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Rookery Bay National Estuarine Research Reserve

Henderson Creek Watershed Engineering Research Project

Task 2.7 – Interim Hydrodynamic Modeling Report

MIKE SHE/MIKE-11 Model Development

Prepared for Rookery Bay National Estuarine Research Reserve
June 27, 2014

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Certification

Not valid unless stamped or embossed with Engineer's Seal, signed and dated in contrasting color ink.

This report titled *Henderson Creek Watershed Engineering Research Project Task 2.7 – Interim Hydrodynamic Modeling Report, MIKE SHE/MIKE-11 Model Development* was prepared under the responsible charge of John E. Loper, P.E.

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Executive Summary

Under a contract with the Florida Department of Environmental Protection, a consultant team led by Taylor Engineering is providing the Rookery Bay National Estuarine Research Reserve (RBNERR) with engineering and scientific services to better understand the fresh water flows needed to maintain the health of the Henderson Creek Watershed's Rookery Bay Estuary. An integral component of these services is the development a local-scale hydrologic model for the Henderson Creek / Rookery Bay watershed. Interflow Engineering, as a subconsultant to Taylor Engineering, has completed **Task 2: Hydrodynamic Modeling**, as outlined in the contract Scope of Work (SOW). Of the overall objectives outlined below, only objective 'A' has been addressed by the work efforts described in this report:

A. Develop a local-scale hydrodynamic model for the Henderson Creek watershed
B. Establish target flows, defined as the amount of freshwater flow needed to sustain a balanced Rookery Bay estuary, where volumes and timing of water at specific locations are set aside from consumptive uses for the protection of fish, wildlife, or public health and safety as defined in Sec. 373.223 (4) Florida Statutes, if deemed necessary by research results
C. Analyze probable freshwater inflow quantity and timing of water management projects and water use scenarios
D. Communicate science to water stakeholders of this project and integrate their perspectives and recommendations into research efforts of this project.

Objectives B, C and D are beyond the scope of the work efforts described in this report and will be addressed through concurrent and subsequent work efforts.

Task 2 of the contract SOW consisted of the following interrelated tasks:

- Task 2.1 Field Reconnaissance and Data Review
- Task 2.2 Update Existing BCB Model
- Task 2.3 Construct Local-Scale Existing Conditions Model
- Task 2.4 Construct Local-Scale Natural System Model

This document serves as the culmination of the previous tasks, and concludes with a characterization of changes in volume, timing, and spatial distribution of freshwater flows to the Rookery Bay Estuary in response to anthropogenic influences.

The starting point for the modeling efforts described herein is the "Collier County Existing Conditions Model" (CC-ECM). The CC-ECM is an integrated groundwater/surface water model, the domain of which encompasses the entire Big Cypress Basin (BCB). The CC-ECM model was developed, refined, and revised over a period of several years with funding from the South Florida Water Management District and Collier County.

The following modeling efforts were conducted and are documented in this report.

- Extend the simulation period of the CC-ECM model from 2002 through 2007 to 2002 through 2012,

- Improve the simulated flow at Henderson Creek and update the model to better represent current conditions and the seasonal flow volume and timing to the Rookery Bay Estuary,
- Create a local scale model (LSM) of a smaller domain, consisting of the Henderson Creek / Rookery Bay Watershed, with a refined grid cell size using the updated CC-ECM model as boundary conditions, and
- Prepare existing and historical conditions simulations using the local scale model for the purpose of characterizing changes in volume and timing of freshwater flows to the estuary.

The Existing-LSM model is useful in characterizing the existing volumes and timing of freshwater flows into Rookery Bay. The Existing-LSM reflects conditions as of December 2012, and was also deemed to be a useful and valid starting point for the development of a Historical Conditions LSM, which required removal of all man-made features from the model such as canals, roadway embankments, impervious surfaces, etc. The Historical-LSM provides results for the analysis of the watershed in a pre-development or historical condition for comparison against conditions as they are today.

Important aspects of the model setup, including saturated zone layering and parameters, rainfall and potential evapotranspiration, soils and land-use dependent parameters, etc. were held constant between the Existing and Historical conditions LSM models in order to provide scientifically defensible comparisons between Existing and Historical Conditions. Care was taken to ensure that differences in model inputs and outputs between the two models are solely attributable to anthropogenic changes in the watershed.

From the comparisons of Historical and Existing Conditions water budgets, flows, and stages, a number of insights into the behavior of the system, and how it has changed in response to anthropogenic influences, can be inferred.

- Evapotranspiration (ET) was shown to have decreased by approximately 3 inches/year or on average from historical conditions to existing conditions. This is to be expected as the historical model domain is dominated by wetland and upland land use types. Urbanization and drainage tend to reduce ET. Furthermore, total surface water flows are similar on a unit area basis between the two scenarios. However, sheet flow has decreased considerably while baseflow to canals has increased. These results are to be expected as more water is thought to have been available to overland flow historically due to the absence of ditching and draining found throughout the watershed under existing conditions. Groundwater baseflow is higher in the Existing Conditions due to the presence of drainage canals which penetrate into the highly permeable surficial aquifer.

- Simulated seasonality in the summed coastal flows has shifted slightly from historical to existing conditions according to the model results. Slightly higher wet season flows occurred in the historical conditions model. Additionally, under existing conditions flows are higher for the 15% to 70% exceedance probabilities, meaning that for most mid-range flows, the existing conditions simulation showed a higher flow rate. Above the 90% exceedance probability, the existing conditions flows were lower than historical or nonexistent. Overall, however, the simulated existing and historical average monthly and seasonal flows are surprisingly similar.

- Watershed-wide, the summed freshwater deliveries were predicted to be very similar overall under historical and existing conditions. This result is consistent with the water budget comparison, which suggested that although the flow has shifted from a sheet flow dominated system to a groundwater dominated system (baseflow to canals), the overall flow volumes are similar on a unit basis.
- The area north of the current Henderson Creek / Rookery Bay Watershed that historically would have contributed flow at times (i.e., the NSM area north of the current Golden Gate Canal) to the Henderson Creek / Rookery Bay system was a relatively insignificant part of the overall water budget, but did contribute some flow during extremely wet times.
- The results for the individual coastal inflows, presented separately for each basin/transect, suggest that the volume and timing differs spatially and seasonally between historical and existing conditions. Most notably, it appears the construction of the I-75 and Henderson Creek Canals have concentrated wet season flows in Henderson Creek at the expense of areas to the east, which have less flow now than historically. Other notable differences are related to the land use changes and associated drainage improvements. This result suggests that future management options that focus on spatial redistribution of flows, as opposed to projects that seek to change the timing of flows by storing freshwater for later releases, may have the greatest chances of success.

Recommendations for Future Study

Several potential future scenarios are recommended for further study. The scenarios described below have been identified based upon the result comparisons between the LSM simulations (Existing vs Historical). Simulating these potential scenarios would provide insight into the ability of each alternative to better mimic historical hydrological conditions within the Rookery Bay watershed. Additionally, there have been recent discussions regarding the conversion of the Belle Meade Agricultural area to an urban land use through Collier County's Transfer of Development Rights (TDR) program. The RBNERR is interested in potential changes in freshwater flows that may result from such a conversion.

- Henderson Creek Weir Modifications – This scenario would simulate weir and gate operation scenarios for the Henderson Creek weir complex, and associated structures, including the Collier County structure on the east fork of Henderson Creek. Operational scenarios for these structures that have the potential to better mimic the historic conditions model results for Henderson Creek and the Rookery Bay Estuary will be identified and evaluated. This should include iterative model runs in an effort to develop ideal operational scenarios for timing, duration and flow results that would support restoration goals while minimizing potential negative upstream impacts.

- Belle Meade Agricultural Area Conversion – This scenario would simulate the potential conversion of the Belle Meade Agricultural Area to urban development, which may occur under the TDR program. This effort will require changing the topography and land use-related parameters in the model and to develop assumed conceptual stormwater routing, storage, and water control features to include in the model. The conversion from agriculture to urban land use would be simulated based on development standards and requirements such as the SFWMD or Collier county specified detention storage, and max allowable runoff for each area (i.e., Cubic Feet per Second per Square Mile CSM) required by development codes. Additionally, topographic changes associated with conversion to urban land use would be assumed consistent with other developments near the subject area. This scenario may also simulate one or more flow-ways through the developed areas to route offsite sheet flow from the north of the current agricultural area southward towards US 41. This scenario would not aim to provide a design level analysis from the land use conversion, rather answer the broader scale "what if?" question as to how the assumed differences in land use may affect run off to Rookery Bay.

- Belle Meade Flow-Way Hydrologic Restoration – The hydrology of the Belle Meade Flow-Way has clearly been impacted through the construction of the I-75 canals and the Henderson Creek Canal. This scenario would simulate a number of conceptual components that would work together to restore the regional hydrology of the Belle Meade Flow-Way. These include features to mitigate the groundwater drawdown effects of the I-75 canals and the Henderson Creek Canal, such as liners, slurry walls, and/or control weirs. Features that would facilitate restoration of north to south sheet flow across the present-day I-75 corridor should also be investigated. This may include construction of one or more pump stations and spreader canals. Another component of this alternative might include diversion of limited quantities of water from the Golden Gate Canal system. This alternative may be simulated independently and in conjunction with the Belle Meade Agricultural Area Conversion. Results would be evaluated with respect to restoring hydroperiods within the Belle Meade Flow Way and freshwater flows to Rookery Bay and adjacent estuarine waters.
- Tamiami Canal as Flow Re-distribution Canal – Based on the results of the distributed flow comparisons generated under Task 2.7, estuarine waters west of SR 951 generally receive more freshwater from the upland watershed today than under historical conditions. Conversely, estuarine waters east of SR 951 generally receive less freshwater inflow compared to historical conditions. Under this alternative, the modeling team would investigate the feasibility of using the existing Tamiami canal as a conveyance mechanism to re-distribute freshwater flows in a geographically and seasonally-appropriate manner. The general goal would be to move water in a southeasterly direction towards those areas that have experienced a decline in freshwater inflows.

Introduction

Purpose and Scope

The National Estuarine Research Reserve System (NERRS) Science Collaborative puts Reserve-based science to work for coastal communities coping with the impacts of land use change, stormwater, nonpoint source pollution, and habitat degradation in the context of a changing climate. A multidisciplinary team led by Florida's Rookery Bay National Estuarine Research Reserve (RBNERR) has received an $815,000 grant for a three-year project to help local communities manage freshwater flows in the Henderson Creek watershed. In consultation with an advisory group consisting of hydrological engineers, social researchers, resource managers, and community stakeholders, the team will generate science to better understand the fresh water flows needed to maintain the health of the watershed's Rookery Bay Estuary and the perspectives of water users and decision makers. As part of this project, investigators will create a framework that stakeholders can use to collaborate and make decisions about water issues into the future.

Taylor Engineering holds the prime contract with the Florida Department of Environmental Protection to provide the Rookery Bay National Estuarine Research Reserve (RBNERR) with engineering services to develop a local-scale hydrologic model for the Rookery Bay watershed. Interflow Engineering, as a subconsultant to Taylor Engineering, has completed **Task 2: Hydrodynamic Modeling**, as outlined in the Scope of Work (SOW). Of the overall objectives outlined below, objective 'A' has been addressed by the work efforts described in this report.

The RBNERR has identified the following objectives for work.

E. Develop a local-scale hydrodynamic model for the Henderson Creek watershed
F. Establish target flows, defined as the amount of freshwater flow needed to sustain a balanced Rookery Bay estuary, where volumes and timing of water at specific locations are set aside from consumptive uses for the protection of fish, wildlife, or public health and safety as defined in Sec. 373.223 (4) Florida Statutes, if deemed necessary by research results
G. Analyze probable freshwater inflow quantity and timing of water management projects and water use scenarios
H. Communicate science to water stakeholders of this project and integrate their perspectives and recommendations into research efforts of this project.

Task 2 consisted of the following interrelated tasks:

- Task 2.1 Field Reconnaissance and Data Review
- Task 2.2 Update Existing BCB Model
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This document serves as the culmination of the previous tasks, and concludes with a characterization of changes in volume, timing, and spatial distribution of freshwater flows to the Rookery Bay Estuary in response to anthropogenic influences.

Atkins and DHI, developers of the previously prepared updates to the BCB model, calibrated the model at several flow and water level monitoring stations. The previously updated BCB model, also known as the “Collier County Existing Conditions Model” (CC-ECM), was accepted by Collier County as part of their November 2011 Watershed Management Plan (Atkins, 2011). Overall, the model was reasonably well calibrated for the purpose of regional-scale evaluations. However, results presented in the previous model report (Atkins, 2011) suggested there was room for improvement in the prediction of Henderson Creek flows at US 41, and the model setup no longer represented current conditions in the watershed. Therefore, an update to the BCB model with emphasis on the Henderson Creek subwatershed was necessary.

The CC-ECM has been chosen as a starting point for the modeling work associated with this project and serves as the boundary condition input for the Existing Conditions Local Scale Model (Existing-LSM) for the “Henderson Creek Watershed Engineering Research Project” (HCWERP). The CC-ECM covers all of Collier County including Rookery Bay, the area of interest for this study and was developed in the DHI MIKESHE/MIKE-11 surface and ground water modeling package. The modeling effort was conducted and completed the following objectives:

- Extend the simulation period from 2002 through 2007 to 2002 through 2012,
- Improve the simulated flow at Henderson Creek and update the model to better represent current conditions and the seasonal flow volume and timing to the Rookery Bay Estuary.
- Create a local-scale model (LSM) with a refined grid cell size using the updated CC-ECM model as boundary conditions.
- Prepare existing and historical conditions simulations using the LSM to characterize changes in volume and timing of freshwater flows to the estuary.

MIKE SHE/MIKE-11 is a physically based, fully integrated Surface water/Groundwater modeling package developed by DHI. **Figure 0** presents a schematic of the hydrologic processes MIKE SHE/MIKE-11 simulates (DHI, 2011). As evidenced, many physically based parameters must be accurately represented when using a model of this type.

The current study conducted a limited re-calibration of the portion of the model draining to Rookery Bay. Consequently, special interest is placed on the streams and other conveyance features of the CC-ECM draining to Rookery Bay. Henderson Creek is considered one of the largest freshwater inputs to the Rookery Bay and is the only stream with measured data available for comparisons, as such specific interest during this study had been focused on comparisons between the simulated flow relative to measured flow. **Figure 1** shows the CC-ECM model domain (Black outline), MIKE-11 network (Streams) and the model boundary for contributing freshwater inputs to Rookery Bay (Red outline) also known herein as the local-scale model (LSM). The modeling associated with **Task 2.2** serves to produce boundary conditions for the LSM.

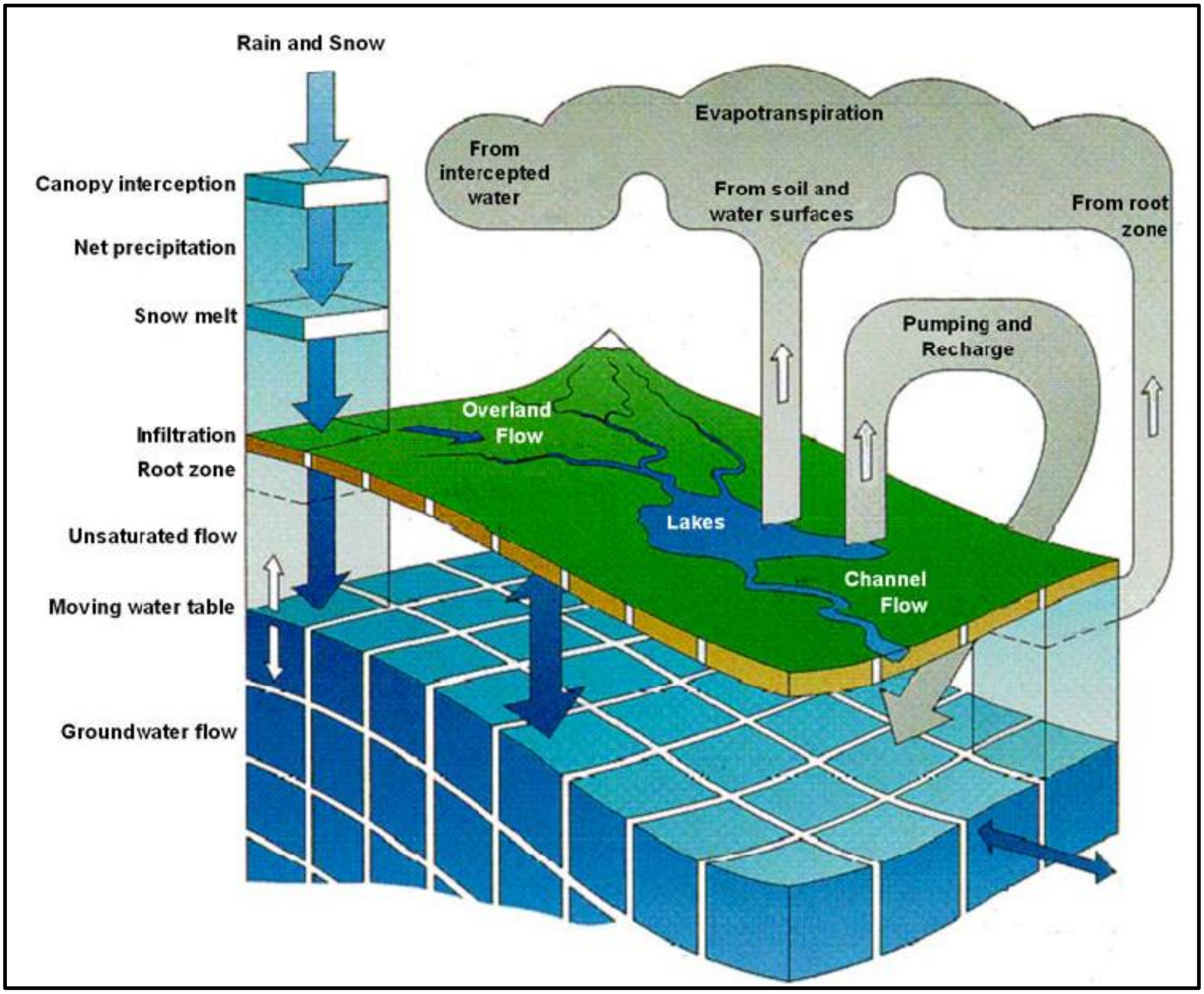


Figure 0. MIKE SHE/MIKE-11 Schematic (Source: DHI, 2011)

Tasks 2.3 and **2.4** are both related to LSM with the objective of comparing existing and historic freshwater inputs to Rookery Bay, where:

The local-scale models were used to simulate existing and historical conditions within the Henderson Creek / Rookery Bay Watershed. Important aspects of the model setup, including saturated zone layering and parameters, rainfall and potential evapotranspiration, soils and land-use dependent parameters, etc. were held constant between the Existing and Historical conditions models to provide scientifically defensible comparisons between Existing and Historical Conditions. Care was taken to ensure that differences in model inputs and outputs between the two models are solely attributable to anthropogenic changes in the watershed.

Through these tasks, the HCWERP has met the modeling objectives outlined in the scope of work with the overall objective of the project to determine the volume and timing of freshwater deliveries to Rookery Bay.

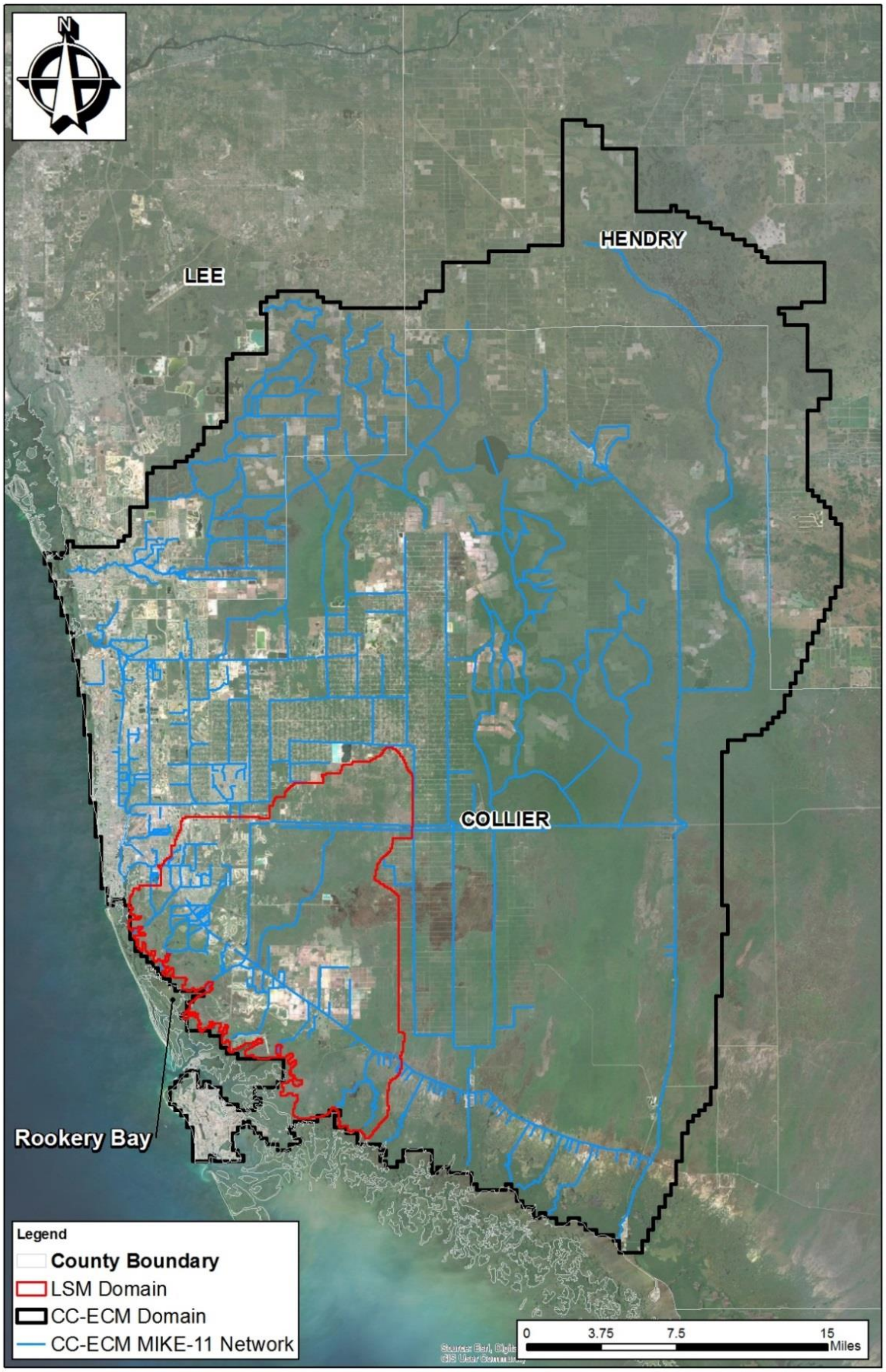


Figure 1. CC-ECM and LSM Model Domains

Study Area Description

The following narrative provides general background information for the modeling work associated with the HCWERP. As depicted in **Figure 2**, the local-scale study area (also referred to as the model domain), comprises 167 square miles and lies completely within Collier County, FL. The local-scale model (LSM) domain can be described by a northern boundary about 2 miles south of Golden Gate Blvd., an eastern boundary about 1.5 miles west of and largely paralleling Everglades Blvd., a western boundary about 1.5 miles east and adjacent to Airport Road, and a southern boundary paralleling the coastline from Thomasson Dr., to about 4 miles southeast of CR 92.

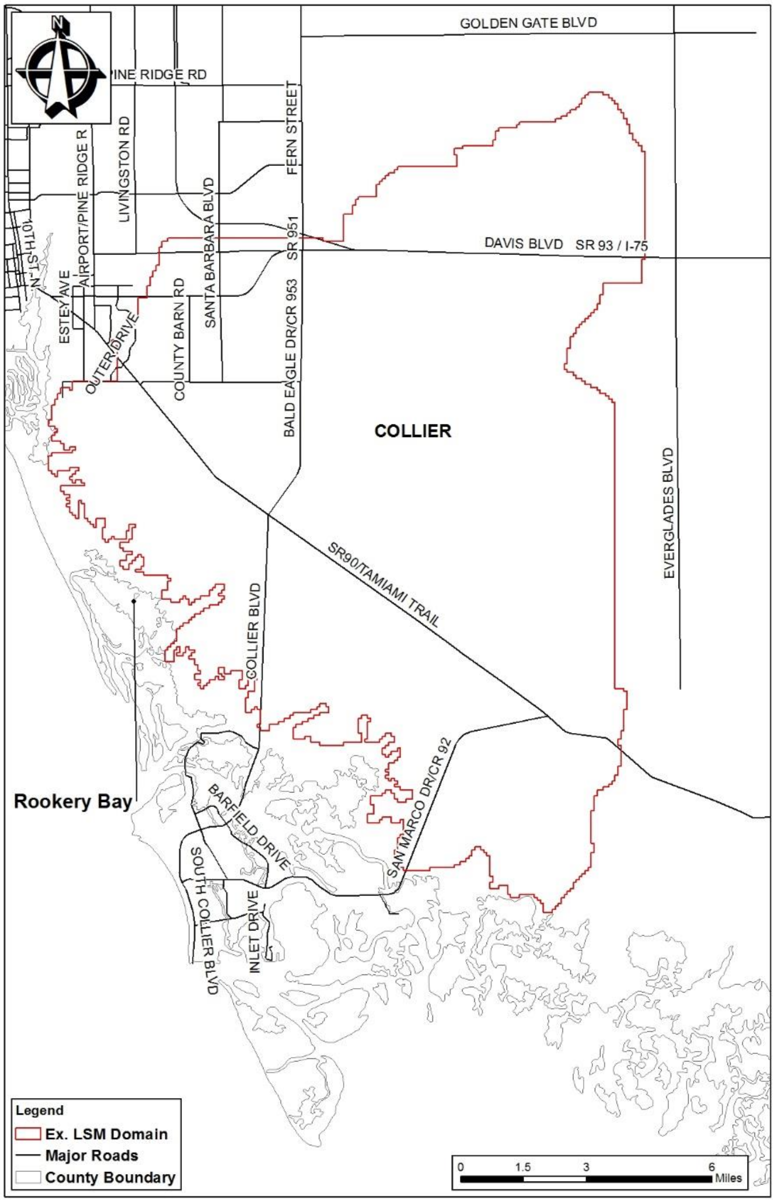


Figure 2.The Local-Scale Study Area

Drainage in the study area naturally occurred due to the gently sloping topography, with no natural stream development except for tidal channels within the coastal estuaries (McCoy, 1972). Collier County has a long history of development, which includes dredging the US-41/Tamiami Canal in 1928 with the building of US-41/Tamiami Trail roadway. Additionally, the development known as Golden Gate Estates and associated drainage canals were dredged in the 1960's as well as the I-75 canal and Alligator Alley roadway being built in the same decade. These disturbances as well as aspects of urbanization within the study area have altered the natural hydrology and drainage. The drainage, which historically occurred through slowly moving slough systems and wide swaths driven by the topography is now strongly influenced by a channelized system which conveys water rapidly away from the source (McCoy, 1972).

The soils within the study area are characterized by a high water table and the majority of the study area classified as sandy textured soils with a portion of the area classified as muck. The soils have been grouped by drainage class, which gives an indication of where the water table is in relation to the soil surface. The vast majority of the study area is underlain by Very Poorly Drained and Poorly Drained soils, which comprise 34 and 58% of the watershed respectively, or 92% of the total study area.

The hydrogeology of the study area can be described by a highly permeable surficial (i.e., Water Table Aquifer [WTA]) and Lower Tamiami Aquifers (LTA), as well as the Tamiami Confining unit, which separates the WTA from the LTA. The WTA and LTA are highly permeable formations separated by a leaky confining which leads to very high rates of production from each formation. Production capacity is measured by transmissivity, where according to the USACE, the WTA has transmissivities ranging from 100,000 to over 1,000,000 gallons per day per foot (gpd/ft), while the LTA ranges from 100,000 to 500,000 gpd/ft (USACE, 1986).

While pockets of urbanization exist, wetland categories (other than mangroves) comprise 38% of the study area, where mangroves occupy 20% and urban land has been calculated to be 14% of the study area. Overall, approximately 70% of the study area is in a relatively natural state, while 30% of the area has undergone some type of development. **Table 1** presents a complete breakdown of hydrologically similar land use types included in the modeling study.

Table 1. Hydrologic Land Use Category

Hydrologic Land Use Category	Area (acres)	Percentage of Study Area
Wetland	41,106	38.5%
Mangrove	20,917	19.6%
Urban Land	14,514	13.6%
Forest, (Non-Wetland Flatwood/Hammock)	14,165	13.3%
Agriculture	6,176	5.8%
Open Water	3,743	3.5%
Pasture/Bare Ground	3,244	3.0%
Golf Course	3,022	2.8%

The study area lies within the Big Cypress Basin (BCB), which has been the subject of several previous studies. The following list provides a synopsis of the known studies within the BCB; while the list is considered complete, not all studies were relevant to the current study.

- Report on Water Management in Collier County, FL, (Smally Wellford & Nalven, 1961)
- † Master Plan for Water Management District No. 6, (BC&E Inc., 1974)
- Master Plan - Water Management District No. 7, (BC&E Inc., 1975)
- Gordon River Watershed Study, Engineering Report, (CH2M Hill, 1980)
- Golden Gate Water Management Study, (Johnson Engr., 1981)
- Belle Meade/Royal Palm Hammock Water Management Plan, (CH2M Hill, 1982)
- A Report on the Henderson Creek Drainage Basin, (Bruns & Bruns, Inc., 1982)
- Master Plan Update for Water Management District No. 6, (WMBSP Inc, 1985)
- Watershed Analysis CR 951 Basin, (Johnson Engr., 1989)
- Imperial River Watershed (Part of the Lee County Surface Water Management Plan, (1990-1991, co-sponsored by Lee County and SFWMD), (Johnson Engr., 1991)
- Engineering and Environmental Studies Report for Lely and Lely Branch and Lely Manor Basins, (Law Engineering and Environmental, 1993)
- Corkscrew H & H Study, (Gee & Jenson, 1993)
- Hydrologic Restoration of Southern Golden Gate Estates (Conceptual Plan), (SFWMD, 1996)
- Big Cypress Basin Watershed Management Plan, (Dames and Moore, 1998)
- Big Cypress Basin Integrated Hydrologic-Hydraulic Model, (DHI, 2002)
- Hydrologic-Hydraulic and Environmental Assessment For The Kamp Keais Strand Flow-way, (HydroGeoLogic, Inc., 2006).
- Belle Meade Stormwater Management Plan, (Parsons, 2006)
- Collier County Watershed Management Plan, (Atkins, 2011)

† Currently known as the Lely Area Stormwater Improvement Project (LASIP), an ongoing drainage system improvement projects continuing into 2015.

