RESTORING THE ROOKERY BAY ESTUARY

A PROJECT CONNECTING PEOPLE AND SCIENCE FOR LONG-TERM COMMUNITY BENEFIT

Rookery Bay National Estuarine Research Reserve

Henderson Creek Watershed Engineering Research Project

Task 2.6 – Fakahatchee Bay Hydrologic Existing Conditions Simulation

Prepared for Rookery Bay National Estuarine Research Reserve

May 2, 2014

Prepared by Taylor Engineering, Inc.

10151 Deerwood Park Blvd, Building 300, Suite 300

Jacksonville, FL 32256

TAYLOR ENGINEERING, INC.

In Association with Interflow Engineering LLC

14499 N Dale Mabry Hwy, Suite 290

Tampa, FL 33618

6/17/15

Rookery Bay National Estuarine Research Reserve

National Estuarine Research Reserve System Science Collaborative

University of New Hampshire

Funding for this project was provided to the Rookery Bay National Estuarine Research Reserve in 2011 – 2015 by the National Estuarine Research Reserve System's (NERRS) Science Collaborative, which is a cooperative agreement between the National Oceanic and Atmospheric Administration (NOAA) and the University of New Hampshire under NOAA grant NA09NOS4190153. The NERRS Science Collaborative puts Reserve-based science to work for coastal communities by engaging the people who need the science in the research process—from problem definition and project design through implementation of the research and use of its results in coastal decisions. For more information about this project, please visit www.rookerybay.org/restoreRB or contact Principal Investigator Tabitha Whalen Stadler at the Rookery Bay National Estuarine Research Reserve in Naples, Florida at 239-530-5940.

Table of Contents

Table of Contents i
List of Figures ii
Executive Summary 1
1.0 Introduction 3
1.1. Purpose 3
1.2. Scope 3
1.3. Methodology 3
1.3.1. Methodology for Comparing Hydrologic Characteristics 3
1.3.2. Methodology for Comparing MIKE-SHE Model Results 4
2.0 Watershed Characteristics 7
2.1. Rookery Bay Watershed Boundary 7
2.2. Rookery Bay Land Use 7
2.3. Rookery Bay Soils 7
2.4. Rookery Bay Surface Water 8
2.5. Fakahatchee Bay Watershed Boundary 16
2.6. Fakahatchee Bay Land Use 16
2.7. Fakahatchee Bay Soils 16
2.8. Fakahatchee Bay Surface Water 16
2.9. Physical Watershed Comparison between Rookery and Fakahatchee Bays 21
3.0 Groundwater Characteristics 22
4.0 MIKE-SHE Model (BCB) 25
4.1. Fakahatchee Bay Model Geometry 30
4.1.1. Model Input and Boundary Conditions 31
4.1.2. Model Calibration 35
4.1.3. Model Results 36
5.0 Hydrologic Response Comparison 44
5.1. Seasonality 45
5.2. Accumulated Runoff Depth 46
5.3. Frequency 47
6.0 Discussion and Recommendations 48
7.0 References 50

List of Figures

Figure 1. Proximity of Fakahatchee Bay to Rookery Bay 6
Figure 2. Rookery Bay's Historic and Existing Watershed Boundaries 9
Figure 3. Existing Rookery Bay Land Use 10
Figure 4. Historic Rookery Bay Land Use 11
Figure 5. Existing Rookery Bay Soils 12
Figure 6. Historic Rookery Bay Soils 13
Figure 7. Existing Rookery Bay Surface Water Flow Paths in LSM Model 14
Figure 8. Historic Rookery Bay Surface Water Flow Paths in NSM Model 15
Figure 9. Fakahatchee Bay Watershed Boundary 17
Figure 10. Fakahatchee Bay Land Use 18
Figure 11. Fakahatchee Bay Soils 19
Figure 12. Fakahatchee Bay Surface Water Flow Paths in LSM Model 20
Figure 13. Connection of Fakahatchee Strand to Okaloacoochee Slough (USGS, 1977) 22
Figure 14. Water Table Aquifer Thickness 27
Figure 15. Water Table Aquifer Horizontal Hydraulic Conductivity 28
Figure 16. Water Table Aquifer Transmissivity 29
Figure 17. Hydrologic Processes Simulated by MIKE-SHE 32
Figure 18. Alignment of the CC-ECM Domain: Coastal Boundary (Shown as Red Line) 34
Figure 19. Alignment of the CC-ECM Domain: Northern/Eastern Boundary (Shown as Red Line) 35
Figure 20. Groundwater Monitoring Sites 36
Figure 21. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site C-296 37
Figure 22. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site C-496 37
Figure 23. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site C-689 38
Figure 24. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site SGT3W7 .. 38
Figure 25. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site SGTSW3... 39
Figure 26. Surface Water Stage Measurement Site 40
Figure 27. MIKE-SHE Surface Water Level Results (solid line) vs. Observations (points) at Site TMBR55 . 41
Figure 28. MIKE-SHE Surface Water Level Results (solid line) vs. Observations (points) at Site TMBR66 . 41
Figure 29. MIKE-SHE Surface Water Level Results (solid line) vs. Observations (points) at Site TMBR77 . 42
Figure 31. Cumulative Coastal Flow Comparison Rookery Bay vs Fakahatchee Watershed 44
Figure 32. Comparison of Monthly Runoff Depth in Inches Rookery Bay vs Fakahatchee Watershed...... 46
Figure 33. Cumulative Runoff Depth: Rookery Bay and Fakahatchee Watersheds 47
Figure 34. Comparison of Flow Duration Curves For Rookery Bay and Fakahatchee Watersheds........ 48

List of Tables

Table 1. Hydrologic Soil Group Summary for the Rookery Bay Watershed.. 8
Table 2. Hydrologic Soils Group Summary for the Fakahatchee Bay Watershed 16
Table 3. Comparison of Physical Watershed Characteristics.. 21
Table 4. Correlation of the Hydrostratigraphy (*Source: Dames and Moore, 1998*) 25
Table 5. Rookery Bay Hydrogeologic Units and Selected Parameters 30
Table 6. Fakahatchee Bay Hydrogeologic Units and Selected Parameters 31
Table 7. Groundwater Boundary Condition Time-series Extension for Each Hydrogeologic Unit............. 33

Executive Summary

This report seeks to gain an understanding of the existing hydrologic conditions of Fakahatchee Bay's watershed and to assess its applicability as a reference site for establishing freshwater inflow goals for the restoration of Rookery Bay's watershed.

Restoring historic or natural system freshwater inflow patterns to Rookery Bay requires an understanding of those patterns. Studying an existing site, similar to Rookery Bay, in its current natural state can provide insight to the function of Rookery Bay in its historic natural state. Fakahatchee Bay's watershed is a mostly undeveloped protected state preserve. Given its close proximity to Rookery Bay, Fakahatchee Bay experiences many of the same environmental conditions. An understanding of the current function of Fakahatchee Bay's watershed can reveal assertions on Rookery Bay's watershed's historic function.

Interflow Engineering and Taylor Engineering (the team) performed an analysis that includes defining and comparing hydrologic characteristics (surface area, land cover types, soil types, surface water flow patterns, and groundwater levels) for the Rookery Bay (historic and existing) and Fakahatchee Bay watersheds. It also includes a summary of the MIKE-SHE/MIKE-11 model geometry, input, boundary conditions, and calibration for the Fakahatchee Bay watershed. Finally, this analysis compares MIKE-SHE/MIKE-11 model results at several locations between the Fakahatchee Bay watershed and the historic Rookery Bay watershed. The watershed comparison includes seasonality, volume, and frequency of freshwater flows to each bay. Comparison of the hydrologic watershed characteristics between Rookery Bay (existing and historic) and Fakahatchee Bay reveals unique aspects that contribute to the hydrologic function of each watershed. The table below summarizes the watershed area, developed and undeveloped land use percentages, soil hydrologic group breakdown, and total length of surface water flow features within each system.

	Existing Rookery Bay	Historic Rookery Bay	Fakahatchee Bay
Watershed Area (SqMi)	167	247	237
% Undeveloped Land Use	30	100	87
% Developed Land Use	70	0	13
% Soil Group A	1	1	< 1
% Soil Group A/D	73	72	71
% Soil Group B/D	3	8	25
% Soil Group C/D	17	15	4
Surface Flow Paths (Mi)	128	15	86

From the comparisons above it is notable that Fakahatchee Bay's watershed, in its existing condition, is less developed but not completely free from anthropogenic impacts. Fakahatchee Bay's watershed contains significantly more B/D type soils and less C/D type soils which impacts rainfall runoff infiltration rates.

The United States Geologic Survey (USGS) published a report in 1977, "*The Effect of the Faka Union Canal System on the Water Levels in the Fakahatchee Strand, Collier County, Florida*." The report documents Fakahatchee Strand (Fakahatchee Bay's watershed) as a unique feature that had its headwaters connected to the Okaloacoochee Slough which differentiates it from the historic function of Rookery Bay's watershed.

MIKE-SHE/MIKE-11 results indicate the Fakahatchee Bay watershed contributes about 2.4 times the volume of water for the period of 2003 – 2012 than historic Rookery Bay's watershed. However, given that the two watersheds cover unique surface areas, model results for seasonality, accumulated runoff depth and frequency were normalized on a per unit acre basis to facilitate a more representative comparison between the two watersheds.

Seasonality: The Fakahatchee Bay watershed consistently delivers more fresh water per unit area to the bay than the Rookery Bay watershed. The dry season months of January – May show little difference with respect to watershed runoff contributions in inches. However, when examining the wet season runoff depths, the differences are greatest in August – November, which in general corresponds to the highest rainfall depths.

Accumulated Runoff Depth: The accumulated runoff depth from the Fakahatchee Bay's watershed is about two times the runoff depth per unit area than from historic Rookery Bay's watershed.

Frequency: Fakahatchee Bay's watershed contributes low-frequency, high-flow events over longer time periods when compared with historic Rookery Bay's watershed. However, for high-frequency, low-flow events, historic Rookery Bay's watershed contributes more water than Fakahatchee Bay's watershed.

Considering the rather large differences in normalized freshwater deliveries and the limited (but significant) flow alterations that have occurred within the Fakahatchee watershed, this analysis does not strongly support the use of Fakahatchee Bay's watershed as a reference site**.** Notably, an investigation into the effects of these differences on salinity distributions within the Rookery and Fakahatchee Bays was beyond the scope of this analysis. Until such an investigation is completed, the suitability of Fakahatchee Bay as a reference site for Rookery Bay should not be ruled out.

1.0 Introduction

Interflow Engineering and Taylor Engineering (the team) updated and refined the MIKE-SHE/MIKE-11 model developed for Collier County (CC-ECM), which includes the Big Cypress Basin (BCB). The aforementioned model domain covers several watersheds including the existing conditions Rookery Bay and Fakahatchee Bay watersheds. The team also developed a Natural Systems Model (NSM) for the historic Rookery Bay watershed. The Fakahatchee Bay watershed is mostly undeveloped, currently managed as a state preserve. Fakahatchee Bay lies approximately 20 miles southeast of the Rookery Bay watershed (Figure 1). Its close proximity and undeveloped state lends itself as a potential reference site for establishing restoration goals in the Rookery Bay watershed.

1.1. Purpose

With this analysis, the team seeks to gain an understanding of the existing hydrologic conditions of Fakahatchee Bay's watershed and to assess its applicability as a reference site for establishing freshwater inflow goals for the restoration of Rookery Bay's watershed.

1.2. Scope

This analysis includes defining and comparing hydrologic characteristics (surface area, land cover types, soil types, surface water flow patterns, and groundwater levels) for the Rookery Bay (historic and existing) and Fakahatchee Bay watersheds. It also includes a summary of the MIKE-SHE/MIKE-11 model geometry, input, boundary conditions, and calibration for the Fakahatchee Bay watershed. Finally, this analysis compares MIKE-SHE/MIKE-11 model results at several locations between the Fakahatchee Bay watershed and the historic Rookery Bay watershed. The watershed comparison includes seasonality, volume, and frequency of freshwater flows to each bay.

1.3. Methodology

Two separate but related analyses are presented for this study. First, a comparison of the hydrologic characteristics of each watershed (Rookery Bay [existing and historic] and Fakahatchee Bay) and secondly, a comparison of MIKE-SHE/MIKE-11 model results between the Fakahatchee Bay watershed and the historic Rookery Bay watershed. This section describes the methodologies utilized by the team to perform each analysis.

1.3.1. Methodology for Comparing Hydrologic Characteristics

The team collected pertinent GIS data to perform the characterization of each watershed including watershed boundaries, land use data, soils data, and surface water flow paths.

The team obtained existing condition watershed boundaries from SFWMD's Arc Hydro Enhanced Database in raw shapefile form. For modeling purposes, these boundaries were modified according to available topographic data and hydrologic features that are included in the LSM. The Historic Rookery Bay watershed was derived from topographic, aerial photographic analysis, and local knowledge of historic flow paths before anthropogenic alterations occurred in the watershed. These boundaries are used by the team as the basis for which the hydrologic characteristic comparisons are made. A comparison of the watersheds is presented in Figure 1.

The team collected land use data from the SFWMD's 2009 land use database for the existing Rookery Bay watershed and the Fakahatchee Bay watershed. The team utilized SFWMD's 2002 Southwest Florida Pre-Development Vegetation Map for the historic Rookery Bay watershed comparison. Both sets of land use data, in GIS shapefile format, contain spatially mapped land use types and associated attributes for the entire domain of the SFWMD's governance. Using functions within ArcGIS, the team clipped the land use data within the boundaries of each watershed. By clipping the data to each of the watershed boundaries, analysts summarized the number of different land use types, the area of each land use type, and calculated the percentage of developed versus undeveloped land use types for each watershed.

Using methodology similar to the comparison of land uses, the team obtained soils data from the Natural Resources Conservation Service (NRCS) soils database (SSURGO). The soils data from SSURGO is provided in GIS shapefile format containing spatially mapped soils and their associated attributes. SSURGO is populated with many different soil parameters and properties at a relatively fine scale. For this analysis, the team grouped the soils by their hydrologic group classification. Using functions within ArcGIS, the team clipped the soils data within the boundaries of each watershed. By clipping the data to each of the watershed boundaries, analysts summarized the area of each hydrologic classification, and the percentage of each classification for each of the watersheds.

The team compared surface water flow paths within each of the watersheds using the MIKE-SHE/MIKE-11 CC-ECM and NSM models. Analysts extracted the surface water flow paths from the CC-ECM for the existing Rookery Bay watershed and for the Fakahatchee watershed and utilized the NSM for the historic Rookery Bay watershed. Analysts converted the model data to GIS shapefile format and computed the total miles of surface water flow paths for each watershed.

The end result of this analysis is a simple comparison table (Table 3) that presents a summary of each analyzed characteristic on a per watershed basis.

1.3.2. Methodology for Comparing MIKE-SHE Model Results

To analyze and compare the MIKE-SHE/MIKE-11 model results for the historic Rookery Bay and Fakahatchee Bay watersheds, the team focused on the coastal flow from each watershed. The coastal flow produced by each watershed is a sum of the shallow overland sheet flows plus the concentrated channel flows.

The team simulated 10 years (from 2002-2012) for each watershed and analyzed the coastal flow produced by each watershed by seasonality, accumulated runoff depth, and frequency. Since the historic Rookery Bay watershed and the Fakahatchee Bay watershed cover unique surface areas, the model results for seasonality, accumulated runoff depth and frequency are normalized on a per unit acre basis to facilitate a more representative comparison between the two watersheds.

Seasonality is determined by averaging all flows for each month for the 10 year simulation period. For example, all flows occurring in January for the 10 year simulation period are averaged then divided by the respective watershed area to yield the normalized flow per unit acre per month as illustrated in Figure 32.

Accumulated runoff depth is determined by accumulating the total volume of coastal flow over the entire 10 year simulation period and dividing by the respective watershed area to yield the normalized runoff depth in inches per acre. This calculation is performed on a daily basis to produce a time-series graph as shown in Figure 33.

Frequency and duration is expressed by flow duration curves for each watershed as illustrated by Figure 34. The flow duration curve is a plot that shows the percentage of time that a computed flow is likely to be equaled or exceeded by all other computed flows. All flows for the 10 year simulation period are ranked from lowest to highest; then the percentage of time each flow is exceeded is computed with the following equation:

$$P = 100 * [M / (n+1)]$$

Where,

P = the probability that a given flow will be equaled or exceeded (% time)

M = the ranked position of a given flow

n = the number of flows for the entire simulation period

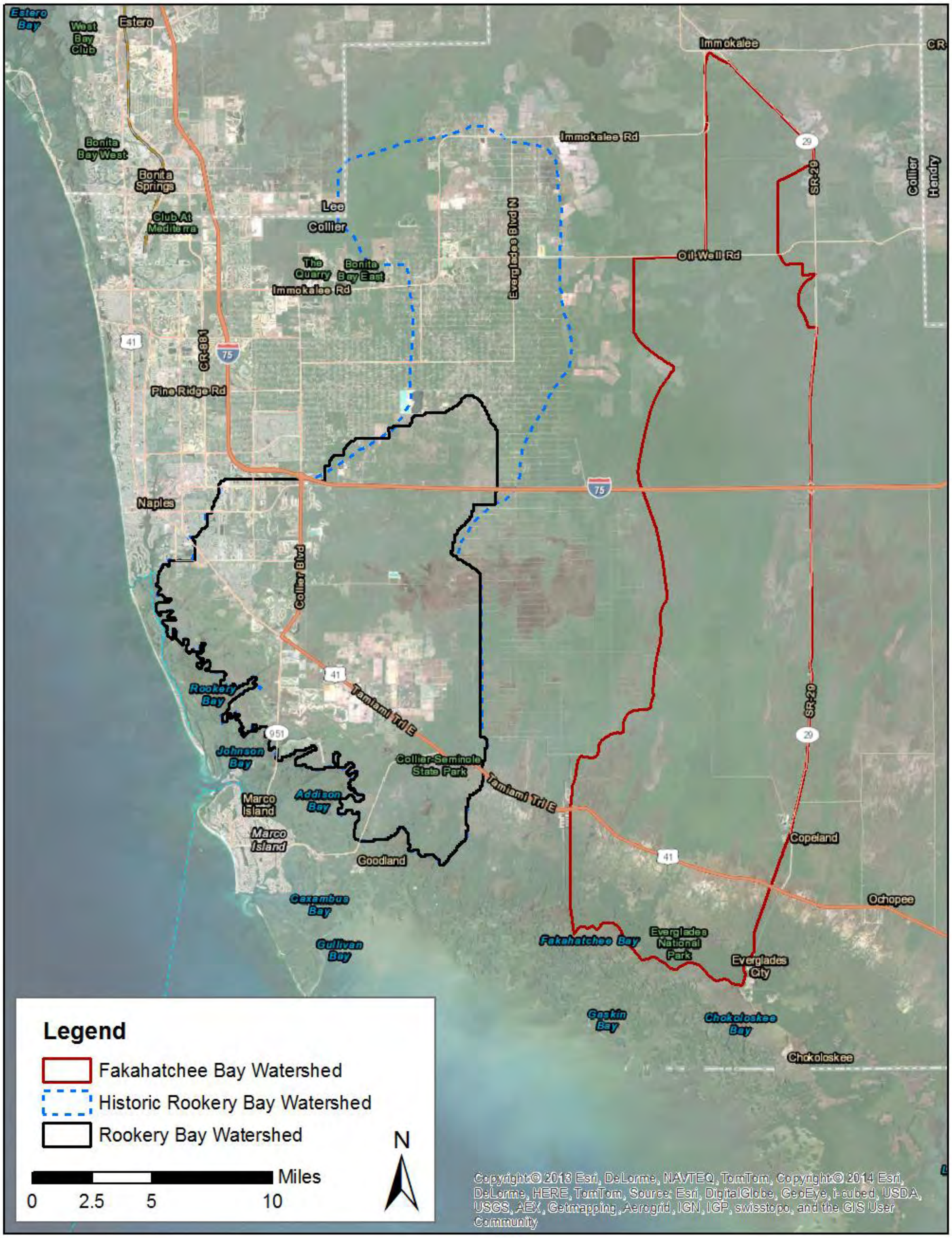


Figure 1. Proximity of Fakahatchee Bay to Rookery Bay

2.0 Watershed Characteristics

Restoring historic or natural system freshwater inflow patterns to Rookery Bay requires an understanding of those patterns. In the case of Rookery Bay, historic records do not predate 1940. For the current project, the team developed a MIKE-SHE Natural Systems Model (NSM) to predict the response of the watershed before anthropogenic changes occurred in Rookery Bay's watershed.

