed to flow to the Withlacoochee River, Gator Hole Slough, Devils Creek, and the Little Withlacoochee River may have changed. A regional location map showing the locations of major creeks exiting the Green Swamp is seen in **Figure 1-1**.

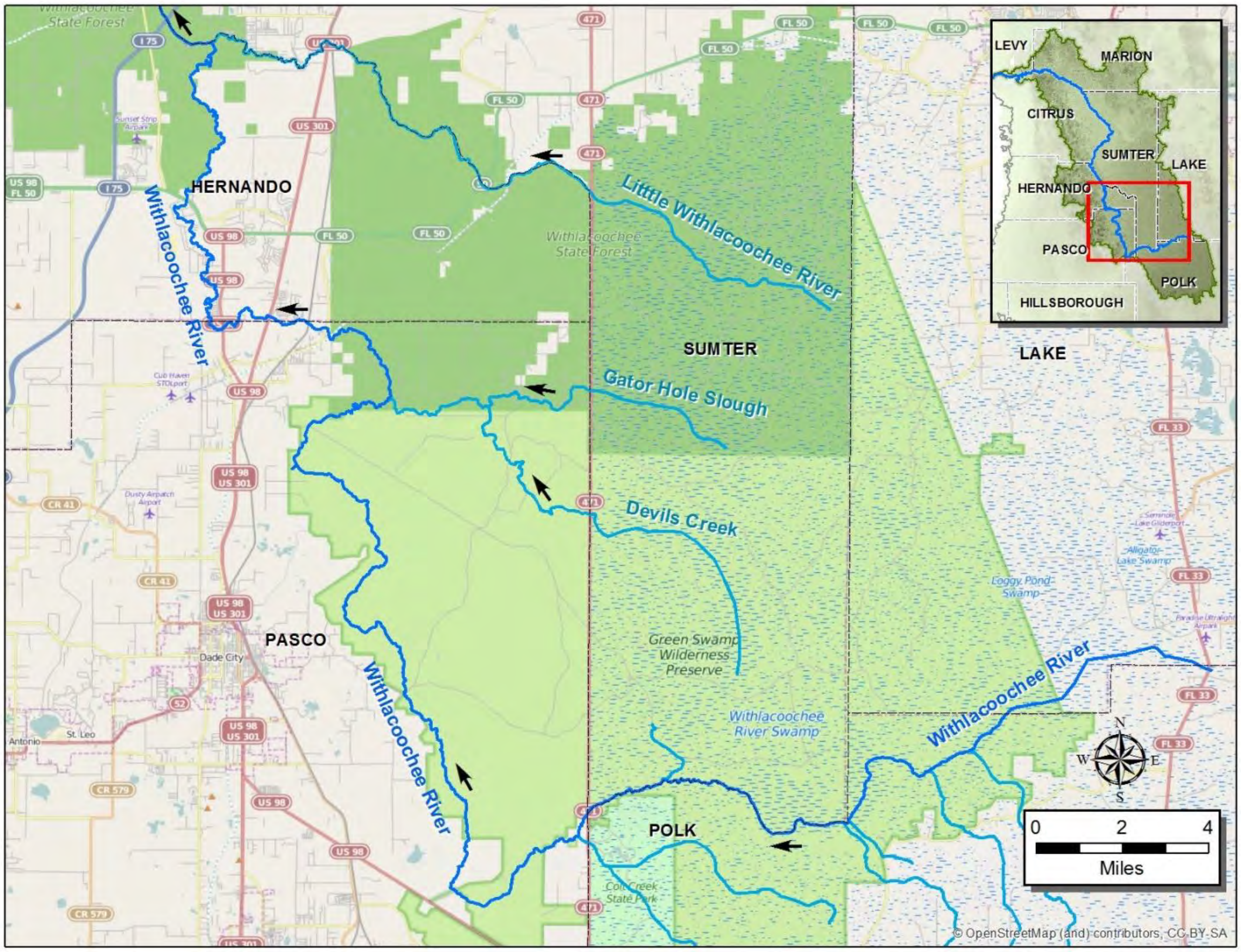

Figure 1-1 Green Swamp Streams and Creeks

The purpose of this scenario is to evaluate the effect that these historical railroad berms have on natural flow patterns within the Green Swamp and locations farther downstream. **Figure 1-2** shows an example of a remnant railroad berm in the Green Swamp (currently used as an access road) with a culvert installed to allow flow.

Figure 1-2 Historic Railroad Berms are used Today as Access for Land Management and Recreation

1.2. Model Set-up

This scenario was set up by first identifying the altered locations using digital topographic information (terrain). These locations were observed where the terrain was built up or cut down to construct a road or railway, and included both berms and ditches. Nearly 300 culverts exist along these altered roadways to maintain the continuity of flow within the Green Swamp. **Figure 1-3** shows the extent of these historic berms including over 200 miles of bermed access trails and railroad berms within the Green Swamp that were addressed as part of this scenario.

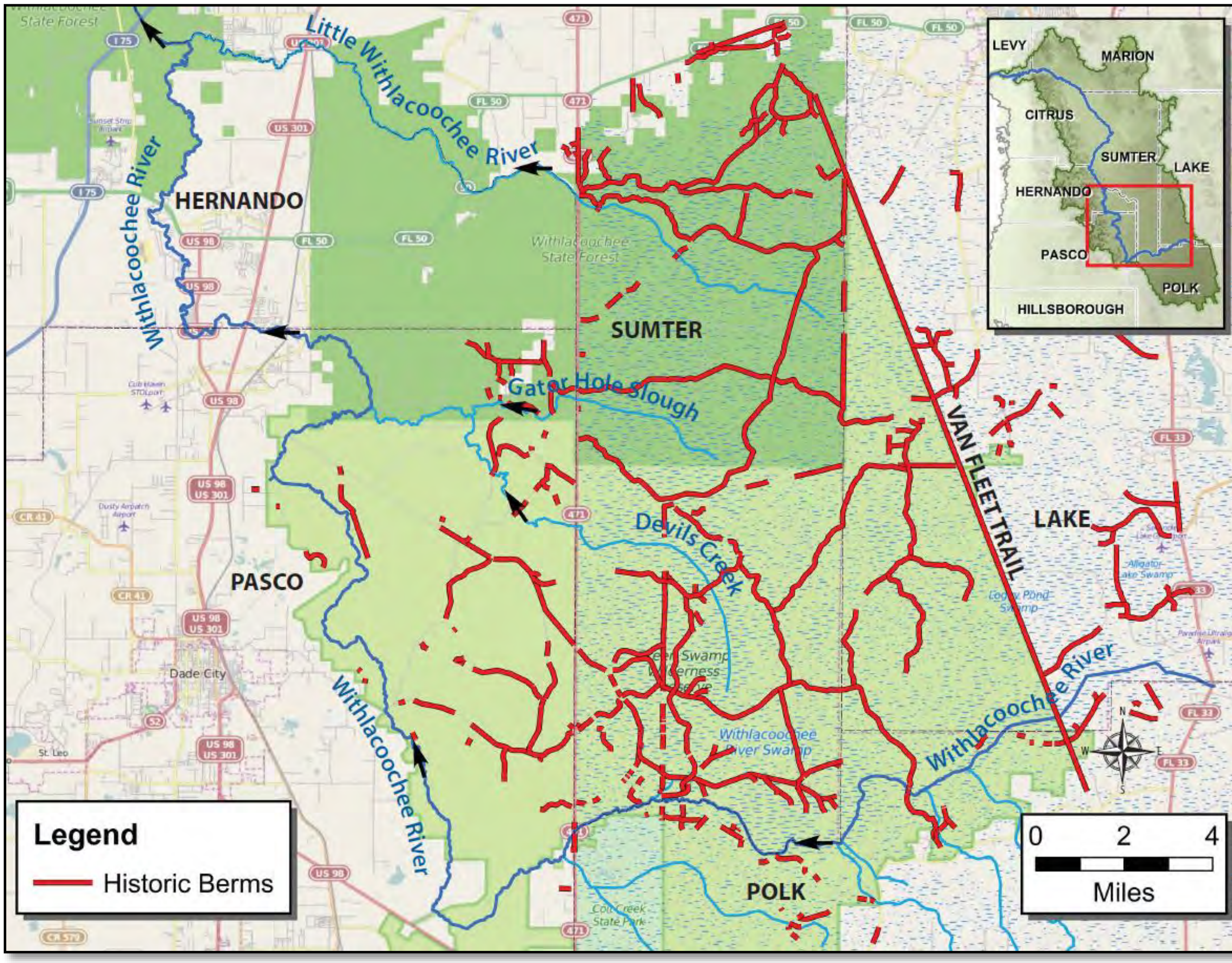

Figure 1-3 Historic Berms in the Green Swamp that were Removed for this Scenario

To evaluate this scenario, the model simulated the removal of these historic alterations by revising the digital terrain to reflect natural elevations in those areas. **Figure 1-4** shows an example of the current altered landscape and how the digital terrain was updated to reflect natural conditions. In addition to simulating the removal of the altered land in these areas, the culverts which currently convey water were also removed. This allowed the natural wetland and marsh elevations within the Green Swamp to control the quantity and direction of flow instead of constricting the flow of water through culverts or forcing the water to back up until it was high enough to overtop a berm.

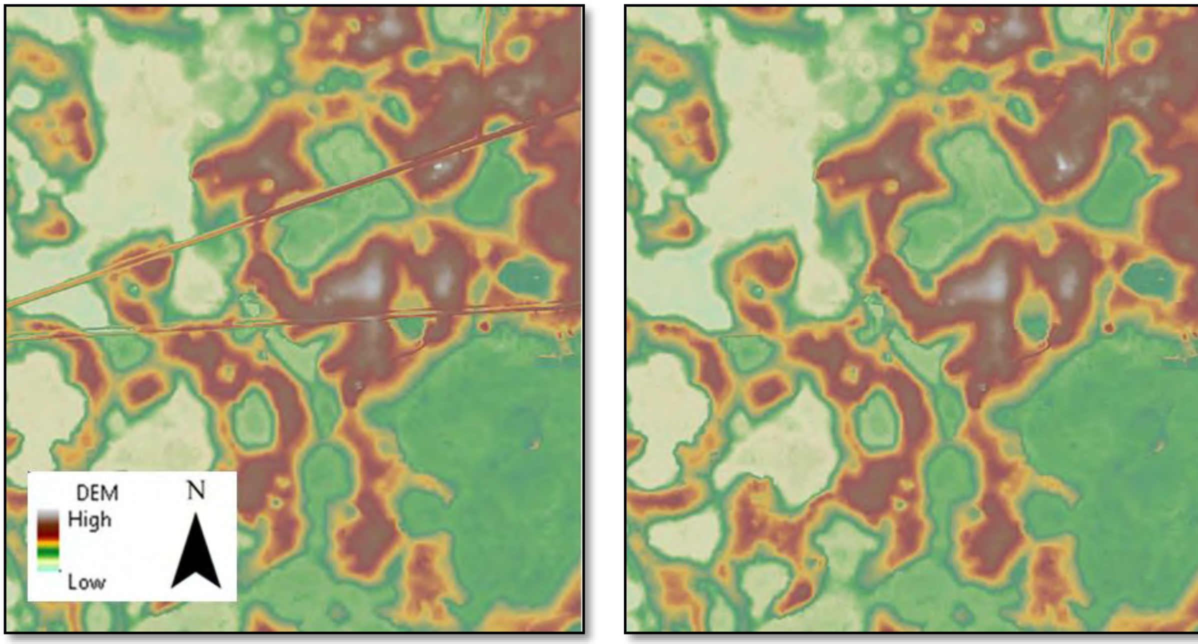

Figure 1-4 Existing Topography with Berms Present (left side) and Simulated Topography with Berms Removed (right side)

1.3. Results

This scenario was simulated using the 2004 hurricanes and mean annual, 10-year, 25-year, and 100-year design storm events with low initial water conditions. The results indicated that the berms both temporarily and permanently held a measurable amount of water in the Green Swamp. The removal of the berms altered the timing and total volume of water flows, particularly during large storm events.

Figure 1-5 shows locations where water levels changed by more than three inches for the 100-year storm event. The 100-year storm represents the highest amount of rainfall simulated for this scenario, providing the greatest potential for changing water levels. East of the Van Fleet Trail, peak water levels were lower, without the restriction provided by the trail. This coincided with observed increases in water levels on the downstream, west side, of the trail. While not all bermed areas showed dramatic changes, the figure highlights where these were most notable, such as the headwaters of the Little Withlacoochee River.

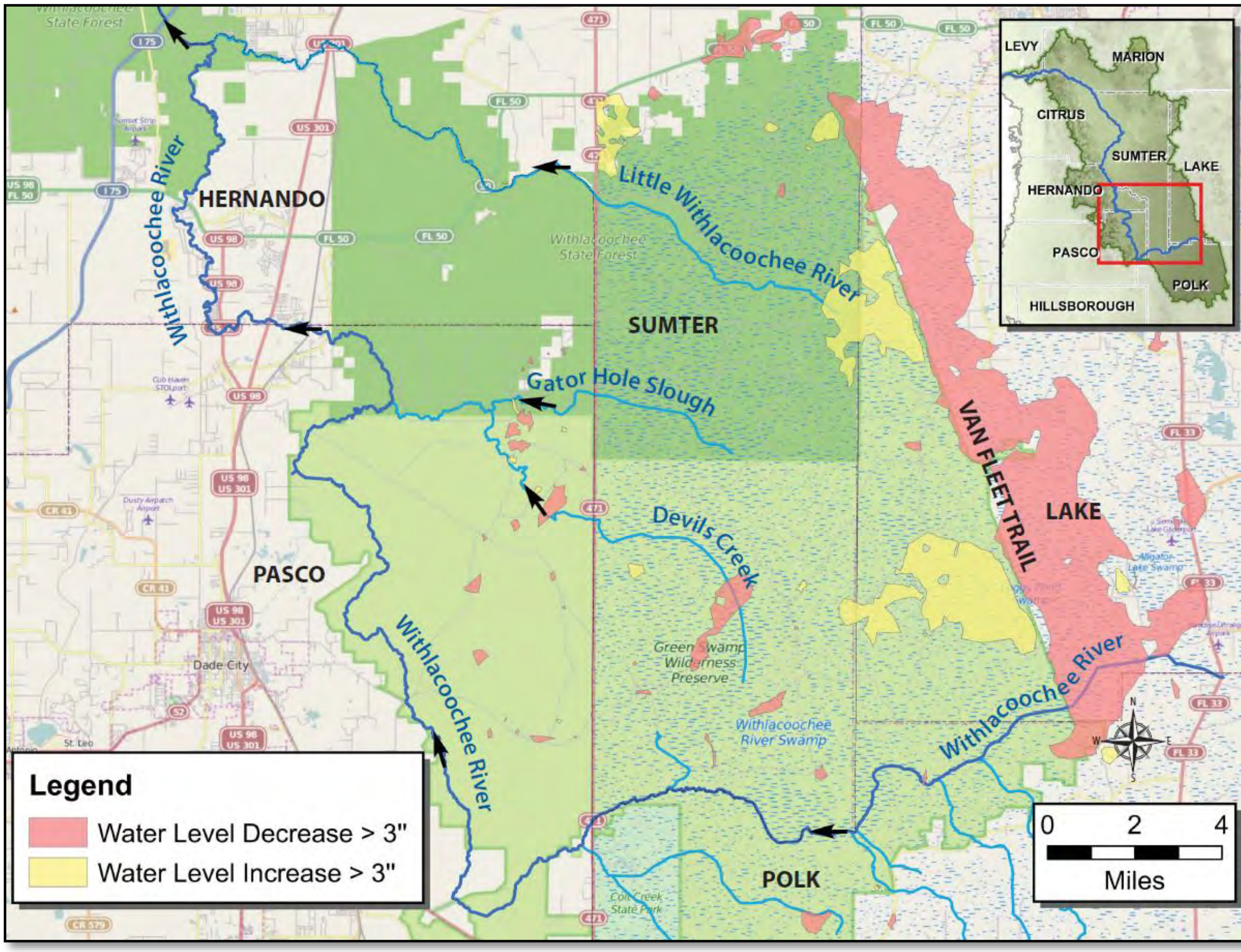

Figure 1-5 Peak Water Level Changes from Simulated Berm Removal

The simulated removal of the railroad berms not only resulted in a water level increase upstream of State Road 471 (SR 471) at the Little Withlacoochee River, but a corresponding peak flow increase as well, as a result of an overall volume increase to the Withlacoochee River. Representative flow results from the 2004 verification event are seen on the Little Withlacoochee River at SR 471 in **Figure 1-6**. In the figure the blue line represents the flows from the existing conditions simulation and the red line represents flows with the berms removed. Results show higher flows along with an overall volume increase of 16 percent throughout the event.

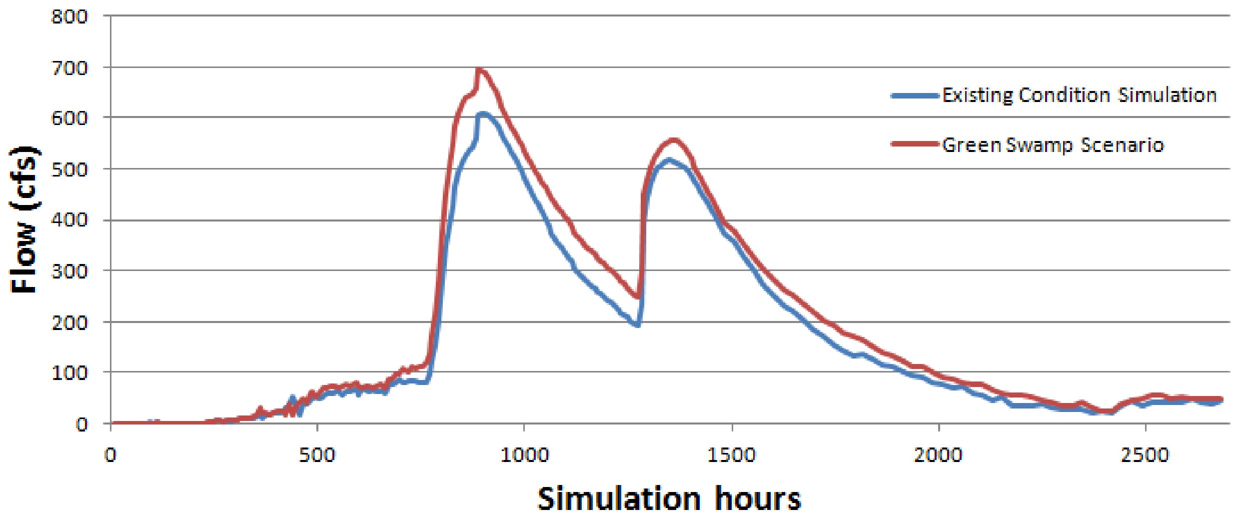

Figure 1-6 Comparison of Flows for the Little Withlacoochee River at SR 471 for the 2004 Hurricanes

This indicates that the flow and volume increases in the Little Withlacoochee River are the result of stored water being released past the previously existing berms. This is supported by the other major outlets from the Green Swamp also having total volume increases. The Withlacoochee River at SR 471 increased in volume by nine percent, and the combined flow from Devils Creek and Gator Hole Slough increased by ten percent. Flow hydrographs for these locations are seen in **Figures 1-7** and **1-8**, respectively. Similar to the flows to the Little Withlacoochee River, the most significant deviation in flow is observed just past the peak of each of the hurricanes, suggesting a larger portion of flow is discharging later in the storm event rather than being stored in the Green Swamp. These volume differences are depicted in **Figure 1-9**, with flow arrows showing the locations and directions of the volume increases at the Withlacoochee River, Little Withlacoochee River and combined flow through Devils Creek and Gator Hole Slough. These water level differences however, are not translated further downstream with only minimal increases in flow seen at the SR 200 crossing at Holder or within the Tsala Apopka Chain-of-lakes.

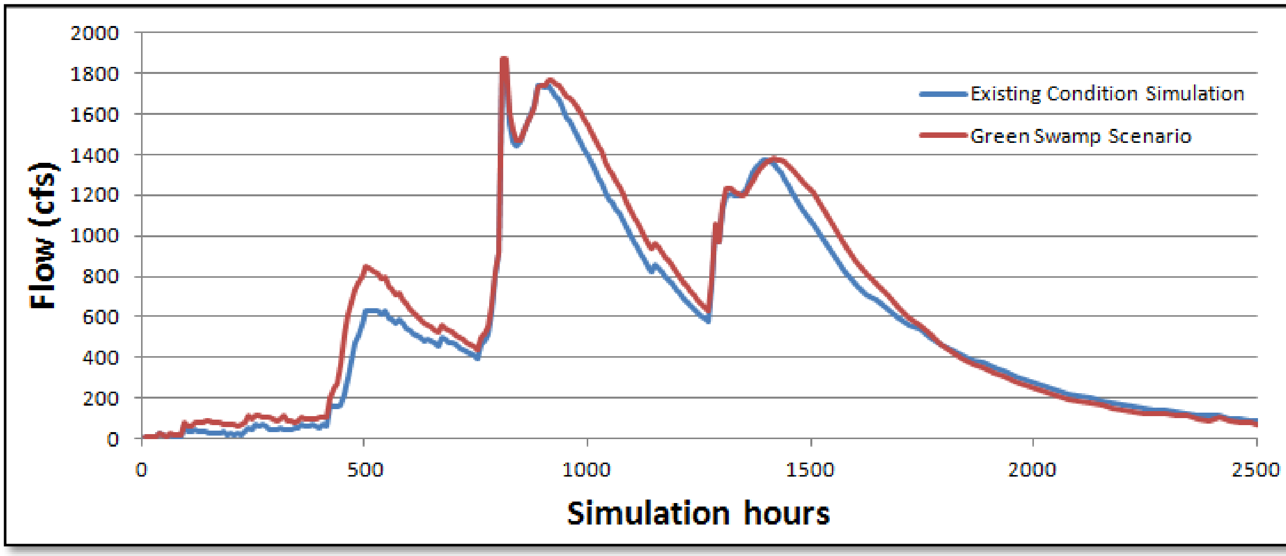

Figure 1-7 Comparison of Flows for the Withlacoochee River at SR 471 for the 2004 Hurricanes

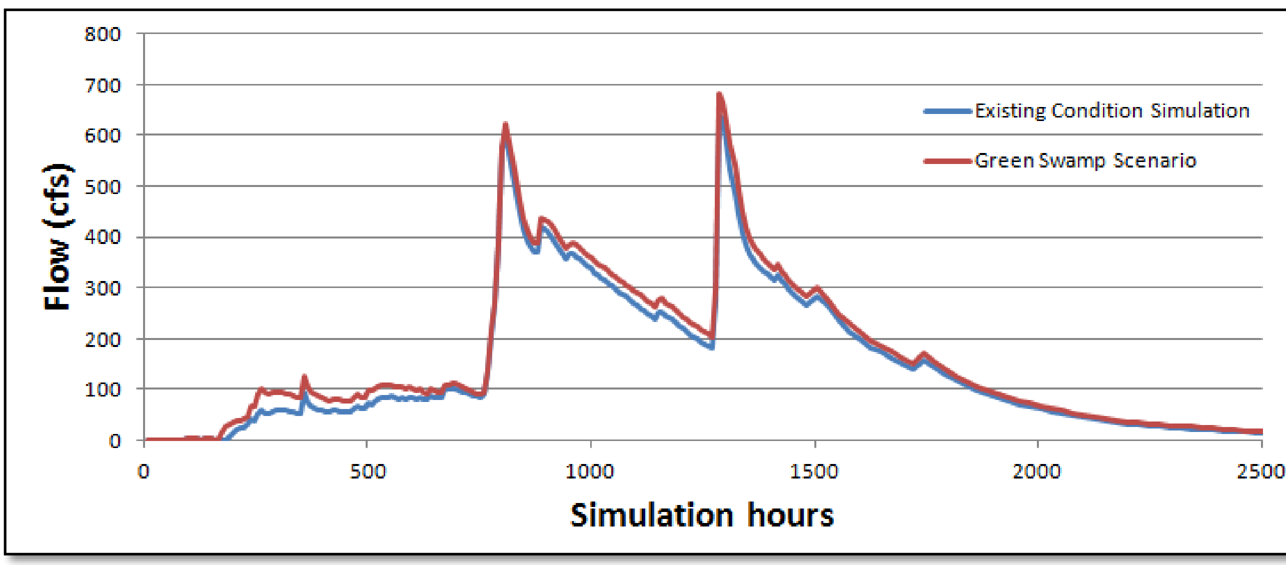

Figure 1-8 Comparison of Combined Flows for Devils Creek and Gator Hole Slough for the 2004 Hurricanes

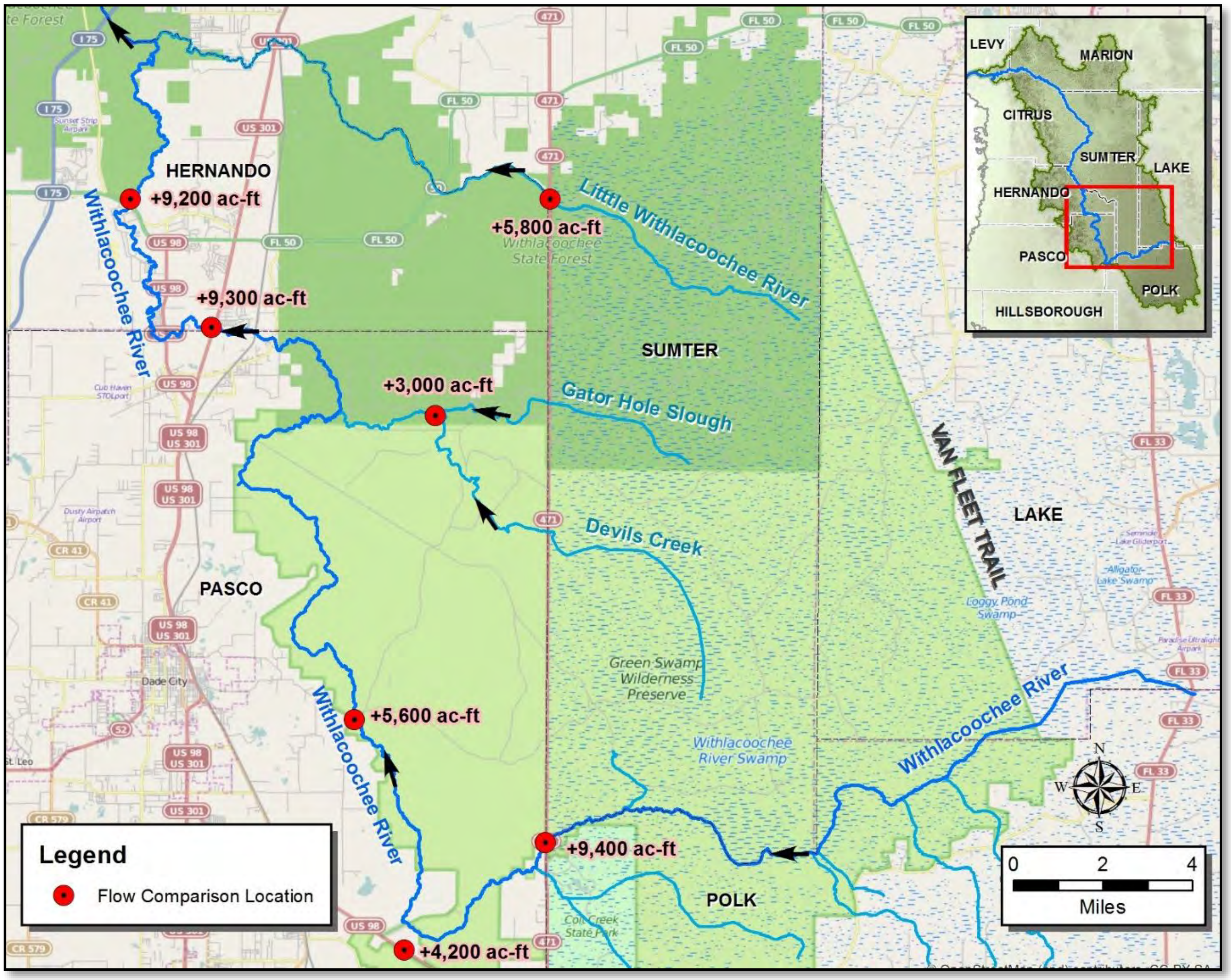

Figure 1-9 Flow Volume Increases (acre-feet) with Historical Railroad Berms Removed

1.4. Conclusion

Various locations within the Green Swamp showed differences in water levels and flows as a result of removing the historical railroad berms, particularly during larger storm events such as the hurricanes of 2004. This difference translated into an overall increase in total flow volume leaving the Green Swamp, indicating that the existing berms serve to hold water in the Green Swamp. This increase in flow from the Green Swamp, however, was much less pronounced in the smaller storm events, such as the mean annual design storm. Water levels in the Green Swamp are a reflection of regional rainfall and groundwater levels. During low water periods, there would be no change to flows leaving the Green Swamp if the berms were removed.

Scenario 2: Green Swamp Railroad Bridge Pilings

2.1. Description

The Withlacoochee River originates from and flows through the Green Swamp. During the early to mid-1900s, extensive logging activities necessitated the construction of railroad bridges that crossed the river's main channel. Although the railroad tracks themselves have since been removed, many of the bridge pilings remain as a reminder of these historical activities. **Figure 2-1** shows an example of remnant bridge pilings across the Withlacoochee River. Several of these locations have created massive log jams as fallen trees and floating debris have been caught by these bridge pilings. In addition, the river's channel bottom at the log jams has filled in with sediments, raising the control elevation well above its natural elevation. This has created artificial obstructions to flow. The purpose of this scenario is to evaluate the impact these log jams have on water levels and flows in the river.

Figure 2-1 Remnant Bridge Pilings across the Withlacoochee River in the Green Swamp

2.2. Model Set-up

There are numerous log jams along the river in the Green Swamp that have naturally formed over time. In addition, there are many locations with historical bridge pilings that have not created significant obstructions to flow. The focus of this scenario is eight locations in the Green Swamp where bridge pilings have artificially created significant log jams along the main channel of the Withlacoochee River. These locations, shown in **Figure 2-2**, were identified during extreme drought conditions in 2007 and 2008 while the bathymetric survey of the Withlacoochee River was being performed.

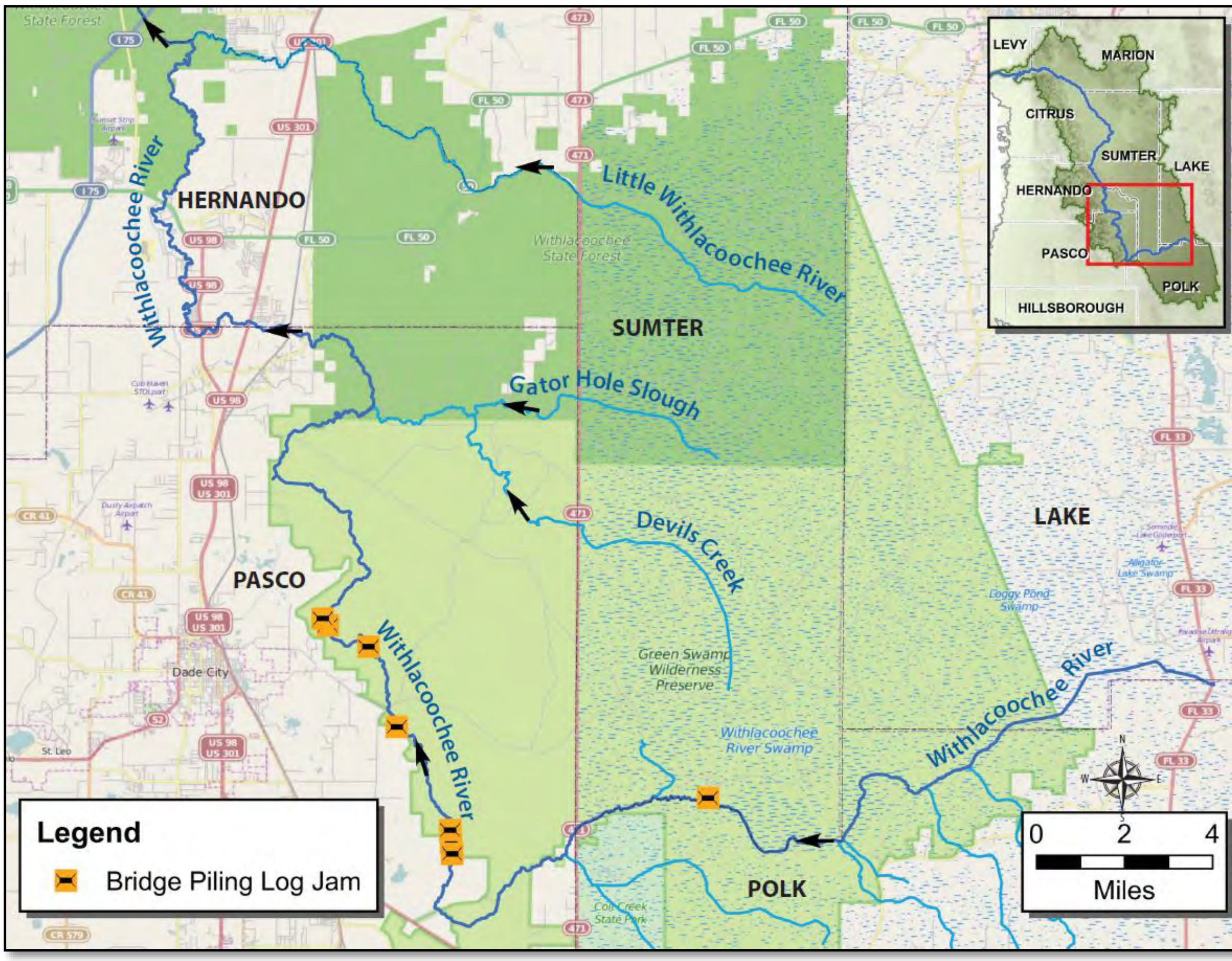

Figure 2-2 Bridge Piling Log Jams along the Withlacoochee River in the Green Swamp

The removal of these obstructions was simulated with the model by adjusting the channel cross sections or modifying the digital terrain at each of the locations. A representative sketch of the channel cross section with and without the log jam is presented in **Figure 2-3**. By removing the log jam and restoring the natural channel, the control shifts to the natural ground.

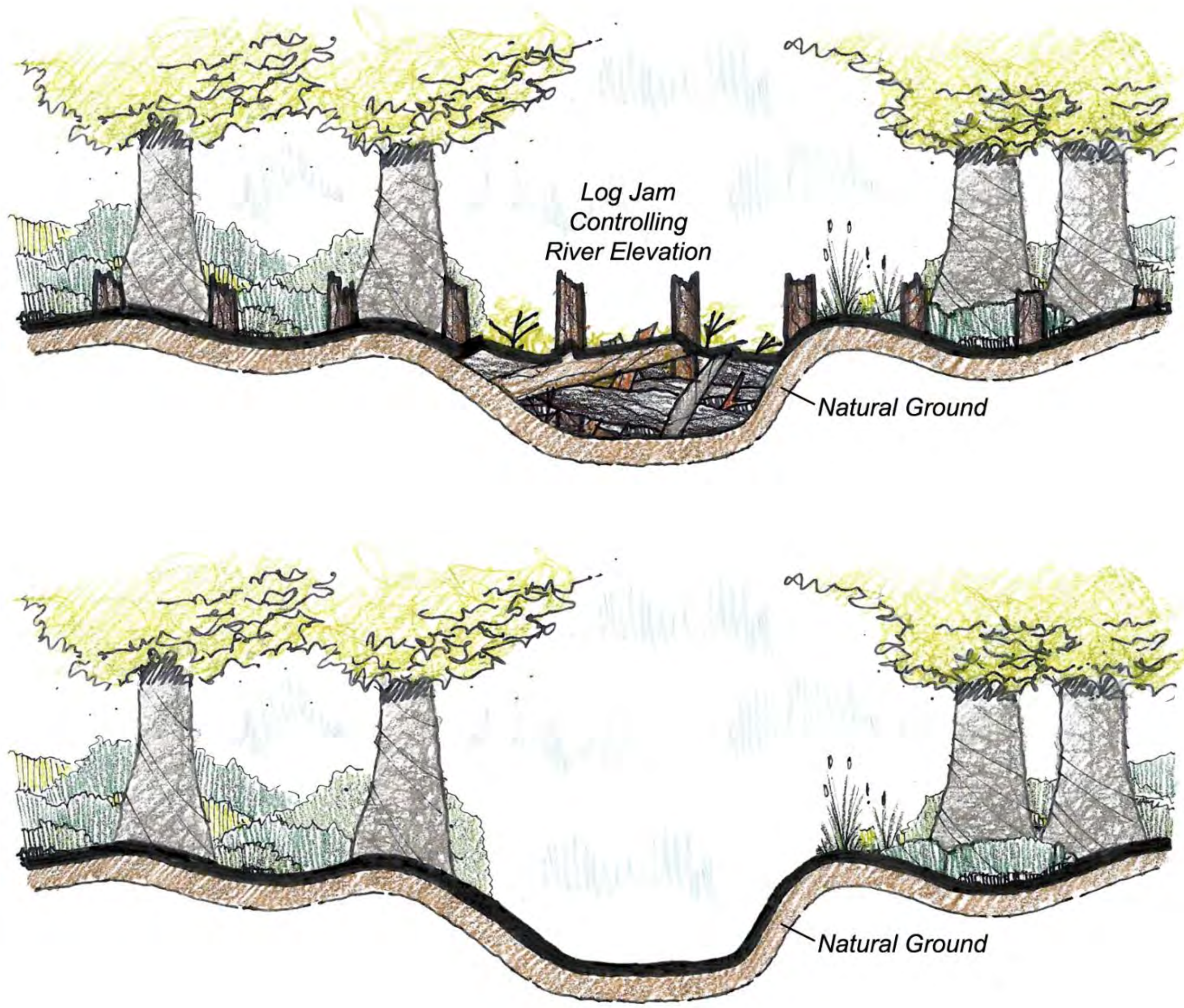

Figure 2-3 Profile and Cross Section of Log Jam

Figure 2-4 shows a location where the digital terrain was modified from the existing condition (channel obstruction) to the natural channel bottom (no obstruction).

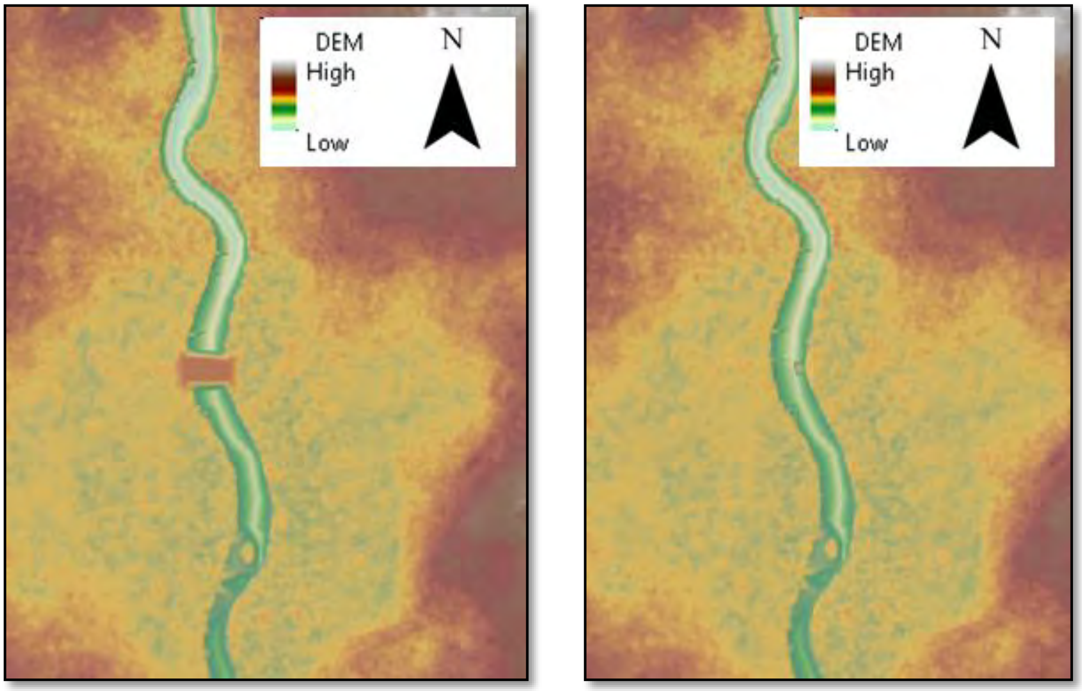

Figure 2-4 Comparison of Existing Flow Obstruction (left side) and Simulated Natural Condition (right side)

2.3. Results

This scenario was simulated using the 2004 hurricanes and mean annual, 10-year, 25-year, and 100-year design storm events with low initial water conditions. Locations along the river and throughout the watershed were compared for differences in peak water level and flow as a result of removing the bridge piling log jams. Model results showed no significant differences during high flows, suggesting the obstructed flow area within the main channel is minimal compared to a much wider floodplain that is inundated. For example, during the 2004 hurricanes, water levels are several feet above the log jams and flows extend up to one mile wide, whereas the obstructed main channel is often less than 50 feet wide. This is shown on the sketch provided as **Figure 2-5**.

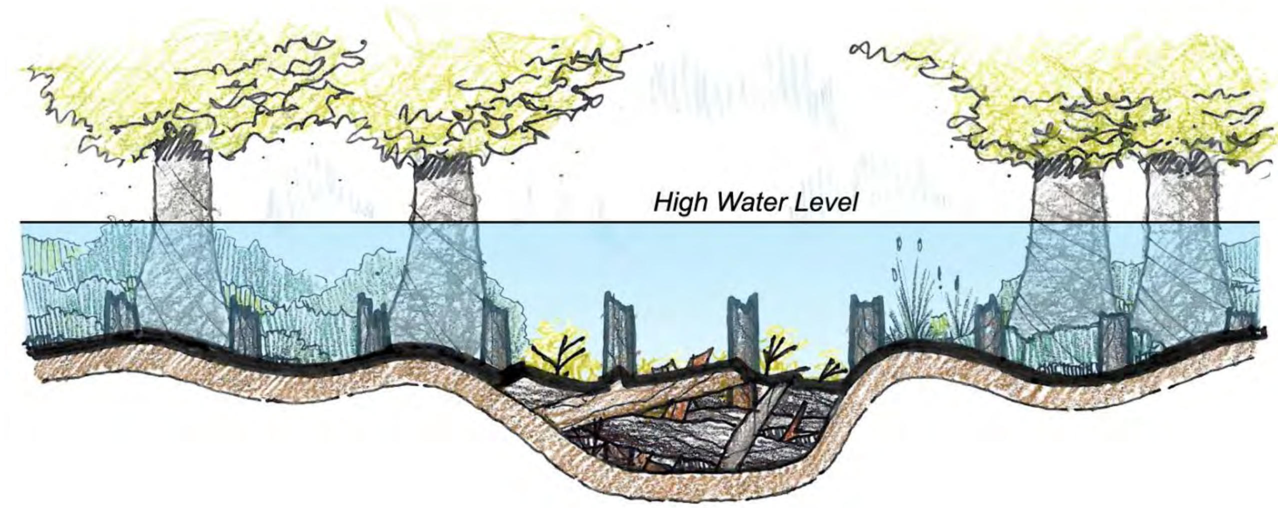

Figure 2-5 Log Jam Cross Section during High Water Event

Additionally, there were no measurable differences in water levels or flow downstream of the Green Swamp for any of the simulated events. The most significant difference of any of the log jams was seen during the mean annual and verification events just upstream of the most downstream log jam. As seen in **Figure 2-6**, the mean annual event at this location has a three inch decrease in the peak water level as a result of removing of the log jam. Then as the river recedes, the log jam holds water in the channel up to two feet higher. Although there was not a difference in peak water level for the verification event at this location, seen in **Figure 2-7**, the water level leading up to and trailing away from the hurricanes is lower as a result of the lower controlling elevation caused by the removal of the log jam. This difference is extremely localized, however, and dissipates a few thousand feet downstream.

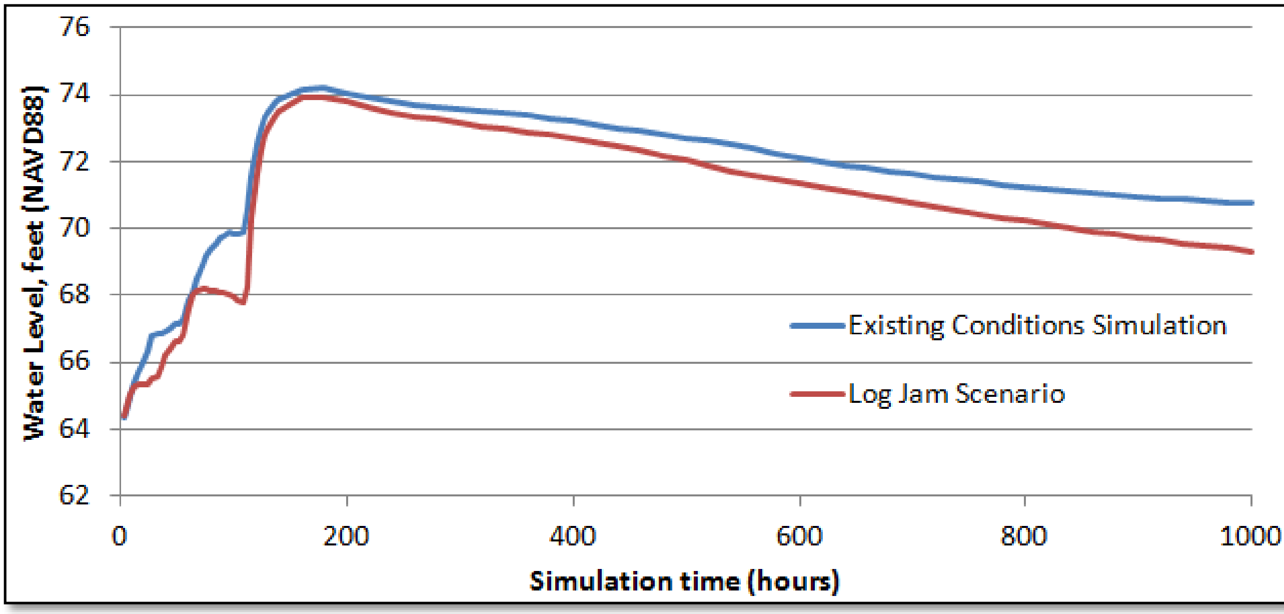

Figure 2-6 Comparison of Water Levels Upstream of Log Jam for the Mean Annual Storm

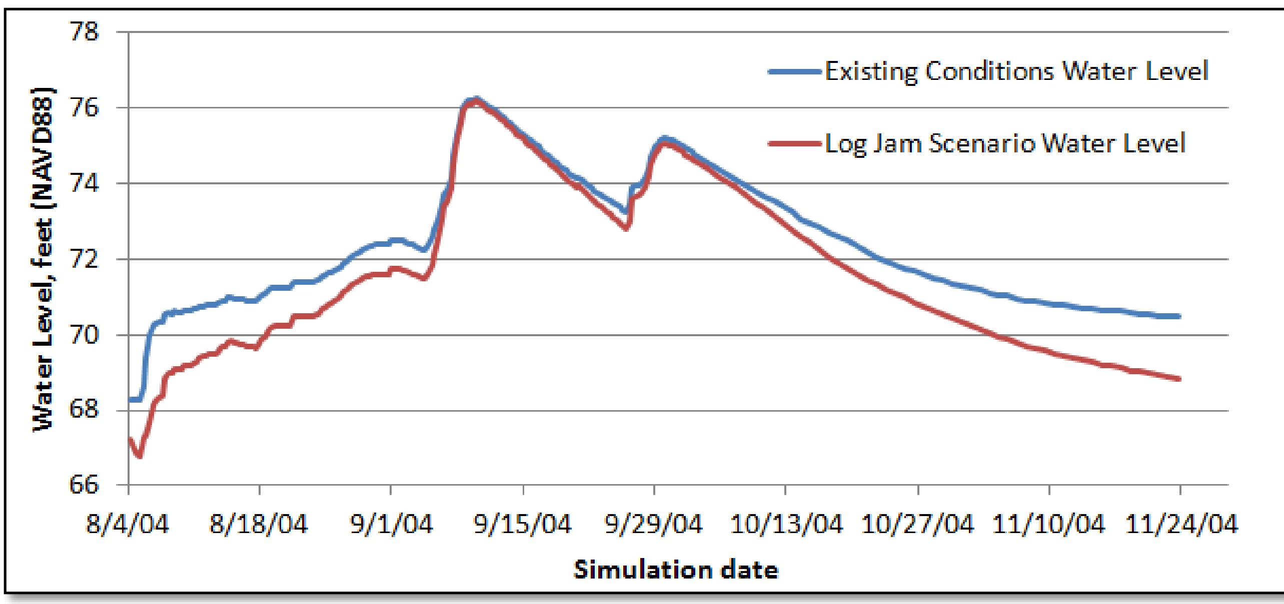

Figure 2-7 Comparison of Water Levels Upstream of Log Jam for the 2004 Hurricanes

2.4. Conclusion

The model results suggest that minor impacts to water levels and flow exist at the log jam locations as a result of the flow obstructions. These are localized impacts, however, that do not affect river hydraulics upstream or downstream because of the extent of the river's floodplain at these locations. **Figure 2-8** shows one of these bridge piling log jams during both low and high water conditions. A high water mark from the 2004 hurricanes is evident on the large cypress on the left side of each photo. Water levels in December of 2014 nearly covered the bridge pilings and represent between a mean annual and 10-year storm event, slightly lower than the peak observed in 2004.

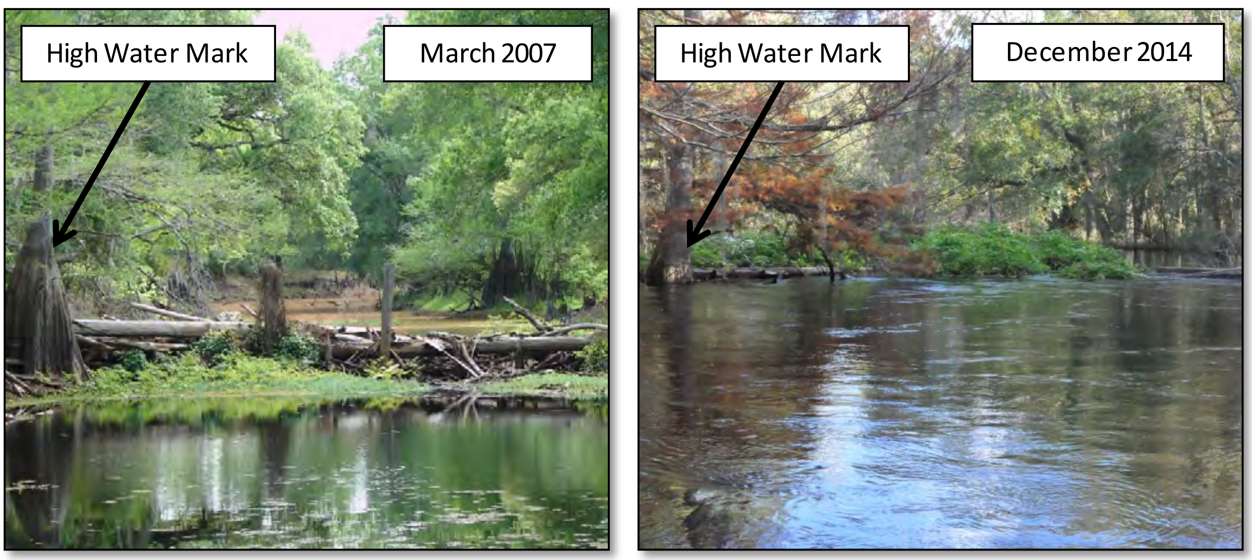

Figure 2-8 Comparison of Low Water (left side) and High Water (right side) at a Bridge Piling Log Jam in the Green Swamp near Dade City

Scenario 3: Green Swamp and SR 471

3.1. Description

State Road (SR) 471 extends northward for 35 miles through the middle of the Green Swamp, between US 98 in Polk County and US 301 in Sumter County. Major bridge crossings are located at both the Withlacoochee and Little Withlacoochee Rivers along with large box culvert crossings at Devils Creek and Gator Hole Slough. In addition to these major crossings, there are over 50 additional culvert crossings where the raised highway bisects natural wetlands and sloughs. Each culvert and the locations of the major stream crossings are shown in **Figure 3-1**.

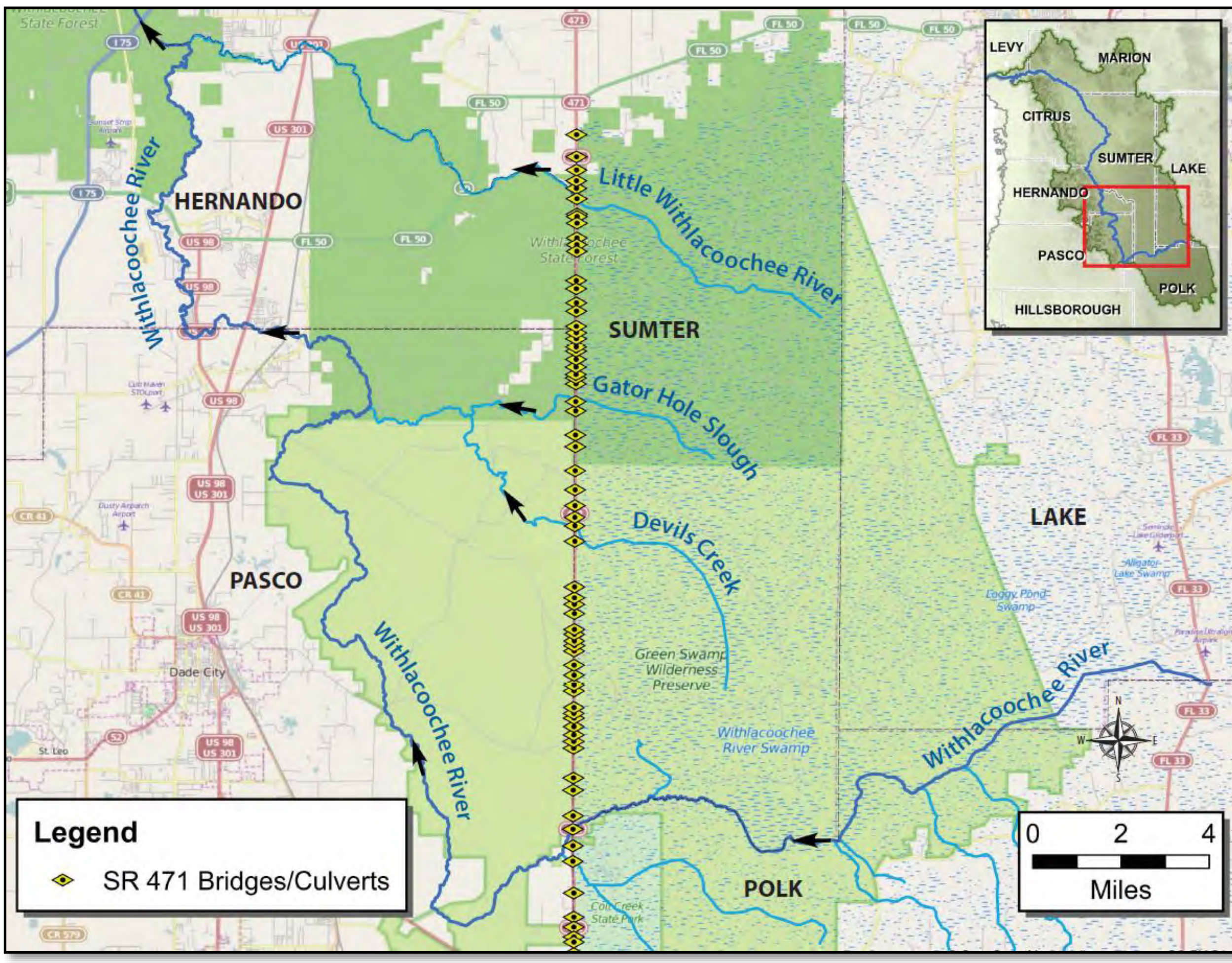

Figure 3-1 Locations of Major Stream and Culvert Crossings under SR 471 in the Green Swamp

This scenario simulates the complete removal of SR 471 to determine the impact its construction has on water levels and flow leaving the Green Swamp as well as points further down the Withlacoochee River. **Figure 3-2** shows the SR 471 Bridge crossing at the Withlacoochee River.