1.0 Field Reconnaissance and Data Review

To develop a detailed understanding of the existing hydrologic and hydraulic features within the Henderson Creek / Rookery Bay Watershed, Taylor Engineering and Interflow (the Team) performed several field reconnaissance trips, met with SFWMD Big Cypress Basin (BCB) staff to discuss the existing MIKE SHE hydraulic model, and collected pertinent data for model development. This task seeks to ensure the hydraulic model correctly simulates the physical conditions in the watershed. This includes critical flow path elements such as canals, channels, streams, flow structures (such as weirs, culverts, and bridges), road obstructions, and low water crossings. Based on collaboration between the Team, SFWMD, and RBNERR and through desktop research and data collection, the Team identified a list of critical hydrologic and hydraulic features that require field investigation. This section of the report summarizes the data collection and field reconnaissance efforts by the Team to develop a detailed understanding of the existing hydrologic and hydraulic features within the Henderson Creek / Rookery Bay Watershed.

1.1 Data Collection

To update the existing MIKE SHE model, the Team collected topographic data, hydraulic structure data, land use data, and climate data from various sources. Those sources include the SFWMD's Big Cypress Basin, SFWMD permits, Collier County, and the Rookery Bay NERR (RBNERR). The purpose of the data collection was to gather data to update the existing model and extend the model boundary conditions for the period of record covering 2007 – 2012.

The following sections highlight some of the data collected to update the MIKE SHE model and extend the model period of record.

1.2 Hydraulic Model

1.2.1 Topographic Data

The Team obtained the SFWMD's 07-08 FDEM LiDAR Digital Elevation Model (DEM), which the SFWMD confirms as the most recent data. The Team updated and revised the existing model topographic data based on this data.

1.2.3 Aerial Photography

The Team obtained FDOT 2012 aerial photography 6-inch and 2-foot resolution for the Henderson Creek Watershed, the FDOT confirms this as the most recent and accurate data available. The Team used this data to develop flow paths, check structures, and revise land-use data.

1.2.4 Climate Data

- Rainfall — The Team obtained and extended through 2012 all rainfall time series using NEXRAD rainfall from the SFWMD
- Evapotranspiration (ET) — The Team obtained and extended through 2012 all ET time series using GOES Satellite Reference Evapotranspiration (RET) data from the USGS

1.2.5 Land-use Data

The Team obtained 2008 land use from SFWMD and will revise all associated files (e.g., Overland Flow (Manning Number, Detention Storage, and Paved Runoff Coefficient), with the latest land use information. In addition, the Team obtained and reviewed SFWMD Environmental Resource Permit (ERP) files for several recent land development projects within the local-scale model domain.

1.2.6 Hydraulic Structure Data

The Team conducted several field investigations, as presented in Section 2.0. The Team obtained this invaluable information for hydraulic structures and other pertinent conveyance features. In addition to field reconnaissance, the Team found a desktop review of the Collier County Stormwater Database, SFWMWD's ERPs, and SFMWD's "DBHYDRO" database excellent sources of structure data.

These sources are:

- Collier County Stormwater Database, includes every stormwater feature the County knows of. This database provides a good resource to compare against as-built drawings, etc.
  http://www.arcgis.com/explorer/?open=ff48f06d08754a53b8649ffd0b94f332

- Collier County has a map of Lely Area Stormwater Improvement Project (LASIP) projects past/present/future:
  http://www.colliergov.net/Modules/ShowDocument.aspx?documentid=34404.

- SFWMD shapefile coverage of their ERP's:
  http://my.sfwmd.gov/gisapps/sfwmdxwebdc/dataview.asp

- SFWMD DBHYDRO breakpoint database, which_contains measured hydrologic data time series such as surface water levels, discharge rates, and groundwater levels.
  http://www.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu.

1.2.7 Unsaturated Flow Data

Unsaturated flow data is vadose zone data for use in the soils parameterization within the MIKE SHE model. The Team updated soil profile definitions for the local-scale model (Henderson Creek Watershed). The Team has downloaded this data (Unique ID 134 FDEP Soils SSURGO – SFWMD) from SFWMD (http://my.sfwmd.gov/gisapps/sfwmdxwebdc/dataview.asp?query=unq_id=134). The Team used this data to aggregate the soil data for the Henderson Creek Watershed model at a refined grid cell size.

1.2.8 Saturated Zone Data

Saturated zone data is groundwater data for use in the geological parameterization within the MIKE SHE model.

- Geological/Computational Layers and Lenses — The Team refined the associated .DFS2 files for each layer from the already calibrated model. Therefore, no new hydrogeology data is necessary.

- Pumping Wells — IE has reviewed the pumping wells and extended the time series to the most current data possible (through December 2012).
- IE has reviewed the pumping well file and identified a series of wells along CR-951 “Collier Blvd;” these wells are part of Collier County Supply Wells. Table 2 presents a list of well time series files (.DFS0) and the associated utility used in the “CC_EC_Calibrated” model. The Team populated Table 2 from the “CC_EC_Calibrated_rev2t_GWWell.WEL” file within the MIKE SHE model.

Table 2. Pumping Well Files and Associated Utility for Data Extension

Pumping Well TS File (DFS0)	Utility
11-00013-W	Immokalee Water & Sewer District
11-00017-W	Naples Coastal Ridge
11-00080-W	Naples Coastal Ridge
11-00148-W	Golden Gate Water Treatment
11-00249-W	Collier County
11-00271-W	Port of The Islands Community Improvement District
11-00419-W	Orange Tree Utility Co PWS
11-00592-W	Summerland Grove
11-01701-W	Hideout Gold Club
11-02298-W	Ave Maria University and Town
26-00164-W	Hendry Correctional Institute
36-00003-W_CS	Lee County Utilities - Corkscrew
36-00003-W_GM	Lee County Utilities - Green Meadows
36-00008-W	Bonita Springs
36-00208-W	Citrus Park Resort

1.3 Field Reconnaissance

The Team made four field visits including one aerial fly over of the watershed to inspect and photograph these critical hydraulic features within the Henderson Creek Watershed. The dates and general locations for field trips were:

- April 12, 2013 — Areas in and around Lely Canal, Naples Manor Outfall, and Treviso Development
- June 14, 2013 — Areas in Lakewood Country Club, Rattlesnake Hammock, Sabal Palm Road, Fiddlers Creek, and Coopers Cove
- June 26, 2013 — Areas within RBNERR, Treviso Development (Upstream of RBNERR), and Culverts Along US 41
- July 5, 2013 (Fly Over) — Belle Meade, Merritt Canal, Six L's Area, Henderson Creek Canal, Power Line Road, Sand Hill Bay Road, and Treviso Bay Outfall Lakes.

2.0 Task 2.2: Update Existing BCB Model

One of the objectives of the Henderson Creek Watershed Engineering Research Project (HCWERP) is to better understand the volume and timing of freshwater deliveries to the Rookery Bay Estuary. The HCWERP is a multi-tasked project with seven individual, interrelated modeling tasks. **Task 2.2:** "Update Existing BCB Model" is the starting point of the modeling tasks, and the focus of **Section 2**.

The Big Cypress Basin (BCB) model, an integrated MIKE SHE/MIKE-11 model, was updated for Collier County in 2011 through a joint effort between Atkins and DHI (Atkins, 2011). MIKE SHE/MIKE-11 is a physically based, integrated (surface water/groundwater) modeling package. This means the model utilizes "real world" physically based data to calculate the distribution of water on the earth's surface and below for a defined area (model domain). A few examples of MIKE SHE/MIKE-11 input data are

- Rainfall
- Evapotranspiration (ET)
- Topography
- Soils characteristics
- Geometry of surface water conveyance features such as streams, canals, and control structures
- Subsurface/Hydrogeological stratigraphy and hydraulic characteristics
- Consumptive use of groundwater and surface water

The previously updated BCB model is now known as the Collier County Existing Conditions Model (CC-ECM). This model is known within the SFWMD BCB Office and the HESM as the 'CC-ECM rev3' model but is referred to in this report simply as the 'CC-ECM'. The model domain covers Collier County, and was previously run for the period of 2002 – 2007. The CC-ECM has been accepted by Collier County for the purposes of watershed planning and has been chosen as the starting point for the HCWERP. To that effect, the CC-ECM was relatively well calibrated, yet based on the results presented in Atkins (2011), the model still over-estimated flows at the Henderson Creek Main Branch SFWMD structure "HENDTAMI."

Using the previously developed CC-ECM model, the main objectives of the HCWERP **Task 2.2:** "Update Existing BCB Model" are as follows.

- Extend the simulation period from 2002 – 2007 to 2002 – 2012,
- Improve the simulated flow at Henderson Creek East Branch to better represent the seasonal flow volume and timing to the Rookery Bay Estuary,
- Prepare model simulations extending from 2002 through 2012, which will provide accurate boundary conditions for a more detailed, local-scale model (LSM) to be developed and calibrated in subsequent tasks. The local-scale model will be used to simulate existing, historical, and potential project conditions.

While a new model has not been developed per-se, the CC-ECM has been revised for this project, in that

- All time-series associated with atmospheric, surface water and groundwater input have been extended to allow the simulation to run for the specified period (2002 through 2012).

- Project-specific areas of the surface water network were revised to better represent current hydrologic and hydraulic conditions in the watershed.

Time-series were extended by utilizing available measured data, or through standard scientific and engineering practices when measured data was not available or not relevant to the development of the local-scale model.

After all relevant time-series were extended a simulation was run, and comparisons for a select group of observation points within the model domain were made against measured data and the previously developed model. These comparisons or model checks are performed for both the surface water and groundwater components of the model, to ensure large errors or discrepancies were not introduced by extending the simulation period. This is a standard practice as models are developed for specific objectives over defined time periods. When a project extends a simulation time period or makes changes to any aspect of the model domain, model instabilities or calculation errors can be inadvertently introduced from the updates/changes. An instability is an indication that a physical parameter or model assumption is incorrect. If an instability should arise, corrective action should be made to ensure accurate water budget calculations, and that the model will run through to completion.

After all appropriate time-series extensions were completed, and verified not to introduce instabilities at or within the model boundary, the surface water network was examined to ensure the appropriate assumptions were made within the Rookery Bay Watershed. This facilitated a proper water budget calculation with respect to the future development of the LSM. After the surface water network was reviewed, instances of the physical location and model assumptions of certain features were deemed inappropriate and have been revised in **Task 2.2**.

The water budget is an accounting method hydrologists use to tabulate the naturally occurring and simulated amounts of rainfall, ET, runoff, and other processes of the hydrologic cycle. The water budget can be calculated for the entire watershed or for a specific area within the watershed, and is compared against measured data. For example, if the average rainfall within the Rookery Bay Watershed was 55 inches/year and the model simulated 65 inches/year, this would indicate the rainfall input to the model was inappropriate and would result in other discrepancies to the water budget (runoff and ET for example). As such, the erroneous rainfall in this example would need to be investigated and corrected.

As previously mentioned, the CC-ECM was developed for a broad range of watershed management planning and large scale water budget analysis, while the HCWERP aims to utilize results from the revised CC-ECM model as boundary condition inputs for a smaller model domain (LSM) with refined grid-cell sizes.

The team has developed a MIKE SHE/MIKE-11 model (DHI, Release 2011, SP 7), which runs through 2012 and meets the goals of **Task 2.2,** in that the model runs seamlessly, and provides reasonable boundary conditions for the LSM. The specific items addressed in **Task 2.2** are presented in **Sections 2.1 through 2.4** of this report.

2.1 Task 2.2 MIKE SHE Updates and Revisions

The CC-ECM model was run for the period of January 2002 – October 2007, and while the model has been accepted by Collier County for the purpose of watershed management planning, flows at Henderson Creek were being over-simulated. After peer review and limited model revisions, the CC-ECM continued to over-simulate flow at the Henderson Creek Structure (DHI, 2011a). The current modeling effort will refine the CC-ECM to better serve the LSM model development through improved results for use in providing boundary conditions for the local scale model.

The first two objectives of this study are to extend the simulation to run through 2012, and from a limited calibration effort, improve the simulated flows at Henderson Creek upstream of US41. To extend the simulation period, specific input files needed to be extended in order for the model to run for the specified time period. Therefore, time-series files associated with all input files within MIKE SHE and MIKE-11 dependent on time-series control were required to be extended for the model to run for the specified time period. Additionally, a limited calibration effort was completed to better simulate flow at Henderson Creek.

The following input parameters within MIKE SHE were updated and extended.

- SFWMD NEXRAD Doppler Radar-Derived Rainfall
- USGS GOES Reference Evapotranspiration (RET)
- Station Based Vegetation Crop Data
- Groundwater Boundary Conditions
- Groundwater Pumpage Files (Obtained from SFWMD or Municipality of Concern)

2.1.1 SFWMD NEXRAD Rainfall

Rainfall data, the single largest driver of watershed hydrologic simulations, is a very important component of this model. For this study, hourly NEXRAD rainfall data from 1/1/2002 to 12/31/2012 was obtained from the SFWMD and processed into a single .DFS2 file, a two-dimensional spatially distributed and temporally varying file unique to DHI software. By selecting specific model grid-cells, the processed NEXRAD rainfall was compared against SFWMD rain-gage data at selected locations shown in **Figure 3** (blue circles). As can be seen in **Figures 4** through **7**, the NEXRAD data compares well against SFWMD measured rain-gage data with approximately nine, five, two, and six percent difference at stations COLGOV_R, COLLISEM, ROOK, and SGGEWX respectively.

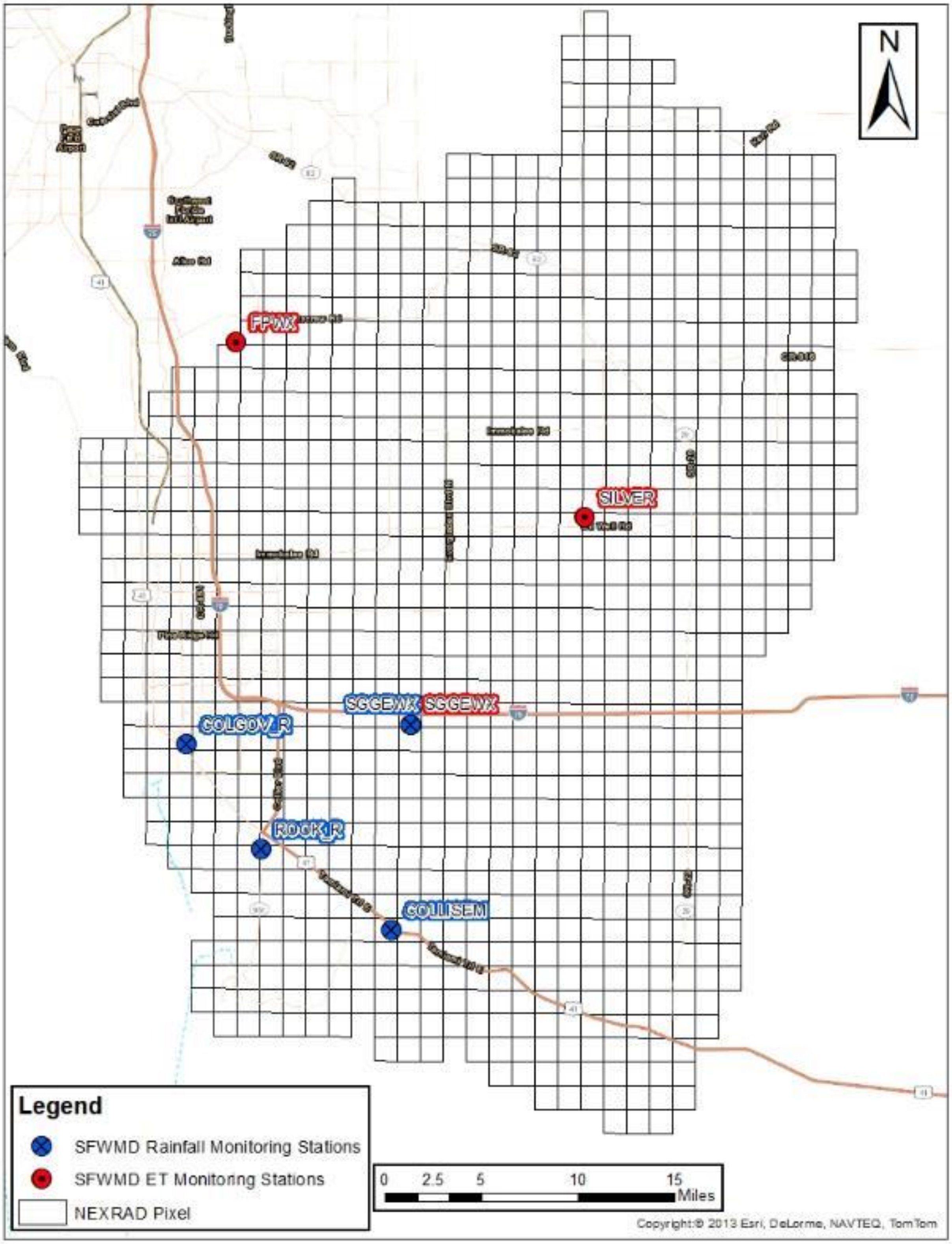


Figure 1. SFWMD Weather and Rain Gage Station Locations Used In NEXRAD Rainfall and USGS GOES RET Comparisons

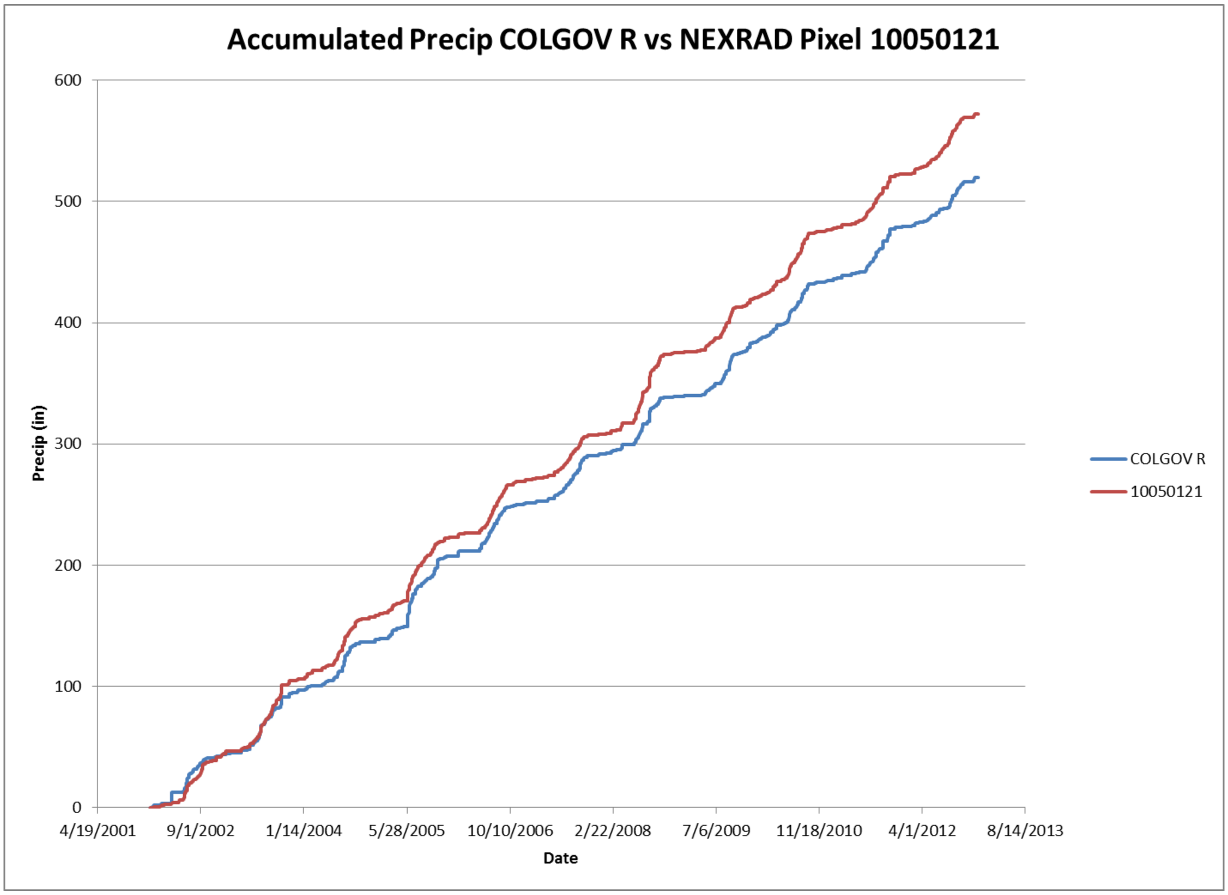


Figure 2. Cumulative Rainfall Comparison: SFWMD Gage COLGOV_R vs SFWMD NEXRAD Pixel 10050121

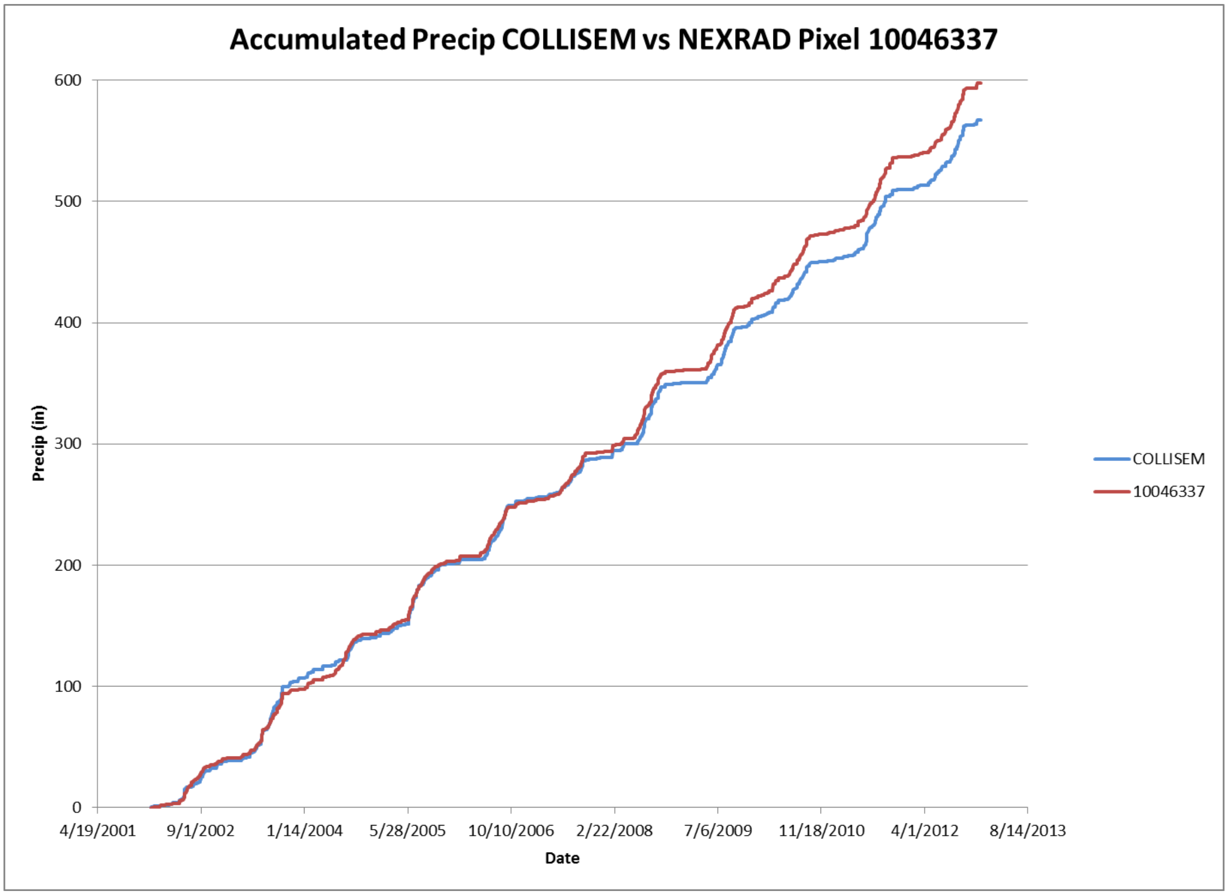


Figure 3. Cumulative Rainfall Comparison: SFWMD Gage COLLISEM vs SFWMD NEXRAD Pixel 10046337

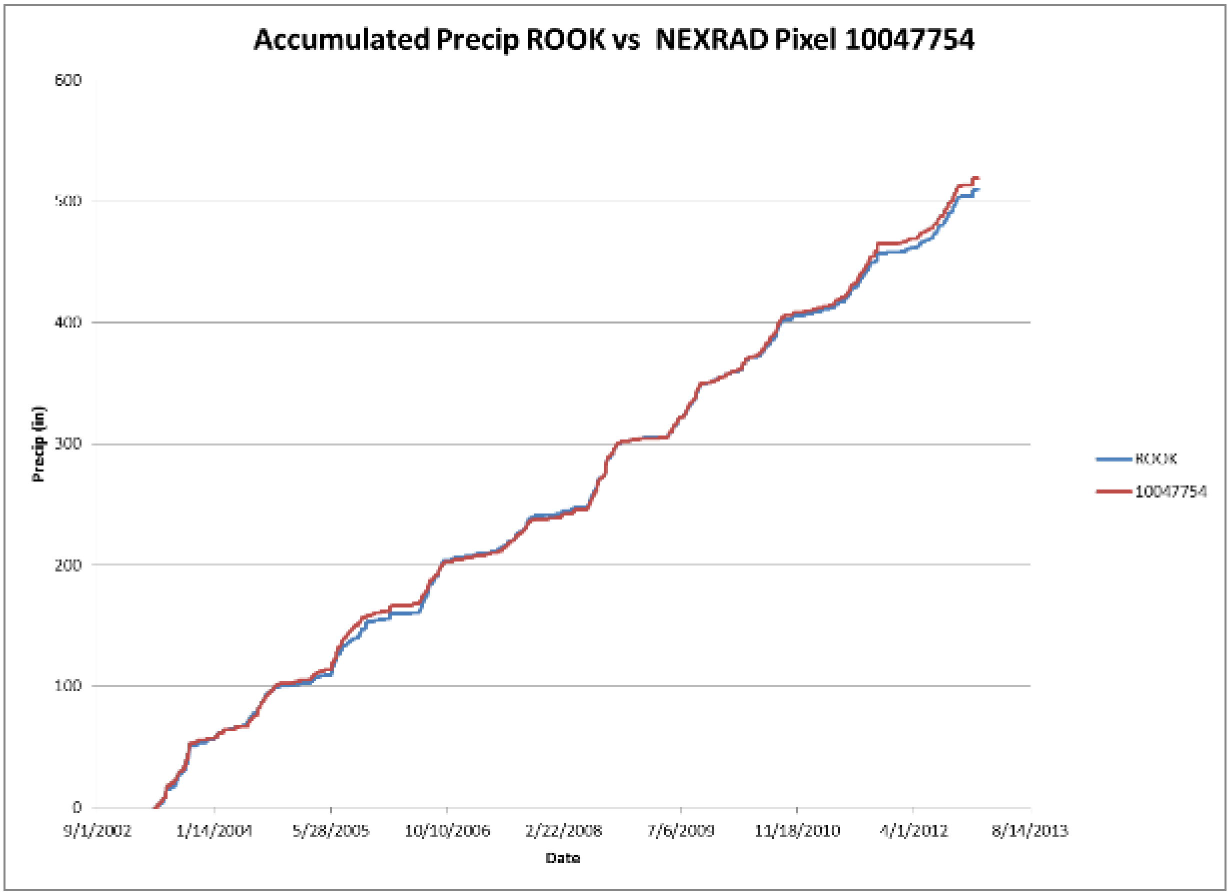


Figure 4. Cumulative Rainfall Comparison: SFWMD Gage ROOK vs SFWMD NEXRAD Pixel 10047754

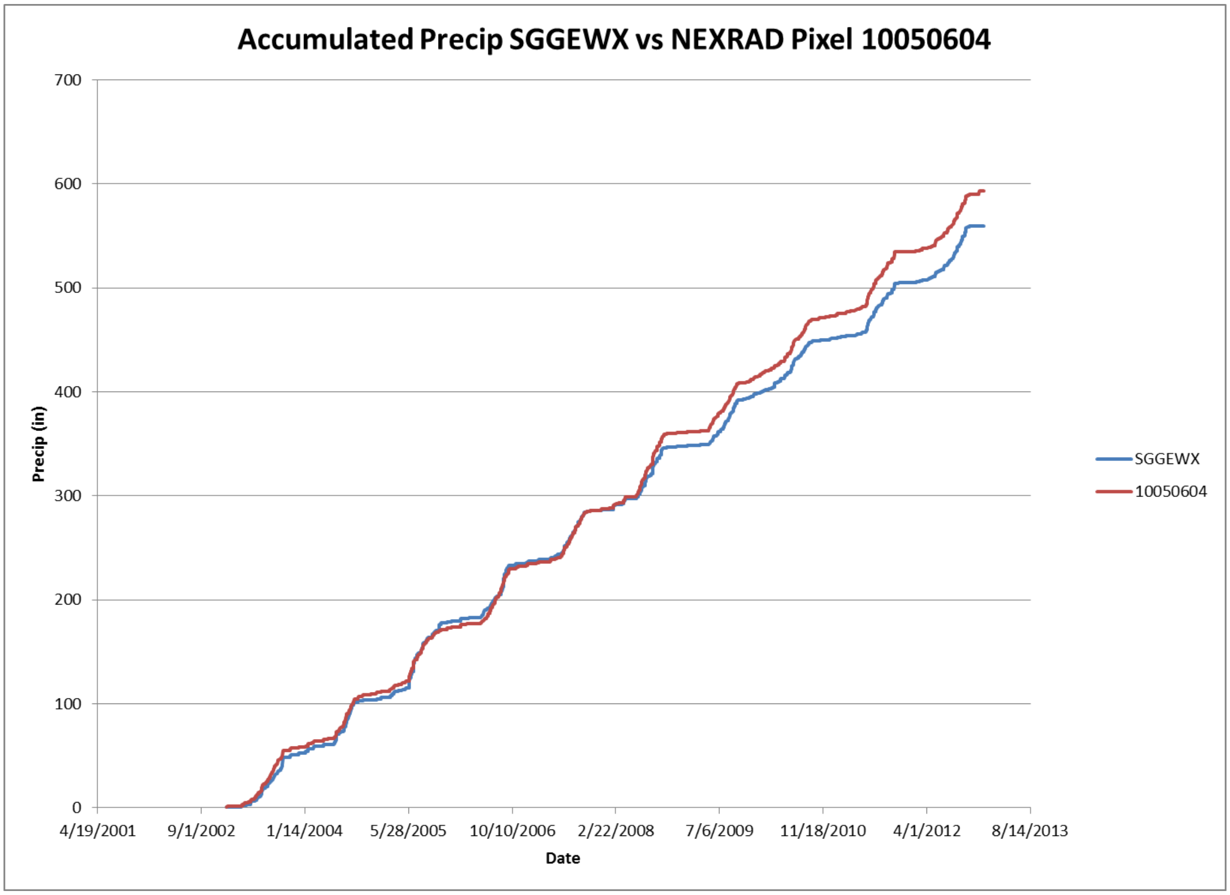


Figure 5. Cumulative Rainfall Comparison: SFWMD Gage SGGEWX vs SFWMD NEXRAD Pixel 10050604

Comparing cumulative totals from each station presented in **Table 3**, the differences are slight, where each comparison is within 10 percent or less of the SFWMD rain-gage data. While there is a slight over estimation in the NEXRAD data, this analysis leads to the conclusion that the rainfall data is reasonable and accurate for use in simulations for this project. The NEXRAD data was used in favor of the station-based data because the NEXRAD data is spatially distributed whereas the station-based data is not.