An alternative method of gaining insight to the function of Rookery Bay in its historic natural state includes studying an existing site, similar to Rookery Bay, in its current natural state. Fakahatchee Bay's watershed is a mostly undeveloped protected state preserve. Given its close proximity to Rookery Bay, Fakahatchee Bay experiences many of the same environmental conditions. An understanding of the current function of Fakahatchee Bay's watershed can reveal assertions on Rookery Bay's watershed's historic function.

The following sections define the physical hydrologic characteristics for both watersheds.

2.1. Rookery Bay Watershed Boundary

Rookery Bay's watershed has experienced drastic anthropogenic changes during its late history. Human alteration of the watershed due to agricultural practices, residential and commercial infrastructure, and canalization has altered the flow characteristics of the historic (pre-development) watershed. The historic watershed encompassed approximately 247 square miles stretching from Immokalee Road to the intertidal zone of the Gulf of Mexico (Figure 2). The existing condition watershed encompasses approximately 167 square miles stretching from north of Interstate 75 to the intertidal zone of the Gulf of Mexico (Figure 2).

2.2. Rookery Bay Land Use

The existing Rookery Bay watershed includes 86 different land use types (Figure 3) as defined by the South Florida Water Management District's (SFWMD) 2009 land use database. The 167 square-mile existing watershed includes approximately 70% natural land use types and 30% developed land use types.

The historic (pre-development) Rookery Bay watershed includes 12 different vegetation types (Figure 4) as defined by the SFWMD 2002 Southwest Florida Pre-Development Vegetation Map. The 247 square-mile historic watershed includes 55% Flatwoods, 15% Swamp Forests, 12% Mangrove, 11% Cypress, and 7% other.

2.3. Rookery Bay Soils

The existing Rookery Bay watershed includes 40 soil types and the historic watershed includes 48 soil types according to the NRCS soils database (SSURGO). The various soil types are assigned to a hydrologic soils group (A – D) based on the soil's runoff potential. Soils in group A are typically loose sands that allow water to infiltrate quickly, with a low potential for surface runoff. Soils in group D are typically fine soils that restrict infiltration, thus generating more surface runoff. Soils assigned to dual groups (e.g. A/D, B/D, and C/D) refer to soils that potentially encounter high water tables. The first letter refers to the runoff potential during drained conditions (low water table) and the second letter refers to the runoff potential during undrained conditions (high water table). Figures 5and 6 illustrate and Table 1 summarizes the hydrologic soil groups within the existing and historic Rookery Bay watersheds.

Table 1. Hydrologic Soil Group Summary for the Rookery Bay Watershed

Group	Description	Historic Area (SqMi)	Historic % Area	Existing Area (SqMi)	Existing % Area
A	Low runoff potential; <10% clay; >90% sand	3	1	2	1
A/D	Low runoff potential when well drained; high runoff potential when undrained; <10% clay; >90% sand	184	72	122	73
B/D	Moderately low runoff potential when well drained; high runoff potential when undrained; 10-20% clay; 50-90% sand	19	8	5	3
C/D	Moderately high runoff potential when well drained; high runoff potential when undrained; 20-40% clay; <50% sand	38	15	28	17
Water	Surface water	11	4	10	6

2.4. Rookery Bay Surface Water

The LSM MIKE-SHE model includes 128 miles of surface water flow paths within the existing Rookery Bay watershed (Figure 7) and the NSM MIKE-SHE model includes 15 miles of surface water flow paths within the historic Rookery Bay watershed (Figure 8). Surface water generally flows in a northeastern to southwestern direction, towards the Rookery Bay estuary, as depicted by the flow path centerlines in Figures 7 and 8. Most of the modeled flow paths in the LSM MIKE-SHE model are man-made canals controlled by hydraulic structures such as weirs, sluice gates, and culverts. In the existing Rookery Bay watershed, the only significant sheet flow exists south of Interstate 75 through a series of culverts before encountering Tamiami Trail.