Figure 3-2 Looking Downstream at the SR 471 Bridge Crossing on the Withlacoochee River (2008)

3.2. Model Set-up

The Green Swamp slopes from east to west as it passes the footprint of SR 471. Under existing conditions, water flowing past SR 471 is diverted through the many culverts and bridge crossings built during the highway's construction. To understand how this construction may have impacted natural flows through the Green Swamp and beyond, the footprint of SR 471 was removed along with each culvert and bridge crossing. This was accomplished by adjusting cross section data in the model and modifying the digital terrain along the length of the road. **Figure 3-3** shows how the digital terrain was updated to evaluate this scenario. On the left side of this figure, the footprint of SR 471 is clearly visible due to its relatively high elevation in the region. The image on the right side depicts the natural condition, prior to the construction of SR 471, which was simulated in this scenario.

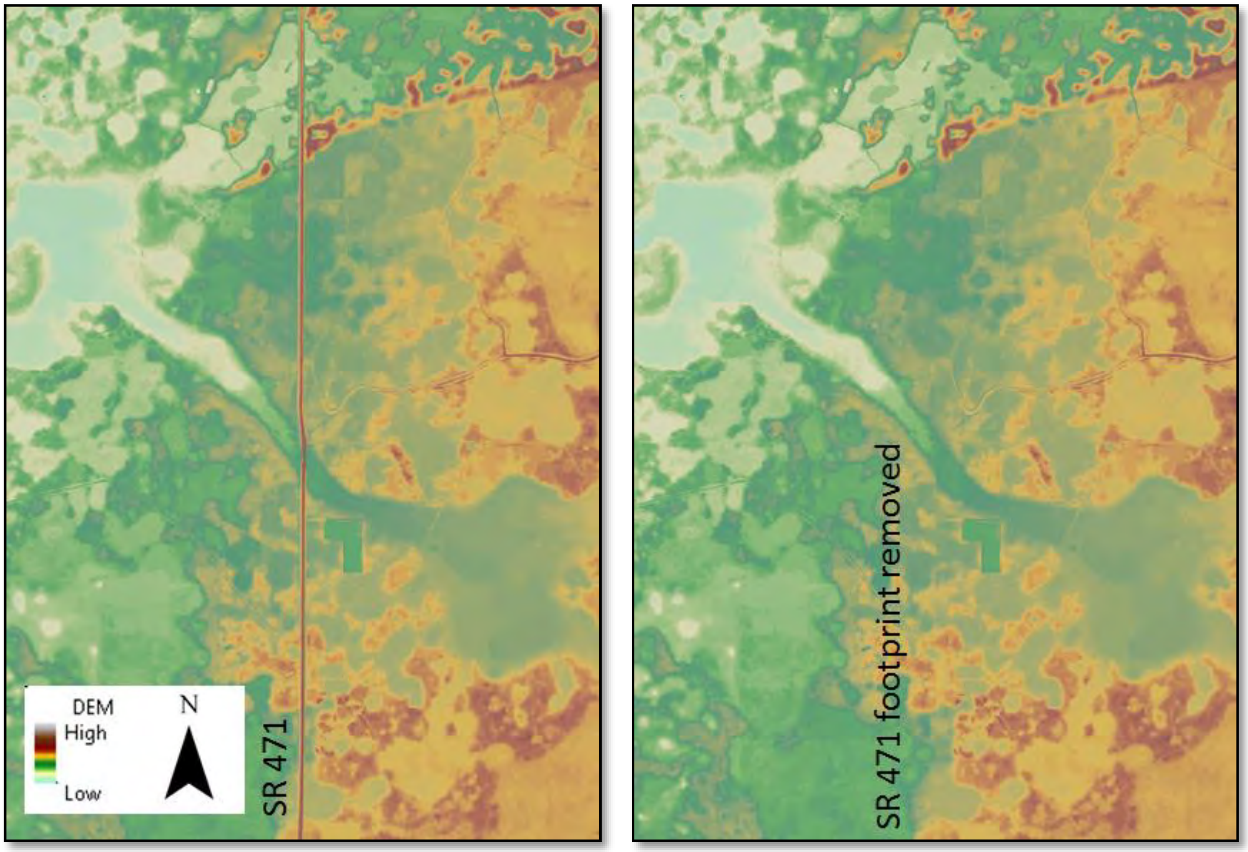

Figure 3-3 Digital Terrain with and without the Footprint of SR 471 at the Little Withlacoochee River

3.3. Results

This scenario was simulated using the 2004 hurricanes and the 25-year and 100-year design storm events with low initial water conditions. Model results indicate very little differences in water levels throughout most of the Green Swamp and on the upstream or downstream sides of SR 471 as a result of its removal. For the design storm events however, differences were seen in the 24 hours surrounding the peak flow associated with the event. The Withlacoochee River at SR 471, for example, showed 25 percent less peak flow during the 100-year storm (**Figure 3-4**), while the remainder of the event following the peak matched almost identically.

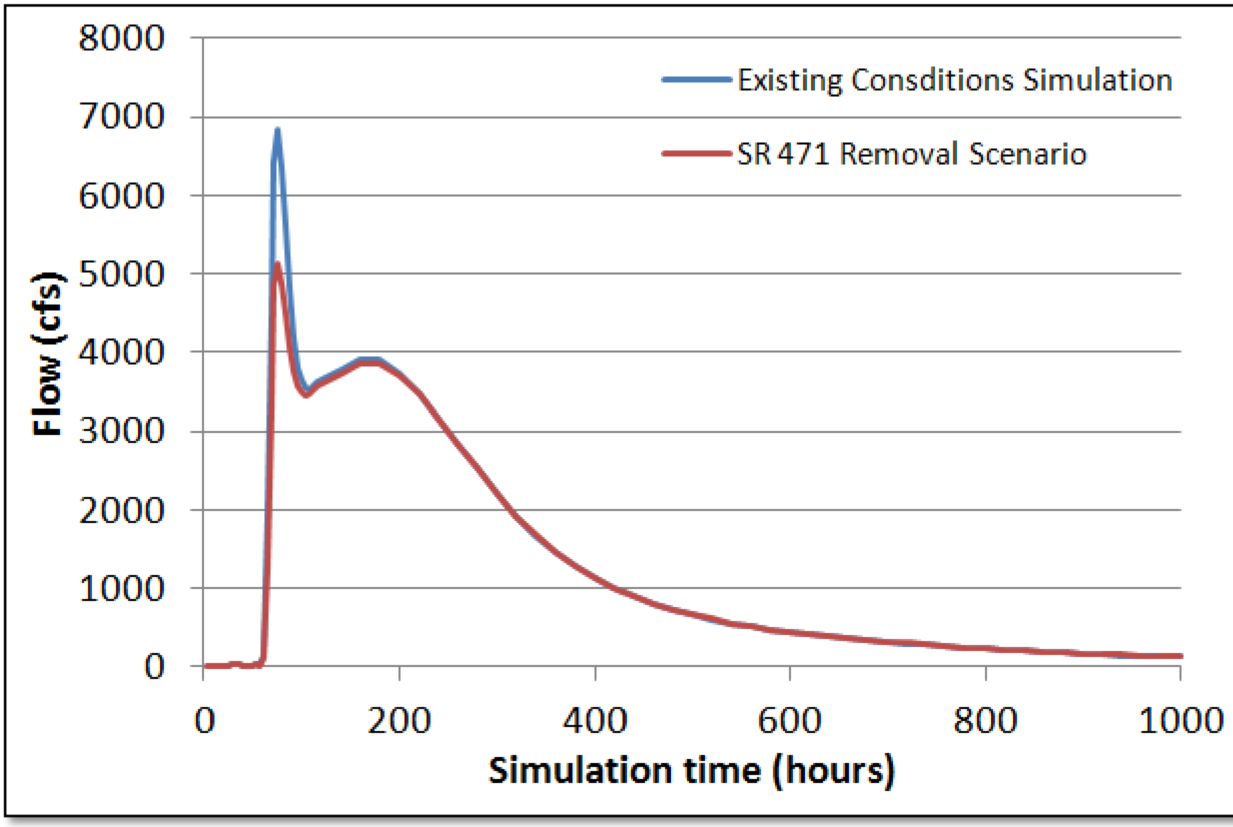

Figure 3-4 Comparison of Flows on the Withlacoochee River at SR 471 for the 100-year Storm Event

The most significant deviations occurred where the Little Withlacoochee River crosses SR 471 and at the confluence of Gator Hole Slough with Devils Creek. The removal of SR 471 enabled increased flow through the swamps past the removed roadway, rather than funnelling it through the Little Withlacoochee River Bridge. As a result, the Little Withlacoochee River at SR 471 showed a seven percent decrease in total flow volume during the 2004 hurricanes with SR 471 removed (**Figure 3-5**). The combined flow in Devils Creek and Gator Hole Slough, which represent less channelized flow paths, showed a five percent increase in total flow volume for this same event (**Figure 3-6)**. Locations downstream along the Withlacoochee River showed almost no difference in flow volume as a result of removing SR 471. **Figure 3-7** shows the total change in flow volume at these locations for the 2004 hurricanes as a result of removing SR 471.

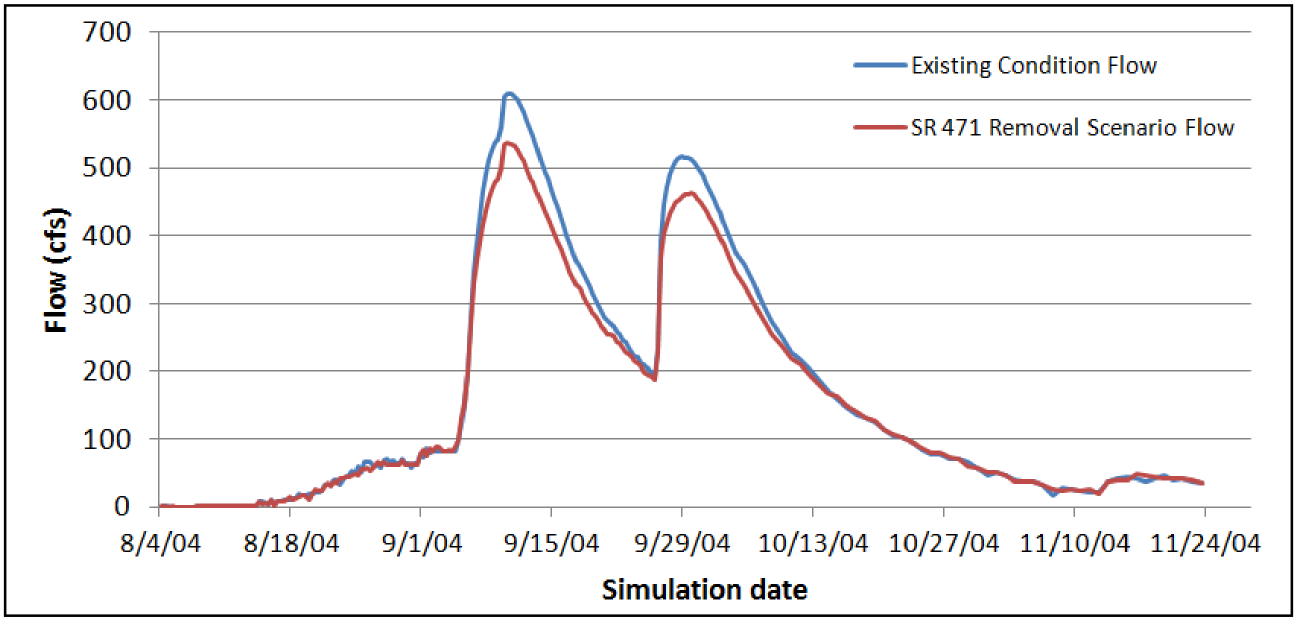

Figure 3-5 Comparison of Flows for the Little Withlacoochee River at SR 471

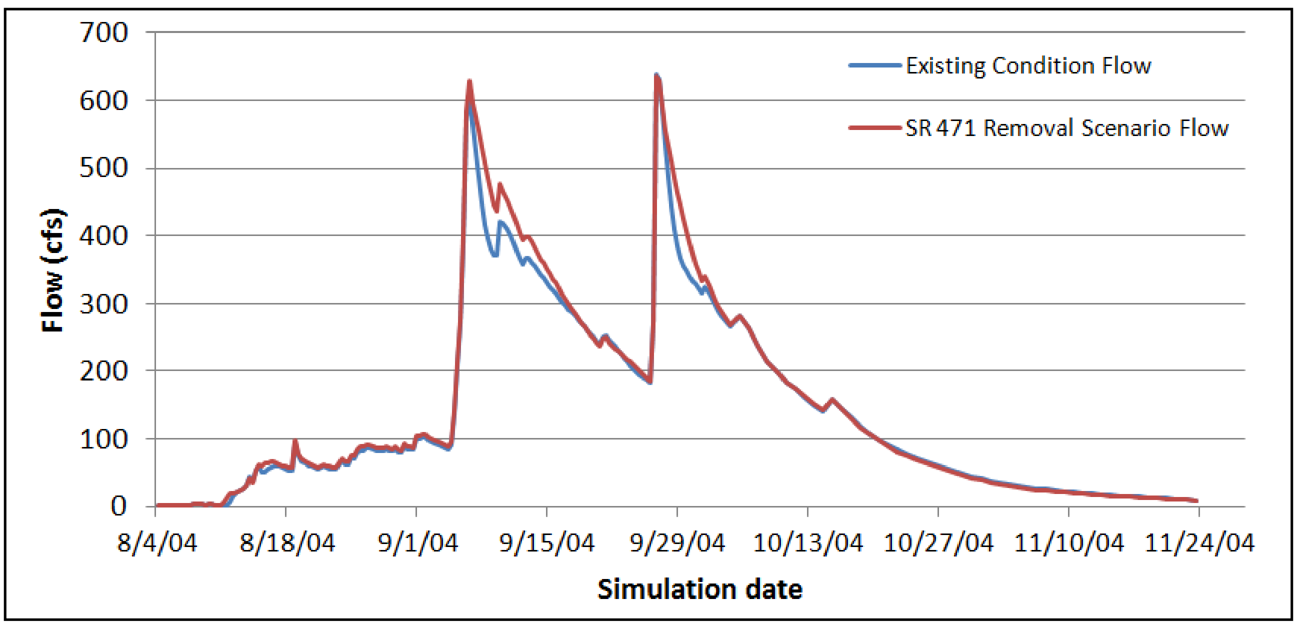

Figure 3-6 Comparison of Combined Flows for Devils Creek and Gator Hole Slough

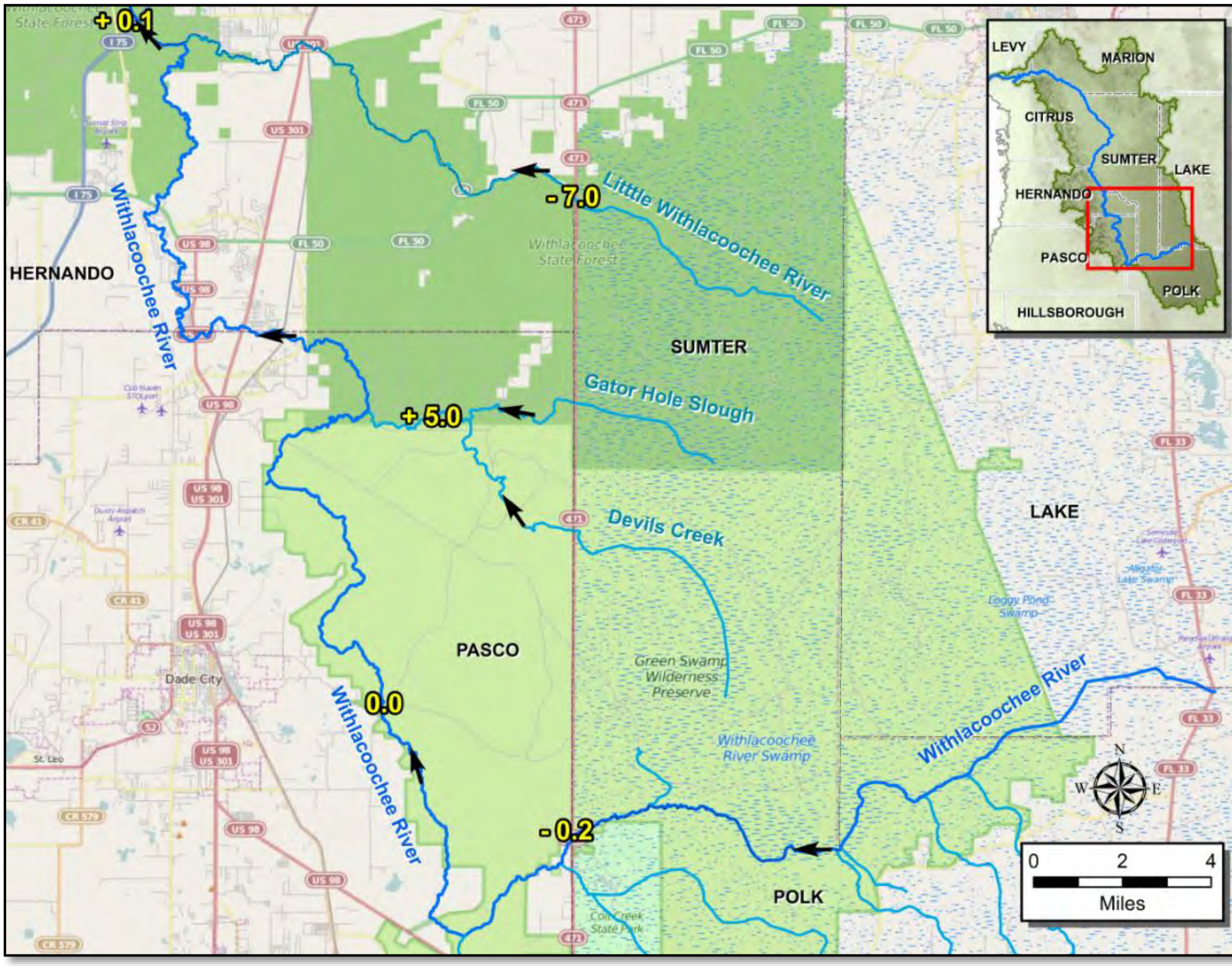

Figure 3-7 Percent Difference in Total Flow Volume for the 2004 Hurricanes

3.4. Conclusion

The results suggest that while the footprint of SR 471 has very little impact on water levels in the Green Swamp, its presence has a local effect on the magnitude of flows at specific locations. This effect is dissipated farther downstream as model results show no overall change in flow volume leaving the Green Swamp. The existing bridge and culvert locations appear to be able to convey the historical capacity of water downstream. The removal of SR 471 shifts some of the flow from the Little Withlacoochee River to the Devils Creek / Gator Hole Slough flow path, yet when the combined flow joins the river again at Croom, there is almost no change. This suggests that SR 471 does not significantly retain water within the Green Swamp, but rather serves to redistribute the flow across a wider area only to reconstitute further downstream

Scenario 4: Hillsborough River Overflow at US 98

4.1. Description

The vast majority of surface water leaving the Green Swamp flows to the Withlacoochee River due to the area's natural topography. Also in this area, the Hillsborough River originates in a wide forested swamp, just north of US 98, where the Withlacoochee turns sharply northward. When water levels in the Withlacoochee River rise above the natural elevations of this flat region, flow occurs from the Green Swamp to the Hillsborough River under the US 98 bridge (**Figure 4-1**).

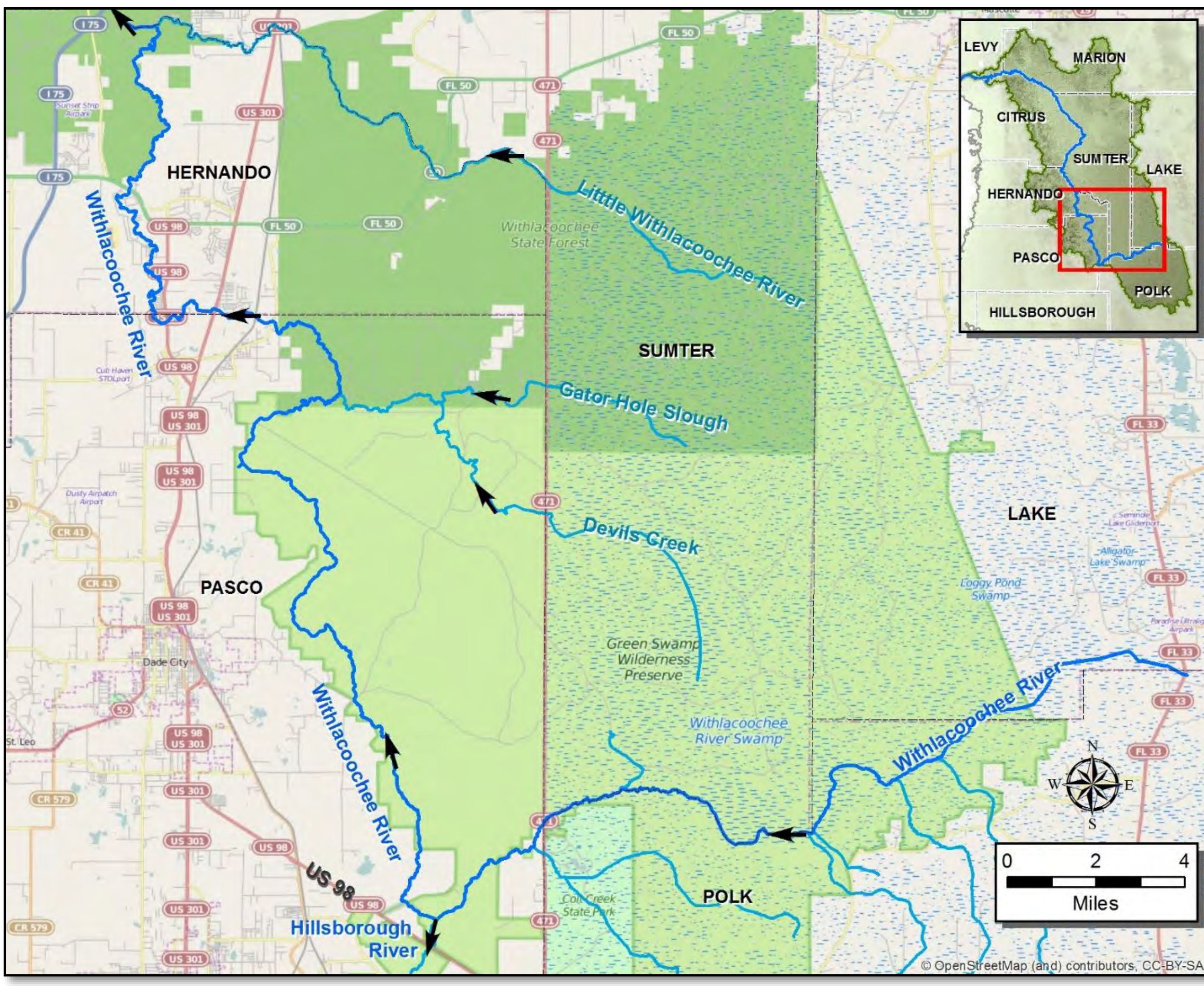

Figure 4-1 Location of the Hillsborough River Overflow from the Green Swamp

The Hillsborough River bridge at US 98, which was originally constructed in 1951 and later reconstructed in 1995, is shown in **Figure 4-2**. Under most water level conditions, very little or no flow occurs at this location. It has been suggested that during high water conditions, historical flooding along the Withlacoochee River may be the result of a constrictive bridge opening at US 98 and sediments that have deposited there over time. This scenario evaluates the role of the US 98 bridge opening to pass flow from the Green Swamp to the Hillsborough River and its impact on water levels downstream along the Withlacoochee River.

Figure 4-2 Aerial View of the US 98 Bridge Crossing on the Hillsborough River

4.2. Model Set-up

When conditions allow, water flows from the Green Swamp under the US 98 bridge between Dade City and Lakeland, marking the start of the Hillsborough River. The construction of this bridge and subsequent sediment build up may constrict natural flows to the Hillsborough River, impacting water levels along the Withlacoochee River. The digital terrain at the US 98 bridge is shown in **Figure 4-3**. As seen in the image, the footprint of the bridge compresses the 2,000 foot wide natural flow path into a 200 foot wide opening at the bridge.

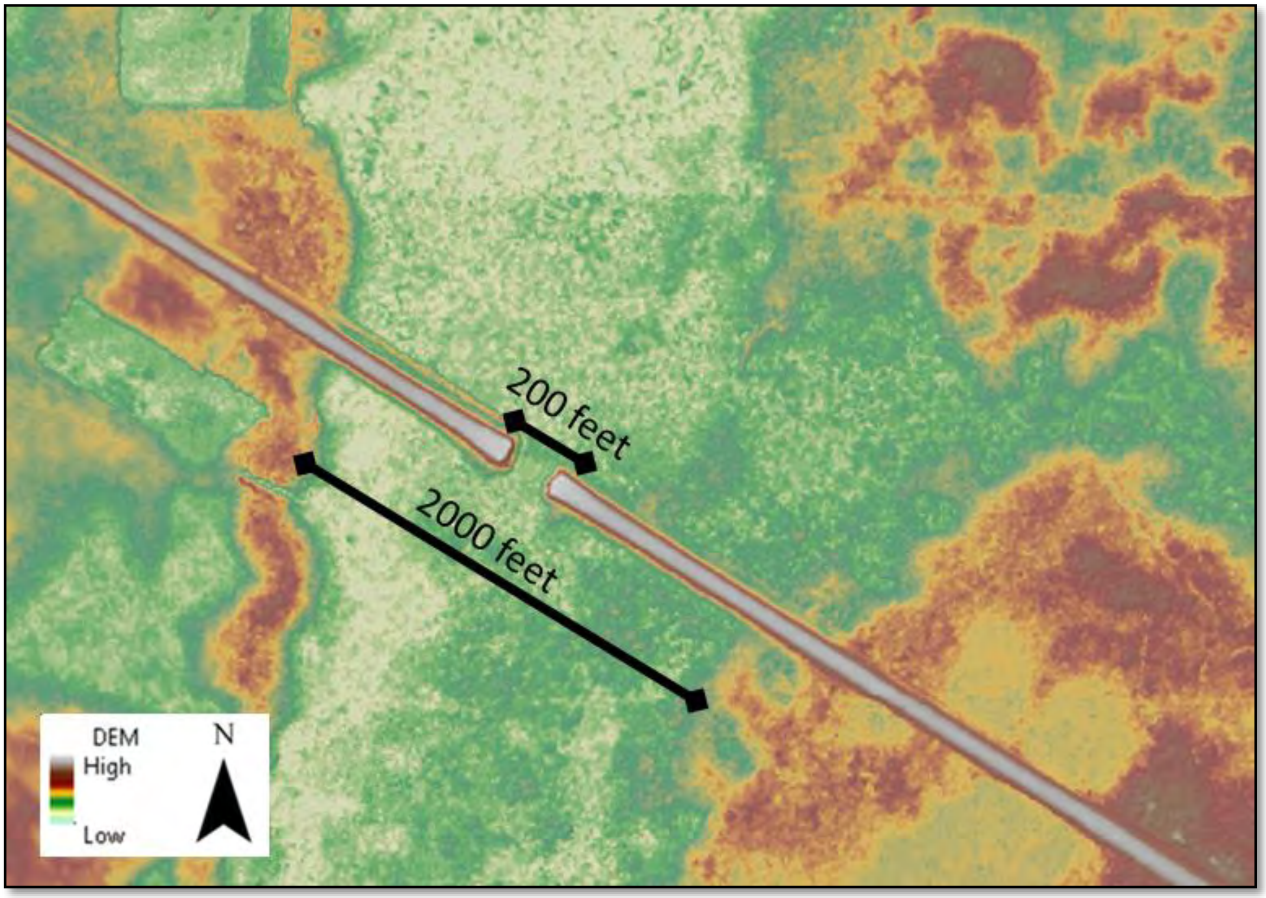

Figure 4-3 Digital Terrain of the Hillsborough River at the US 98 Bridge

To evaluate this scenario, the model was adjusted to simulate the removal of the US 98 bridge and adjacent roadway berm. This was accomplished by modifying the cross section at this location to match the natural flow path. In addition, the channel bottom at the bridge was lowered two feet in the model to simulate the removal of sediment. **Figure 4-4** shows a graphic of the existing bridge opening compared to the historic cross section (shown as the thick black line) that was simulated for this scenario.

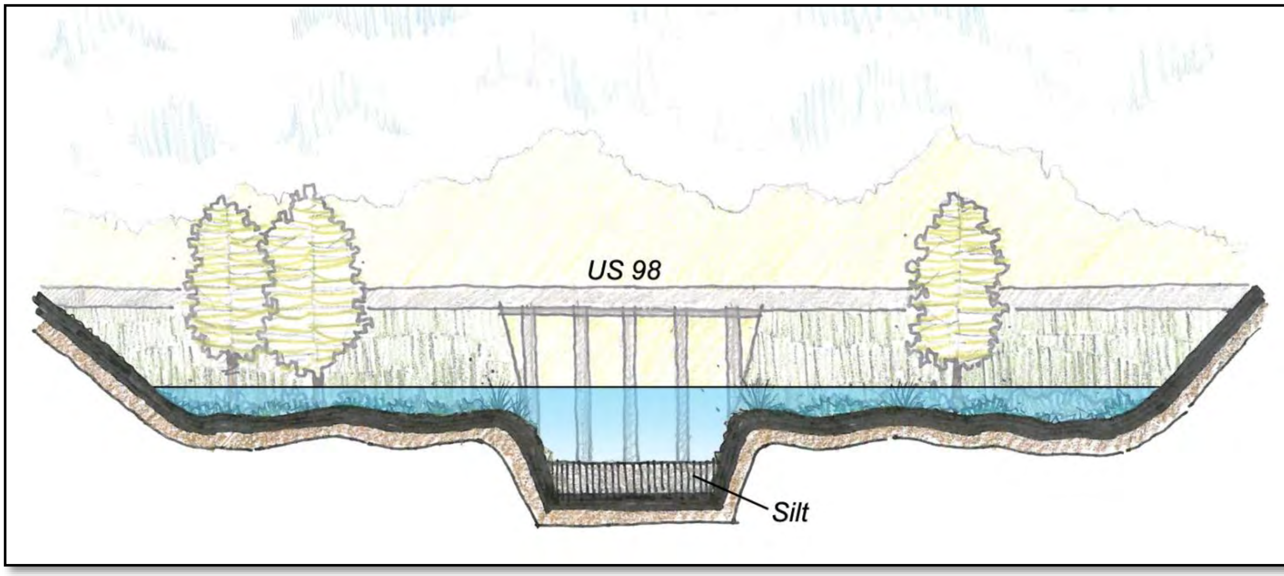

Figure 4-4 Comparison of the Current US 98 Bridge Opening to the Natural Flow Path (black line)

4.3. Results

This scenario was simulated using the 2004 hurricanes and the 25-year and 100-year design storm events with low initial water conditions. Model results indicate that during the peak of the 2004 hurricanes, water levels were one to two inches lower and peak flows five percent higher at the US 98 bridge location, as a result of its removal. Over the entire four months of simulation for these hurricanes, this resulted in a 1.7 percent increase in overall flow volume to the Hillsborough River. Similar results were observed for the 25-year and 100-year storms at this location, with overall flow volume increases of 1.2 percent and 1.9 percent, respectively.

Overall flow volumes for the 2004 hurricanes, 25-year storm and 100-year storms decreased by 0.3 percent, 0.5 percent and 1 percent, respectively, to the Withlacoochee River just downstream of the overflow to the Hillsborough River. This slight difference in flows is further dissipated farther downstream along the Withlacoochee River. Model results show slight differences in water levels downstream along the Withlacoochee River, as a result of removing the US 98 bridge. **Figure 4-5** shows peak water level differences at key points along the river for the 2004 hurricane simulation.

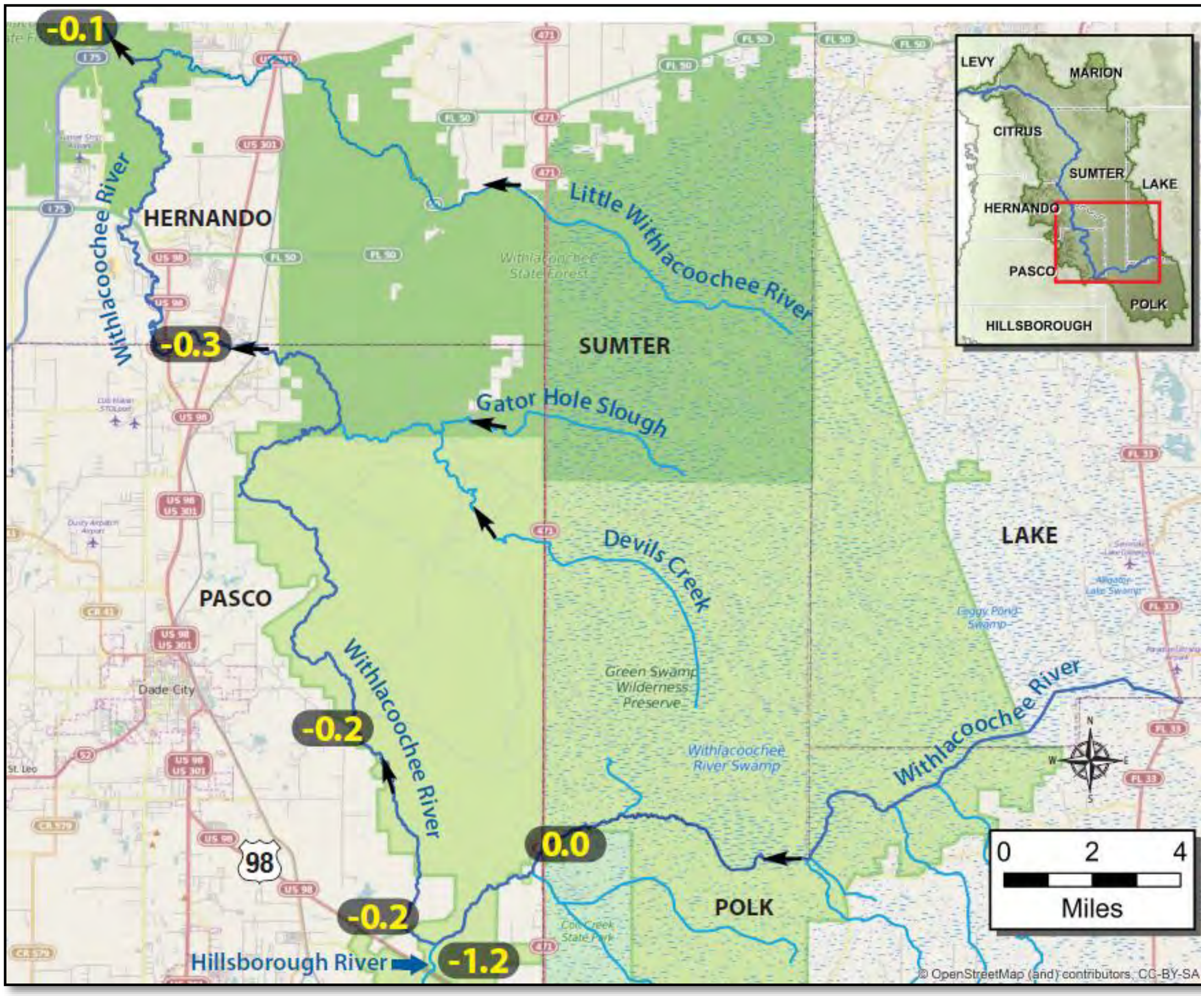

Figure 4-5 Peak Water Level Changes (inches) from the Simulated Removal of US 98 (2004 Hurricanes)

4.4. Conclusion

Removing the footprint of the US 98 bridge increases the potential for greater flow to the Hillsborough River by increasing the area of flow that is currently restricted to the bridge opening. Model results show only slightly higher flows, however, since water levels at US 98 are lower in the model as a result of this wider flow path. Substantially greater flows would require higher water levels in the floodplain swamps of the Withlacoochee River, where the Hillsborough River originates. Results also suggest that the US 98 bridge at the Hillsborough River does not significantly affect water levels and flows along the Withlacoochee River, which appear to be driven by hydrologic conditions and the natural topography of the region. Conditions farther downstream along the Hillsborough River may also affect flows at US 98, however, simulating those locations was beyond the scope of this effort.

Scenario 5 : Bridge Crossings near Trilby and Lacoochee

5.1. Description

Near the border of Hernando and Pasco counties, the Withlacoochee River passes through the communities of Trilby and Lacoochee as it exits the Green Swamp. In this area the wide flows of the Green Swamp naturally constrict into a single, well-defined channel with high banks. Numerous residential and commercial properties have developed along the river in this area, taking advantage of easy access to the river from high ground. This transition from shallow, wide flows to deep, narrow flows causes the river to fluctuate up to 15 feet vertically depending on hydrologic conditions. Within a three-mile stretch of the river, SR 575, US 301, US 98, and a railroad trestle cross the main channel of the Withlacoochee River. These four bridge crossings are shown in **Figure 5-1**.

Figure 5-1 **Bridges crossing the Withlacoochee River near Trilby and Lacoochee**

Photos of SR 575 and US 301 are shown in **Figures 5-2** and **5-3**, respectively. Stain lines from high water in recent decades are evident on the bridge pilings several feet below the bottom of each bridge.

Figure 5-2 Bridge over the Withlacoochee River at SR 575

Figure 5-3 Bridge over the Withlacoochee River at US 301

There is a history of flooding near the towns of Trilby and Lacoochee, documented as far back as 1933 and most recently in 2004. **Figure 5-4** shows an example of historical flooding in this area.

Figure 5-4 Flooding in Trilby, FL from High Water on the Withlacoochee River in 1933

During flood events in 1933, 1950 and 1960, river water flowed over several of the bridges that existed at the time. More recent high water events in 1979, 1998 and 2004 affected many homes and businesses along the river that had developed since the earlier floods. It has been suggested that the four major bridge crossings in close vicinity in this area may constrict natural flows exiting the Green Swamp. This scenario will evaluate the impact that these four bridge crossings have on water levels and flows along the Withlacoochee River to determine if their construction has led to increased flooding in this area.

5.2. Model Set-up

To evaluate this scenario, the model was adjusted to simulate the removal of the four bridges and their adjacent roadway berms. This was accomplished by modifying the cross section at each location and adjusting the terrain to match the natural flow path. This allowed the model to simulate flows across the entire width of the natural channel where they are currently constricted to the bridge openings. The current terrain is depicted in **Figure 5-5**, showing the footprint of these bridge crossings. **Figure 5-6** shows the altered terrain with bridges removed to simulate natural flow conditions.

Figure 5-5 Existing Terrain with Bridges and Roadway Berms near Trilby, FL

Figure 5-6 Modified Terrain with Bridges and Roadway Berms Removed in the Model

5.3. Results

This scenario was simulated using the 2004 hurricanes and mean annual, 10-year, 25-year and 100-year design storm events with low initial water conditions. In addition the 100-year design storm event was simulated with high initial water conditions. For most of the storm events, the river flow stayed within the main channel and did not reach the height necessary to take advantage of the increased flow area available with the bridges and adjacent roadways removed. The largest impact was seen near SR 575, the first major bridge crossing, during the 100-year design storm simulation under high initial water conditions. For this simulation, the water level decreased over six inches on the upstream side of SR 575 and almost five inches on the downstream side of SR 575 and less than three inches at US 301. This decrease would not have alleviated the flooding in the area, but for these extreme events was large enough to mention. **Figure 5-7** shows the hydrograph of the upstream side of the SR 575 bridge under 100-year design storm, simulated with high initial water conditions.

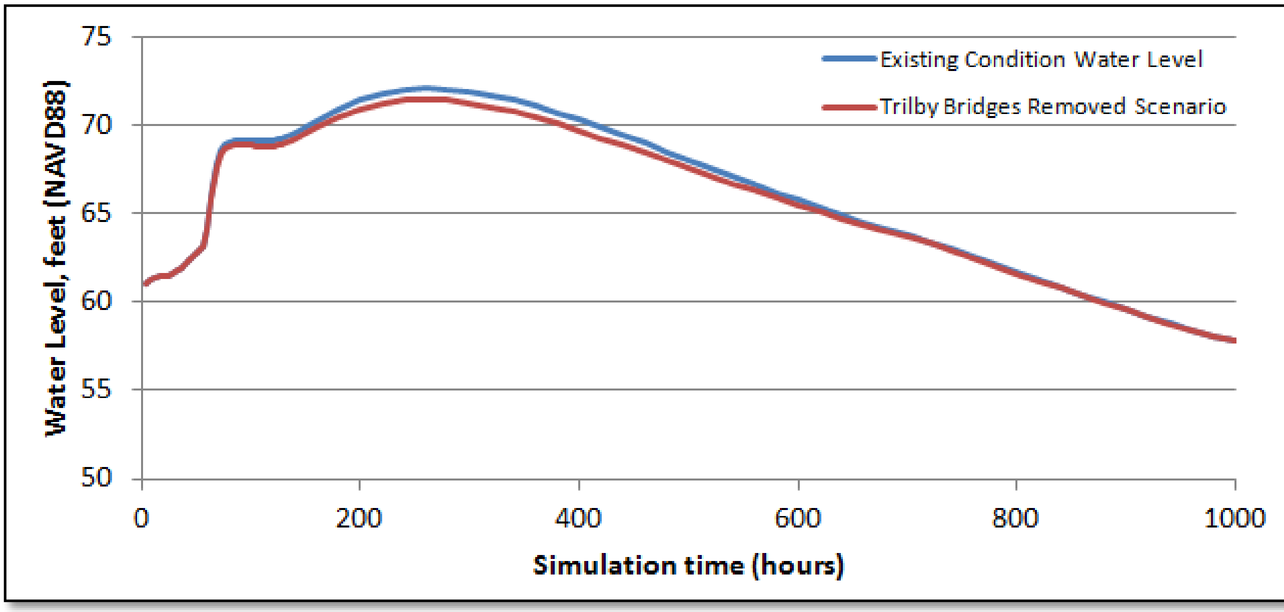

Figure 5-7 Upstream Side of SR 575 during the 100-year Design Storm

For the 2004 hurricanes, peak water levels would have also decreased, however not as significantly as the 100-year design storm event. The results presented in **Figure 5-8** show the change in water levels, in inches, achieved by the removal of the bridges. During the 2004 hurricanes, peak water levels were lowered one inch or less at each bridge crossing as a result of their simulated removal.

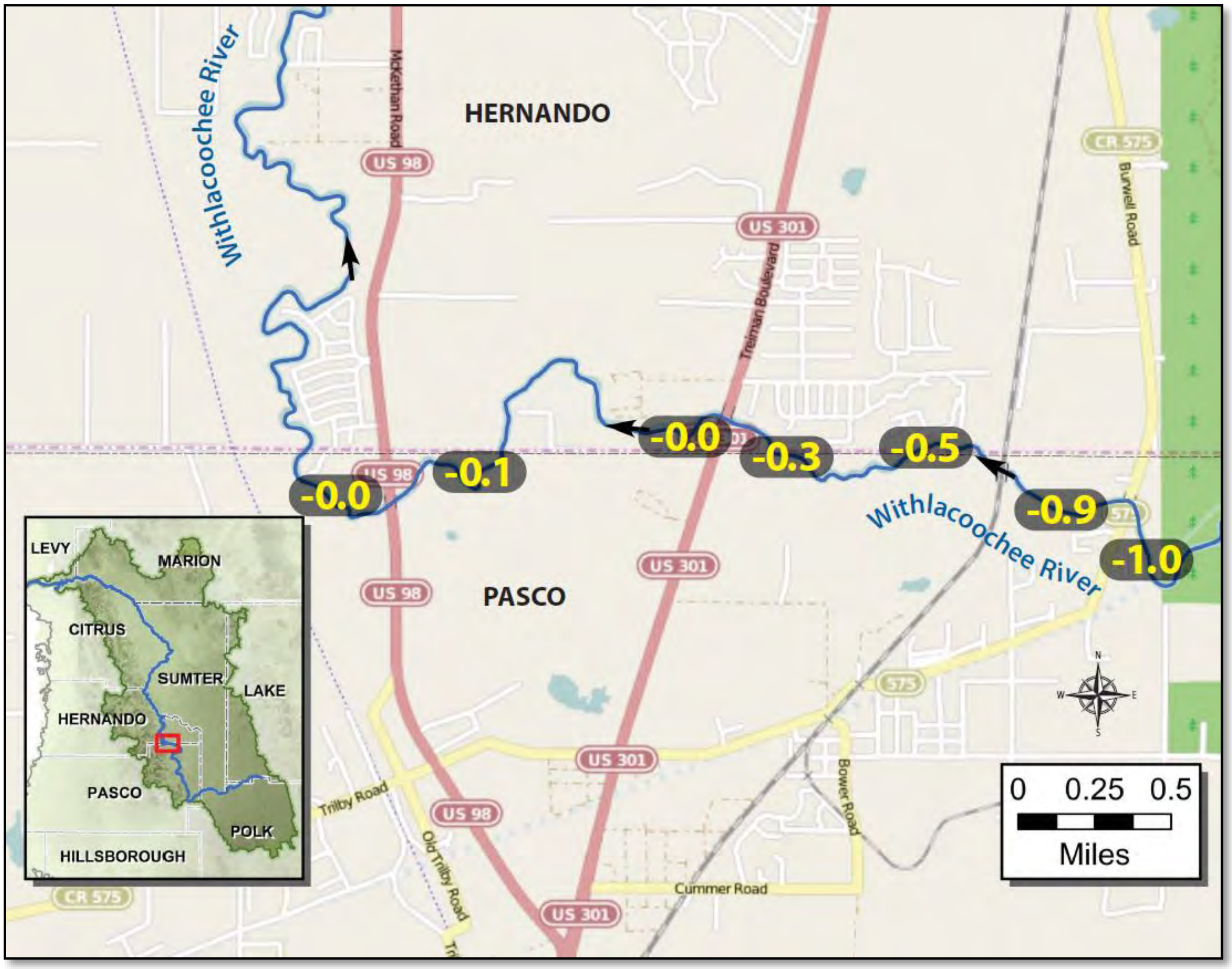

Figure 5-8 Peak Water Level Changes (inches) during the 2004 Hurricanes

5.4. Conclusion

The model suggests that the Withlacoochee River bridge crossings in Trilby and Lacoochee are not a major factor contributing to flooding in that region. The impact of the bridges is negligible compared to several feet of floodwaters many homes and businesses endured during the 2004 hurricanes. The Withlacoochee River's natural transition from the expansive wetlands of the Green Swamp into a narrow, high-banked channel in this area is the main reason for the extreme fluctuations that this area naturally experiences.

Scenario 6: Lake Oriole

6.1. Description

Lake Oriole is located in Hernando County, north of State Road 50 and east of I-75, approximately one mile west of the Withlacoochee River (**Figure 6-1**). The lake is typically isolated, although under certain conditions a flow connection exists between the lake and the Withlacoochee River. During times of high water, flow can occur back and forth between the river and the lake, through Rock Pond and across several ridges that are normally dry. Under normal or low water conditions there is no surface water connection between Lake Oriole and the Withlacoochee River, effectively isolating the lake, which is located entirely within private property.

Figure 6-1 Proximity of Lake Oriole to the Withlacoochee River in Hernando County

Over the past century, several roadway berms were constructed between the lake and the river and culverts were placed under each berm to maintain a flow connection. A topographic map showing this flow connection and the locations of the berms is shown as **Figure 6-2**. In recent decades it has been suggested that these alterations have caused chronically low water levels in Lake Oriole by preventing available flows from the Withlacoochee River to fill the lake. This scenario evaluates the existing flow connection and how changes to the land between the lake and the river would impact opportunities for additional inflow from the Withlacoochee River to Lake Oriole.

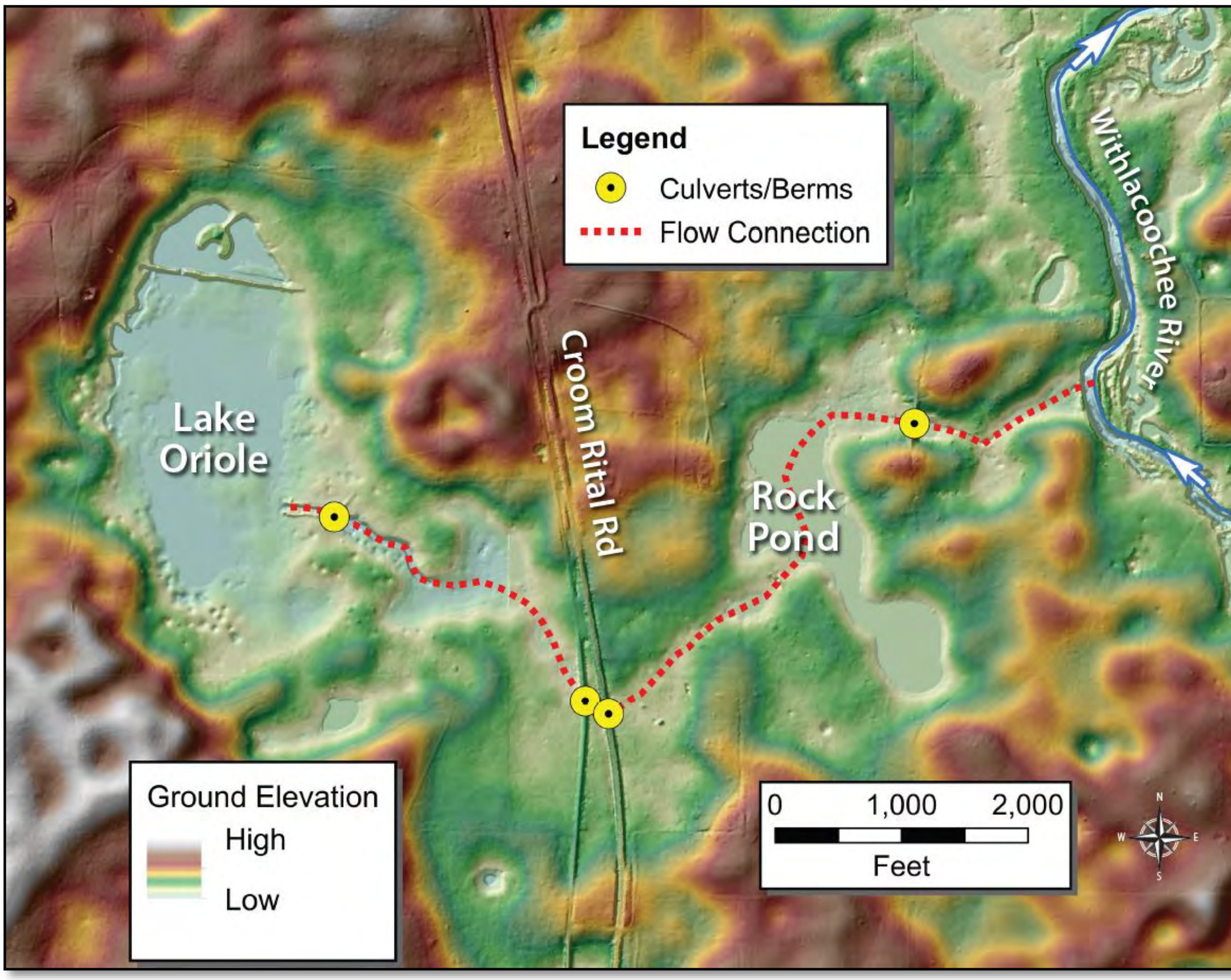

Figure 6-2 Topography of the Flow Connection between Lake Oriole and the Withlacoochee River

6.2. Model Set-up

To understand the connection between Lake Oriole and the Withlacoochee River, ground and culvert measurements were obtained to determine both the historical and current elevations that would allow flow to occur. Elevations along this flow connection, which is over a mile long, are shown in **Figure 6-3**. For flow to occur, water levels would have to rise above elevation 50.5 feet (NAVD88) to flow through a culvert under the multi-use trail (originally a railroad berm). The highest natural ground elevation between the Withlacoochee River and Lake Oriole is nearly as high at elevation 50.0 feet (NAVD88). Historically, water levels in the river would have had to rise above this natural high ground elevation for flow to reach Lake Oriole.

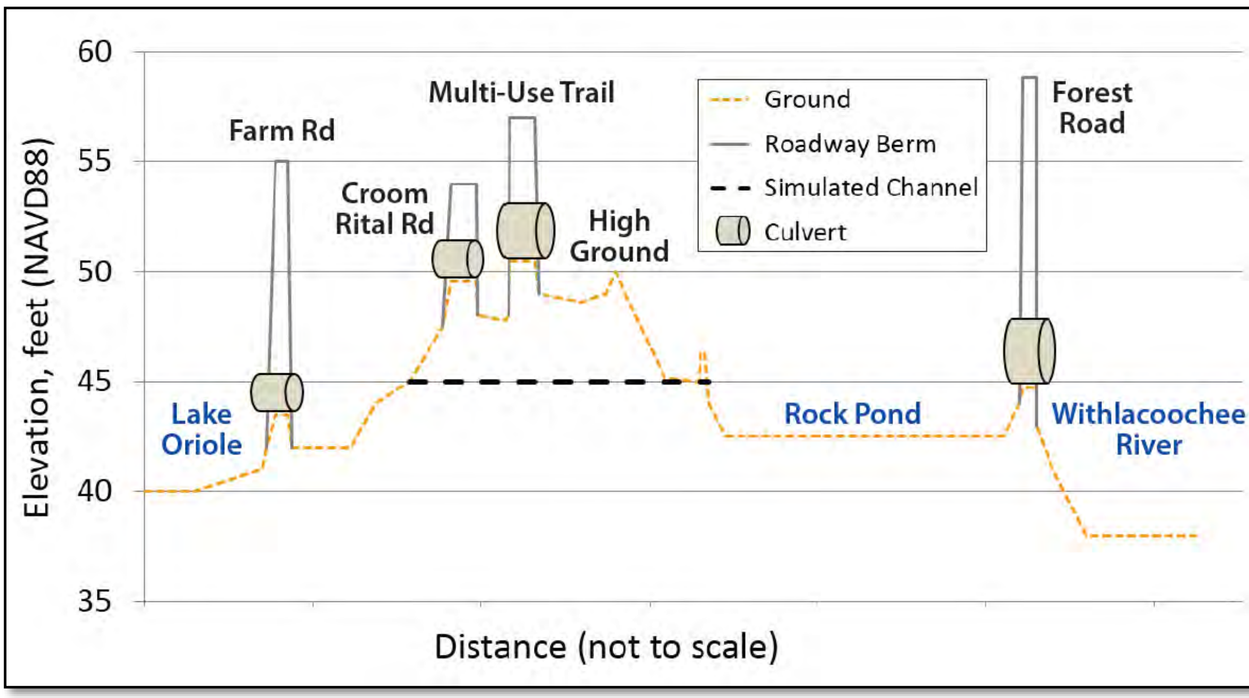

Figure 6-3 Profile of Ground and Culvert Elevations between Lake Oriole and the Withlacoochee River

To evaluate this scenario, the current configuration of this flow path was lowered several feet and the availability of river water to fill Lake Oriole was analyzed. This included cutting a 2,000 foot long channel through the natural high ground between Lake Oriole and Rock Pond down to an elevation of 45 feet (NAVD88) in the model. In addition, the culverts under Croom Rital Road and the multi-use trail were increased in size and also lowered to an elevation of 45 feet (NAVD88) in the model. This allowed water flow in the model between the Withlacoochee and Lake Oriole to occur five feet lower than historic conditions could have allowed.

6.3. Results

A long-term analysis of surface water and groundwater levels was performed to determine the historical availability of flow between the Withlacoochee River and Lake Oriole. Water levels in the river and lake were derived from gage data and validated with observed high water marks and aerial imagery. The model used these data to estimate flows under both the existing condition and the scenario condition with the flow path lowered several feet.

Available water level data from 1939 to 2014 were analyzed to determine how often water could have flowed from the Withlacoochee River to Lake Oriole past the natural high ground of 50 feet (NAVD88). **Figure 6-4** shows the availability of river inflow to the lake under natural conditions.