Table 3. SFWMD Gage vs SFWMD NEXRAD Rainfall Cumulative Total Comparison

SFWMD Gage Name	Period of Comparison	NEXRAD Rainfall inches	SFWMD Gage	Difference %
COLGOV_R	1/1/2002 to 12/31/2012	572.4	519.8	9
COLLISEM	1/1/2002 to 12/31/2012	597.5	567.2	5
ROOK	5/3/2003 to 12/31/2012	519.2	509.6	2
SGGEWX	1/1/2003 to 12/31/2012	593.6	559.8	6

2.1.2 USGS GOES RET

Reference Evapotranspiration (RET) is one of the most important components of the MIKE SHE model, as evapotranspiration is typically the second-largest component of a watershed's overall water budget. Daily Geostationary Operational Environmental Satellite (GOES) Satellite Based RET data was obtained from the USGS, which is considered the best available data for a distributed watershed model such as this. The USGS RET data is available on a daily time step and is applied on the same grid as the NEXRAD rainfall data.

The USGS GOES RET data was processed into individual .DFS0 files, which are one-dimensional temporally varying files unique to DHI software. The USGS GOES Satellite grid was overlaid to the model domain via a shapefile, containing an attribute for each USGS pixel ID. For each unique pixel an associated .DFS0 file is applied to the entire pixel area (2km x 2km), where RET is varied with time over the simulation period. At the time of model development, RET data through 2011 was available, to extend the time-series through 2012 an extrapolation from the Julian Day Average was conducted for years 2002 to 2010. The USGS RET data has been compared against SFWMD measured data to ensure reasonableness of input data. As shown in **Figures 8** and **9** the USGS RET data compares well against SFWMD measured data for stations FPWX and SGGEWX only varying by 3 percent and 8 percent respectively (**Table 4**). However, when comparing USGS RET data to SFWMD SILVER station there is approximately 21% difference, where SFWMD SILVER (**Figure 10**) is showing about 21% less PET for the comparison period. This can be explained by the fact that there are 750 days of missing data from the SILVER dataset. When taking the number of missing days and multiplying by the average PET from the SILVER data set, and adding this “missing” data sum back to the cumulative total PET, the comparison is vastly improved. This indicates that there is not a gross over approximation from the USGS GOES RET data, rather a large enough number of missing data points from the SFWMD SILVER station to cause significant discrepancies in the comparison.

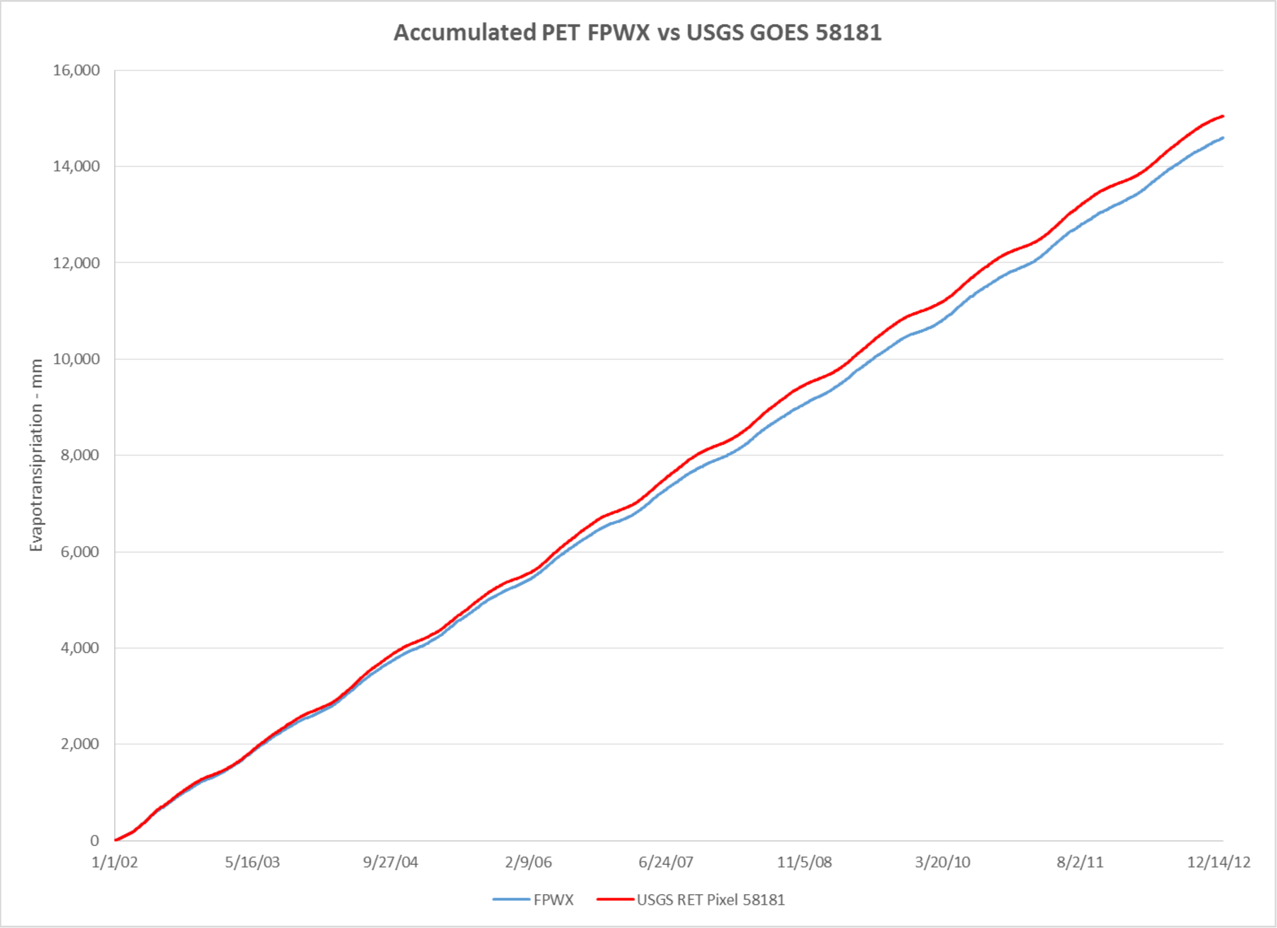


Figure 6. FPWX PET vs USGS GOES RET Pixel 58181 Comparison

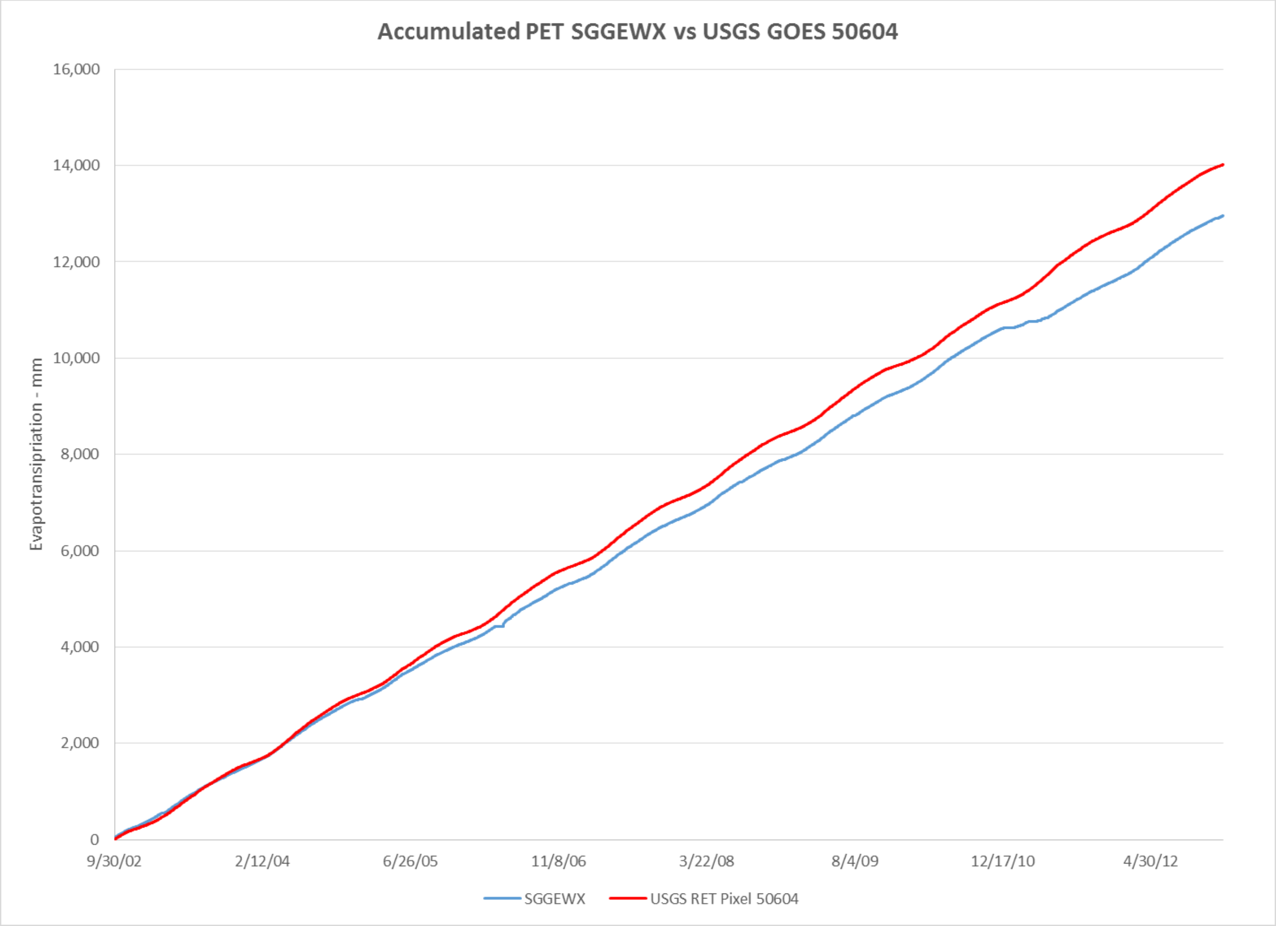


Figure 7. SGGEX PET vs USGS GOES RET Pixel 50604 Comparison

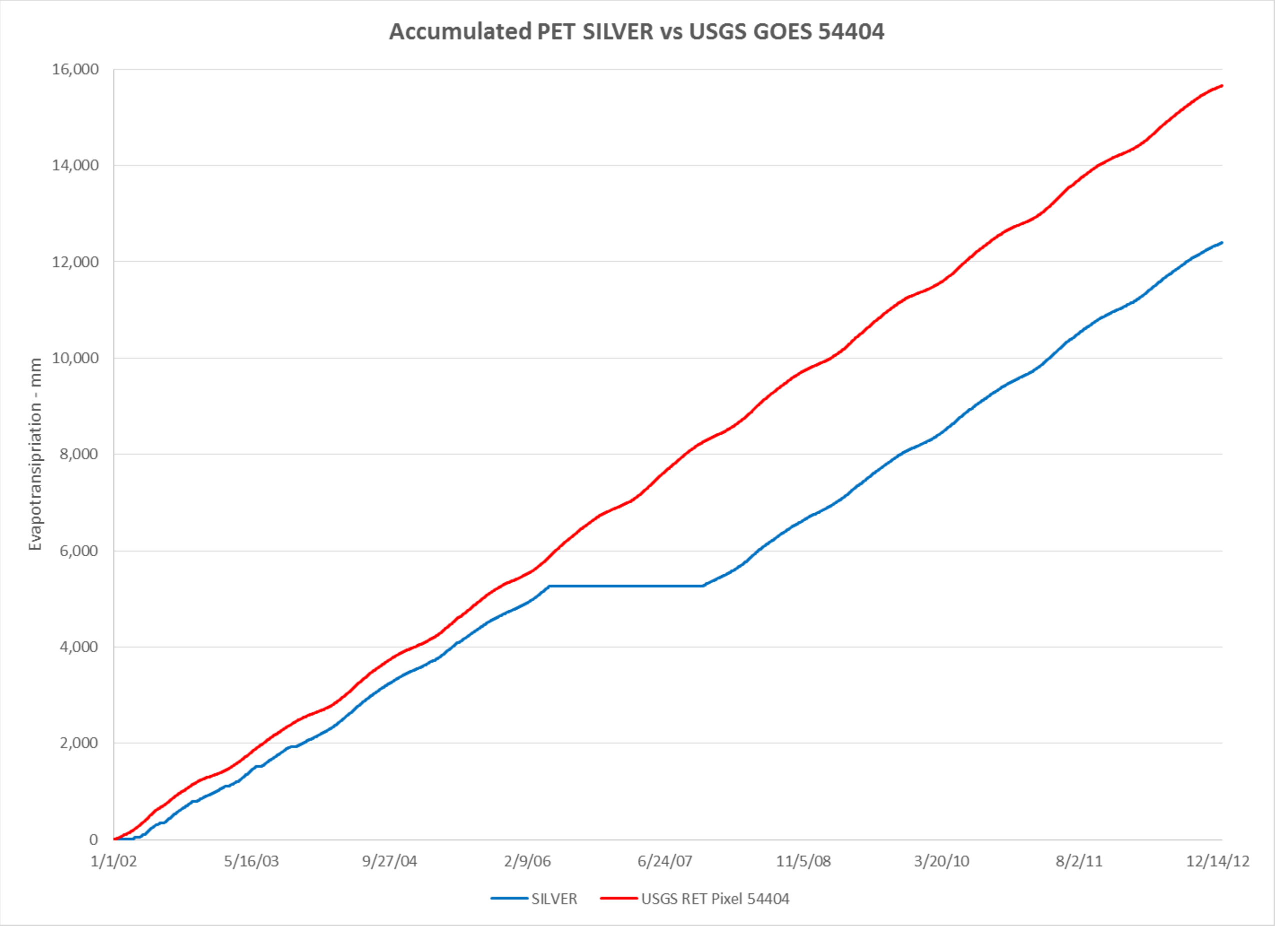


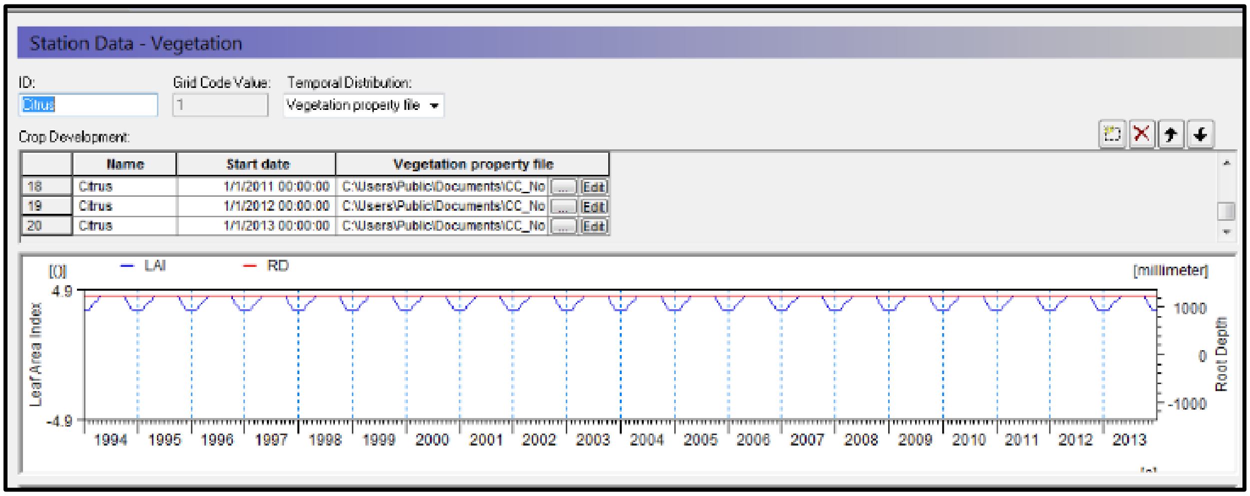
Figure 8. SILVER PET vs USGS GOES RET Pixel 54404 Comparison

Table 4. SFWMD PET and USGS RET Data Comparisons

SFWMD Weather Station	**Period of Comparison**	**USGS RET mm**	**SFWMD Gage mm**	**Difference %**	**No. of Days Missing Data**
FPWX	1/1/2002 to 12/31/2012	15,051	14,598	3	6
SGGEX	09/30/2002 to 12/31/2012	14,020	12,959	8	112
SILVER	1/1/2002 to 12/31/2012	15,660	12,399	21	750

2.1.3 MIKE SHE Station Based Vegetation Data

Station based vegetation crop data is the method MIKE-SHE employs to define the growing season and apply crop/vegetation dependent evapotranspiration to the model for each of the independent land use types throughout the model domain. These data are used to convert RET to actual ET. This time-series extension was accomplished by inserting the appropriate lines within the vegetation crop data for each land use type, through the end of 2012. See **Figure 11** for an example of how these parameters are defined for the land use classification of Citrus groves.


Station Data - Vegetation

ID: Citrus

Grid Code Value: 1

Temporal Distribution: Vegetation property file

Crop Development:

	Name	Start date	Vegetation property file
18	Citrus	1/1/2011 00:00:00	C:\Users\Public\Documents\CC_No
19	Citrus	1/1/2012 00:00:00	C:\Users\Public\Documents\CC_No
20	Citrus	1/1/2013 00:00:00	C:\Users\Public\Documents\CC_No

Figure 9. Station Data for Citrus Land use Extended for the CC-ECMv2 Model

As shown in **Figure 11**, each line represents a full growing season for the specified land-use defined in the MIKE SHE setup. In this example, citrus is shown and can be seen that the data has been extended to simulate a growing season through 2012. These files were not changed from the CC-ECM model, only extended to satisfy the simulation period.

2.1.4 MIKE SHE Saturated Zone Boundary Conditions

MIKE SHE utilizes an explicit model domain defining the areal extent of all portions of the hydrologic cycle, including processes such as atmospheric, overland-flow, surface water, and unsaturated zone and saturated zone "groundwater" (**Figure 0**). 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 within the CC-ECM model; as such, a complete description will not be presented here (PBS&J, 2011). Additionally, Element 3 Task 10 states that the surficial aquifer has many observation stations which were used to generate an interpolated grid map for the heads within the surficial aquifer from 2001 to 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. This is considered appropriate as the north and eastern groundwater boundary of the model is over 8 miles in any direction from the proposed Rookery Bay (LS) Watershed Boundary. Due to the large distance of the groundwater boundary from the Rookery Bay Watershed, it has been assumed that no instabilities or other influences from the CC-ECM groundwater boundaries would be introduced by extending the CC-ECM boundary time-series. As such, groundwater boundary conditions were extended for the .DFS2 files associated with the hydrogeologic units presented in **Table 5**. 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 through 2007 and the seasonal pattern in groundwater elevations were shown to be reflected from 2004 to 2007. Each .DFS2 file was extended from the end of the previous simulation by copying the data from 2004 to 2008, into the newly created files, for the remainder of the simulation. This means that for the groundwater boundary condition files, years 2009 – 2012 correspond to the previously developed water levels from 2004 to 2007. Notably, the Surficial or Water Table Aquifer has a coastal southern boundary which borders Rookery Bay, Dollar Bay, Sand Hill Bay, Mud Bay and Blackwater Bay. The coastal boundary condition is defined from actual tide data from the Naples Tide Gage (NOAA Station 8725110).

Figures 12 and **13** present screen captures of the southern "coastal boundary" and northern/eastern Boundary condition extent within MIKE SHE. It is important to note that 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 zero-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 5. Groundwater Boundary Condition Time-series Extension for Each Hydrogeologic Unit

Hydrogeological 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

To ensure the groundwater boundary time-series extension and boundary condition assumptions were appropriate, six observation wells within and along the Rookery Bay Watershed boundary were selected as check stations (**Table 6)**. These wells (**Figure 14**) were chosen as comparison points as they had measured data available from SFWMD DBHYDRO and their proximity within or near the Rookery Bay Watershed.

Table 6. SFWMD Observation Well Identification, and Strata From DBHYDRO

SFWMD ID	DBKEY	Well Depth (ft)
C-968_G	06560	23
C1224	NV383	178
SGT1W1	PT043	20
SGT2W1	PT051	20
SGT3W1	PT063	20
SGT4W1	PT077	19

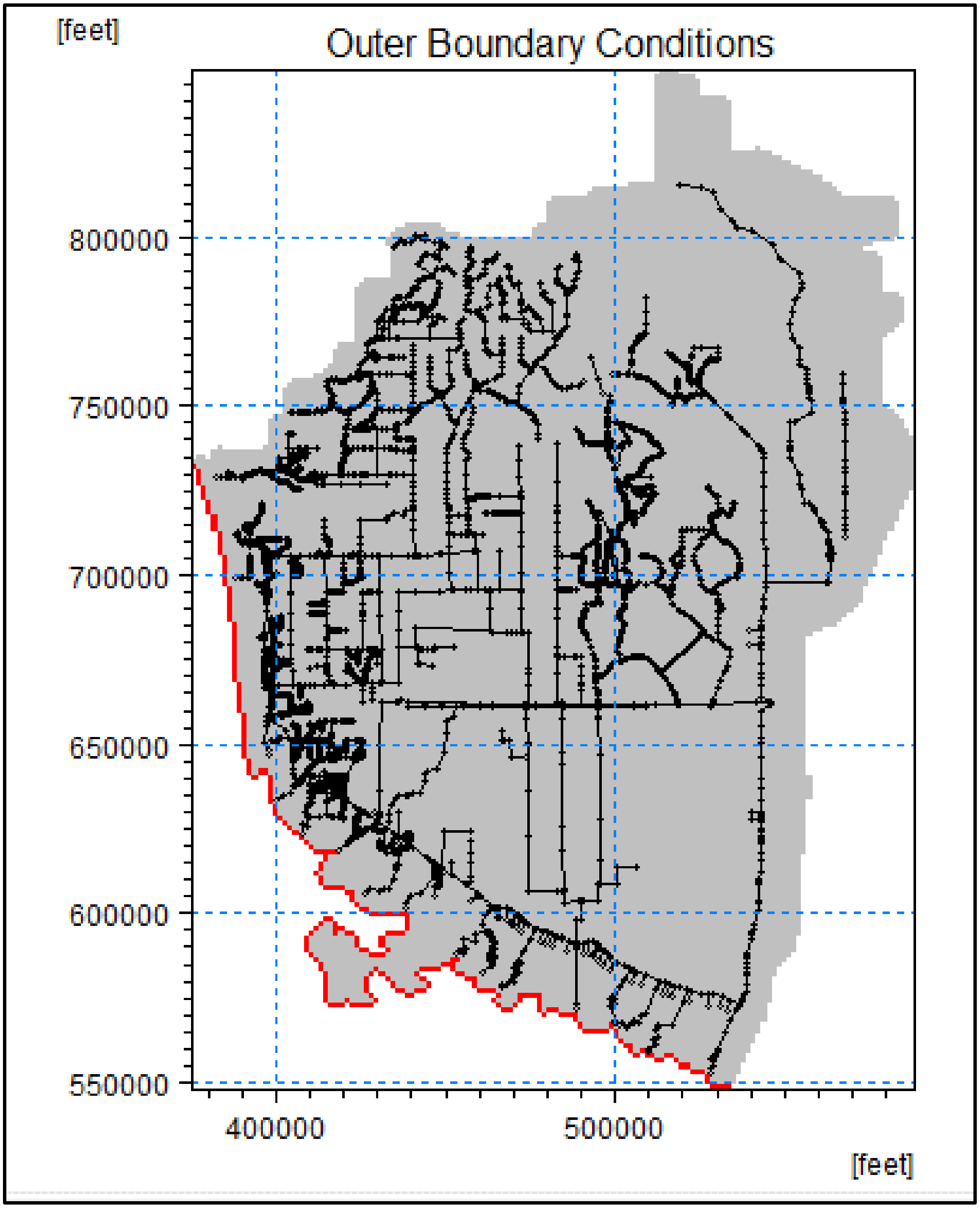


Figure 10. Alignment of the CC-ECM Domain: Coastal Boundary (Red Line)

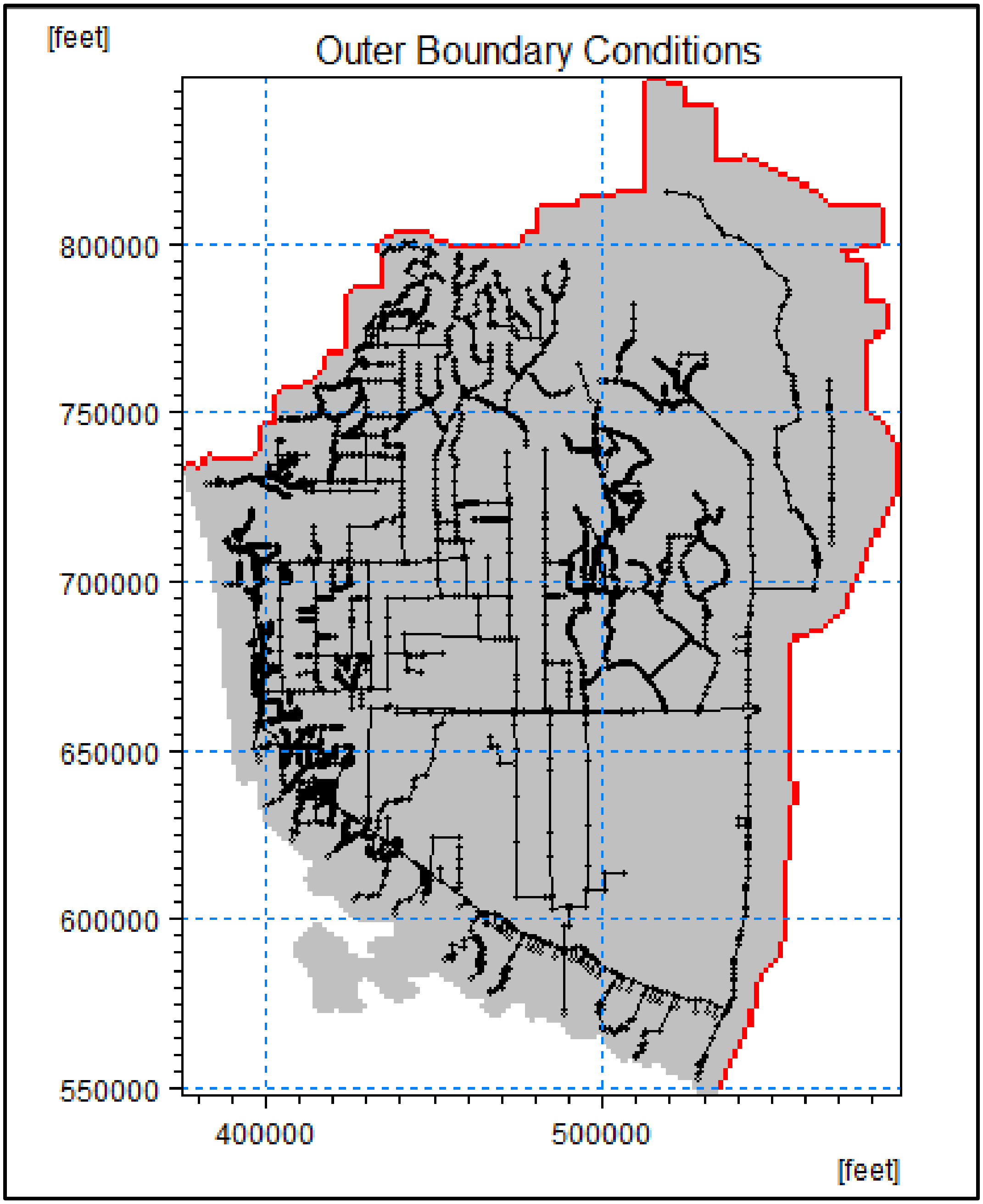


Figure 11. Alignment of the CC-ECM Domain: Northern/Eastern Boundary (Red Line)

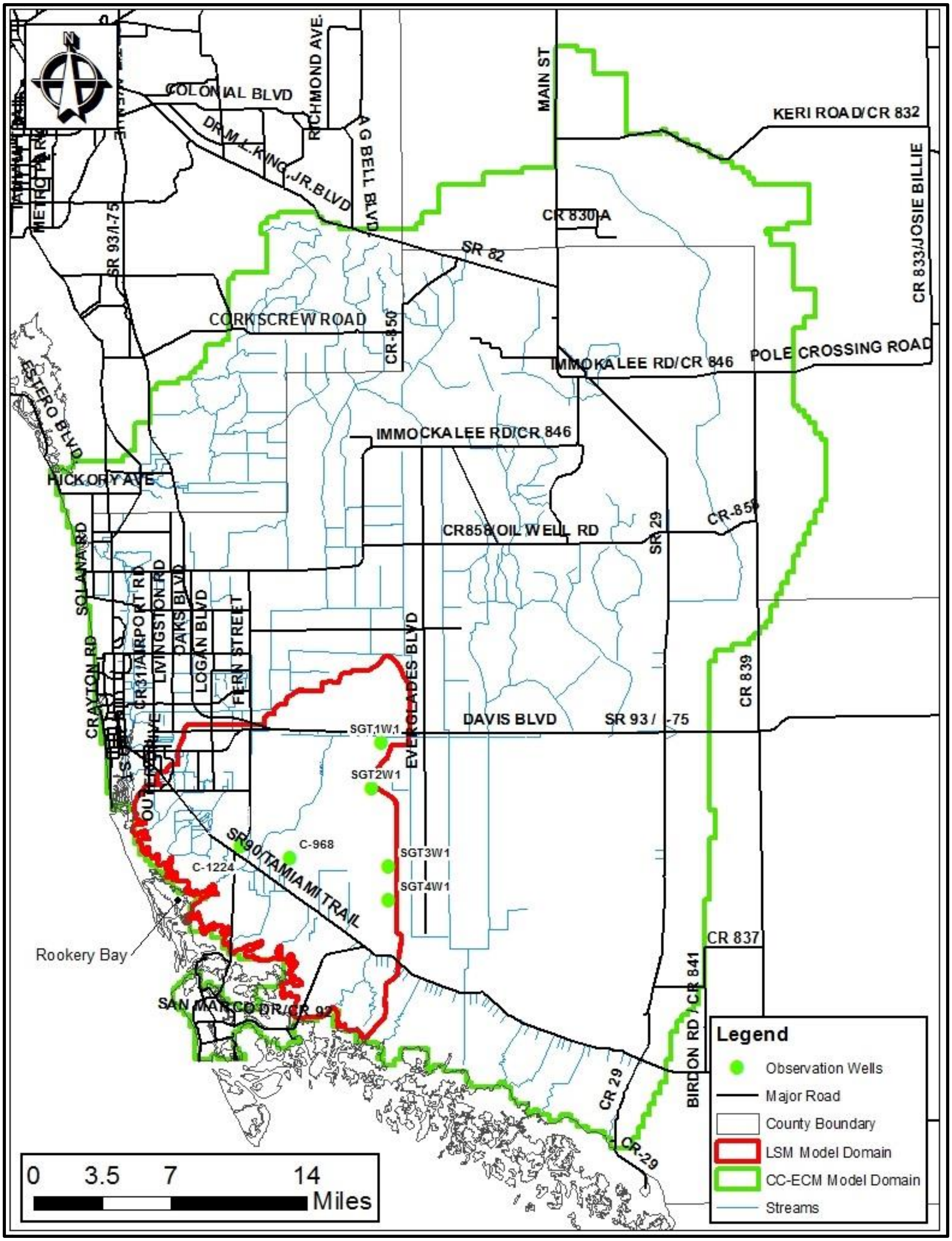


Figure 12**. Observed Groundwater Stations Within and Near The Rookery Bay Watershed (LSM) Model Domain**

2.2 Task2.2. MIKE-11 Revisions

MIKE-11 is the calculation engine that drives the 1-D hydraulic portion of the MIKE SHE/MIKE-11 modeling package. MIKE-11 is coupled with MIKE SHE and provides the surface water component of the integrated modeling package where exchanges with overland flow and groundwater processes are accounted for within the hydraulic network. MIKE-11 is the 1-D hydraulic model where drainage features such as streams, canals, and control structures were modified as appropriate for the current study. The CC-ECM model was reviewed and we found instances where a refined or improved representation was warranted in a few locations within the Rookery Bay Watershed. Using the CC-ECM model as a starting point, model revisions (time series extension, control structure revisions/additions) were made in an iterative process. After any major revisions were made, a simulation was completed and compared against the CC-ECM results as a benchmark or check against the previous model, and ultimately the available measured data.