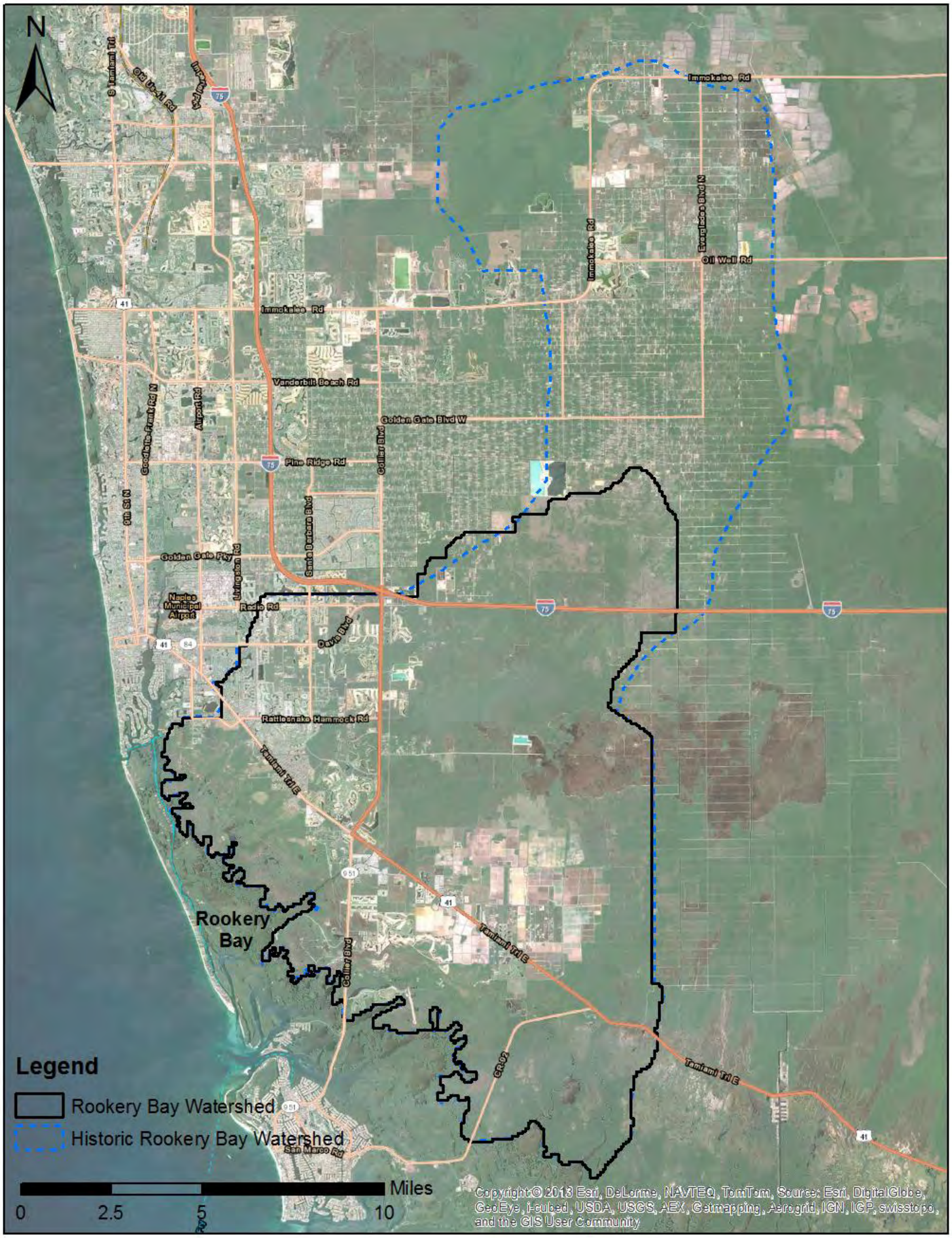


Figure 2. Rookery Bay's Historic and Existing Watershed Boundaries

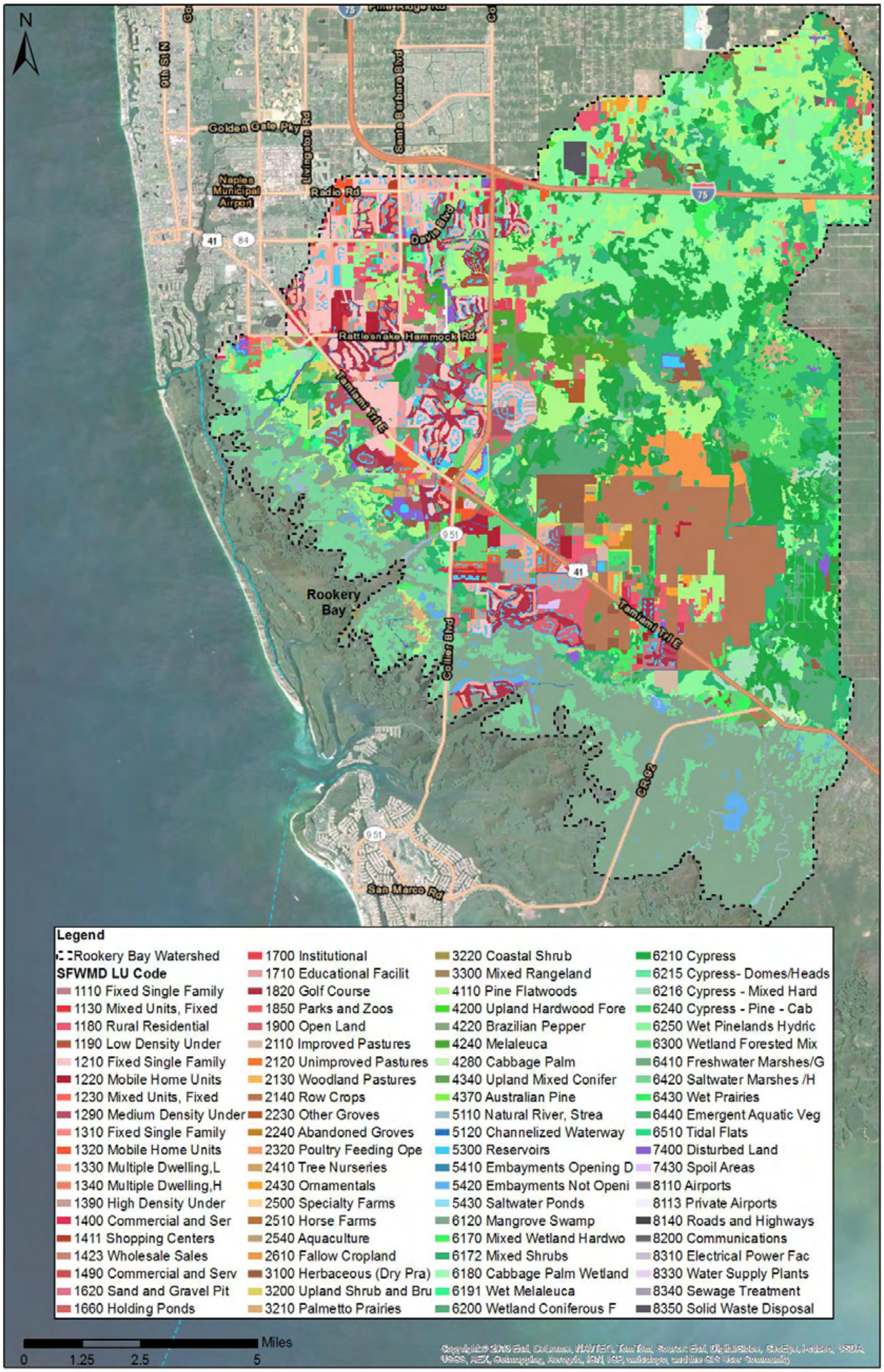


Figure 3. Existing Rookery Bay Land Use

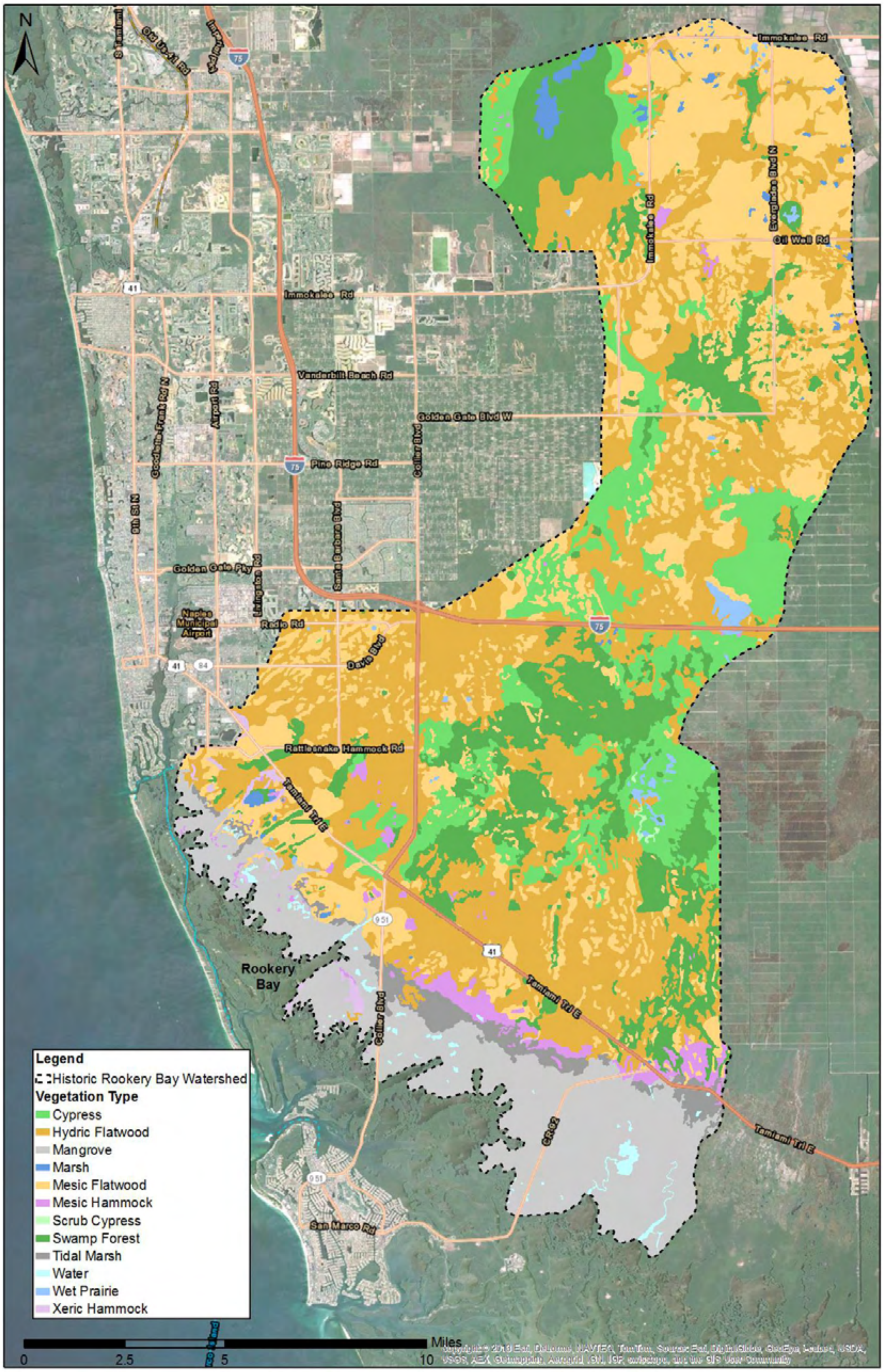


Figure 4. Historic Rookery Bay Land Use

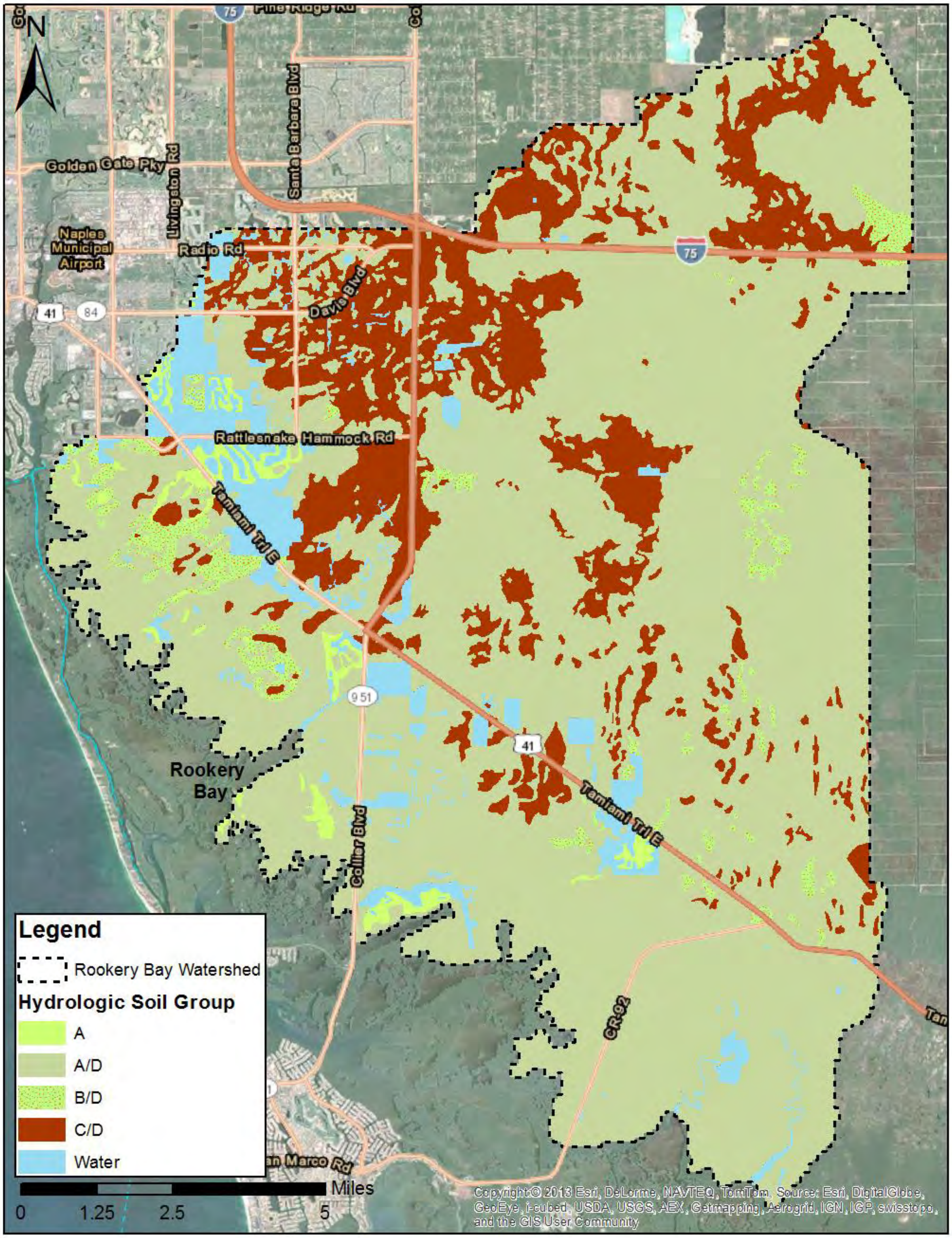


Figure 5. Existing Rookery Bay Soils

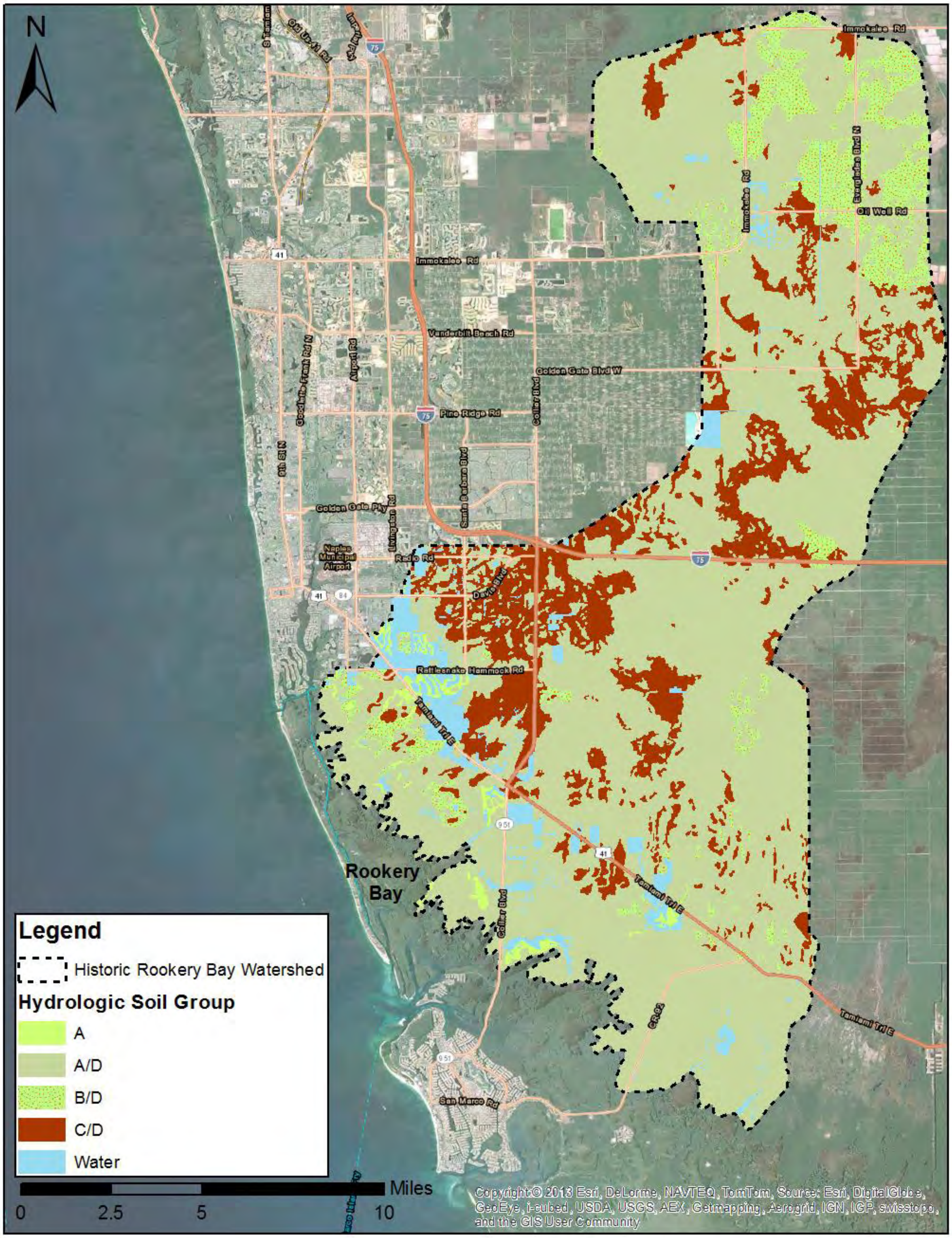


Figure 6. Historic Rookery Bay Soils

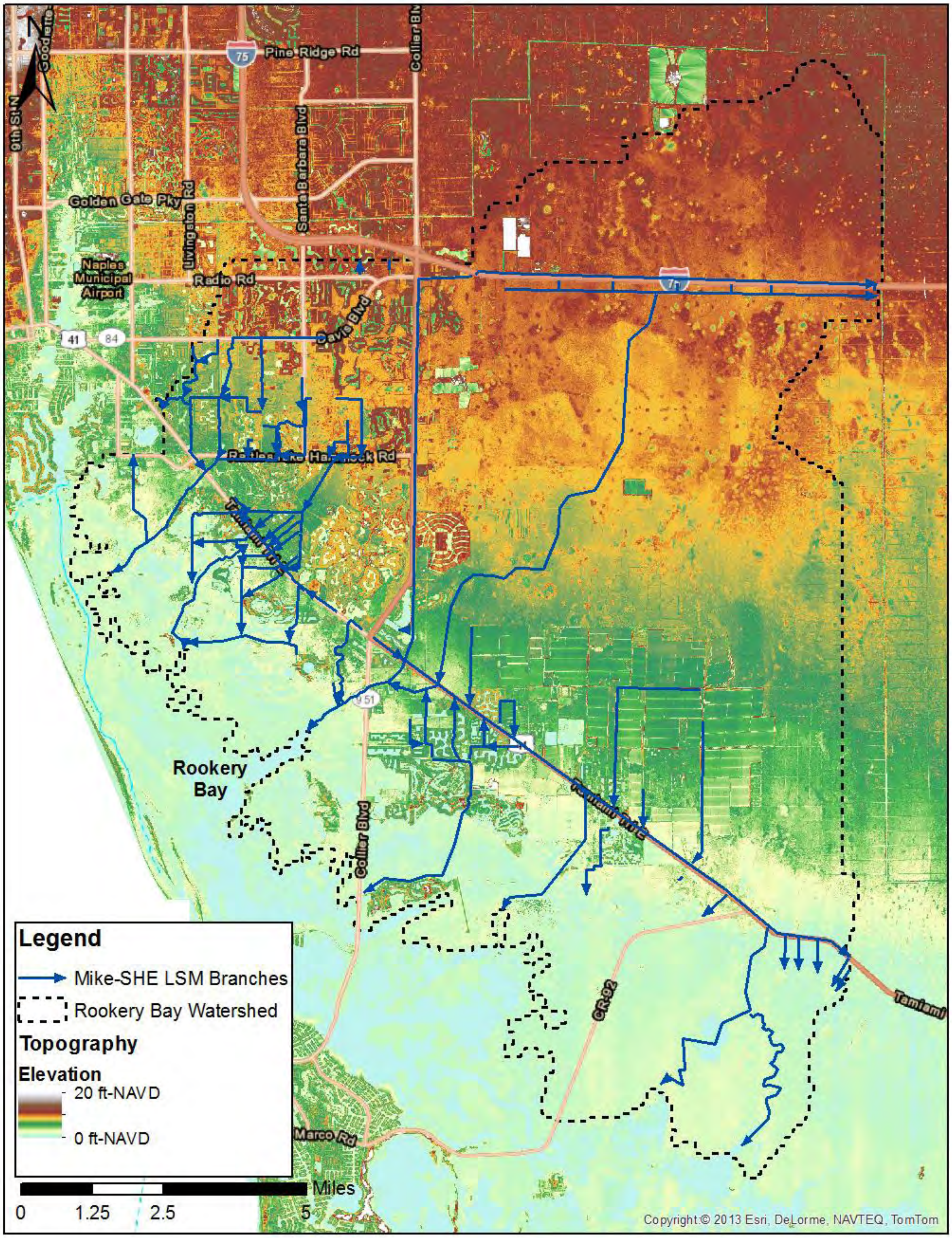


Figure 7. Existing Rookery Bay Surface Water Flow Paths in LSM Model

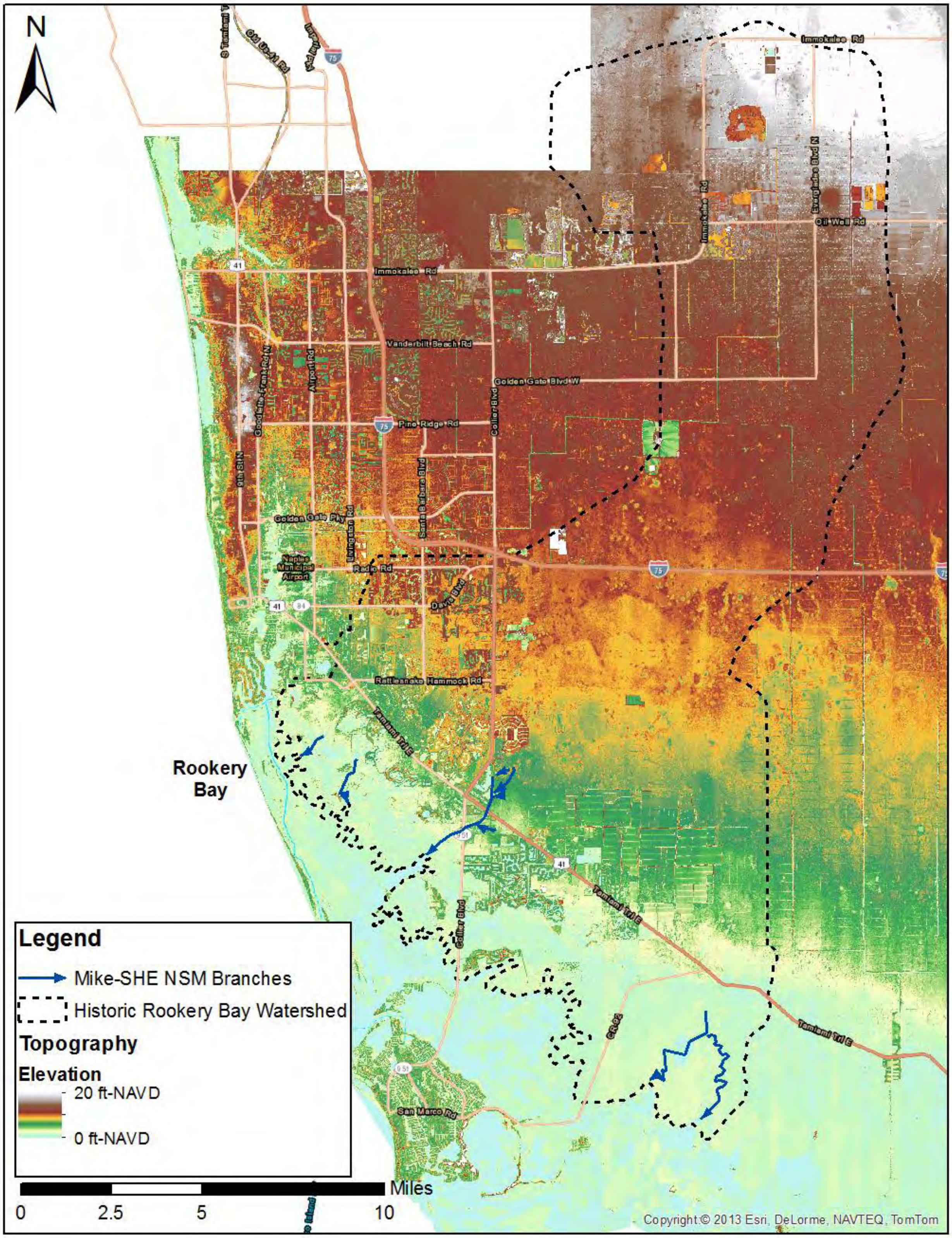


Figure 8. Historic Rookery Bay Surface Water Flow Paths in NSM Model

2.5. Fakahatchee Bay Watershed Boundary

Fakahatchee Bay's watershed encompasses approximately 237 square miles stretching from CR-848 to the intertidal zone of the Gulf of Mexico (Figure 9).

2.6. Fakahatchee Bay Land Use

The Fakahatchee Bay watershed includes 71 different land use types (Figure 10) as defined by the SFWMD's 2009 land use database. The 237 square-mile watershed includes approximately 87% natural land use types and 13% developed land use types.

2.7. Fakahatchee Bay Soils

The Fakahatchee Bay watershed includes 26 soil types according to the NRCS soils database (SSURGO). Figure 11 illustrates and Table 2 summarizes the hydrologic soil groups within the Fakahatchee Bay watershed.

Table 2. Hydrologic Soils Group Summary for the Fakahatchee Bay Watershed

Group	Description	Area (SqMi)	% Area
A	Low runoff potential; <10% clay; >90% sand	< 1	< 1
A/D	Low runoff potential when well drained; high runoff potential when undrained; <10% clay; >90% sand	168	71
B/D	Moderately low runoff potential when well drained; high runoff potential when undrained; 10-20% clay; 50-90% sand	58	25
C/D	Moderately high runoff potential when well drained; high runoff potential when undrained; 20-40% clay; <50% sand	10	4
Water	Surface water	1	< 1

2.8. Fakahatchee Bay Surface Water

The BCB MIKE-SHE model includes 86 miles of surface water flow paths within the Fakahatchee Bay watershed (Figure 12). Surface water generally flows from north to south, towards the Fakahatchee Bay estuary, as depicted by the flow path centerlines in Figure 9. Most of the modeled flow paths are natural flow paths consisting of shallow creeks, wetlands, and slough flow paths. A significant slough feature exists between Interstate 75 and Tamiami Trail. Flow through this slough is shallow and slow moving.