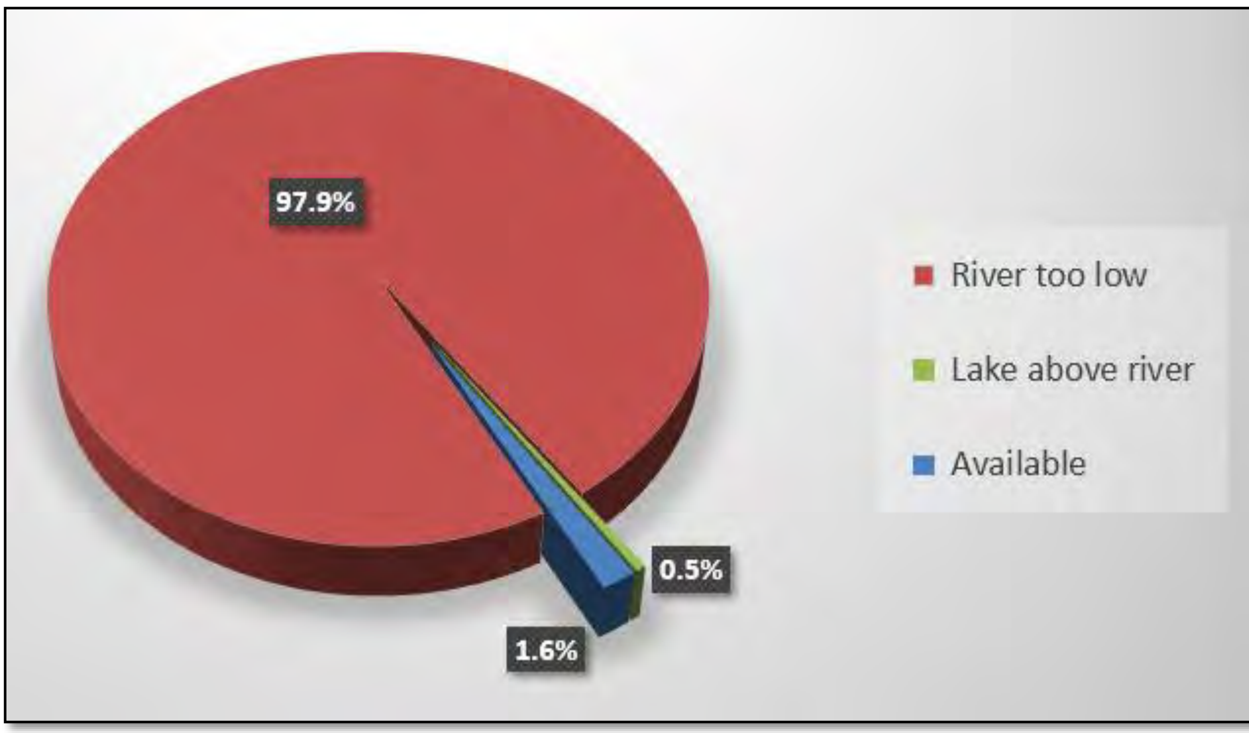

Figure 6-4 Availability of River Water to enter Lake Oriole under Natural Conditions

Over the past 75 years, the Withlacoochee River was unable to flow towards Lake Oriole almost 98 percent of the time because the river was below the natural ground elevations that exist in the flow connection. When the Withlacoochee River was above 50 feet (NAVD88) at this location, which only occurred two percent of the time in the last 75 years, the river was typically experiencing a flood event. In fact the last time the river flowed towards Lake Oriole was during the 2004 Hurricanes.

Annual average water levels for both the Withlacoochee River and Lake Oriole are shown in **Figure 6-5** from 1980 through 2014. Although there is rarely inflow from the river towards the lake, these data show similar rising and falling water level trends for both Lake Oriole and the Withlacoochee River. A recent example is the summer of 2012, when Lake Oriole was nearly dry and water levels rose several feet in a matter of months. Withlacoochee River levels rose sharply during this time as well, although not high enough to contribute flows towards Lake Oriole.

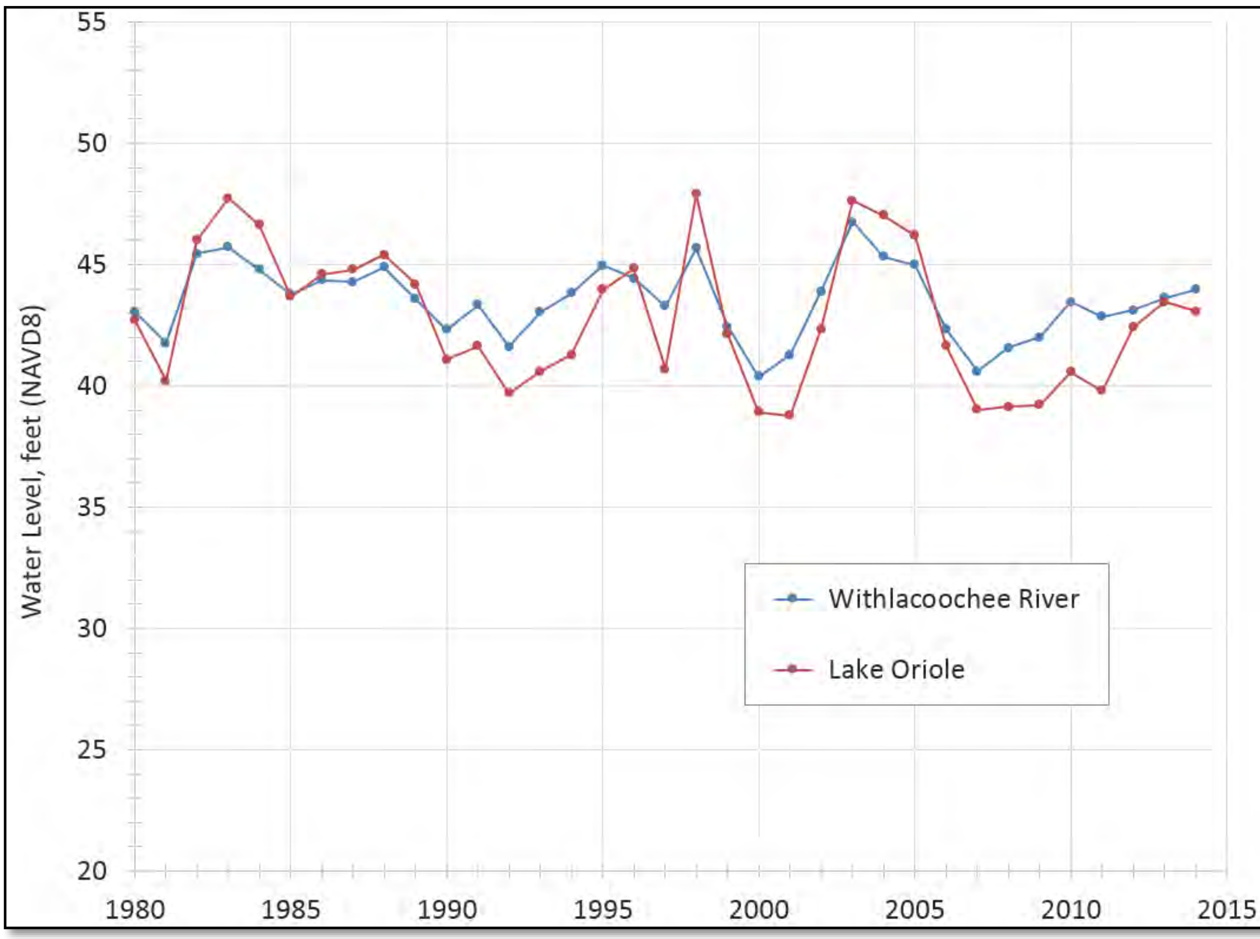

Figure 6-5 Comparison of Annual Average Water Levels since 1980

These data suggest that water levels in Lake Oriole are a reflection of regional aquifer levels that rise and fall in response to rainfall trends. This is further supported by **Figure 6-6** which shows a clear trend between annual rainfall departure (inches above or below the average) and annual average water levels in Lake Oriole.

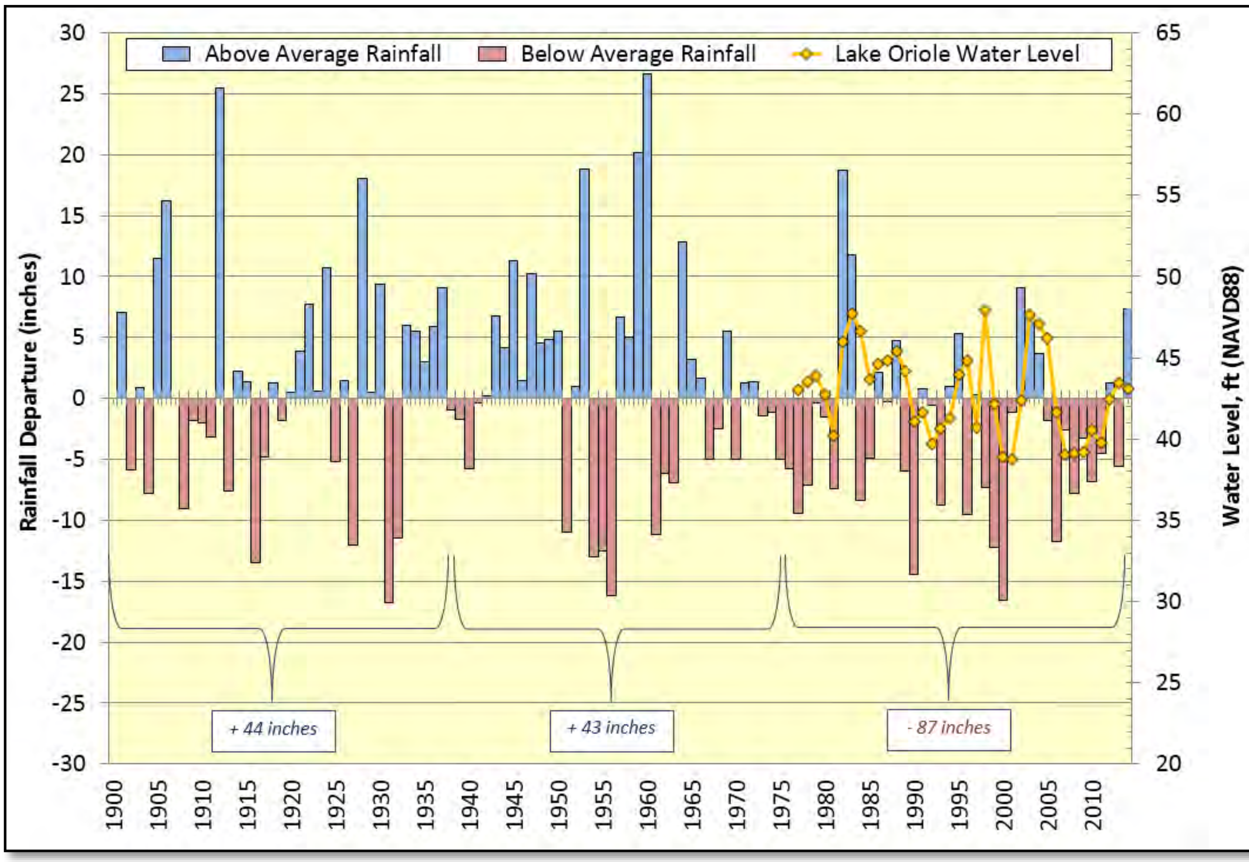

Figure 6-6 Annual Rainfall Departure and Annual Average Water Levels in Lake Oriole

Since inflows from the Withlacoochee River to Lake Oriole are rare under existing conditions, the availability of additional inflow to Lake Oriole by constructing a channel and lowering the culverts was also investigated. Available water level data from 1939 to 2014 were analyzed to determine how often water could have flowed from the Withlacoochee River to Lake Oriole if the connection were lowered five feet to an elevation of 45 feet (NAVD88). **Figure 6-7** shows the availability of river inflow to the lake if a channel were constructed through the high ground and culverts were lowered.

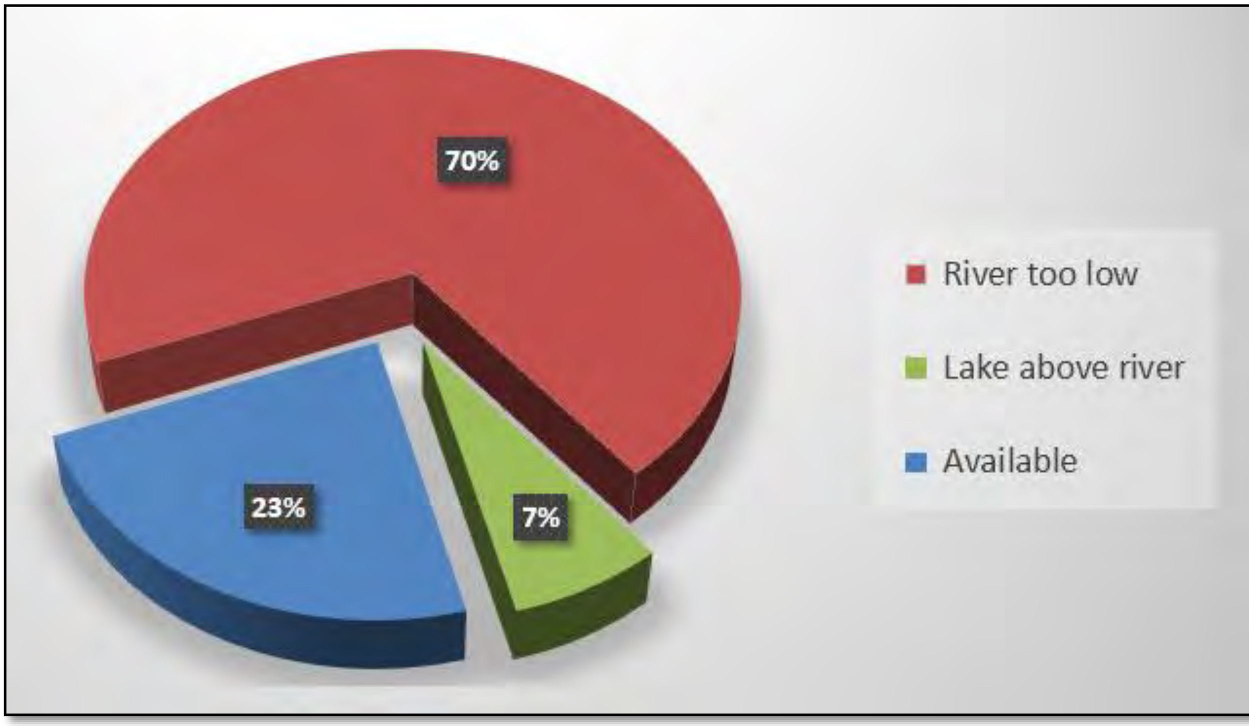

Figure 6-7 Availability of River Water to enter Lake Oriole under Simulated Conditions

By constructing a channel through the high ground and lowering the existing culverts, the Withlacoochee River would be available to flow into Lake Oriole approximately 23 percent of the time, a significant increase from natural conditions. Approximately 70 percent of the time since 1939, the Withlacoochee River was lower than elevation 45 feet (NAVD88) and would have been unavailable for inflow into Lake Oriole under this altered condition. It is anticipated that increased inflows to Lake Oriole would raise water levels in the lake above natural conditions, during periods when inflows are occurring. Since hydrologic data suggests the lake is directly connected to the underlying aquifer system, sustained increases to water levels would not be expected.

6.4. Conclusion

The results of this scenario indicate that natural inflows from the Withlacoochee River to Lake Oriole are rare. Water levels in Lake Oriole are a reflection of aquifer levels that rise and fall from changing rainfall conditions. Simulating a lower connection resulted in additional days that water would be available to flow from the river to the lake. It is anticipated that once river levels cease contributing flow, lake levels would quickly return to regional groundwater levels and not result in sustained water level increases. Additionally, to establish a lower connection between Lake Oriole and the Withlacoochee River would require both lowering of existing culverts and construction of a channel that connects Lake Oriole to Rock Pond.

Scenario 7: Wysong-Coogler Water Conservation Structure

7.1. Description

The Wysong-Coogler water conservation structure is located within the Withlacoochee River approximately two miles downstream (north) of the Outlet River confluence from Lake Panasoffkee (**Figure 7-1**). Originally constructed in 1965, the structure was designed to conserve water levels upstream along the river. Following years of maintenance issues, the structure was removed in 1988. A new structure was later installed in 2002 after much debate over its relevance and impact on regional water levels. Today the structure consists of two inflatable gates; a 230 foot wide main gate and a 19 foot wide independent gate. Additionally, a lock system and airboat slide provide a means for boaters to bypass the structure. **Figure 7-2** provides an aerial view of the structure and **Figure 7-3** shows an image of the main gate in operation. The main and independent gates are raised or lowered, depending on hydrologic conditions. These gate operations can affect water levels in Lake Panasoffkee and impact the Withlacoochee River as far upstream as Nobleton.

Currently, the Wysong structure is operated to maintain a target upstream water level while ensuring adequate outflow from Lake Panasoffkee and required flows down the Withlacoochee River. The structure's impact is limited, however, by changing flow conditions along the river and within the surrounding watershed. For example, during high water events the river may be naturally above the target elevation of 38.65 feet NAVD88, with the Wysong structure fully deflated (lowered). Similarly, during low water events, the structure is deflated to allow minimum flows to pass downstream and prevent the Withlacoochee River from backflowing into Lake Panasoffkee.

Over the past decade, it has been suggested that the regulated configuration and operation of the Wysong structure has played a role in low water levels in the Tsala Apopka chain-of-lakes. The purpose of this scenario is to simulate the regional effects of raising the gates an additional foot to achieve a higher target water level on the upstream side of the structure. Impacts to water levels and flow on the Withlacoochee River, Lake Panasoffkee and the Tsala Apopka chain-of-lakes will be evaluated.

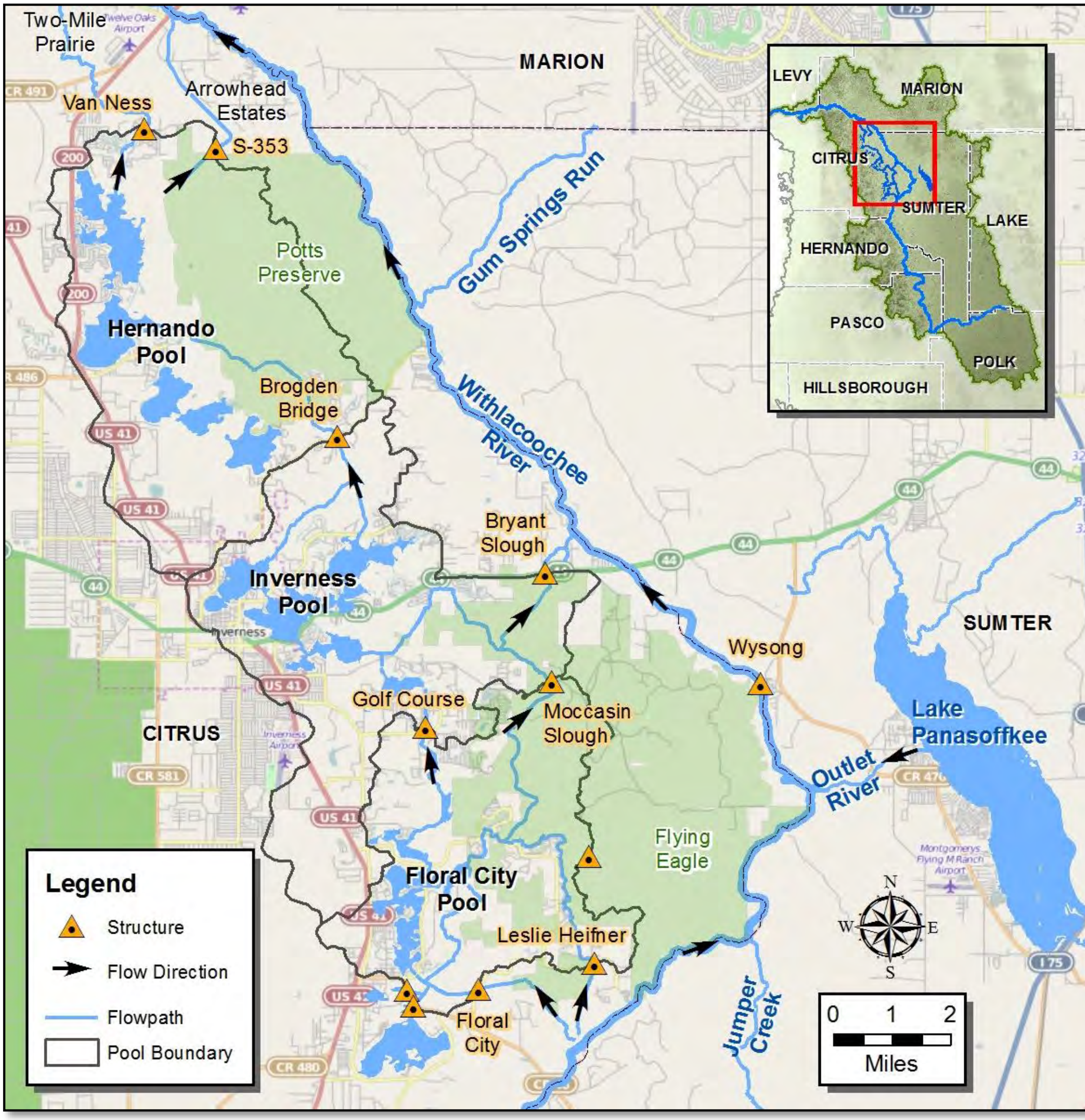

Figure 7-1 General Location of the Wysong-Coogler Water Conservation Structure

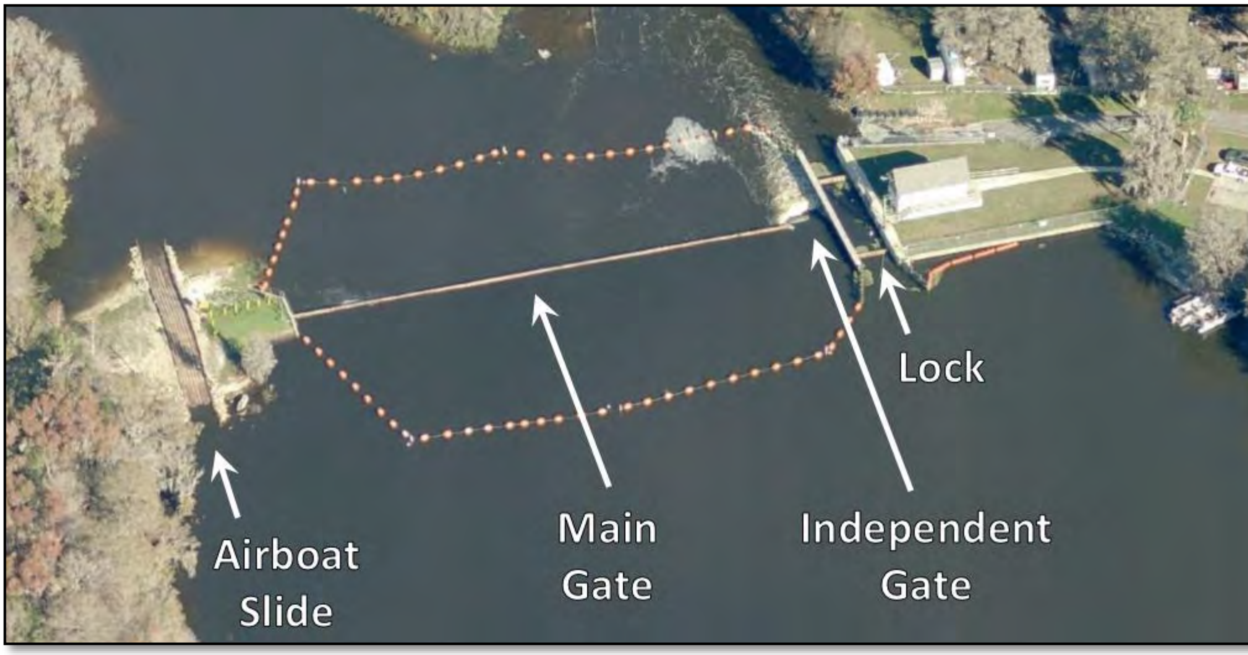

Figure 7-2 Aerial View of the Wysong-Coogler Water Conservation Structure

Figure 7-3 Wysong Structure with Main Gate Fully Inflated (Raised)

7.2. Model Setup

The current design of the Wysong structure allows the gates to be inflated (raised) five feet above the channel bottom up to an elevation of 38.15 feet NAVD88 to achieve a target water level of 38.65 feet NAVD88 on the upstream side of the structure. To evaluate this scenario, the operational range of the structure and the target water level just upstream were both increased by one foot in the model. To mimic current gate operations and permit requirements, when natural conditions exceeded the target water level in the model, the structure was lowered. Additionally, when upstream water levels receded, the structure was raised to hold the new target water level, if possible, while ensuring minimum flows pass downstream.

7.3. Results

This scenario was simulated using the 2004 hurricanes and the mean annual and 10-year design storm events simulated with low initial water conditions. Locations along the river and within the Tsala Apopka chain-of-lakes and Lake Panasoffkee were compared for differences in water levels and flow as a result of raising the Wysong structure a foot higher than its current capability.

During the 2004 hurricanes, model results suggest that river levels just upstream of the Wysong structure would initially rise 12 inches if the structure were modified as described above. By the second hurricane, however, additional rainfall and increased flows would allow the river to naturally reach its target level, triggering a lowering of the structure, resulting in no significant differences to water levels along the Withlacoochee River or Lake Panasoffkee throughout the remainder of the event. **Figure 7-4** compares water levels in the Floral City Pool of Tsala Apopka during the 2004 hurricanes under existing conditions and with modifications to the Wysong structure. Raising the Wysong structure had minimal impact on water levels in Tsala Apopka, since diversions from the river only occurred for a short period of time during this event and additional rainfall filled the lakes.

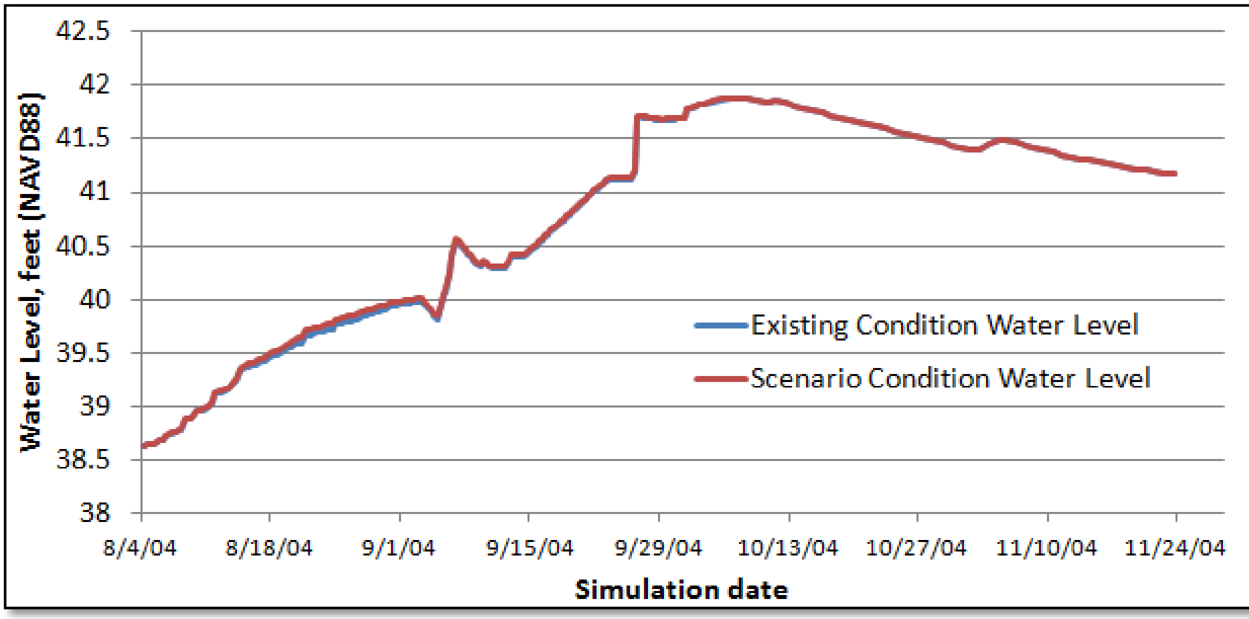

Figure 7-4 Floral City Pool Water Level Comparison – 2004 Hurricanes

The 10-year and mean annual design storm events simulated with low initial conditions each showed increases in water levels upstream of Wysong as a result of changing the structure elevation. The mean annual represented the best comparison, since the Wysong structure remained fully raised and diversions to Tsala Apopka occurred during the entire 40-day simulation period. **Figure 7-5** shows peak water level changes at select locations for this event. The greatest differences are seen directly upstream of the Wysong structure, within the Outlet River, and in Lake Panasoffkee. Minimal changes were observed further upstream.

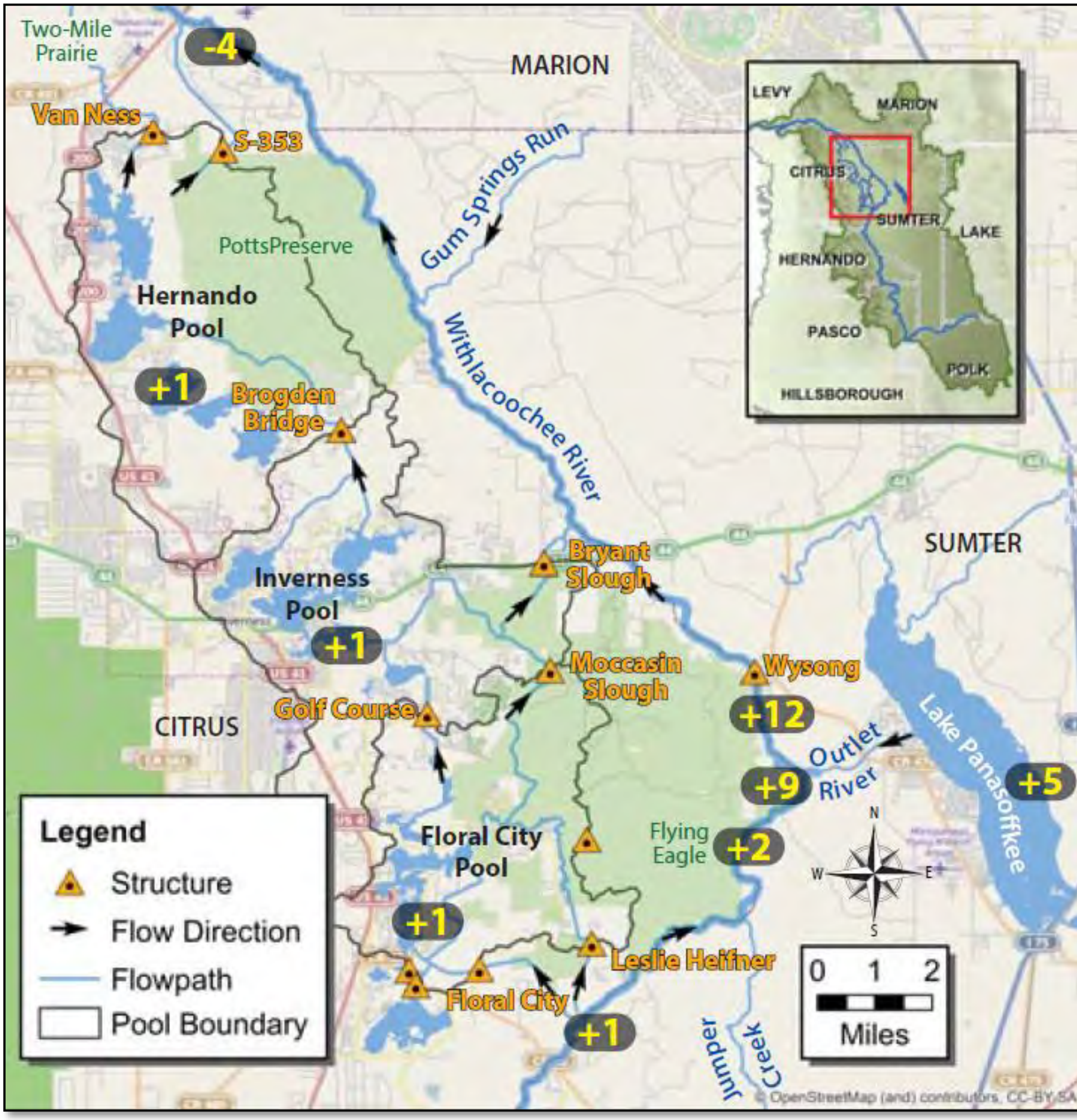

Figure 7-5 Peak Water Level Changes (inches) for the Mean Annual Storm Event

Figure 7-6 compares water levels in the Floral City Pool during the mean annual event under existing conditions and with modifications to the Wysong structure.

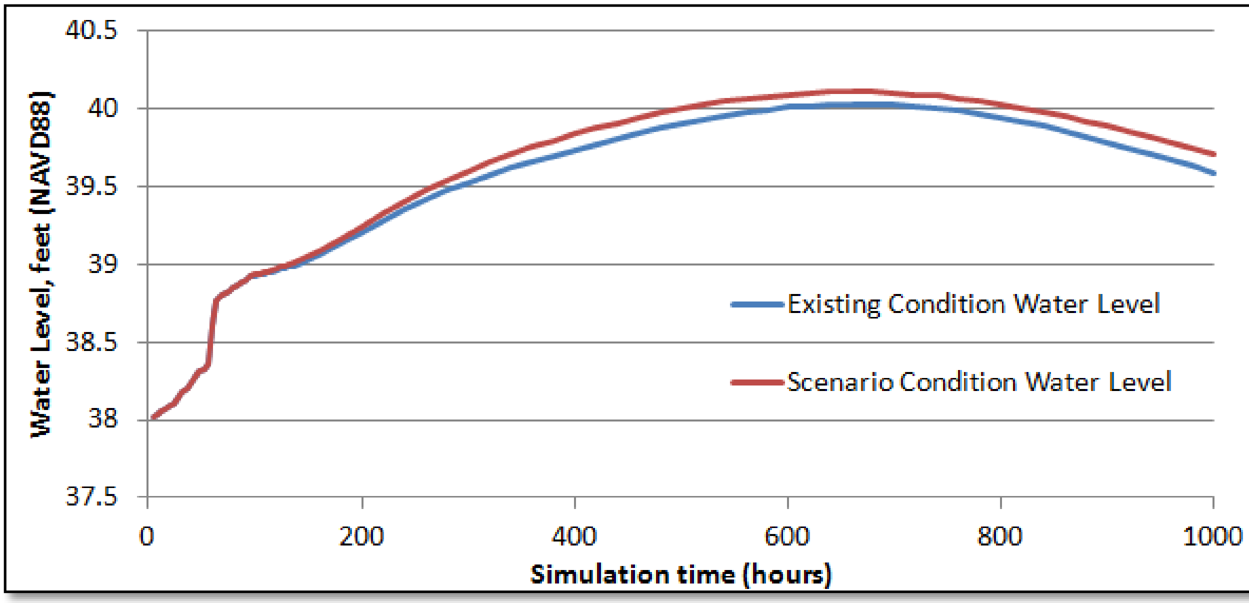

Figure 7-6 Mean Annual Design Storm Event: Floral City Pool

The results show water levels increasing by approximately one inch in the Floral City Pool as a result of raising the Wysong structure, while the Inverness and Hernando Pools showed slightly smaller increases in peak water levels. Overall, the entire Tsala Apopka chain-of-lakes received an additional 1500 acre-feet of water which accounts for approximately two percent of the overall volume of water in Tsala Apopka during that time.

A comparison of peak water levels along the Withlacoochee River from Wysong to Bonnet Lake (location of Tsala Apopka diversions) is shown in **Figure 7-7**. The blue line represents the existing condition for the mean annual event while the red line shows the scenario results. As seen in the figure, raising water levels by 12 inches on the upstream side of the Wysong structure translates to an increase of one inch at Bonnet Lake. These results show the greatest change in water levels occurs just upstream of the Wysong structure. The impacts are less significant downstream of the structure and a few miles upstream.

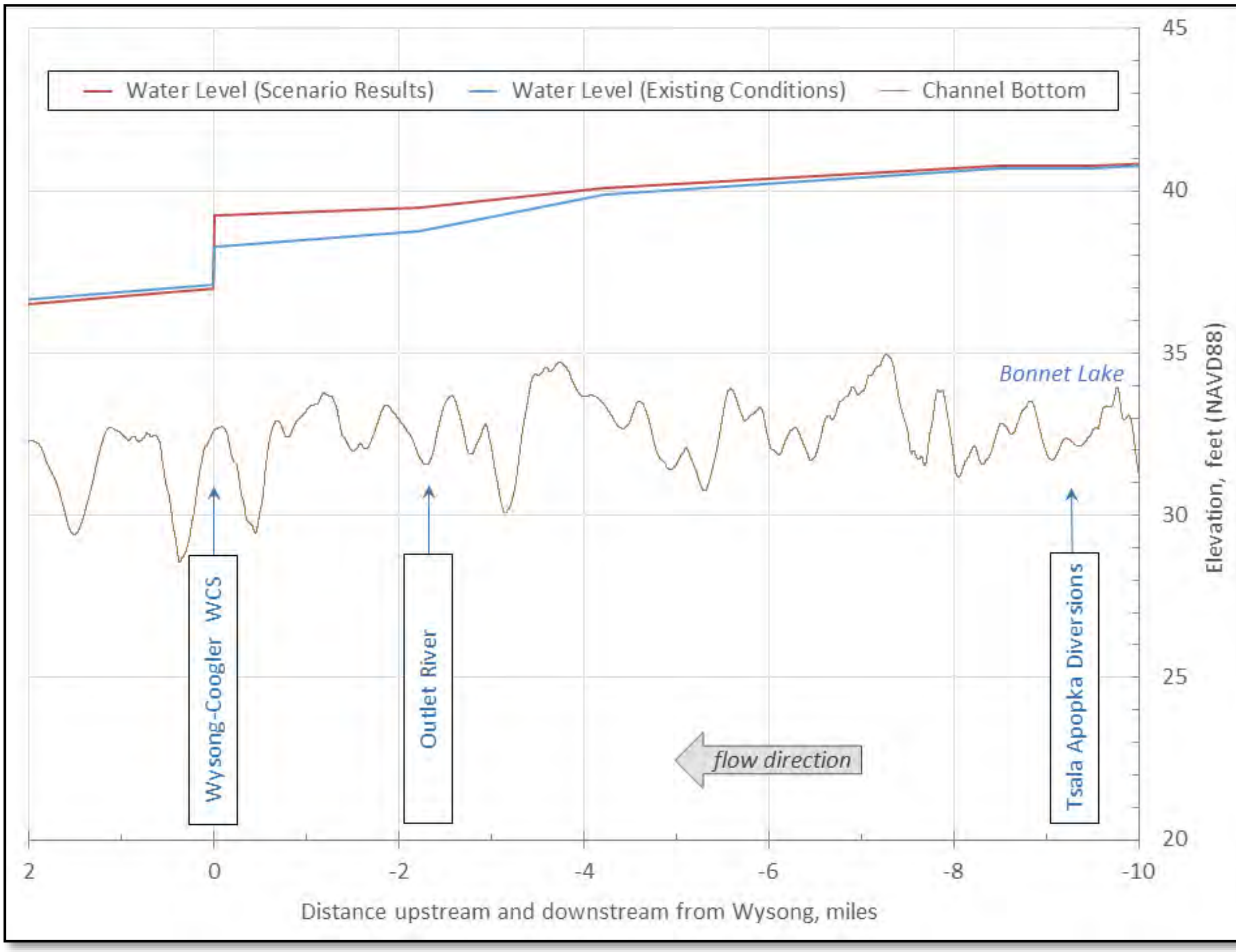

Figure 7-7 Peak River Profile between Wysong and Bonnet Lake for Mean Annual Event

Water levels in the Withlacoochee River at the junction of the Outlet River were approximately nine inches higher during the mean annual event as a result of raising the Wysong structure 12 inches. This increase along the river caused water levels in Lake Panasoffkee to increase by approximately six inches throughout the mean annual event. In addition, the volume of water flowing out of Lake Panasoffkee throughout this entire event was reduced by approximately 20 percent.

7.4. Conclusion

In summary, raising the Wysong-Coogler water conservation structure by one foot raises water levels upstream of the structure. The magnitude and duration of that increase, however, depends on specific watershed conditions during that time which include rainfall and initial water levels. Rainfall events typically occur in small amounts over long periods of time and water levels in the river and adjacent lakes are the result of those long-term trends. Model results indicated that elevating the Wysong structure an additional foot would translate into a six inch rise in Lake Panasoffkee and a one inch rise in the Floral City Pool. In contrast, the Tsala Apopka chain of lakes have remained nearly full for the past 20 months (August 2013 through April 2015) as a result of regional above average rainfall and operating the Wysong structure with its current configuration and protocol.

For several years, following a large-scale dredging effort to restore Lake Panasoffkee, the Wysong structure was operated to allow the lake to naturally fluctuate to ensure a sustainable healthy aquatic ecosystem and fishery. Today the structure is operated to balance water quality and aquatic habitat within the lake along with optimizing water levels for recreation and local businesses. Although model results show raising the Wysong structure could measurably increase water levels in Lake Panasoffkee, changes to outflow from the lake, water quality impacts, and flood protection would need to be investigated.

Scenario 8: Flood Storage

8.1. Description

Along the border of Citrus and Marion counties the Withlacoochee River transitions from a wide, shallow channel with an extensive floodway near Tsala Apopka into a narrow, high-banked channel in the vicinity of State Road (SR) 200 (**Figure 8-1**). This area has a history of flooding, most recently during the 2004 hurricanes, greatly affecting Arrowhead Estates and other properties both upstream and downstream of SR 200 (**Figure 8-2**). It has been suggested that building a storage reservoir to capture these high flows might limit the extent of flooding that this area experiences.

The Hálpata Tastanaki Preserve is over 8,000 acres of conservation land, managed by the Southwest Florida Water Management District and located along the Withlacoochee River just downstream of SR 200. Since 2010, the Withlacoochee Regional Water Supply Authority (WRWSA) has conceptually identified this location for a future reservoir that, if needed, could capture excess river flows during high water times. This model scenario simulates how a reservoir at this location would affect water levels and river flows during flood events.

Figure 8-1 State Road 200 Bridge over the Withlacoochee River

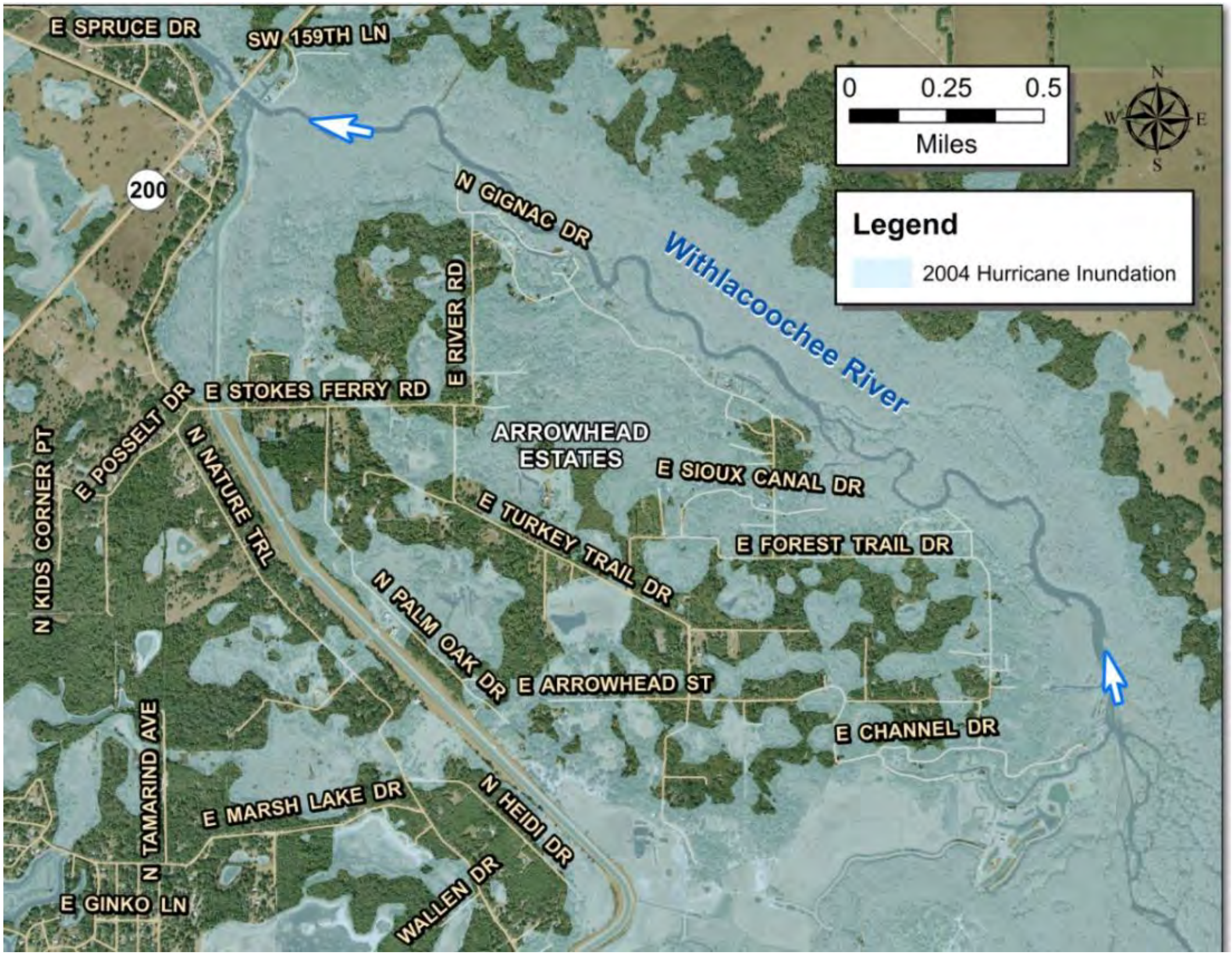

Figure 8-2 Areas Flooded by the 2004 Hurricanes near Arrowhead Estates

8.2. Model Setup

A conceptual reservoir was placed into the model to simulate the withdrawal of high flows during flood events. Based upon the information outlined in the WRWSA's 2014 Regional Water Supply Plan and draft Minimum Flows and Levels (MFLs) for the Withlacoochee River, the maximum rate of water extraction from the river to the reservoir was limited to a rate of 9 percent when flows are lower than 1250 cubic feet per second (cfs) and seven percent when river flows are greater than 1250 cfs. For this scenario, two alternative model setups were utilized. The first was based on the physical location of the conceptual reservoir assuming that water would be gravity fed from the river to the site. The second implements a pumping alternative, based on the theoretical removal rate from the river as specified in the 2014 plan.

8.3. Results

The scenario alternatives were simulated for the 2004 hurricanes and the 25-year and 100-year design storm events with high initial water conditions. Results from the gravity alternative showed minimal changes since the physical length of the required connection between the river and a reservoir would limit the maximum withdrawal rate from the river and therefore the ability to reduce water levels in the river. Additionally, high river flows would completely fill the reservoir prior to peak flood levels occurring on the river in this area.

Simulating the theoretical pump alternative slightly reduced river flows and water levels in the vicinity of SR 200. Complying with the maximum pumping rate percentages from the projected MFLs yielded a maximum pumping rate of 265 cfs for the verification event and 410 cfs for the 100-year design storm event. This reduced the flow rate in the Withlacoochee River at SR 200 from 4,813 cfs to 4,548 cfs during the 2004 hurricanes and from 7,260 cfs to 6,850 cfs during the 100-year design storm event. This corresponded to a reduction in water level at SR 200 of around 5 inches for both the verification and the 100-year design event. At Arrowhead Estates, which is just upstream of SR 200 and the simulated reservoir intake, there was a reduction of 1.2 inches for the verification event and 3.6 inches for the 100-year design storm event. **Table 8-1** shows the peak stage and flow results for both of the model set-ups comparing the existing condition to the 2004 hurricanes and 100-year design storm event.

Table 8-1 Peak Water Level and Flow Comparison at SR 200 and Arrowhead Estates

Verification Event

	SR 200				Arrowhead	
	Peak Stage	Reduction in Water Level	Peak Flow	Reduction in Peak Flow	Peak Stage	Reduction in Water Level
	Feet, NAVD88	Inches	cfs	cfs	Feet, NAVD88	inches
Existing Condition	37.5		4813		38.7	
Gravity Alt.	37.5	0	4792	21	38.7	0
Pump Alt.	37.1	4.8	4548	265	38.6	1.2

100 year Design Storm Event

	SR 200				Arrowhead	
	Peak Stage	Reduction in Water Level	Peak Flow	Reduction in Peak Flow	Peak Stage	Reduction in Water Level
	Feet, NAVD88	Inches	cfs	cfs	Feet, NAVD88	inches
Existing Condition	39.9		7260		40.7	
Gravity Alt.	39.8	1.2	7225	35	40.6	1.2
Pump Alt.	39.5	4.8	6850	410	40.4	3.6

8.4. Conclusion

During the 2004 hurricanes, water levels in the Withlacoochee River at SR 200 rose nearly 10 feet in a matter of months, resulting in several feet of floodwaters impacting many properties and homes in the vicinity. Model results indicate that using the gravity flow alternative to divert river flows to a conceptual reservoir would not significantly lower peak water levels and flows along the river. Simulating a pumped withdrawal, would lower water levels several inches at SR 200 and slightly less upstream near Arrowhead Estates, providing minimal flood relief. This simulated reduction in flood levels would require a reservoir capable of storing 29,000 acre-feet of water and pumps that were capable of diverting 265 cfs. It is important to note that a reservoir is this area has only been discussed by the WRWSA as a conceptual idea that may or may not be necessary several decades into the future. The feasibility of placing a reservoir at this area, with its karst geology and diverse wildlife habitat, has not been considered and would require extensive study.

Scenario 9: Withlacoochee River High Initial Water Level Comparisons

9.1. Description

The 2,100 square mile area that makes up the Withlacoochee River watershed has experienced times of droughts and floods. From the earliest inhabitants, the river has been characterized as, “We-Thalko-Chee” or “Little-Big-Water”. They recognized the cyclical fluctuations in water levels and flow due to naturally changing hydrologic conditions. Also, observed from the long term history of flow and water levels along the river, the largest flooding events that the river has experienced in the 1930’s, 1960’s and most recently in 2004, were caused by multiple storm events.

For example, during the 2004 hurricane season, it was not a single rainfall event that caused river levels to crest their banks and cause weeks of flooding. Instead it was a compounding effect from three hurricanes over two months. **Figure 9-1** shows water levels on the Withlacoochee River at State Road (SR) 200 during the 2004 hurricanes. A dry winter and spring left water levels relatively low in August of 2004. The first hurricane (Charley) brought modest rainfall and helped saturate soils throughout the watershed. Following Hurricane Charley was Hurricane Frances, which arrived in early September 2004. Frances brought additional rainfall that produced runoff from many parts of the watershed, significantly raising water levels in the river. Finally, when Hurricane Jeanne occurred in late September, the initial water level in the river at SR 200 was seven feet higher than it was prior to Hurricane Frances. The extensive flooding from Hurricane Jeanne was the result of high rainfall on a watershed with high initial water levels from the previous hurricanes.

Several design storm events (mean annual, 10-year, 25-year and 100-year) were also simulated by the model to provide a range of rainfall events to compare with each of the model scenarios. These were initially simulated with low initial water levels, similar to the conditions prior to the 2004 hurricanes. In order to provide a higher range of water levels resulting from each of these design storms, all four rainfall events were simulated with higher initial water levels. This provided four additional model simulations to compare each scenario against.

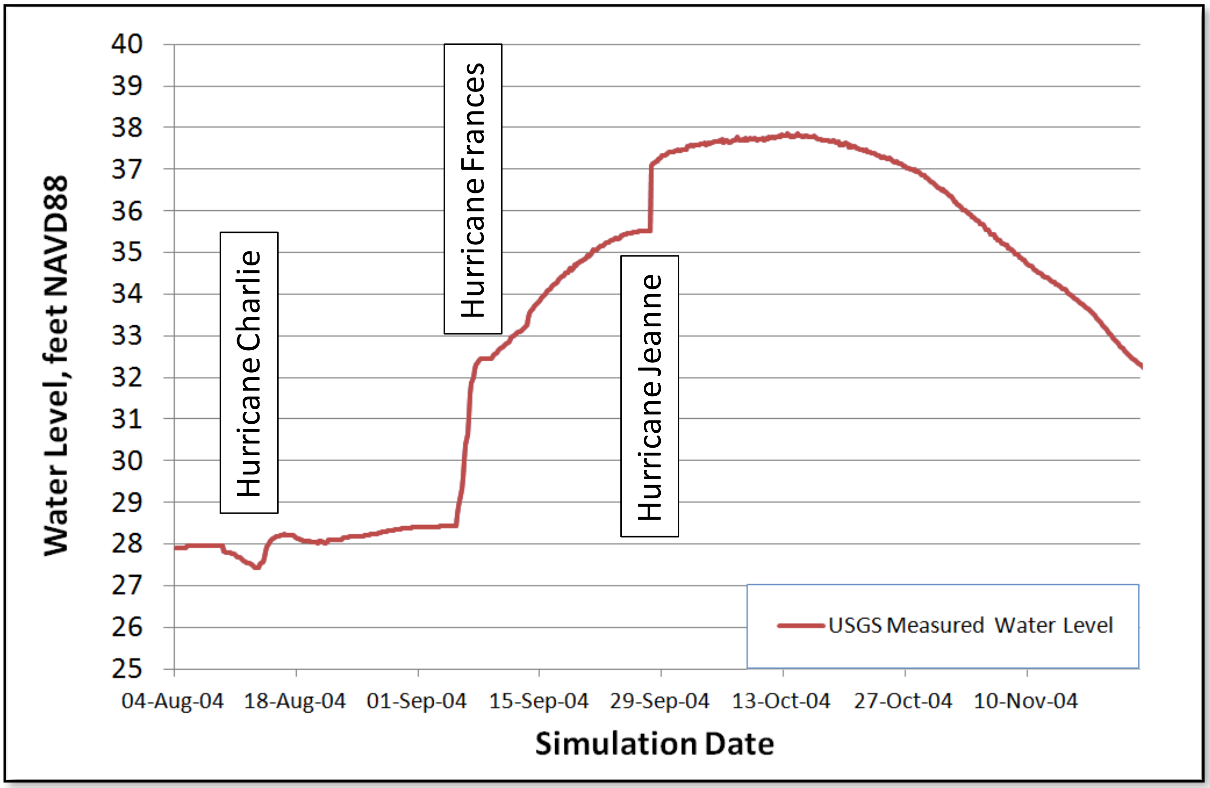

Figure 9-1 Water Levels on the Withlacoochee River at SR 200 during the 2004 Hurricanes

9.2. Model Setup

This scenario simulated each of the design storm rainfall amounts shown in **Table 9-1** with high initial water levels. **Figures 9-2** and **9-3** provide a visual comparison of low and high initial water levels in the river prior to a rainfall event. As seen in **Figure 9-2**, initial water levels are contained within the river channel and the adjacent wetlands are relatively dry. When rain falls on the watershed under this condition, the water will initially soak into the ground, and then fill up the available watershed storage prior to discharging into the stream and contributing to river flows. In contrast, **Figure 9-3** shows high initial water levels. Under this condition, prior to the storm event, available watershed storage is already full, the watershed's soils are saturated and rainfall immediately contributes to downstream flows.