The first goal was to extend the simulation period through 2012, using field conditions as they are up to the end of the simulation period. This is not always a straightforward process as models are calibrated to a specific time period through project specific parameters, whether they are control structure operations based on time series or construction of storm water improvement projects (i.e., LASIP) or Best Management Practice (BMP) feature installation. Certain control structures are calibrated for a simulation-specific time period and should be able to run properly for any time period after the fact. However, through model revisions, certain instabilities that were not present in the previous simulation may unexpectedly present themselves, from either an inappropriate representation of the structure, or other model instability due to computational error introduced by updated climatic conditions, cross-sectional revisions, or other model parameter revisions. All such instabilities that caused the model to crash due to the time-series extension were resolved successfully and the model ran to completion; an example of this is discussed in **Section 2.1**.

The major drainage features and water utilities within the model domain are

1. Henderson Creek Main Branch, East Branch and associated structures
2. The Lely Area (LASIP)
3. Belle Meade Stormwater Management Master Plan (SWMMP)
4. Marco Island Utilities (MIU)

From these major drainage features or water utilities, specific information was analyzed and, if appropriate or relevant to the model, added to the current CC-ECMv2 to enhance the calibration, better represent the physical conditions in the watershed, or determine the appropriate course of action for future phases of the modeling effort.

The CC-ECM domain covers a large land area, containing many hydraulic control structures including culverts, fixed crest weirs, and pump-stations. **Table 7** presents the number of control structures, culverts, and weirs within the CC-ECM model as well as two versions of the currently revised CC-ECM. The differences in the revised CC-ECM versions 1 and 2 can be explained by the addition of a single LASIP project called “Lely Main”(LMB-00-S0122), which is an operable control structure and fixed crest weir along the Lely Main Branch in CC-ECMv1. CC-ECMv2 includes all LASIP projects completed to 2012 (For a complete description on the LASIP projects incorporated in the current model see Section 4.3.)

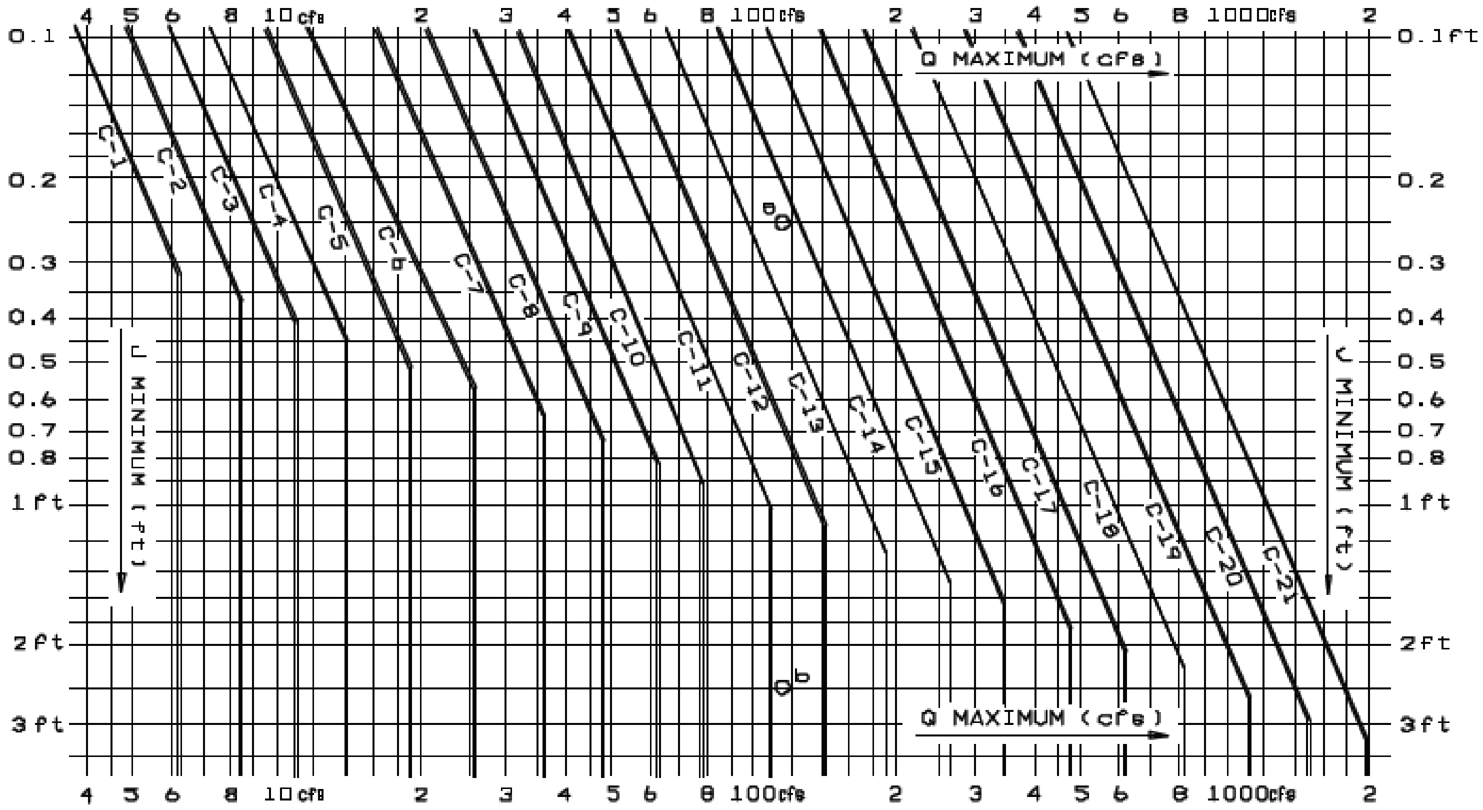
Consequently, the CC-ECMv2 model has been chosen as the appropriate version to use for the boundary condition development of the LSM.

Table 7. Control Structure Comparisons between Simulations

Simulation	Operable Structures	Culverts	Fixed Crest Weir
CC-ECM	79	228	161
CC-ECM v1	80	229	162
CC-ECM v2	83	261	168

2.2.1 Model Instabilities/Crashes

During the calibration process, the model crashed from an instability at Collier County Control Structure "Airport Road Canal North Weir" (ARN-00-S0160), which is a D-500 Amil Gate (Radial Gate). Investigation into this instability revealed this structure was being modeled as an operable underflow gate, when in reality it should be modeled as a discharge structure with a rating curve. Where the rating curve for the structure is based on the head difference (dH) between the upstream and downstream water levels near the control structure. The instabilities were assumed to be from the gate set up and operations and associated simulated head differential across the structure, causing unrealistic stage and flow results. When looking into the instabilities from the Airport Road North Structure, a similar structure was shown on the Airport Road South Canal. This structure (ARS-00-S0120) was also modeled as an underflow gate with seasonal operation, when in reality it is a D-710 Amil gate. Both structures: ARN-00-S0160 and ARS-00-S0120 were revised to be simulated as radial gates with a stage/discharge rating curve based on the dH across the structure. A radial gate can be simulated using a dH/flow relationship at a specific structure, and will only allow the prescribed flow to pass through the structure. Using published data for a Waterman Industries © Type "C" C17 and C-20 gate (2011, Waterman), dH/flow rating curves were developed for the aforementioned structures and the model ran to completion without instabilities. **Figure 15** presents the chart from Waterman Industries © used to develop the each rating curve (2011, Waterman).



GATE SIZE SELECTION CHART
Hydraulic Data based on TRANOR Standard Structure (see next page)

Figure 13. Hydraulic Data Used to Create dH Rating Curves For ARN-00-S0160 and ARS-00-S0120 Discharge Structures

2.2.2 Henderson Creek Revisions

As previously mentioned, the second yet equally important goal of this study was to improve the simulated flows at Henderson Creek Main Branch. Henderson Creek is also known as the Henderson Creek Main Branch and Henderson Creek East Branch. The Main Branch flows directly under US41 with a defined channel north of US41 and is controlled by three structures. Henderson Creek East Branch also flows under US41. The Henderson Creek East Branch is connected to the canal along north bound lanes of US41, this branch is not fed from a defined north/south flow-way north of US41 and essentially begins at the TAMIHEND control structure, which is a fixed crest weir and a single manually operated slide gate.

SFWMD names control structures based upon a unique station name and DBHYDRO key (dbkey). From these station names and dbkeys, SFWMD manages data within the SFWMD DBHYDRO database. From within the DBHYDRO database, HENDTAMI and TAMIHEND are the names of the operable control structures on Henderson Creek Main and East Branches respectively.

Control Structures at Henderson Creek Main Branch (**Figure 16**):

- **HC-1_W**: an Ogee weir
- **HENDTAMI**: Automated sluice gates installed in 2001 to allow for more control and better representation of the historic seasonal flow patterns from Henderson Creek.
- **HC-1_C**: Upstream sluice gate and downstream flap gated culvert used to assist in the wet season when the variable weir is over powered

Figure 14. Upstream via of Henderson Creek Control Structure No.1 Showing Ogee Weir, Automated Sluice Gates, and Manual Sluice Gate (Photo Courtesy: SFWMD)

Figure 17 presents the channel alignment and structure locations for Henderson Creek Main and East Branches, as well as the alignment of Marco Lakes (just north of the HENDTAMI structure), and a portion of the Belle Meade Flow-way north of the TAMIHEND structure. As shown in **Figure 17,** the Belle Meade Flow-way is represented in the 1-D (MIKE-11) portion of the model as the grid-cell size of the CC-ECM does not lend itself to the detail necessary to represent the system explicitly in the 2-D portion of MIKE-SHE. The opposite is true when discussing the Belle Meade Flow-way for the LSM models in that the grid-cell refinement allows for the representation of the system to be wholly within the 2-D portion of the model domain. For a complete discussion see **Section 3.2.2** of this report.

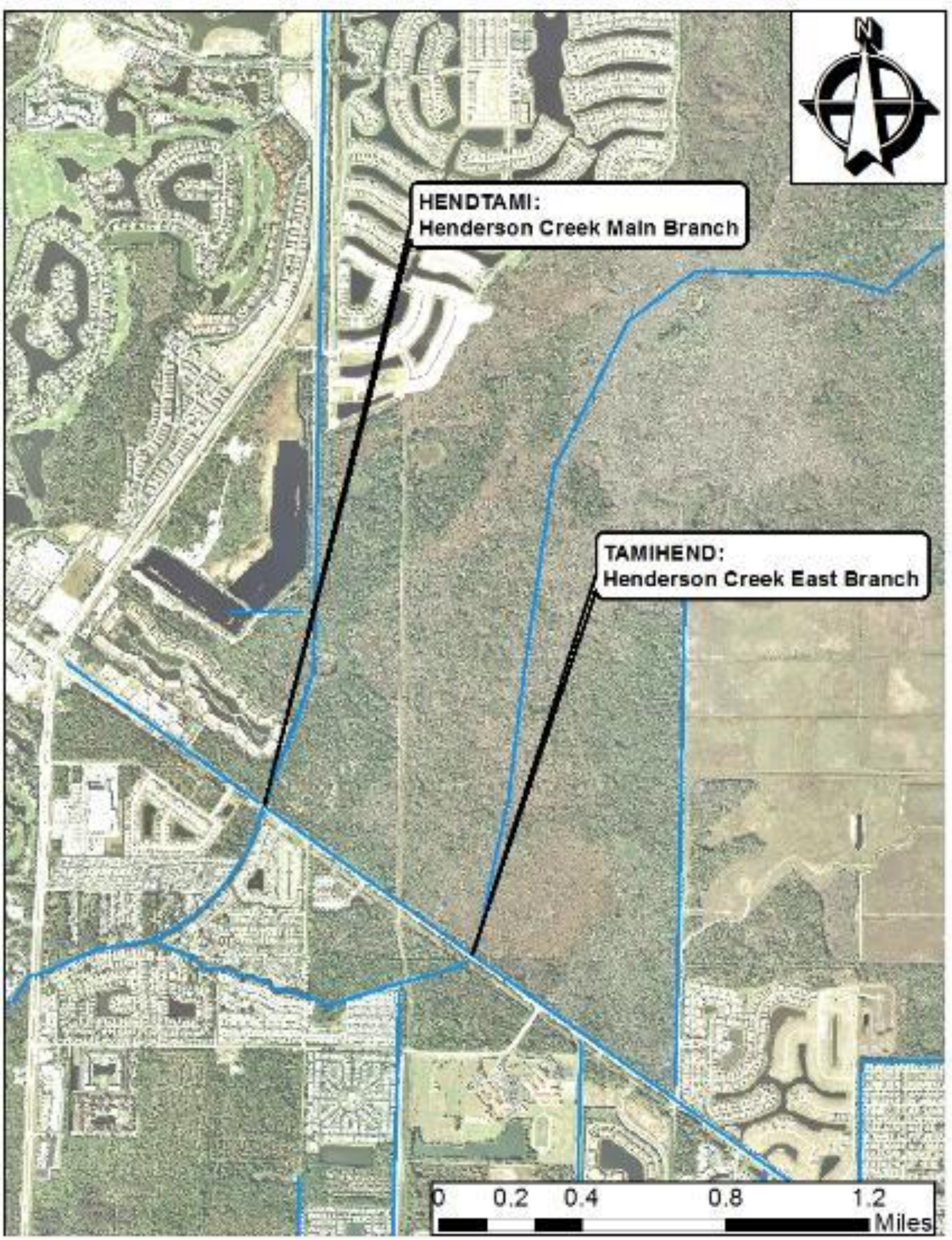


Figure 15. Location of Henderson Creek Main Branch, East Branch and Associated Control Structures

The Henderson Creek East Branch is controlled by a fixed crest weir and single 4ft x 4ft SLIDE gate (TAMIHEND), shown in **Figure 18**. The TAMIHEND structure is operated by Collier County to provide wet season control within the Tamiami Canal and to prevent over draining of the adjacent wetlands and flow-way systems to the north.

Figure 16. TAMIEHEND Structure Looking North (06/26/2013) Note: Belle Meade Flow-way To East

According to the Collier County Stormwater Database ,the gate is opened to allow discharge when water levels are 3.5 FT-NGVD29 (2.2 FT-NAVD88) or above, and the gate is closed when upstream water levels decrease to 3.5 FT-NGVD (2.2 FT-NAVD88) at the start of the dry season (Collier County Storm water Database: http://maps.colliergov.net/pdf/stormwater/manual/slidegateweir/hec-03-s0100.pdf).

Previously, the CC-ECM had the TAMIHEND structure set up to operate from seasonal rules based on the aforementioned description. However, when examining the DBHYDRO gate level data for structure TAMIHEND and CC-ECM results at the structure, it was noted that observed gate levels were remaining open longer than what the model was simulating. Therefore, the structure was revised to utilize measured gate levels as operational controls rather than user-defined logical operands specified by season. **Figure 19** presents gate level data for the CC-ECM and the refined CC-ECMv2 for the TAMIHEND gate. The figure indicates that switching to a time-series of gate openings allows the gate to be open for longer durations and in some instances higher elevations. This change has the potential to allow more flow through the TAMIHEND structure from the Tamiami Canal into the Henderson Creek East Branch and ultimately to the Rookery Bay Estuary.

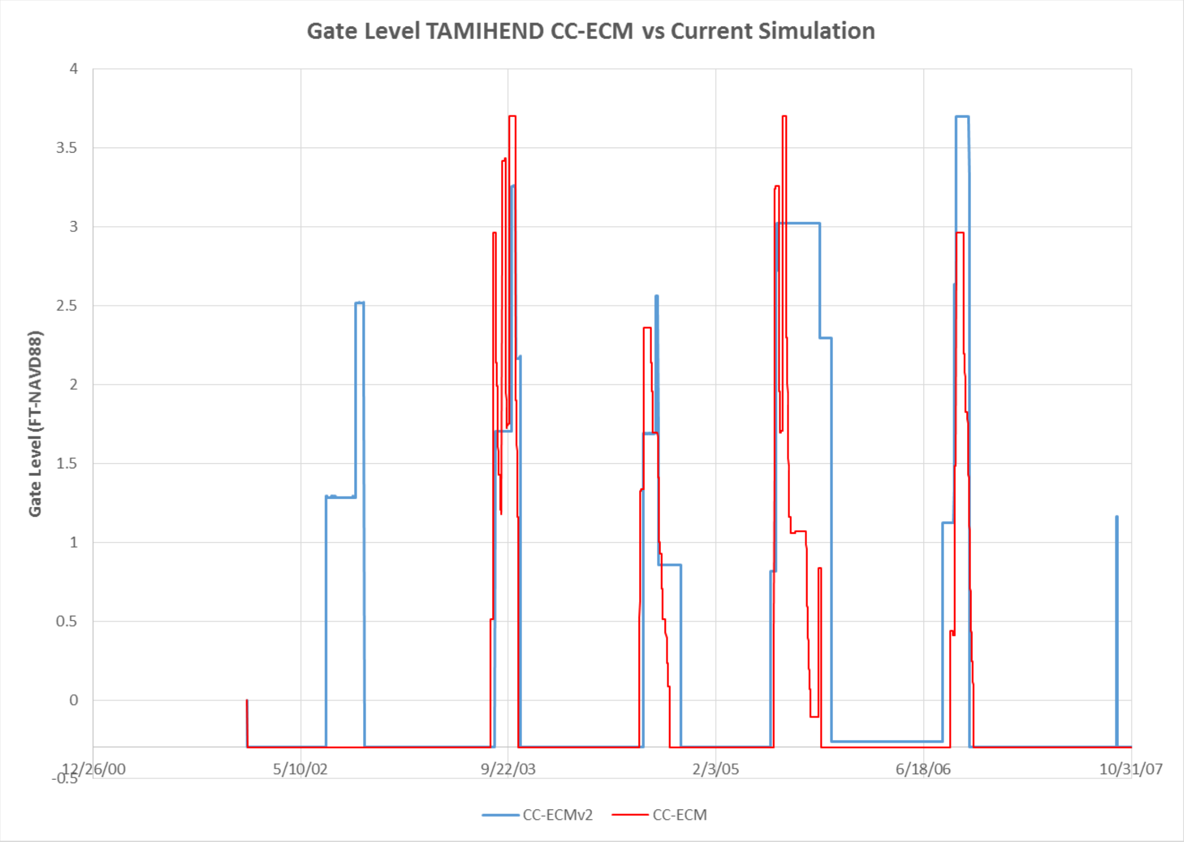


Figure 17. Gate Levels Comparisons of Previous and Current CC-ECMv2 Simulations

Additionally, the physical representation was found to be inconsistent with local knowledge and aerial image review, where the location of the structure in the CC-ECM model domain was upstream of the actual location. **Figures 18** and **20** show the structure alignment of TAMIHEND and indicate that the structure allows water to flow from the Tamiami Canal, west into Henderson Creek East Branch.

From **Figures 18** and **20,** as well as LiDAR and other data review, the CC-ECMV2 MIKE-11 network was revised to appropriately model the TAMIHEND structure as well as the Belle Meade Flow-way.

Along with changing the simulated location of structure TAMIHEND (**Figure 21**), another revision to the model was how the Belle Meade Flow-way connects to the Tamiami Canal. After a review of LiDAR topography, aerial photography, and some familiarity with the system, this change was accomplished by promoting a “spill over” effect. Revising the way Belle Meade Flow-way interacts with the Tamiami Canal, allows water to build up to a certain stage along the Belle Meade Flow-way/Tamiami Canal junction, and spill over an existing LiDAR derived cross-section from Belle Meade Flow-way into the Tamiami Canal. In other words, while there is a connection from the Belle Meade Flow-way to the Tamiami Canal, the CC-ECM configuration allowed water to flow directly into the Tamiami Canal via a misrepresentation of the TAMIHEND structure. The current model is set up how the team believes it should be modeled — as a combination of Overland flow + Groundwater flow, and not a direct open channel connection from Belle Meade.

Figure 18. TAMIHEND Structure At US41/Tamiami Canal Henderson Creek East Branch Headwaters

Figures 21 and **22** present the CC-ECM and CC-ECMv2 MIKE-11 network for the TAMIHEND structure. As shown, the physical placement of the structure has been revised to better represent actual field conditions.

In summary, the aforementioned changes to the TAMIHEND structure and Belle Meade Flow-way are anticipated to

- Accurately represent the overland flow of water from Belle Meade in the area near the I-75 S. Canal to the Tamiami Canal.
- Simulate flow and stage in the Tamiami Canal in a more realistic fashion.
- Accurately simulate flow under US41 from the Tamiami Canal to Henderson Creek East Branch.

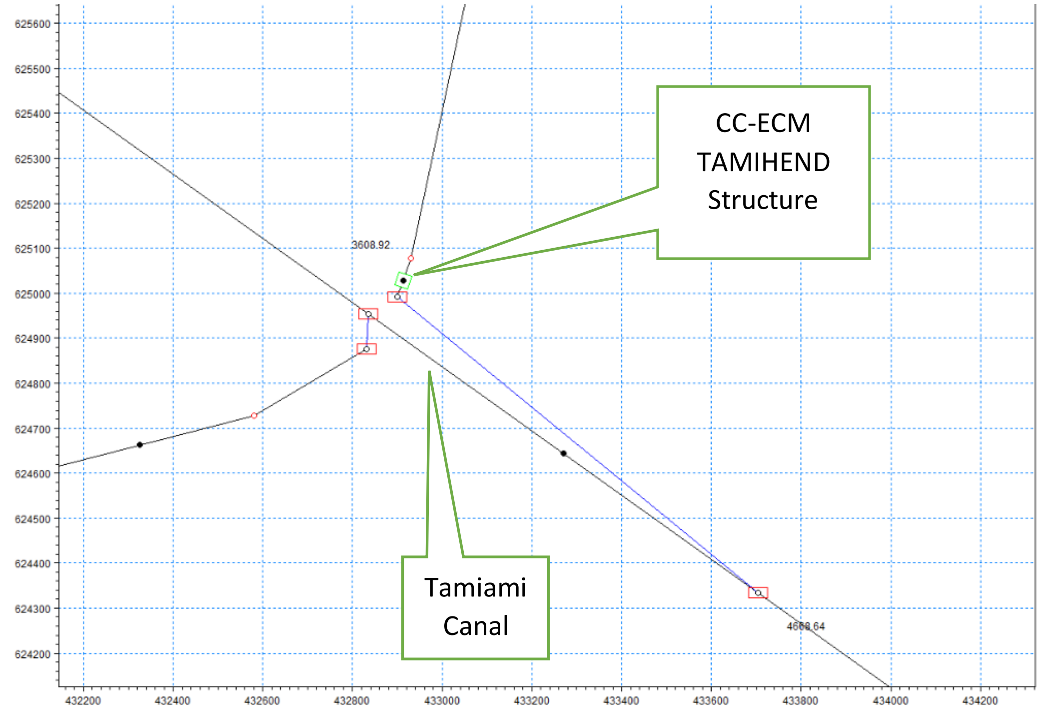


Figure 19. TAMIHEND Structure Location (Green Square) – CC-ECM MIKE-11 network

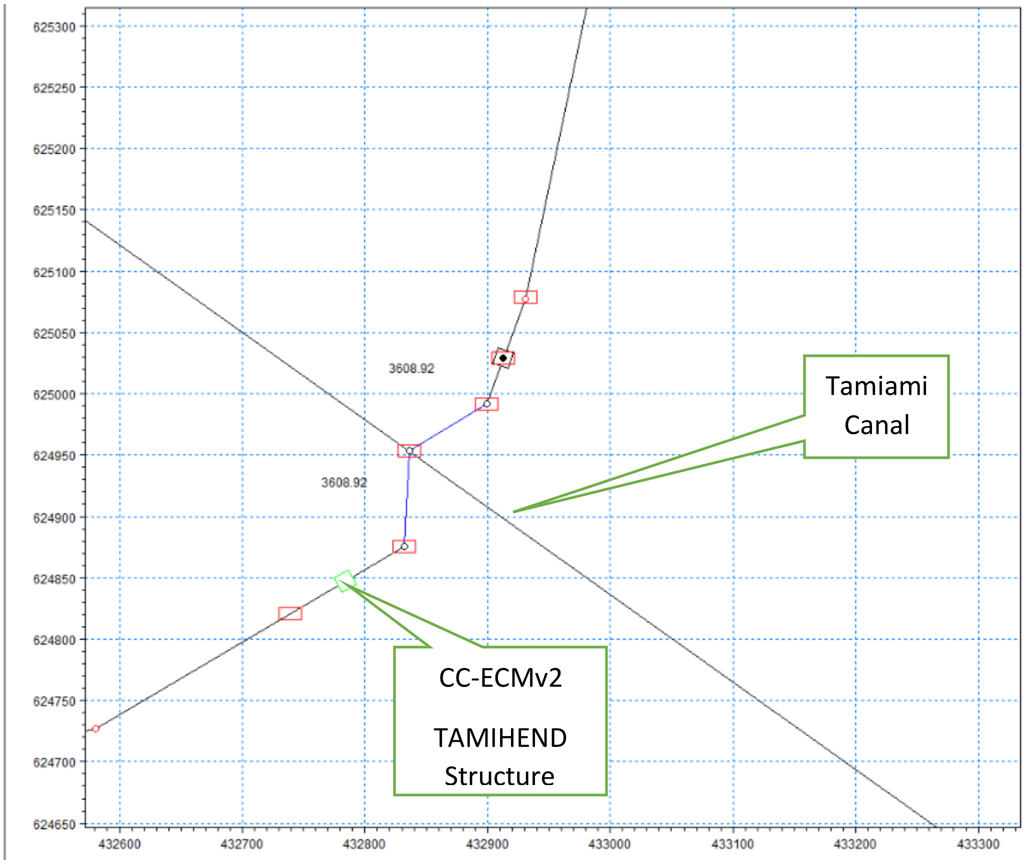


Figure 20. TAMIHEND Structure Location (Green Square) – CC-ECMv2 MIKE-11 network

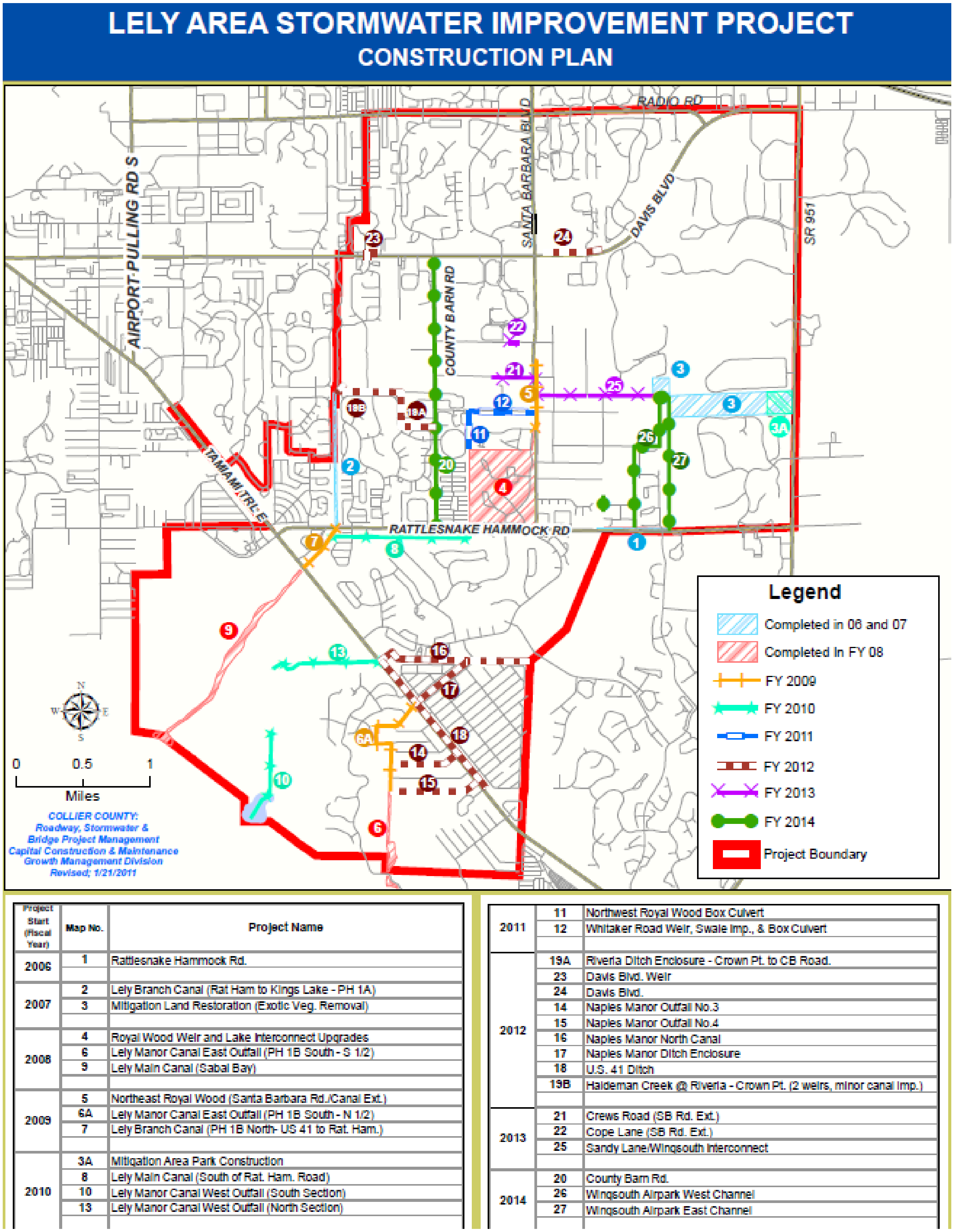
2.2.3 Lely Area Stormwater Improvement Projects (LASIP)

The LASIP was first conceptualized in 1993 under SFWMD Permit No.: 11-01140-S under project name “District 6 Water Management System.” The LASIP (FKA District 6 Water Management system) has undergone many updates and permit applications, some as current as 2013. The LASIP is a series of stormwater improvement projects including weirs, culverts, swales, and operable control structures to provide flood control and improve the water quality within and leaving the Lely Area. **Figure 23** presents the Collier County map of the LASIP projects from 2006 to 2014; of these projects, only elements constructed on or before 2012 are included in this modeling study. Additionally, any weir, culvert or other structure not directly affecting the volume or timing of water deliveries to the Rookery Bay Estuary have not been added to the CC-ECMv2. These structures or other conveyance features not directly affecting the volume or timing of water deliveries to the estuary are assumed to be designed for flood control and inherently have the ability to pass a wide array of flows and will not reduce water volumes or influence the CC-ECMv2 simulation results.