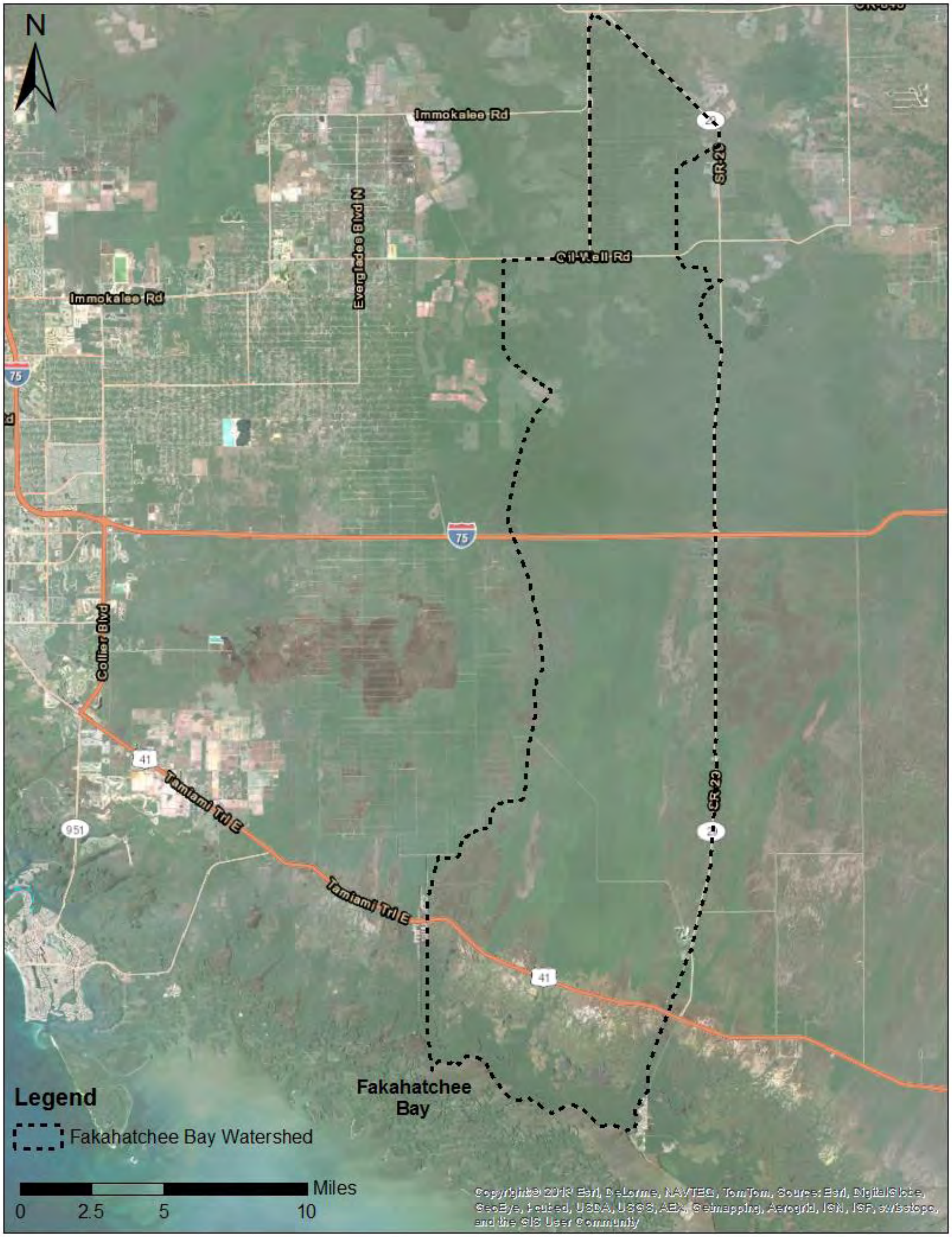


Figure 9. Fakahatchee Bay Watershed Boundary

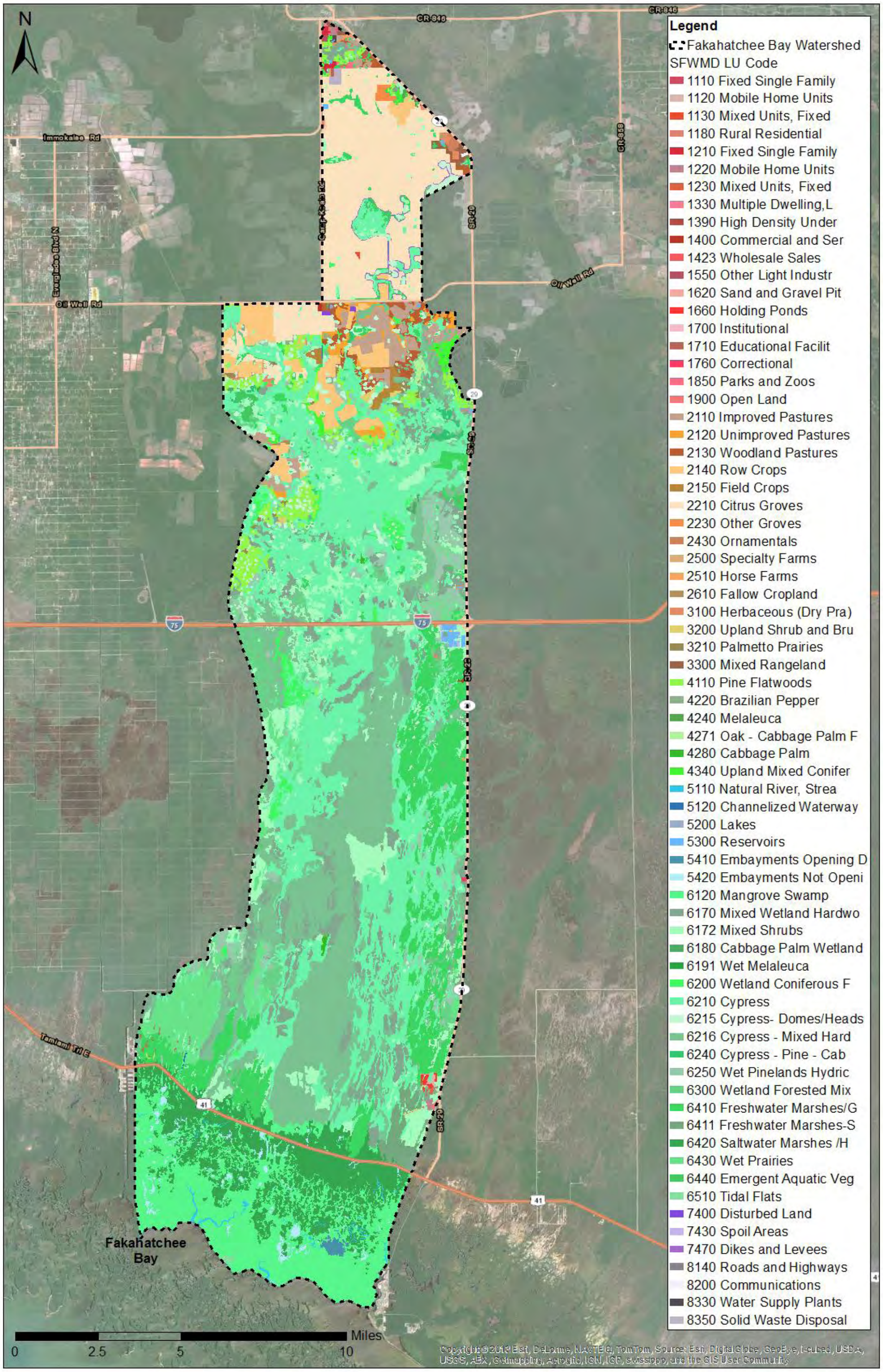


Figure 10. Fakahatchee Bay Land Use

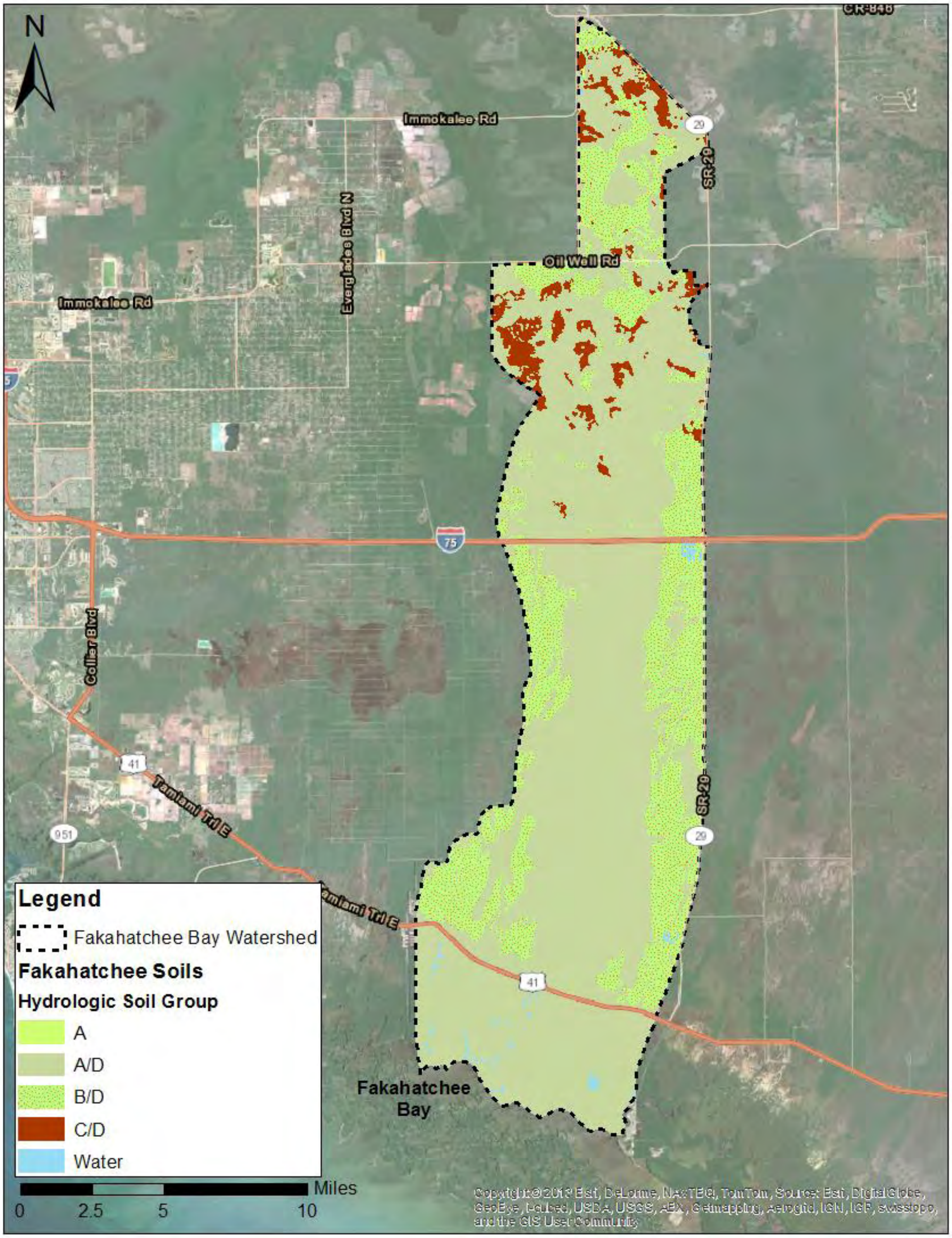


Figure 11. Fakahatchee Bay Soils

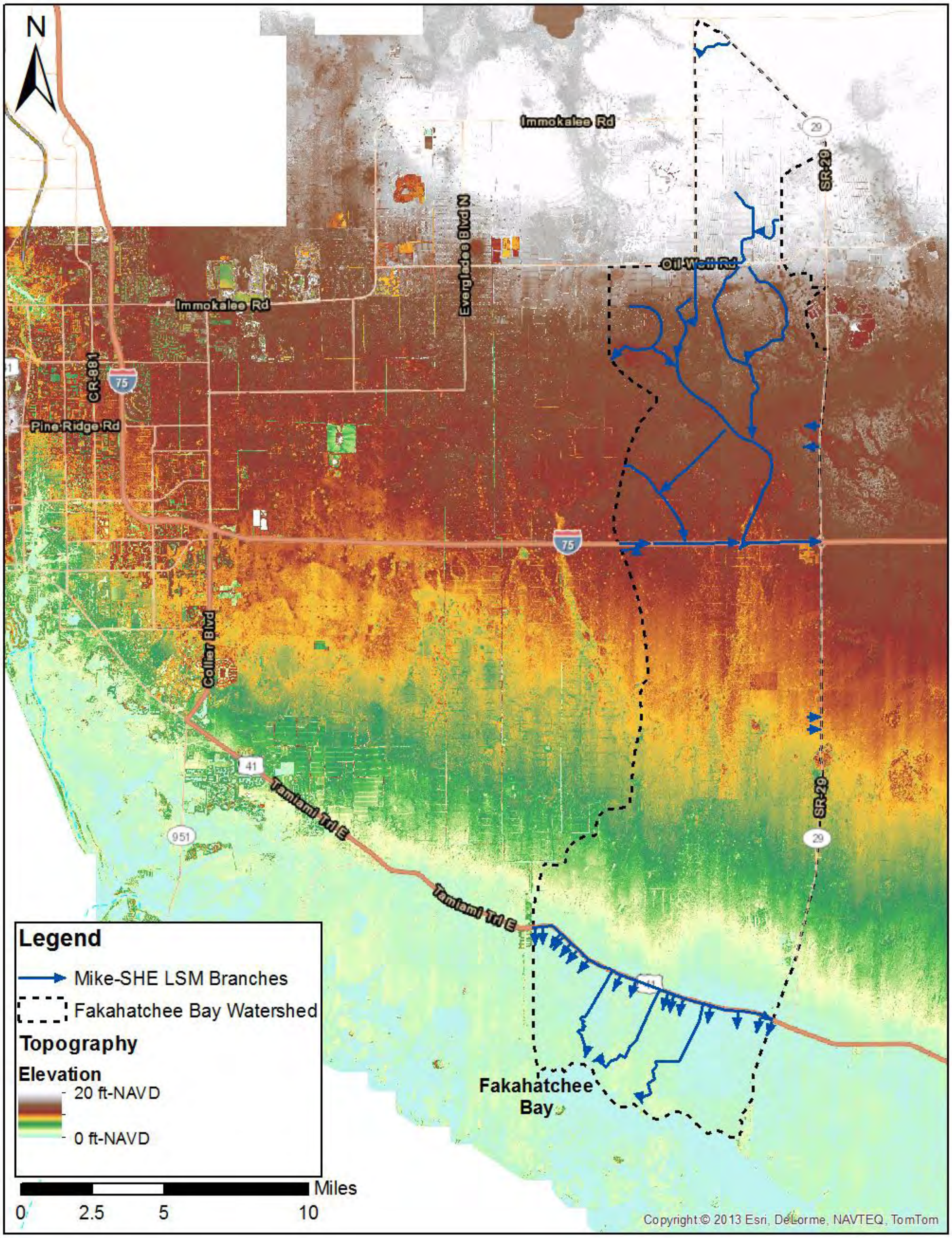


Figure 12. Fakahatchee Bay Surface Water Flow Paths in LSM Model

2.9. Physical Watershed Comparison between Rookery and Fakahatchee Bays

Comparison of the hydrologic watershed characteristics between Rookery Bay (existing and historic) and Fakahatchee Bay reveals unique aspects that contribute to the hydrologic function of each watershed. Table 3 summarizes the watershed area, developed and undeveloped land use percentages, soil hydrologic group breakdown, and total length of surface water flow features within each system.

Table 3. Comparison of Physical Watershed Characteristics

	Existing Rookery Bay	Historic Rookery Bay	Fakahatchee Bay
Watershed Area (SqMi)	167	247	237
% Undeveloped Land Use	30	100	87
% Developed Land Use	70	0	13
% Soil Group A	1	1	< 1
% Soil Group A/D	73	72	71
% Soil Group B/D	3	8	25
% Soil Group C/D	17	15	4
Surface Flow Paths (Mi)	128	15	86

From the comparisons above it is notable that Fakahatchee Bay's watershed, in its existing condition, is less developed but not completely free from anthropogenic impacts. Fakahatchee Bay's watershed contains significantly more B/D type soils and less C/D type soils which impacts rainfall runoff infiltration rates. Also, the Fakahatchee Bay's watershed contains significantly fewer surface water flow paths than the existing Rookery Bay watershed but significantly more than the historic Rookery Bay watershed.

The United States Geologic Survey (USGS) published a report in 1977, "*The Effect of the Faka Union Canal System on the Water Levels in the Fakahatchee Strand, Collier County, Florida*." The report documents Fakahatchee Strand (Fakahatchee Bay's watershed) as a unique feature that had its headwaters connected to the Okaloacoochee Slough which differentiates it from the historic function of Rookery Bay's watershed as illustrated in Figure 13.

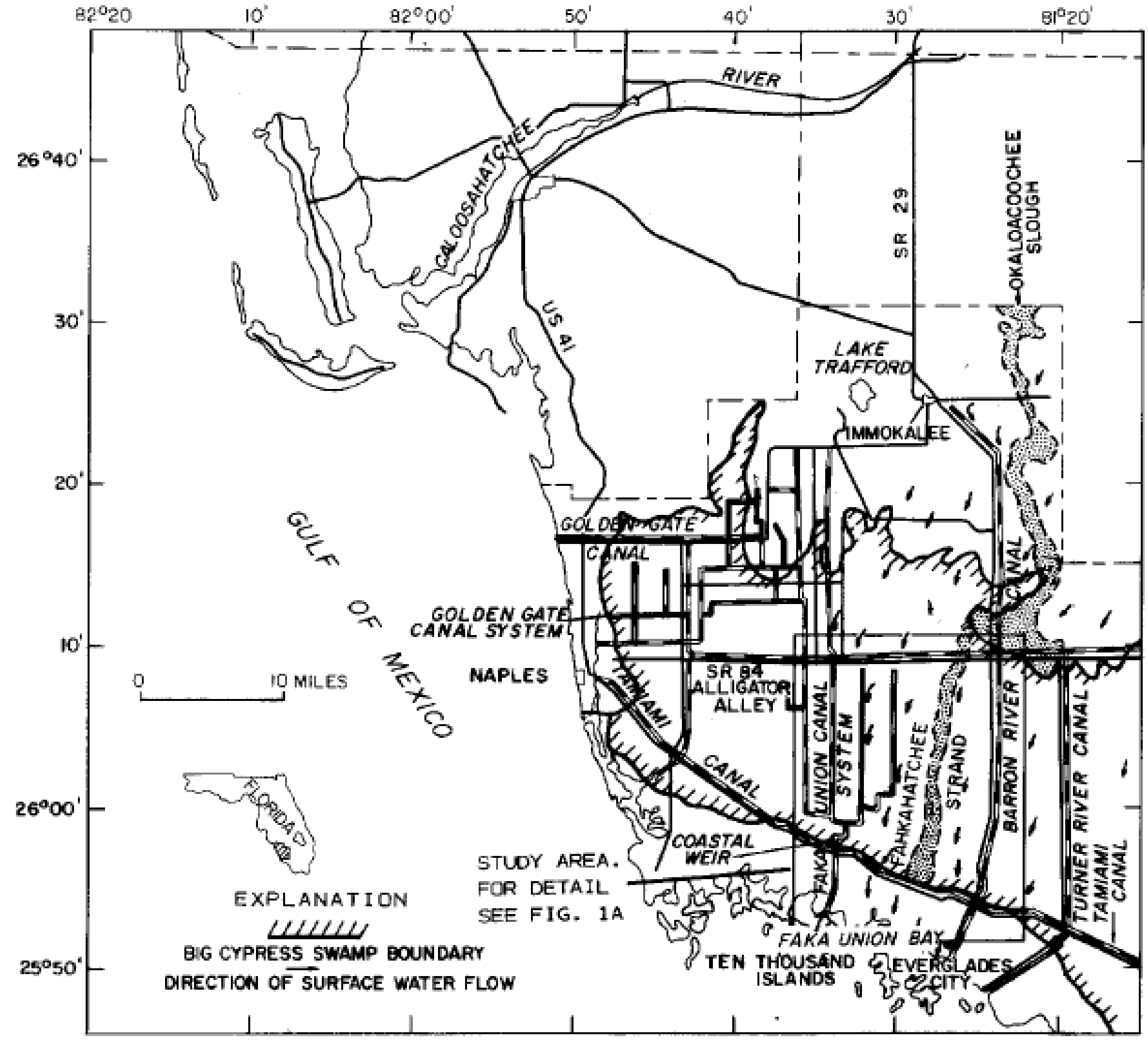


Figure 13. Connection of Fakahatchee Strand to Okaloacoochee Slough (USGS, 1977)

3.0 Groundwater Characteristics

The following hydrogeologic descriptions come from Section 2.6 Groundwater Hydrology from "Task D – Model Development Big Cypress Basin Watershed Plan" prepared by Dames and Moore (1998). This section has been cited as the information has not changed and remains accurate as well as relevant to the Henderson Creek (Rookery Bay) and Fakahatchee watersheds within the Big Cypress Basin.

The hydrogeology of the Big Cypress Basin consists of a water table or surficial aquifer system, an intermediate aquifer system, and the Floridan aquifer system. The stratigraphy that composes these aquifer systems ranges in age from the Holocene to Paleocene (Table 4). The surficial aquifer system is generally composed of Holocene and Pleistocene undifferentiated sand deposits and the Pliocene Tamiami Formation. The intermediate aquifer system lies within the Hawthorn Group sediments. The Floridan aquifer system found in the Miocene to Paleocene age sediments has poor water quality and is not used for potable supplies or irrigation. The following discussion is from SFWMD (1986) unless otherwise noted.

The surficial aquifer system includes all deposits from the most recent deposits down to the Tamiami Formation. This system is broken down into three groups — the water table aquifer, the leaky Tamiami confining zone, and the lower Tamiami aquifer.

The water table aquifer consists of Holocene to Pleistocene undifferentiated deposits, typically well-sorted sands, and sandy limestone of the upper Tamiami Formation. The sandy limestone can produce prodigious amounts of water where present, with transmissivities ranging from 100,000 to over 1,000,000 gallons per day per foot (gpd/ft) (USACE, 1986). Water quality is typical for surficial aquifers in Florida.

The underlying Tamiami confining bed is generally continuous throughout the region, except around the Immokalee area, where it appears to be absent. The leakage of this unit can be high with leakage coefficients ranging from 1×10^{-4} to 1×10^{-1} per day.

The lower Tamiami aquifer consists of the limestones of the Tamiami Formation and in some areas, the siliciclastics found in the upper part of the Peace River Formation of the Hawthorn Group. This zone is a major potable water resource for much of Collier County. The water quality is similar to that of the water table aquifer, but it can have lower iron concentrations, making it more suitable for potable supplies. However, chloride concentrations near the coast can be over 10,000 milligrams per liter (mg/l). This aquifer can be locally very productive, with transmissivities ranging from 100,000 – 500,000 gpd/ft (USACE, 1986). The thickness of the aquifer system can range from more than 250 feet to less than 150 feet.

Water levels of the surficial aquifer system generally slope downwards to the coast in a southwesterly direction, with a groundwater recharge or high area just north of Immokalee (Immokalee Rise) discharging primarily along the coast and surface water bodies. In the vicinity of Immokalee, the lower Tamiami aquifer is unconfined. There is very little seasonal fluctuation of the aquifer water levels, although groundwater is generally recharged by rainfall or surface water bodies. The hydraulic gradient can range from less than one foot per mile to five feet per mile with the steepest gradients occurring in the vicinity of local well fields. The lower Tamiami aquifer is pumped extensively in Collier County for potable water supplies, potentially causing the normal hydraulic gradients to be reversed with salt water intrusion occurring along the low-lying coastal areas.

The Hawthorn Group sediments include two aquifers that compose the Intermediate aquifer system. The Hawthorn also acts as the primary confining zone for the Floridan aquifer system. The two confined, or in some locations semi-confined, aquifers in the Hawthorn sediments are the Sandstone aquifer, which is present in Collier County north of Alligator Alley, and the mid-Hawthorn aquifer, which underlies all of Collier County.

The Sandstone aquifer appears to be part of the Peace River Formation, based on the contour maps depicting the top of the aquifer mapped by SFWMD (1986), and the top of formation mapped by Scott (1988). The aquifer comprises sandy limestones and dolomites, and sandstone with a maximum thickness of approximately 100 feet. The aquifer dips to the southeast as it thins and eventually pinches out in the downdip direction. The transmissivity is generally below 100,000 gpd/ft (USACE, 1986). Water quality is generally good with low iron content, but hardness and alkalinity increase towards the coast. Chloride concentrations are generally less than 600 mg/l.

The potentiometric surface of the Sandstone aquifer depicted in SFWMD (1986) shows a recharge zone just northeast of Immokalee and radial flow from the groundwater mound. The flow direction for most is generally to the southwest within Collier County and hydraulic gradients range from 0.5 feet per mile to 5 feet per mile. The higher gradients are generally within the cone of depression of the well fields that tap the Sandstone aquifer.

The mid-Hawthorn aquifer comprises limestones and dolomites found in the Arcadian Formation (Scott, 1988), with transmissivities less than 50,000 gpd/ft (USACOE, 1986). This aquifer dips to the east southeast and the thickness averages 100 feet. Water quality is generally highly mineralized, with high levels of chlorides, calcium, magnesium, and sulfate. Insufficient data exists to detail the potentiometric surface, but it is probably under flowing artesian conditions for wells penetrating this zone. However, it was not being used for potable or irrigation purposes at the time of the investigation for the SFWMD (1986) report.

The Floridan aquifer system generally includes (from top to bottom) the Tampa Formation where it is permeable and in hydraulic connection with the underlying Oligiocene age Suwannee Limestone, the Ocala Limestone and Avon Park Formation of late Eocene age, the Oldsmar Formation of early Eocene age, and the Paleocene age Cedar Keys Formation. The transmissivity of the upper part of the aquifer ranges from 75,000 to 450,000 gpd/ft (Meyer, 1989). The water quality at best is brackish and water quality degrades with depth and towards the coast. Water movement is generally to the southwest in Collier County (Meyer, 1989).