Table 9-1 Design Storm Rainfall Amounts

Storm Event Simulation	Design Events			
	Mean Annual	10-Year	25-Year	100-Year
Rainfall Amount	6.9 inches	10.8 inches	12.3 inches	16.3 inches

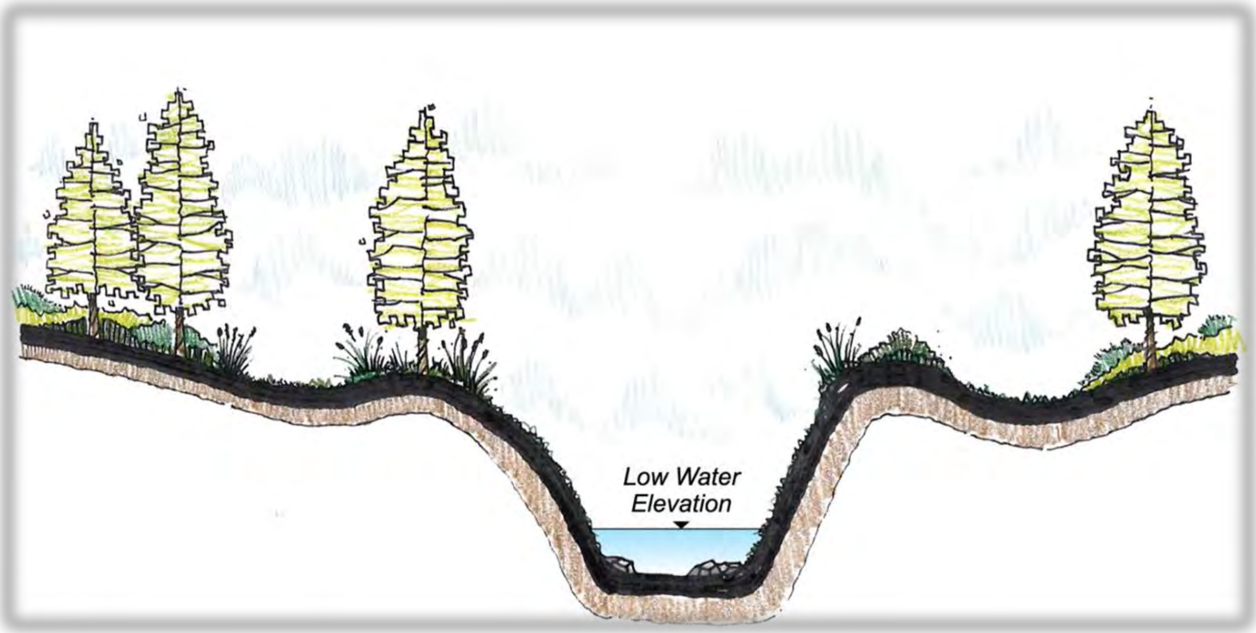

Figure 9-2 Low Initial Water Level

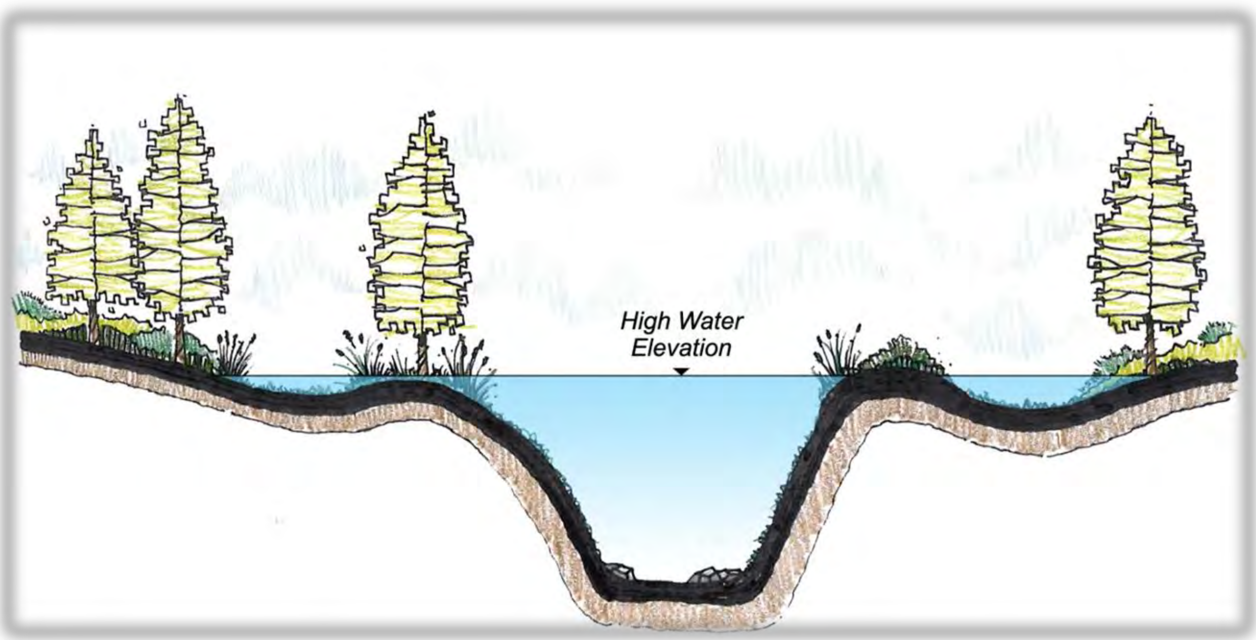

Figure 9-3 High Initial Water Level

The high initial water levels used for this scenario were the peak water levels from the mean annual event with low initial conditions. For example the 100-year design storm was simulated immediately following the mean annual storm. The exception was the Tsala Apopka chain-of-lakes whose high minimum lake levels are managed by several water control structures. The high initial water levels set for the Tsala Apopka Pools are shown in **Table 9-2,** which are reasonable target levels during periods of above average rainfall.

Table 9-2 High Initial Water Levels in Tsala Apopka

Pool	Target Water Level
Floral City Pool	40.35 feet NAVD88
Inverness Pool	39.25 feet NAVD88
Hernando Pool	37.85 feet NAVD88

Figure 9-4 compares the inundated areas for both low and high initial water levels for a portion of the Withlacoochee River upstream of Lake Panasoffkee. The image on the left shows low initial water levels that are limited to the river channel and some isolated areas adjacent to the river. The image on the right shows the areas inundated by high initial water levels, where much of the watershed contains standing water. Another difference between these low and high initial water levels are the flow paths that are available at the beginning of the design storm simulations. In the low condition, flow is contained within the main channel and needs to rise before isolated wetland marshes are connected and open to alternate flow paths parallel to the river. Many of these pathways connect under high initial conditions providing more pathways for water to flow.

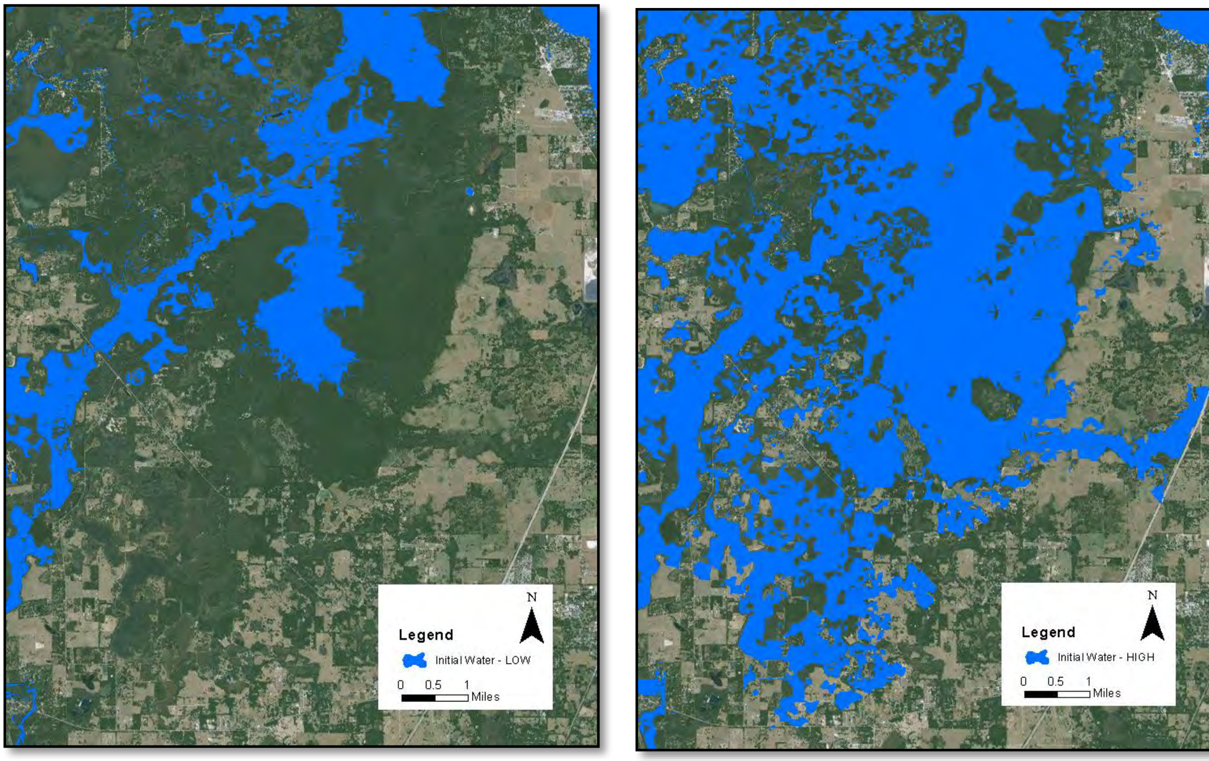

Figure 9-4 Comparison of Low (left side) and High (right side) Initial Water Levels

9.3. Results

The model was simulated for the mean annual, 10-year, 25-year, and 100-year design storm events simulated with high initial water conditions and compared to the results of the existing conditions model simulated with low initial water conditions. The results of this analysis demonstrate the range of river stages and flows possible depending upon the initial watershed conditions prior to the rainfall event. The results also provide an additional basis of comparison for many of the other scenarios simulated during this project.

Figure 9-5 compares the peak stage results in profile view between the Withlacoochee River at SR 471 (Cumpressco) and Lake Rousseau for the 25-year design storm event. Additionally, the 2004 hurricane season verification event was overlaid on the graph as a reference. Results show that in the upper portion of the watershed, where the slope of the watershed is steepest, the verification event aligns more closely to low initial condition results. However, as the river bed slope flattens near Tsala Apopka and Lake Panasoffkee, river conditions become more sensitive to volume and initial conditions, seen by the verification event aligning to the results of the high initial water conditions simulation.

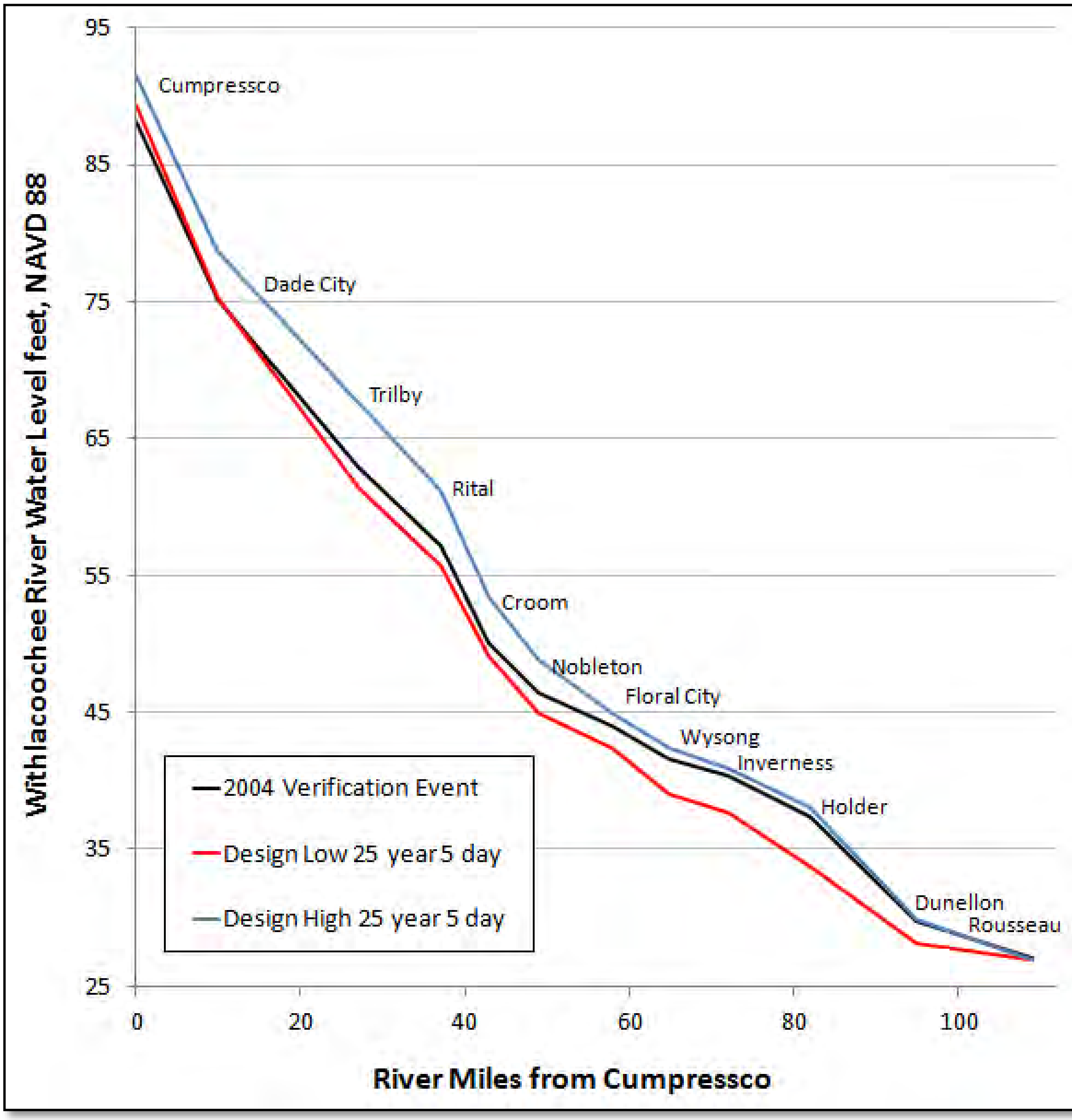

Figure 9-5 Peak Water Levels for the 25-Year Storm Event with Low and High Initial Conditions

In addition to the high initial conditions simulation generating higher peak stages and flows than the existing conditions simulation with low initial water level conditions, it is observed that the timing of the peak will also shift. In general, the peak stage and flow in a watershed will coincide with the highest intensity of rainfall in the design storm simulation. For the Withlacoochee River watershed, however, a double peak is generated. The first associated with the highest intensity rainfall and the second being the result of runoff from the contributing watershed. In the existing conditions simulation with low initial water levels, the first peak is generally the larger of the two, however with the high initial water simulation, the peak conditions tend to merge, with the highest water levels and largest peak flows occurring during the second peak. **Figure 9-6** shows the 100-year, 5-day existing condition model simulation with low and high initial water conditions at the USGS gage at Croom. As seen in the figure, the low initial conditions simulation peaks just after hour 100, whereas, the high initial conditions simulation peaks a full 200 hours (8.5 days) later. One other observation is that the peak water level achieved under design low water conditions is exceeded by the simulation with high initial water conditions for more than two weeks (400+ hours).

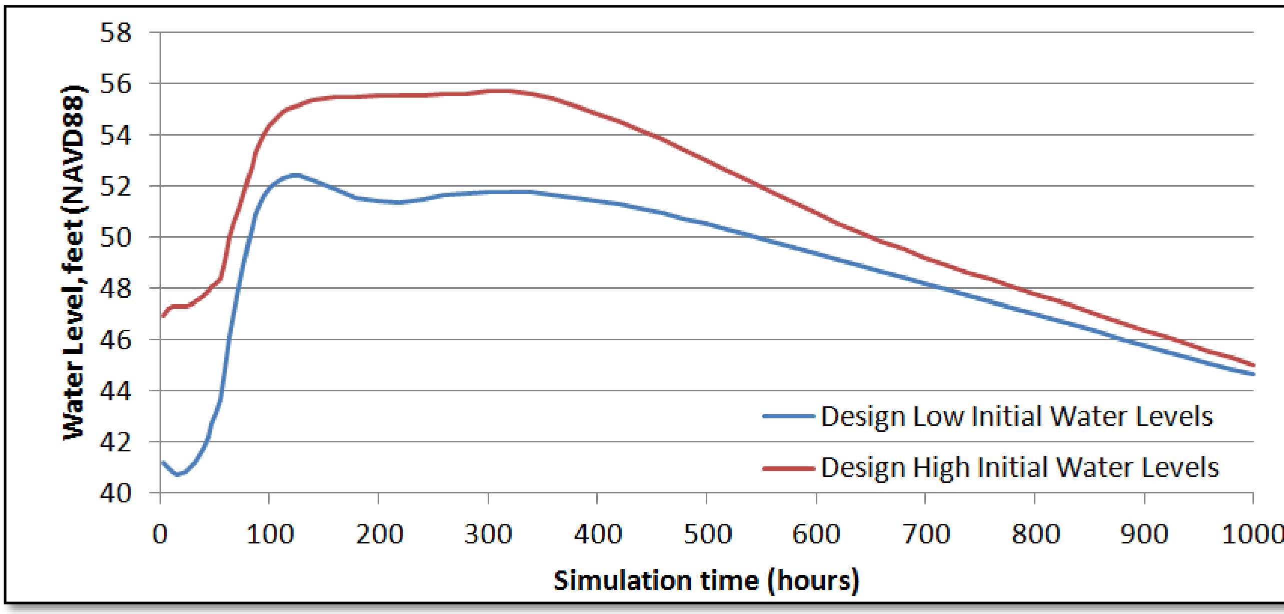

Figure 9-6 Comparison of Water Levels on the Withlacoochee River at Croom for the 100-Year Storm Event

A good measure of assessing the results of design storm simulations is to compare them to observed data recorded at gages along the river. Two of the USGS gages along the river with the longest period of record are the USGS streamflow gages at Croom and at Holder (SR 200). Both of these gages have more than 75 years of recorded data which captured observations from the river in times of drought and times of flooding. **Figures 9-7** and **9-8** show a flood frequency analysis for the river at these two separate locations. A flood frequency analysis is used to predict flooding for design storm events using probability. In this case, it is used to compare the results of the model design storm results to that of actual recorded data. In the graphs below, the annual peak flows at the respective gages are plotted on a log graph (blue dots). From that data, estimates for peak flows for the various design storm event can be predicted using a USGS statistical program (orange squares). This software also gives confidence limits of the results (yellow lines). The results from the design storm events for the low initial conditions and the high initial conditions are overlaid for a visual comparison. It can be seen that the results from the high initial conditions model simulation (design high) more closely correspond to the observed data. This comparison indicates that, the higher flows observed along the river correspond to conditions related to those simulated using the high initial conditions and that flood stages in the river are highly sensitive to initial water levels when extreme rainfall events occur.

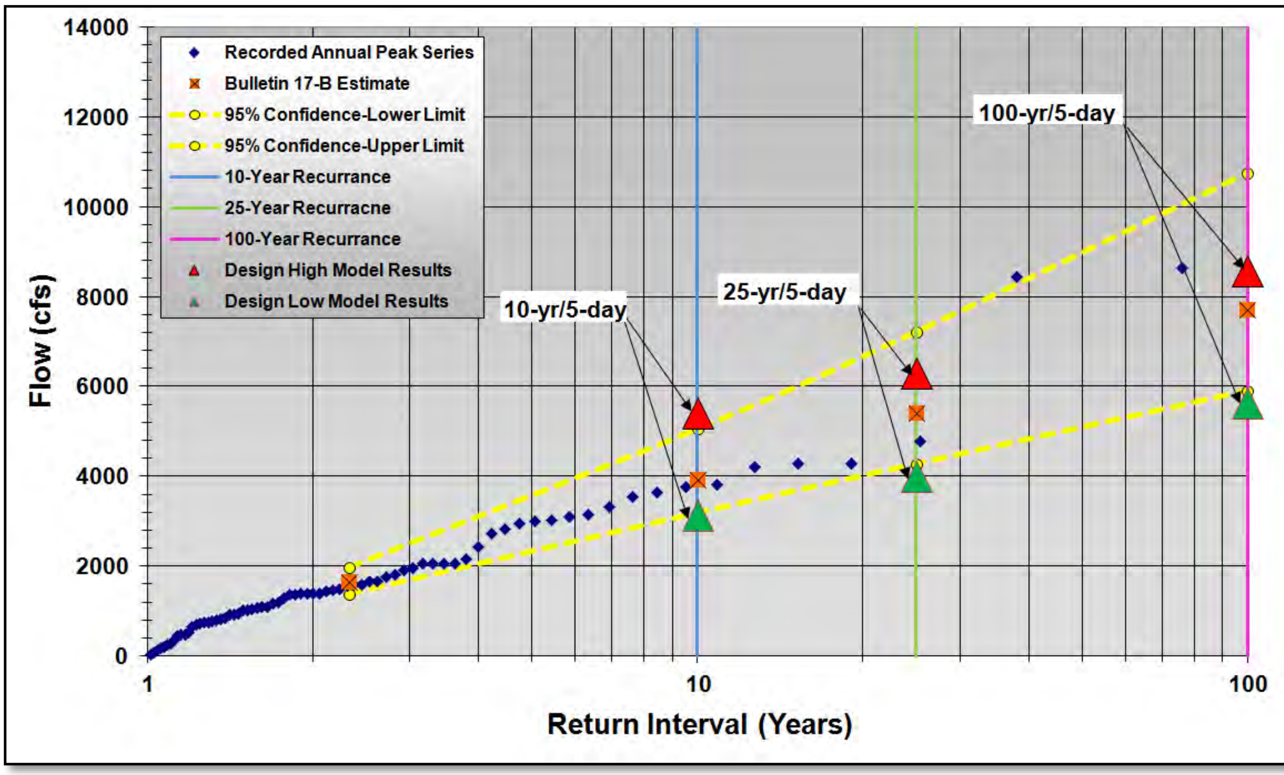

Figure 9-7 Flood Frequency Analysis for the Withlacoochee River at Croom

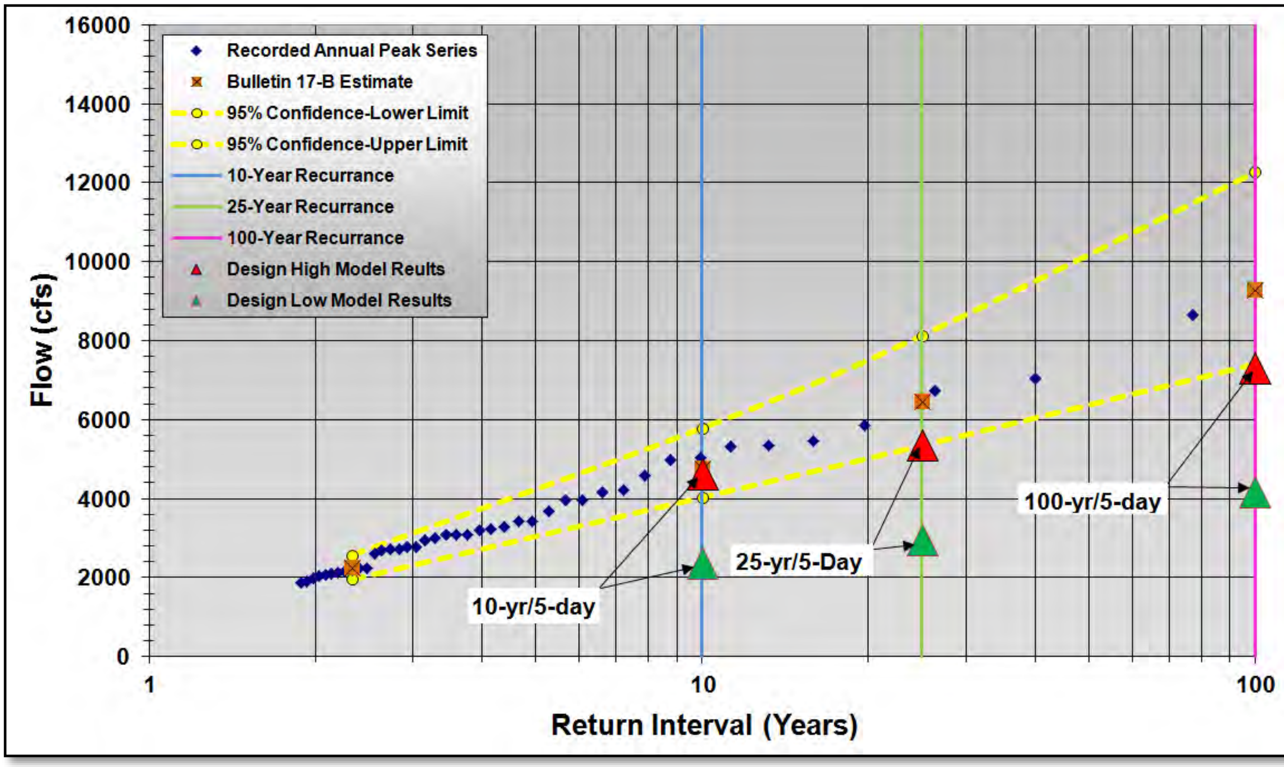

Figure 9-8 Flood Frequency Analysis for the Withlacoochee River at SR 200

9.4. Conclusion

The Withlacoochee River has experienced high and low river conditions, often persisting over long periods of time. When large rainfall events occur, the watershed will respond differently depending upon the initial conditions prior to the incidence of rainfall. When conditions are relatively dry leading up to a large hurricane type event, much of the rainfall is trapped in the depressions throughout the watershed. In contrast, when this storage has been previously filled, the entire watershed will contribute immediately to flows along the river, resulting in higher water levels and flows. Simulating the design storms with high initial water levels provided a better prediction of return frequency flood events that have been observed along the river in year's past. The results of the design storm simulations with both low and high initial water levels provide a range of comparison for each of the scenarios. The effect of each model scenario is defined in part by the initial water levels present throughout the watershed.

Scenario 10: Flying Eagle Berm in Tsala Apopka

10.1. Description

In pre-settlement times, water naturally flowed back and forth between the Tsala Apopka chain-of-lakes and the Withlacoochee River through extensive marshlands that would flood or dry out with changing hydrologic conditions. The Flying Eagle Marsh, a mosaic of shallow swampland interspersed with upland islands, was one of these locations that historically connected the river with the lakes during high water times. Small boats and barges could traverse this inundated marsh at depths of two to three feet during high water. One of the first major changes to the natural hydrology occurred in 1884 when the Orange State canal was dug to transport people and supplies between the lakes and the river. Many decades later, a berm was constructed between some of the islands in Flying Eagle that also altered the natural flow of water. **Figure 10-1** shows the location of the Flying Eagle Berm in relation to the Tsala Apopka chain-of-lakes. Soon after the berm's construction, the Leslie Heifner canal was built to divert additional water from the river into the lakes. These canals are several feet lower than the natural Flying Eagle Marsh connection, and join the river several miles upstream, allowing for more frequent transfer of water into Tsala Apopka than historically occurred. In addition, water conservation structures in these canals limit the natural outflow back to the river that historically occurred across the Flying Eagle Marsh (**Figure 10-2**).

The region's geology allows natural leakage to occur from the Tsala Apopka chain-of-lakes downward into the Floridan Aquifer. This outflow, coupled with evapotranspiration, will cause a daily decrease in lake levels that is only offset by direct rainfall or river inflow. Chronic low water levels in recent decades, have caused many residents to desire increased inflows from the Withlacoochee River when available. In addition, it has been suggested that restoring the historic flow through the Flying Eagle Marsh will help maintain higher water levels in Tsala Apopka. This scenario will evaluate the regional impact of removing the Flying Eagle Berm and provide insight into its effectiveness under current lake/river system conditions.

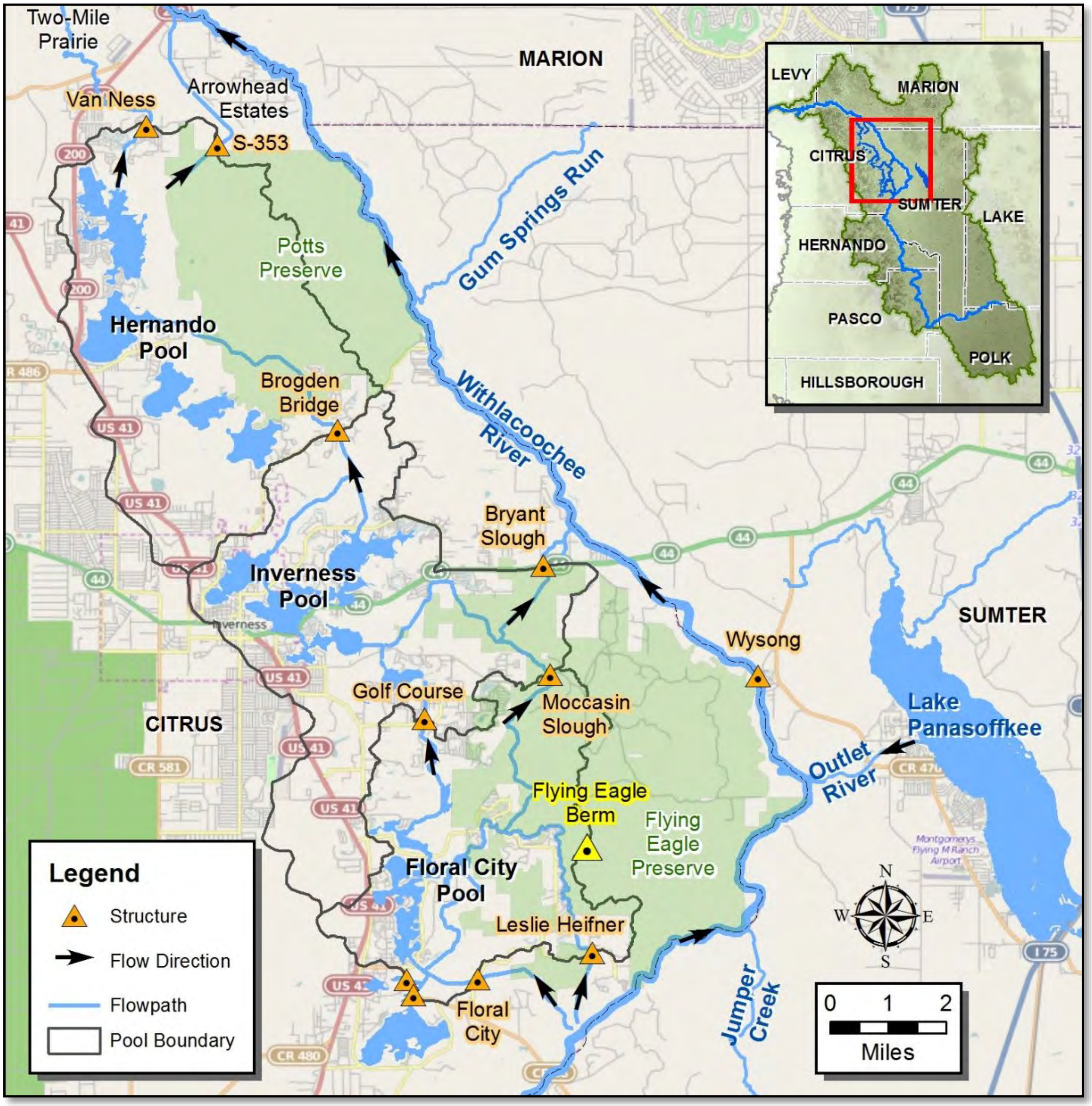

Figure 10-1 Flying Eagle and Tsala Apopka Area Map

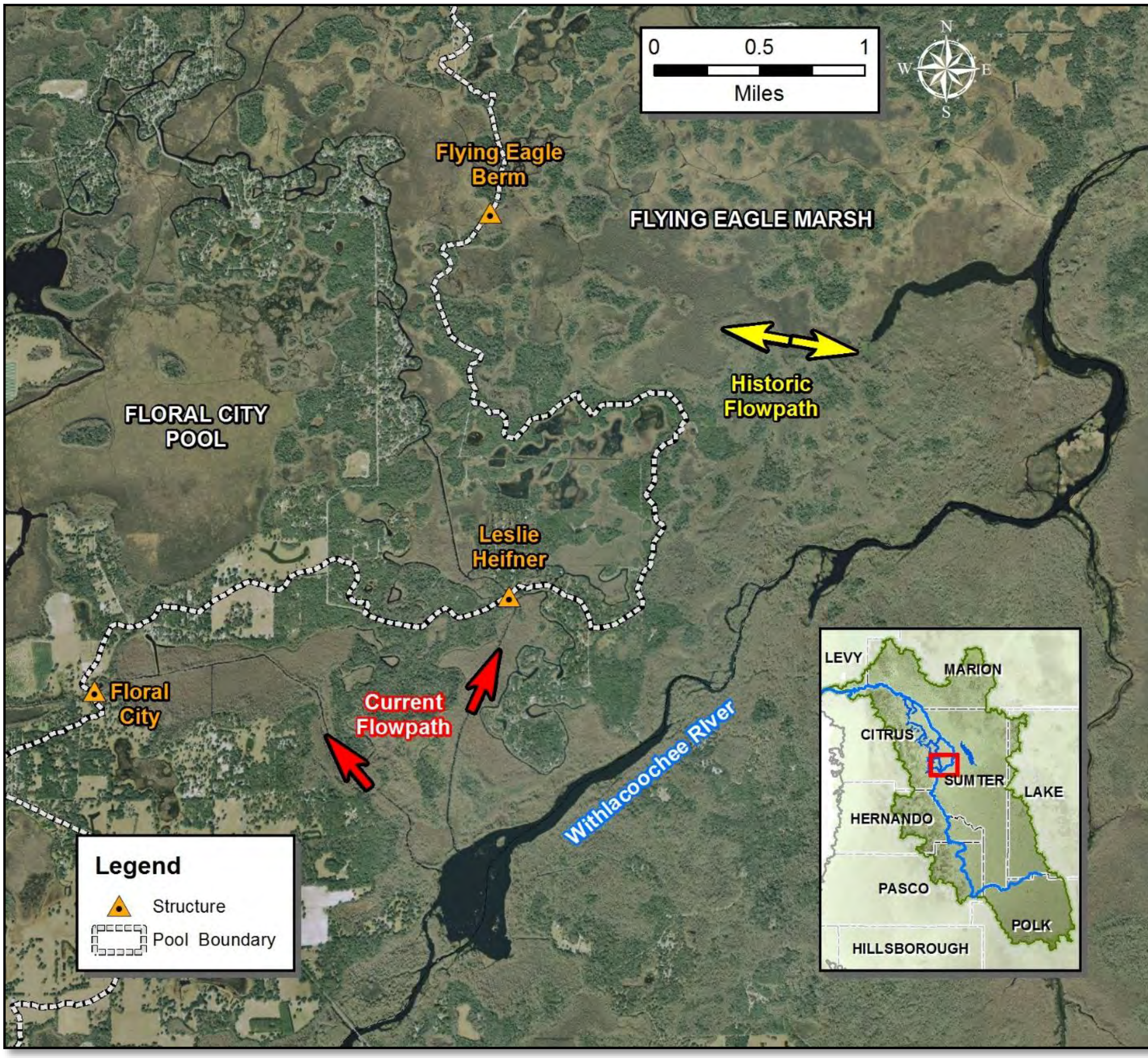

Figure 10-2 Comparison of Current and Historical Flowpaths between the Withlacoochee River and the Tsala Apopka Chain-of-lakes

10.2. Model Set-up

In the Flying Eagle Marsh, interconnected marshlands surround numerous forested islands that are at elevations much higher than the contiguous marsh. The Flying Eagle Berm includes more than a dozen narrow fill segments that connect several of these interspersed islands. The berm's elevation rises approximately five feet higher than the natural marsh bottom. In its current state, flow past this berm would require high water levels similar to what was observed during the 2004 hurricanes. To evaluate this scenario, the terrain was altered in the model to simulate the removal of over two miles of berms within the Flying Eagle Marsh. **Figure 10-3** provides an example of the berm segments and how the digital terrain was updated to reflect historical conditions.

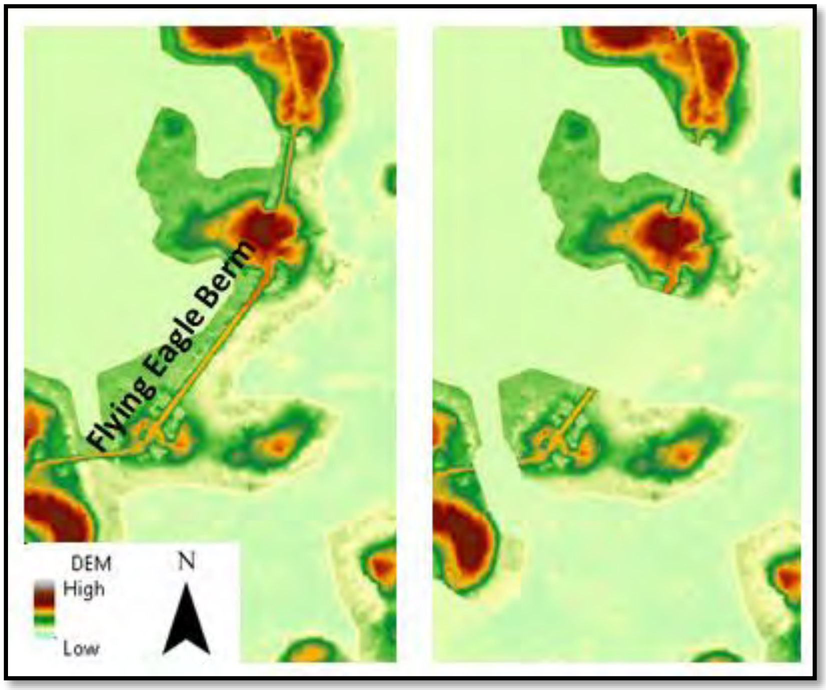

Figure 10-3 Comparison of Existing Altered Landscape (left side) and Simulated Natural Condition (right side)

10.3. Results

This scenario was simulated using the 2004 hurricanes and four design storm events (mean annual, 10-year, 25-year and 100-year) simulated with both low and high initial water conditions. Locations along the Withlacoochee River and throughout the Tsala Apopka chain-of-lakes were compared for differences in water level and flow as a result of removing the berms in Flying Eagle.

Figure 10-4 compares actual water levels in the Floral City Pool during the 2004 hurricanes to the simulated water levels with the Flying Eagle Berm removed. During the month of August, water levels in the pool would have been slightly lower with the berm removed, suggesting lake water was flowing back to the river through Flying Eagle. In late September when the lakes were above capacity, water levels in the Floral City Pool would have peaked nearly seven inches higher than they did in 2004 as a result of unregulated flow from the river through the Flying Eagle Marsh. Following the hurricanes, results show water flowing back to the river through the marsh, dropping lake levels much quicker than occurred in 2004 and settling at the lower level of the connection through the Flying Eagle Marsh rather than the lake's target water level.

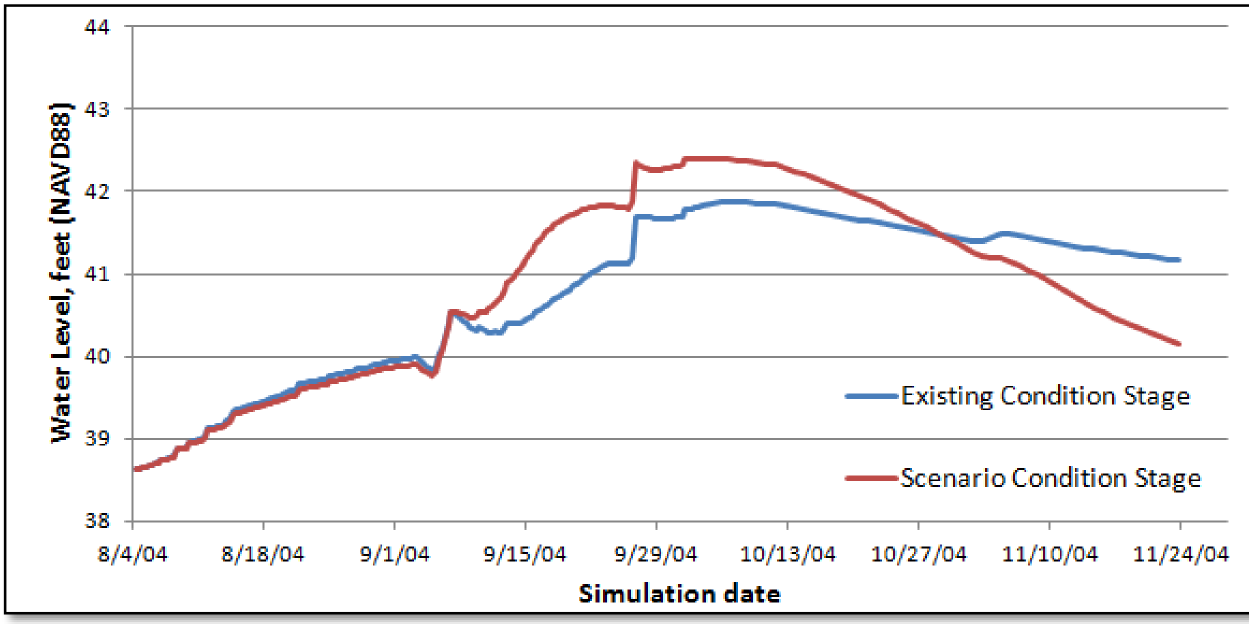

Figure 10-4 Floral City Pool Stage Comparison, Verification Storm Event

Similar results were observed for the 10-year, 25-year and 100-year storm events. The lakes typically reached their target levels quickly, without contribution through Flying Eagle, then peaked higher during flood events due to additional flows that would have been blocked by the berm. Under extreme high water conditions, similar to the 100-year event, the existing berm does not prevent floodwaters from the river to entering the Tsala Apopka pools. Peak water levels for the 100-year event were similar with and without the berm.

The mean annual event with low initial conditions represented the best opportunity for additional water to enter Tsala Apopka, since the lakes were below their target levels. **Figure 10-5** compares water levels in the Floral City Pool under existing conditions and with the Flying Eagle Berm removed.

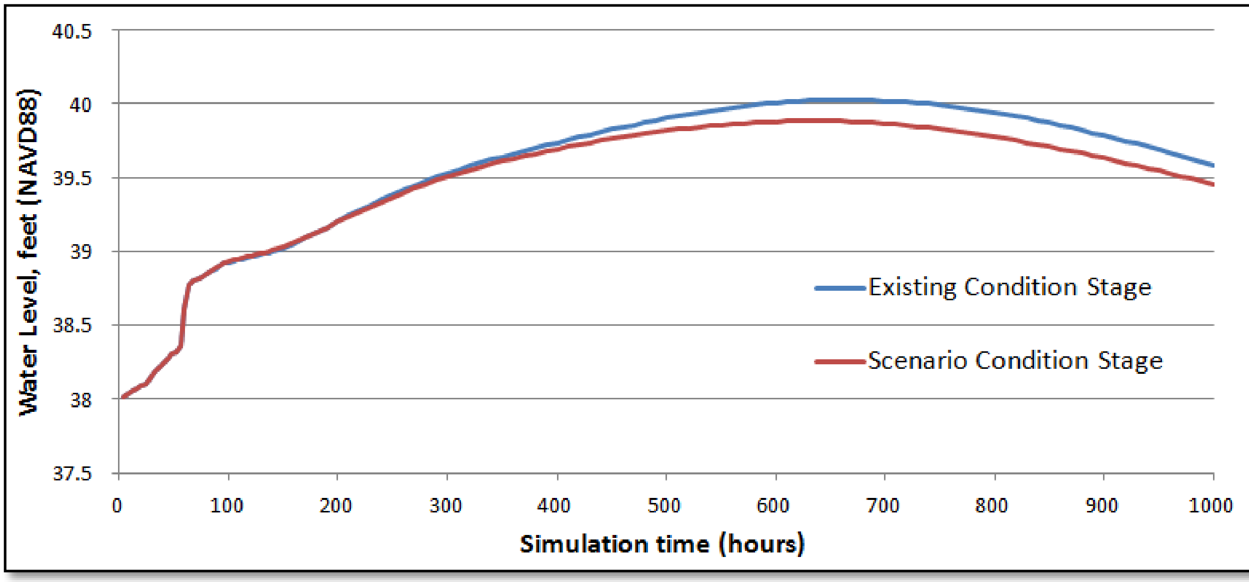

Figure 10-5 Comparison of Water Levels in the Floral City Pool for the Mean Annual Event

Overall, lower water levels were observed in the Floral City Pool with the berm removed. This suggests that river water entering the Floral City Pool through the canals upstream, would drain back to the river through Flying Eagle, when river levels are lower.

In addition to simulating storm events, an analysis was also conducted to determine the historical availability of additional river water to enter the Floral City Pool if the berm was removed. This involved field work to ground truth the marsh bottom elevations in Flying Eagle. Over 200 ground elevations were collected throughout the Flying Eagle Marsh to determine how high water would have had to rise historically to flow between the Withlacoochee River and Tsala Apopka. This natural “pop-off” elevation between the river and the lakes was determined to be around 38.5 feet (NAVD88). **Figure 10-6** depicts these elevations in the historic flowpath as compared to the current flowpath (Leslie Heifner Canal) which is several feet lower.

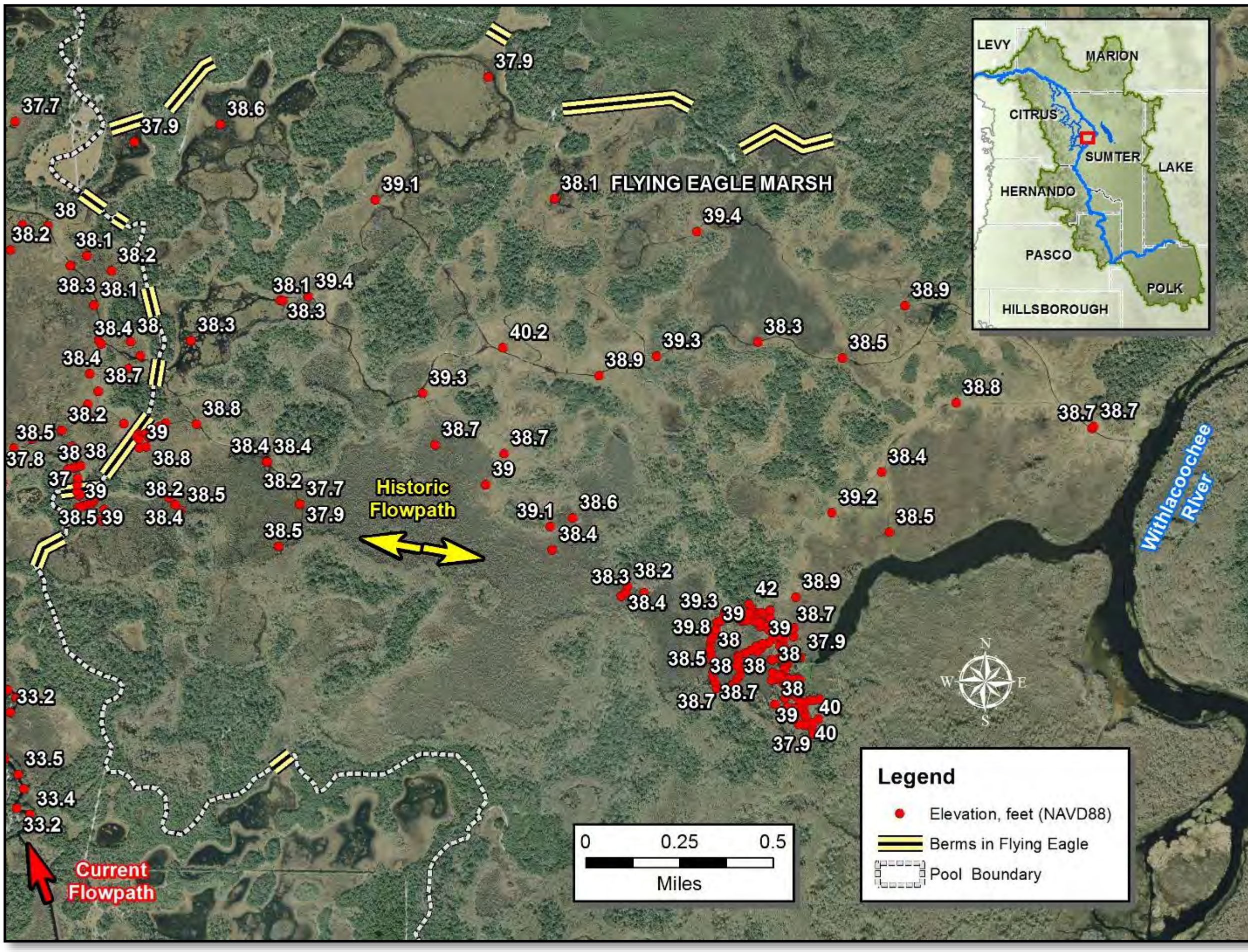

Figure 10-6 Ground Elevations Measured in the Flying Eagle Marsh

Available water level data from 1983 to 2014 were then analyzed to determine how often water could have flowed from the Withlacoochee River to the Floral City Pool if the Flying Eagle Berm did not exist. **Figure 10-7** provides a summary of this analysis.

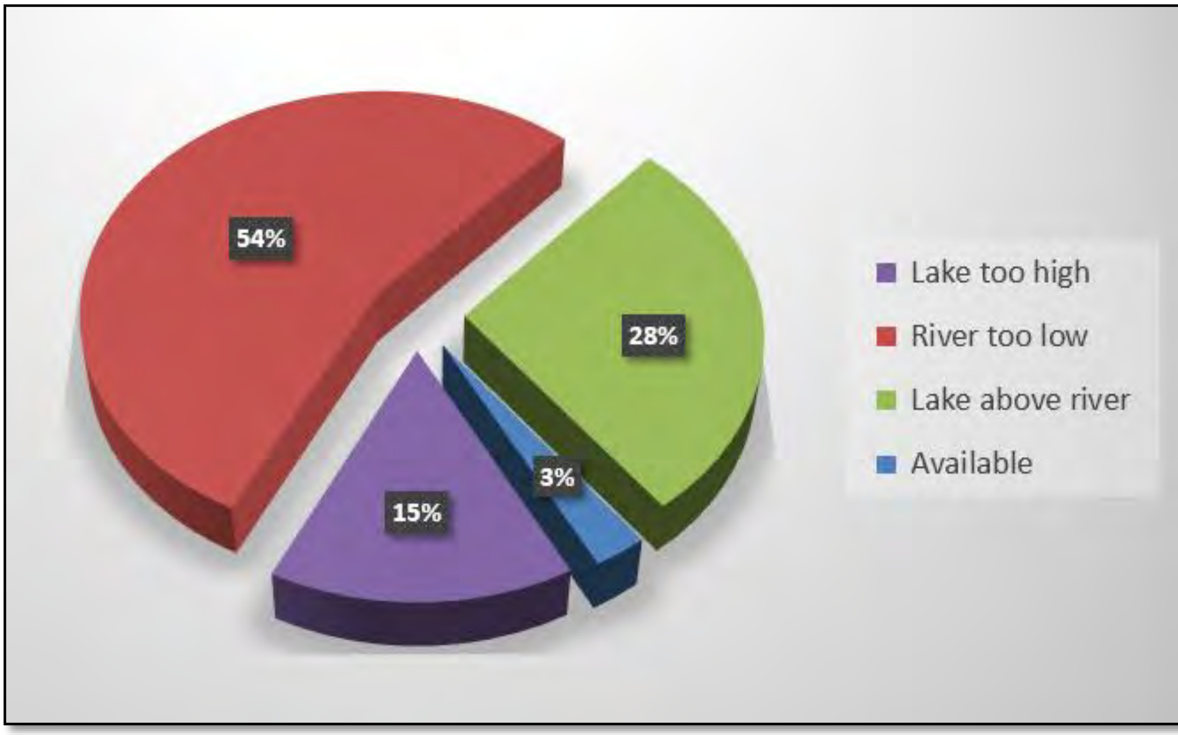

Figure 10-7 Availability of River Water to Tsala Apopka through Flying Eagle Marsh

Within the past 31 years, the Withlacoochee River was lower than the natural elevations of the Flying Eagle marsh over 50 percent of the time. Floral City Lake was already above its high minimum lake level 15 percent of the time. Of the remaining days, when the lake was below its high minimum level and the river was above the marsh, the lake was typically already higher than the river. In the 31 years of data, river water would have been available to flow into the lake only three percent of the time (11 days per year on average). It is important to note that 52 percent of the time, water would have flowed back to the river from the lake if the Flying Eagle Berm were not in place.

10.4. Conclusion

The results of this scenario suggest that the Flying Eagle Berm serves to conserve water in the Floral City Pool under normal conditions, while providing some level of flood protection during high water events. For example, during the 2004 hurricanes, water levels in the Tsala Apopka chain-of-lakes would have been higher if the berm was not in place.

Results also indicate that very few opportunities exist to bring additional river water through the Flying Eagle Marsh to help fill the lakes. During low water conditions, however the river is typically below the natural marsh elevations of Flying Eagle. When the river is high enough to flow through the marsh, a condition usually driven by significant rainfall in the watershed, water levels in the Floral City Pool are typically higher, risen by the same rainfall, and removal of the berm would drain the lake back to the river.

Scenario 11: Tsala Apopka Pre-Settlement Conditions

11.1. Description

In pre-settlement times, water naturally flowed back and forth between the Tsala Apopka chain-of-lakes and the Withlacoochee River through extensive marshlands or forested wetlands that would flood or dry out with changing hydrologic conditions (**Figure 11-1**). These historic connections included the Flying Eagle Marsh, Bryant Slough and several locations near Potts Preserve. Over the past 130 years, man-made alterations have transformed this region's natural function into one that benefited navigation, industry and private needs. Today, the Tsala Apopka chain-of-lakes is a highly altered system with many canals, structures and berms that conserve water for recreation while balancing flood protection. This scenario will evaluate how these alterations have changed water levels and flow by simulating pre-settlement conditions throughout Tsala Apopka.

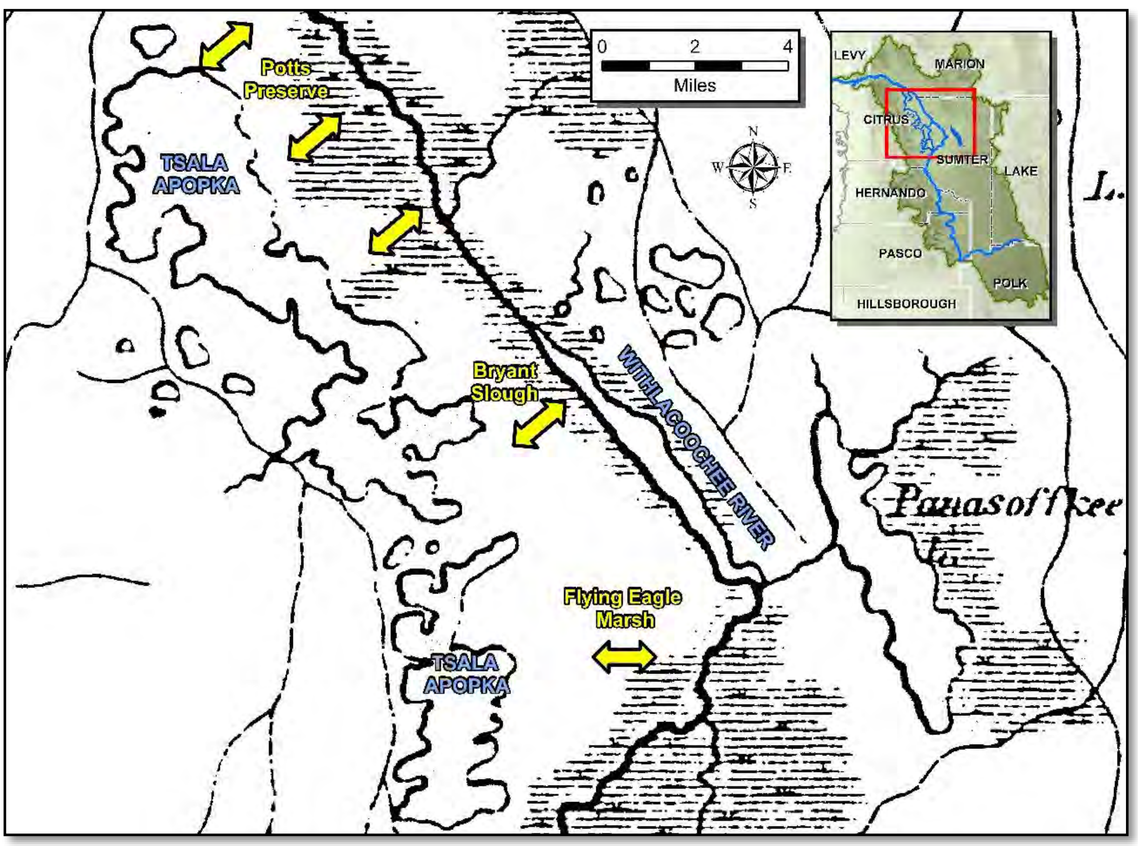

Figure 11-1 Historical Connections between the Withlacoochee River and Tsala Apopka

11.2. Model Setup

To evaluate this scenario, man-made channels, structures and berms that have altered the natural flow of water in Tsala Apopka were removed in the model's digital terrain (**Figure 11-2**). For example, canals between the lakes and the Withlacoochee River were filled in, forcing flows through the natural marsh connections between each water body.