Many LASIP project elements were added to the CC-ECMv2 model. Specific elements were developed from **Figure 23**, the LASIP permit files, and the Collier County Stormwater Database. **Tables 8** and **9** present the features from the LASIP permit added or revised within the CC-ECMv2 Model.

Table 8. LASIP Operable Control Structures and Fixed Crest Weirs Added to CC-ECMv2 Model

Name	Type	Level (ft-NGVD)	Level (ft-NAVD)	Width (ft)
LMB-00-S0100	*Fixed Crest Weir*	2.8	1.504	1000
		5	3.704	1020
LMB-00-S0120	Fixed Crest Weir	3	1.704	52
		5	3.704	85
LMB-07-S0070	*Fixed Crest Weir*	3	1.704	200
		5	3.704	216
LCB-00-S0122	*Fixed Crest Weir*	4	2.704	50
		6.7	5.404	50
	2 Slide Gates (underflow)	-1	-2.296	5
		4	2.704	5
LCB-00-S0230	*Fixed Crest Weir*	10.3	9.004	50
		12.3	11.004	50
	2 Slide Gates (underflow)	3.8	2.504	5
		8.8	7.504	5
LCB-00-S0210	Fixed Crest Weir	9.8	8.504	50
		11.8	10.504	50
	2 Slide Gates (underflow)	3.8	2.504	5
		8.8	7.504	5
LCB-00-S0190	Fixed Crest Weir	8.8	7.504	50
		10.8	9.504	50
	2 Slide Gates (underflow)	3.8	2.504	5
		8.8	7.504	5



Project Start (Fiscal Year)	Map No.	Project Name
2006	1	Rattlesnake Hammock Rd.
2007	2	Lely Branch Canal (Rat Ham to Kings Lake - PH 1A)
	3	Mitigation Land Restoration (Exotic Veg. Removal)
2008	4	Royal Wood Weir and Lake Interconnect Upgrades
	6	Lely Manor Canal East Outfall (PH 1B South - S 1/2)
	9	Lely Main Canal (Sabal Bay)
2009	5	Northeast Royal Wood (Santa Barbara Rd./Canal Ext.)
	6A	Lely Manor Canal East Outfall (PH 1B South - N 1/2)
	7	Lely Branch Canal (PH 1B North- US 41 to Rat. Ham.)
2010	3A	Mitigation Area Park Construction
	8	Lely Main Canal (South of Rat. Ham. Road)
	10	Lely Manor Canal West Outfall (South Section)
	13	Lely Manor Canal West Outfall (North Section)
2011	11	Northwest Royal Wood Box Culvert
	12	Whitaker Road Weir, Swale Imp., & Box Culvert
2012	19A	Riveria Ditch Enclosure - Crown Pt. to CB Road.
	23	Davis Blvd. Weir
	24	Davis Blvd.
	14	Naples Manor Outfall No.3
	15	Naples Manor Outfall No.4
	16	Naples Manor North Canal
	17	Naples Manor Ditch Enclosure
	18	U.S. 41 Ditch
	19B	Haldeman Creek @ Riveria - Crown Pt. (2 weirs, minor canal imp.)
2013	21	Crews Road (SB Rd. Ext.)
	22	Cope Lane (SB Rd. Ext.)
	25	Sandy Lane/Wingsouth Interconnect
2014	20	County Barn Rd.
	26	Wingsouth Airpark West Channel
	27	Wingsouth Airpark East Channel

Figure 21. Collier County LASIP Construction Plan Map

Table 9. LASIP Culverts Added To CC-ECMv2 Model

Culvert	Type	Size	Length (ft)	US Invert (ft-NGVD)	DS Invert (ft-NGVD)	US Invert (ft-NAVD)	DS Invert (ft-NAVD)	Mannings n
LMB-11-S0100-1:2	ECMP	24"x32"	92	1.756	1.696	0.46	0.4	0.024
LMB-00-S0130-1:2	Box	4'x8'	162	-0.505	-0.853	-1.801	-2.149	0.013
LMB-07-S0102-1:2	Box	6'x10'	32	2.05	1.99	0.754	0.694	0.013
LMB-03-S0090	RCP	30"	29	0	-0.61	-1.296	-1.906	0.013
LMB-01-S0100	Box	4'x8'	30	-0.65	-0.77	-1.946	-2.066	0.013
LMB-01-S0104	RCP	30"	290	1.296	1.296	0	0	0.013
LMB-00-S0140	CMP	48"	61	1.716	1.636	0.42	0.34	0.024
LCB-02-S0120	RCP	36"	73	-0.874	-1.204	-2.17	-2.5	0.013
LCB-01-S0100-1:2	Box	4.5'x8'	96	0.796	0.296	-0.5	-1	0.013
LCB-00-S0110-1:2	Box	5'x8'	80	2.04	-1.83	0.744	-3.126	0.013
LCB-00-S0120-1:2	Box	4'x10'	47	-0.9	-0.9	-2.196	-2.196	0.013
LCB-00-S0130-1:8	RCP	48"	40	-0.65	-0.92	-1.946	-2.216	0.013
LCB-13-S0100	Box	4'x7'	107	1.296	0.796	0	-0.5	0.013
LCB-00-S0140-1:3	Box	4'x8'	103	1.296	0.796	0	-0.5	0.013
LCB-00-S0158-1:2	Box	4'x8'	26	2.5	2.5	1.204	1.204	0.013
LCB-00-S0162-1:2	Box	4'x8'	95	2.5	2.5	1.204	1.204	0.013
LCB-00-S0164	Box	4'x8'	24	2.5	2.5	1.204	1.204	0.013
LCB-00-S0180-1:2	Box	4'x8'	272	2.5	2.5	1.204	1.204	0.013
LCB-01-S0130-1:2	CMP	84"	170	-0.228	-0.417	-1.524	-1.713	0.024
LCB-01-S0120-1:2	Box	4'x8'	45	1.296	1.296	0	0	0.013
LCB-01-S0150-1:2	RCP	72"	188	-1.058	-1.233	-2.354	-2.529	0.013
LCB-01-S0160-1:2	RCP	72"	126	-0.938	-1.118	-2.234	-2.414	0.013
LCB-01-S0170	Box	4.2'x7'	167	0.366	0.296	-0.93	-1	0.013
LCB-01-S0180	Box	5'x8'	99	2.646	2.626	1.35	1.33	0.013
LCB-01-S0190	Box	6'x12'	100	2.439	2.382	1.143	1.086	0.013
LCB-01-S0230	Box	6'x12'	330	2.296	2.296	1	1	0.013
C4C-03-S0100-1:2	Box	4'x12'	131	2.296	2.296	1	1	0.013
LMB-07-S0110	RCP	54"	161	1.106	1.065	-0.19	-0.231	0.013
LMB-03-S0100-1:3	RCP	54"	165	0.636	0.506	-0.66	-0.79	0.013
LMB-01-S0120	Box	4.25'x8'	189	-0.297	-0.4	-1.593	-1.696	0.013
C4C-02	Box	4'x8'	85	2.296	2.296	1	1	0.013
C4C-01-S0100	Box	4'x8'	2750	2.296	2.296	1	1	0.013

2.2.4 Belle Meade Stormwater Management Master Plan (SWMMP)

The Belle Meade SWMMP (Parsons, 2006) was reviewed for potential projects or other existing infrastructure that may need to be incorporated into the current modeling efforts. Of the seven projects identified in the Belle Meade SWMMP (Table 6.1 p. 6-2), only the Tomato Road Diversion had relevant information to the CC-ECMv2. While there are plans for culvert replacement under Sabal Palm Road (currently under construction), these culverts were not included in the CC-ECM model, and are not in the CC-ECMv2 simulation. However, these culverts were added to the LSM in Task 2.3. Review of ERP, aerial photos, and other GIS indicated that none of the other projects had been built to date. The proposed plans for the Tomato Road Diversion show three existing 48 x 30 inch reinforced concrete pipe (RCP) culverts under US41 just downstream (southeast) of where Tomato Road joins US41. **Figure 24** presents the project elements detailed in the Belle Meade SWMMP Figure 6.13, which shows an improved swale as the outfall from upstream Tamiami Cana via the existing culverts. This swale does not appear to be improved but the connection currently exists. These culverts were not included in the CC-ECM, but have been incorporated to the CC-ECMv2 model.

Figure 22. Figure 6.13 Tomato Road Diversion: From Belle Meade SWMMP

The addition of these existing culverts near Tomato Road seems to have improved the calibration of stage upstream of the Tomato Road Culvert (See **Appendix B**: Plot 9).

2.2.5 Marco Island Utilities MIU (Marco Lakes)

The MIU Utilities Master Plan (UMP) presents the past, current, and projected water supply needs of Marco Island (MWH, 2005).

The portions of the MIU-UMP of specific interest to the Henderson Creek Volume and Timing Study are

- Permitted water use from Marco Lakes A and B
- How Marco Lakes A and B interact with Henderson Creek
- The volume of water assumed available from Henderson Creek
- Utilization of the water for ASR (inject in the wet season, recover in the dry season).

MIU receives surface water from two abandoned quarries known collectively as Marco Lakes (A and B); the lakes are supplemented by water from an ASR system interspersed within the boundary of the lakes where water is injected in the wet season and recovered in the dry season. The majority of the water in Marco Lakes enters through lateral flow (bank filtration) from Henderson Creek. The water stored and supplied by Marco Lakes is treated by one of two lime-softening facilities on Marco Shores or Marco Island. Additional water is supplied from wells located on Marco Island, which pump brackish water that is then treated at an RO plant on the island.

The permitted annual withdrawal volume from the brackish production wells and Marco Lakes is 6,008 million gallons per year (mgy) or an average of 16.46 mgd.

2.2.5.1 Marco Lakes

Figure 25 presents the geographical location and spatial orientation of Marco lakes. Marco lakes are separated by an embankment and culvert interconnect; if the stage in Lake A falls below the invert of the culvert a pump can lift water from Lake A to B. Additionally if water levels fall below 0 FT-NGVD in Lake B, weekly chloride samples are taken and submitted to the SFWMD.

The storage equivalent reported in the UMP is based upon the treatment capacity of the lime softening WTP's on Marco Island and Marco Shores of 7.69 MGD, which does not include adjacent groundwater percolation when lake levels are lowered. The UMP report goes on to present Table 2-1 with various parameters of lake storage, area, and capacity (MIU UMP: Table 2-1). The combined storage volume in the dry season is 120 mg for a storage capacity of 16.2 days, while the storage volume and capacity in the wet season is 239 mg and 32.4 days respectively.

Figure 23. Marco Lakes General Location Map: Figure 2-1 from 2005 MUI-UMP

2.2.5.2 Marco Lakes Inflow Sources

The UMP states that Marco Lakes are filled from five sources**:**

1. Groundwater inflow (Water Table Aquifer and lower Tamiami Aquifer)
2. Direct Precipitation
3. Percolation from Henderson Creek
4. Direct Diversions from Henderson Creek
5. Surface Runoff

The UMP describes the aforementioned inflow sources, but not in the particular order as presented in 1 – 5. As such, a summary of each source is presented here using the same organization as the UMP.

Direct Diversions from Henderson Creek

Flows from Henderson Creek can be diverted via a 1.5-ft H x 3-ft W sluice gate constructed in 2001, the gate directs flows into an excavated canal that flows into the northern portion of Lake A. At the time of the UMP, there were no flow records from the gate, thus it does not include quantification of the raw water from Henderson Creek.

Shallow Groundwater

Marco Lakes is separated from Henderson Creek by a strip of land about 100-ft wide and 3,000-ft long, with surficial deposits (0-30 ft) comprising materials that create high transmissivity 320,000 – 400,000 gpd/ft. According to the UMP, potential subsurface flow between Henderson Creek and Marco Lakes is 5.28 – 6.6 mgd with a head difference of up to 1 ft. The report does not specify the amount of water from the Water Table or Lower Tamiami Aquifers in this section, nor does it provide an input of “groundwater inflow.” The UMP only reports the potential flows from a head differential between Henderson Creek and Marco Lakes.

Henderson Creek Watershed

The size of the watershed contributing to Henderson Creek was estimated to be 50 square miles (Johnson Engineering, 1997), with a reported average discharge from Henderson Creek to Rookery Bay of 36.8 mgd and maximum flows of 323 mgd (Viriogroup, 1995). The UMP states Henderson Creek has the potential to dry out in the dry season, as well as during periods of low flow.,

Overland Flow (Surface Runoff)

The UMP did not calculate overland flow for the Marco Lakes watershed as it is comparatively small. However, the UMP does state that direct surface runoff has large implications for water quality in Henderson Creek, Marco Lakes and the surficial aquifer. While the inputs of surface water runoff were not calculated for the UMP, future water quality degradation is a major concern, as the long term sustainability of Marco Lakes will depend on the quality of water flowing into the system.

Direct Rainfall

Average annual precipitation over the past five years (UMP publication date was 2005) of 62.6 inches was measured at Marco Island station OPS 32. The annual variation in precipitation was from a low of 46.26 inches in 2000 and the highest recorded was 87.18 inches in 2002. Marco Lakes is approximately 52.5 acres, for an estimated annual average of 96 million gallons.

2.2.5.3 MIKE-11 Representation of MIU Lakes

The CC-ECM and CC-ECMV2 are parameterized to remove water from Marco Lakes based on an upstream stage. The water is removed from the model domain to account for the MIU consumptive water use. The current representation of Marco Lakes does not account for the lake interconnection and may not accurately represent the lake storage, as the cross-sectional profile does not extend to the lake bottom presented in Table 2-1 of the MIU UMP. Marco Lakes are modeled as a single channel with an invert of -3.773 FT-NAVD, while the MIU-UMP shows the average lake bottom elevation to be -16.3 and -11.3 FT-NAVD for Lakes A and B respectively. The single structure removing water from Marco Lakes has a simulated annual average of 4.63 MGD and 4.58 MGD or about 1,690 and 1,671 MGY for both CC-ECM and CC-ECMv2 simulations respectively. While this removal of water is adequate to represent withdrawals from the lake for potable water treatment, it does not provide an adequate representation of the cumulative withdrawal from Marco Lakes for the permitted ASR system and withdrawal for potable water treatment.

SFWMD Water Use Permit (WUP) Permit No.11-0080-W; App. No. 041027-12: effective 2006, was reviewed for consumptive use allocations from the Henderson Creek Watershed. MIU annual allocation shall not exceed 4535 MG, with the following limitations placed on annual withdrawals from specific sources.

- Marco Lakes – ASR: 1,600 MG
- Marco Lakes : 1,935 MG
- Mid-Hawthorne Aquifer: 1,460 MG

Comparison of the simulated results of the Marco Lakes withdrawals reveals that the cumulative withdrawal is about 1,935 MG less than what is permitted. This is due to the discrepancy in the ASR system withdrawals not being simulated. As such it is expected that the LSM will utilize measured data from the SFWMD permit file to simulate all withdrawals from Marco Lakes.

2.3 Task 2.2. Results and Discussion

MIKESHE is able to provide detailed results from the post-processing routines within the software package. The results are available for the groundwater/overland flow (MIKESHE) and 1-dimensional surface water (MIKE-11) portions of the model. These results are compared against measured data when specified, and MIKESHE has the ability to calculate simulation statistics for each station being compared. The focus of this study was to extend the simulation period to run through 2012, and did not include an in-depth calibration effort across the model domain. While care was taken to ensure modeled results were reasonable and within the previous CC-ECM range of results, stringent calibration parameters (targets of statistics) were not set for this phase of the model development. **Figures 26** and **27** present the overall water balance for Collier County (CC-ECMv2 model domain) and the Rookery Bay Watershed (Preliminary Proposed LSM model domain), respectively. **Table 10** presents a comparison of the water balance components for each model in cumulative totals in inches and inches/yr for the 11-year duration of the simulation 1/1/2002 through 12/31/2012.

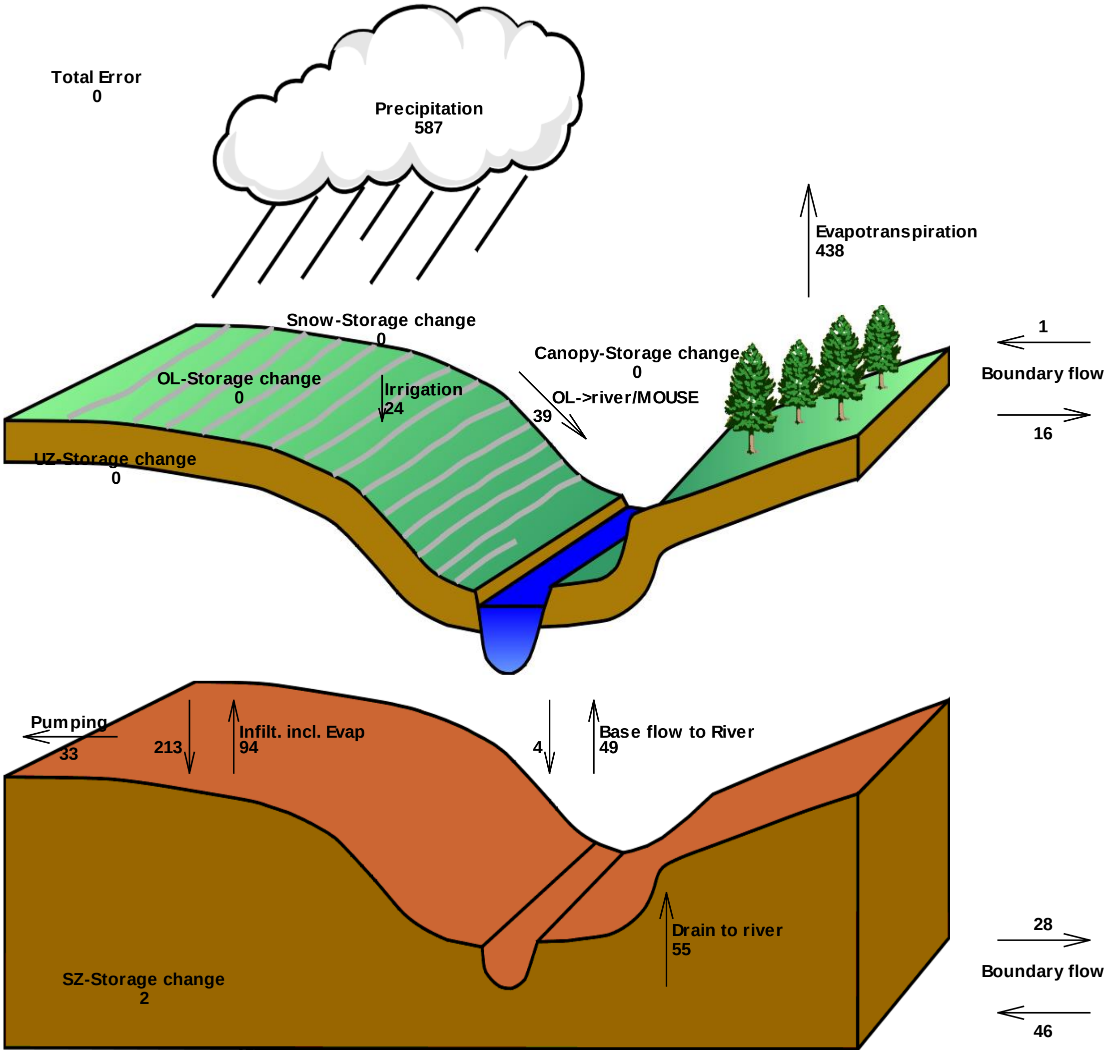


Figure 24. Overall Water Balance CC-ECMv2 Simulation: Collier County (Values are Cumulative Inches)

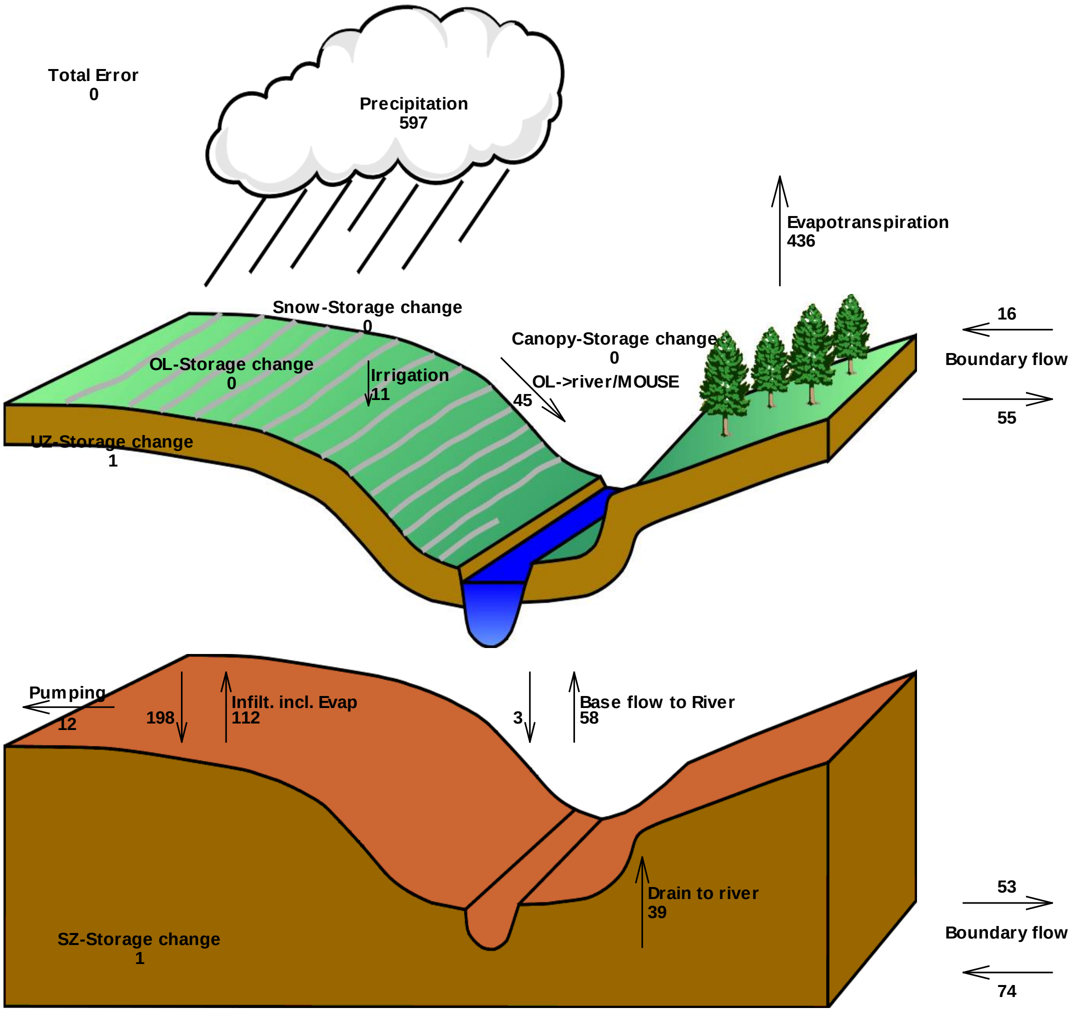


Figure 25. Overall Water Balance CC-ECMv2 Simulation: Rookery Bay Watershed/LSM Domain (Values are Cumulative Inches)

Table 10. Water Balance Components from Overall Model Domain and Proposed Rookery Bay LSM Model Domain

Water Balance Year	Water Balance Presented	Rain	Actual ET	Canopy-OL Storage Change	Runoff +Drainage to River	OL Boundary Flows	Baseflow	Irrigation	Pumpage	SZ Boundary Flow	SubSurface Storage Change	Total Error
CC-ECMv2	11yr WB Total	586.90	-438.41	-0.17	-94.05	-14.908	-45.92	24.16	-33.35	17.83	-1.86	-0.014
CC-ECMv2 LSM Domain	11yr WB total	596.63	-435.70	-0.26	-84.13	-39.078	-55.43	10.82	-11.51	20.78	-2.12	-0.003
CC-ECMv2	11yr Avg. in/yr	53.35	-39.86	-0.02	-8.55	-1.36	-4.17	2.20	-3.03	1.62	-0.17	-0.014
CC-ECMv2 LSM Domain	11yr Avg. in/yr	54.24	-39.61	-0.02	-7.65	-3.55	-5.04	0.98	-1.05	1.89	-0.19	-0.003

Actual ET: The Calculated Evapotranspiration. **OL**: Overland; **SZ**: Saturated Zone

2.3.1 Task 2.2. MIKESHE Results

The MIKESHE results provide a comparison of simulated to observed groundwater levels at selected stations from the CC-ECM and CC-ECMv2 simulations. As shown in the **Table 11**, the CC-ECMv2 groundwater simulation results do not significantly differ from the CC-ECM results. This indicates that no major instabilities or other inappropriate model assumptions were used when extending the duration of the CC-ECMv2 simulation through 2012. This was a goal in this phase of the modeling, as the results from the CC-ECMv2 will be used as boundary conditions for the LSM developed in the next phase of this project.

Table 11. Statistical Comparison of Selected Wells within Rookery Bay Watershed Domain

Well	Simulation	ME	MAE	RMSE	STDres	R(Correlation)
C-968	CC-ECM	0.48	0.73	0.93	0.79	0.84
	CC-ECMv2	0.59	0.73	0.93	0.72	0.86
C-1224	CC-ECM	-1.04	1.07	1.21	0.61	0.88
	CC-ECMv2	-1.02	1.04	1.17	0.59	0.88
SGT1W1	CC-ECM	-1.98	1.99	2.13	0.76	0.88
	CC-ECMv2	-1.93	1.93	2.03	0.64	0.92
SGT2W1	CC-ECM	-0.21	0.55	0.87	0.84	0.91
	CC-ECMv2	-0.13	0.45	0.71	0.67	0.94
SGT3W1	CC-ECM	-1.99	1.99	2.05	0.46	0.96
	CC-ECMv2	-2	2	2.05	0.44	0.96
SGT4W1	CC-ECM	-0.67	0.77	0.96	0.71	0.89
	CC-ECMv2	-0.56	0.66	0.79	0.57	0.93

ME: Mean Error; **MAE**: Mean Absolute Error; **RMSE**: Root Mean Square Error, **STDres**: Standard Deviation of Residuals; **R:** Correlation Coefficient.

Please refer to **Figure 14** for a graphic showing the locations of the observation wells presented in **Table 11**.

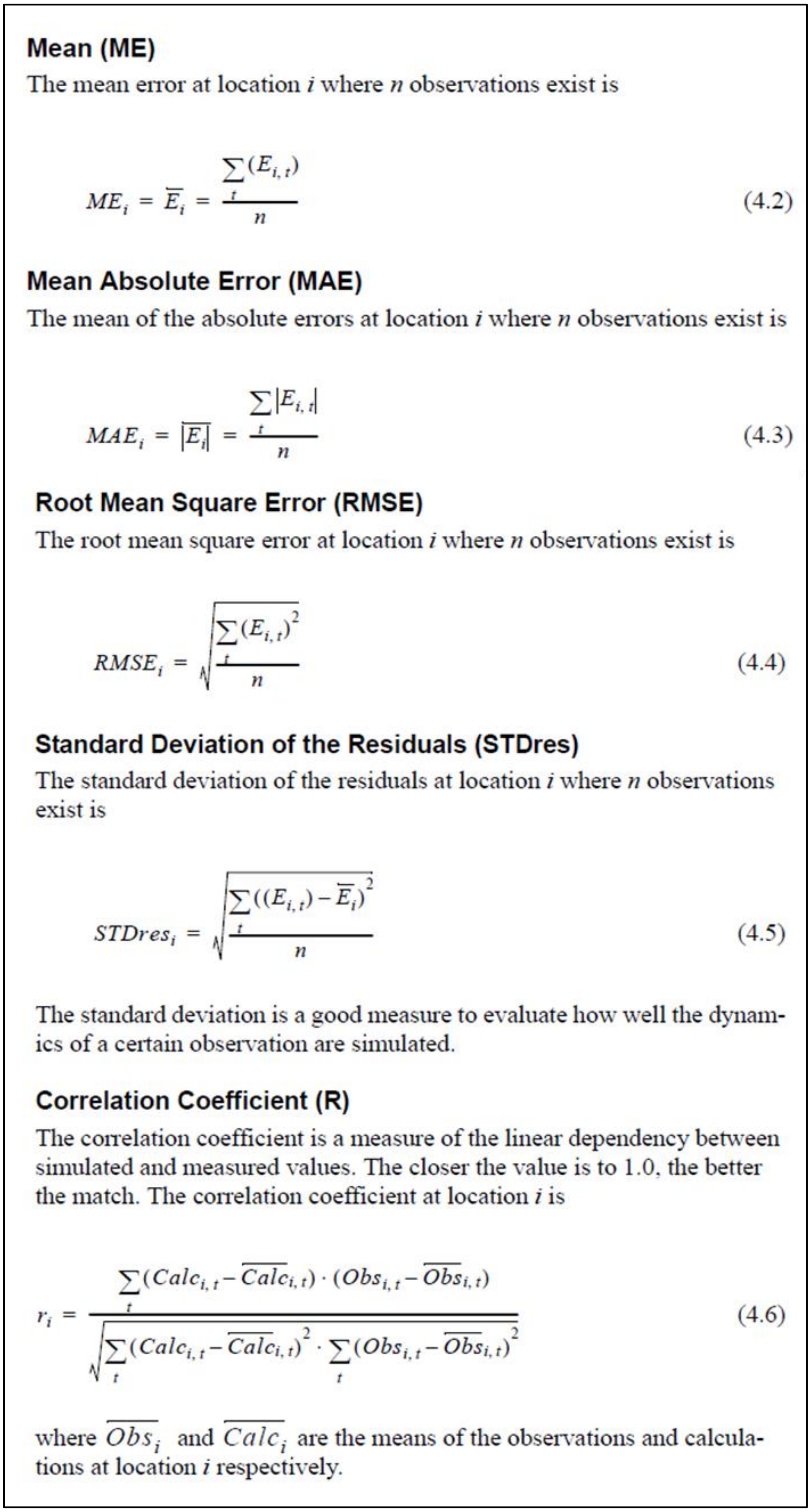
The MIKE-SHE Reference Manual provides a description of the statistic calculations presented in **Tables 11** and **12**, a brief summary including the formulae used in MIKESHE is presented here.