Table 4. Correlation of the Hydrostratigraphy (*Source: Dames and Moore, 1998*)

<table>
<tr><th>Age</th><th>Formation</th><th colspan="2">Hydrogeologic Unit</th></tr>
<tr><td>Recent to Pleistocene</td><td>Undifferentiated Sands</td><td rowspan="3">Surficial Aquifer System</td><td>Water Table Aquifer</td></tr>
<tr><td rowspan="2">Pliocene</td><td rowspan="2">Tamiami Formation</td><td>Tamiami Confining Beds</td></tr>
<tr><td rowspan="2">Lower Tamiami Aquifer</td></tr>
<tr><td rowspan="7">Miocene</td><td rowspan="3">Hawthorn Group - Peace River Formation</td><td rowspan="6">Intermediate Aquifer System</td></tr>
<tr><td>Upper Intermediate Confining Zone</td></tr>
<tr><td>Sandstone Aquifer</td></tr>
<tr><td rowspan="4">Hawthorn Group - Arcadian Formation</td><td>Mid Intermediate Confining Zone</td></tr>
<tr><td>Mid-Hawthorn Aquifer</td></tr>
<tr><td>Lower Intermediate Confining Zone</td></tr>
<tr><td colspan="2" rowspan="2">Floridan Aquifer System</td></tr>
<tr><td>Oligocene to Paleocene</td><td>Suwannee Limestone, Ocala Limestone, Avon Park Formation, Oldsmar Formation, and Cedar Keys Formation</td></tr>
</table>

4.0 MIKE-SHE Model (BCB)

The MIKE-SHE parameters used for each simulation (Historic-LSM and CC-ECMv2) come from the same source (For a complete description on the saturated zone parameters, see Tech Memo: Task 2.2 Recalibrate Existing BCB Model). Therefore, the following figures and narrative are meant to give a description of the selected MIKESHE saturated zone parameters as they relate to the Rookery Bay and Fakahatchee Bay Study areas. Figures 14 – 16 present Layer Thickness, Horizontal Hydraulic Conductivity, and Transmissivity saturated zone parameters for the Water Table Aquifer (WTA), where the black outline represents the Rookery Bay and the white outline represents the Fakahatchee Bay study areas respectively.

As shown in Figure 14, the WTA is substantially deeper (as related to layer thickness) for a large majority of the Rookery Bay study area when compared to the Fakahatchee Bay study area. This difference is substantial when considering other saturated zone parameters such as transmissivity as it is the product of layer thickness and horizontal hydraulic conductivity (Kh). Additionally, the Kh (Figure 15) is about an order of magnitude larger for the vast majority of the Rookery Bay study area where the green color is related to a Kh of 1,000 - 1,500 ft/day, where the purple and blue colors indicate a Kh of 100-500 ft/day. These differences are not surprising as saturated zone parameters are generally heterogeneous in both extent and magnitude within the study area. These differences are noted here, to bring attention to the fact that these differences exist, as well as highlight the tendency of saturated zone parameters to be heterogeneous in both spatial extent and magnitude within and between study areas.

When comparing the MIKESHE parameters to the groundwater information presented in Section 3, all transmissivity values used in the current simulation are within the previously derived ranges for each aquifer. The similarity in groundwater parameters corroborates the data of both models, and while the ranges are not exact, the data presented here is comparable between data sources.

Table 5 presents the hydrogeological parameters within each layer for the Rookery Bay study area. This data provides a quick comparison to the same data presented in Section 4.1 (Table 6), and to show that while the ranges in parameters are similar between study areas, differences do exist, with the most pronounced differences between maximum transmissivity in the WTA as well as the Lower Tamiami Aquifer. These differences compliment the data presented in Figures 14 – 16.

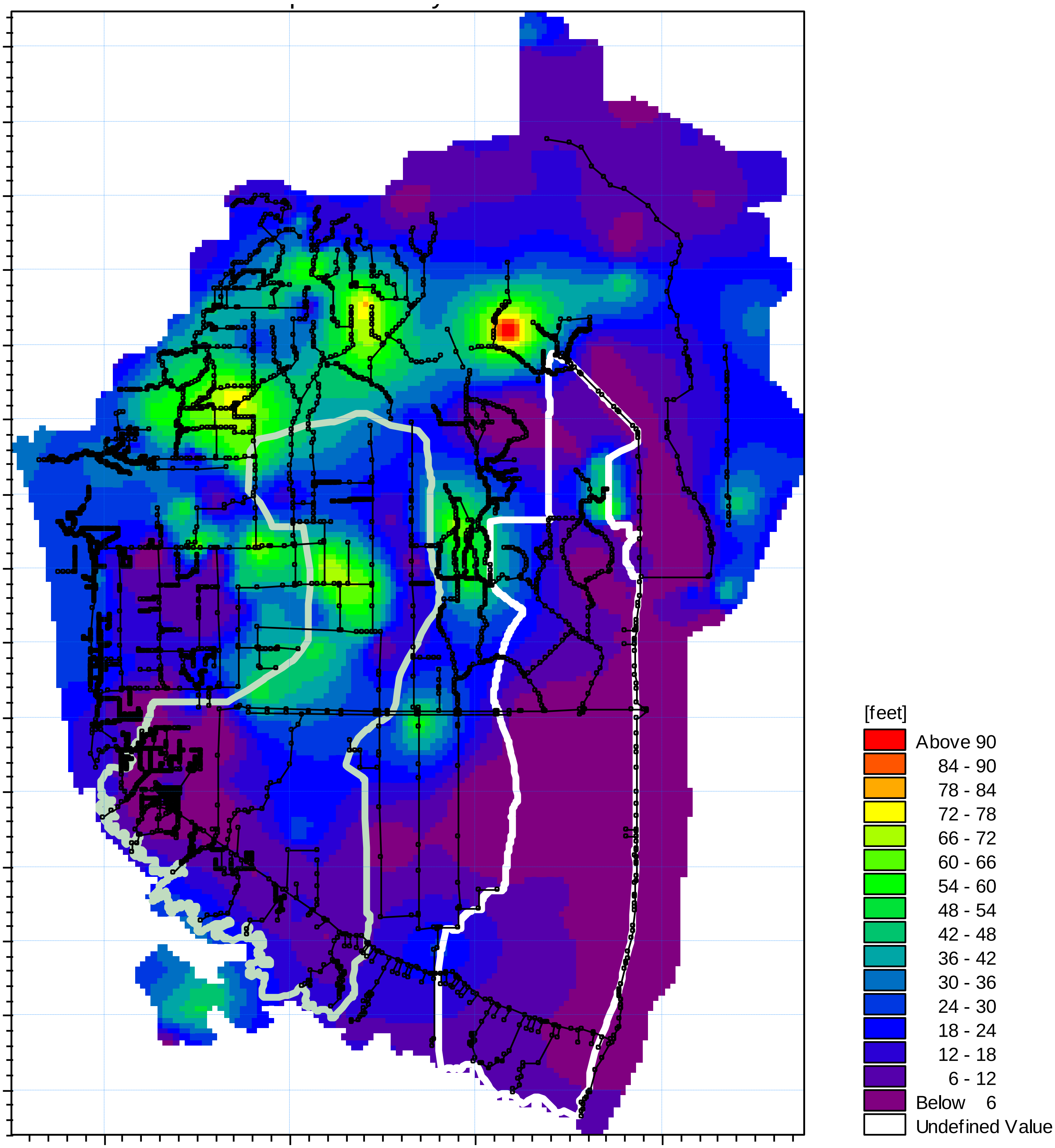


Figure 14. Water Table Aquifer Thickness

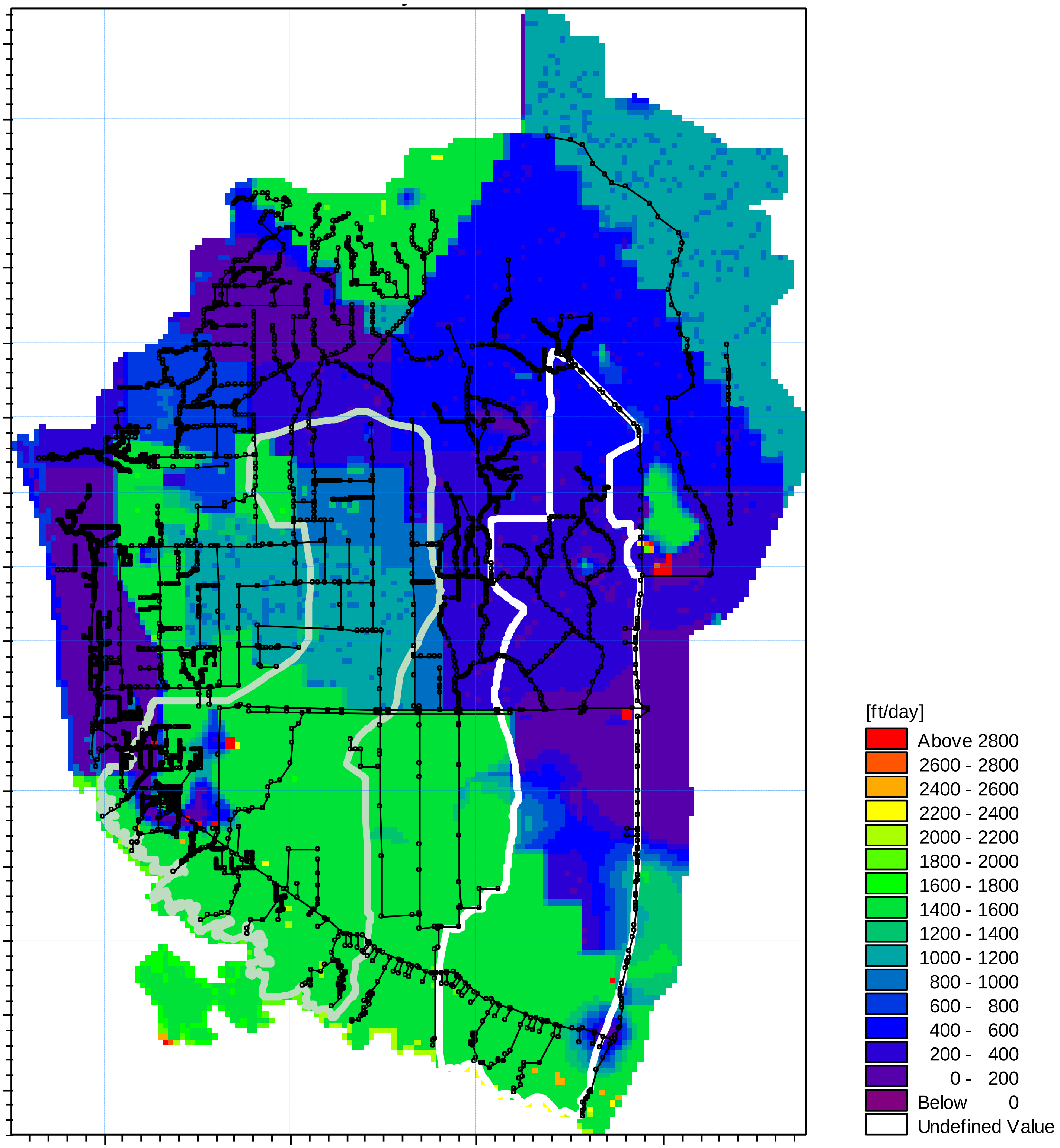


Figure 15. Water Table Aquifer Horizontal Hydraulic Conductivity

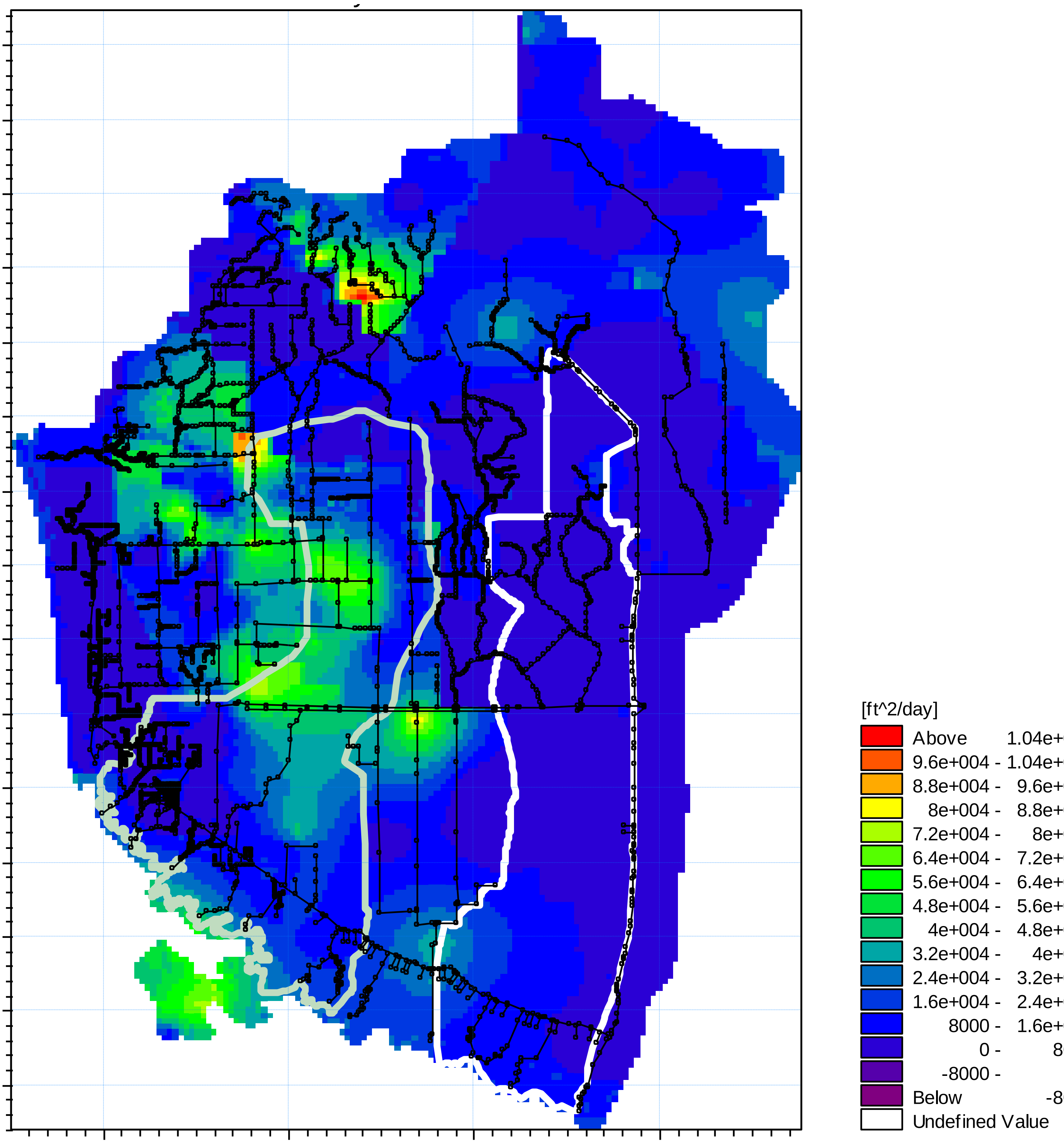


Figure 16. Water Table Aquifer Transmissivity

Table 5. Rookery Bay Hydrogeologic Units and Selected Parameters

Model Layer	Geologic Unit	Geologic Layer/Lens	Hydrogeologic Unit	Kh Range (ft/day)	Transmissivity Range (ft^2/day)
1	Holocene-Pliocene	Holocene-Pliocene	Water Table Aquifer	0.5 - 2,834	2.5 - 93,000
2	Tamiami Formation	Bonita Springs Marl	Tamiami Confining Unit	0.04 - 1,500	0.19 - 7,381
3		Ochopee Limestone	Lower Tamiami Aquifer	200 - 1,500	16,573 - 267,720
4	Hawthorn Group (Peace River Formation	Upper Peace River	Upper Peace River Confining Unit	0.26 - 122	1.32 - 600
5		Peace River Sandstone	Sandstone Aquifer	13 - 131	170 - 34,458
6		Basal-Peace River Sandstone	Mid-Hawthorn Confining Unit	0.01 - 146	0.2 - 717
7	Hawthorn Group (Arcadia Formation)	Arcadia	Mid-Hawthorn Aquifer	50 - 150	1,499 - 25,5654

4.1. Fakahatchee Bay Model Geometry

The Fakahatchee Bay watershed covers 237 square miles and is not exclusive to the CC-ECMv2 model domain presented in "Task 2.2 Recalibrate Existing BCB Model," but rather lies within the framework of this model domain. As such, this report will not present a new discussion, but rather a discussion of the attributes of the Fakahatchee Bay watershed within the CC-ECMv2 framework. The CC-ECMv2 as described in "Task 2.2 Recalibrate Existing BCB Model," as well as in Section 4.2 of this memo, has seven distinct hydrogeological layers ranging from the Water Table Aquifer to the deepest layer, the mid-Hawthorn Aquifer. The model geometry was unaltered from the CC-ECMv2 simulation and Table 6 presents the hydrogeological parameters within each layer.

Table 6. Fakahatchee Bay Hydrogeologic Units and Selected Parameters

Model Layer	Geologic Unit	Geologic Layer/Lens	Hydrogeologic Unit	Kh Range (ft/day)	Transmissivity Range (ft^2/day)
1	Holocene-Pliocene	Holocene-Pliocene	Water Table Aquifer	1.77 - 2,834	8.75 - 37,339
2	Tamiami Formation	Bonita Springs Marl	Tamiami Confining Unit	0.04 - 1,500	0.19 - 7,381
3		Ochopee Limestone	Lower Tamiami Aquifer	550 - 1,500	14,443 - 164,188
4	Hawthorn Group (Peace River Formation)	Upper Peace River	Upper Peace River Confining Unit	0.01 - 225	0.05 - 1,111
5		Peace River Sandstone	Sandstone Aquifer	122 - 227	11,529 - 71,841
6		Basal-Peace River Sandstone	Mid-Hawthorn Confining Unit	0.01 - 100	0.36 - 493
7	Hawthorn Group (Arcadia Formation)	Arcadia	Mid-Hawthorn Aquifer	150	1,499 - 27,710

4.1.1. Model Input and Boundary Conditions

MIKE-SHE utilizes an explicit model domain defining the areal extent of portions of the hydrologic cycle (processes such as: atmospheric, overland-flow, surface water, unsaturated zone, and saturated zone "groundwater" [Figure 17]).

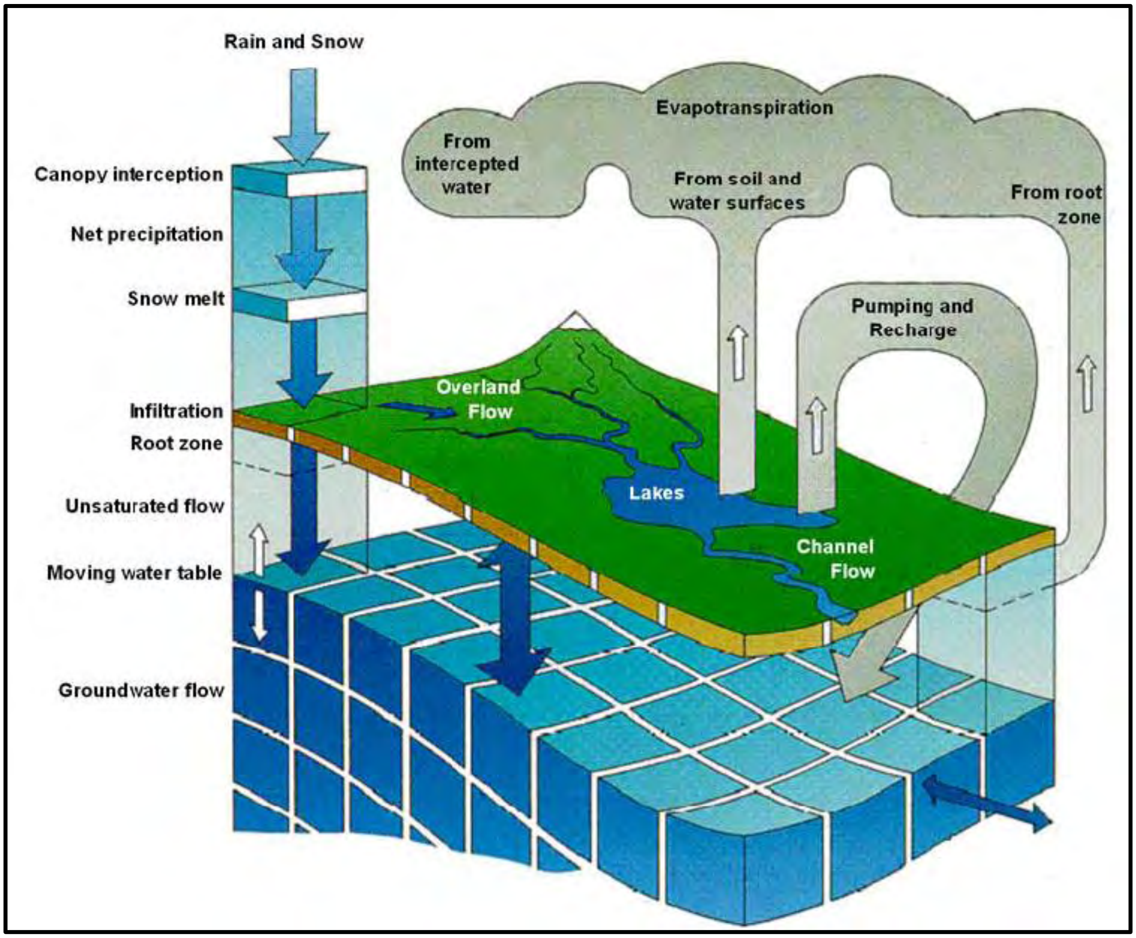


Figure 17. Hydrologic Processes Simulated by MIKE-SHE

From this model domain, boundaries must be set up to ensure accurate representation of the hydrologic cycle. The groundwater model boundary was unaltered as defined and developed for the CC-ECM. Element 3 Task 10 describes the boundary conditions for each aquifer; as such, this report will not present a complete description (PBS&J, 2011). The Memo states that the surficial aquifer has many observation stations that were used to generate an interpolated grid map for the heads within the surficial aquifer from 2001 – 2007 (PBS&J, 2011).