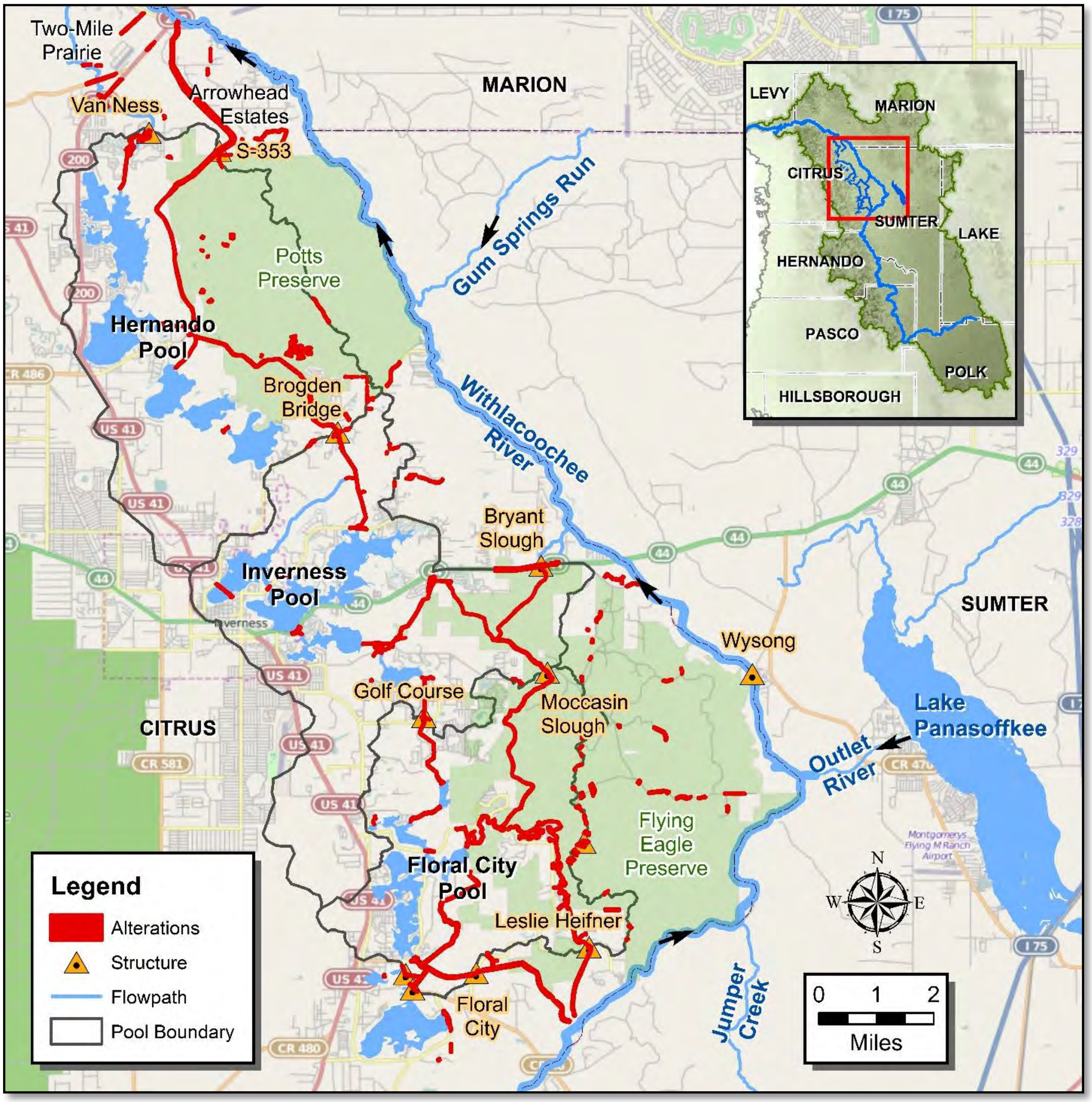

Figure 11-2 Alterations that were Removed to Simulate Pre-Settlement Conditions

These changes create a system where water is allowed to flow freely, similar to historic conditions, and prior to the construction of these alterations. In the model, the footprint of dozens of miles of canals were blended back into the natural terrain of the land. Structures that currently exist to manage flows through these canals were removed in the model as well. In addition, miles of berms, many of which were constructed for agricultural uses and some that exist today as major roadways, were restored to their natural elevations in the model. **Figure 11-3** shows an example of how the digital terrain was altered to remove the footprint of the Tsala Apopka Outfall Canal (C-331). The image on the left shows the canal as it exists today, while the image on the right shows how the canal was removed in the model.

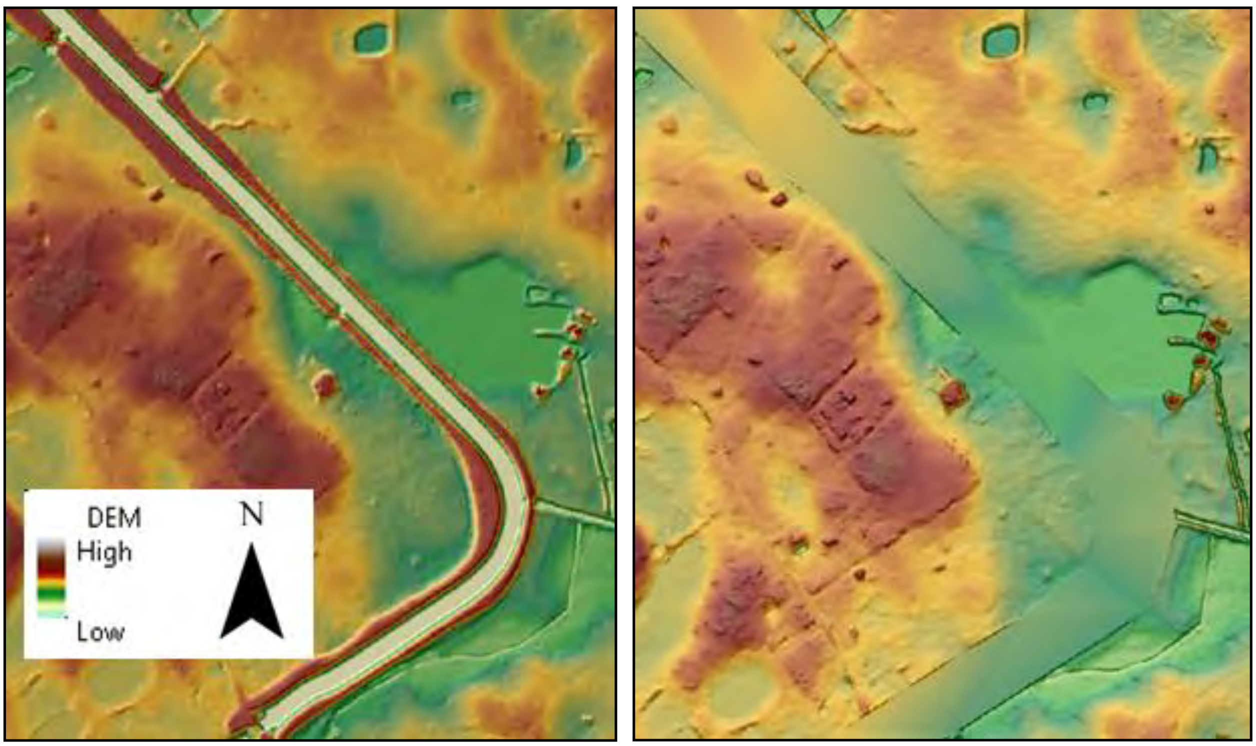

Figure 11-3 Comparison of the Digital Terrain for the Tsala Apopka Outfall Canal

11.3. Results

This scenario was simulated using the 2004 hurricanes and all four design storm events (mean annual, 10-year, 25-year and 100-year) with both low and high initial water conditions. Locations along the Withlacoochee River and throughout the Tsala Apopka chain-of-lakes were compared for differences in water levels and flow as a result of simulating the removal of constructed channels, structures and berms within Tsala Apopka.

In the summer of 2004, water levels in the Tsala Apopka chain-of-lakes were rising as a result of normal rainfall and river inflows. By September, the pools were full and as hurricanes brought significantly more rainfall, the structures were operated to prevent inflow from the river and water was being released from each pool to prevent further flooding. **Figure 11-4** shows how water levels in the Floral City Pool would have varied under actual conditions (blue line) and under pre-settlement conditions (red line) for the 2004 hurricanes.

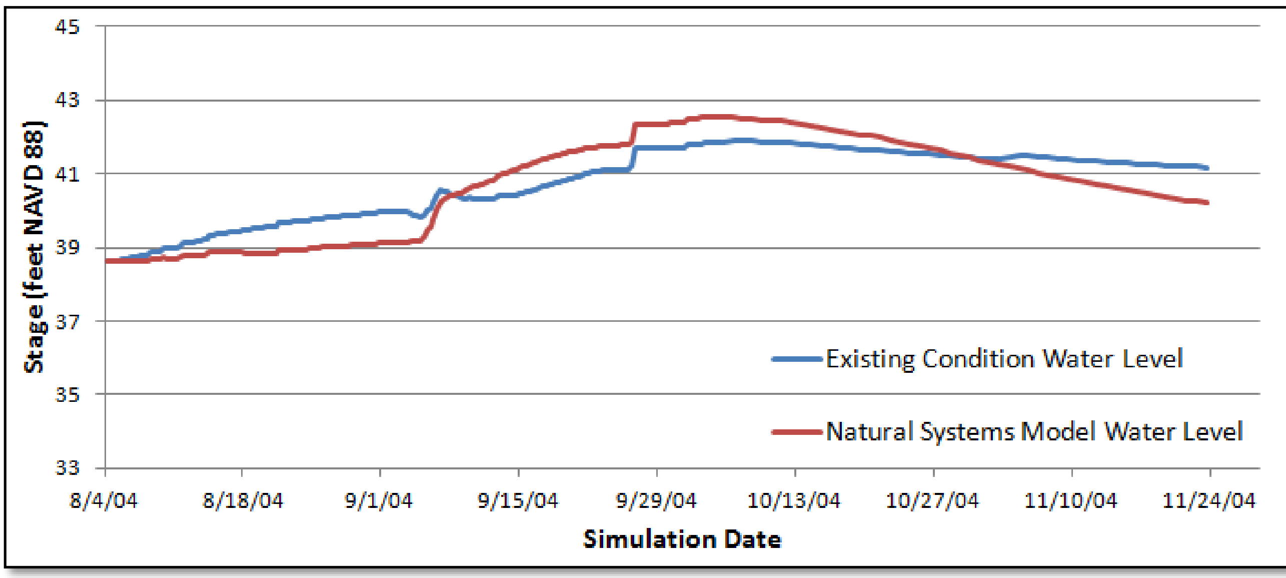

Figure 11-4 Comparison of Water Levels in the Floral City Pool during the 2004 Hurricanes

Under pre-settlement conditions, the Floral City Pool would have been lower initially, since inflow could not occur through the man-made canals. After the hurricanes, water levels would have peaked more than seven inches higher as a result of unregulated flow through the Flying Eagle Marsh. Following the storms, water levels would have receded quicker, flowing out through Moccasin Slough and Flying Eagle back to the Withlacoochee River. Similar comparisons for the Inverness and Hernando Pools are shown in **Figures 11-5** and **11-6**.

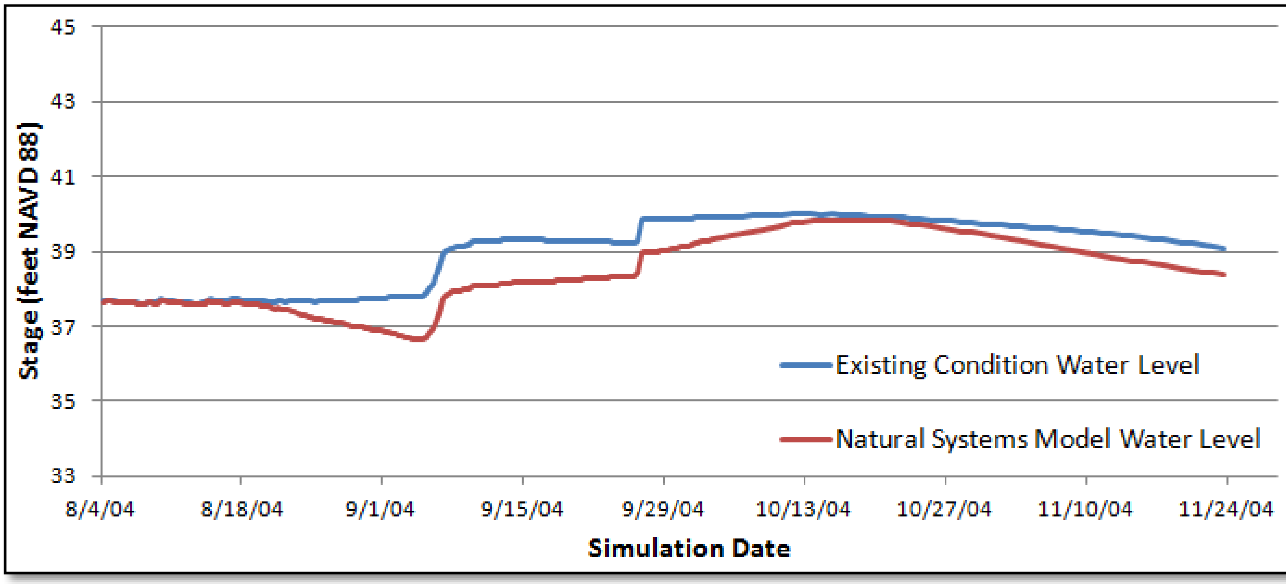

Figure 11-5 Comparison of Water Levels in the Inverness Pool during the 2004 Hurricanes

Water levels in the Inverness Pool were lower under pre-settlement conditions for nearly the entire simulated period. Early on, water levels dropped as outflow occurred to both the Hernando Pool and the Withlacoochee River through Bryant Slough. As the hurricanes brought significant rainfall and river levels increased, water levels in the Inverness Pool also rose to within two inches of the peak level observed under existing conditions.

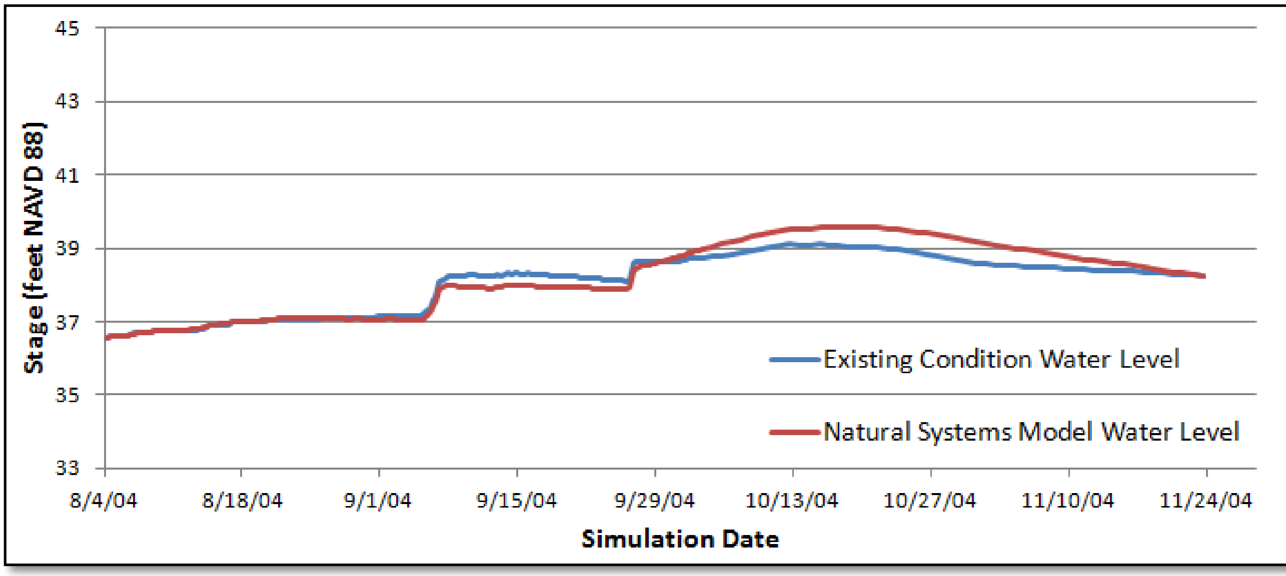

Figure 11-6 Comparison of Water Levels in the Hernando Pool during the 2004 Hurricanes

Throughout August and part of September, water levels in the Hernando Pool were similar to existing conditions because of unregulated flow from the Inverness Pool. Following Hurricane Jeanne, in late September, water levels peaked nearly six inches higher than existing conditions.

All three pools peaked higher than their high guidance levels during the 2004 hurricanes (**Figure 11-7**). Under pre-settlement conditions, the Floral City and Hernando Pools would have peaked even higher, creating greater flood potential in Tsala Apopka.

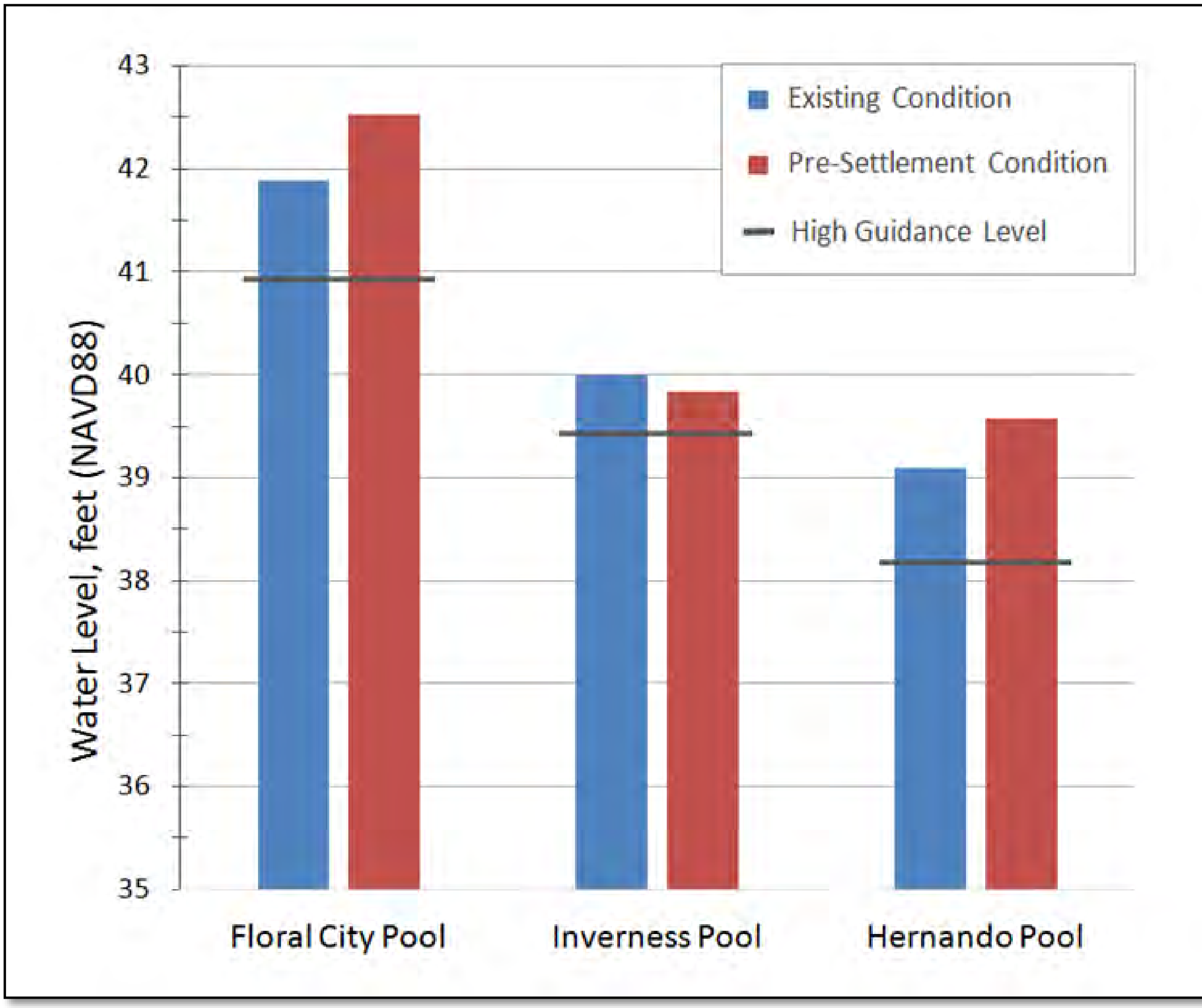

Figure 11-7 Comparison of Peak Water Levels during the 2004 Hurricanes

Similar results were observed for the larger design storm events that were simulated. Water levels were typically lower under pre-settlement conditions but peaked higher due to unregulated flow from the Withlacoochee River. During flood events, the natural connection between the Inverness and Hernando pools would allow them to merge into a single pool. As river levels receded, this larger pool would then discharge back to the river through Bryant Slough and Potts Preserve.

The mean annual storm event represented normal water levels throughout the watershed and a 40-day capture window when the Tsala Apopka chain-of-lakes were being filled in an attempt to reach their target guidance levels. Average and peak water levels were compared from this simulation to pre-settlement conditions show that under existing conditions, all three pools peaked higher, yet still well below their high guidance levels during the mean annual storm event (**Figure 11-8**). Under pre-settlement conditions, water levels throughout Tsala Apopka peaked even lower due to less interaction with the Withlacoochee River.

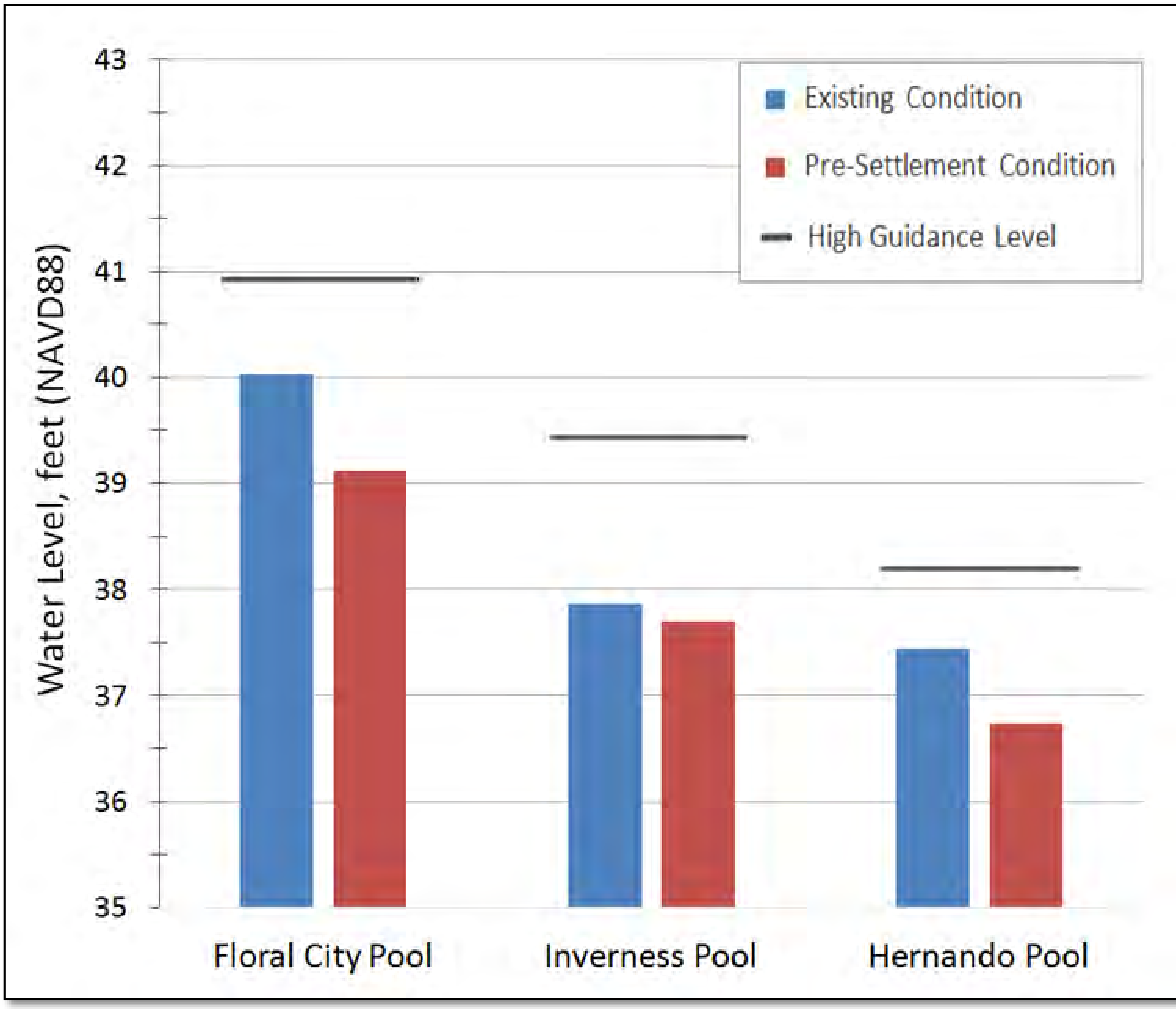

Figure 11-8 Comparison of Peak Water Levels during the Mean Annual Storm Event

11.4. Conclusion

Model results suggest that without the existing canals, structures and berms, the Tsala Apopka chain-of-lakes would not fill as quickly under normal river conditions. Without the canals, river levels would be required to rise higher before inflow could occur across the natural marshlands. Likewise, water levels in Tsala Apopka, which are currently maintained by the berms and structures, would naturally drain back to the river. Under high water conditions, the lakes would receive significant, uncontrolled inflows from the river, causing their levels to peak well above high guidance levels.

Scenario 12: Tsala Apopka and the Orange State Canal

12.1. Description

In pre-settlement times, water naturally flowed back and forth between the Tsala Apopka chain-of-lakes and the Withlacoochee River through extensive marshlands that would flood or dry out with changing hydrologic conditions. After its construction in 1884, the 3.5 mile long Orange State canal became the first man-made connection between these waterbodies. It was originally used to transport produce and other goods between Tsala Apopka and a railroad at Lake Panasoffkee. Since this canal was constructed several feet lower than the natural marsh connection, it allowed more frequent transfer of water between the Withlacoochee River and Tsala Apopka. By 1959, the Floral City structure was placed in the Orange State Canal to control this flow of water. Later in 1967, the Leslie Heifner canal and structure were constructed, providing an additional means for water to transfer between the river and lakes. Today, there is little potential for natural flow as numerous canals, berms and structures have been constructed throughout the Tsala Apopka region (**Figure 12-1**). The District inherited many of these structures in the 1960s and currently manages water levels within Tsala Apopka to balance recreation and flood protection. It is important to note that the S-353 structure, located near Arrowhead Estates, was the only structure designed for flood protection. The remaining structures are operated for water conservation purposes. When water levels in the river are above the lakes, water can enter through both the Orange State and Leslie Heifner canals. This inflow is distributed to all three pools through operation of additional structures. Under normal conditions, as river levels drop, the structures are closed to conserve water in the lakes.

The region's unique geology creates a natural leakage from the Tsala Apopka chain-of-lakes downward into the Floridian Aquifer. This outflow, coupled with evapotranspiration, will cause a daily decrease in lake levels that is only offset by direct rainfall or river inflow. Chronically low water levels in recent decades, have caused many residents to desire increased inflows from the Withlacoochee River when available. The Leslie Heifner canal is the preferred path to move water into the lakes due to existing structure and channel elevations. This scenario will evaluate how changes to the Orange State Canal and Floral City structure might impact flows from the Withlacoochee River and water levels within the Tsala Apopka chain-of-lakes.

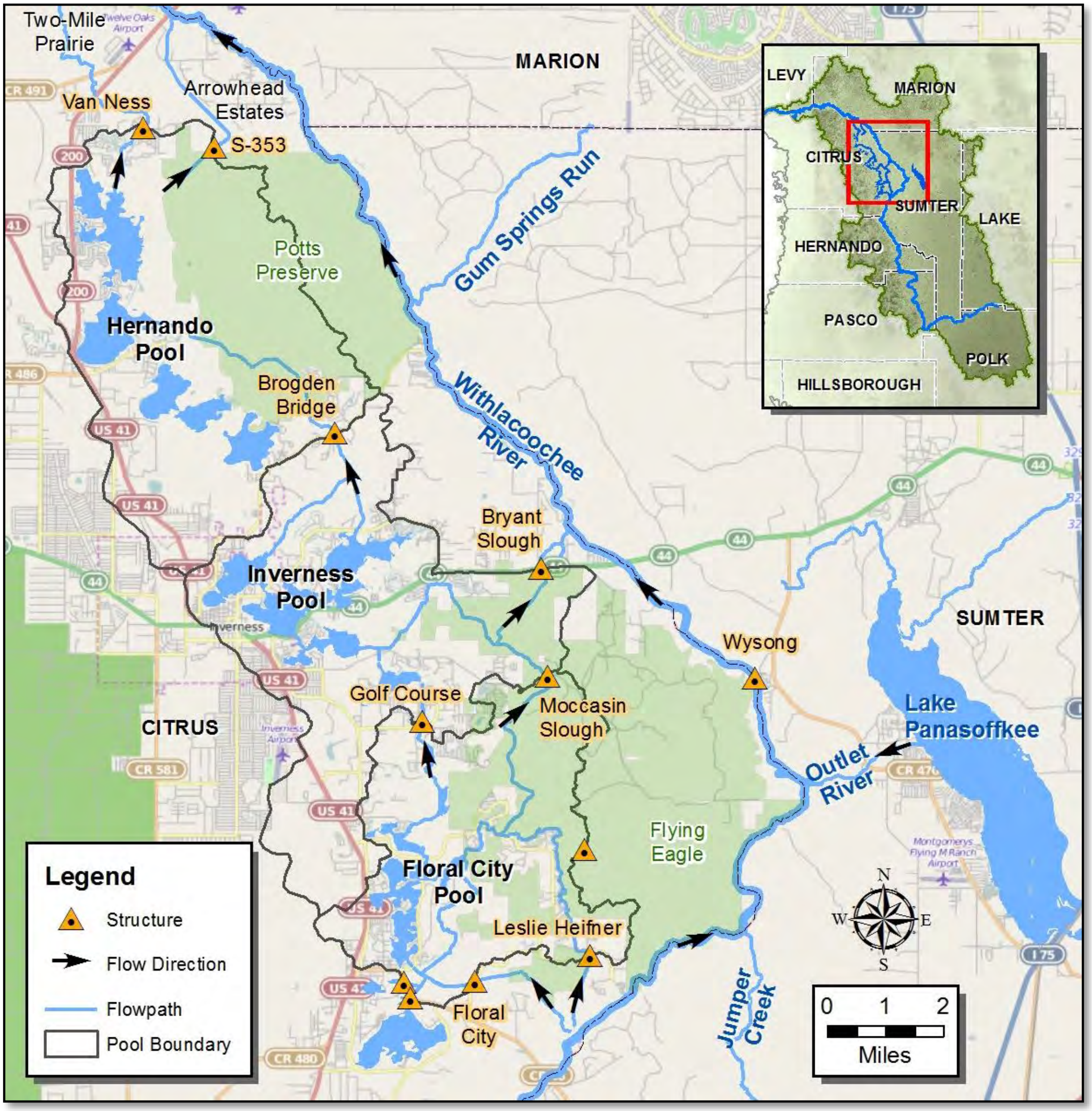

Figure 12-1 Area Map for the Tsala Apopka Chain-of-lakes

12.2. Model Set-up

The Floral City structure (shown in **Figure 12-2**) consists of a 14 foot wide by seven foot high lift gate with a concrete bottom elevation of 37.1 feet NAVD88, three feet higher than the Leslie Heifner structure. Subsequently, the bottom of the Orange State Canal is currently two to three feet higher than the Leslie Heifner canal bottom. Both structures and canals are lower than the natural marsh and allow for movement of river water into the lake at lower elevations.

Figure 12-2 The Floral City Structure and Orange State Canal during Drought Conditions

To simulate alterations to the Orange State Canal, the existing channel cross sections were modified as shown in **Figure 12-3**. The channel bottom was lowered in the model approximately two to four feet while the Floral City structure was lowered three feet to match the elevation of the Leslie Heifner structure at elevation 34.1 feet NAVD88.

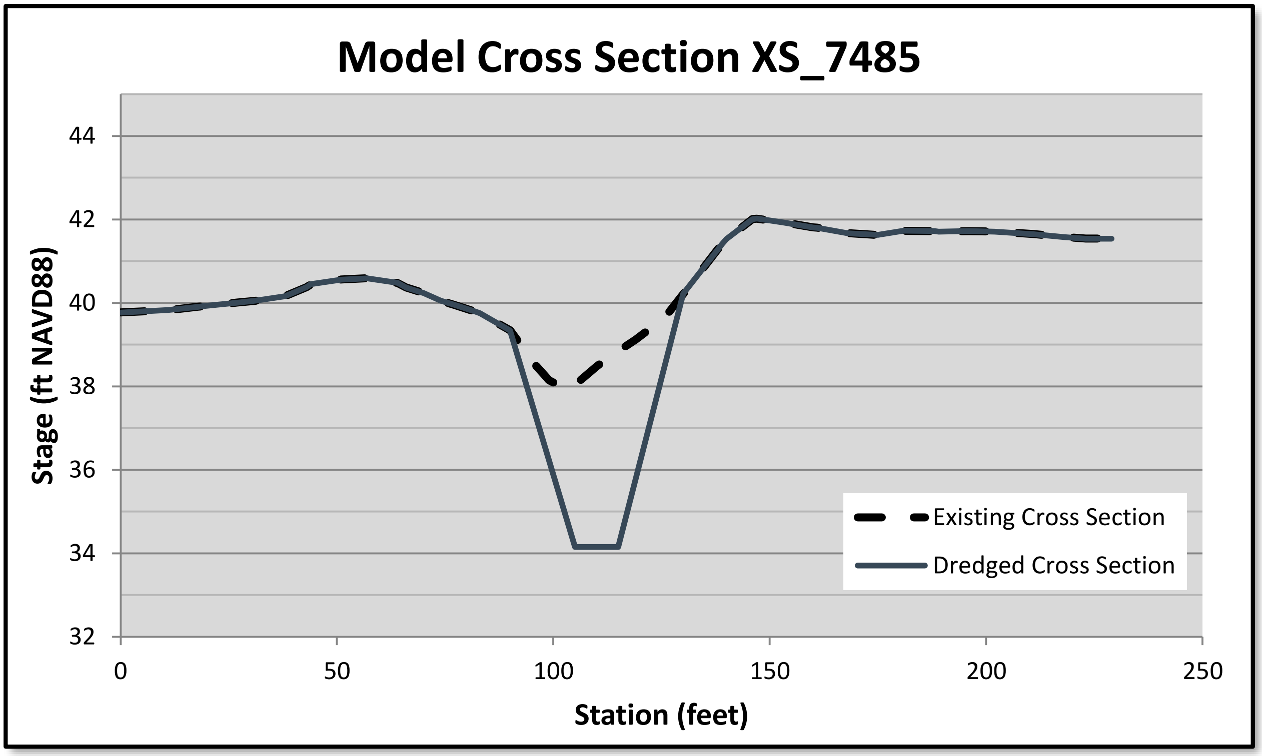

Figure 12-3 Typical Orange State Canal Cross Section

12.3. Results

This scenario was simulated using the 2004 hurricanes and the mean annual, 10-year and 25-year design storm events with low initial water conditions. The results confirmed that lowering the Orange State Canal increased overall flows into the Tsala Apopka chain-of-lakes for each of the events simulated, with the mean annual event having the largest difference. Under this event, even with the structures open throughout the simulation, none of the lakes reached their target levels in either the existing or scenario simulations.

Figure 12-4 compares flows during the mean annual event through the Orange State Canal under existing conditions and with modifications to the structure and canal. There is an average increase of 49 cubic feet per second (cfs) through the Orange State Canal (from 58 cfs to 107 cfs), as a result of the increased flow area and lower bottom elevations.

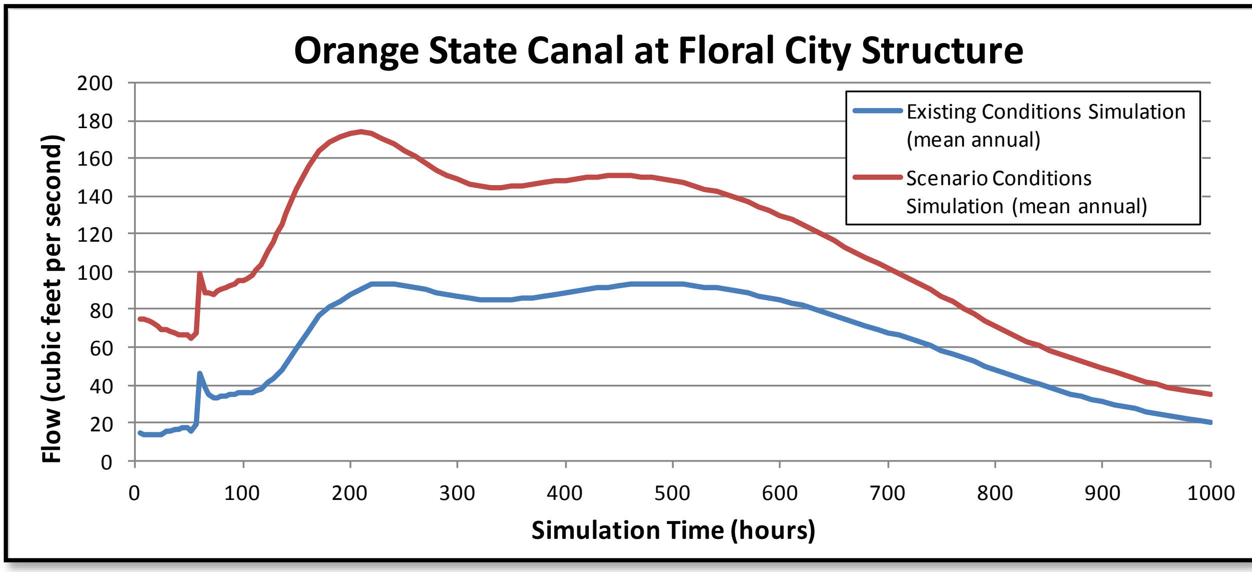

Figure 12-4   Orange State Canal Flow Comparison – Mean Annual Storm Event

Figure 12-5 compares flows through the Leslie Heifner canal as a result of these changes. There is an average decrease of 26 cfs through the Leslie Heifner canal (154 cfs to 128 cfs). This is due to slightly higher water levels in Tsala Apopka and slightly lower river levels at Bonnet Lake as a result of more flow being diverted from the river through the Orange State Canal. These results suggest the effectiveness of dredging the Orange State Canal and lowering the Floral City structure is reduced by half due to decreased flows through Leslie Heifner.

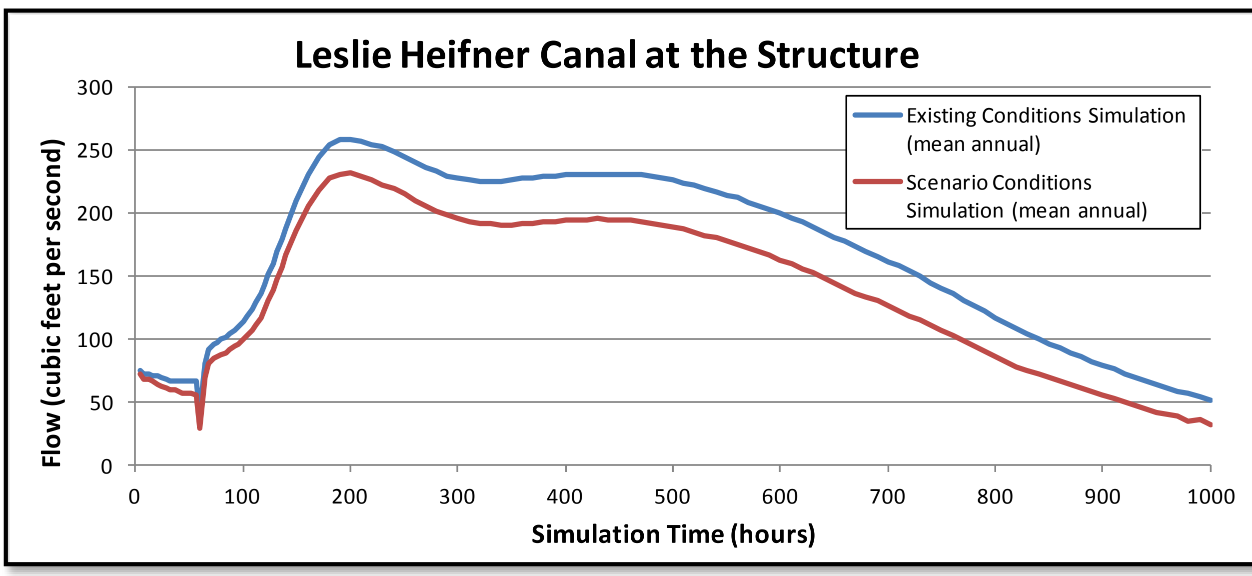

Figure 12-5 Leslie Heifner Canal Flow Comparison – Mean Annual Storm Event

The net increase in flow resulted in an overall water level increase of two inches to the Floral City Pool from lowering the Orange State Canal and modifying the structure. **Figure 12-6** shows this difference in water levels throughout the mean annual storm event. The Inverness and Hernando pools each rose approximately one inch as a result of these changes.

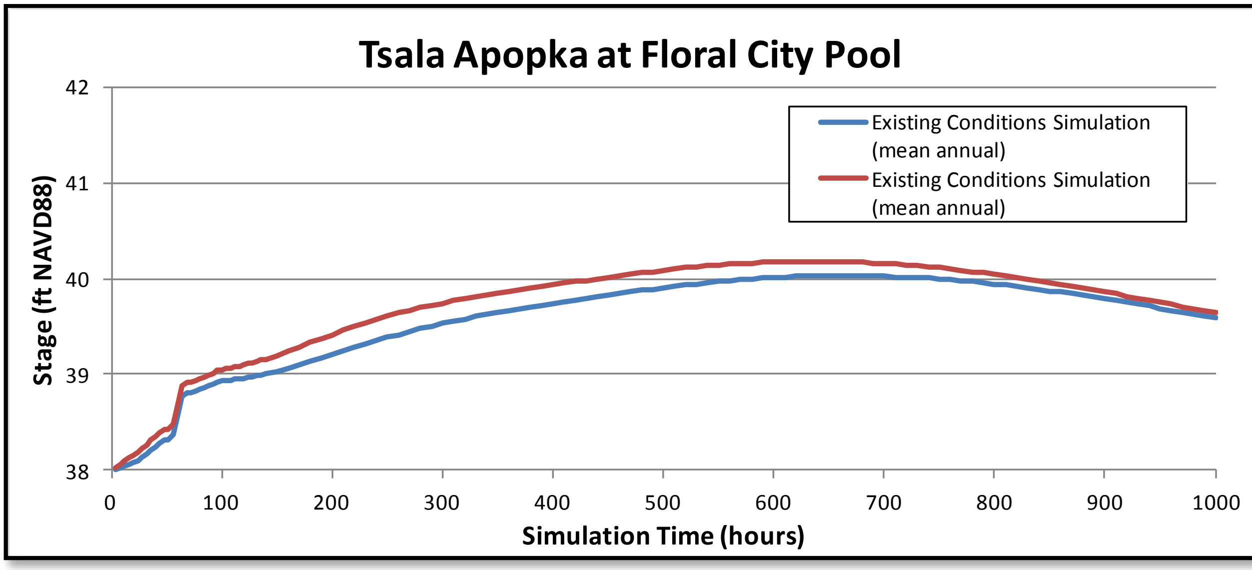

Figure 12-6 Comparison of Water Levels in the Floral City Pool for the Mean Design Storm Event

In the larger events, all of the Tsala Apopka pools fill up completely. As seen in **Figure 12-7**, model results for the 10-year storm event indicate the Floral City Pool reaches its high minimum lake level of 40.35 feet NAVD88 in about seven days under the scenario condition, one day sooner than it does in the existing condition. The Inverness and Hernando pools also show similar results. Model results for the 25-year storm event generally mimic those of the 10-year event.

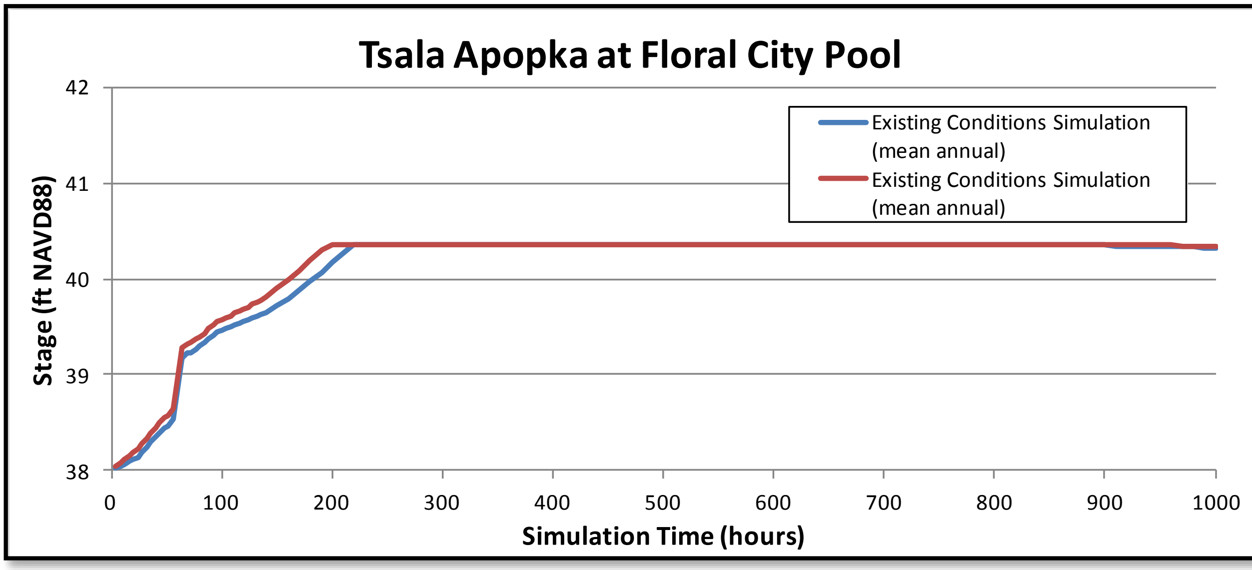

Figure 12-7 Floral City Pool Stage Comparison – 10-year Storm Event

During the 2004 hurricanes, inflow from the Withlacoochee River only occurred for a limited amount of time due to rising water levels in the pools from direct rainfall as a result of the hurricanes. All three Tsala Apopka pools were filled and releases were made in an effort to control flooding. As seen in **Figure 12-8**, there is minimal difference in the peak stage in the Floral City Pool for the 2004 hurricanes verification event as a result of modifying the Orange State Canal. Although flows are increased in the Orange State Canal for the scenario condition, this increase was limited due to rising water levels and necessary structure operations. Water levels in the Floral City Pool did peak approximately one inch higher during a time when water was being released and increased water levels were not desirable.

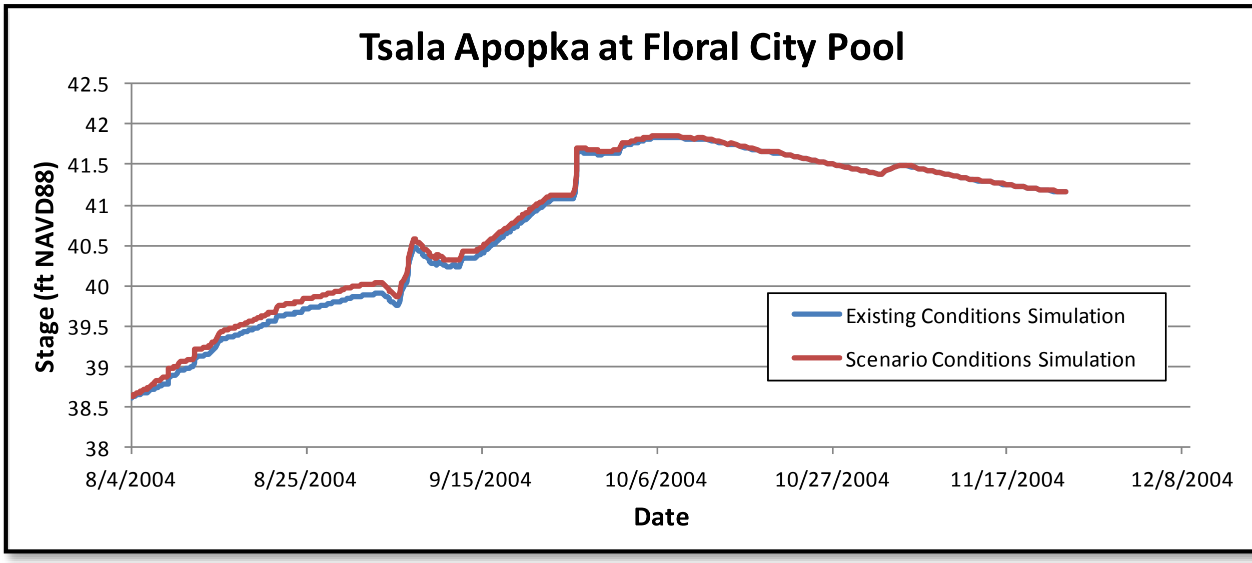

Figure 12-8 Floral City Pool Stage Comparison – 2004 Verification Event

Historical water levels in the Withlacoochee River and Floral City Pool were also compared to better understand how often water has flowed through the Orange State Canal in the past. Data from 1958 through 2015 shows that the Withlacoochee River was available to flow through the Orange State Canal approximately 28 percent of the time (**Figure 12-9**). Forty four percent of the time the Floral City Pool is above the Withlacoochee River and the remaining 30 percent of the time the lake is either already full or the river is too low to contribute.

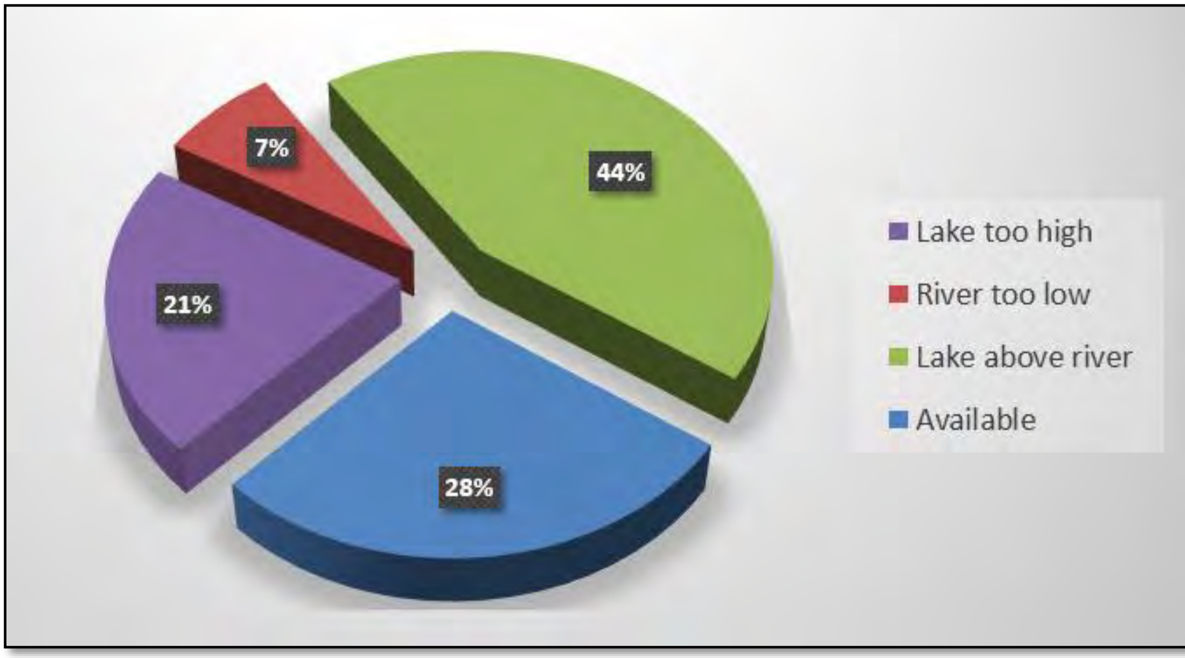

Figure 12-9 Historical Availability of Flow from the Withlacoochee River through the Orange State Canal

12.4. Conclusion

In summary, model results indicated that dredging the Orange State Canal and lowering the Floral City structure did increase the flow rate to the Tsala Apopka chain-of-lakes from the river by almost twofold (from 58 cfs to 107 cfs) for the mean annual storm event. This is a substantial increase; however, as a result of increasing flows through the Orange State Canal, the flow rate through the Leslie Heifner Canal was reduced from 154 cfs to 128 cfs. This results in an average overall increase of 23 cfs to the Floral City Pool or a total volume of 1,900 acre-feet (the volume of a NFL football stadium). While this is a considerable amount of water it only results in stage increases in the Tsala Apopka pools of approximately one to two inches. This small increase in stage is due to the immense amount of storage volume within the pools. Furthermore, this increase is not expected to have a detrimental impact on the river as increased flow diversions from the Withlacoochee River were minimal compared to the magnitude of river flows, decreasing by only two percent at the Wysong-Coogler water conservation structure. For larger storm events, such as the 10-year storm event, where the pools reach their target elevations during the event, the Orange State Canal dredging allows the pools to fill slightly faster.

Scenario 13: Tsala Apopka Structure Sizes

13.1. Description

Changing water levels in the Tsala Apopka chain-of-lakes are the result of inflows and outflows from several sources. The lakes receive inflow through direct rainfall, runoff from adjacent higher ground, and diversions from the Withlacoochee River that are split between each pool. Outflows include evapotranspiration of water back to the atmosphere, natural leakage downward into the underlying Floridan Aquifer, and diversions back to the Withlacoochee River or to Two-Mile Prairie.

Currently, the Floral City Pool receives inflow from the Withlacoochee River through the Leslie Heifner and Floral City structures whenever it is available and Tsala Apopka is not already full. That inflow is split with the Inverness Pool through the Golf Course and Moccasin Slough structures and with the Hernando Pool through the Brogden Bridge and Brogden Culvert structures. When the lakes are full, water can then be released to lower or maintain high water levels. Water can be released from the Inverness Pool through the Bryant Slough structure and from the Hernando Pool through the Van Ness and S-353 structures. These structures and flow paths are shown in **Figure 13-1**.

It has been suggested that some of the Tsala Apopka structures are undersized, preventing adequate flow into the pools. This scenario will evaluate the ability of existing structures to convey flows through the Tsala Apopka chain-of-lakes. Structures that are identified as flow constrictions will be enlarged in the model. Water levels and flow throughout Tsala Apopka will then be evaluated to determine the effect of increasing the sizes of these structures.

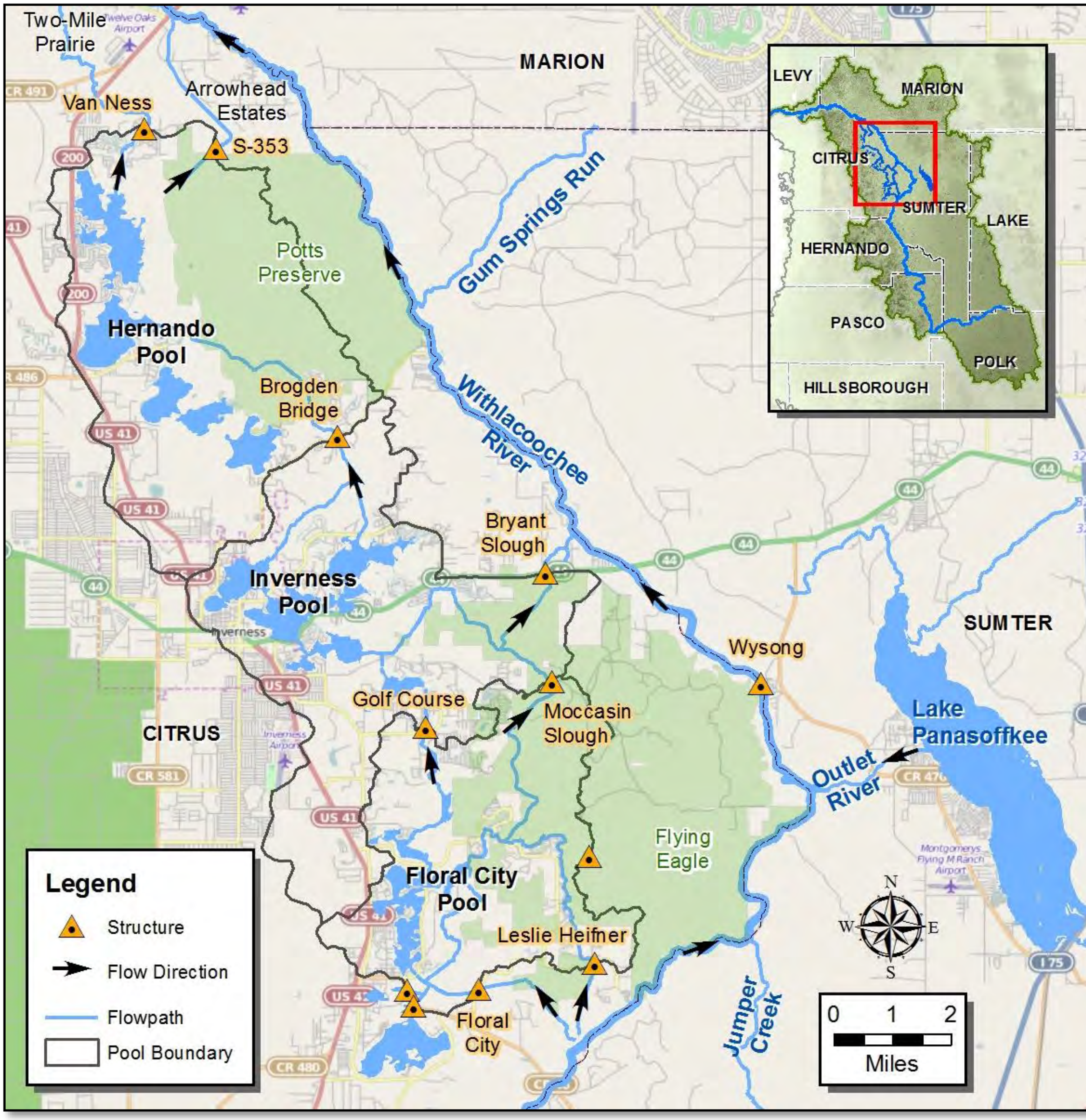

Figure 13-1 Flowpaths, Structures and Pools within the Tsala Apopka Chain-of-lakes

13.2. Model Setup

The model was simulated under existing conditions to identify where flow restrictions currently exist within the Tsala Apopka chain-of-lakes. This included fully opening the Leslie Heifner and Floral City structures to allow flow into the Floral City Pool, fully opening the Golf Course and Moccasin Slough structures to allow flow into the Inverness Pool and fully opening the Brogden Bridge structure to allow flow in the Hernando Pool. Under existing conditions, the model showed that while the Floral City and Hernando Pools would fill, water levels in the Inverness Pool would drop if all of these structures were opened fully. Also, more flow can typically be released from the Inverness Pool than can enter if all structures were opened fully. This indicated that the Golf Course and Moccasin Slough structures could not pass enough flow to keep the Inverness Pool from lowering. Recent structure operations and field measured flow data confirm this result. During 2014 when river diversions were being managed between each pool, limitations were observed by comparing flows between the Floral City and Inverness Pools.