MIKESHE calculates the standard calibration statistics based on the differences between observed (measured) and calculated (simulated) values, at a single location for a given time (DHI, 2011b). MIKESHE calculates the error **($E_{i,t}$)** or residual as

$$E_{i,t} = Calc_{i,t} - Obs_{i,t}$$

Where $E_{i,t}$ is the difference between observed and calculated values at location *i* and time t (DHI, 2011b).

The following statistic calculation descriptions were taken verbatim from the DHI MIKESHE Reference Manual Volume 1 (DHI, 2011b).



Mean (ME)

The mean error at location *i* where *n* observations exist is

$$ME_i = \overline{E}_i = \frac{\sum_t (E_{i,t})}{n} \tag{4.2}$$

Mean Absolute Error (MAE)

The mean of the absolute errors at location *i* where *n* observations exist is

$$MAE_i = \overline{|E_i|} = \frac{\sum_t |E_{i,t}|}{n} \tag{4.3}$$

Root Mean Square Error (RMSE)

The root mean square error at location *i* where *n* observations exist is

$$RMSE_i = \sqrt{\frac{\sum_t (E_{i,t})^2}{n}} \tag{4.4}$$

Standard Deviation of the Residuals (STDres)

The standard deviation of the residuals at location *i* where *n* observations exist is

$$STDres_i = \sqrt{\frac{\sum_t ((E_{i,t}) - \overline{E}_i)^2}{n}} \tag{4.5}$$

The standard deviation is a good measure to evaluate how well the dynamics of a certain observation are simulated.

Correlation Coefficient (R)

The correlation coefficient is a measure of the linear dependency between simulated and measured values. The closer the value is to 1.0, the better the match. The correlation coefficient at location *i* is

$$r_i = \frac{\sum_t (Calc_{i,t} - \overline{Calc}_{i,t}) \cdot (Obs_{i,t} - \overline{Obs}_{i,t})}{\sqrt{\sum_t (Calc_{i,t} - \overline{Calc}_{i,t})^2 \cdot \sum_t (Obs_{i,t} - \overline{Obs}_{i,t})^2}} \tag{4.6}$$

where $\overline{Obs_i}$ and $\overline{Calc_i}$ are the means of the observations and calculations at location *i* respectively.

DHI Statistic Calculation Formulae. DHI, 2011

2.3.2 Task 2.2. MIKE-11 Results

The MIKE-11 results provide a comparison of simulated stage or flow to observed stage or flow depending on the station. **Figure 28** presents the location of the SFWMD stage monitoring stations within the Rookery Bay Watershed, with available data used for comparisons with simulation results.

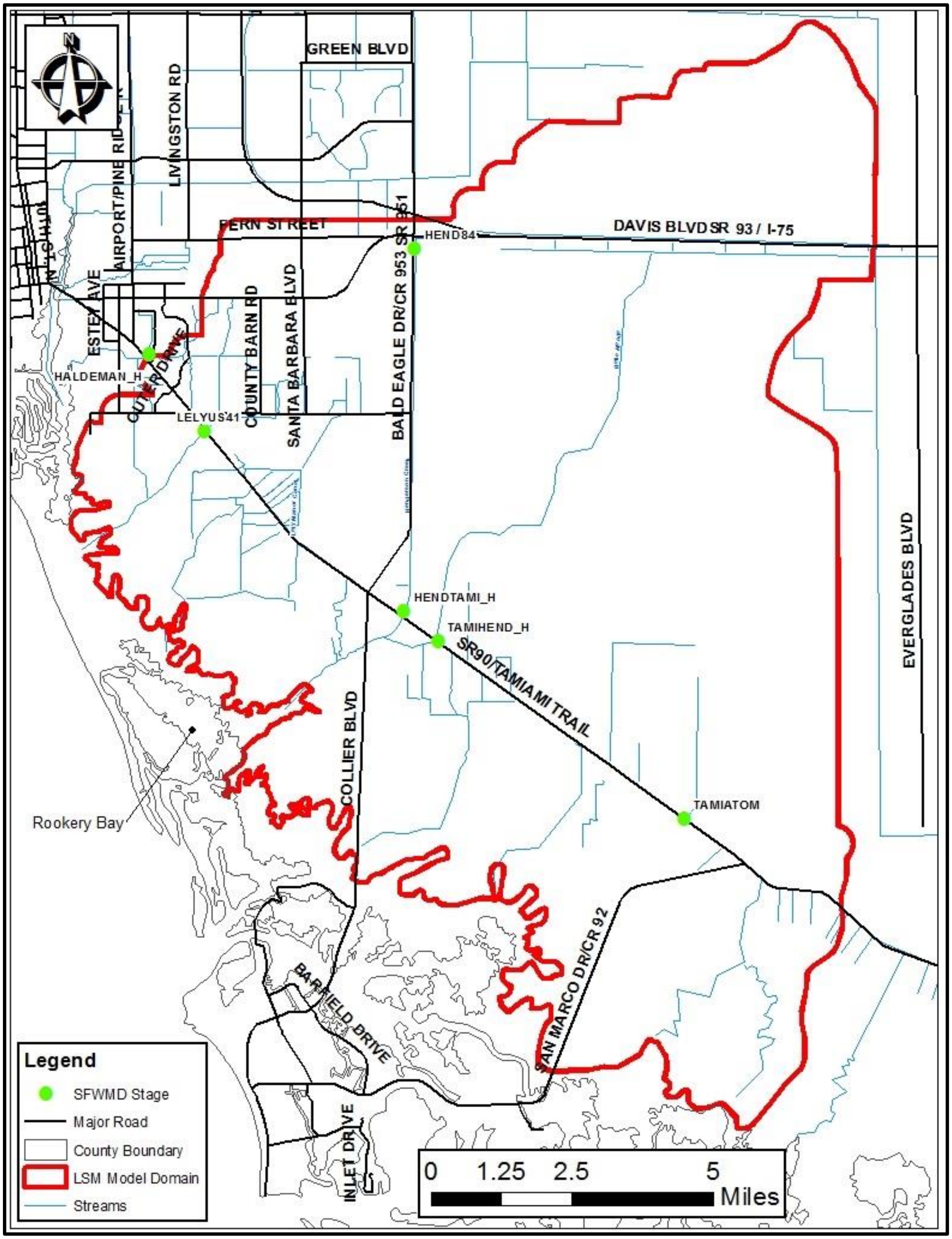


Figure 26. SFWMD Stage Monitoring Stations Within The Rookery Bay Watershed (LSM) Model Domain

Table 12 presents a stage comparison between the CC-ECM and CC-ECMv2simulations. As shown in the MIKESHE results, the MIKE-11 surface water results provide a similar comparison in that no major changes or large-scale errors have been introduced when extending the time series of the CC-ECMv2simulation through 2012. Certain stations did show slight improvement in simulated stages, including the HENDTAMI_H structure where ME and MAE were slightly reduced. Additionally, total accumulated flow at the HENDTAMI structure was also shown to be improved through the limited calibration effort in this phase of the study. This was one of the goals in this phase of the modeling, as flows and stages from the CC-ECMv2 were later used as boundary conditions for the LSM developed in the next phase of this project. These result comparisons are done as due diligence to ensure the simulated results are reasonable.

Table 12. Comparison of Selected Surface Water Stations within Rookery Bay Watershed Domain

MIKE-11 Station	Simulation	ME	MAE	RMSE	STDres	R(Correlation)
HALDEMAN_H	CC-ECM	0.07	0.21	0.28	0.27	0.18
	CC-ECMv2	0.01	0.19	0.27	0.27	0.18
HEND84	CC-ECM	-0.6	1.09	1.27	1.1	0.75
	CC-ECMv2	-0.77	1.07	1.24	0.97	0.8
HENDTAMI_H	CC-ECM	0.19	0.58	0.75	0.73	0.87
	CC-ECMv2	0.27	0.58	0.73	0.67	0.88
LELYUS41	CC-ECM	-0.19	0.36	0.43	0.38	0.87
	CC-ECMv2	-0.36	0.47	0.75	0.66	0.53
TAMITOM	CC-ECM	-0.68	0.81	0.93	0.62	0.85
	CC-ECMv2	-0.63	0.76	0.87	0.61	0.86
TAMIHEND_H	CC-ECM	-1.13	1.5	1.86	1.32	0.48
	CC-ECMv2	-0.85	1.22	1.52	1.25	0.64

ME: Mean Error; **MAE**: Mean Absolute Error; **RMSE**: Root Mean Square Error, **STDres**: Standard Deviation of Residuals; **R:** Correlation Coefficient.

Initially, flow data for SFWMD structure HENDTAMI was not available after March 2010. The team investigated why flow data for HENDTAMI was unavailable from March 2010 to present by reviewing the available stage, flow, and gate operations data for the HENDTAMI structure. This review raised created questions regarding the accuracy of the flow calculation at this structure and the team worked with the SFWMD to resolve this issue. The flow calculations were revised and updated flow data was placed on DBHYDRO in time to incorporate the updated flow records in the local-scale model development phase. However, the records were not updated in time for the updates to the regional CC-ECMv2 described in this section. Therefore, the flow comparisons presented in this section extend only through the end of 2007. Other updates to the CC-ECMv2 involved revisions to the TAMIHEND structure location and operations, and Belle Meade Flow-way representation. Other improvements were made within the Belle Meade Flow-, Tamiami Canal, and the Henderson Creek drainage network.

For example, moving the physical location of the TAMIHEND structure results in less flow from the Belle Meade Flow-way to the Tamiami Canal (**Fig. 29**). This revision also results in less flow from the Tamiami Canal to the Henderson Creek East Branch by about 42 percent (**Figure 30**).

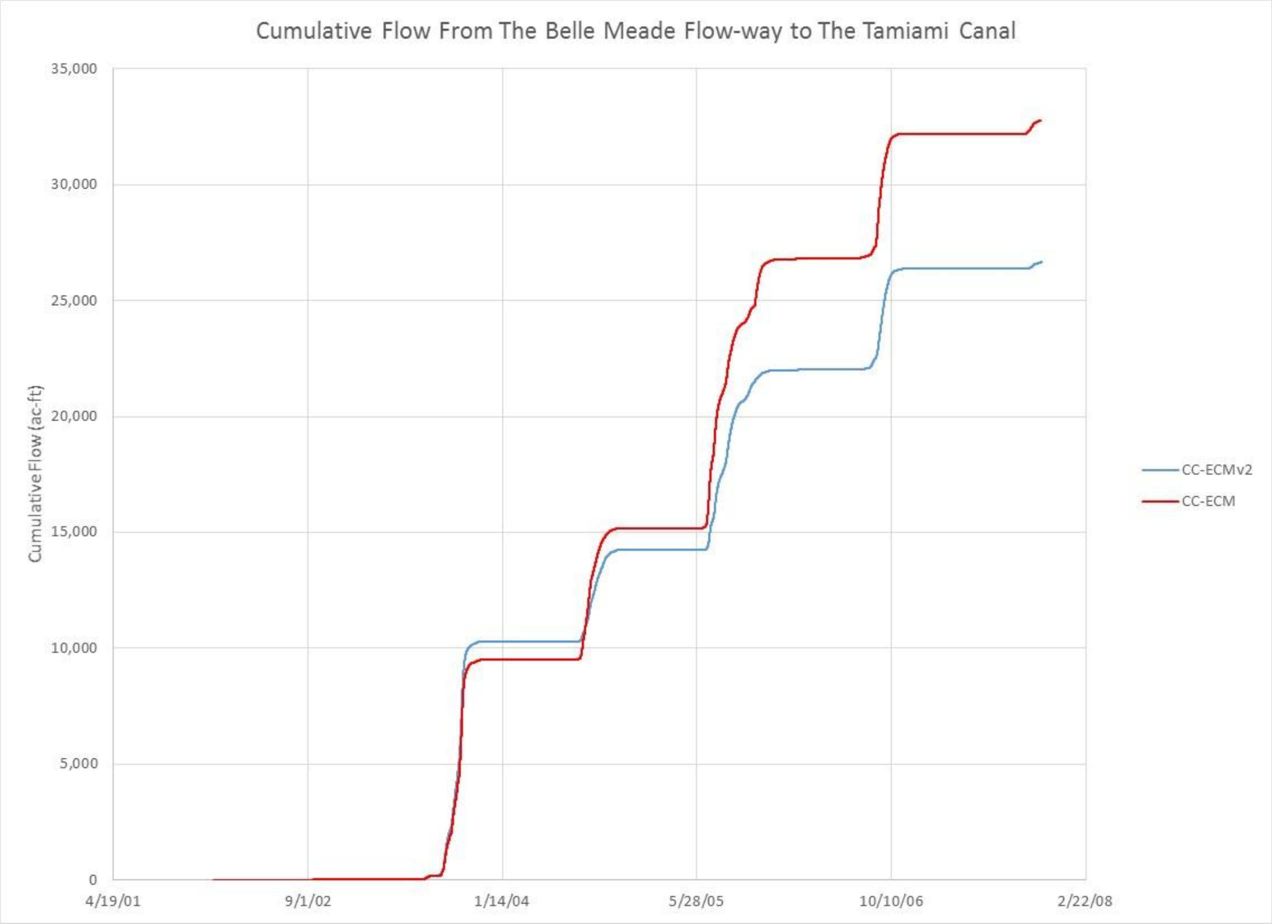


Figure 29. Cumulative Flow From Belle Meade Flow-way to The Tamiami Canal (CC-ECMv2 vs CC-ECM)

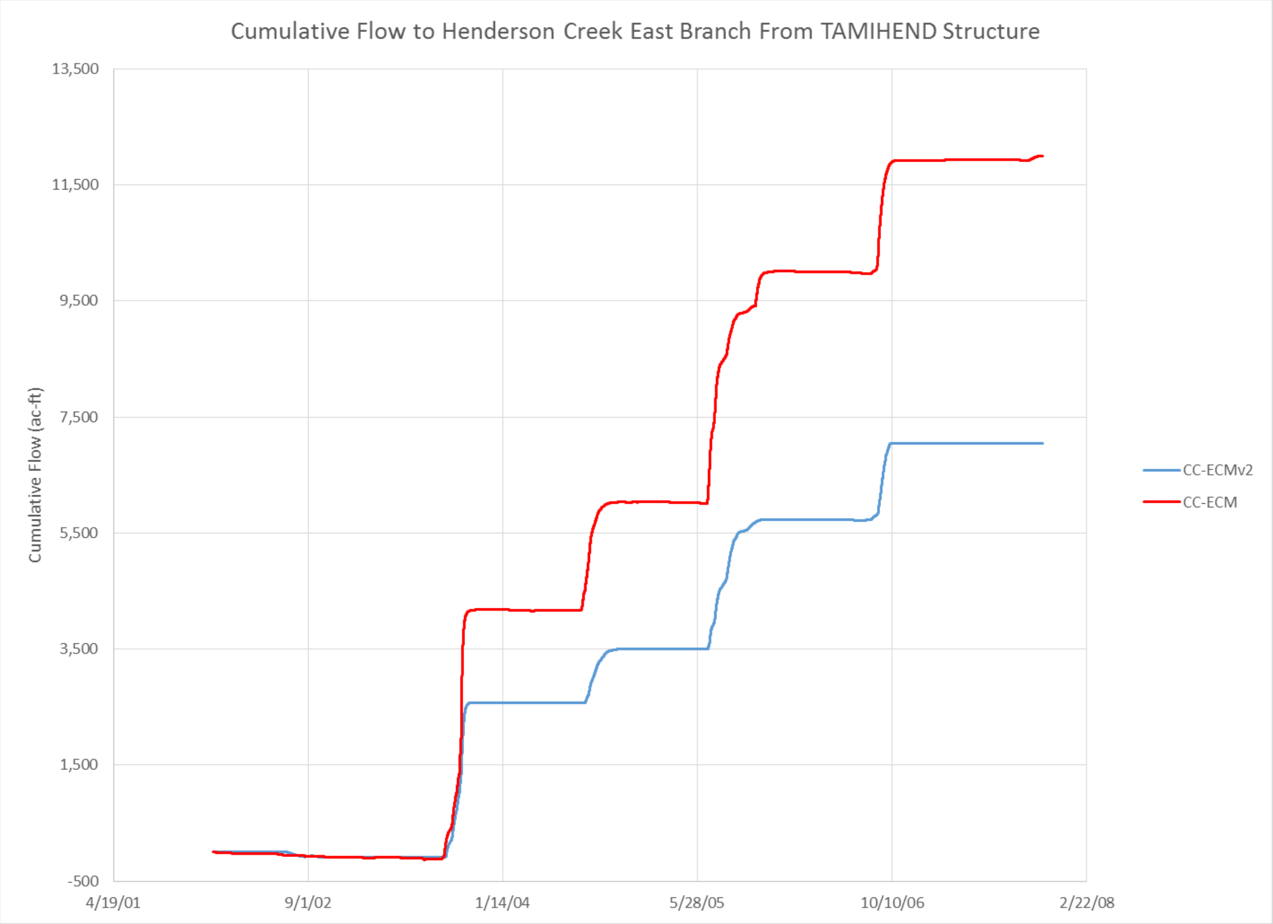


Figure 30. Cumulative Flow TAMIHEND Structure to The Henderson Creek East Branch (CC-ECMv2 vs CC-ECM)

2.3.3 Task 2.2. MIKE-11 Boundary Flow

The MIKE-11 results file was checked to ensure that the proposed Rookery Bay Watershed (LSM) model domain was appropriate in terms of the surface water inflows and outflows. The process of developing the LSM must ensure that simulations are not adversely influenced from outside sources (boundary condition appropriateness). In other words, the model domain is appropriately defined where a natural or man-made (structural) watershed divide is accurately represented. This analysis is necessary when the boundary conditions for a smaller model (LSM) are being developed from a similar model with a larger domain (CC-ECMv2).

Figure 31 presents the location of boundary flow check points, where the model was examined to ensure the proposed Rookery Bay Watershed/LSM model domain was appropriate, with respect to surface water flows into or out of the domain. The results of this analysis were

- No significant boundary inflows occur via the MIKE-11 surface water network at the boundary points.
- The I-75 N. Canal and Bridge 39 had the largest outflows, with average annual flows of 20.2 and 12.2 cfs respectively. All other boundary points had insignificant average annual flows.

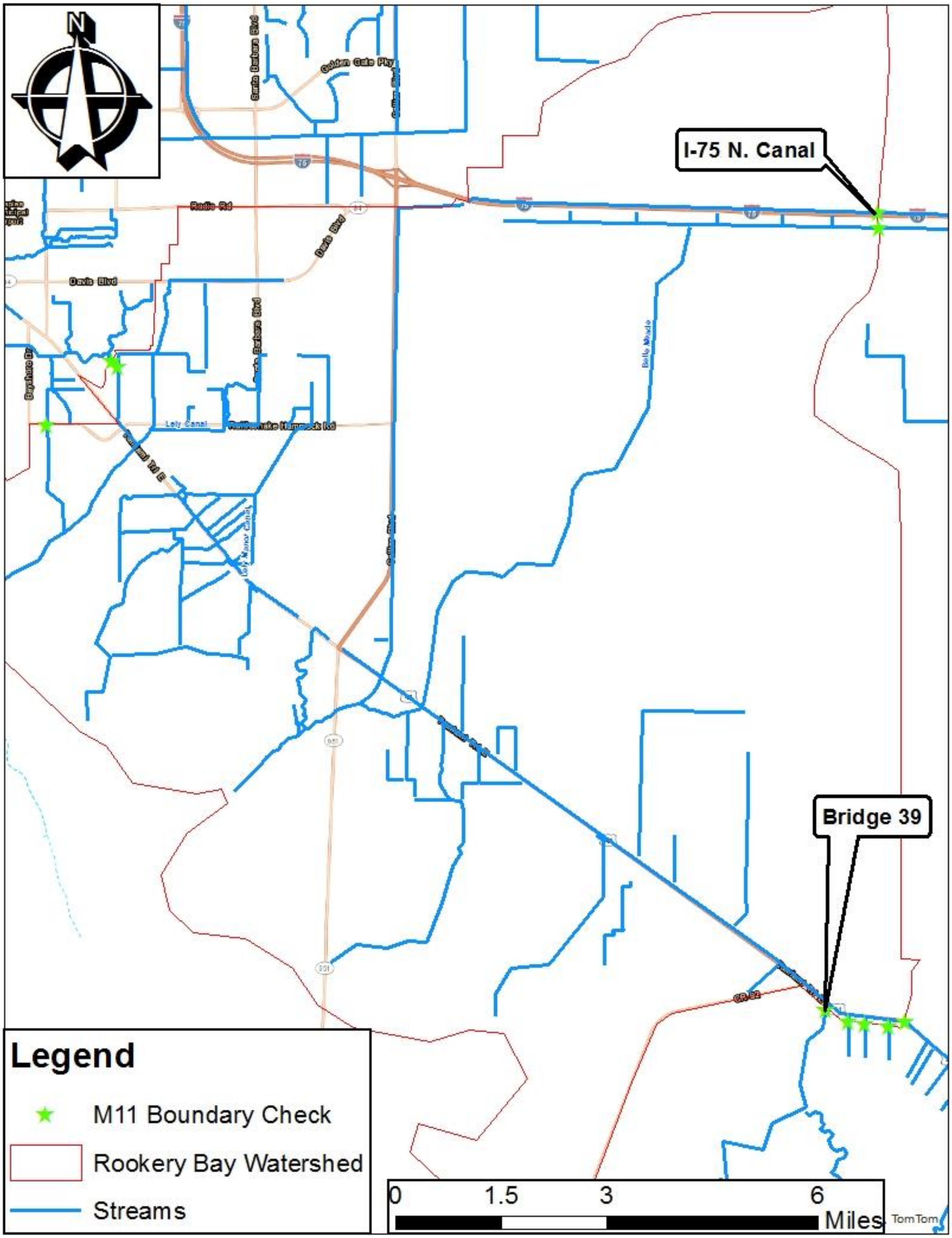


Figure 31. Selected Boundary Check Points along Proposed LSM Model Domain

2.4 Task 2.2. Conclusion and Recommendations

Based on the modeled results as compared against observed and previously developed CC-ECM model, the current CC-ECMv2 simulation is adequate for boundary condition development for use in the Local Scale model.

The CC-ECMv2 simulation has met the goals of the study in that

- The model has been extended to run through 2012
- The model runs seamlessly without significant instabilities or outside influences from boundary condition extension or other model assumptions for the specified time period
- The model adequately simulates boundary conditions for the Local Scale model
- Calibration has been generally improved
- A more realistic representation of the physical characteristics within the watershed has been achieved through this modeling study (TAMIHEND structure placement and results; LASIP structures, Belle Meade Flow-way Representation; Culverts under US41 near Tomato Road).

The fact that the simulation runs reasonably well and has acceptable predicted results within the watershed of interest leads to the conclusion that the model is suitable for boundary condition inputs to the Local Scale model and the objectives of this phase of the study have been met.

Through the efforts completed in this task, the following recommendations for the Local Scale Model Development were identified.

- Better Represent Marco Island Utilities through improved lake cross-sections, interconnections between lakes and time-series of lake withdrawals for potable water and ASR use.
- Investigate updated land-use data from the SFWMD
- Investigate detention storage throughout the watershed
- Investigate vegetation parameters to better simulate crop related parameters throughout the watershed
- Investigate manning’s n of the overland flow plain
- Add representation of recent land development projects through 2012 where appropriate.

The recommendations above were addressed in the Local Scale Model Development, as described in Section 3.

3.0 Task 2.3. Construct Existing-LSM

This section contains details of **Task 2.3** of the Henderson Creek Watershed Engineering Research Project (HCWERP). The HCWERP is a multi-tasked project with seven individual, interrelated modeling tasks with the major objectives of gaining a better understand of the volume and timing of freshwater deliveries to the Rookery Bay Estuary.

Using the previously developed Collier County Existing Conditions (CC-ECM) model, model simulations were extended from 2002 through 2012 to provide accurate boundary conditions for a more detailed, local-scale model (LSM) to be developed and calibrated in subsequent tasks. This effort was documented in the previous section. All simulations run as part of the HCWERP were performed with MIKE Zero v2011, SP7.

In this current effort, the local-scale model was used to simulate existing and historical conditions within the Henderson Creek / Rookery Bay Watershed. Important aspects of the model setup, including saturated zone layering and parameters, rainfall and potential evapotranspiration, soils and land-use dependent parameters, etc. were held constant between the Existing and Historical conditions models to provide scientifically defensible comparisons between Existing and Historical Conditions. Care was taken to ensure that differences in model inputs and outputs between the two models are solely attributable to anthropogenic changes in the watershed.

The Existing-LSM was developed with a refined model domain covering 167 square miles, at a grid-cell size of 375-ft. This grid-cell size was chosen to allow for a more detailed representation of all MIKE SHE input files using spatially varied parameters, such as

- Topography
- Overland flow parameters
- Vegetation and other land-use based parameters
- Soils and unsaturated zone parameters

Additionally, the LSM incorporated a reduced domain in the vertical direction, where the saturated zone (groundwater) layers were reduced from seven to four. The reduced number of saturated zone layers was accomplished by applying a boundary condition at the deepest unit of the LSM (Layer 4). As such, the LSM simulates water surface elevations for layers above the "Upper Hawthorn Confining Unit" and uses the aforementioned results from **Task 2.2** as a time varying head boundary condition.

The MIKE-11 network (surface water portion representing canals and streams) of the Existing-LSM was also substantially reduced where only conveyance features within the newly developed LSM domain were simulated. Areas within the LSM domain that do not flow to the coast were assigned time-varying, stage boundary conditions from **Task 2.2.** These boundary conditions from **Task 2.2** were chosen to allow for a proper distribution of flows within the model domain and to give an accurate representation of these flows to the coast (Rookery Bay, Dollar Bay, etc.), while all canals which drain to the coast were given a boundary condition of the average tidal elevation from the Naples Tide gage.

Features added to the MIKE-11 network include the Marco Island Utilities Lakes, Winding Cypress Subdivision, and three branches that were deemed to contribute flows to Henderson Creek. Each of these branches run east/west south of Sabal Palm road. Another revision to the MIKE-11 network was the removal of the Belle Meade Flow-way. While the Belle Meade Flow-way is still represented within the MIKE-11 model, it is now simulated explicitly in the overland flow portion of the MIKE SHE.

The Historical-LSM provides results for the analysis of the watershed in a pre-development or historical condition against conditions as they are today or existing conditions. The Historical-LSM was refined to from the "Big Cypress Basin – Natural Systems Model" (BCB-NSM) and now covers an area of 1,256 sq. mi. at a grid cell size of 375-ft. For historical conditions, all man-made features from ditches/canals and control structures, to detention/retention ponds and Mining operations have been removed from the network of the both NSM simulations (Regional and Local Scale). As a result, the model simulates the flow of water in a natural manner to an outfall based upon the topography and other physical properties within the watershed. The Regional-NSM model was used to provide boundary condition inputs to the Historical Local Scale Model (LSM) for this project. The Regional-NSM model simulations were also extended through year 2012 for this purpose.

Results of the Existing Conditions LSM model demonstrated that the surface water calibration was good, and that the model results are useful for characterizing the existing volumes and flows of freshwater into Rookery Bay. The model was also deemed an acceptable starting point for developing a historical condition model within the constraints shown above. An historical conditions model simulation was then used for comparison with the existing conditions model.

The results of the existing and historical models were compared, with the goal of estimating the changes in freshwater inflow quantity and timing of Henderson Creek that have occurred due to construction of ditches, embankments, canals and control structures, other land development activities, and groundwater withdrawals.

The primary point of comparison was in Henderson Creek, upstream of US-41, at the present-day location of the SFWMD "HENDTAMI" structure. Although no control structure exists in the Historic-LSM, this was chosen as a viable comparison point as the Existing-LSM showed a good calibration at this location and this is the main freshwater inflow point for Rookery Bay. To maintain uniform simulation periods between all models listed herein, the simulation period is defined as 2002 through 2012. Under historic conditions, the model shows that slightly more water was delivered in the dry season (January through June and November through December), and considerably less in the wet season at this location.

3.1 Task 2.3. MIKE SHE Updates and Revisions

The re-calibrated and updated BCB model prepared under Task 2.2 (referred to as the CC-ECMv2 model) covered a land area of 1,416 sq. miles with a grid cell size of 1,500 ft. In contrast, the Existing-LSM model domain covers an area of 167 sq. miles, or about 12% of the BCB model domain. **Figure 32** presents a comparison of the CC-ECMv2 and the Existing-LSM domains. The MIKE SHE model developed as part of Task 2.3 "Construct Local-Scale Existing Conditions Model" (Existing-LSM), has a much smaller model domain than the Collier County ECM model in order to focus on lands draining specifically to the Rookery Bay. This includes the Lely Manor and Lely Canal Basins, Henderson Creek, the Belle Meade

Flow Way and portions of the Coastal Basin south of US41. As such, the entire model domain was refined and the grid cells were reduced to a size of 375ft.

Increasing model grid-cell resolution (reducing grid-cell size) has an inverse relationship with model domain area, meaning the higher resolution grid-cell sizes require a smaller model domain due to model complexity, scale, and computational burden. Due to the aforementioned parameters, and available computer processors currently available, keeping the previous CC-ECMv2 model domain is not practical or feasible at this time to. Thus the Existing-LSM was developed. The scientific and practical reasons for reducing the model scale are to hone in on the area of interest (Henderson Creek Watershed) and refine the model grid cell sizes to enable the model to have a more refined scale utilizing the physically based parameters such as topography, land use, soils, and saturated zone processes. This finer scale allows the team to incorporate a better representation of the topography and the other parameters due to the higher resolution of the model scale, with an expectation of a more robust model and detailed results in the area of interest. These model refinements and their impacts will be discussed in further detail in the appropriate subsequent sections.