The boundary-specific heads defined in the CC-ECM model for all other layers were derived from the regional Lower West Coast Floridan Aquifer System Model, a MODFLOW model developed for the SFWMD (PBS&J, 2011). These boundary conditions were not re-simulated, meaning the MODFLOW model was not used in the development of the CC-ECM model. As such, groundwater boundary conditions were extended for the .DFS2 files associated with the hydrogeologic units presented in Table 7.

Please note, a ".DFS2" file is a two-dimensional spatially distributed and temporally varying file, while a ".DFS0" file is a one-dimensional temporally varying file, both of which are unique to DHI software. The saturated zone layers with boundary conditions defined by a .DFS2 file were examined for a seasonal or normal pattern within the simulation period.

The previously developed CC-ECM model was run from 2002 – 2007 and the seasonal pattern in groundwater elevations were shown to be reflected from 2004 on. Each .DFS2 file was extended from the end of the previous simulation by copying the data from 2004 – 2008, into the newly created files, for the remainder of the simulation. Meaning for the groundwater boundary condition files, years 2009 – 2012 correspond to the previously developed water levels from 2004 – 2007. Notably, the Surficial or Water Table Aquifer has a southern boundary of the coast (Rookery Bay); the boundary condition here is actual tide data from the Naples Tide Gage (NOAA Station 8725110).

Figures 18 and 19 present screen captures of the southern "Coastal Boundary" and Northern/Eastern Boundary condition extent within MIKE SHE. Notably, the Surficial Aquifer is the only hydrogeologic unit to utilize the Naples Tide Gage as a time-varying Coastal Boundary, while the Lower Tamiami Aquifer has a fixed head of 0 feet at the coastal boundary, and each Confining Unit (CU) has a closed boundary for the entire model domain. The Sandstone and mid-Hawthorne Aquifers have time varying boundary conditions derived from the previously mentioned MODFLOW model and utilize .DFS2 files for the entire model domain.

Table 7. Groundwater Boundary Condition Time-series Extension for Each Hydrogeologic Unit

Hydrogeologic Unit	**Time-series Extended From**	**File Type**
Surficial Aquifer	NOAA Tide Gage and Previous File	.DFS0 Coastal/.DFS2 Northern/Eastern Boundary
Tamiami Confining Unit	N/A	N/A
Lower Tamiami Aquifer	Previous File	.DFS2
Upper Hawthorn Confining Unit	N/A	N/A
Sandstone Aquifer	Previous File	.DFS2
Mid-Hawthorn CU	N/A	N/A
Mid-Hawthorn Aquifer	Previous File	.DFS2

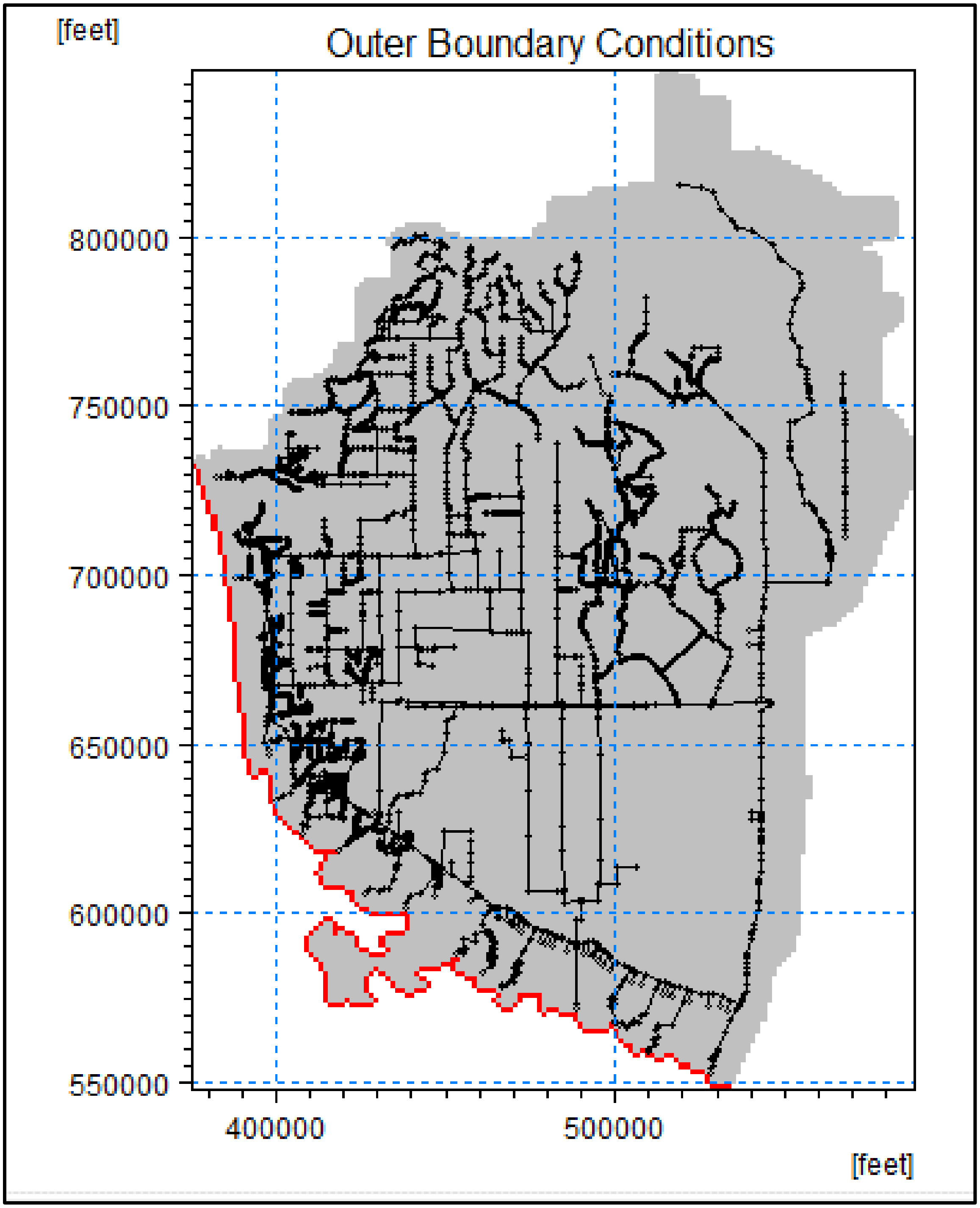


Figure 18. Alignment of the CC-ECM Domain: Coastal Boundary (Shown as Red Line)

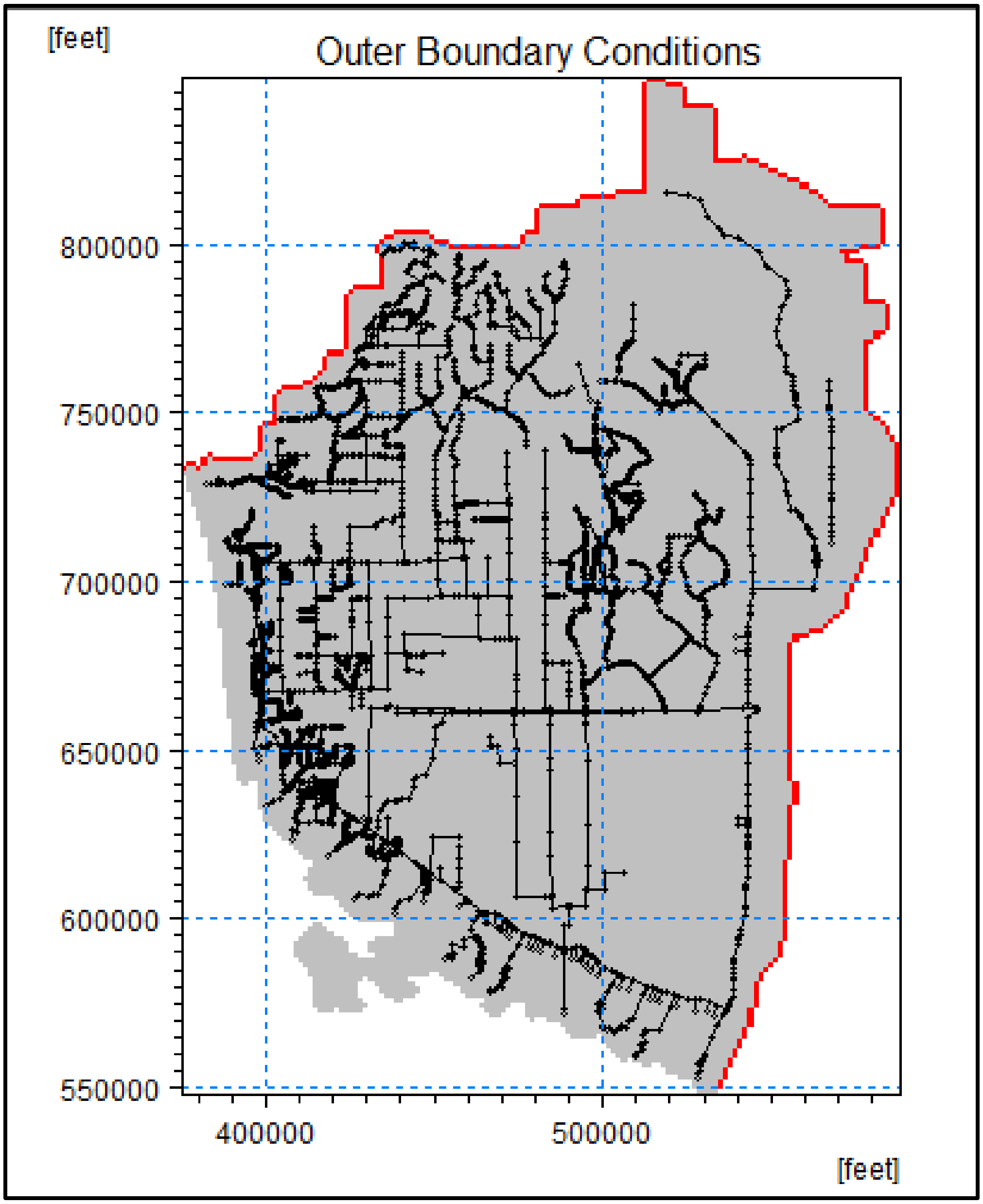


Figure 19. Alignment of the CC-ECM Domain: Northern/Eastern Boundary (Shown as Red Line)

4.1.2. Model Calibration

As specified in the scope of work (SOW), no calibration was specified, but an adjustment was made when detecting an assumption at the coast, which was an unreasonably high initial overland water depth. This initial overland water depth led to inappropriate overland depths of water throughout the simulation period and therefore was corrected.

4.1.3. Model Results

MIKESHE allows the user to define points within the watershed to provide comparisons to measured data. The following wells (Table 8, Figure 20) are locations within the Fakahatchee watershed where simulated results were compared against measured data (Figures 21 – 25) and reported herein.

Table 8. Groundwater Monitoring Site Depth and Aquifer Monitored

GW Monitoring Site	**Depth** (ft)	**Aquifer**
SGT5W3	11	Water Table
SGT3W7	16	Water Table
C-296	45	Lower Tamiami
C-496	57	Lower Tamiami
C-689	265	Sandstone

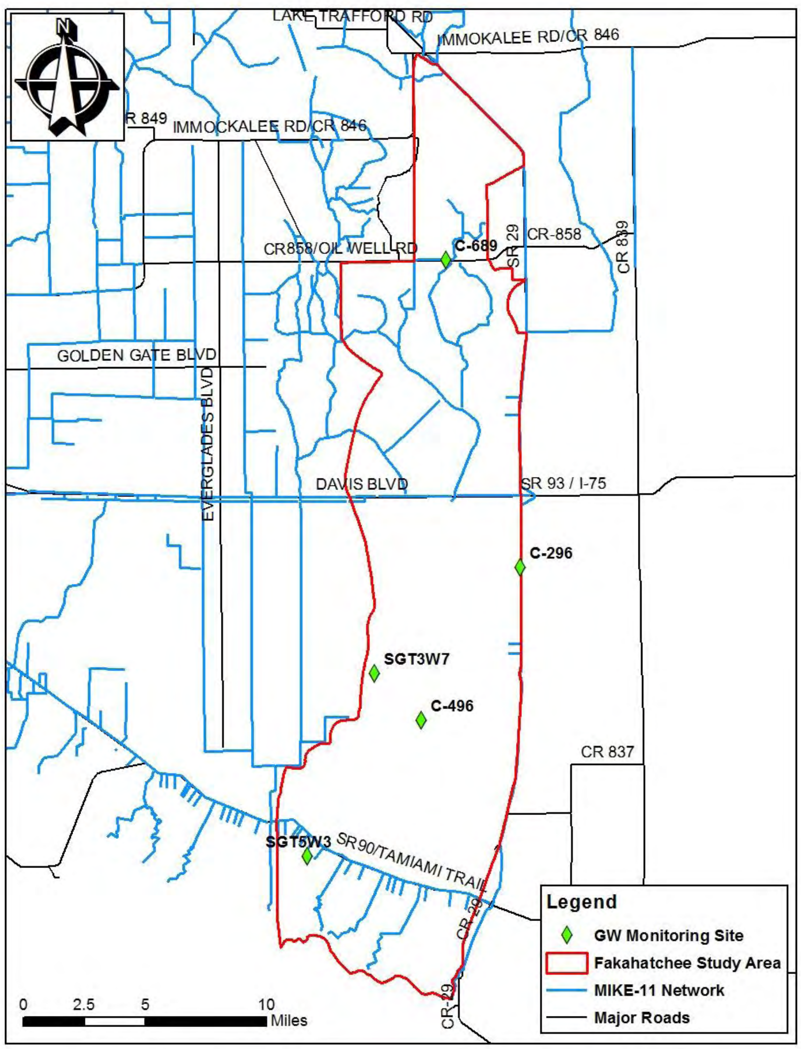
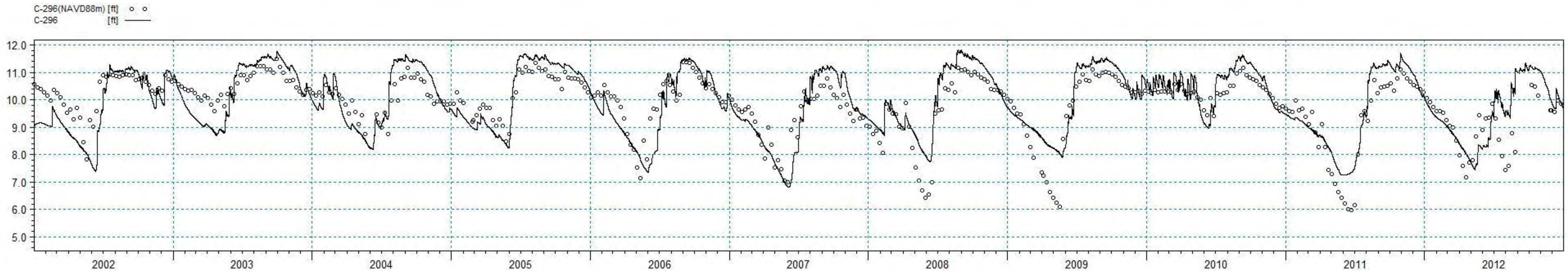
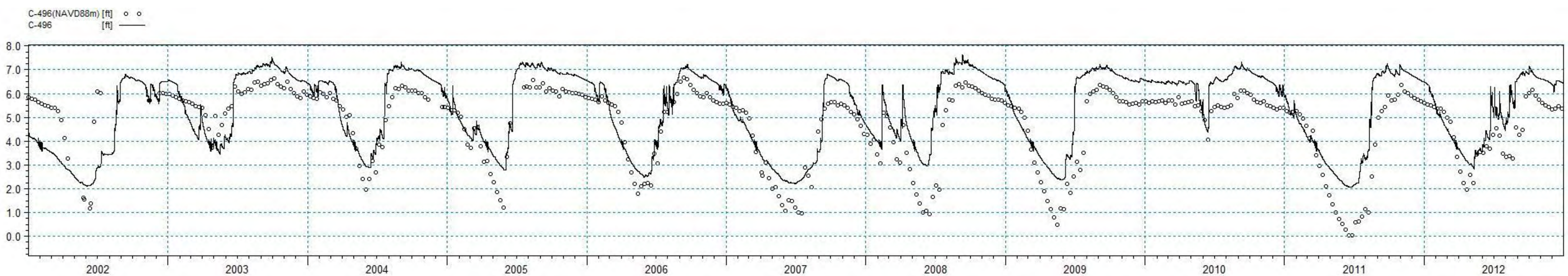