The Golf Course structure is located in a canal that was dug through high ground. It includes four gates (each four feet in width) that lower to an elevation of 37.16 feet (NAVD88), which is approximately four feet higher than the channel bottom of the Golf Course Canal. The Moccasin Slough structure is located in Moccasin Slough, the only historic connection between the Floral City and Inverness Pools. This structure includes one operable gate (12 feet in width) that lowers to an elevation of 37.06 feet (NAVD88), similar to the bottom elevation of Moccasin Slough. Both structures have overtopping weirs that allow for flow downstream when water levels in the Floral City Pool are high enough.

To evaluate this scenario, structure openings were increased in the model for the Golf Course and Moccasin Slough structures. The Golf Course structure was modified to allow all four gates to lower an additional four feet, flush with the bottom of the Golf Course Canal, doubling the flow area. **Figure 13-2** shows the current range the gates can lower (blue arrow) and the additional four feet of lowering that was simulated (yellow arrow). The Moccasin Slough structure was modified in the model to allow for three, 12 foot wide gates to lower to the bottom of the channel, effectively tripling the flow area. **Figure 13-3** shows how water can flow through the single existing operable gate (blue arrow) of the Moccasin Slough structure along with simulated flow through additional gates (yellow arrows) in the model.

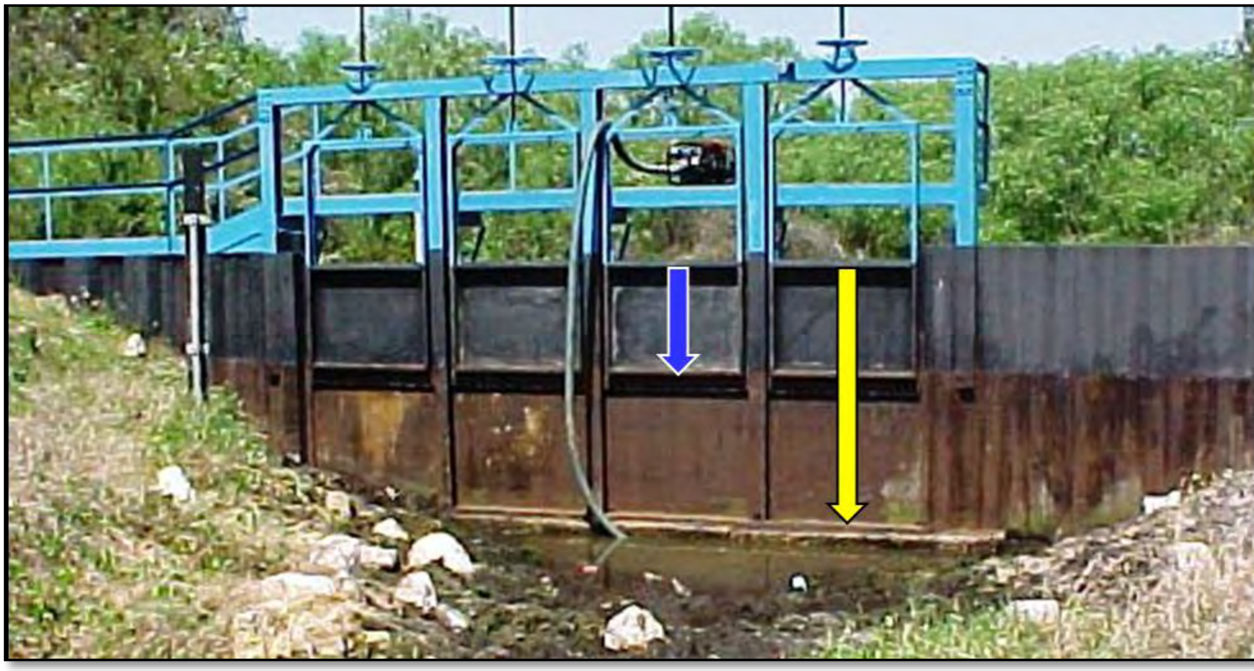

Figure 13-2 Golf Course Structure with Existing and Simulated Gate Openings

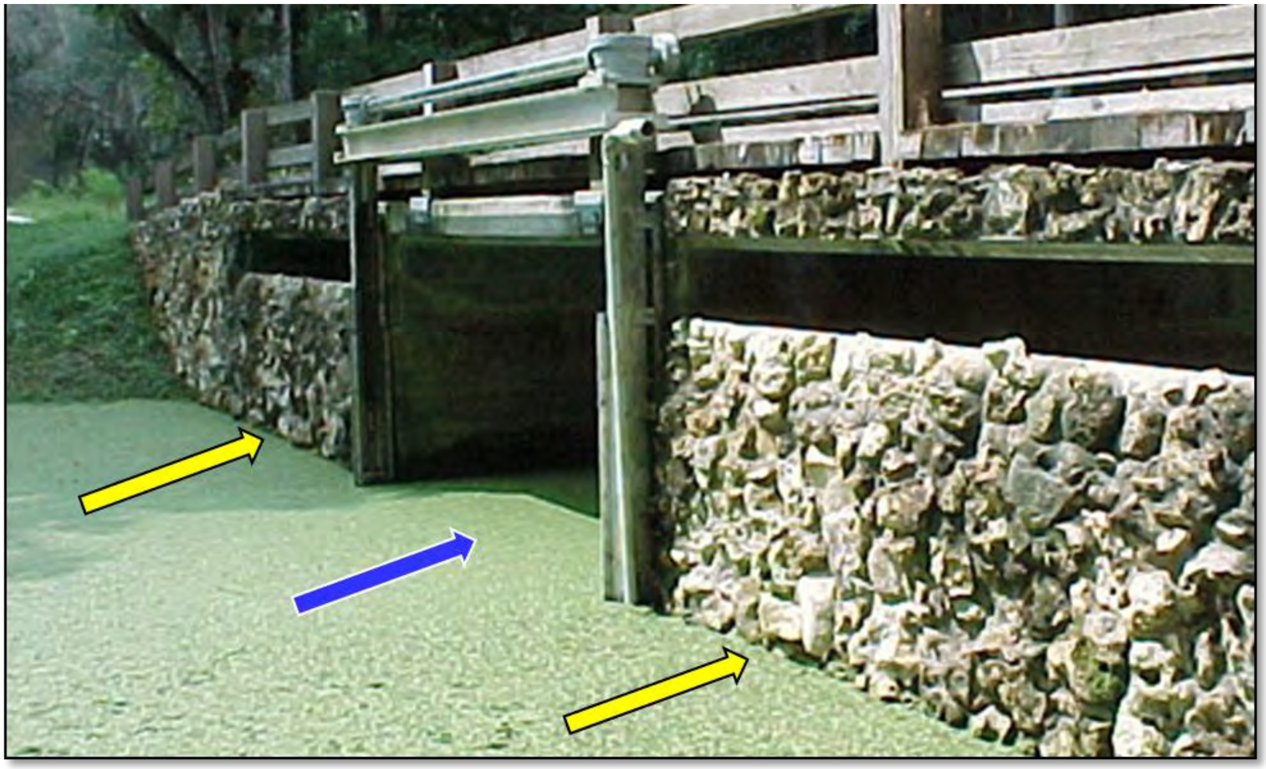

Figure 13-3 Moccasin Slough Structure with Existing and Simulated Gate Openings

13.3. Results

This scenario was simulated using the mean annual and 10-year design storm events with low initial water conditions. These simulations represented conditions where the lakes were not full and could receive significant inflow from the Withlacoochee River. Locations throughout the Tsala Apopka chain-of-lakes and along the Withlacoochee River were compared for differences in water levels and flow as a result of increasing the sizes of the Golf Course and Moccasin Slough structures.

The mean annual event provided a 40 day simulation period where inflow from the Withlacoochee River was constantly filling the Tsala Apopka chain-of-lakes. Model results showed that increasing the sizes of the Golf Course and Moccasin Slough structures increased the volume of water entering each of the Tsala Apopka pools for this event. Outflows from the Floral City and Inverness Pools also increased. These increased flows resulted in a decrease to water levels in the Floral City Pool and increases to water levels in the Inverness and Hernando Pools. **Table 13-1** summarizes the changing inflows and outflows for each pool, the peak water level differences, and the overall gain or loss in water volume for each pool. Overall, the total volume of water in the entire Tsala Apopka chain-of-lakes increased by 1 percent.

Table 13-1 Differences in Flows, Water Levels and Volumes with Structure Modifications

Location	Inflow (Gain/Loss)	Outflow (Gain/Loss)	Peak Water Level Difference	Pool Volume (Gain/Loss)
Floral City Pool	+ 4 percent	+ 13 percent	- 1.4 inches	- 4 percent
Inverness Pool	+ 13 percent	+ 9 percent	+ 1.5 inches	+ 2 percent
Hernando Pool	+ 9 percent	+ 0 percent	+ 1.2 inches	+ 2 percent

Flow increases were also observed for the 10-year storm event with the structure size increases. This simulation provided enough rainfall and river flow to fill all of the Tsala Apopka Pools. Increased flows through the Golf Course and Moccasin Slough structures caused the Floral City Pool to fill one day later while the Hernando Pool filled two days sooner. The Inverness Pool, which did not fill under existing conditions, was able to fill during the 40-day simulation. Both the Golf Course and Moccasin Slough structures passed an average of 20 percent more flow while the Inverness Pool was filling.

Figure 13-4 shows how peak flows increased for each modified structure during both the mean annual and 10-year storm events. Larger peak flow increases were observed for the larger storm event as a result of higher water levels in the Floral City Pool. Peak flow increases of 11 percent for the Golf Course structure and 4 percent for the Moccasin Slough structure were observed during the mean annual storm event. For the 10-year storm event, peak flow increases of 20 percent were observed for each structure.

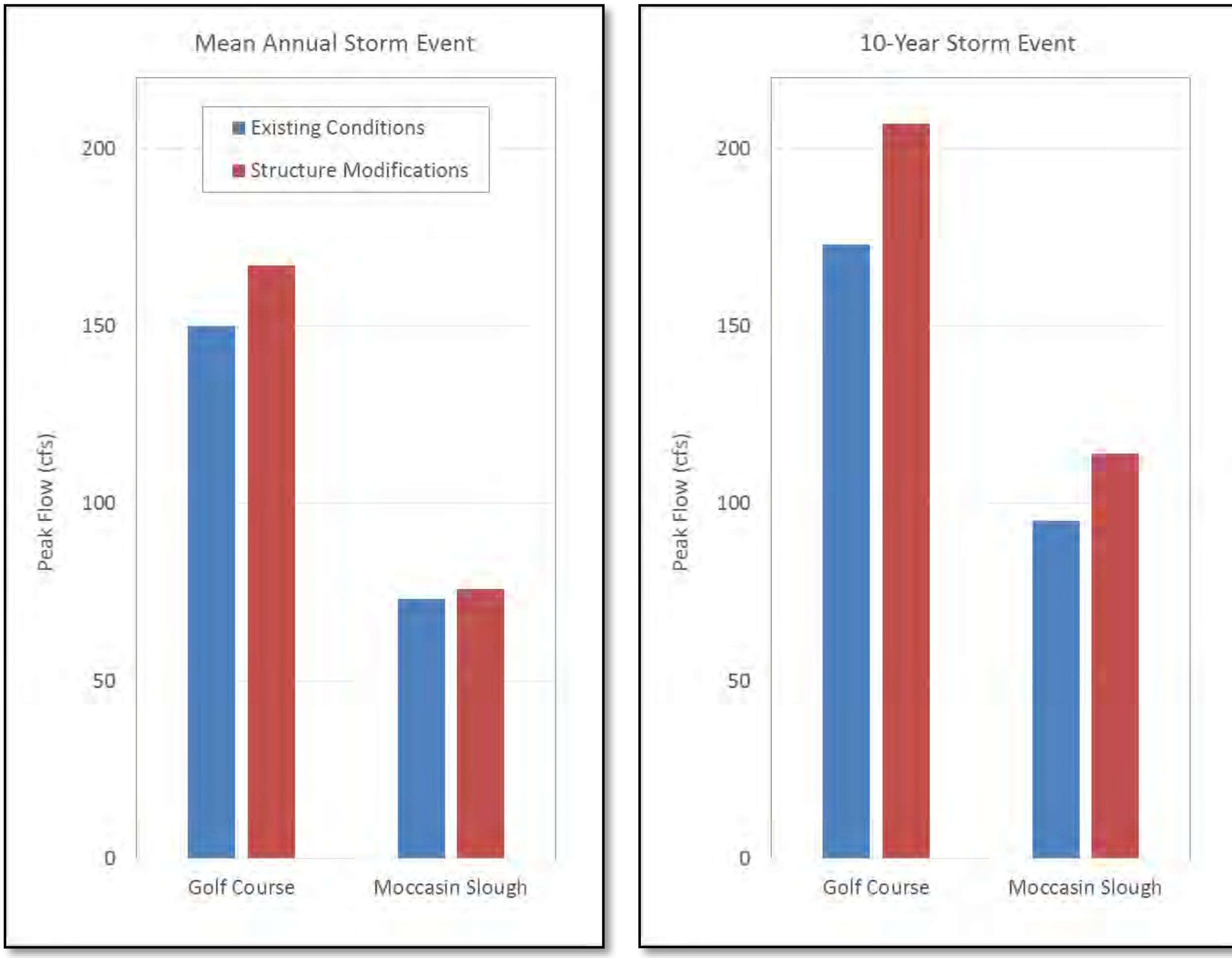

Figure 13-4 Comparison of Peak Flows for the Golf Course and Moccasin Slough Structures during the Mean Annual and 10-Year Storm Events

These modifications did not result in measurable changes to water levels or flows upstream or downstream along the Withlacoochee River.

13.4. Conclusion

Structure flows within Tsala Apopka depend on several factors. The most significant are upstream and downstream water levels, structure gate openings, and the conveyance potential of the channels between each pool. It was determined through modelling results and field observations that flow limitations exist between the Floral City and Inverness Pools. Under existing conditions, if the structures that flow into the Tsala Apopka pools were opened fully and an endless supply of river water were available as inflow, the Floral City and Hernando Pools would fill much quicker than the Inverness Pool. To address this, the model evaluated the effects of making significant modifications to the Golf Course and Moccasin Slough structures to provide additional inflow to the Inverness Pool.

During a 40 day window when river water is available to fill the Tsala Apopka chain-of-lakes (mean annual storm event), model results indicate that doubling the flow area of the Golf Course structure and tripling the width of the Moccasin Slough structure would increase the total volume of water in Tsala Apopka by approximately one percent. This resulted in Floral City Pool water levels that were 1.4 inches lower and Inverness and Hernando Pool water levels that were 1.5 and 1.2 inches higher, respectively.

After modifying the structures, the rate at which the Inverness Pool filled remained much lower than the Floral City and Hernando Pools. These results indicate that modifying the structures alone has a limited ability to significantly increase flows into the Inverness Pool. The conveyance potential of the Golf Course Canal and Moccasin Slough are also significant factors affecting flow into the Inverness Pool.

Scenario 14: Tsala Apopka Structure Operations

14.1. Description

More than a dozen water control structures exist throughout the Tsala Apopka chain-of-lakes (**Figure 14-1**). Throughout history, these structures have been managed in an attempt to balance two competing forces, recreation and flood protection. The majority of these structures were constructed in the 1950s and 1960s and were originally operated by the Tsala Apopka Basin Recreation and Water Conservation Control Authority. By the late 1960s, when this special authority was abolished, the Southwest Florida Water Management District (District) assumed management responsibility for the Tsala Apopka structures.

During the several decades that followed, the structures were operated in accordance with U.S. Army Corps of Engineer guidelines which suggested lowering the lakes in early summer and holding water levels up throughout the winter. In response to low water concerns, the operational guidelines were changed in the 1990s in an effort to better conserve water in Tsala Apopka. During that time, the structures were operated to fill the Floral City Pool first, then pass flow to the Inverness Pool and when it reached its target level, allow flow into the Hernando Pool. Since river inflows were only available during certain times when the system received adequate rainfall, there were many years when only one or two of the pools were filled, while others remained low.

Concerns regarding both high and low water levels have persisted for many decades and it was clear that a better understanding of the system and enhanced structure operation guidelines were needed. Over the past several years, this study has provided key understanding related to how much water is available in the system and how effective the structures are in conveying that water.

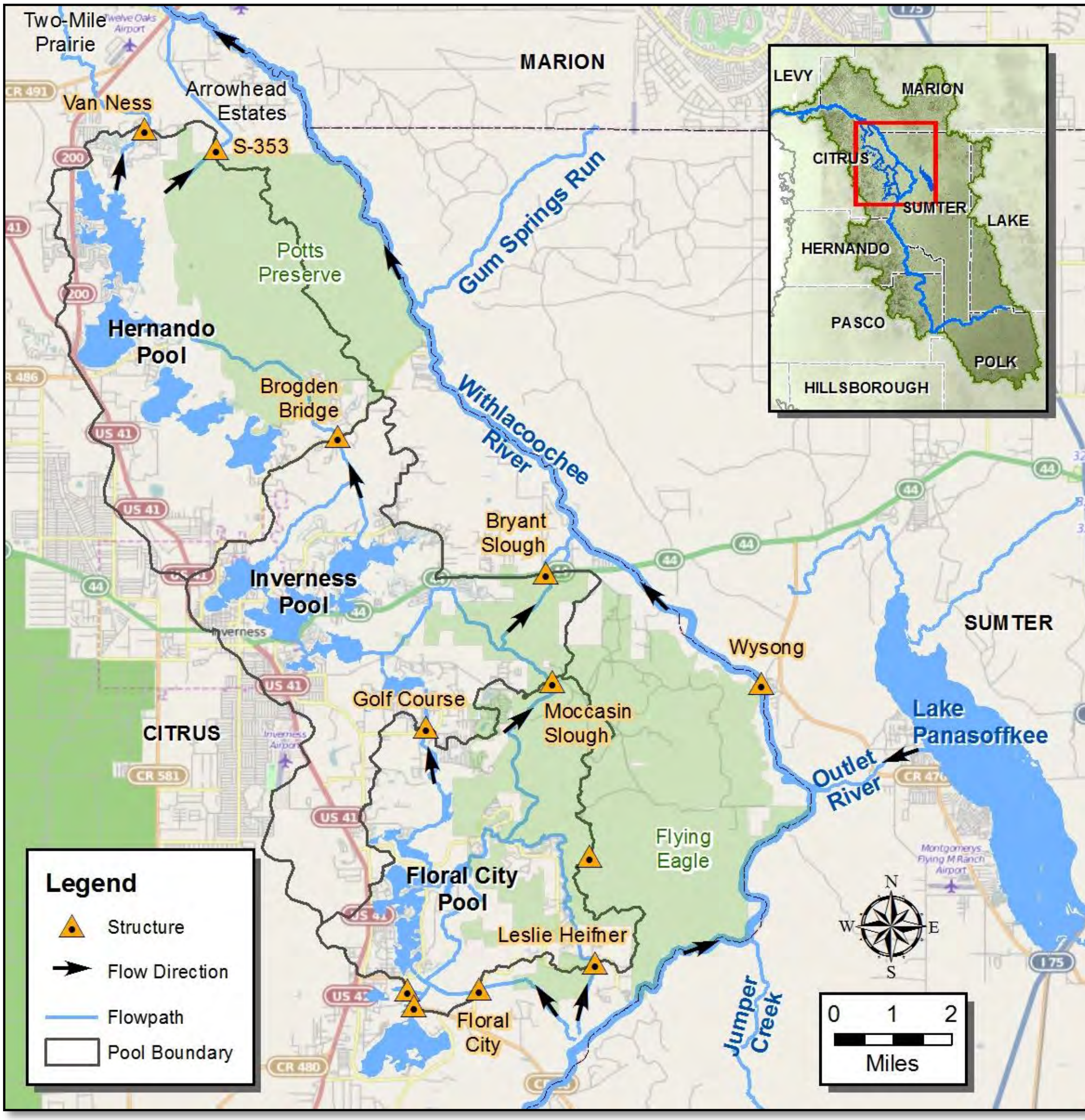

Figure 14-1 Flowpaths, Structures and Pools within the Tsala Apopka Chain-of-lakes

By 2010, the operational guidelines for the Tsala Apopka structures were significantly changed based on input from the public and data developed through this study. These new guidelines provide for an equal distribution of river inflow to all three of the Tsala Apopka pools. They also call for releases when each pool reaches its target water level to either maintain high levels or create flood storage. To evaluate how the current structure operations have impacted water levels in Tsala Apopka, this scenario will simulate the previous methodology of filling each upstream pool first. Water levels in each pool will be compared using both operational strategies.

14.2. Model Setup

The Tsala Apopka structures are operated in the model with logical controls that open or close them based on target water level in the pools. Under existing conditions, when water levels in the Withlacoochee River are above the Floral City Pool, the Leslie Heifner and Floral City structures are opened fully to bring all available water into the lakes. At the same time, the Golf Course, Moccasin Slough and Brogden Bridge structures are also open to divide the incoming water among each of the pools. During high water conditions, the appropriate structures are opened or closed to maintain target water levels in each pool.

To evaluate this scenario, the structure operations were revised in the model to simulate different operational guidelines for Tsala Apopka. Model results compared two specific conditions; opening all of the structures to fill each pool simultaneously and regulating the structure openings to fill the most upstream pool first.

14.3. Results

This scenario was simulated using the mean annual and 10-year design storm events with low initial water conditions. These simulations represented conditions where the lakes were not already full and could receive significant inflow from the Withlacoochee River. Locations throughout the Tsala Apopka chain-of-lakes and along the Withlacoochee River were compared for differences in water levels and flow as a result of revising the operational guidelines of the structures.

Under existing conditions, when river inflows are available to help fill the Tsala Apopka chain-of-lakes, all structures are opened and flows are added to each pool. For this scenario, the structures were operated to fill the upstream pools first. For the mean annual event (**Table 14-1**), the Floral City Pool would have risen four inches higher, reaching its target water level after two and a half weeks of continuous river inflows. Likewise, the Inverness Pool would have peaked slightly higher, receiving inflows from the Floral City Pool after it filled and never releasing water to the Hernando Pool. As a result, the Hernando Pool, which normally would have been filling from its share of river inflows, would have fallen nearly a foot lower than existing conditions after approximately one month. It also would have remained approximately seven inches lower on average during the 40-day simulation.

Table 14-1 Summary of Changes to the Tsala Apopka Pools during the Mean Annual Storm Event

Location	Reached Target Level (Existing Condition)	Reached Target Level (Scenario Condition)	Average Water Level Difference
Floral City Pool	No	Yes	+ 4.3 inches
Inverness Pool	No	No	+ 3.5 inches
Hernando Pool	No	No	- 7.4 inches

Overall, filling the upstream pools first resulted in a 25 percent decrease in flow volume entering the Tsala Apopka chain-of-lakes from the Withlacoochee River during the mean annual event. River flows along the river at Wysong increased by approximately three percent during the mean annual storm event, as a result of less flow diversion into Tsala Apopka. Flows along the river at State Road 200 increased by less than two percent during this simulation.

Similar results were observed for the 10-year event (**Table 14-2**), which simulated greater rainfall over the entire watershed. For this simulation, minimal changes were observed for the Floral City Pool, which also filled under existing conditions during the 10-year storm event. The Inverness Pool would have filled two weeks sooner, if the Brogden Bridge structure was kept closed until the Inverness Pool reached its target level. The Hernando Pool, would have stayed approximately 7 inches lower than existing conditions, however, eventually receiving inflows once the Inverness Pool was filled.

Table 14-2 Summary of Changes to the Tsala Apopka Pools during the 10-Year Storm Event

Location	Reached Target Level (Existing Condition)	Reached Target Level (Scenario Condition)	Average Water Level Difference
Floral City Pool	Yes	Yes	+ 0.3 inches
Inverness Pool	No	Yes	+ 4.5 inches
Hernando Pool	Yes	No	- 7.3 inches

For the 10-year event, filling the upstream pools first resulted in an 11 percent decrease in overall flow volume entering the Tsala Apopka chain-of-lakes from the Withlacoochee River. Flows along the river downstream increased by two percent as a result of smaller diversions into Tsala Apopka.

14.4. Conclusion

In summary, operating the Tsala Apopka structures to fill upstream pools first would raise water levels in the Floral City and Inverness Pools for the events simulated. Water levels in the Hernando Pool would remain lower, however, with little or no opportunity to receive river inflows. These results confirm previous citizen concerns regarding low water levels in the Hernando Pool, especially during years when river inflow was limited from below average rainfall. Model results also indicate that the current operational protocol of sharing river inflows between all three pools increases the overall volume of water entering the Tsala Apopka chain-of-lakes from the Withlacoochee River.

Scenario 15: Tsala Apopka Outflows and Arrowhead Estates

15.1. Description

Historically water flowed from the Hernando Pool of Tsala Apopka to the Withlacoochee River through low marshlands just north of present day Potts Preserve (**Figure 15-1**), particularly during high water events. Major flooding in 1960 led to the modification of this natural outflow and the creation of the S-353 structure and C-331 canal, which were completed by the U.S. Army Corps of Engineers (USACE) in 1968. Berms were constructed to channel flood waters to the Withlacoochee River just upstream of State Road 200 (SR 200) from the Hernando Pool.

About the same period, the community of Arrowhead Estates was developed in eastern Citrus County, southeast of SR 200 between the Withlacoochee River and the C-331 canal. Today, when water levels in the Hernando Pool exceed high guidance levels, water is released through the Van Ness structure towards Two-Mile Prairie or through the S-353 structure (**Figure 15-2**) and C-331 canal towards the Withlacoochee River. During high water conditions that exceed the capacity of the S-353 structure, water will find its natural outlet to the river again through Potts Preserve. Although there are two operable structures that release water from the Hernando Pool, only the S-353 structure is designed for flood control. The Van Ness structure is only able to convey a small fraction of the water being released due to limited conveyance and storage potential of Two-Mile Prairie.

The Arrowhead Estates community has a long history of flooding during high water events, including the 2004 hurricanes. This has led to concerns regarding how the release of water from Tsala Apopka may affect flood levels in Arrowhead. To address those concerns, this scenario will simulate the effects of not releasing water through S-353 during high water events. The resulting impacts to water levels in both Tsala Apopka and Arrowhead Estates will be evaluated.

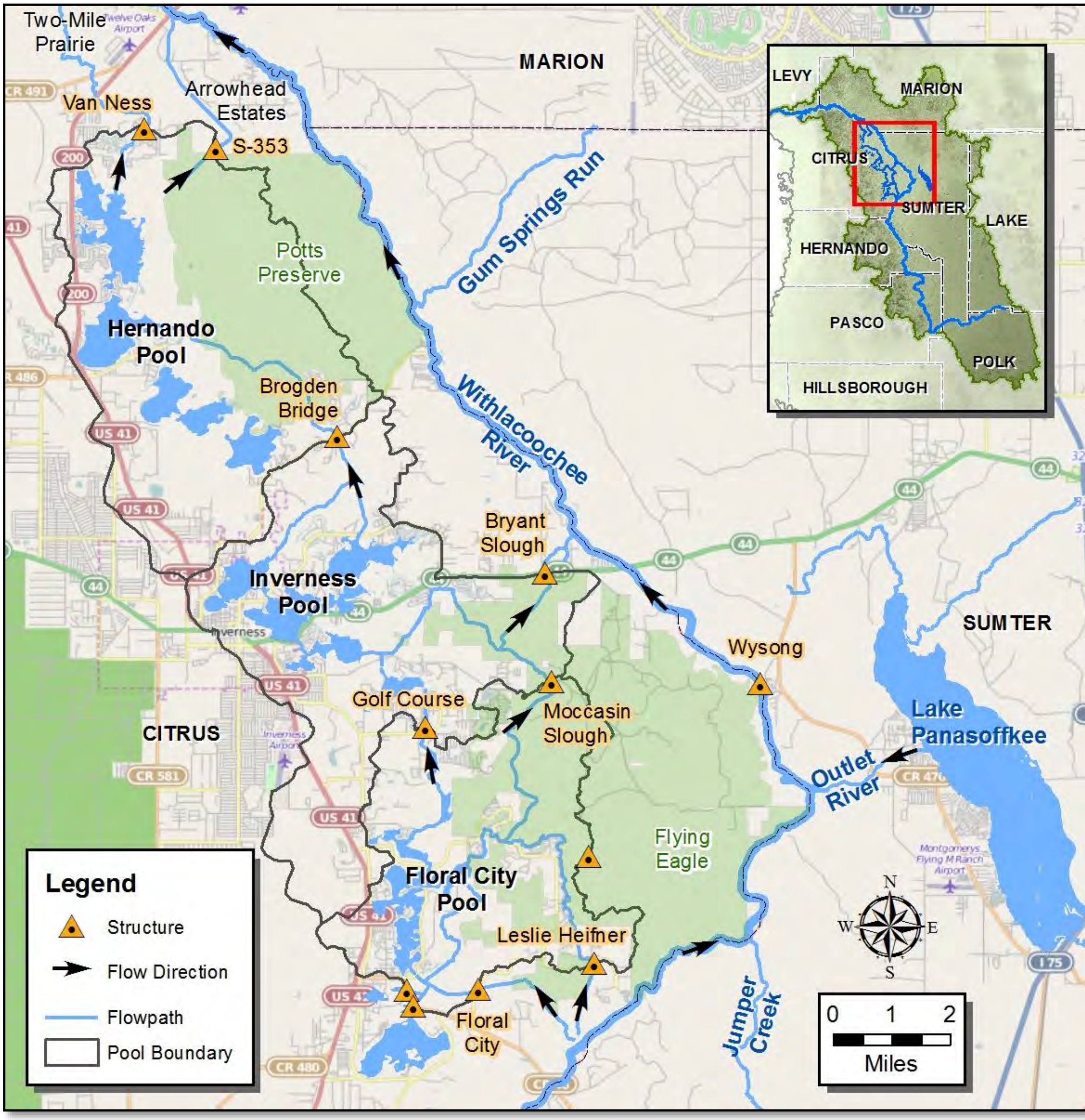

Figure 15-1 Area Map for the Tsala Apopka Chain-of-lakes

Figure 15-2 Flow through S-353 Structure (January 2015)

15.2. Model Setup

To isolate the impacts of outflow from Tsala Apopka on water levels in Arrowhead Estates, the structure operations of the S-353 structure were modified in the model to not allow any flow through the C-331 canal. By simulating the structure fully closed in the model, any outflow from the Hernando Pool occurred through the Van Ness structure towards Two-Mile Prairie or through Potts Preserve back to the Withlacoochee River.

15.3. Results

This scenario was simulated using the 2004 hurricanes and the 25-year and 100-year design storm events with high initial water conditions. To demonstrate these flood conditions and possible flood reductions, locations within Arrowhead Estates, the Hernando Pool and the Withlacoochee River at SR 200, were compared for differences in peak water levels as a result of keeping the S-353 structure closed. The results are tabulated in **Table 15-1.**

Table 15-1 Peak Stage Comparison: S-353 Scenario

	2004 Hurricanes		
	Existing	Scenario	Difference
Hernando Pool	39.11	39.34	**Increased 3 inches**
Arrowhead Estates	38.69	38.69	**No change**
Withlacoochee River at SR 200	37.48	37.41	**Decreased 1 inch**
	25 year 5 day Design Event		
	Existing	Scenario	Difference
Hernando Pool	39.68	40.15	**Increased 6 inches**
Arrowhead Estates	39.09	39.21	**Increased 1 inch**
Withlacoochee River at SR 200	38.04	37.98	**Decreased 1 inch**
	100 year 5 day Design Event		
	Existing	Scenario	Difference
Hernando Pool	41.24	41.33	**Increased 1 inch**
Arrowhead Estates	40.62	40.67	**Increased 1 inch**
Withlacoochee River at SR 200	39.86	39.91	**Increased 1 inch**

The results show that during the 2004 hurricanes, water levels in the Hernando Pool (**Figure 15-3**) would have risen three inches higher as a result of not allowing flow through the S-353 structure. This would, in turn, cause an increase in flows to the Withlacoochee River through the natural terrain of Potts Preserve (elevation 38.5 feet NAVD88), bypassing the S-353 structure. This results in no change to the flood levels in Arrowhead Estates and a one inch decrease in stages further downstream at SR 200 where the S-353 structure would have released flows.

The simulation of the design storm events indicates an increase of one inch in the peak water level in Arrowhead Estates. This increase is due to the change in timing of the water being released from the Hernando Pool. Under existing conditions, in both the 25-year and 100-year simulations, water will flow out Potts Preserve. Closing the S-353 structure throughout the storm event, caused a greater volume to flow out through the preserve leading to the slight increase in peak water level.

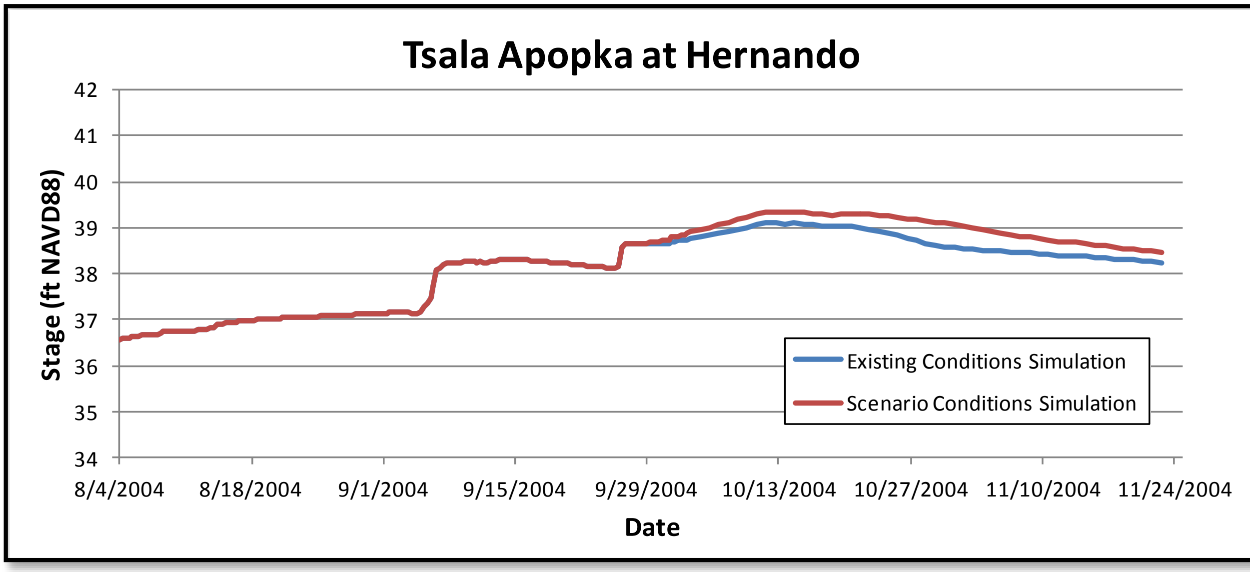

Figure 15-3 Comparison of Water Levels in the Hernando Pool during the 2004 Hurricanes

Figure 15-4 shows the simulated stages in Arrowhead Estates for the 25-year design storm event. The effect of keeping the S-353 structure closed during this simulated flood produced a slight increase in water level at the Arrowhead development as a result of additional flow from the Hernando Pool through Potts Preserve to the Withlacoochee River. Similar results were observed for the 100-year design storm event.

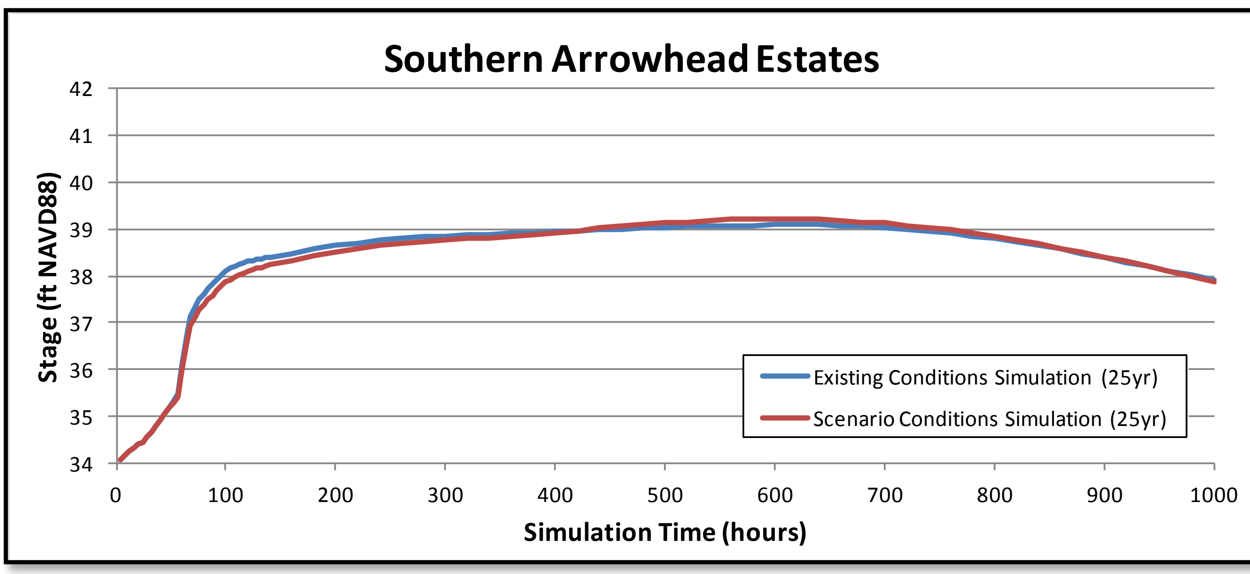

Figure 15-4 Comparison of Water Levels at Arrowhead Estates during the 25-Year Design Storm Event

Farther downstream at SR 200, water levels were initially lower for the 100-year event but then peaked higher (one inch) as a result of no flows through S-353 (**Figure 15-5**). This result is due to the timing of flow releases from the Tsala Apopka pools. Under existing conditions water was released prior to the peak flood wave, whereas preventing this initial outflow elevated water levels later in the storm event producing increased flows through Potts Preserve.

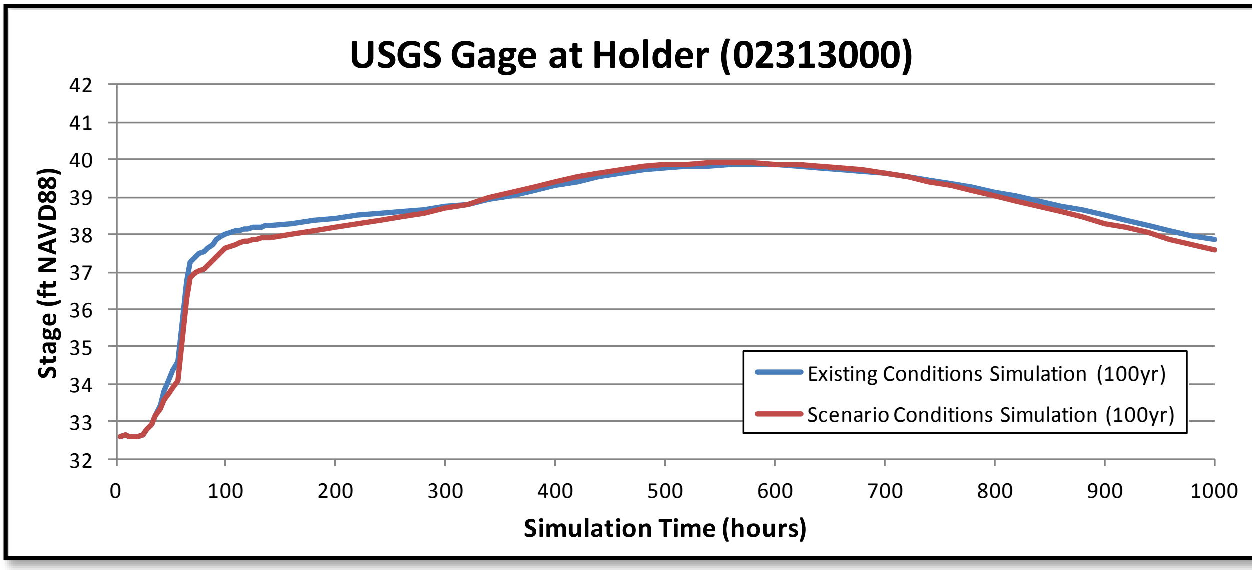

Figure 15-5 Comparison of Water Levels at SR 200 during the 100-year Design Storm Event

15.4. Conclusion

In summary, model results suggest that keeping the S-353 structure closed during a high water event will not reduce flood levels in Arrowhead Estates. It would raise water levels in the Hernando Pool and cause an increase in flow through Potts Preserve into the Withlacoochee River upstream of Arrowhead. These results were consistent for the 2004 hurricanes and the design storms simulated. They suggest that the current practice of releasing water through the S-353 structure into the Withlacoochee River keeps water levels in the Hernando Pool lower, with little or no impact to water levels as Arrowhead Estates.

During the 2004 hurricanes, water was released from the Hernando Pool through the S-353 structure for 35 days at an average rate of 150 cubic feet per second (cfs). The maximum flow through this structure was 234 cfs in late October of that year. These amounts were only a fraction of the corresponding average and maximum Withlacoochee River flows of 5,000 cfs and 5,340 cfs, respectively. In fact, outflow from the Hernando Pool accounted for less than five percent of the overall river flow at SR 200 during the peak flooding from the 2004 hurricanes. These results indicate that past flooding near Arrowhead Estates is more the result of flood conditions along the Withlacoochee River rather than releases from the Hernando Pool through the S-353 structure.

Scenario 16: Green Swamp Rock Formations

16.1. Description

The Withlacoochee River originates in the Green Swamp, an important natural resource in central Florida that occupies around 570,000 acres (890 square miles) in portions of Hernando, Lake, Pasco, Polk and Sumter Counties. Beneath the land surface of the Green Swamp lies the highest Floridan aquifer levels in peninsular Florida, which directly affect river flows leaving the swamp. During low water times, the Green Swamp acts as a sponge storing rainfall and limiting flow downstream. During periods of above average rainfall, the Green Swamp becomes saturated providing substantial flows to the Withlacoochee River. The interaction of the Floridan aquifer system and surface water is evident by numerous limestone outcroppings that exist at or near land surface in the vicinity of the Green Swamp. In addition, the river channel itself is incised into limestone at several locations (**Figure 16-1**). These rock outcroppings can also serve as natural obstructions to flow at certain times.

Concerns relating to over drainage of the Green Swamp have emerged over claims that critical rock outcroppings within the Withlacoochee River were removed decades ago. This scenario will simulate the addition of rocks at several locations along the main river channel within the Green Swamp. Changes to water levels and flow within the Green Swamp and locations downstream were evaluated.

Figure 16-1 Rock Outcropping along the Withlacoochee River in the Green Swamp

16.2. Model Set-up

Numerous rock outcroppings naturally exist along many portions of the Withlacoochee River. These locations were identified during a physical survey of the entire river during low water periods and are included in the model as part of its current configuration. To evaluate this scenario, the existing river channel was adjusted in the model to simulate the addition of rocks at seven locations where rocks were reported to have been removed or altered in some way (**Figure 16-2**). The bottom of the river channel at these locations is approximately four to five feet lower than the adjacent swamplands that border the river. When water levels in the Withlacoochee River are higher than the adjacent swamplands, flow occurs not only in the main channel but also across the entire width of inundated swampland (which varies between 500 feet and over 2,000 feet for these seven locations). To simulate the addition of rocks at these locations, the modelled cross sections were adjusted by filling in the main channel until it was level with the adjacent swamplands on either side. **Figure 16-3** provides a visual comparison of how the existing condition was modified with the simulated addition of rocks.

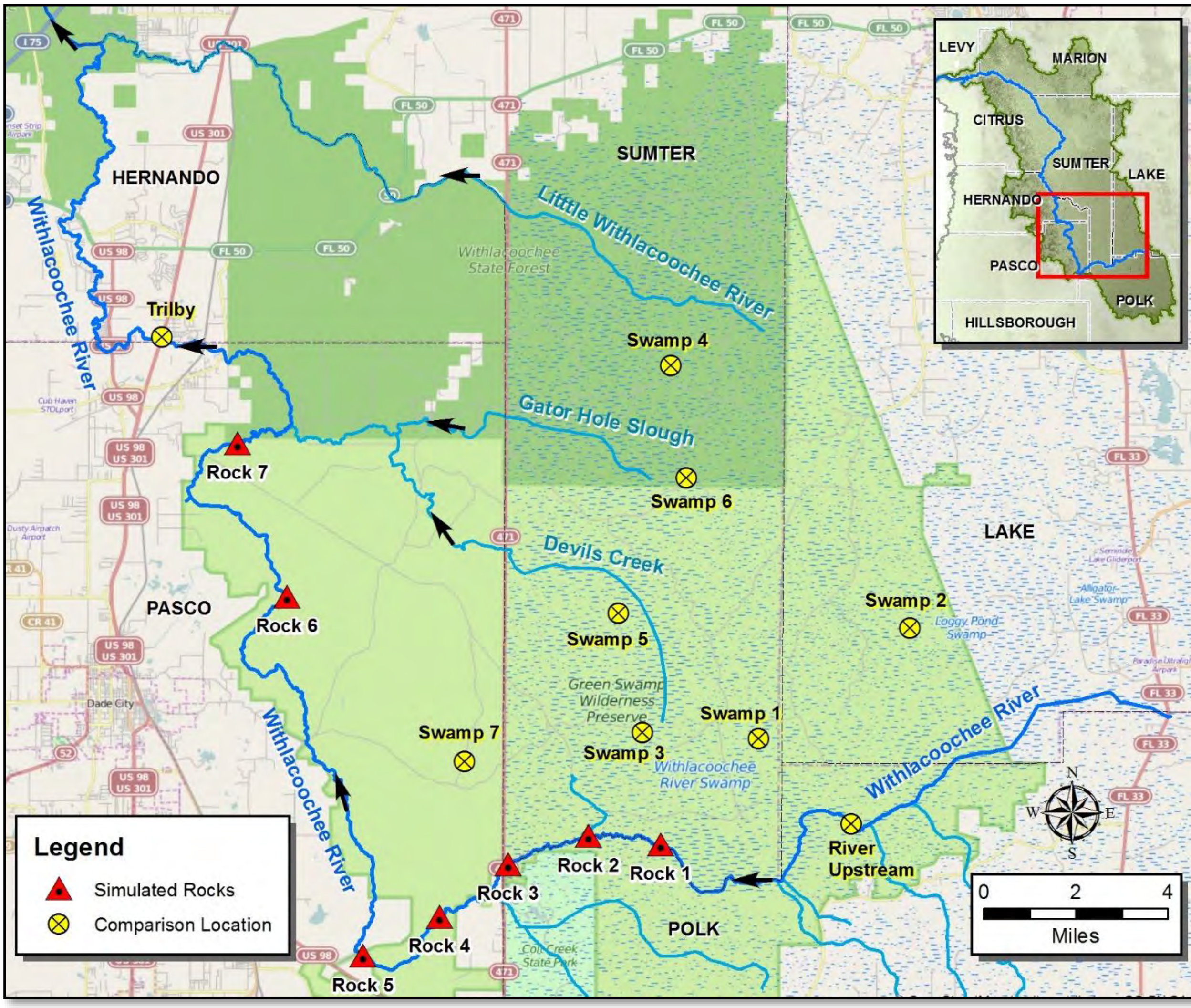

Figure 16-2 Simulated Rocks and Water Levels Compared in the Green Swamp

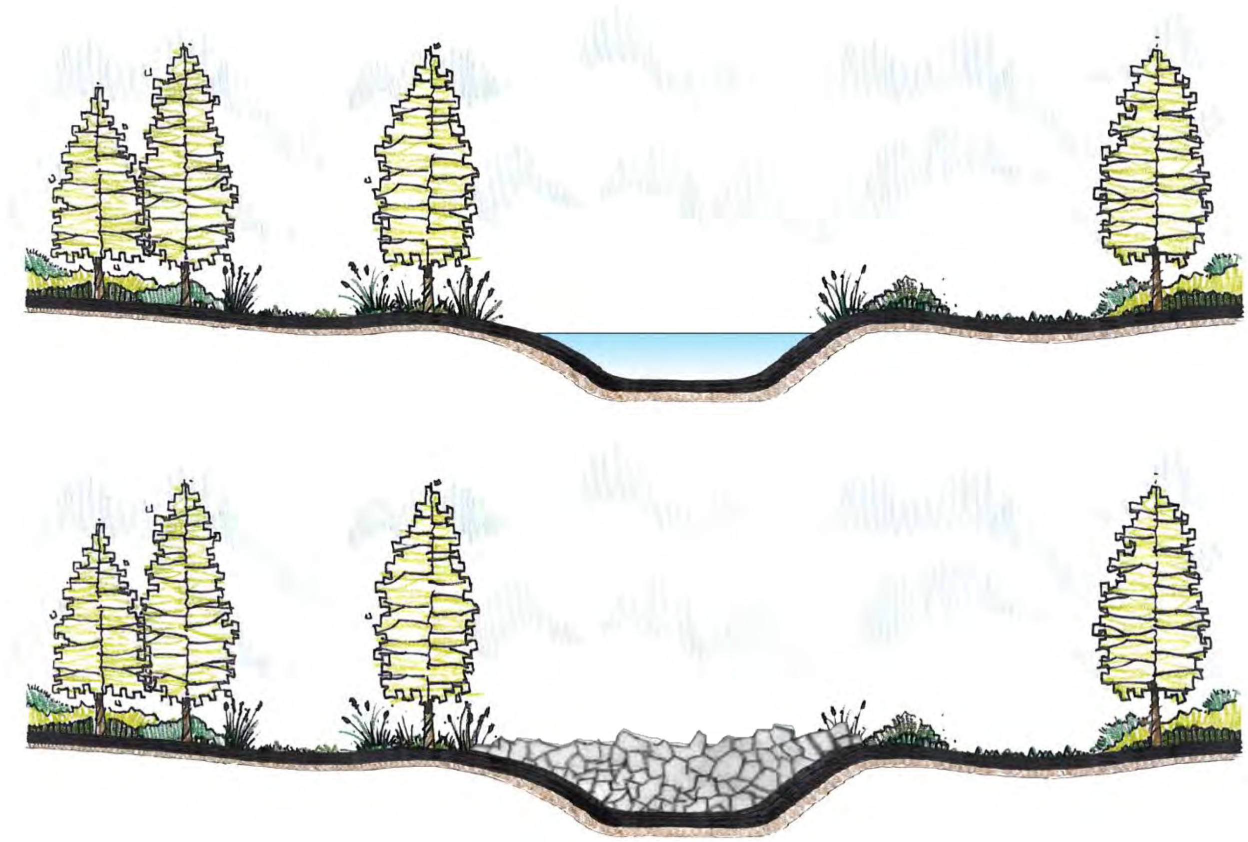

Figure 16-3 Comparison of River Channel with and without the Addition of Rocks

16.3. Results

This scenario was simulated using the 2004 hurricanes and all four design storm events (mean annual, 10-year, 25-year and 100-year) with both low and high initial water conditions. Locations along the river and throughout the Green Swamp were compared for differences in water level and flow as a result of simulating the addition of rocks in the main channel of the Withlacoochee River.

Table 16-1 shows average water level changes just upstream of each rock location for the smallest (mean annual with low initial conditions) and largest (100-year with high initial conditions) storm events simulated. There were no differences in average water levels within the Withlacoochee River at the farthest upstream rocks (Rock 1) that were simulated in the model. The greatest changes were water levels were observed immediately upstream of Rock 7. At this location, the width of flow is constrained by higher ground close to the river channel, causing the addition of rocks to more significantly hold back water in the river. In the other locations the increase in stage was less, due to the width of the flood plain. As water is able to spread out and incorporate a large flow area, the rocks within the channel have less of an impact.

Table 16-1 Average Water Level Increase (inches) at Locations of Simulated Rocks

Location[1]	Mean Annual Event[2]	100-year Event[3]
Rock 1	0	0
Rock 2	7	3
Rock 3	2	0
Rock 4	13	9
Rock 5	-1	0
Rock 6	5	2
Rock 7	24	6

[1] *immediately upstream of simulated rocks*
[2] *low initial water levels*
[3] *high initial water levels*

Figure 16-4 shows the spatial distribution of increases or decreases in average water level in response to simulating rocks within the river's channel, in inches. As seen in the figure, locations in the Green Swamp do not show any change in water level. Immediately upstream of the simulated rocks, the figure shows average water level differences, which dissipate further upstream. In general, the mean annual storm event with low initial water levels showed the greatest difference in water levels immediately upstream of the simulated rocks. This difference did not occur during the peak of the storm, but rather while water levels were rising and falling in the river before and after the rainfall occurred.