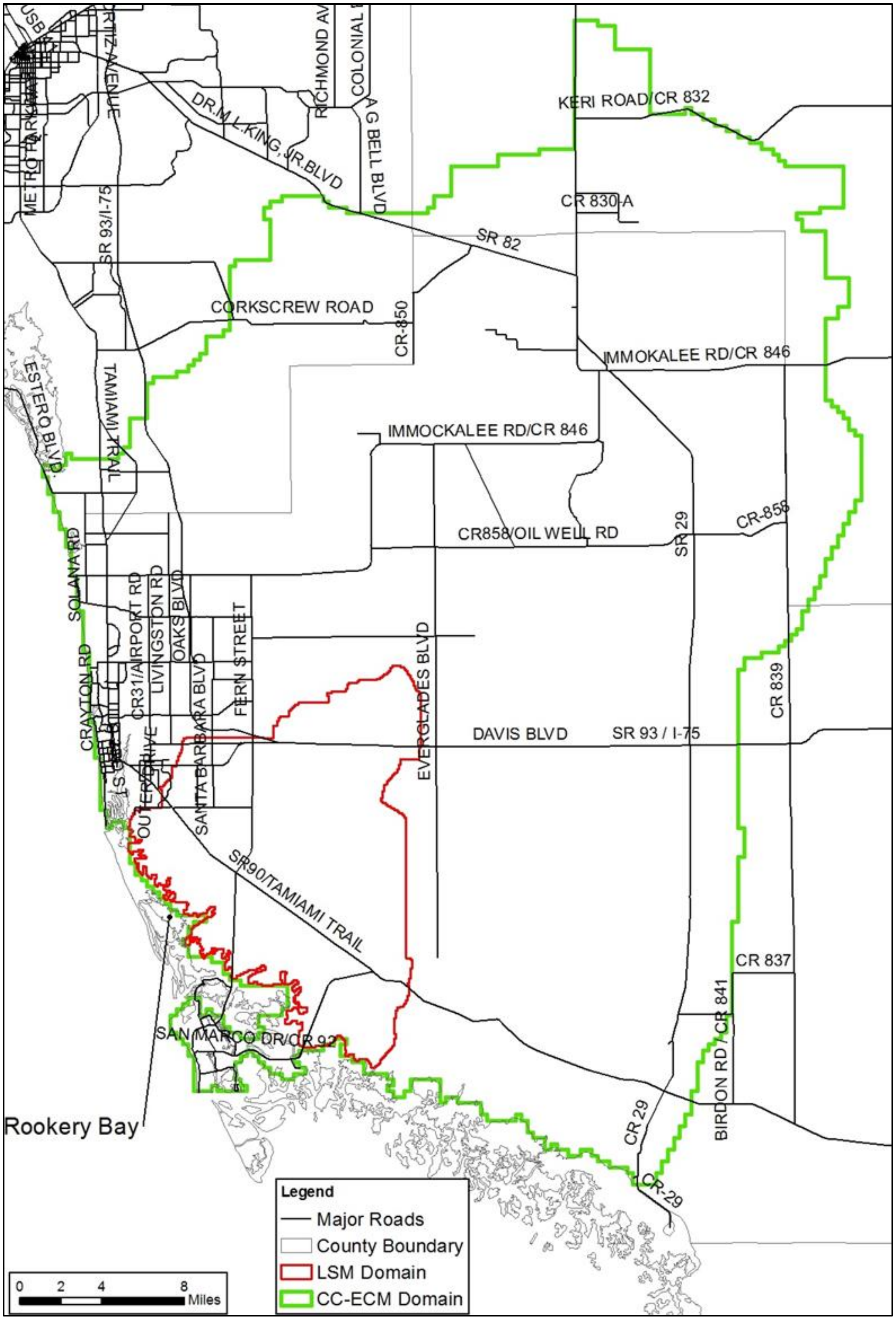


Figure 32. CC-ECMv2, Existing-LSM Model Comparison.

3.1.1 Climate

Tech. Memo 2.2 “Recalibrate Existing BCB Model” provides an in-depth discussion and analysis of each meteorological model input, as such will not be discussed in the same detail in this report. While no specific revisions to the climate components of the MIKE SHE/MIKE-11 model were conducted as a part of the Existing-LSM model development per-se (meaning the data utilized in the CC-ECMv2 was also used as forcing conditions in the Existing-LSM model). Two notable exceptions are

- Differences in file types used to distribute the precipitation data over the watershed and
- Extending the evapotranspiration data to utilize USGS GOES calculated RET data through 2012.

The reasons for these changes are the CC-ECMv2 model covered such a large domain , that the model would not run with single .DFS0 files as this file type was too much of a computational burden, and at the time the CC-ECMv2 model was developed the GOES reference evapotranspiration (RET) data was not available through 2012.

3.1.2 NEXRAD Data

NEXRAD rainfall time-series were distributed according to the published NEXRAD 2km x 2km grid. This methodology is used throughout South Florida and is widely accepted as standard practice. The difference with this model is that we utilize the shapefile of NEXRAD pixels (aforementioned grid) and time-series files. Whereas the CC-ECMv2 model utilized a time-varying grid (.DFS2) file covering all of Collier County. Consequently, for the Existing-LSM model, a selected sub-set was utilized for the refined model domain. This limits the amount of data to be transferred for model review or other refinements as well as reduce the amount of data within the file structure. **Figure 33** presents the NEXRAD rainfall grid utilized for the Existing and Historical-LSM model development.

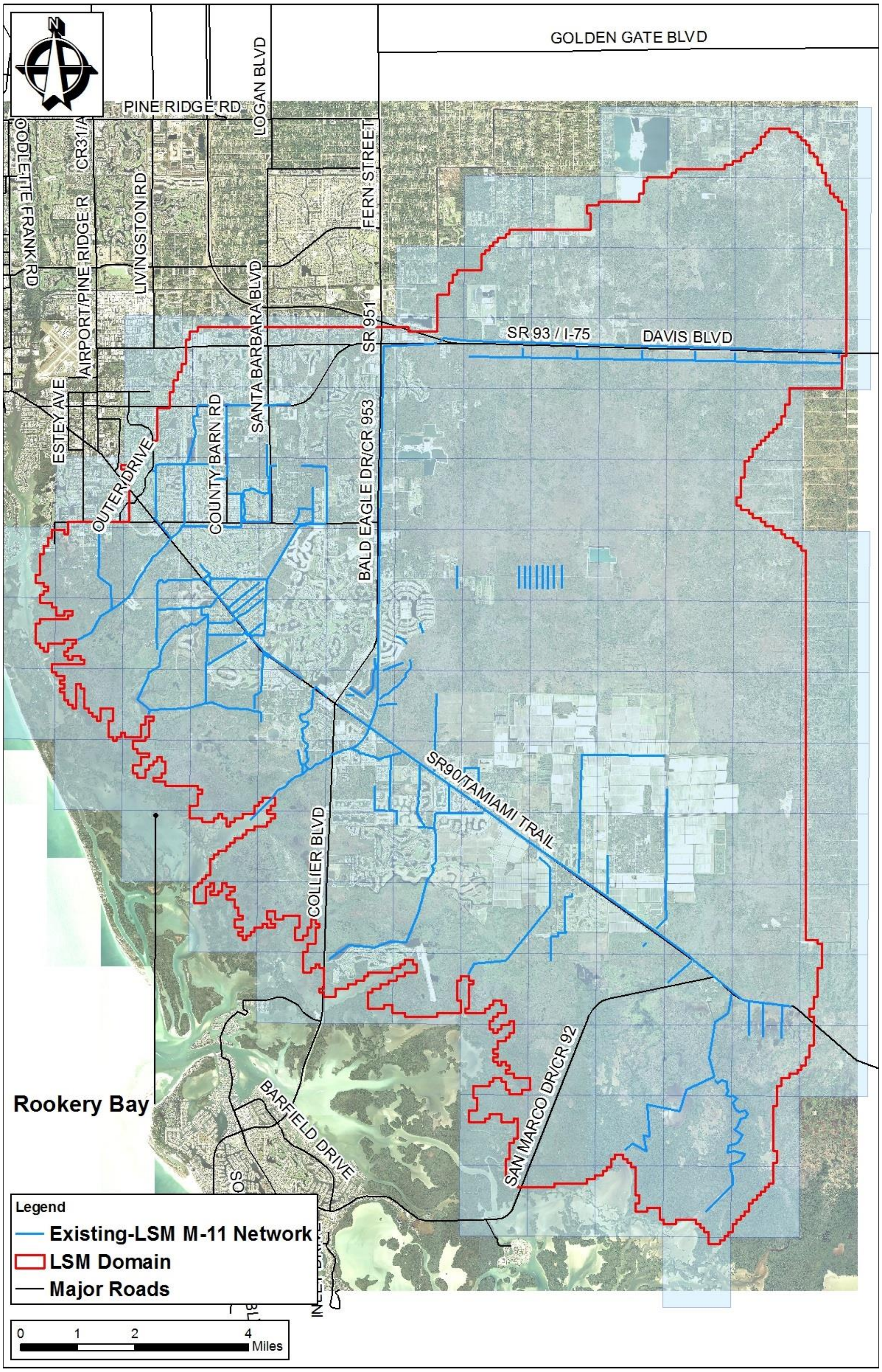


Figure 33. Existing-LSM Domain, NEXRAD Rainfall Pixel Distribution

3.1.3 USGS GOES RET

Since the CC-ECMv2 model was revised to its current state, the USGS has published RET data for calendar year 2012. As such, this data was obtained and incorporated into the model. This was done previously as a Julian Day extrapolation and was employed to allow the model to run for the specified simulation period 2002 through 2012. A water balance conducted in early development runs of the Existing-LSM indicate no issues with the incorporation of the USGS GOES calculated RET data. The USGS GOES Ret is distributed via the same grid as NEXRAD, only differing in unique Pixel ID. The difference in Pixel ID is due to separate entities (USGS vs. SFWMD) maintaining the database. Please refer to **Figure 33** for the spatial extent of the RET distribution.

3.1.4 SFWMD Topography

The SFWMD maintains LiDAR topographic data in the form of a Digital Elevation Model (DEM) for most, if not all, of the land area the District manages. The DEM is a raster file that can be manipulated in a Geographical Information Systems (GIS) software package, such as ArcMap. LiDAR or Light Detection and Ranging is a technique where topography of the land surface is determined by the amount of time a near infrared light beam takes to leave the sensor on an airplane and return to the sensor while the plane maintains a consistent altitude (For more information on LiDAR and accuracy please see: http://oceanservice.noaa.gov/facts/lidar.html). LiDAR is considered one of the best sources of topographic data for water resource modeling studies from small- to large-scale domains, because a watershed can be mapped in a single day, where traditional survey would be unfeasible due to the amount of time required to survey the watershed extent.

While survey data is the most accurate, LiDAR data is more than acceptable for water resources modeling and in general falls within close range of surveyed or ground-truthed data. The data for the Existing-LSM model was flown between 2007 and 2008 and was processed to create a DEM with a 10-ft resolution. This means that each elevation pixel equals a 10ft x 10ft grid cell. This very detailed representation of the ground surface elevation was then processed for model input. Topographic data for model input was obtained from the 10-ft LiDAR by calculating the median elevation values from the LiDAR DEM for the Existing-LSM model domain over the larger (375-ft) grid-cell size. The median statistical values were used over each grid-cell as the low points within channels will not be captured in the topography, rather in the MIKE-11 open channel network. This is important because when the MIKE SHE and MIKE-11 models are coupled, only the land surface elevations are represented in the MIKE SHE topography file. The vertical datum for the SFWMD LiDAR and MIKE SHE model are both referenced to NAVD-88.

Figure 34 presents the Collier County 10-ft x 10-ft LiDAR grid coverage over the Existing-LSM model domain, while **Figure 35** presents the Collier County LiDAR processed to median values over a 375-ft grid-cell size. As shown in **Figures 34** and **35**, the land slopes naturally from the northeast to the southwest. While the 10-ft grid-cell size captures much more detail, the topography processed for the Existing-LSM MIKE SHE model captures the natural slope and has an appropriate resolution to allow for accurate representation of the topography over the Existing-LSM domain.

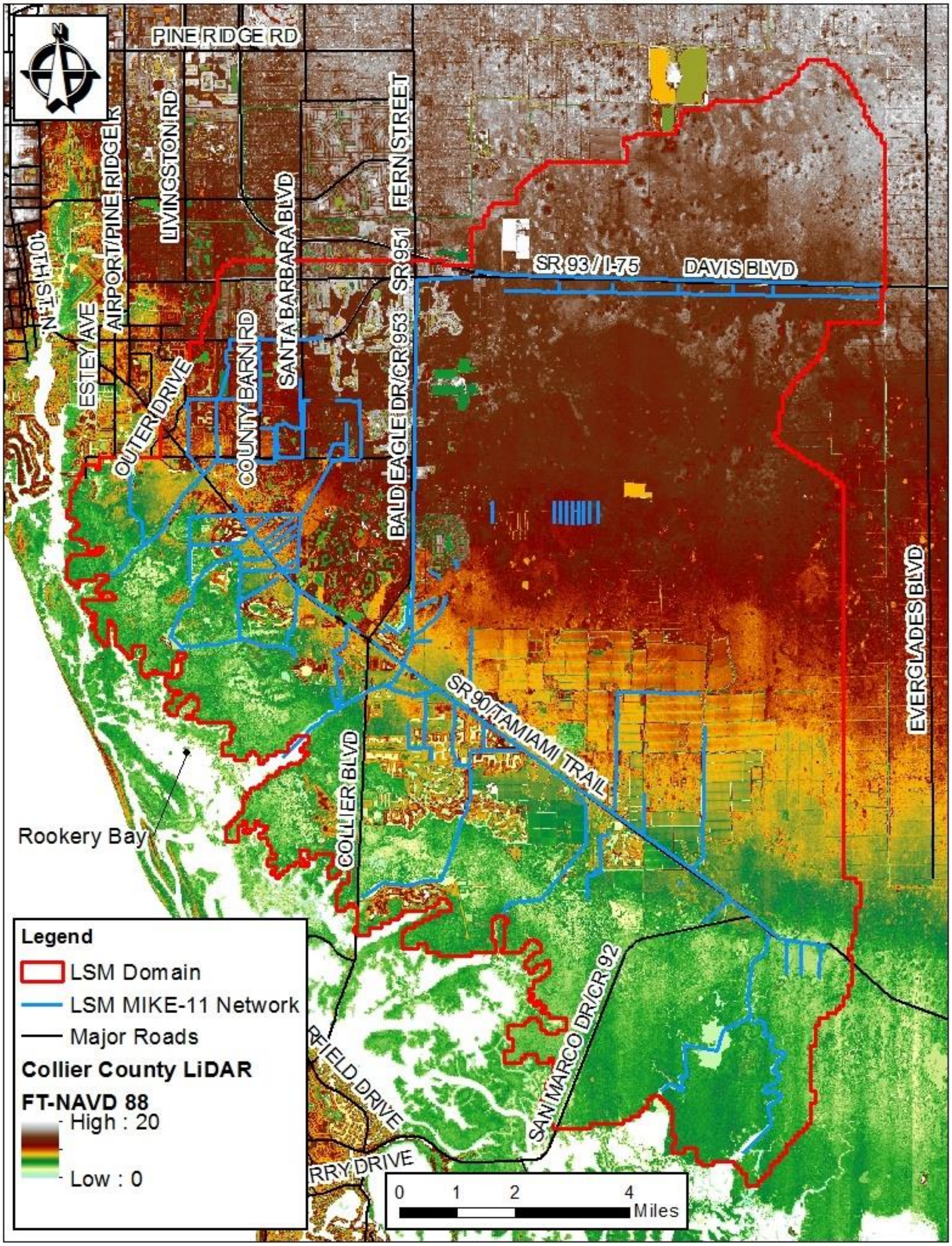


Figure 34. Collier County LiDAR Topography (10-ft x 10-ft Resolution)

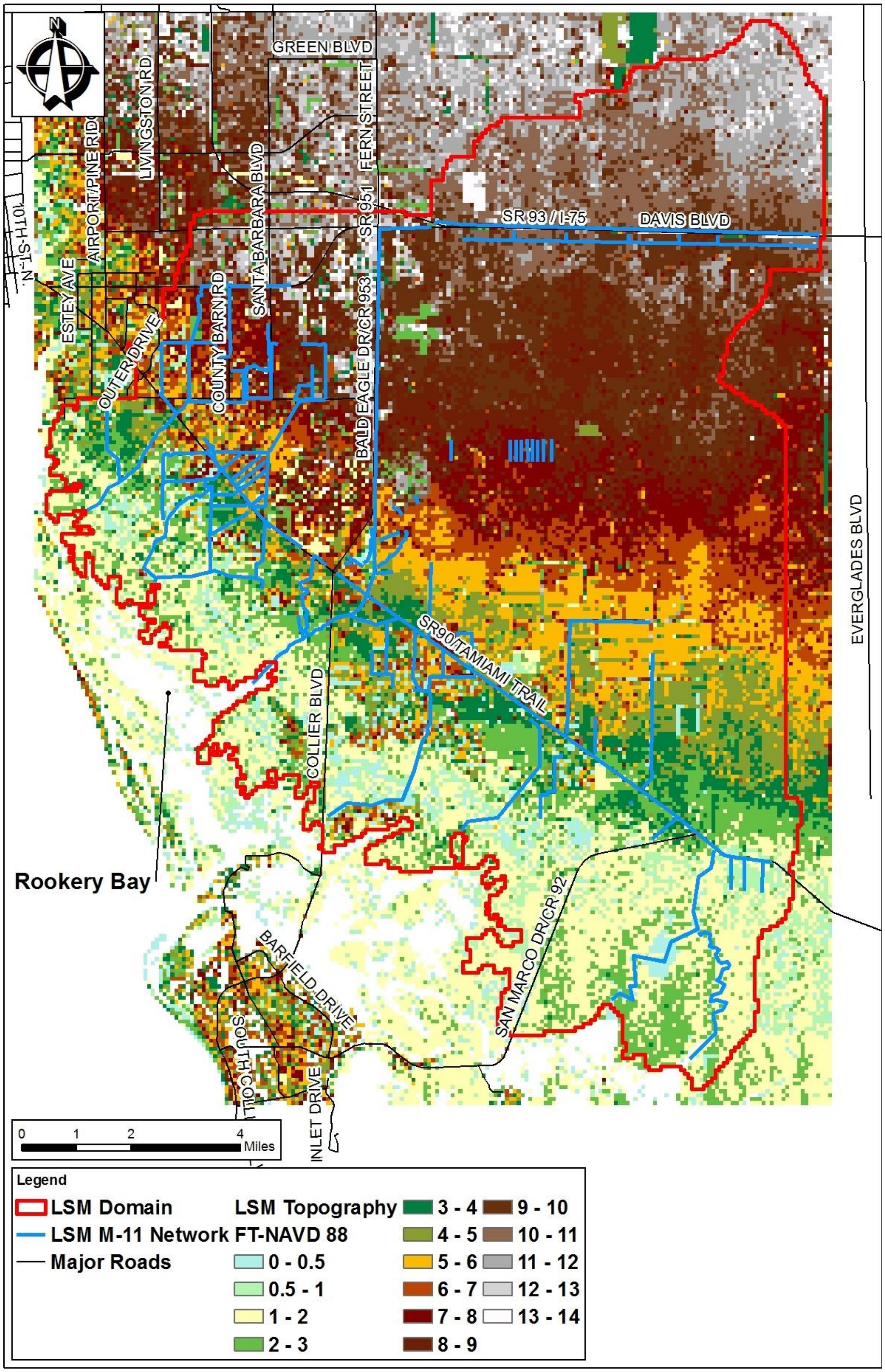


Figure 35. Collier County LiDAR Topography (10-ft x 10-ft Resolution) Processed to 375-ft Grid-Cell Size

3.1.5 SFWMD Land Use

2008 Land use data was obtained from the SFWMD and processed for the Existing-LSM model domain; this data was updated between 2008 and 2009 from aerial photograph interpretation. The land use was similar to the CC-ECMv2 where the types and distributions remained similar, and from the FLUCCS codes there are 86 unique land use types grouped into 20 hydrologically similar land use categories. While the land use classifications were largely similar, there was an additional land use type of "Costal Shrub" (FLUCCS code 3220, Hydrologic Classification of Xeric Hammock in MIKE SHE). Xeric Hammock was not included in the CC-ECMv2 model, either because the grid resolution was too coarse or the land use was determined as such after the model was developed. This is plausible as the CC-ECMv2 model utilized a 1500-ft grid-cell resolution and the 2004 land use from SFWMD, which was the best data available at the time the model was built. The updated 2011 land use data was then incorporated into the Existing-LSM by taking the average FLUCCS code value for each land use type over a 375-ft grid-cell resolution. This process was similar to that employed for the topographic data, but used an average value of the FLUCCS code over each 375-ft grid-cell. This is a widely acceptable practice that yields appropriate results. **Figure 36** presents the spatial extent of the hydrologic land use distribution over the Existing-LSM domain and **Table 1a** in **Appendix C** presents the Hydrologic Land Use Percentages for the Existing-LSM model domain. As can be seen from **Figure 36**and **Table 13**, the land use is dominated by wetland and forested land use categories while urban land use and water make up 13.6% and 3.5% of the Existing-LSM domain respectively. These land use categories are expected due to the Belle Meade Flow-way, the extensive Mangrove and Swamp Forests along the coast line, and the number of retention ponds and canals throughout the Existing-LSM domain.

Table 13. Major Hydrologic Land Use Comparisons

Hydrologic Land Use	Area Sq. Miles	Percentage of Watershed
Mangrove/Swamp Forest	37.3	22.3
Cypress/Hydric Flatwoods/Marsh	55.9	33.5
Mesic Flatwood	20.0	11.9

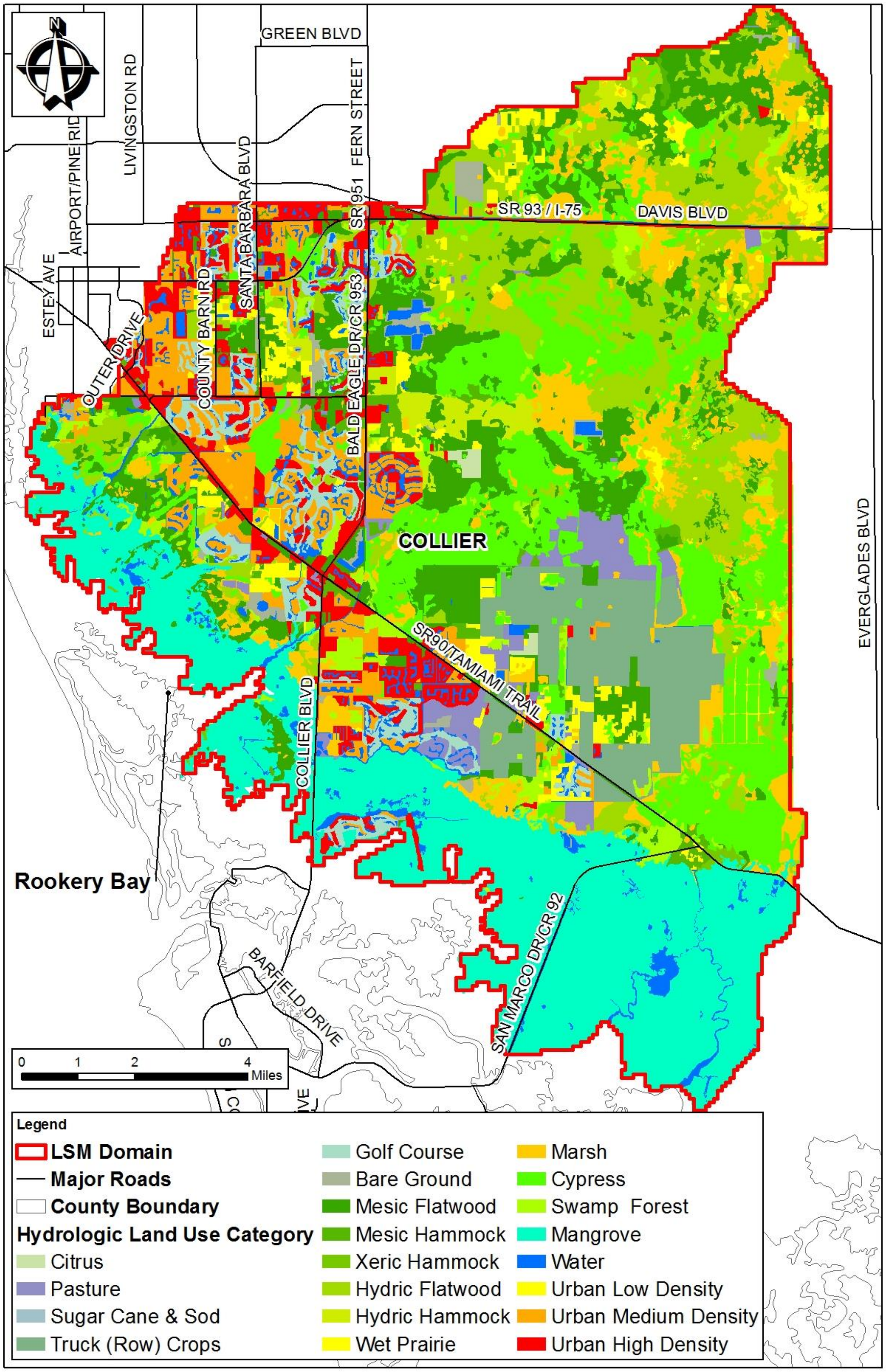


Figure 36. 2011 SFWMD Land Use Distributed Over the Existing-LSM Model Domain

3.1.6 Overland Manning's M

Overland flow (OL) is the water that flows over the land surface after the soil has become saturated or the rainfall intensity exceeds the infiltration capacity of the soil. Overland Manning's M governs the velocity calculations where the land surface or albedo changes due to vegetative coverage or increases in impervious surface. The Overland Manning's M is the inverse of the Manning's n coefficient of roughness, which is used in the model calculations of the overland flow component of the model. A densely vegetated forest would exert increased friction (roughness) to flow, while an urban area with impervious surfaces would provide a smooth surface with reduced friction to flow. Overland flow, also known as surface runoff, is an important process in all watersheds and can become a major factor when land use changes, creating a large area of impervious surface leading to increases in surface runoff, or in the opposite case where lands are restored to a more natural state, which can improve infiltration capacities and reduce runoff. The Overland Manning's M is related to the land use, as in this application has a range of 2.5 to 16.67. These values were not changed from the CC-ECMv2 model development and are seen as appropriate. **Table 14** presents the Hydrologic Land Use type (Vegetative Cover) and the associated OL Manning's M coefficients. As can be seen in **Table 14**, vegetative coverages with lower values (Marsh, Hydric Hammock, Swamp Forest) have low OL Manning's M values, which allow for the calculation over a "rougher" land surface than Urban which ranges from 7.14 to 9.01. Conversely, Water and Bare Ground are the least restrictive vegetative/Hydrologic Land Use types and are represented by the highest OL Manning's M values.

Table 14. Existing-LSM Hydrologic Land Use and Associated OL Manning's M Parameters

Hydrologic Land Use	OL Mannings M
Citrus	5.88
Pasture	7.14
Sugar Cane/Sod	5.88
Truck Crops	5.88
Golf Course	7.14
Bare Ground	11.36
Mesic Flatwood	5
Mesic Hammock	3.33
Xeric Hammock	5
Hydric Flatwood	4
Hydric Hammock	2.5
Wet Prairie	3.33
Marsh	2.33
Cypress	3.33
Swamp Forest	2.5
Mangrove	5
Water	16.67
Urban Low Density	7.14
Urban Medium Density	8.33
Urban High Density	9.01

Figure 37 presents the spatial distribution of the OL Manning's M coefficients over the Existing-LSM domain. The OL Manning's M coefficients follow the Hydrologic Land Use categories presented in Section 3.6. This is expected, as the OL Manning's M is directly related to the Hydrologic Land Use classification.

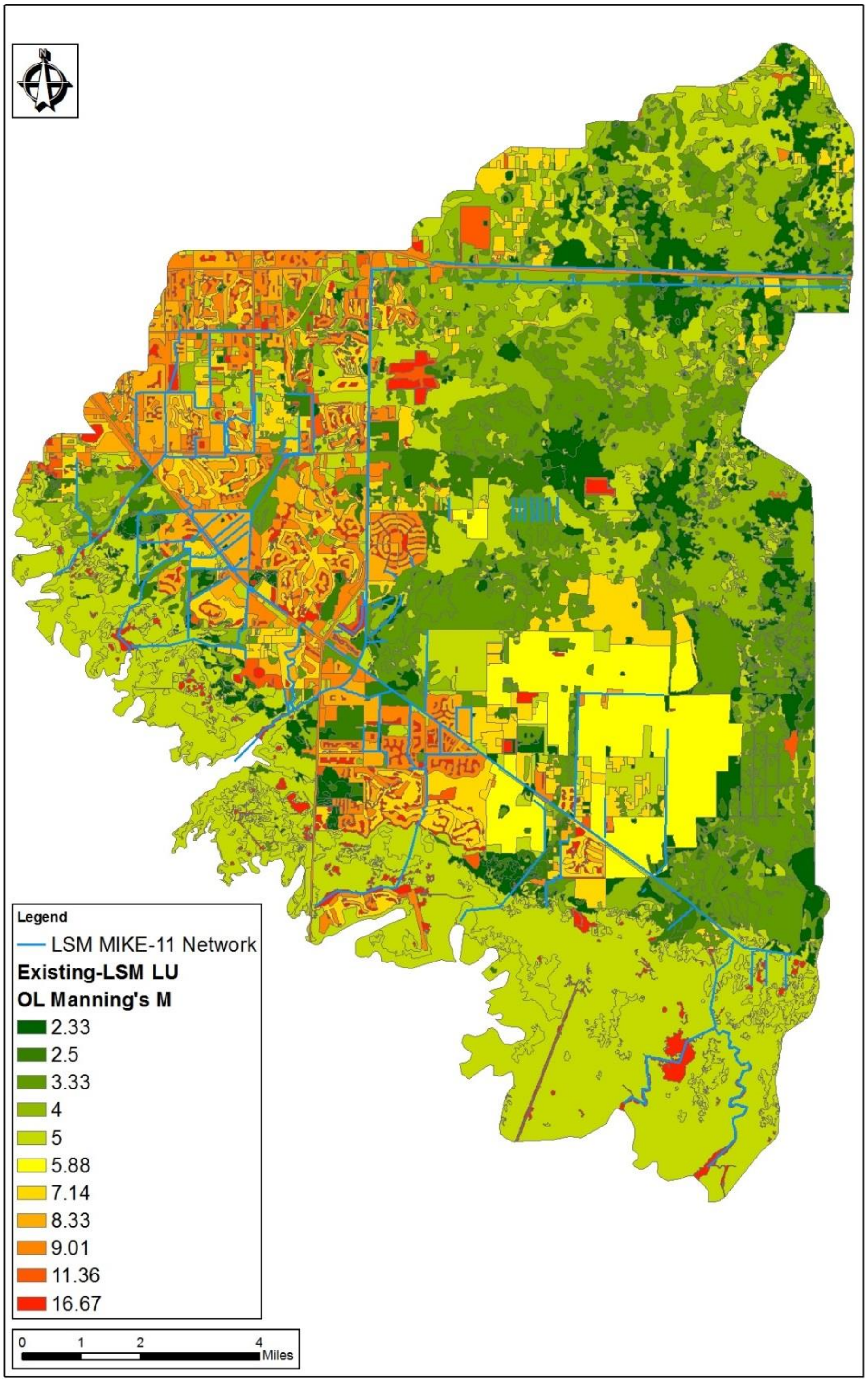


Figure 37.Spatial Distribution of The OL Manning's M over the Existing-LSM Domain

3.1.7 Separated Overland Flow Areas

MIKE SHE utilizes a .DFS2 (grid) file of unique grid codes to account for sub-grid scale topographic barriers such as roadway embankments or other manmade divide features which limit the overland flow of water. For example, a drainage basin, a large development with a berm around the perimeter, or a large land area bisected by a road would require a unique separated flow area. This allows the model to simulate the overland flow paths as they exist in reality. **Figure 38** presents the separated overland flow map developed for the Existing-LSM. The figure indicates separated flow areas for the Lely Canal and Lely Manor Basins, and other major drainage basins or sub-watersheds in the Existing-LSM domain, which remain relatively similar to the Separated Overland Flow Areas defined in the CC-ECMv2 model. Additional separated flow areas were deemed necessary for The Naples land-fill just north of I-75/Alligator Alley, as well as the area of the Belle Meade Flow-way bisected by Sabal Palm road. Another notable revision to the separated overland flow areas was the addition of the Winding Cypress/Verona Walk Subdivision, which is located on the east bank of Henderson Creek just north of the Marco Island Utilities Lakes and has outfalls to the Belle Meade Flow-way. This subdivision has been divided into two separate flow areas (**Figure 38** Pink and Black polygons) to account for the separate drainage basins shown in the plans (Permit 11-02132-P).