Figure 20. Groundwater Monitoring Sites



ME=-0.0948845
MAE=0.529771
RMSE=0.67494
STDres=0.668237
R(Correlation)=0.833507

Figure 21. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site C-296



ME=-0.630685
MAE=0.911106
RMSE=1.09974
STDres=0.900927
R(Correlation)=0.840802

Figure 22. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site C-496

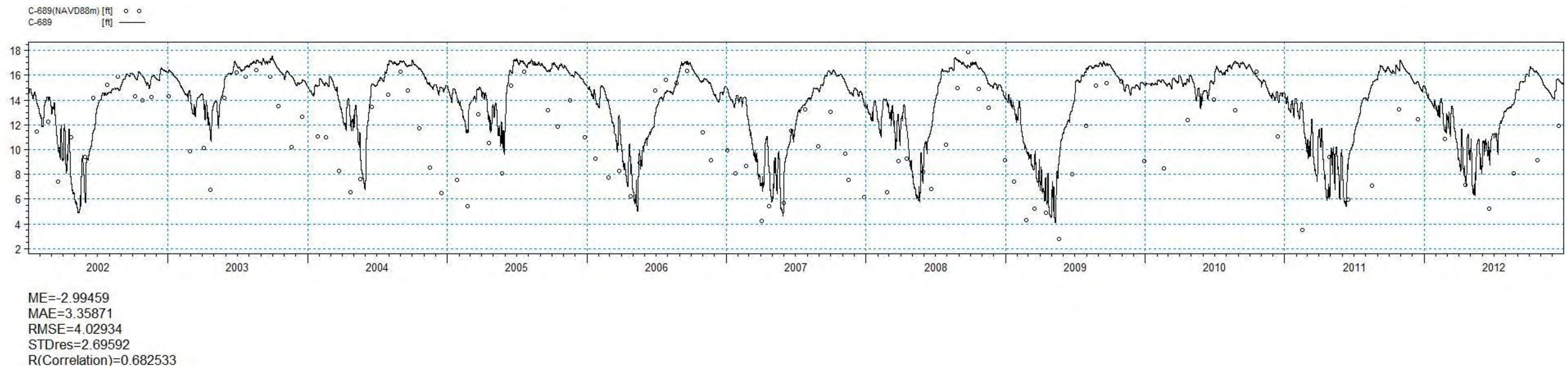


Figure 23. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site C-689

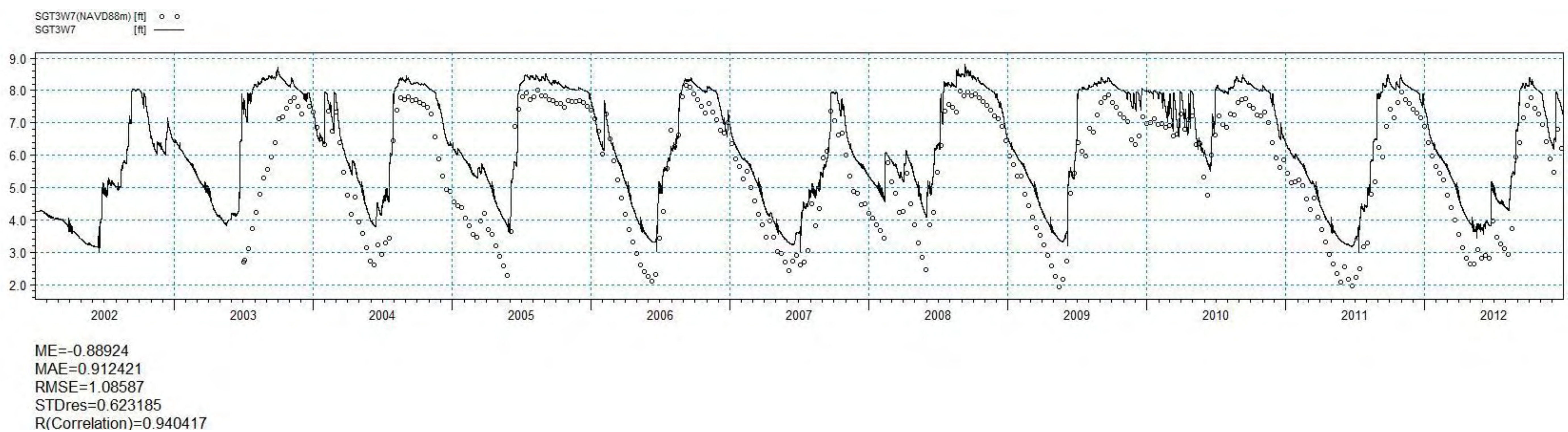


Figure 24. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site SGT3W7

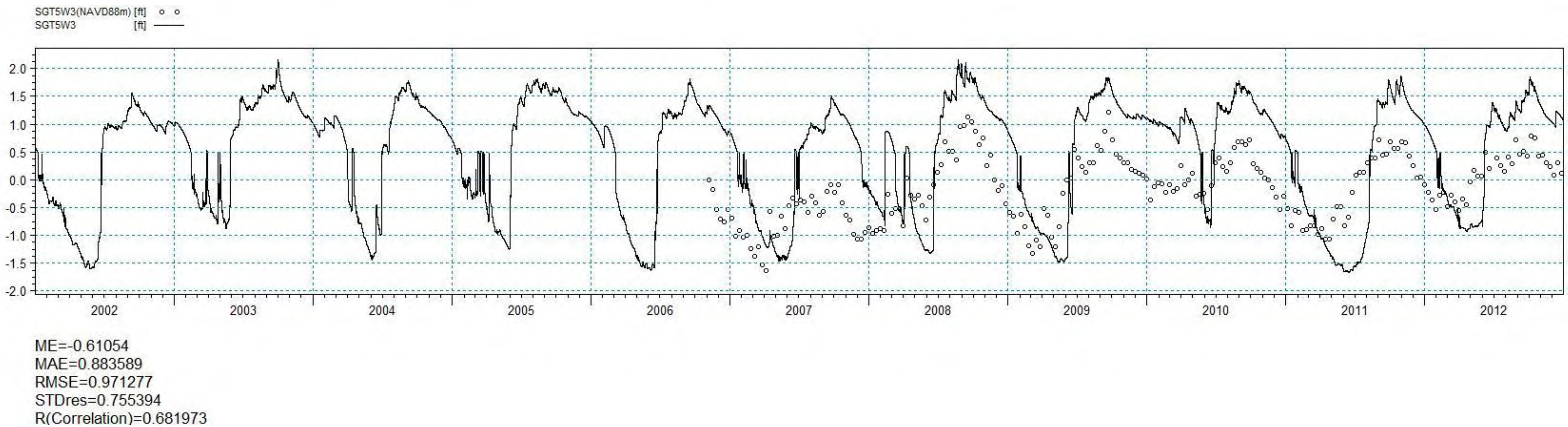


Figure 25. MIKE-SHE Groundwater Level Results (solid line) vs. Observations (points) at Site SGTSW3

Additionally in the same manner, MIKE 11 results are reported at specified locations along a certain channel. The following are MIKE 11 reaches within the Fakahatchee watershed where results are compared against measured data (Figures 27 – 30) and reported herein.

- TMBR55
- TMBR66
- TMBR71
- SR29_I75

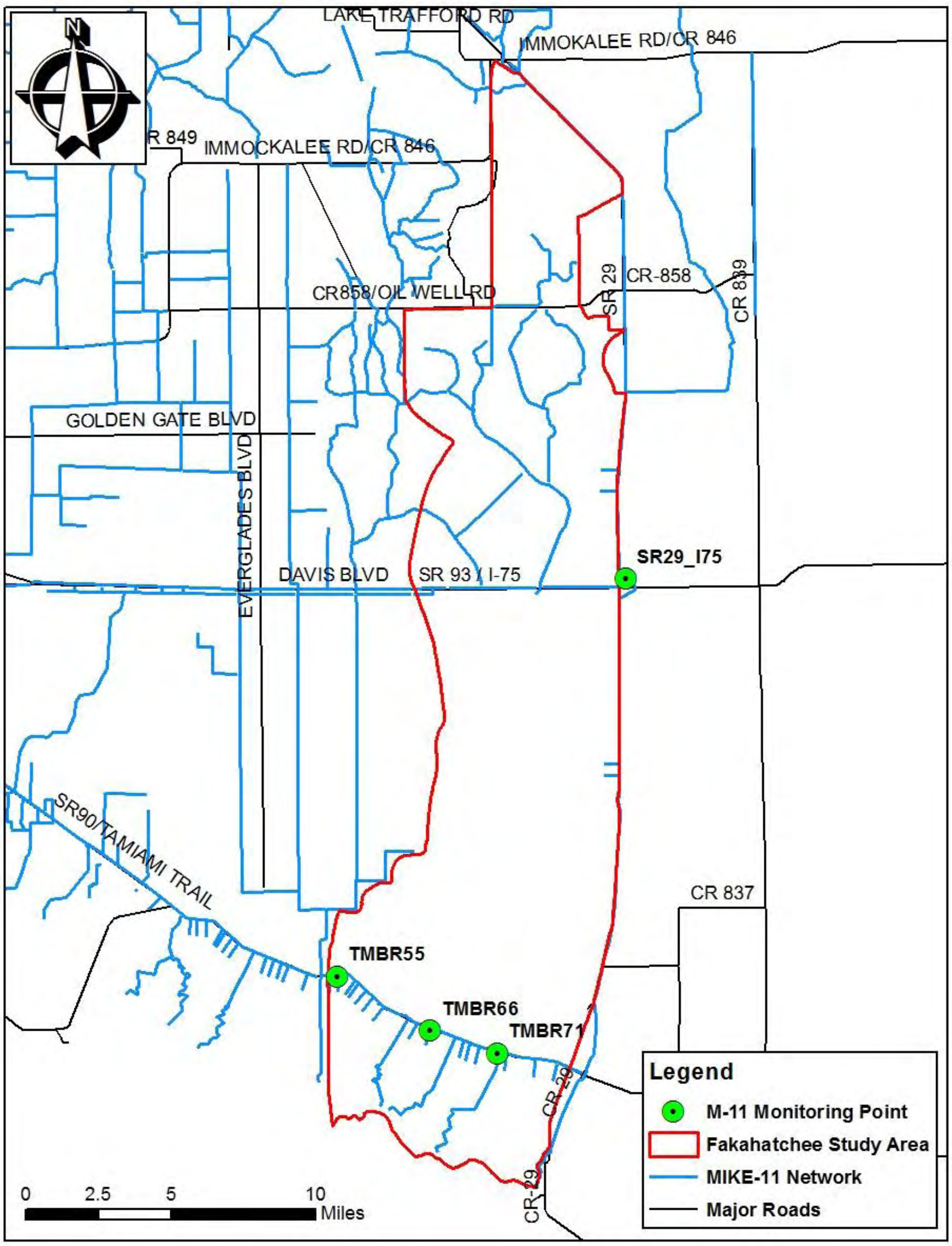


Figure 26. Surface Water Stage Measurement Site

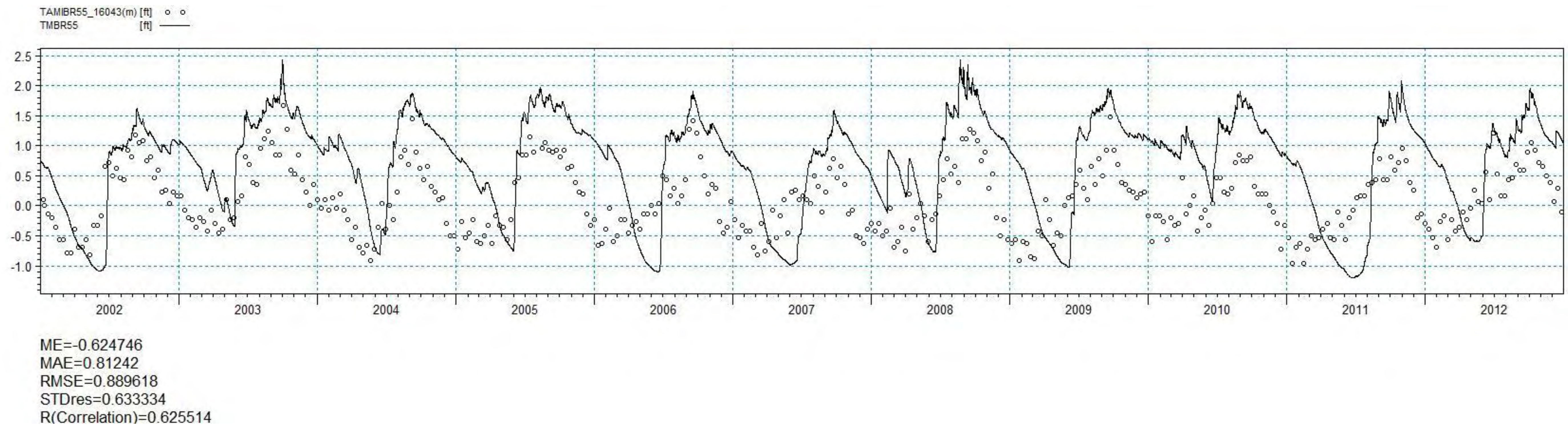


Figure 27. MIKE-SHE Surface Water Level Results (solid line) vs. Observations (points) at Site TMBR55

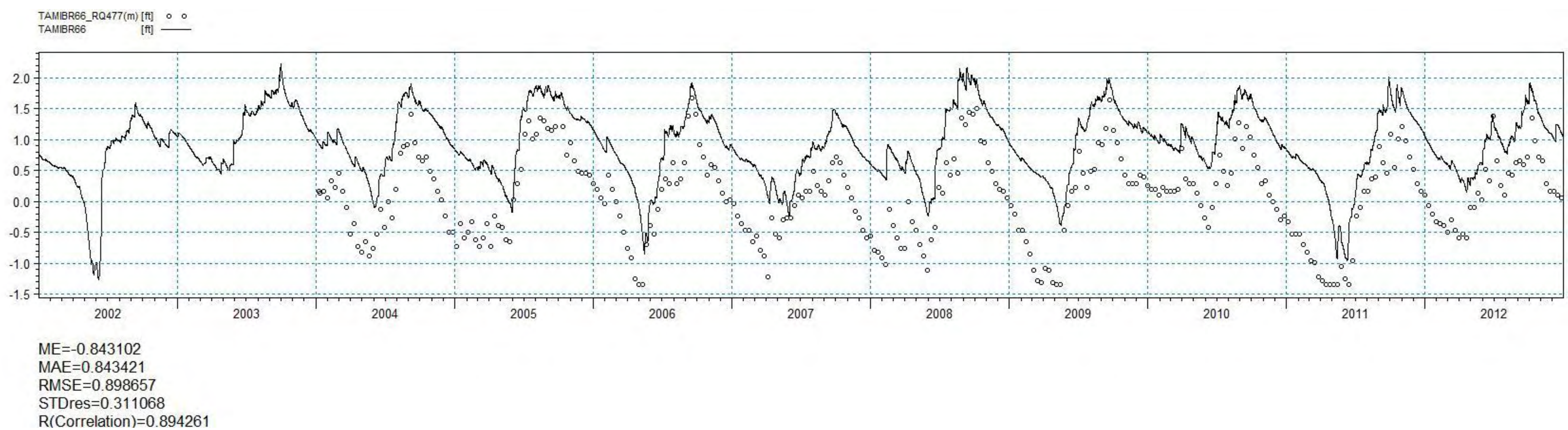
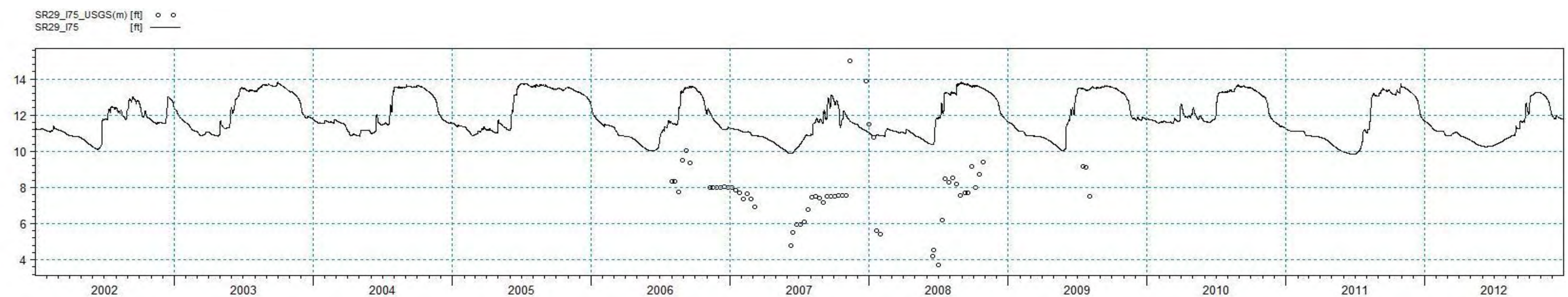


Figure 28. MIKE-SHE Surface Water Level Results (solid line) vs. Observations (points) at Site TMBR66

ME=-0.901381
MAE=0.90167
RMSE=0.954262
STDres=0.313254
R(Correlation)=0.90003

Figure 29. MIKE-SHE Surface Water Level Results (solid line) vs. Observations (points) at Site TMBR77



ME=-4.04705
MAE=4.24844
RMSE=4.3674
STDres=1.64184
R(Correlation)=0.370266

Figure 30. MIKE-SHE Surface Water Level Results (solid line) vs. Observations (points) at Site SR29_I75

As shown in the previous MIKESHE results plots, the model produces reasonable results within the Fakahatchee watershed with over predictions of groundwater elevations in most wells with well C-689 showing the greatest over predictions and the least goodness of fit. Considering that well C-689 lies 265 ft deep in the model domain and corresponds to the Sandstone Aquifer, the impacts to the surficial aquifer are considered marginal. Marginal impacts to the surficial aquifer is also evidenced when comparing plots of the remaining wells, which all lie within the upper layers of the model, where C-296 and C-496 penetrate the Lower Tamiami Aquifer and both "SGT" wells lie within the Water Table Aquifer.

Additionally, the MIKE 11 results plots also show slight over prediction in stage for the three bridges (55, 66, and 71) along the Tamiami Canal. The last MIKE 11 calibration plot at SR29_I75 shows large over predictions of stage with a very low correlation coefficient. This station does not lie within the Fakahatchee watershed, but is very close to the eastern boundary. As such, this station has been presented to show that while the model is reasonable within the Fakahatchee watershed, this point near the boundary could lead to unrealistic water from the SR-29 canal into the Fakahatchee watershed.

These aforementioned MIKESHE/MIKE 11 plots agree with the previous CC-ECMv2 model. The plots show that no major instabilities or errors in the predictive capabilities of the model have been introduced after adjusting the initial overland water depth as described in Section 4.1.2.

Evaluating the contributions of each watershed (Rookery Bay and Fakahatchee) to their respective bay requires a comparison of the simulated outflow to the coast. Figure 31 presents a cumulative flow contribution analysis (Cumulative Coastal Flow = MIKE-11 Canal + Overland Sheet Flow)**,** showing that the Fakahatchee watershed contributes about 2.4 times the volume of water in acre-feet for the period of 2003 – 2012. The Rookery Bay Watershed lies within the Historical-LSM boundary (see Task 2.3/2.4 Local Scale Model Development for a complete description of both LSM model domains) and does not include the northern portions of said boundary (see Figure 14 for the extent of the Rookery Bay Watershed as accounted for in this project). As presented in Section 5 Hydrologic Response Comparison, these flows will be normalized to each watershed to facilitate meaningful comparisons.

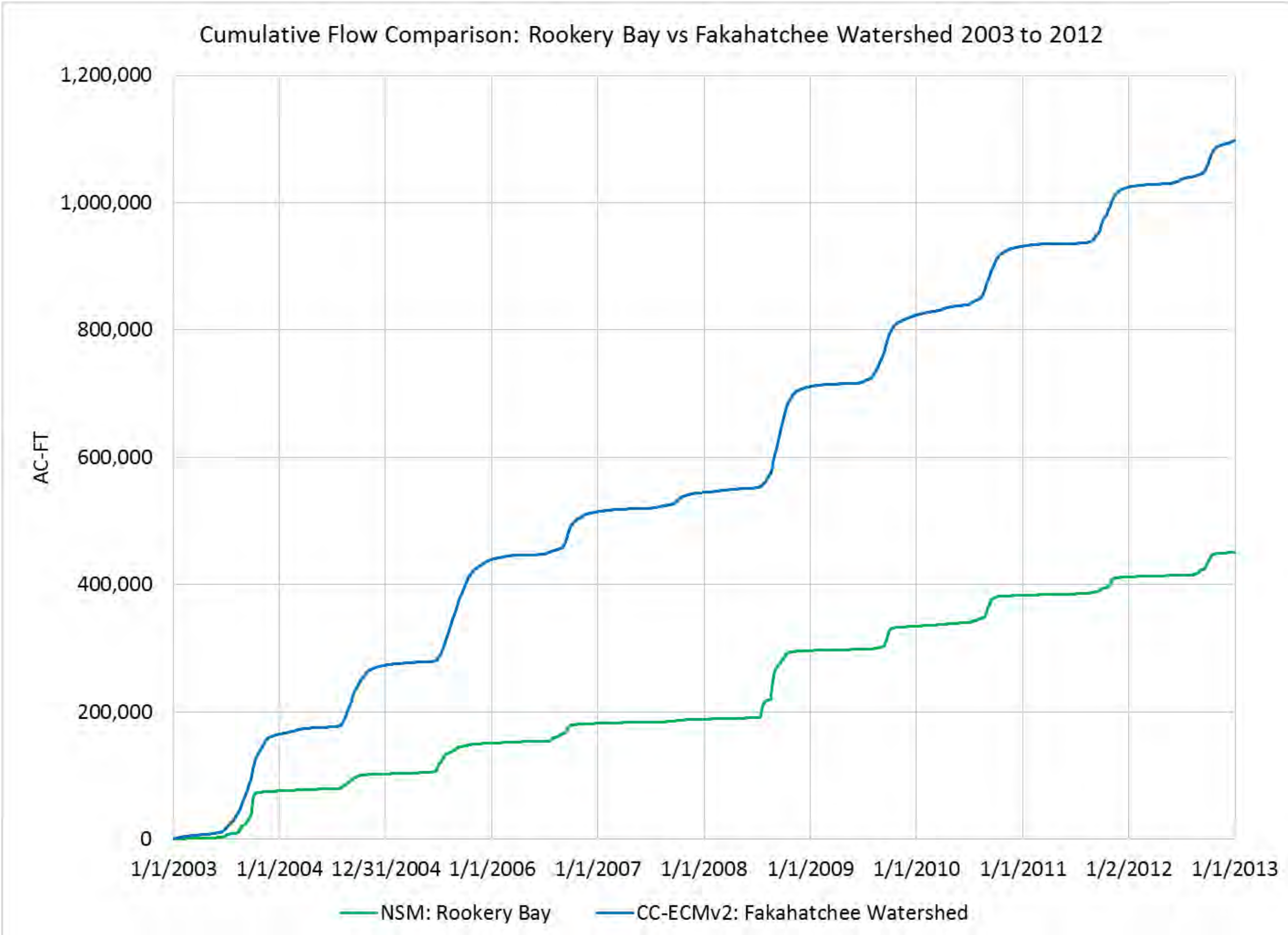


Figure 31. Cumulative Coastal Flow Comparison Rookery Bay vs Fakahatchee Watershed

5.0 Hydrologic Response Comparison

As specified in the SOW, Fakahatchee Bay is a largely undeveloped system that could serve as a reference site for Rookery Bay and regional research projects. Understanding the existing hydrologic conditions of Fakahatchee Bay could help the RBNERR establish target hydrologic conditions for the ongoing research in the Rookery Bay Estuary and elsewhere in the region. If the normalized flow contribution to Fakahatchee Bay from the existing conditions model for the "undeveloped" Fakahatchee Watershed is similar to that of Rookery Bay Natural Systems Model normalized flow contribution to Rookery Bay then Fakahatchee Bay could serve as a reference site to Rookery Bay. Notably, while the simulation comparisons between the Rookery Bay and Fakahatchee Bay study areas are valid, they are not a true "apples to apples" comparison, in that the MIKESHE grid-cell size differs for each model. The NSM: Rookery Bay comparisons come from a local-scale model (Historic-LSM, see Task 2.3/2.4 Local Scale Model Development), while the Fakahatchee Watershed data has been extracted from the regional scale CC-ECMv2 model (See Task 2.2 Recalibrate Existing BCB). The Historic-LSM utilizes a 375-ft while the CC-ECMv2 utilizes a 1,500-ft grid-cell spacing, respectively. This does not discount the comparisons presented within this report, because the simulation periods as well as the assumptions within the saturated zone are equivalent.