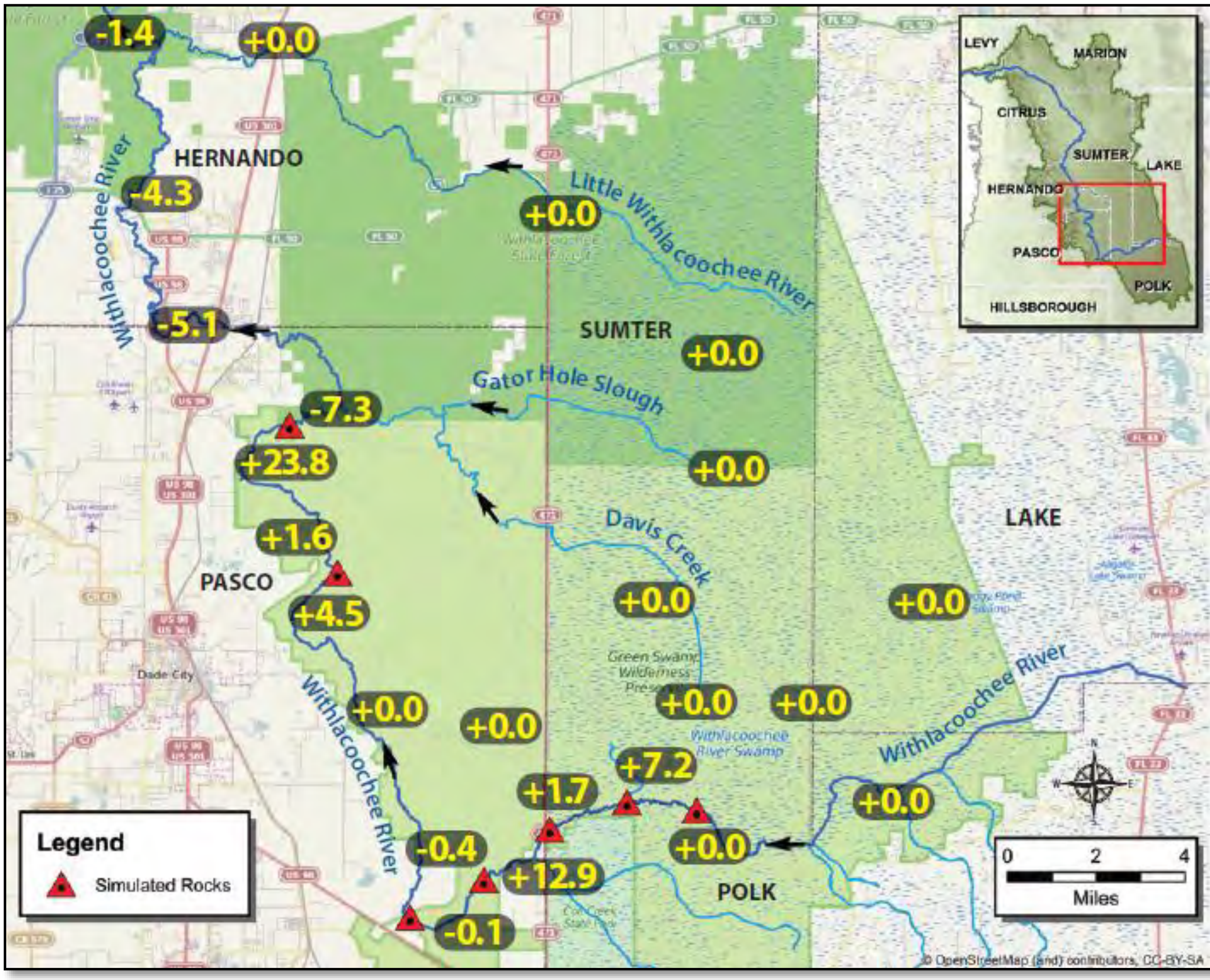

Figure 16-4 Water Level Comparisons with Rocks Simulated along the Withlacoochee River for the Mean Annual Design Storm Event

16.4. Conclusion

The model results suggest that adding rocks to the main channel of the Withlacoochee River would have little effect on regional water levels within the Green Swamp. Larger storm events have almost no impact since the obstructed flow area created by the rocks is relatively small compared to the overall flow area in the swamplands adjacent to the main channel. Smaller storm events have the most notable impact, holding water levels higher immediately upstream of the rocks. The river channel bottom, which drops slightly more than one foot per mile on average, would limit water level increases to the immediate vicinity of the added rocks. Water levels downstream of Rock 7 would decrease under normal flow conditions. That decrease would slowly dissipate farther down river and would be less noticeable for larger storm events. No changes are expected during low water periods when the Green Swamp does not naturally produce significant flows downstream.

Scenario 17: Rocks near Jumper Creek

17.1. Description

The Withlacoochee River forms the border of Citrus and Sumter counties as it passes the Tsala Apopka chain-of-lakes to the west and several tributaries to the east including the Outlet River from Lake Panasoffkee and Jumper Creek (**Figure 17-1**). This portion of the river is characterized by a relatively shallow channel, hundreds of feet wide, with a floodplain that extends more than a mile wide in some areas. Several narrow segments exist, however, that serve as natural control points (especially in low water conditions) to an otherwise generally wide and shallow river. Considering the natural terrain of the river, the Wysong-Coogler water conservation structure (Wysong), located downstream of the outlet river, was designed to store water within this region particularly during low water conditions.

Two miles downstream of the Jumper Creek confluence, the floodplain of the Withlacoochee River narrows to approximately ¼ mile wide with a 180-foot wide main channel as it passes between high ground on either side (**Figure 17-2**). It has been suggested that rocks at this location were removed potentially lowering water levels upstream. This scenario will evaluate what effect adding rocks to the main channel of the Withlacoochee River may have on water levels in this region with qualitative regard to navigation effects.

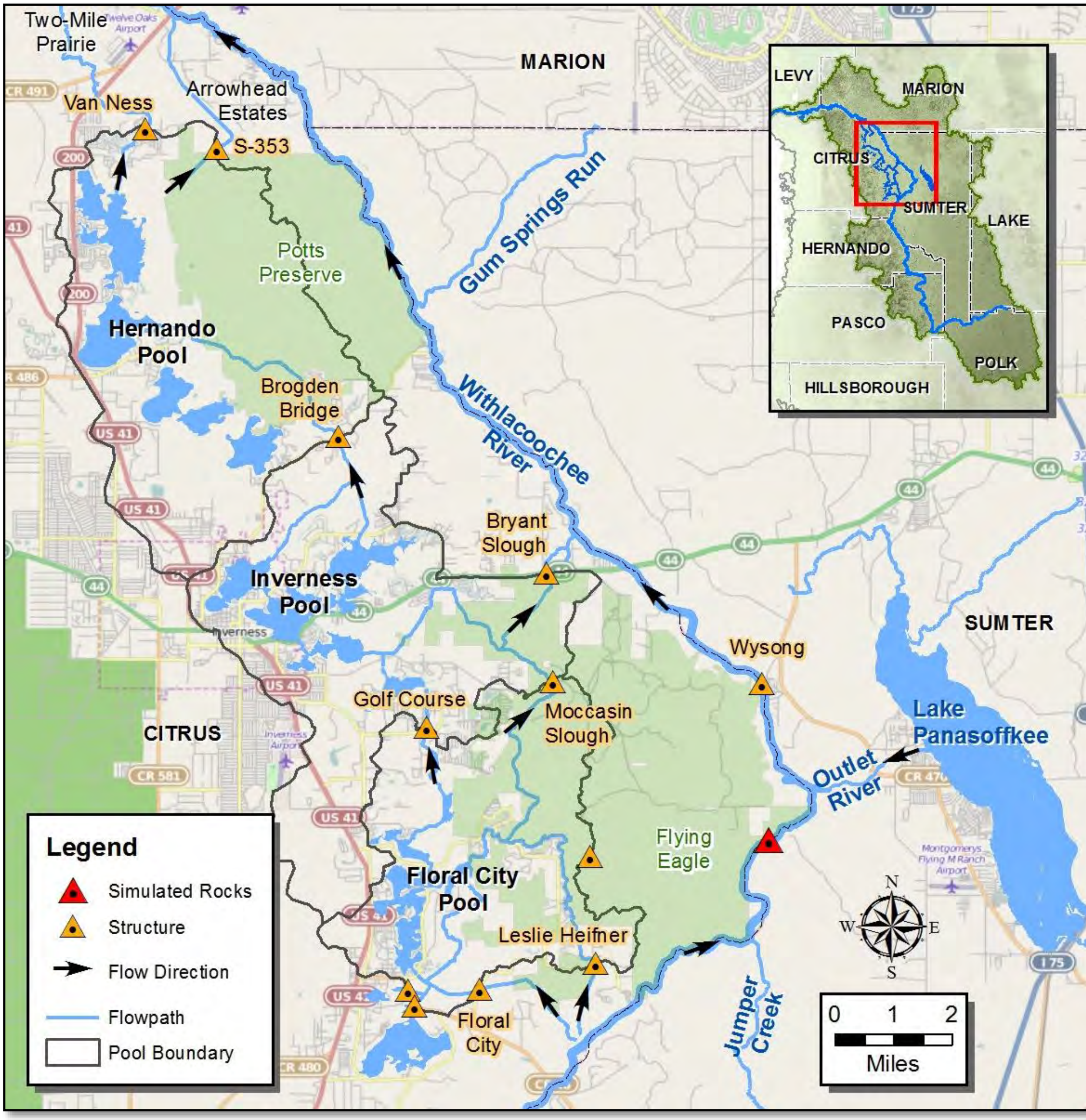

Figure 17-1 Location of Simulated Rocks between Jumper Creek and the Outlet River

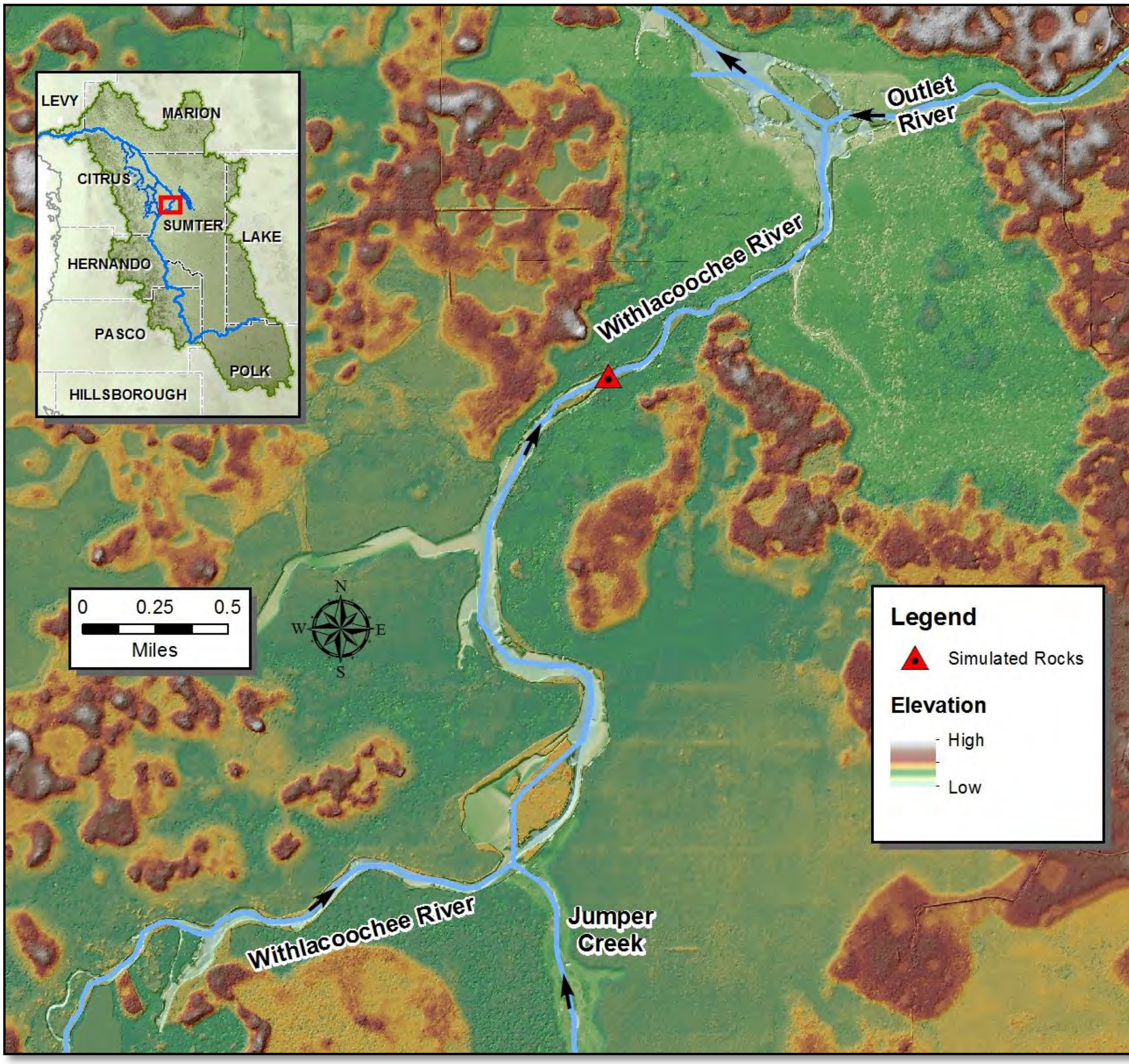

Figure 17-2 Terrain Map Showing the Main Channels (light blue) and Floodplain Extent (green)

17.2. Model Set-up

To evaluate this scenario, the existing river channel was adjusted in the model to simulate the addition of rocks at the location shown in Figure 17-2. The bottom of the river channel at this location is approximately elevation 34 feet NAVD88, while the adjacent swamplands (floodway) are approximately 3 ½ feet higher at elevation 37.6 feet NAVD88. When the Withlacoochee River is above the latter elevation, flow occurs not only in the main channel but also across the entire floodway (approximately ¼ mile wide). Under normal conditions the floodway at this location is inundated by about one foot of water, or elevation 38.5 feet NAVD88, and up to elevation 40 feet NAVD88 at the peak of a mean annual event at this location. To simulate the addition of rocks, the modelled cross section was adjusted by filling in the main channel until it was level with the adjacent swamplands on either side. **Figure 17-3** provides a sketch of the addition of rocks at this location.

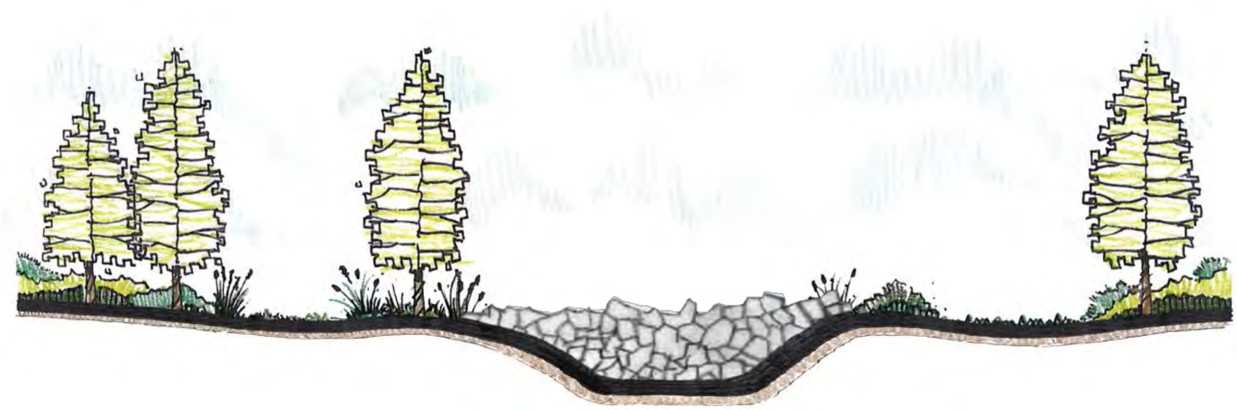

Figure 17-3 River Channel with the Addition of Rocks

17.3. Results and Analysis

This scenario was simulated using the 2004 hurricanes and the mean annual, 10-year, 25-year and 100-year design storm events with both low and high initial water conditions. Locations along the river and throughout the watershed were compared for differences in peak water levels and flow as a result of simulating the addition of rocks in the Withlacoochee River near Jumper Creek.

Model results during the 2004 hurricanes showed water levels increasing an average of ½ inch in the river just upstream of the simulated rocks. Two miles upstream at the confluence with Jumper Creek, water levels were ¼ inch higher on average. This translated to negligible differences in water levels in the Floral City Pool. During the peak of the 2004 hurricanes simulation, the simulated rocks were inundated by more than 5 feet of water (**Figure 17-4**). Since the area of flow obstructed by the rocks is relatively small (180 feet wide), as compared to several feet of water flowing over the entire 1,500 foot (quarter mile) width, minimal changes to water levels and flow throughout the region were observed. Negligible changes were also seen for the larger design storm events including the 10-year, 25-year and 100-year storms.

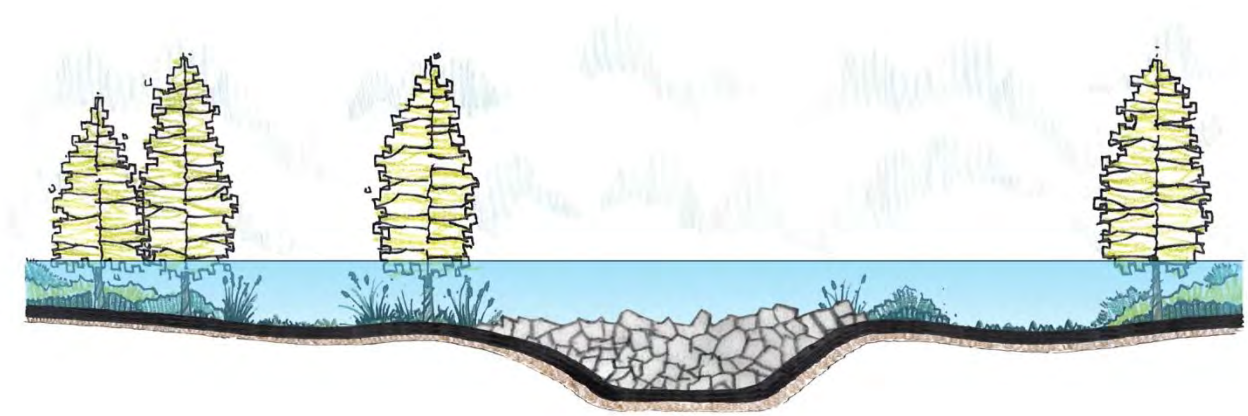

Figure 17-4 Flood Depth Comparison at Flood Stage

The simulated event with the greatest difference in water levels, as a result of adding rocks to the main channel, was the mean annual event with low initial water conditions. For this event, water levels in the Withlacoochee River and Tsala Apopka chain-of-lakes started low prior to the seven inches of rain occurring throughout the entire 2,100 square mile watershed. Both river and lake levels increased two feet as a result of this rainfall. Simulating the addition of rocks, increased water levels an additional one inch in the river just upstream of the rocks (**Figure 17-5**), which were inundated by approximately two feet of water during the peak of the event. Water levels increased less than one inch at the confluence with Jumper Creek and less than ¼ inch in the Floral City Pool as a result of simulating rocks for this event. Peak water levels immediately downstream of the simulated rocks decreased by less than ½ inch and farther downstream there were similar decreases in peak stages.

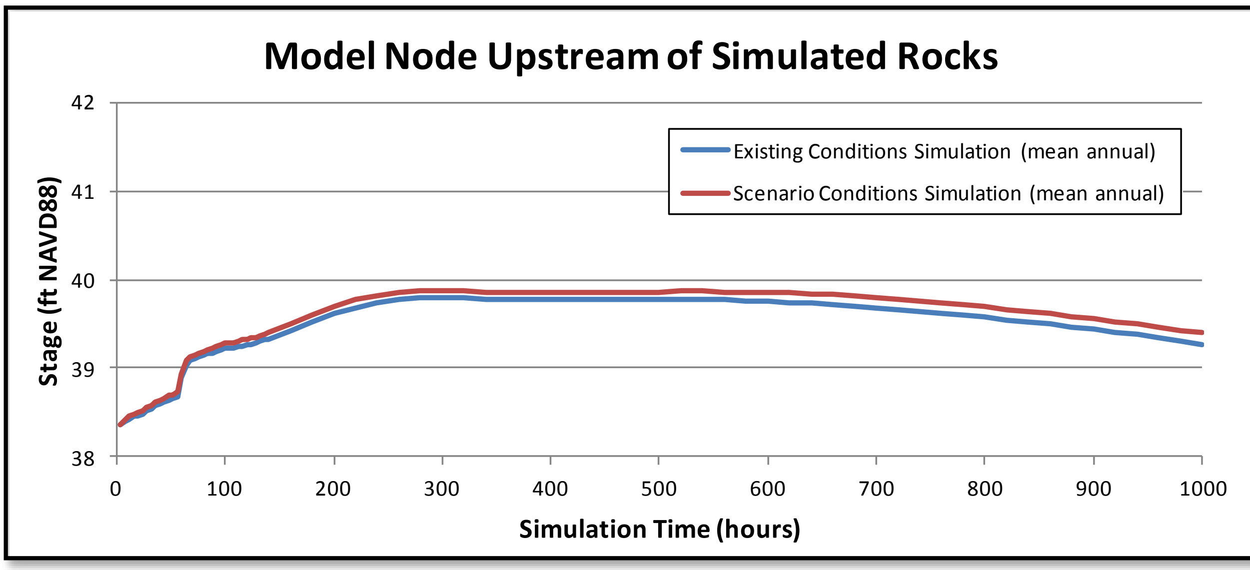

Figure 17-5 Comparison of Water Levels just Upstream of the Simulated Rocks for the Mean Annual Design Storm Event

17.4. Conclusion

The model results indicate that adding rocks to the main channel of the Withlacoochee River near Jumper Creek has minimal impact on water levels and flow within the river. Even during the smaller storm events, when the simulated rocks have the greatest impact, the entire ¼ mile floodway is inundated by at least two feet of water, causing the obstructed main channel to be insignificant compared to the overall flow area. Results also show that filling the main channel of the river with rocks has minimal impact on water levels throughout the Tsala Apopka chain-of-lakes and within the headwaters of Jumper Creek.

Scenario 18 and 19: Modifications to Lake Rousseau Outflow to the Lower Withlacoochee

18.1. Description

At its terminus, the Withlacoochee River discharges into the Gulf of Mexico near Yankeetown, Florida. Major changes to the river's natural flow path, which began over a century ago, have transformed this section of the river into a highly altered system as shown in **Figure 18-1**. In 1909, Lake Rousseau was formed by the construction of a spillway and lock structure to support navigation and commerce. The structure was modified by Florida Power Corporation, who used it to generate hydroelectric power from 1927 to 1965. Portions of the Cross Florida Barge Canal were also constructed throughout Florida from 1965 to 1969. This included a segment from the Gulf of Mexico to Lake Rousseau with a large lock system for boat traffic. Construction of the Barge Canal severed the Lower Withlacoochee River, requiring the construction of a bypass channel and additional structure to ensure downstream flows.

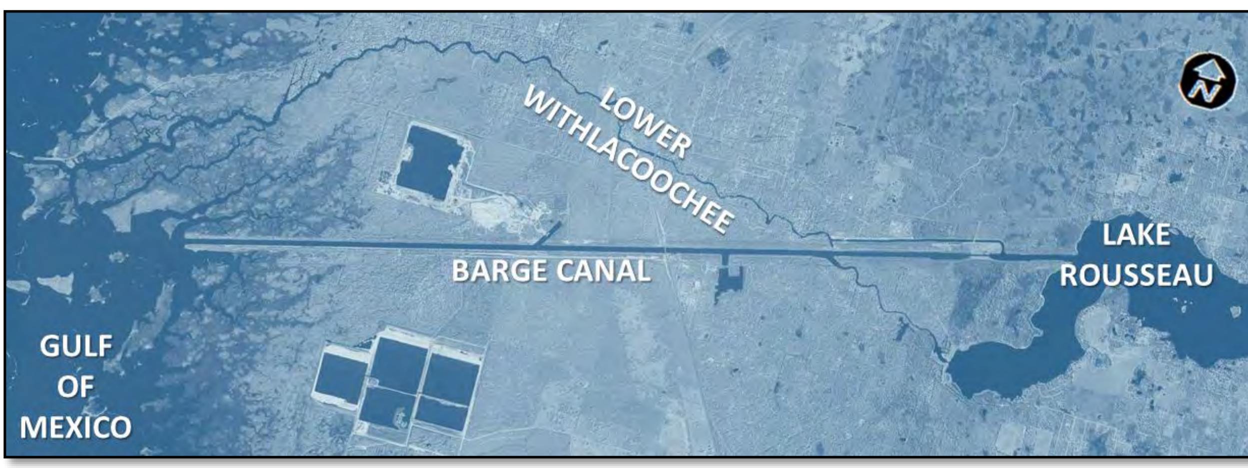

Figure 18-1 Lake Rousseau, Lower Withlacoochee River and the Barge Canal

Today, the Bypass Channel is the primary outlet from Lake Rousseau. It is used to pass normal flows to the Lower Withlacoochee River through the Inglis Bypass structure. When the Inglis Bypass reaches is maximum capacity, the Inglis Dam is used to release high flows to the Gulf of Mexico through the Barge Canal. Both structures are used to regulate water levels in Lake Rousseau as shown in **Figure 18-2**.

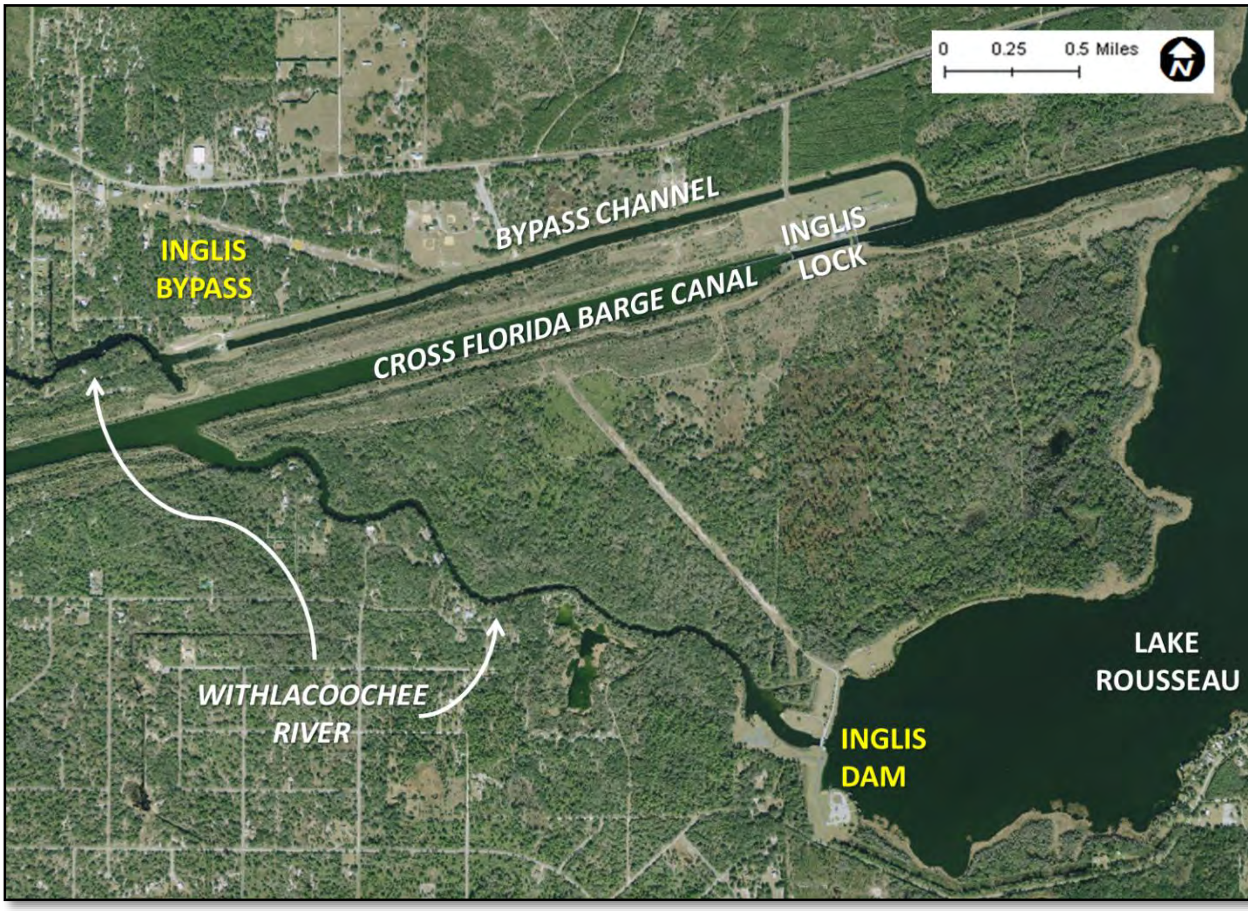

Figure 18-2 Outflow Channels and Structures at Lake Rousseau

There have been decades of concerns and numerous studies related to the altered state of this section of the Withlacoochee River. While many of those concerns deal with environmental changes to the river, some involve restoring historical flows. These scenarios will evaluate alternatives to provide additional flow to the Lower Withlacoochee through the existing Inglis Bypass structure. Scenario 18 involves changing the conveyance potential of the Bypass Channel while Scenario 19 includes connecting the Barge Canal to the Lower Withlacoochee River through the Inglis Bypass structure. These scenarios were evaluated independently and summarized together in this chapter for comparison purposes.

18.2. Model Setups

When Lake Rousseau is at its target water level of 26.4 feet NAVD88 and the Withlacoochee River is experiencing high flows, the Inglis Bypass structure (**Figure 18-3**) typically allows 1,400 cubic feet per second (cfs) of water downstream to the Lower Withlacoochee River. Its capacity is limited by water levels immediately upstream of the structure, which are several inches lower than water levels in Lake Rousseau. This is due to energy loss that occurs along the channel’s 8,000 foot length. Two scenarios were evaluated by the model to limit this drop in water level and increase flows through the Inglis Bypass structure.

Figure 18-3 Arial View of Inglis Bypass Structure (2007)

Scenario 18: Bypass Channel Expansion

The existing Bypass Channel is approximately 80 feet wide with a relatively flat channel bottom. To evaluate this scenario, the bottom width of the channel was widened an additional 70 feet in the model to increase its flow capacity. This was accomplished by modifying the channel cross sections of the entire Bypass Channel. **Figure 18-4** compares the existing channel with the modified version that was simulated by the model.

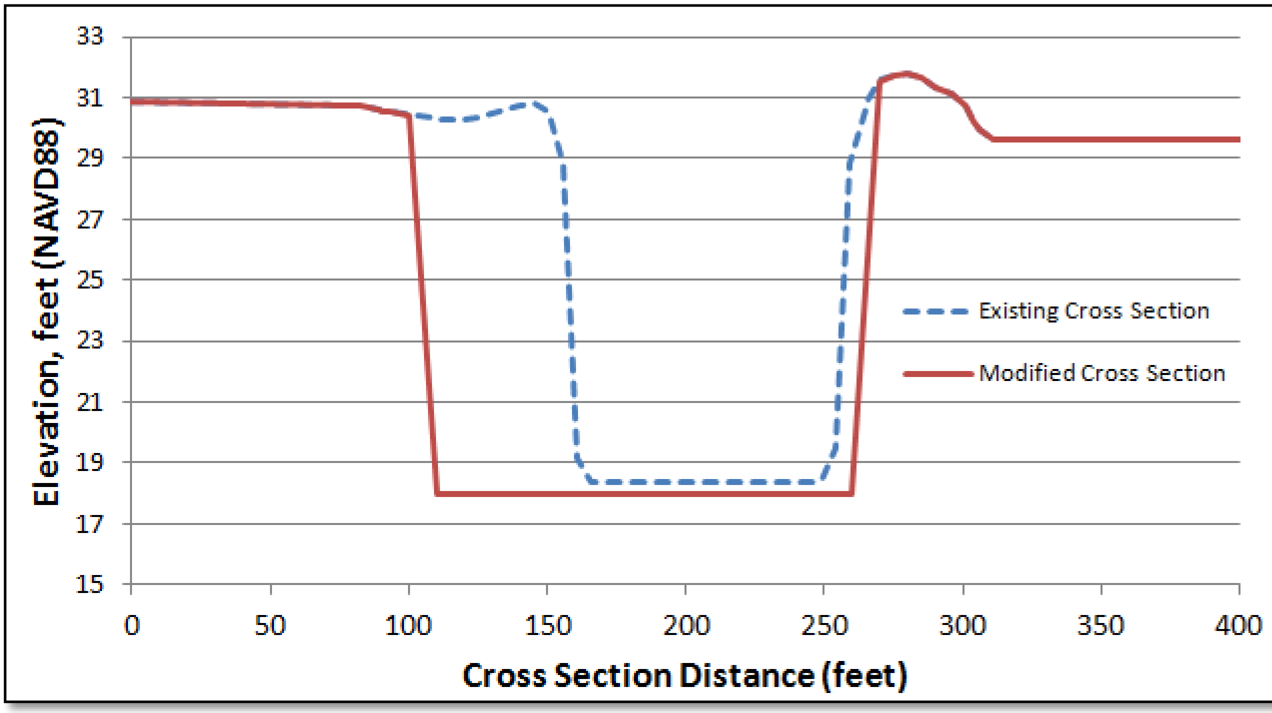

Figure 18-4 Comparison of Existing and Modified Bypass Channel Cross Section

Scenario 19: Barge Canal

As an alternative to expanding the existing Bypass Channel, Scenario 19 utilizes the Barge Canal to connect Lake Rousseau to the upstream side of the Inglis Bypass structure. The Barge Canal is significantly deeper and wider than the Bypass Channel, and it represents a much larger flow area from Lake Rousseau. This configuration requires the removal of the Inglis Lock (which has not been operational since the late 1990s) and disconnects the uppermost portion of the Barge Canal, effectively extending the lake to the upstream side of the structure. A plan view of this modification is shown in **Figure 18-5**.

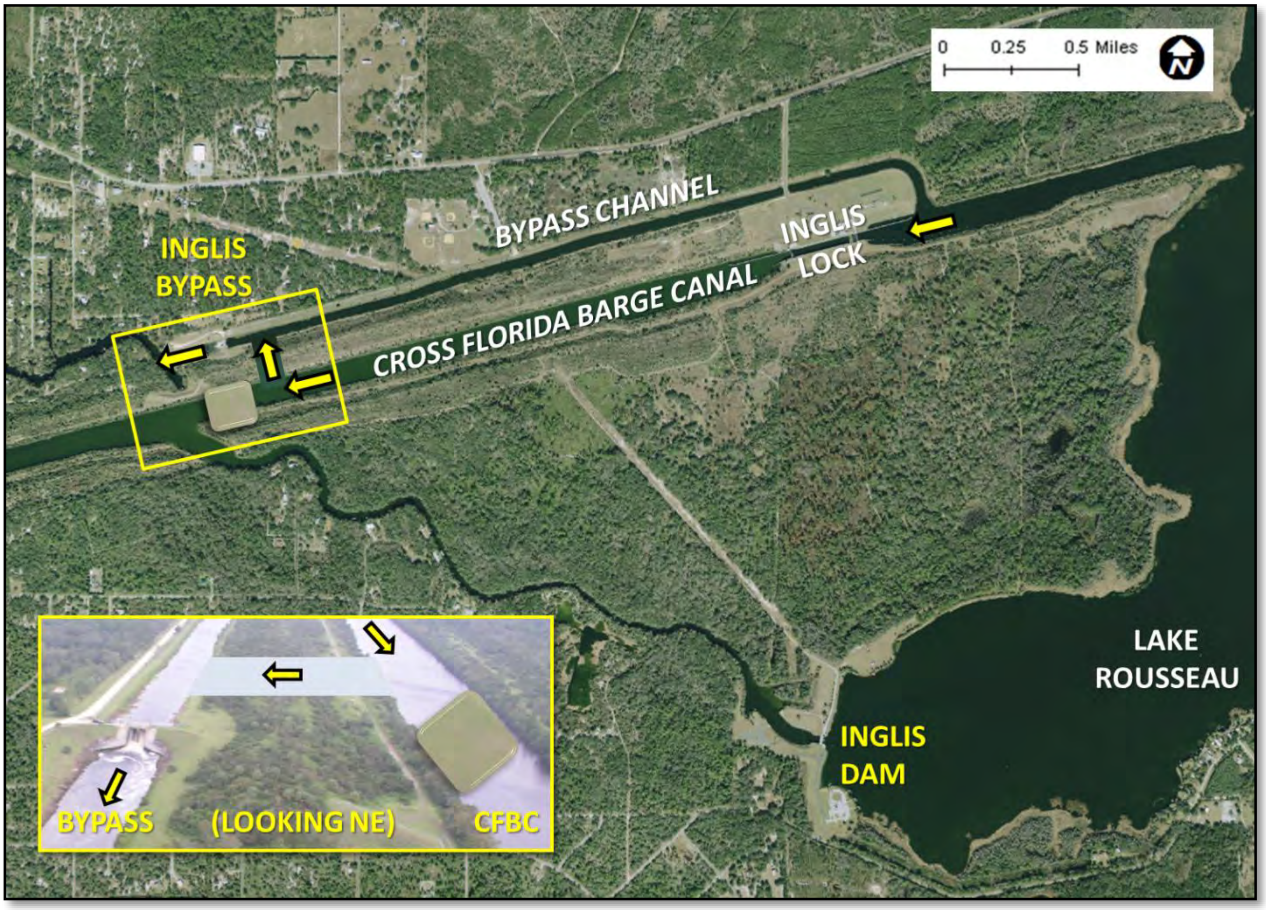

Figure 18-5 Modified Flow Path from Lake Rousseau through the Barge Canal

18.3. Results

These scenarios were simulated using the 2004 hurricanes. Locations within Lake Rousseau, the Bypass Channel and the Lower Withlacoochee River were compared for differences in water level and flow as a result of expanding the Bypass Channel (Scenario 18) and connecting the Barge Canal to the Inglis Bypass structure (Scenario 19).

Table 18-1 compares existing water level differences between Lake Rousseau and the Inglis Bypass structure with the results of both Scenario 18 and Scenario 19. As seen in the table, the water level difference between Lake Rousseau and the Inglis Bypass structure is typically about four inches. This water level difference is representative of normal conditions when the lake is at its target water level of 26.4 feet NAVD88, the Withlacoochee River is experiencing high flows, and the structure is fully open.

Table 18-1 Flow and Water Level Comparison at Bypass Spillway

	Water Level Difference (inches)	Flow to Lower Withlacoochee (cfs)	Flow Increase
Existing Conditions	4.2	1,400	–
Scenario 18 (Bypass Channel widening)	2.2	1,466	5 percent
Scenario 19 (Barge Canal connection)	0.0	1,532	9 percent

Results of Scenario 18 indicate that widening the Bypass Channel reduces the water level difference between Lake Rousseau and the upstream side of the Inglis Bypass structure by about 50 percent. This equates to a two inch increase in water levels at the structure which results in a flow increase of 66 cfs. This is about a five percent increase in flow to the Lower Withlacoochee River under these conditions. The Scenario 19 simulation indicates that using the Barge Canal to convey water to the upstream side of the Inglis Bypass structure would eliminate the water level difference between the lake and the bypass structure, maximizing the flow rate through the structure as currently configured. This would result in an additional 132 cfs to the Lower Withlacoochee, which under these conditions is a flow increase of nearly 10 percent.

18.4. Conclusions

Model results suggest that increasing channel conveyance to the Inglis Bypass structure would increase flows to the Lower Withlacoochee River. These increases would occur when Lake Rousseau is at its target water level, the entire Withlacoochee River is experiencing above average flow, and the current configuration of the Bypass Channel is unable to pass additional flows downstream. Under these conditions, widening the Bypass Channel would result in a five percent flow increase while re-directing flows through the Barge Canal would result in a nine percent flow increase. Model results indicate that Scenario 19 completely eliminates the water level difference between the upstream side of the structure and Lake Rousseau. This represents the maximum expected flow increase through the current configuration of the Inglis Bypass structure. When the Withlacoochee River is experiencing normal or low water levels/flow, increases to the Lower Withlacoochee River would not be expected since the Inglis Bypass structure would be partially closed to conserve target water levels in Lake Rousseau.

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Appendix A: Scenario Summaries

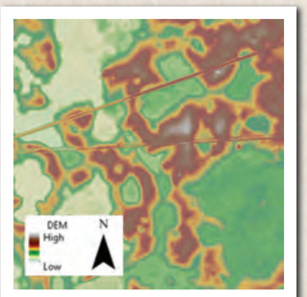
Scenario 1
Green Swamp Railroad Berms

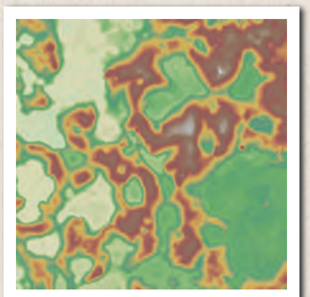
Logging Industry

- From the 1920s through the 1950s, large-scale logging operations were active throughout much of Florida, including the headwaters of the Withlacoochee River in the Green Swamp.

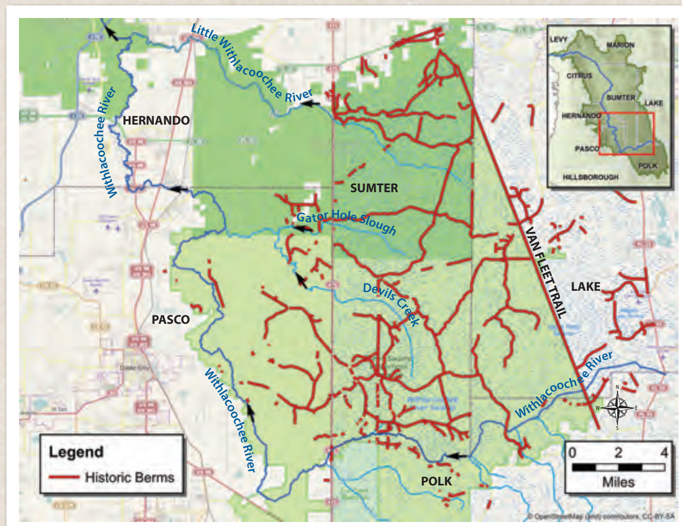
Scenario Description

- Railroad berms and drainage ditches in the Green Swamp were built decades ago to support logging and other industries.
- This scenario evaluated the removal of 200 miles of berms and nearly 300 culverts to simulate natural flow conditions within the Green Swamp.

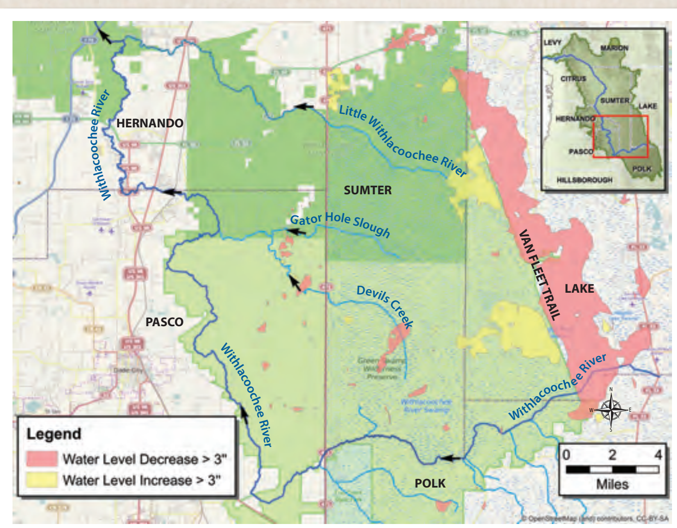




Existing Topography with Berms Present (left side)
Simulated Topography with Berms Removed (right side)



Historic Berms in the Green Swamp that were Removed for this Scenario



Peak Water Level Changes from Simulated Berm Removal (100-year Design Storm Event)

Historic Railroad Berms are used Today as Access for Land Management and Recreation

Preliminary Results

- Changes in water levels were observed at some locations within the Green Swamp.
- During the 2004 hurricane season, 10 percent more flow would have been released from the Green Swamp.
- There were no measurable changes to water levels downstream of the Green Swamp.

Conclusions

- Water levels in the Green Swamp are a reflection of regional rainfall and aquifer levels.
- The model results indicate that removing the berms would temporarily increase water flow from the Green Swamp.
- During low-water periods, there would be no change to flows leaving the Green Swamp.

Scenario 2
Green Swamp Bridge Piling Log Jams

Remnant Bridge Pilings

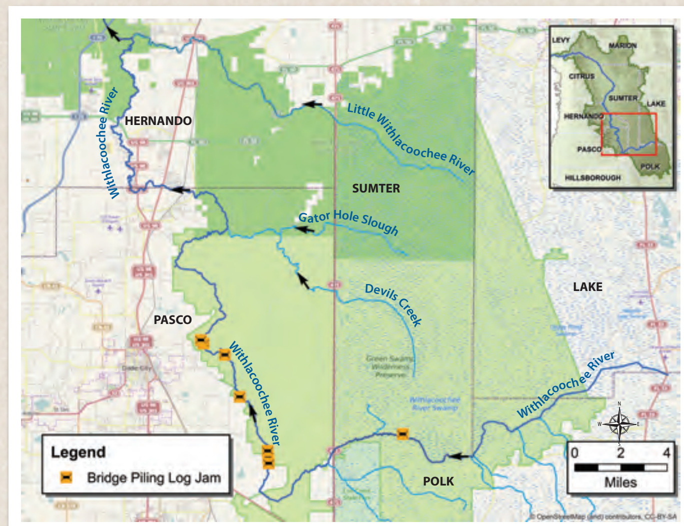
- During the early-to-mid 1900s, extensive logging activities in the Green Swamp necessitated the construction of railroad bridges that crossed the river's main channel.
- Although the railroad tracks themselves have since been removed, many of the bridge pilings remain as a reminder of these historical activities.

Scenario Description

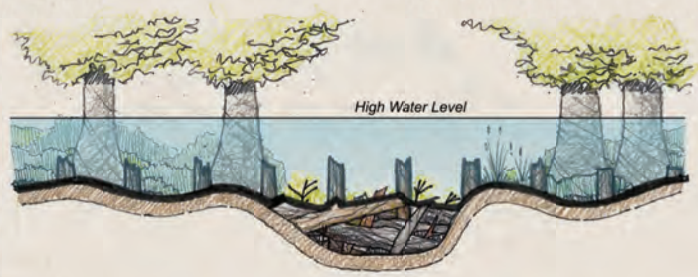
- Bridge pilings in the Green Swamp have collected debris and artificially created significant log jams at eight locations along the Withlacoochee River.
- These bridge piling log jams were removed in the model to evaluate what effect they have on water levels and flow along the Withlacoochee River.

Preliminary Results

- Water level decreases were observed immediately upstream of the removed log jams.
- These differences did not translate to other locations along the river or within the Green Swamp.
- When water levels in the Green Swamp are high enough for flows downstream, the area obstructed by the log jams is minimal compared to the overall flow area of the adjacent swamp.



Location of Major Bridge Piling Log Jams along the Withlacoochee River in the Green Swamp



Typical Extent of Flow Area in the Green Swamp as Compared to Obstructed Area

Conclusions

- The model results suggest that minor changes to water levels and flow exist at the log jam locations as a result of the flow obstructions.
- These are localized changes and do not significantly affect river levels or flows upstream or downstream.

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Comparison of Low Water (left side) and High Water (right side) at the same Bridge Piling Log Jam in the Green Swamp near Dade City

Scenario 3
Green Swamp and SR 471

SR 471

- SR 471 extends through the middle of the Green Swamp, from US 98 in Polk County to US 301 in Sumter County.
- Major bridge crossings are located at both the Withlacoochee and Little Withlacoochee rivers along with large box culvert crossings at Devils Creek and Gator Hole Slough.
- In addition to these major crossings, there are more than 50 additional culvert crossings where the raised highway bisects natural wetlands and sloughs.

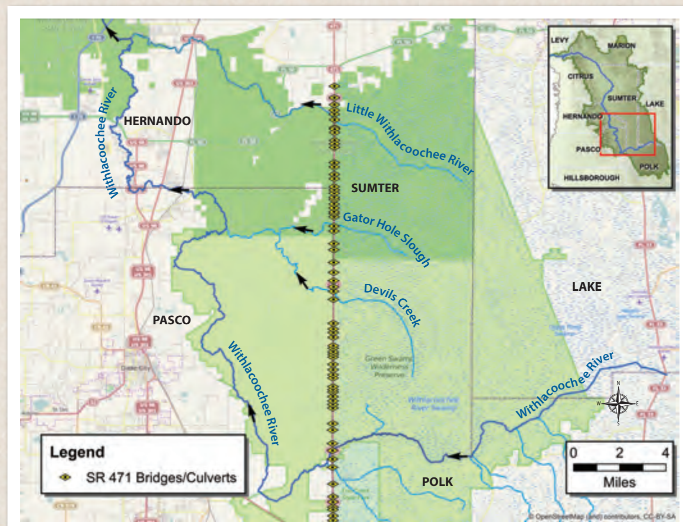
SR 471 Bridge at the Withlacoochee River

Scenario Description

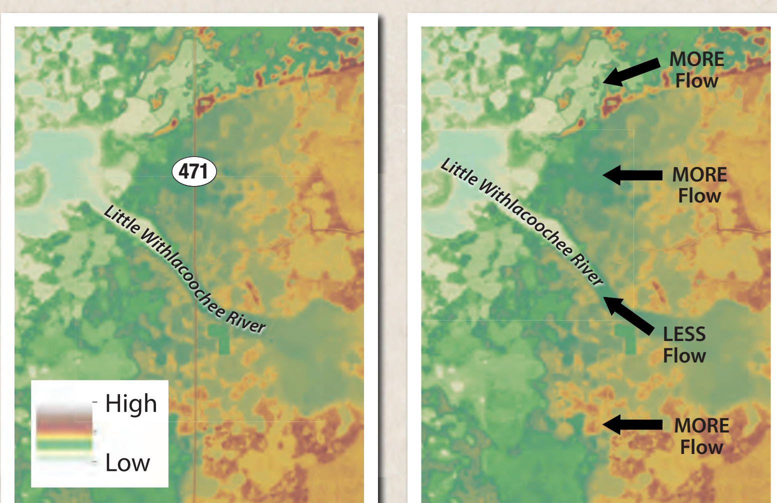
- SR 471 was constructed several feet higher than the natural elevations of the adjacent land.
- This scenario evaluated the removal of nearly 20 miles of SR 471 in the Green Swamp to determine its impact on regional water levels and flow.

Preliminary Results

- Model results indicate minor differences in water levels throughout the Green Swamp as a result of removing SR 471.
- Less flow was observed at the major stream crossings during the peak of simulated storm events.
- Flow increases were observed in non-channelized areas.
- Overall, there were no changes to water levels or flow in the Withlacoochee River downstream of the Green Swamp.



Location of Major Streams and Culvert Crossings under SR 471 in the Green Swamp



Existing Topography with SR 471 (left side)
Simulated Topography with SR 471 Removed (right side)

Conclusions

- The results suggest that while the footprint of SR 471 has very little impact on water levels in the Green Swamp, its presence has a local effect on the magnitude of flows at specific locations.
- This effect is diminished further downstream as model results show no overall change in flow volume leaving the Green Swamp.
- Model results indicate the existing bridge and culvert locations are able to convey the necessary capacity of water downstream.

Scenario 4
Hillsborough River Overflow at US 98

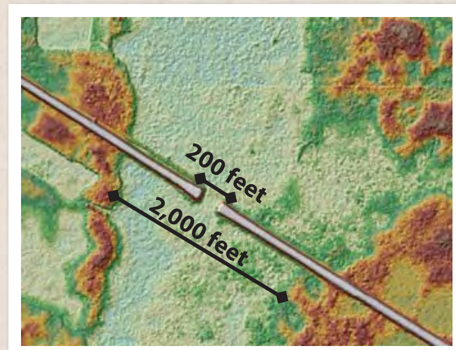
Hillsborough River Overflow

- The vast majority of surface water leaving the Green Swamp flows to the Withlacoochee River because of the area's natural topography.
- The Hillsborough River originates in a wide-forested swamp, just northeast of US 98, where the Withlacoochee turns sharply northward.
- When water levels in the Withlacoochee River rise above the natural elevations of this flat region, flow occurs from the Green Swamp to the Hillsborough River under the US 98 bridge.

Aerial View of the US 98 Bridge Crossing on the Hillsborough River

Scenario Description

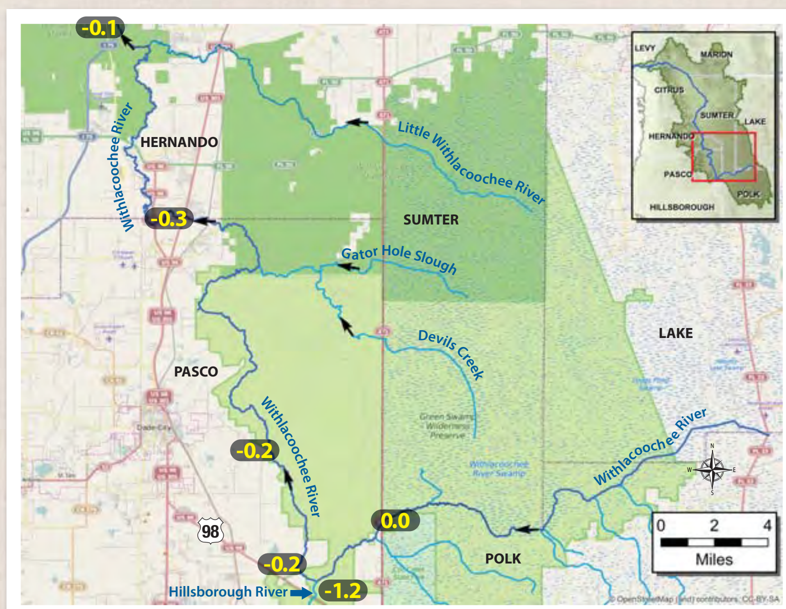
- It has been suggested that during high-water conditions, historical flooding along the Withlacoochee River may be the result of a constrictive bridge opening at US 98 and sediment that may have deposited there over time.
- The graphic (right) shows how the footprint of the bridge compresses the 2,000-foot-wide natural flow path into a 200-foot-wide opening at the bridge.
- This scenario evaluated the role of the US 98 bridge opening to pass flow from the Green Swamp to the Hillsborough River and its impact on water levels along the Withlacoochee River.



Existing Topography of the Hillsborough River at the US 98 Bridge

Preliminary Results

- During the 2004 hurricane season, less than two percent more flow would have diverted to the Hillsborough River.
- Negligible changes to water levels and flow were observed downstream along the Withlacoochee River.



Peak Water Level Changes (inches) from Simulated US 98 Bridge Removal (2004 Hurricanes)

Conclusions

- Removing the footprint of the US 98 bridge increases the potential for greater flow to the Hillsborough River by increasing the area of flow that is currently restricted to the bridge opening.
- Model results show only slightly higher flows since water levels at US 98 are lower in the model as a result of this wider flow path.
- Substantially greater flows would require higher water levels in the floodplain swamps of the Withlacoochee River, where the Hillsborough River originates.
- Results also suggest that the US 98 bridge at the Hillsborough River does not significantly affect water levels and flows along the Withlacoochee River, which appear to be driven by hydrologic conditions and the natural topography of the region.

Comparison of the Current US 98 Bridge Opening to the Natural Flow Path (black line)

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Scenario 5
Bridge Crossings near Trilby and Lacoochee

History of Flooding

- Near the border of Hernando and Pasco counties, the Withlacoochee River passes through the communities of Trilby and Lacoochee as it exits the Green Swamp.
- There is a history of flooding in this area, documented as far back as 1933 and occurring most recently in 2004.

Trilby

SR 575 Bridge

Scenario Description

- Within a three-mile stretch, SR 575, US 301, US 98, and a railroad trestle cross the main channel of the Withlacoochee River.
- It has been suggested that these crossings have constricted the natural flows exiting the Green Swamp impacting flood levels in the area.
- This scenario evaluated the impact that these four bridge crossings have on water levels and flows along the Withlacoochee River.

US 301 Bridge over the Withlacoochee River

Preliminary Results

- There were no changes to river flows upstream within the Green Swamp or downstream along the Withlacoochee River after simulating the removal of these crossings.
- Water levels that rose more than 10 feet during the 2004 Hurricanes would have decreased by one inch or less as a result of removing the footprint of the bridge crossings.

Conclusions

- The model suggests that the existence of the bridge crossings near Trilby and Lacoochee are not a major factor contributing to flooding in the region.
- The Withlacoochee River's natural transition from the expansive wetlands of the Green Swamp into a narrow, high-banked channel in this area is the main reason for the extreme water-level fluctuations.