To assess the applicability of Fakahatchee Bay serving as a reference site to Rookery Bay, the results of two models at the point where water flows into Fakahatchee Bay and Rookery Bay were normalized by dividing by the watershed area and comparing the results.

The following sections compare the seasonality, cumulative volume, and flow frequencies between the Rookery Bay and Fakahatchee watersheds.

5.1. Seasonality

Multiple sources agree that the wet season in south Florida occurs during June – October, and the dry season occurs November – May. While slight variations may exist in this seasonal definition, in general this definition holds true throughout south Florida, and moreover, within Collier County. As such, a seasonal comparison was prepared to assess how each watershed responds to the wet and dry seasons on a monthly basis, where the seasonality corresponds to the average monthly rainfall. This analysis was completed for the average monthly flow in cfs and normalized to inches over the watershed area as described in Section 5**.**

As presented in Figure 32, the Fakahatchee watershed consistently delivers more fresh water per unit area to the bay than the Rookery Bay watershed. The dry season months of January – May show little difference with respect to watershed runoff contributions in inches. However, when examining the wet season runoff depths, the differences are greatest in August – November, which in general corresponds to the highest rainfall depths.

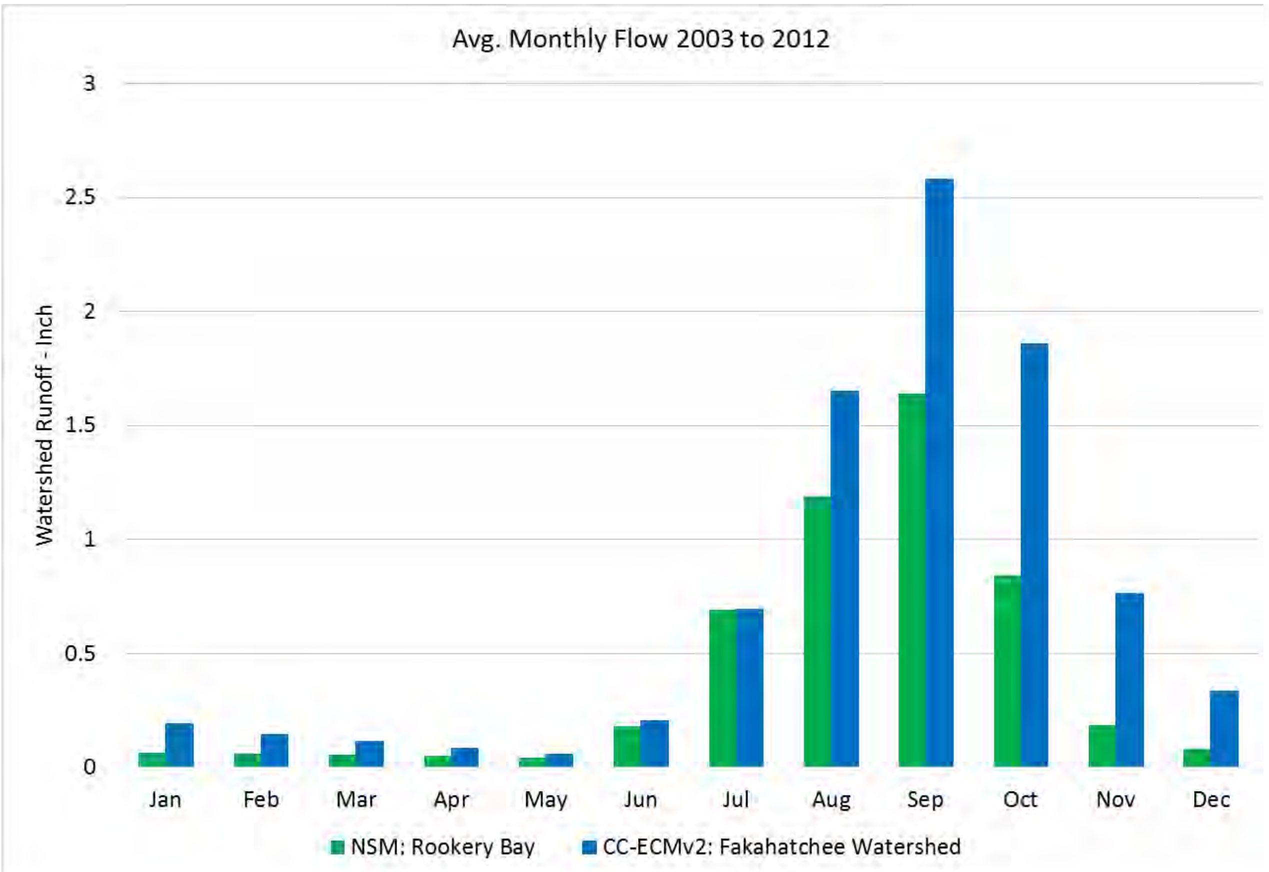


Figure 32. Comparison of Monthly Runoff Depth in Inches Rookery Bay vs Fakahatchee Watershed

5.2. Accumulated Runoff Depth

Accumulated runoff depth is a measure of the total depth (amount) of runoff in inches that has occurred over the simulation period. This measure is similar to the cumulative volume of runoff in acre-feet as presented previously in Section 4.1.3. However, the accumulated runoff depth has been normalized for each watershed area, as described in Section 4.1.3. This data indicates how the watershed responds to rainfall inputs with respect to the total amount of runoff simulated across the watershed; it also gives insight into whether the model appropriately simulates the rainfall runoff response within the watershed. Figure 33 presents a comparison of the simulated runoff depth accumulated for the period of 2003 – 2012 for each watershed (Rookery Bay and Fakahatchee). As evidenced by Figure 33, the accumulated runoff depth within the Fakahatchee watershed is much larger than the runoff depth from Rookery Bay. While runoff from the Fakahatchee watershed is higher than Rookery Bay, the average runoff in inches/yr in both watersheds falls within an acceptable range of 5 – 10 inches/yr. The runoff depth of 5 – 10 inches/yr is based upon a Hydrologic Unit runoff map developed by G. H. Hughes (Hughes, 1978).

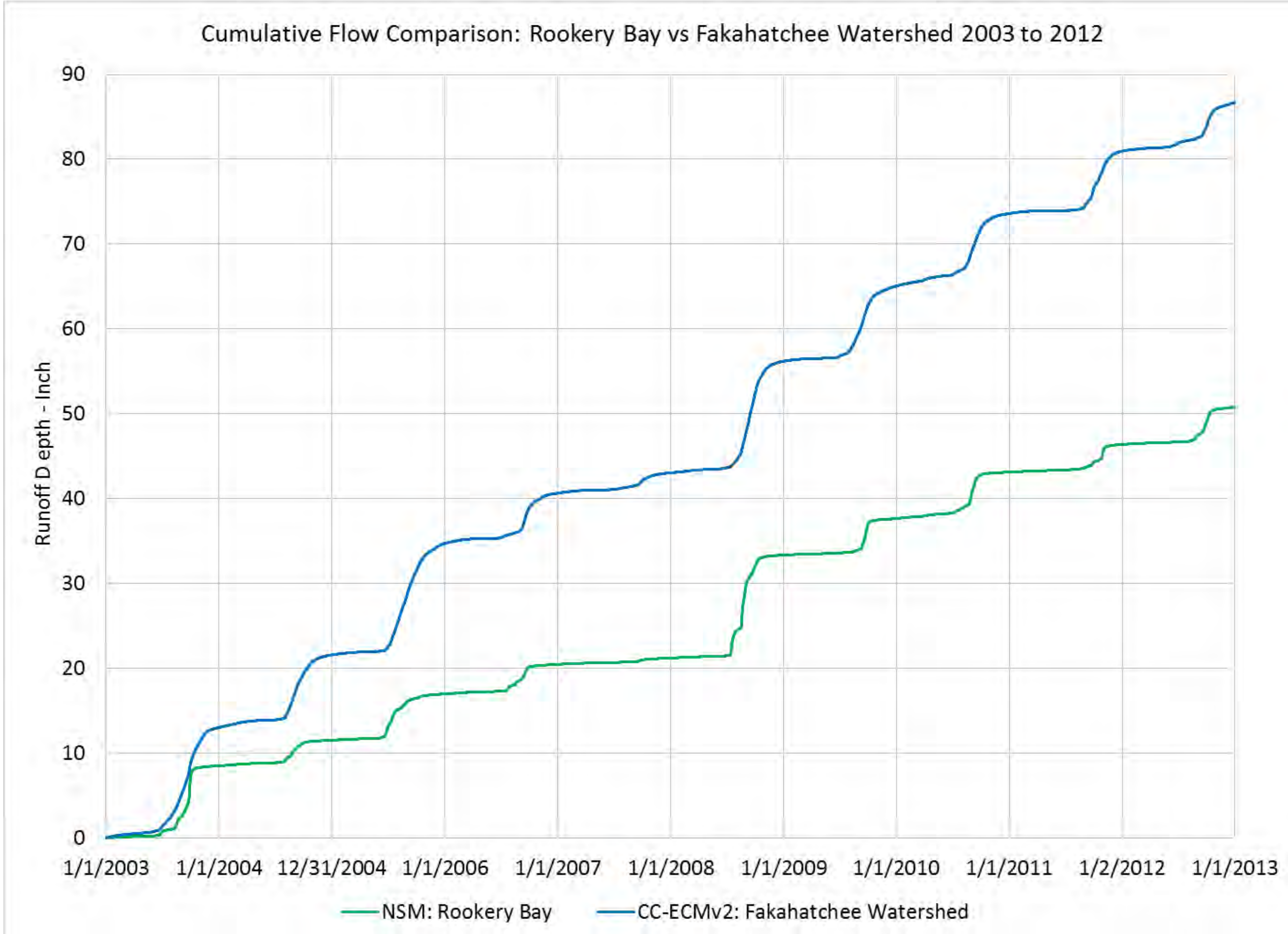


Figure 33. Cumulative Runoff Depth: Rookery Bay and Fakahatchee Watersheds

5.3. Frequency

Analysis of a system's performance in response to rainfall or how the rainfall runoff relationship is characterized can occur via various methods. The previous sections have described this process in terms of seasonality and accumulated depth of runoff (which relates to the volumetric flow within a watershed). This section will present the flow duration curves (Figure 34) of each watershed to provide an analysis of the duration and frequency of flows over the range of exceedance percentages, where an exceedance percentage of 1 (1% chance of being exceeded in a given year) corresponds to large flows, while an exceedance percentage 99 (99% chance of being exceeded in a given year) corresponds to low flows. In other words, this sheds light on which flows are the most probable and represents the statistical duration over an analysis period.

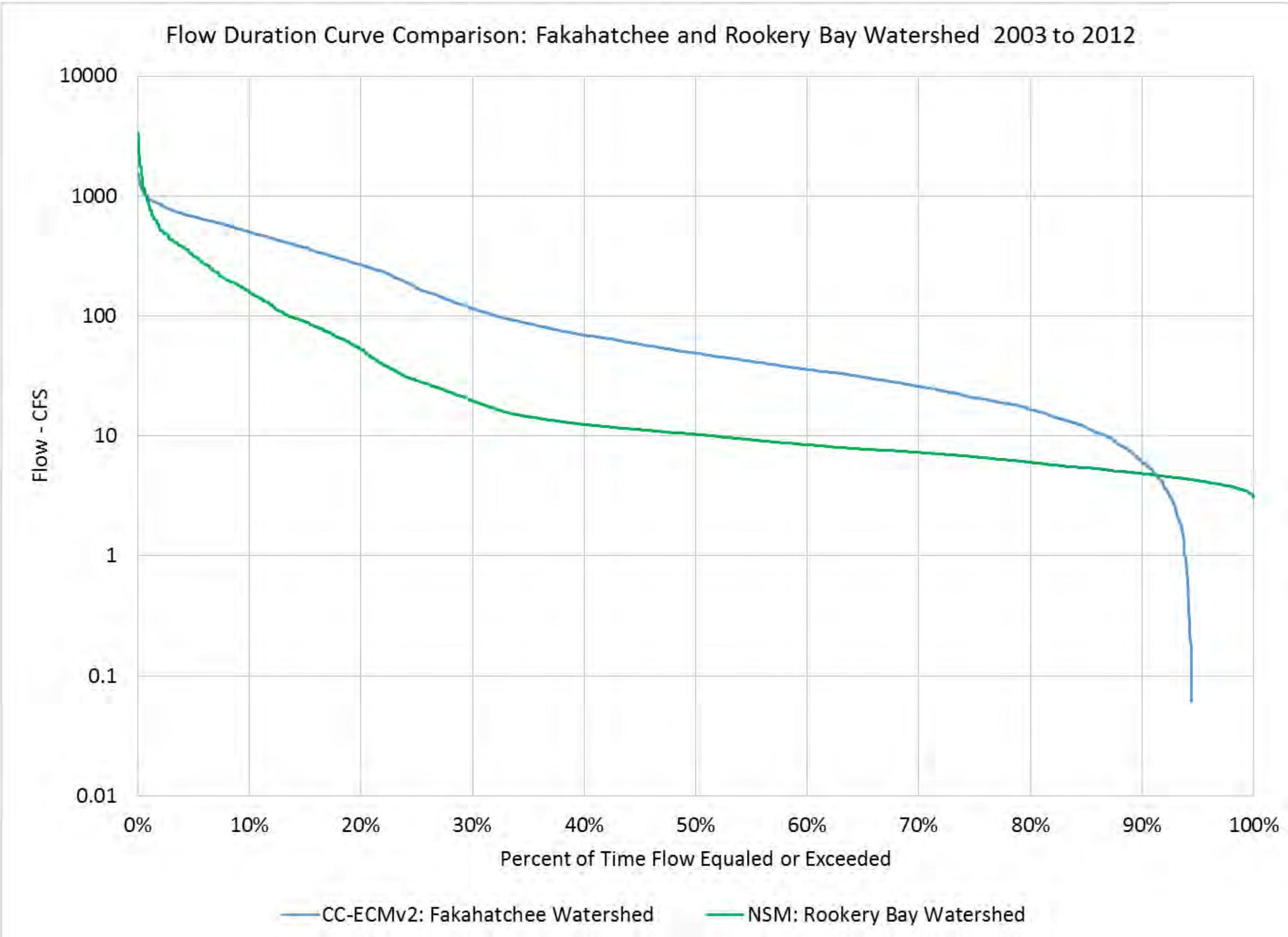


Figure 34. Comparison of Flow Duration Curves For Rookery Bay and Fakahatchee Watersheds

As shown in Figure 34, the Fakahatchee watershed contributes low-frequency, high-flow events over longer time periods when compared with the Rookery Bay watershed. However, for high-frequency, low-flow events, the Rookery Bay watershed contributes more water to the estuary (or bay) than the Fakahatchee watershed. These results are likely due the Fakahatchee watershed having much more channelization both upstream and downstream of I-75, a multitude more channels conveying water under US-41, and provides the capability to deliver water from the Tamiami Canal. Furthermore, under current conditions the SR-29 canal rehydrates the Fakahatchee strand from culverts 6a and 6b.

6.0 Discussion and Recommendations

While the revisions made herein have not changed the calibration (with slight over predictions in both surface water stage and ground water elevations), there is concern over assuming the model represents a natural system when several man-made or unnatural features exist within the Fakahatchee watershed.

While the Fakahatchee strand remains relatively intact from I-75 south to US-41, there are still indicators that the system as a whole is not functioning as it did under historic conditions. For example, as mentioned previously, two culverts divert water west from the SR-29 canal. These culverts provide water to Fakahatchee strand based upon the stage within the SR-29 canal, and may not represent historic conditions. A natural system would be the general north–south flow of water within the Fakahatchee strand to the Fakahatchee bay, where the water flows in a broad low-velocity system. Section 5 presents comparisons between the Rookery Bay watershed Natural Systems Model to the CC-ECMv2 model for the Fakahatchee watershed. As shown over the simulation period, the Fakahatchee watershed delivers about two times as much fresh water per acre to the bay when compared to the freshwater deliveries from the Rookery Bay watershed.

Considering the rather large differences in normalized freshwater deliveries and the limited (but significant) flow alterations that have occurred within the Fakahatchee watershed, the watershed modeling analysis does not seem to support the use of Fakahatchee Bay as a reference site**.** Notably, an investigation into the effects of these differences on salinity distributions within the Rookery and Fakahatchee Bays was beyond the scope of this analysis. Until such an investigation is completed, the suitability of Fakahatchee Bay as a reference site for Rookery Bay should not be ruled out.

7.0 References

Dames & Moore, 1998. Task D – Model Development Big Cypress Basin Watershed Plan.

Hughes, G. H., 1978. Runoff From Hydrologic Units In Florida, Prepared by USGS in cooperation with the Bureau of Water Resources Management, Florida Department of Environmental Regulation

Meyer, F.W., 1989. Hydrogeology, Ground-Water Movement, and Subsurface Storage in the Floridan

Aquifer System in Southern Florida. USGS Professional Paper 1403-G. As reported in Dames & Moore, 1998.

Scott, T.M., 1988. The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida. Florida Geological Survey, Bulletin No. 59. As reported in Dames & Moore, 1998

SFWMD, 1986. Preliminary Assessment of the Groundwater Resources of Western Collier County. As reported in Dames & Moore, 1998

USACE - Jacksonville District, 1986. Golden Gate Estates, Collier County, Florida – Draft Feasibility Study. As reported in Dames & Moore, 1998

United States Geological Survey, 1977. The Effect of the Faka Union Canal System on the Water Levels in the Fakahatchee Strand, Collier County, Florida. Water Resources Investigations 77-61.