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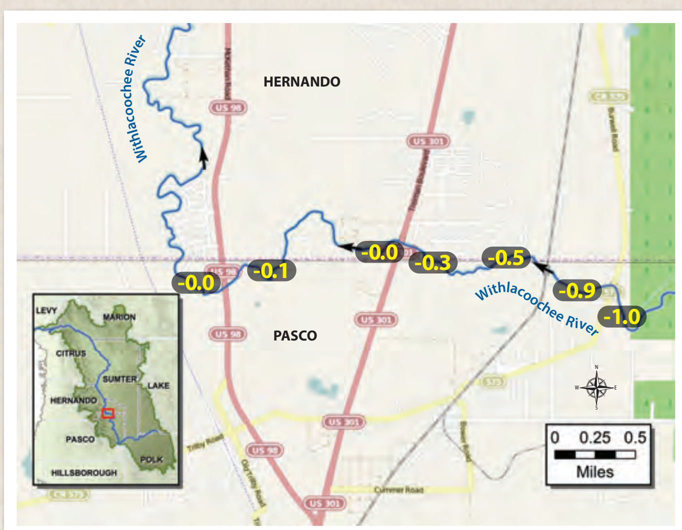
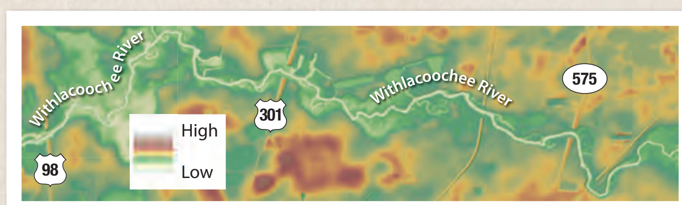
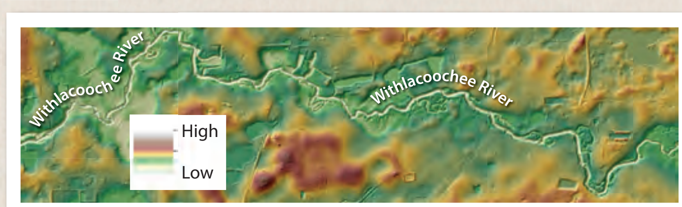


Peak Water Level Changes (inches) from Simulated Bridge Removal (2004 Hurricanes)



Existing Topography with Bridges and Roadway Berms Present



Simulated Topography with Bridges and Roadway Berms Removed

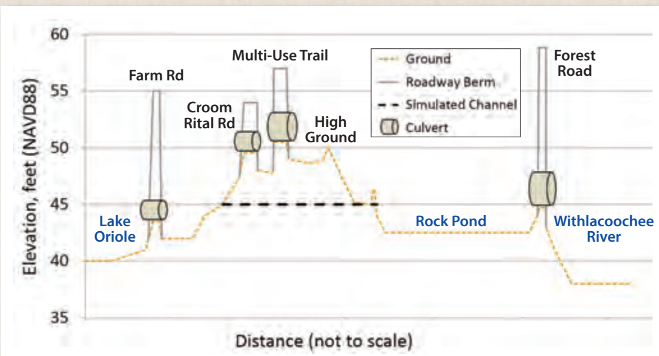
Scenario 6
Lake Oriole

Lake Oriole

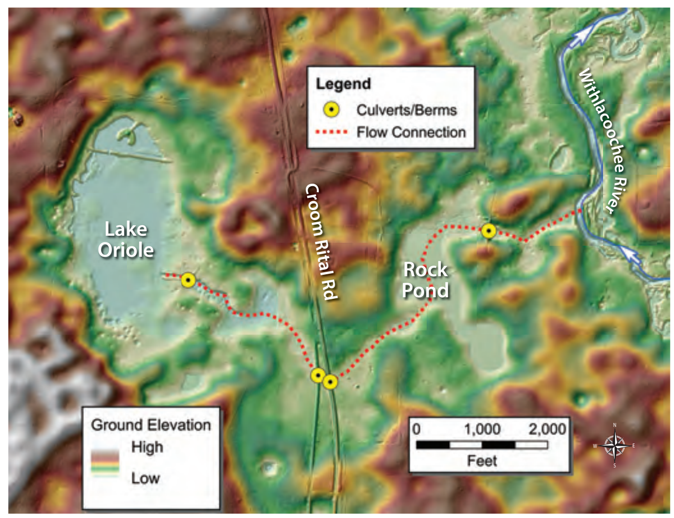
- Lake Oriole is located in Hernando County, north of SR 50 and east of I-75, approximately one mile west of the Withlacoochee River.
- The lake is typically isolated, although during times of high water, a flow connection exists between the lake and the Withlacoochee River.

Scenario Description

- Over the past century, several roadway berms and culverts were constructed between the lake and the river.
- This scenario evaluates the existing flow connection and how changes to the land between the lake and the river would impact opportunities for additional inflow from the Withlacoochee River to Lake Oriole.



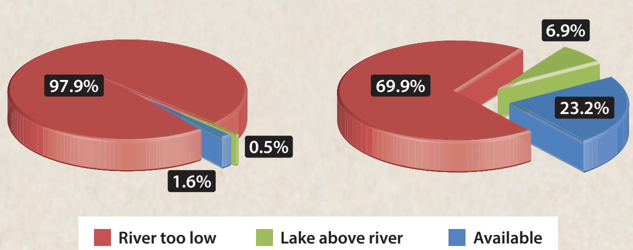
Profile of Ground and Culvert Elevations between Lake Oriole and the Withlacoochee River



Topographic Map showing the Flow Connection between Lake Oriole and the Withlacoochee River

Preliminary Results

- Water levels in Lake Oriole rise and fall in response to rainfall and changing groundwater levels.
- Over the past 75 years, the Withlacoochee River was above elevation 50 feet (NAVD88) and able to flow towards Lake Oriole less than two percent of the time.
- If a channel was constructed through the high ground and the existing culverts were lowered, the Withlacoochee River would be available to flow into Lake Oriole approximately 23 percent of the time.



Historic Availability of River Inflow to Lake Oriole (left side) and Simulated Availability of River Inflow (right side)

Conclusions

- The results of this scenario indicate that natural inflows from the Withlacoochee River to Lake Oriole are rare.
- Water levels in Lake Oriole are a reflection of aquifer levels that rise and fall from changing rainfall conditions.
- Simulating a lower connection resulted in additional days that water would be available to flow from the river to the lake.
- It is anticipated that once river levels cease contributing flow, lake levels would quickly return to regional groundwater levels and not result in sustained water level increases.

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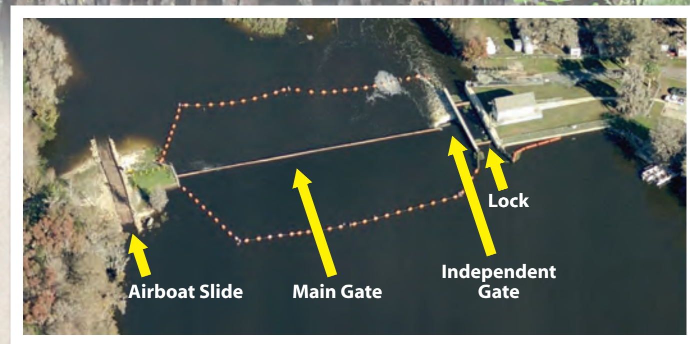
Scenario 7
Wysong-Coogler Water Conservation Structure

Wysong Structure

- The Wysong-Coogler water conservation structure is located within the Withlacoochee River approximately two miles downstream (north) of the Outlet River confluence from Lake Panasoffkee.
- The structure consists of two inflatable gates; a 230-foot-wide main gate and a 19-foot-wide independent gate. A lock system allows boaters to pass through the structure and an airboat slide provides an alternative means for passage.



Aerial View of the Wysong Structure

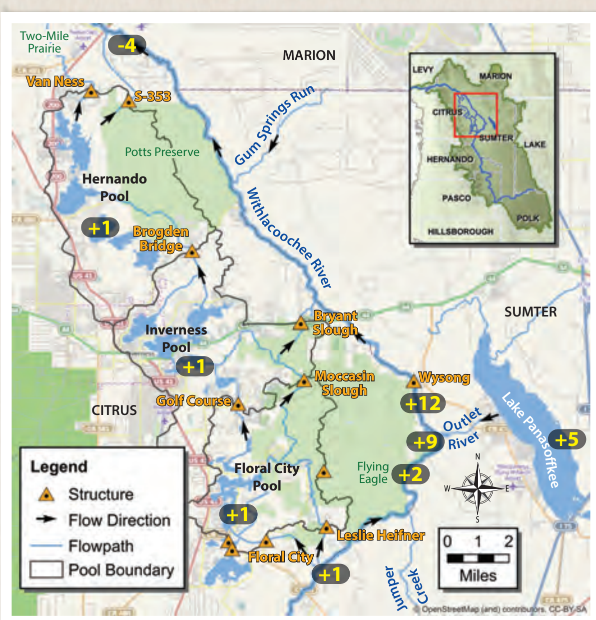
Scenario Description

- The Wysong structure is operated to maintain a target upstream water level while ensuring adequate outflow from Lake Panasoffkee and required flows down the Withlacoochee River.
- The ability of the structure to maintain upstream water levels is limited because of changing rainfall patterns and river flows.
- To evaluate this scenario, the operational range of the structure and the target water level just upstream were both increased by one foot in the model.

Wysong Structure with Main Gate Fully Inflated (Raised)

Preliminary Results

- The greatest differences in water levels were observed directly upstream of the Wysong structure, within the Outlet River and in Lake Panasoffkee.
- Raising the Wysong structure decreased average flows leaving Lake Panasoffkee.
- A water level increase of 12 inches at the Wysong structure translated into a one-inch increase farther upstream along the Withlacoochee River and throughout Tsala Apopka.



Peak Water Level Changes (inches) for the Mean Annual Event.

Conclusions

- The operation of the Wysong structure is limited by water levels and flow in both the Withlacoochee River and the Outlet River.
- Results indicate that increasing the operational range of the Wysong structure an additional foot would cause minimal changes to water levels in the Tsala Apopka Chain-of-Lakes.
- Water-level increases immediately upstream of the Wysong structure are significantly diminished a few miles upstream along the Withlacoochee River.

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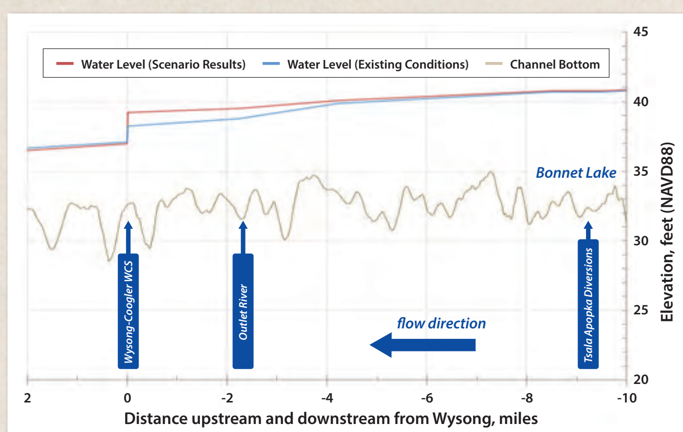


Scenario 8
Flood Storage

History of Flooding

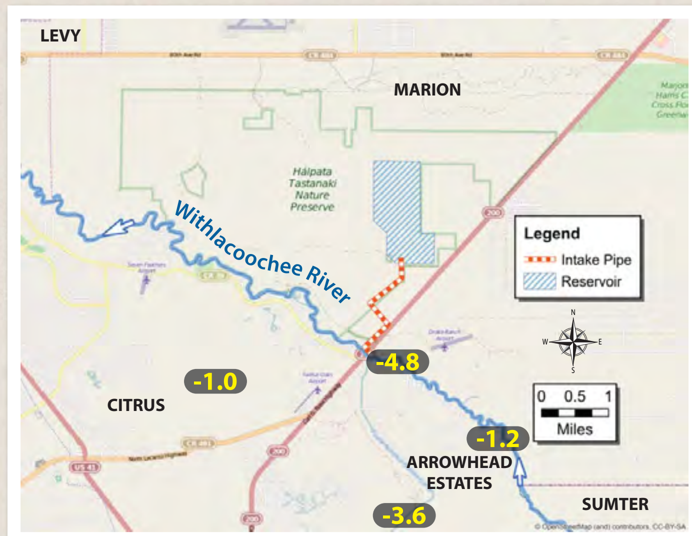
- Along the border of Citrus and Marion counties, in the vicinity of State Road 200, the Withlacoochee River transitions from a wide, shallow river near Tsala Apopka into a narrow, high-banked channel once again.
- There is a history of flooding in this area both upstream and downstream of the State Road 200 bridge.

Withlacoochee River at SR 200

Scenario Description

- As part of the Withlacoochee Regional Water Supply Authority's (WRWSA) 2014 Regional Water Supply Plan, locations for potential future water supply are identified.
- A location in Halpata Tastanaki Preserve was proposed, where excess water from the river could be diverted, stored and used as a drinking water source.
- Using the conceptual design and withdrawal rates as specified in the WRWSA 2014 Regional Water Supply Plan, this model scenario simulates whether withdrawals from the river will have the additional benefit of lowering peak flood levels in this region.

Areas flooded by the 2004 Hurricanes near Arrowhead Estates.



Peak Water Level Changes (inches) with Simulated Pumping to Reservoir during the 2004 Hurricanes.

Preliminary Results

- During the 2004 Hurricanes, Withlacoochee River water levels rose nearly 10 feet and peak flow rates were more than 5,000 cubic feet per second (cfs) at the SR 200 bridge.
- Assuming an unlimited reservoir size, the maximum pumping rate, per the 2014 Regional Water Supply Plan, was 265 cfs during the 2004 Hurricanes.
- This would have lowered water levels by five inches at SR 200 and one inch near Arrowhead Estates.

Conclusions

- The simulated reduction in flood levels would require a reservoir capable of storing 29,000 acre-feet of water, similar to the entire Hernando Pool.
- In addition, the pumps would need to be capable of diverting a flow equivalent to one-third the discharge of the Rainbow River.
- Results indicate that if the reservoir and pump requirements could be met, minimal flood relief would be achieved for properties along the Withlacoochee River in this area.

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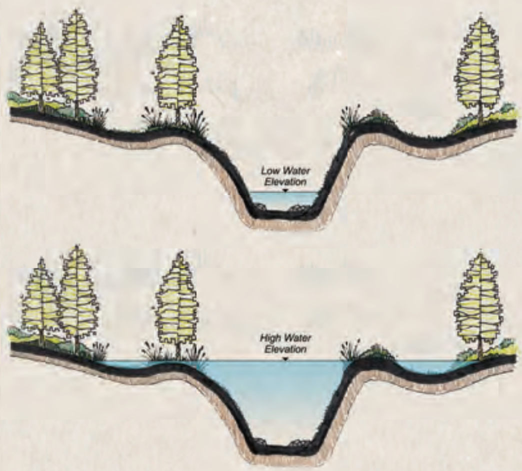
Scenario 9
Withlacoochee River High Initial Water Levels

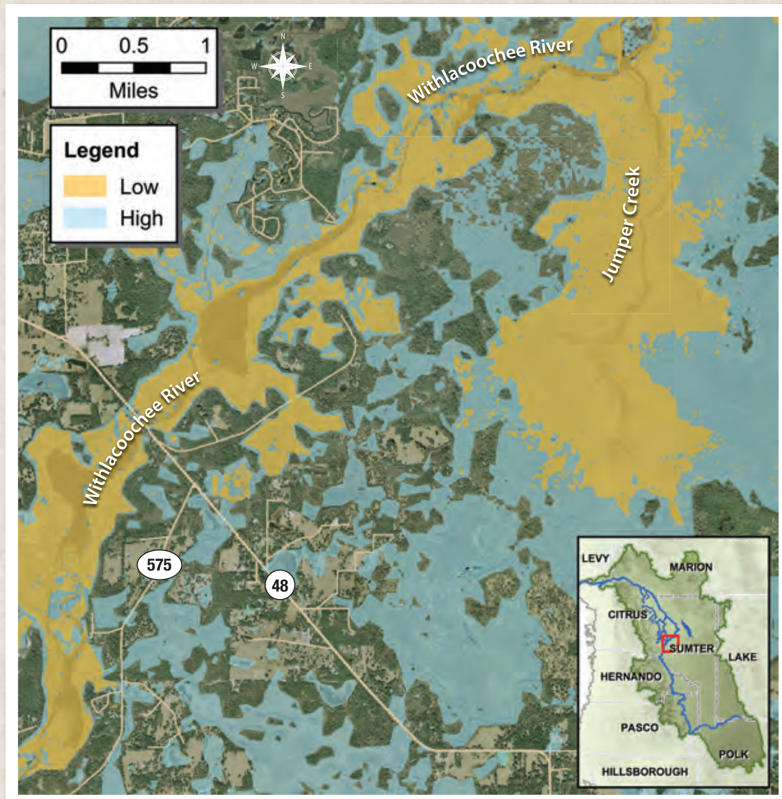
Extreme Fluctuations

- The Withlacoochee River has historically experienced extreme high and low conditions due to natural fluctuations in rainfall and groundwater levels.
- The areas earliest inhabitants named the river "We-thalko-chee," meaning "little-big-water."

Comparison of Low-Water (left side) and High-Water (right side) Levels Just Downstream of I-75 Bridge



Comparison of Low and High Initial Water Levels That Were Simulated for Each of the Design Storms



Comparison of Areas Inundated by Low and High Initial Water Levels

Scenario Description

- The initial, or starting, water levels within the Withlacoochee River watershed have a significant impact on how high river levels and flows will increase following a rainfall event.
- Each design storm event was originally simulated with low to normal initial water levels.
- To match historic flood conditions and to provide an additional basis of comparison for each of the scenarios, the design storms were simulated with higher initial water levels.

Storm Event Simulation	DESIGN EVENTS			
	Mean Annual	10-Year	25-Year	100-Year
Rainfall Amount	6.9 inches	10.8 inches	12.3 inches	16.3 inches

Rainfall Amounts Simulated Over the Entire Watershed

Preliminary Results

- Water levels along the Withlacoochee River rose several feet higher and peaked several days later when simulated with high initial water levels.
- Results of the design storms with high initial water levels more closely matched published gage data along the river.

Conclusions

- Historical flood events along the Withlacoochee River are the result of significant rainfall on an already saturated watershed, rather than a single event with low initial water levels.
- Simulating the design storm events with both low and high initial conditions resulted in a wide range of water levels and flows along the Withlacoochee River and throughout the watershed.
- The results provide an additional basis of comparison for many of the other scenarios simulated by the model.

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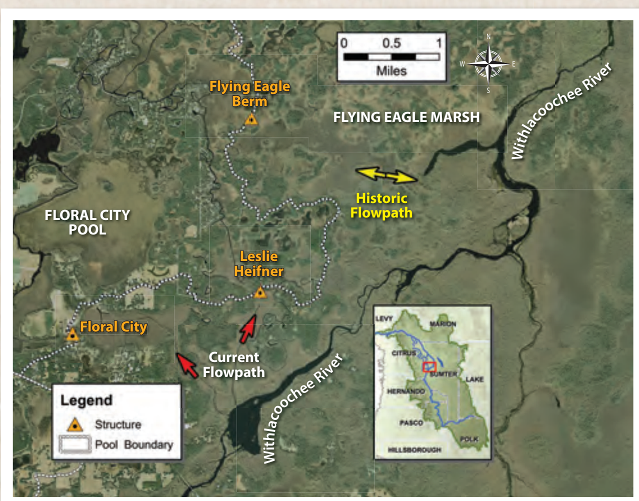
Scenario 10
Tsala Apopka Flying Eagle Berm

Historic vs. Existing Connection

- The Flying Eagle Marsh historically connected the Withlacoochee River with the Tsala Apopka Chain-of-Lakes during high water times.
- The Flying Eagle Berm was constructed in the late 1950s, altering the natural flow connection through the Flying Eagle Marsh.
- Today, inflow from the river occurs several miles upstream of the Flying Eagle Marsh through the Orange State and Leslie Heifner canals.

Scenario Description

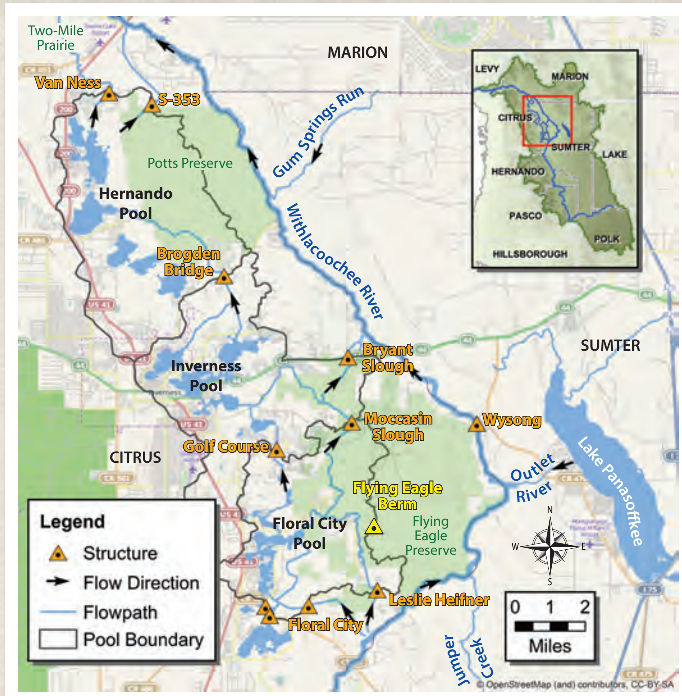
- It has been suggested that restoring the historic flow through the Flying Eagle Marsh will help maintain higher water levels in Tsala Apopka.
- This scenario evaluated the regional impact of removing the Flying Eagle Berm, which includes nearly two miles of filled road segments between several islands in the Flying Eagle Marsh.
- An analysis also was conducted to determine the historical availability of additional river water to enter the Floral City Pool if the berm were removed.



Comparison of Current and Historical Flowpaths between the Withlacoochee River and the Tsala Apopka Chain-of-Lakes

Conclusions

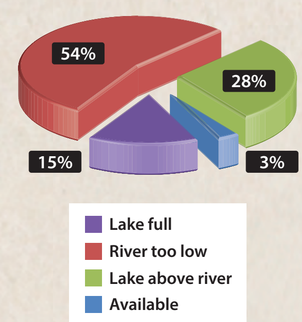
- The results of this scenario suggest that the Flying Eagle Berm serves to conserve water in the Floral City Pool under normal conditions, while providing some level of flood protection during high-water events.
- Results also indicate that the existing canals are more effective at filling the Tsala Apopka Chain-of-Lakes and very few opportunities exist to bring additional river water through the Flying Eagle Marsh.



Flying Eagle and Tsala Apopka Area Map

Preliminary Results

- Overall lower-water levels were observed in Tsala Apopka with the berm removed, as water flowing in through the existing canals flowed back out across the Flying Eagle Marsh.
- During flood events, water levels peaked higher throughout the Tsala Apopka Chain-of-Lakes, as unregulated flow entered through the Flying Eagle Marsh.
- Over the past 31 years, desired river water would have been available to flow into the lake three percent of the time (11 days per year on average).
- Water would have flowed back to the river from the lake 52 percent of the time if the Flying Eagle Berm were not in place.



Availability of River Water to enter Tsala Apopka through the Flying Eagle Marsh

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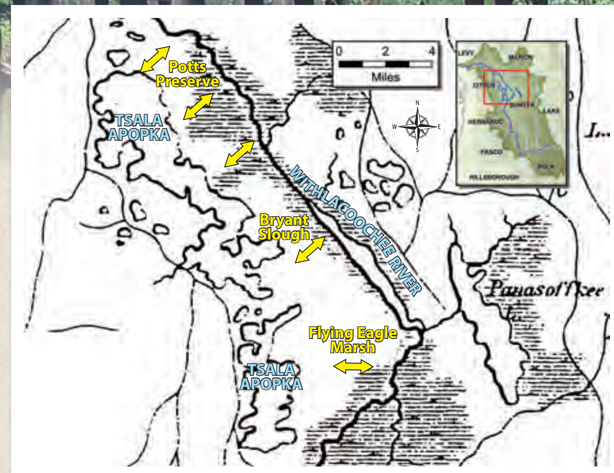
Scenario 11
Tsala Apopka Pre-Settlement Conditions



Pre-Settlement Conditions

- In pre-settlement times, water naturally flowed back and forth between the Tsala Apopka Chain-of-Lakes and the Withlacoochee River through extensive marshlands and forested wetlands that would flood and dry out with changing hydrologic conditions.

Scenario Description

- Since the late 1800s, constructed alterations have transformed this region's natural function into one that benefited navigation, industry and private needs.
- This scenario evaluated how these alterations have changed water levels and flow by simulating pre-settlement conditions throughout the Tsala Apopka Chain-of-Lakes.

Preliminary Results

- Water levels were typically lower under pre-settlement conditions but peaked higher due to unregulated flow from the Withlacoochee River.
- During flood events, the natural connection between the Inverness and Hernando pools would allow them to merge into a single pool.
- Without the canals, river levels would be required to rise higher before inflow could occur across the natural marshlands to the Tsala Apopka Chain-of-Lakes.

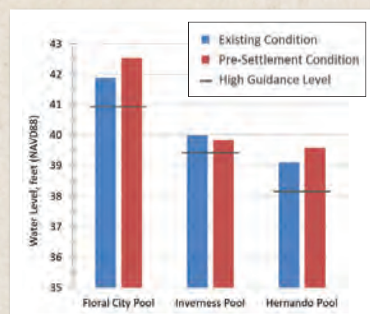
Orange State Canal

S-353 Structure

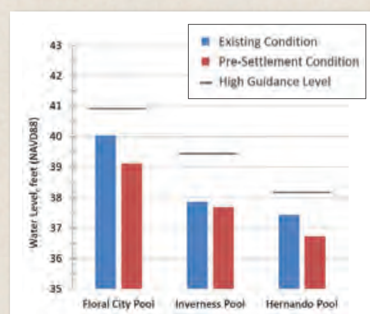
Alterations that were Removed to Simulate Pre-Settlement Conditions

Conclusions

- Model results suggest that without the existing canals, structures and berms, the Tsala Apopka Chain-of-Lakes would not fill as quickly under normal river conditions.
- Water levels in Tsala Apopka, which are currently maintained by the berms and structures, would naturally drain back to the river.
- Under high water conditions, the lakes would receive significant, uncontrolled inflows from the river, causing their levels to peak higher.



Peak Differences during High Water (2004 Hurricanes)



Peak Differences during Low Water (Mean Annual Event)

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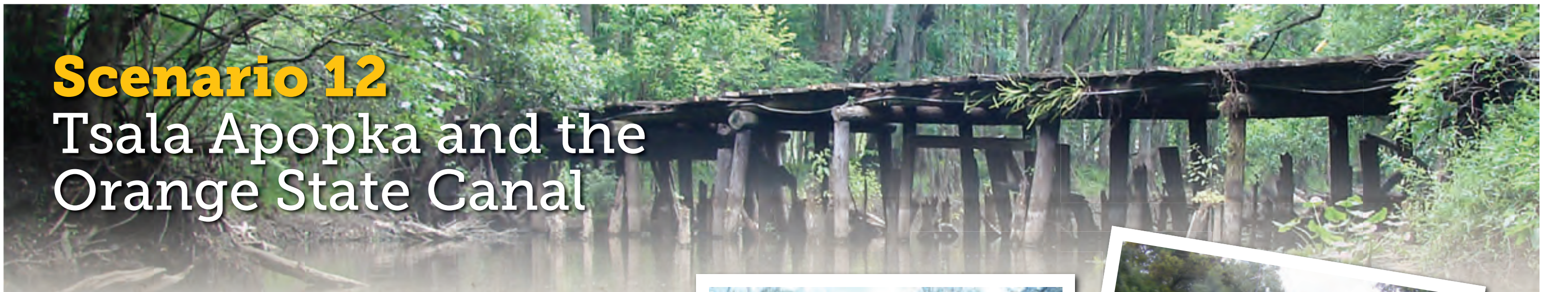
Scenario 12
Tsala Apopka and the Orange State Canal



River Inflows

- In pre-settlement times, water naturally flowed back and forth between the Tsala Apopka Chain-of-Lakes and the Withlacoochee River through extensive marshlands that would flood and dry out with changing hydrologic conditions.
- Today, the Leslie Heifner and Orange State canals directly connect the river to the lakes, allowing for more frequent inflow to the lakes at lower elevations than the natural marsh.

Orange State Canal

Leslie Heifner Canal

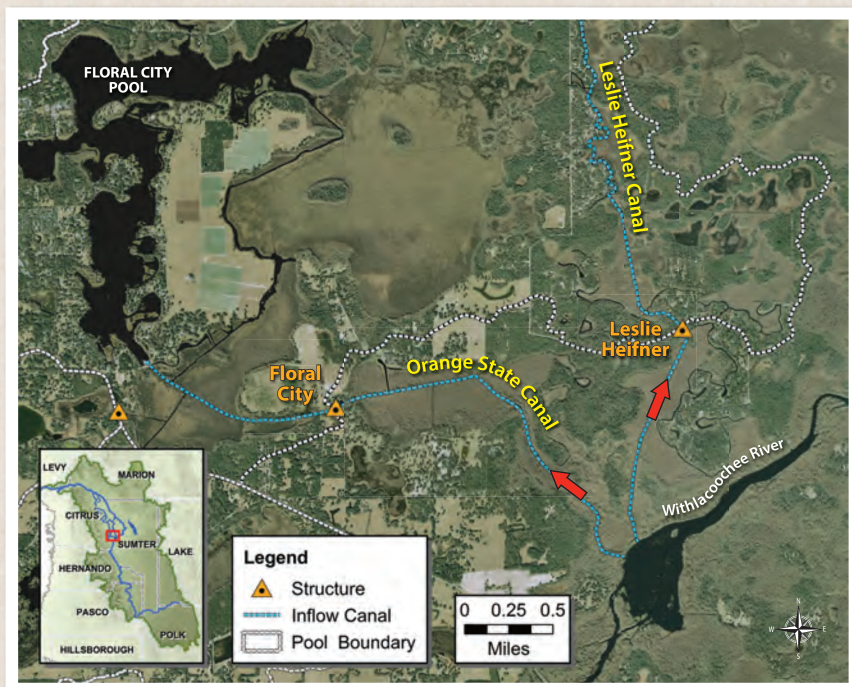
Scenario Description

- The Leslie Heifner canal is the preferred path to move water into the lakes because of its lower channel bottom and control structure elevations.
- This scenario evaluated how lowering the Orange State canal and Floral City structure to match the Leslie Heifner canal and structure would impact flows from the Withlacoochee River and water levels within the Tsala Apopka Chain-of-Lakes.

Simulated Lowering of the Orange State Canal

Preliminary Results

- Average inflows from the river to the Floral City Pool increased through the Orange State canal.
- Overall inflows through the Leslie Heifner canal were reduced when the Orange State canal and Floral City structure were lowered.
- Over a 40-day period when river water was available, water levels in the Tsala Apopka Chain-of-Lakes rose by one to two inches.



Conclusions

- The effectiveness of dredging the Orange State Canal and lowering the Floral City structure is cut in half from decreased flows through Leslie Heifner.
- In the past 60 years, the Withlacoochee River was available to flow into Tsala Apopka through the Orange State canal 28 percent of the time and through the Leslie Heifner canal 31 percent of the time.

Historical Availability of River Inflow

Southwest Florida Water Management District

Scenario 13
Tsala Apopka Structure Sizes

Flowpaths, Structures and Pools within the Tsala Apopka Chain-of-Lakes

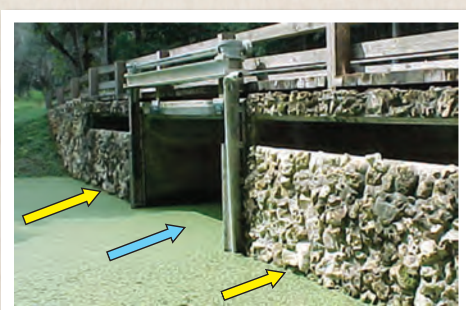
Tsala Apopka Chain-of-Lakes: Inflows and Outflows

- Water enters the Tsala Apopka Chain-of-Lakes from direct rainfall, runoff from adjacent higher ground, and diversions from the Withlacoochee River that are split between each pool.
- Outflows include evapotranspiration of water back to the atmosphere, natural leakage downward into the underlying Floridan aquifer system, and diversions back to the Withlacoochee River or to Two-Mile Prairie.

Scenario Description

- The most significant flow constriction in Tsala Apopka is the movement of water between the Floral City Pool and the Inverness Pool.
- To evaluate this scenario, structure openings were increased in the model for the Golf Course and Moccasin Slough structures.

Golf Course Structure with Simulated Lower Gate Opening



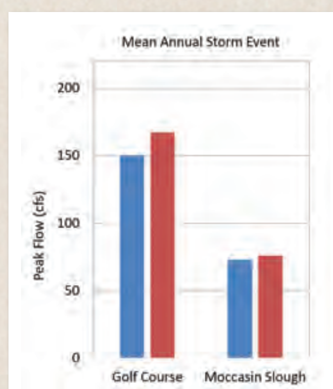
Moccasin Slough Structure with Simulated Wider Gate Opening

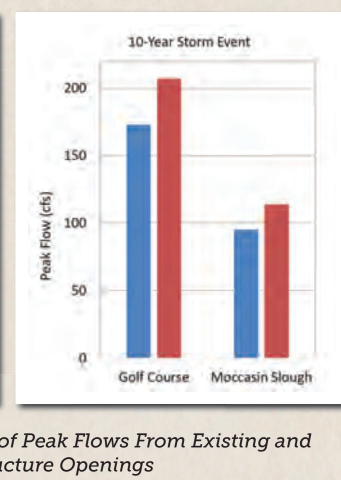
Conclusions

- Flow between the Floral City Pool and Inverness Pool was historically limited to the natural elevations of Moccasin Slough.
- Several decades ago the Golf Course Canal was built through high ground to enhance this movement of water.
- Model results indicate that modifying the structures increased flows into the Inverness Pool; however, that increase is limited by the conveyance potential of the Golf Course Canal and Moccasin Slough.

Preliminary Results

- Overall, the total volume of water in Tsala Apopka increased by approximately one percent during the mean annual storm event.
- This resulted in Floral City Pool water levels that were 1.4 inches lower and Inverness and Hernando Pool water levels that were 1.5 and 1.2 inches higher, respectively.
- Even after modifying the structures, the Inverness Pool filled slower than the Floral City and Inverness pools.
- Increased flows were observed through the Golf Course and Moccasin Slough structures as a result of larger openings.





Comparison of Peak Flows From Existing and Modified Structure Openings

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Scenario 14
Tsala Apopka Structure Operations

Water Control Structures

- More than a dozen water control structures exist throughout the Tsala Apopka Chain-of-Lakes.
- The majority of these structures were constructed in the 1950s and 1960s and were originally operated by the Tsala Apopka Basin Recreation and Water Conservation Control Authority.
- By the early 1970s, the Southwest Florida Water Management District (District) assumed management responsibility of many of the existing Tsala Apopka structures.

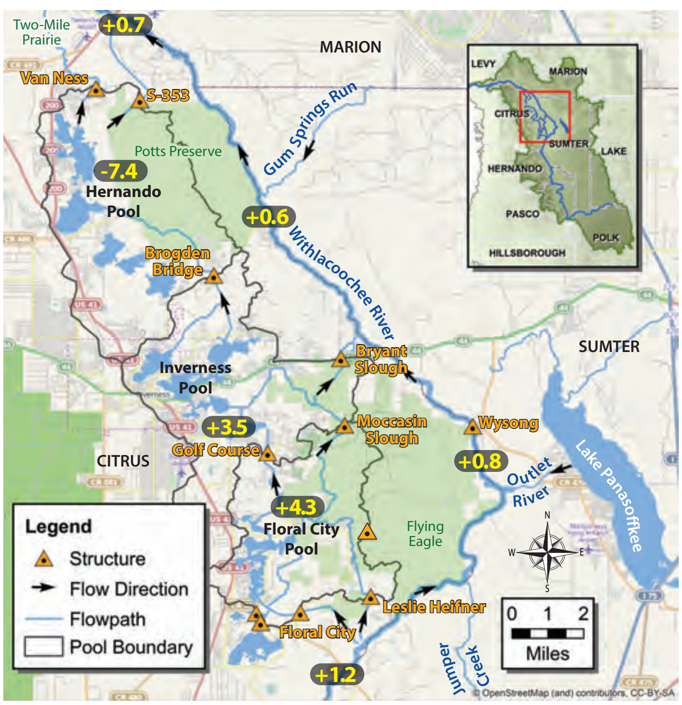
Brogden Bridge Structure

Scenario Description

- Throughout history, these structures have been managed in an attempt to balance two competing activities — recreation and flood protection.
- Concerns regarding both high and low water levels in the Tsala Apopka Chain-of-Lakes have persisted for many decades.
- This scenario compared the current District guideline of sharing river inflow equally with all three pools to the previous guideline of filling each upstream pool first.

Low Water in Inverness Pool

High Water in Hernando Pool



Average Water Level Changes (inches) from Filling Upstream Pools First During the Mean Annual Event

Preliminary Results

- Filling the upstream pools first resulted in a 25 percent decrease in flow volume entering the Tsala Apopka Chain-of-Lakes during the mean annual storm event and an 11 percent decrease during the 10-year storm event.
- Withlacoochee River flows at the Wysong structure increased by approximately three percent during the mean annual storm event, because of less flow diversion into Tsala Apopka.
- On average, higher water levels were observed in the Floral City and Inverness pools while lower water levels were observed in the Hernando Pool as a result of filling the upstream pools first.

Conclusions

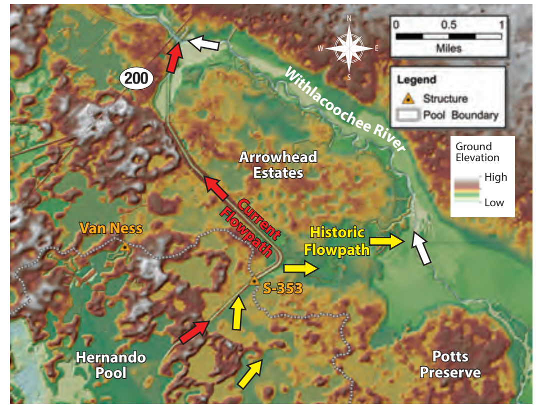
- Operating the Tsala Apopka structures to fill upstream pools first would raise water levels in the Floral City and Inverness pools for the events simulated.
- Water levels in the Hernando Pool would remain lower; however, with little or no opportunity to receive river inflows.
- Model results indicate that the current guideline of sharing river inflows between all three pools increases the overall volume of water entering the Tsala Apopka Chain-of-Lakes from the Withlacoochee River.

Scenario 15

Tsala Apopka Outflows and Arrowhead Estates

Tsala Apopka Outflow

- Historically, high water in the Hernando Pool flowed to the Withlacoochee River through low marshlands just north of present-day Potts Preserve.
- Major flooding in 1960 led to the modification of this natural outflow and the creation of the S-353 structure and C-331 canal, which were completed by the U.S. Army Corps of Engineers in 1968.
- Berms were also constructed to channel flood waters from the Hernando Pool to the Withlacoochee River just upstream of SR 200.



Historic and Current Outflow From the Hernando Pool to the Withlacoochee River

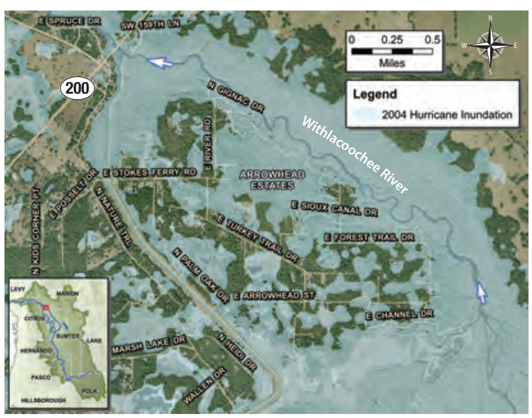
Scenario Description

- The Arrowhead Estates community has a long history of flooding during high-water events, including the 2004 Hurricanes.
- This has led to concerns regarding how the release of water from the Tsala Apopka Chain-of-Lakes may affect flood levels in Arrowhead Estates.
- To address these concerns, this scenario evaluated the effects of not releasing water through S-353 during high-water events.

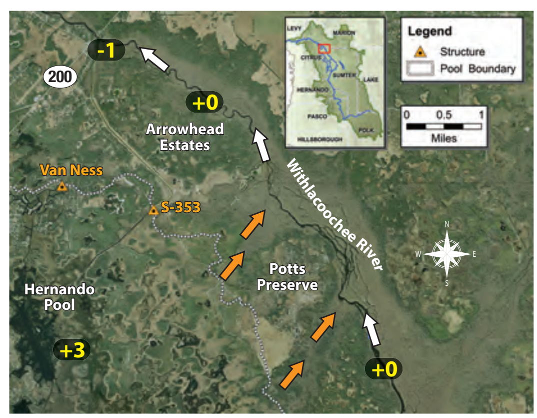
High Water in the Hernando Pool Prompted Outflow Through the S-353 Structure in 2014 and 2015

Preliminary Results

- Model results showed that during the 2004 Hurricanes, water levels in the Hernando Pool would have risen three inches higher as a result of keeping the S-353 structure closed.
- This resulted in greater flows through the natural wetlands of Potts Preserve back to the Withlacoochee River, which is upstream of Arrowhead Estates.
- No changes to water levels were observed in Arrowhead Estates as a result of closing S-353 during the 2004 Hurricanes.
- Keeping the S-353 structure closed in 2004 would have lowered flows on the Withlacoochee River at SR 200 by three percent during the 35 days the structure was open.
- For the larger simulated storm events, water levels at Arrowhead Estates would peak slightly higher if the S-353 structure remained closed.



Areas Flooded by the 2004 Hurricanes Near Arrowhead Estates



Peak Water Level Changes (inches) With S-353 Structure Closed During the 2004 Hurricanes

Conclusions

- Model results suggest that keeping the S-353 structure closed during a high-water event will not reduce flood levels in Arrowhead Estates.
- Past flooding near Arrowhead Estates is the result of high-water conditions along the Withlacoochee River rather than releases from the Hernando Pool through the S-353 structure, which are minimal compared to river flows.

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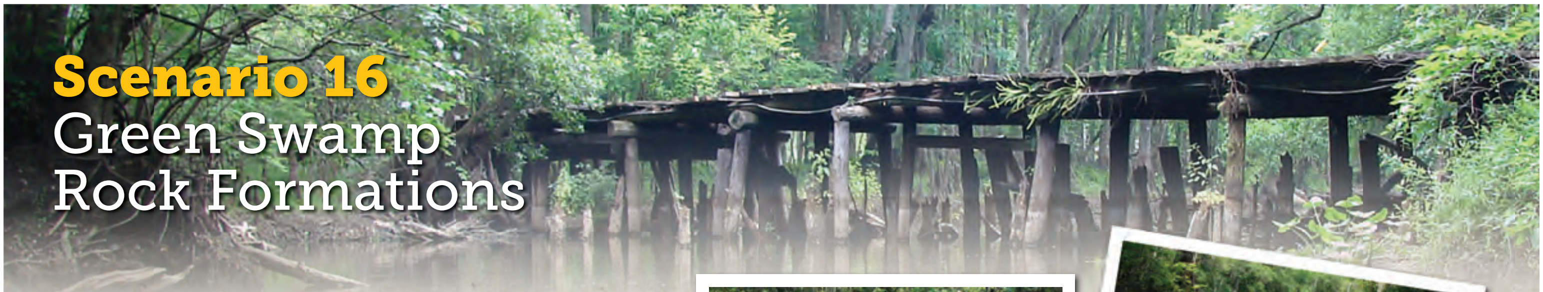


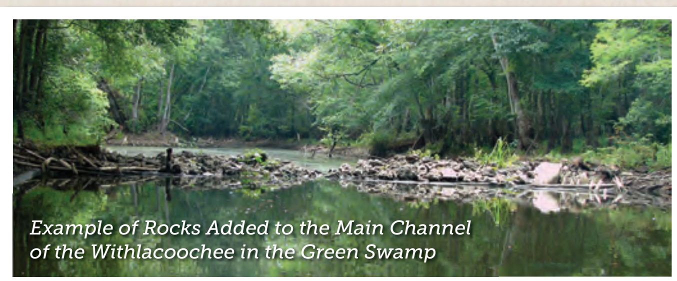
Scenario 16
Green Swamp Rock Formations

Rock Outcroppings

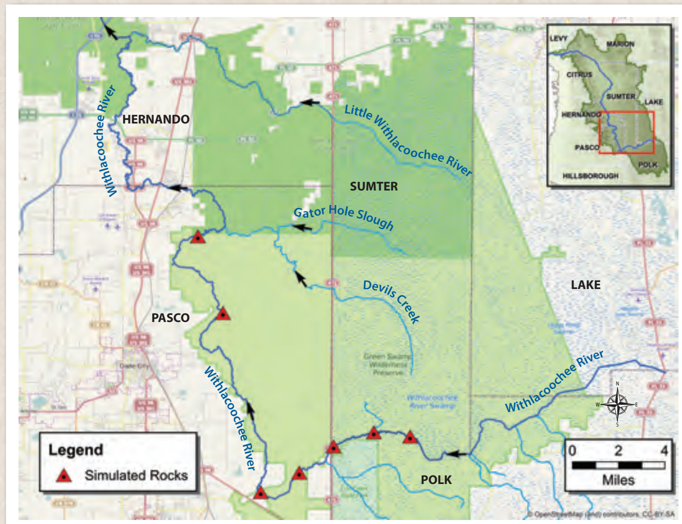
- The interaction of groundwater and surface water is evident by numerous limestone outcroppings that exist at or near land surface in the vicinity of the Green Swamp.

Scenario Description

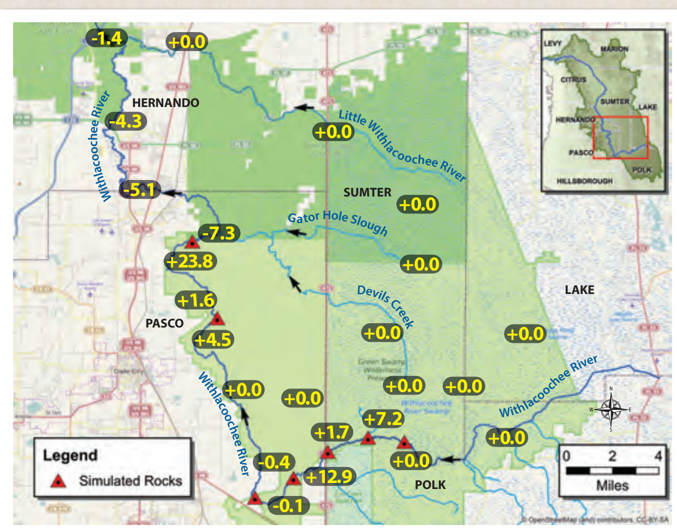
- Concerns relating to low-water levels in the Green Swamp have emerged from claims that critical rock outcroppings within the Withlacoochee River were removed decades ago.
- To evaluate this scenario, the existing river channel was adjusted in the model to simulate the addition of rocks at seven locations where rocks were reported to have been removed or altered in some way.



Example of Rocks Added to the Main Channel of the Withlacoochee in the Green Swamp



Locations of Simulated Rocks



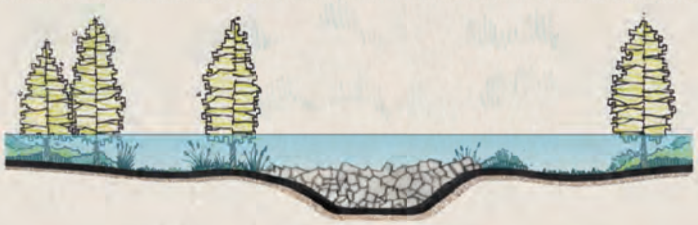
Average Water Level Changes (inches) for the Mean Annual Storm Event

Preliminary Results

- Water level increases were observed immediately upstream of the simulated rocks for the smallest simulated storm.
- These differences were confined to the channel and did not translate far upstream.
- No changes were observed throughout the Green Swamp.
- Water level decreases were observed downstream of the simulated rocks.

Conclusions

- The model results indicate that adding rocks to the main channel of the Withlacoochee River would have little effect on regional water levels within the Green Swamp.
- The graphic (left) demonstrates how the obstructed flow area created by the rocks is relatively small compared to the overall flow area in the swamplands adjacent to the main channel.



Comparison of River Channel With and Without the Addition of Rocks

Scenario 17
Rocks near Jumper Creek

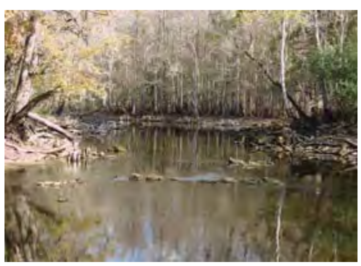
Description

- The Withlacoochee River forms the border of Citrus and Sumter counties as it passes the Tsala Apopka Chain-of-Lakes to the west and several tributaries to the east including the Outlet River from Lake Panasoffkee and Jumper Creek.
- This portion of the river is characterized by a relatively shallow channel, hundreds of feet wide, with a floodplain that extends more than a mile wide in some areas.

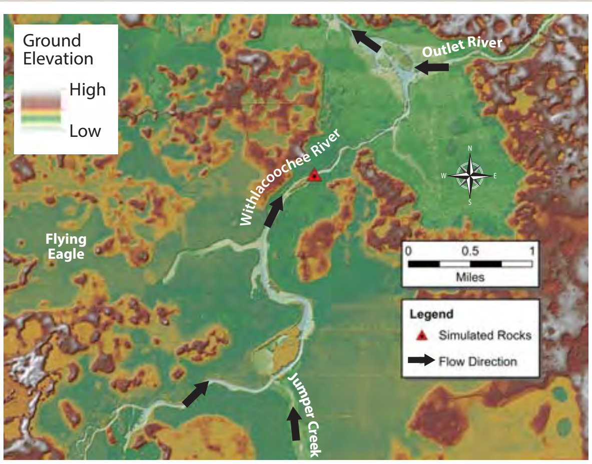
Typical View Along the Withlacoochee River Near Tsala Apopka and Lake Panasoffkee

Scenario Description

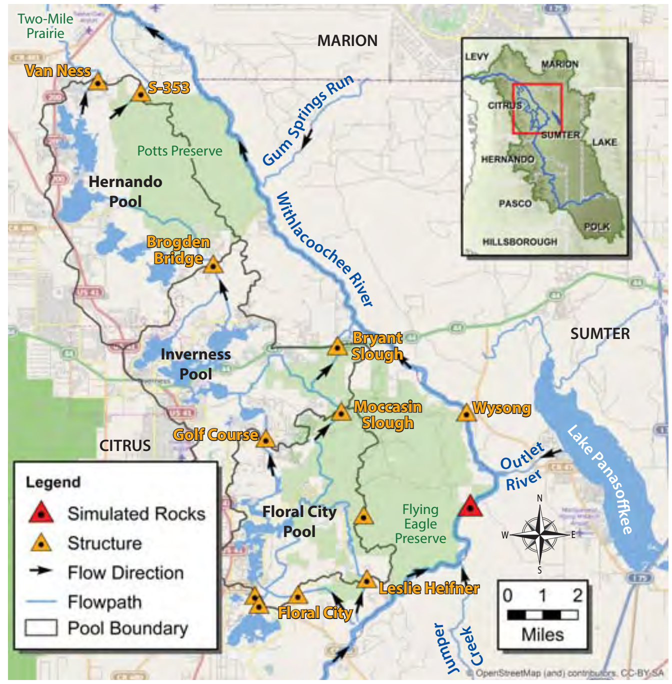
- Two miles downstream of Jumper Creek, the floodplain of the Withlacoochee River narrows to approximately one-quarter mile wide with a 180-foot-wide main channel as it passes between high ground on either side.
- It has been suggested that rocks at this location were removed potentially lowering water levels upstream.
- This scenario evaluated the effects of adding rocks to the main channel of the Withlacoochee River at this location.



Withlacoochee River Near the Location of the Simulated Rocks (2007)



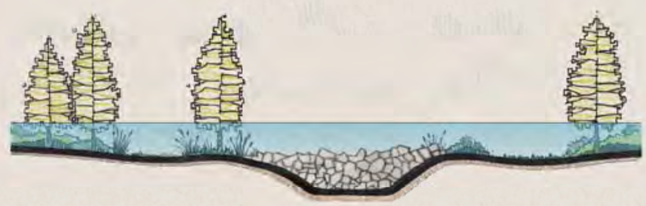
Topography of the Withlacoochee River Between Jumper Creek and the Outlet River



Location of Simulated Rocks Between Jumper Creek and the Outlet River

Preliminary Results

- The simulated storm event with the greatest difference in water levels, as a result of adding rocks to the main channel, was the mean annual event with low initial water conditions.
- Water levels increased by less than one inch on the Withlacoochee River at Jumper Creek and less than one-quarter inch in the Floral City Pool during this event.
- Under high-water conditions there are almost no changes to water levels or flow.



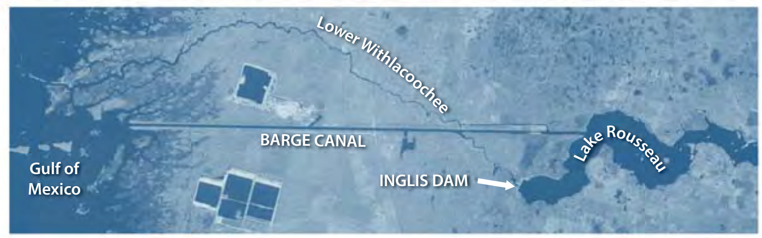
Conclusions

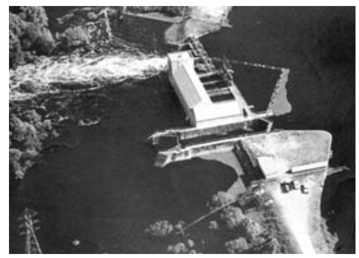
- Model results indicate that adding rocks to the main channel of the Withlacoochee River near Jumper Creek would cause minimal changes to water levels and river flows.
- The area of flow obstructed by the rocks is relatively small (180-feet-wide), as compared to several feet of water flowing over the entire 1,500-foot (quarter-mile) width of the river and adjacent wetlands.

Scenario 18 and 19
Flows to the Lower Withlacoochee

Alterations

- In 1909, Lake Rousseau was formed by the construction of a spillway and lock structure to support navigation and commerce.
- In the 1960s, the Cross Florida Barge Canal severed the Lower Withlacoochee River, requiring the construction of a bypass channel and an additional structure to ensure downstream flows.
- Today, the Inglis Bypass structure, which is located at the end of the Bypass Channel, passes normal flows downstream to the Lower Withlacoochee River while the Inglis Dam conveys excess flows to the Barge Canal.



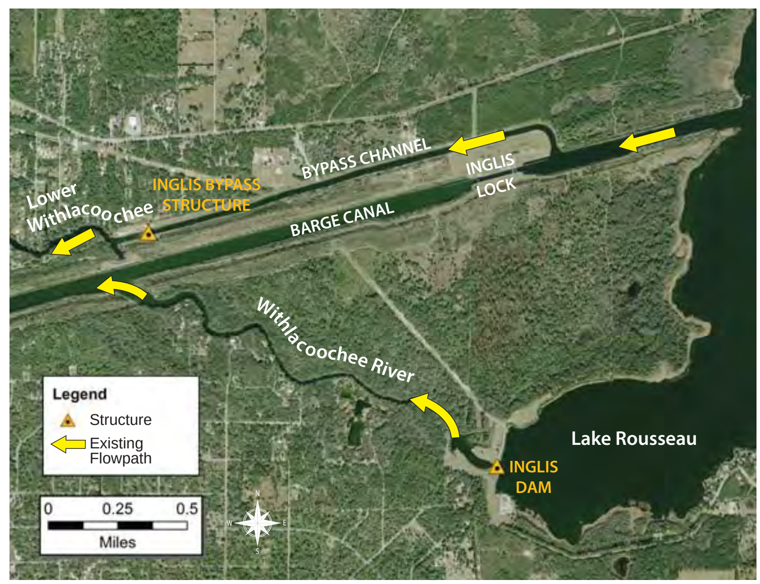


Original Spillway and Lock Structure

Inglis Bypass Structure

Scenario Description

- The flow capacity of the Inglis Bypass structure is limited by water levels that decrease along the Bypass Channel's 8,000 foot length.
- These scenarios evaluated alternatives to provide additional flow to the Lower Withlacoochee through the existing Inglis Bypass structure.
- Scenario 18 simulated a wider Bypass Channel while Scenario 19 simulated a modified flow path from Lake Rousseau through the Barge Canal.



Preliminary Results

- When Lake Rousseau is at its target water level of 26.4 feet (NAVD88) the Inglis Bypass structure allows approximately 1,400 cubic feet per second (cfs) of water downstream to the Lower Withlacoochee River.
- Water levels immediately upstream of the Inglis Bypass structure are typically four inches lower than water levels in Lake Rousseau.
- Doubling the width of the Bypass Channel in Scenario 18 increased water levels on the upstream side of the Inglis Bypass structure by two inches and increased flows through the structure by five percent.
- Using the Barge Canal to convey water to the upstream side of the Inglis Bypass structure in Scenario 19 eliminated the water level difference between the lake and the structure and increased flows through the structure by nine percent.

	Water Level Difference (inches)	Flow to Lower Withlacoochee (cfs)	Flow Increase
Existing Conditions	4.2	1,400	–
Scenario 18 (Bypass Channel widening)	2.2	1,466	5 percent
Scenario 19 (Barge Canal connection)	0.0	1,532	9 percent

Comparison of Water Level and Flow Differences for Scenarios 18 and 19

Conclusions

- Model results suggest that modifying the existing flow path by increasing water levels at the Inglis Bypass structure would increase flows to the Lower Withlacoochee River under certain conditions.
- These increases would occur when Lake Rousseau is at its target water level, the Withlacoochee River is experiencing above average flow, and the current configuration of the Bypass Channel is unable to pass additional flow downstream.
- No increases in flows to the Lower Withlacoochee would be expected under normal or low flow conditions with the simulated modifications.

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