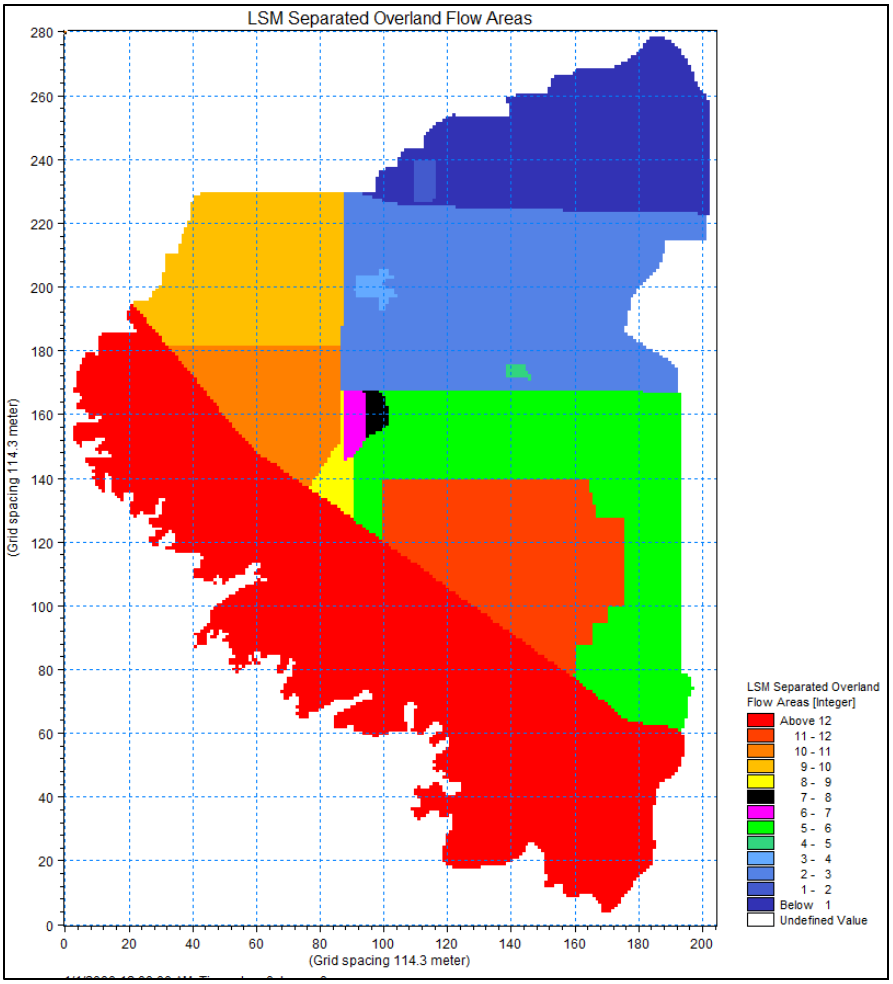


Figure 38. Existing-LSM Separated Overland Flow Areas

3.1.8 Paved Runoff Coefficient

Utilizing the paved areas option in MIKE SHE allows the user to route a portion of the overland flow directly to the saturated zone drainage network (DHI, 2011 v2 p.92/444). The paved runoff coefficient defines the fraction of ponded water that is partitioned to a drainage feature. The ponded water is the water available after infiltration to the unsaturated zone and ET losses are calculated (DHI, 2011 v2 p.100/444). The Paved Runoff Coefficient serves MIKE SHE by defining where paving is present and defines how much overland flow is available for infiltration and the fraction that is allowed to drain away. Thus, the Paved Runoff Coefficient is a fraction from 0 to 1 and applies the user-specified fraction of ponded water directly to Saturated Zone drainage, which is routed to the nearest surface water feature (MIKE-11 branch). For example, if the Paved Runoff Coefficient is set to 0.3, 30% of the water ponded in the overland flow plain will be removed and sent to the drainage network where the remaining 70% of the water will be available for infiltration and what does not infiltrate will be sent to the adjacent overland flow cell. Therefore, only areas with pavement or other impervious surfaces such as the “Urban” land use classifications have an associated Paved Area Runoff Coefficient within the MIKE SHE framework. **Table 15** presents the Paved Area Runoff Coefficients associated with each land use type. **Figure 39** presents the spatial extent of the Paved Runoff Coefficient of the Existing-LSM model domain, and as shown the majority of the watershed has “0” (Blue Grid Cells) associated with respect to the Paved Runoff Coefficient. The remaining pockets of Green, Yellow, and Red show increasing Paved Runoff Coefficients corresponding to increased urban density and associated coefficients as defined in **Table 15.**

Table 15. Existing-LSM Paved Runoff Coefficients

Hydrologic Land Use	Paved Runoff Coefficient
Urban Low Density	0.05
Urban Medium Density	0.15
Urban High Density	0.45

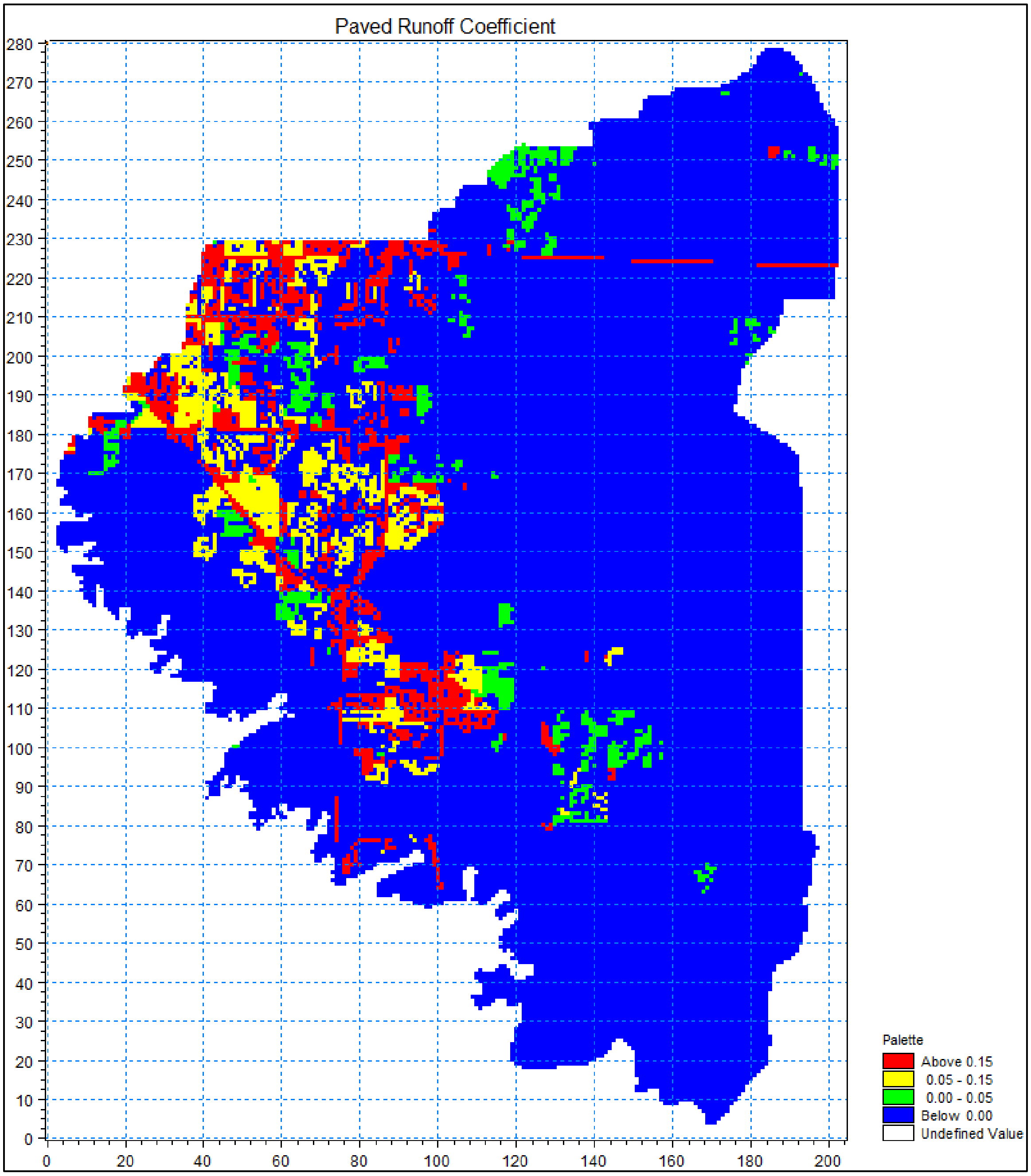
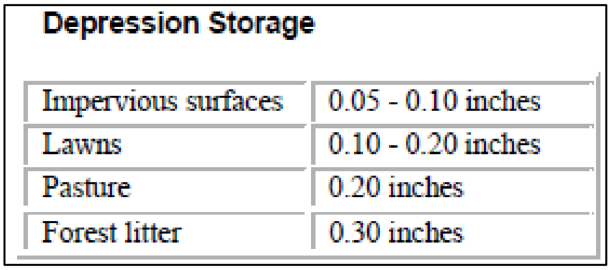


Figure39. Existing-LSM Paved Runoff Coefficient

3.1.9 Detention Storage

The detention storage is an accounting of the storage due to depressions in the land surface, or those associated with developments and other built or urban land use types, such as small ponds. Detention storage limits the amount of water than can flow over the land surface. Water ponded on the land surface/overland flow plan must exceed the detention storage for each land use before overland flow can be initiated. In the CC-ECMv2 model, excessively large values of detention storage were used in the model development, which may not have been appropriate for the Existing-LSM model due to the refinement of the grid cell size from 1500-ft (CC-ECMv2) to the currently developed 375-ft (Existing-LSM). The current values for urban land use categories were obtained from the EPA SWMM-5 manual as well as other land use categories being back checked against the values presented in the manual and shown in **Figure 40** (EPA, 2010). The values obtained from the SWMM-5 manual are appropriate, as SWMM-5 is a widely used and recognized watershed management planning model developed for flood studies where water levels in urban areas are very important. In contrast, a natural land use type such as a forest or wetland area will likely not have any man made detention storage, but do have interspersed depressions that need to be accounted for. **Table 16** presents the Detention Storage values, while **Figure 41** presents the spatial distribution within the Existing-LSM model.



Depression Storage

Impervious surfaces	0.05 - 0.10 inches
Lawns	0.10 - 0.20 inches
Pasture	0.20 inches
Forest litter	0.30 inches

Figure 40. Table A.5 From SWMM 5 User's Manual (EPA, 2010)

Table 16. Existing-LSM Detention Storage Values

Hydrologic Land Use	Detention Storage (inch)
Citrus	0.3
Pasture	0.25
Sugar Cane/Sod	0.25
Truck Crops	0.25
Golf Course	0.3
Bare Ground	0.15
Mesic Flatwood	0.4
Mesic Hammock	0.4
Xeric Hammock	0.4
Hydric Flatwood	0.4
Hydric Hammock	0.4
Wet Prairie	0.4
Marsh	0.4
Cypress	0.4
Swamp Forest	0.4
Mangrove	0.4
Water	0.00
Urban Low Density	0.1
Urban Medium Density	0.1
Urban High Density	0.1

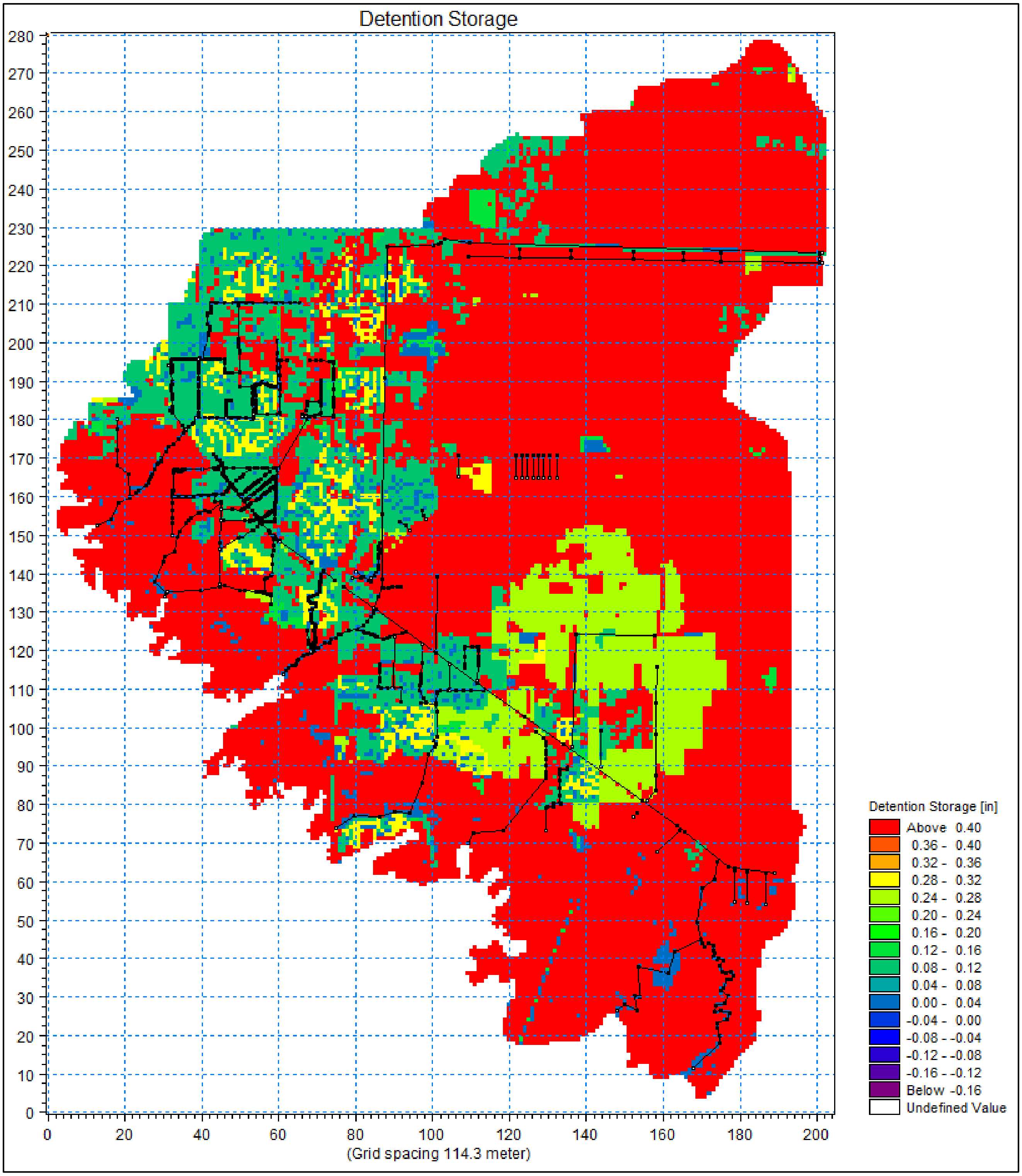


Figure 41. Existing-LSM Detention Storage

3.1.10 Unsaturated Zone (Soils)

Soils data were obtained from the SFWMD “sosrunt” shapefile covering most of the counties within the SFWMD boundaries, similar to the published shapefile for Collier County produced by the NRCS or SSURGO data. The Existing-LSM model domain contains 39 distinct soil series including water. **Figure 42** presents the spatial distribution of the NRCS soil series within the Existing-LSM model domain. As shown, the soils are highly heterogeneous throughout the Existing-LSM domain; modeling each soil series would prove arduous and computationally intensive. **Table 17** presents the NRCS SSURGO Mapping Unit Name and Soil Series shown in **Figure 42.**

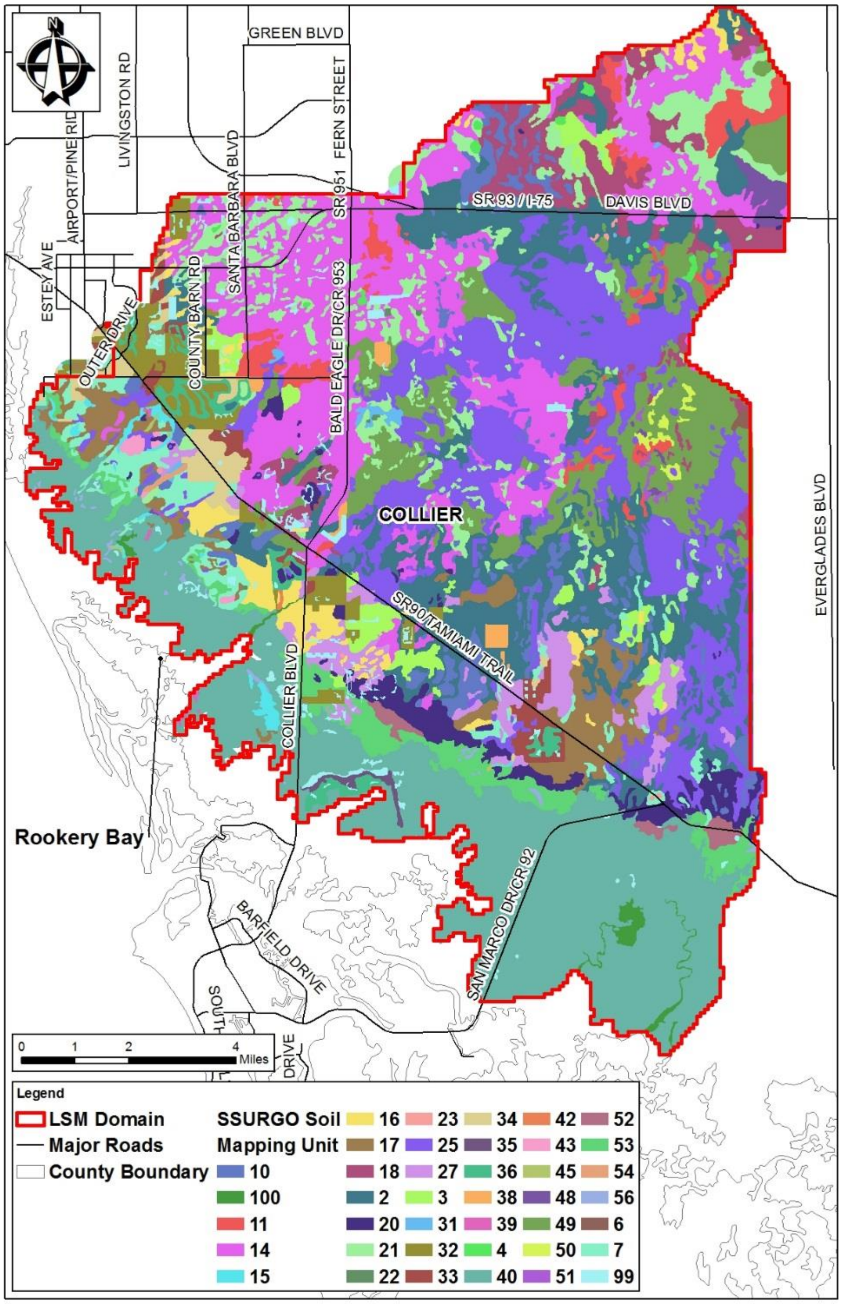


Figure 42. Existing-LSM Soil Distribution NRCS Classification

Table 17. NRCS Mapping Unit and Soil Series within Existing-LSM Domain

Mapping Unit	NRCS Soil Series	Mapping Unit	NRCS Soil Series
2	HOLOPAW FINE SAND, LIMESTONE SUBSTRATUM	33	URBAN LAND-HOLOPAW-BASINGER COMPLEX
3	MALABAR FINE SAND	34	URBAN LAND-IMMOKALEE-OLDSMAR, LIMESTONE SUBSTRATUM, COMPLEX
4	CHOBEE, LIMESTONE SUBSTRATUM, AND DANIA MUCKS, DEPRESSIONAL	35	URBAN LAND-AQUENTS COMPLEX, ORGANIC SUBSTRATUM
6	RIVIERA, LIMESTONE SUBSTRATUM-COPELAND FINE SANDS	36	UDORTHENTS, SHAPED
7	IMMOKALEE FINE SAND	38	URBAN LAND-MATLACHA-BOCA COMPLEX
10	OLDSMAR FINE SAND, LIMESTONE SUBSTRATUM	39	SATELLITE FINE SAND
11	HALLANDALE FINE SAND	40	DURBIN AND WULFERT MUCKS, FREQUENTLY FLOODED
14	PINEDA FINE SAND, LIMESTONE SUBSTRATUM	42	CANAVERAL-BEACHES COMPLEX
15	POMELLO FINE SAND	43	WINDER, RIVIERA, LIMESTONE SUBSTRATUM, AND CHOBEE SOILS, DEPRESSIONAL
16	OLDSMAR FINE SAND	45	PAOLA FINE SAND, GENTLY ROLLING
17	BASINGER FINE SAND	48	PENNSUCO SILT LOAM
18	RIVIERA FINE SAND, LIMESTONE SUBSTRATUM	49	HALLANDALE AND BOCA FINE SANDS
20	FT. DRUM AND MALABAR, HIGH, FINE SANDS	50	OCHOPEE FINE SANDY LOAM, LOW
21	BOCA FINE SAND	51	OCHOPEE FINE SANDY LOAM
22	CHOBEE, WINDER, AND GATOR SOILS, DEPRESSIONAL	52	KESSON MUCK, FREQUENTLY FLOODED
23	HOLOPAW AND OKEELANTA SOILS, DEPRESSIONAL	53	ESTERO AND PECKISH SOILS, FREQUENTLY FLOODED
25	BOCA, RIVIERA, LIMESTONE SUBSTRATUM, AND COPELAND FINE SANDS, DEPRESSIONAL	54	JUPITER-BOCA COMPLEX
27	HOLOPAW FINE SAND	56	BASINGER FINE SAND, OCCASIONALLY FLOODED
31	HILOLO, JUPITER, AND MARGATE FINE SANDS	99	WATER
32	URBAN LAND	100	WATERS OF THE GULF OF MEXICO

As previously mentioned, the soils within the Existing-LSM domain are numerous with respect to NRCS soil series. Therefore, the soil series were then grouped according to a hydrologic soil drainage class, which is the soil characteristic from which the soil properties are derived for the calculations within MIKE SHE and provides the unsaturated zone component of the water balance. **Figure 43** presents the spatial distribution of the hydrologic soil drainage class for the Existing-LSM domain.

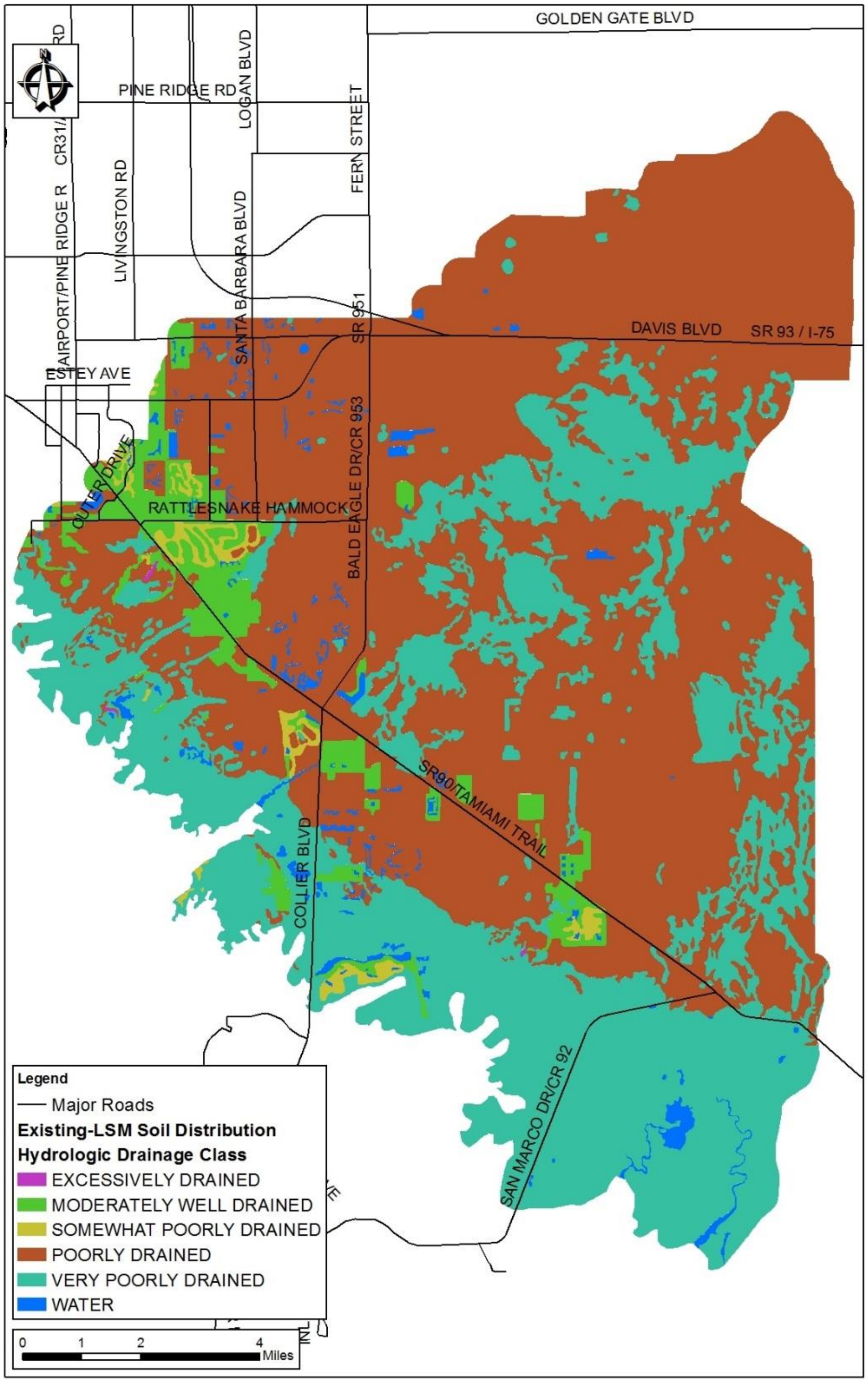


Figure 43. Existing-LSM Soil Distribution Drainage Classification

The drainage class of a soil is related to the position of the water table, where the soil allows infiltration until the wetting front meets the water table at variable depths depending on season, soil type, and other land use or water control practices. Once the wetting front reaches the water table, infiltration no longer occurs and the soil is considered saturated. As shown in **Figure 43**, the soils were distributed across the Existing-LSM model domain based on the drainage class for each associated soil series. It should be noted here that soil series "Urban Land" was classified as Moderately Well Drained. From the drainage class grouping five distinct drainage classes were identified and a sixth classification of "open water."

Each soil drainage class was parameterized with the soil series comprising the largest land area within the Existing-LSM domain. **Table 18** presents the drainage classification and associated soil series used in the Existing-LSM model domain:

Table 18. Existing-LSM Soil Drainage Class, Associated Soil Series

Drainage Class	Existing-LSM Soil Series	Drainage Class Area (acres)	Percentage of Existing-LSM
Very Poorly Drained	Plantation Muck	36,687.52	34.22%
Poorly Drained	Pineda Sand	62,506.45	58.31%
Somewhat Poorly Drained	Satellite Fine Sand	5,111.74	4.77%
Moderately Well Drained	Pomello Fine Sand	1,123.25	1.05%
Excessively Drained	Paola Sand	36.85	0.03%
Open Water	Open Water	1,738.77	1.62%

As shown in **Table 18** "Open Water" is a Drainage Class and Soil Series. It was necessary to classify open water in MIKE SHE, as the distributed soils are coupled with the vegetation, and an Actual Evapotranspiration rate (AET) is calculated and applied to the model domain based on the soil moisture characteristics and associated vegetative community. The soil moisture properties govern the availability of water for the overlying vegetation to remove from the soil, or in the case of "Open Water," AET will be calculated differently as the model assumes no plant roots or other form of transpiration will be active in these cells and is essentially an open pit.

Existing-LSM soil moisture characteristics (soil moisture retention curves, saturated hydraulic conductivities, unsaturated hydraulic conductivities, and water contents at effective saturation θsat, field capacity θfc and wilting point θwp), were developed for several soils not already in the CC-ECMv2 unsaturated zone database. Most of these parameters were estimated from laboratory data published throughout the 1970's to early 1990's by the Soil Characterization Laboratory and the University of Florida Institute of Food and Agricultural Sciences (IFAS) Soil Science Department (Carlisle, et. al., 1978; Carlisle, et. al., 1981; Carlisle, et. al., 1989; Sodek, et. al., 1990). The majority of the soils within the Existing-LSM domain can be classified as either Very Poorly Drained or Poorly Drained covering 34.2 and 58.3 per cent respectively of the Existing-LSM domain. **Appendix D** provides a detailed description of soil series, drainage class and areas associated with each NRCS soil series, and **Appendix E** lists the IFAS laboratory data for each of the NRCS soil series updated for the Existing-LSM model development.

The relationship between unsaturated hydraulic conductivity and moisture content was simulated using the Averjanov equation. Details of this method can be found in the MIKE SHE Technical Reference (DHI, 2011b). The primary model input parameter for the Averjanov equation is an exponent (n) which can be related to the Brooks and Corey pore size distribution index (λ) by the following relationship (Assouline and Tartakovsky, 2001):

$$n = \frac{2 + 2.5\,\lambda}{\lambda}$$

Pore size distribution index was estimated for each soil horizon, based on average values for each of the 11 USDA soil texture classes. These data are presented in Rawls, et. al. (1982).

Soil Series Plantation and Pineda were available within the CC-ECMv2 unsaturated zone database and used for the associated drainage class. Soils not included in the CC-ECMv2 set up and parameterized for the Existing-LSM model development were:

- Satellite Fine Sand
- Pomello Fine Sand
- Paola Fine Sand

Table 19 lists the MIKE SHE soils parameters of each soil horizon for the aforementioned soils.

Table 19. MIKE SHE Soils Parameters Developed For Existing-LSM

Soil Series	Drainage Class	Horizon	Ksat (cm/hr)	θ_{sat}	θ_{fc}	θ_{wp}	Averjanov n
Satellite Fine Sand	Somewhat Poorly Drained	A	43.05	0.48	0.058	0.022	5.4
		C1/C2	26.65	0.37	0.023	0.006	5.4
		C3	27.60	0.39	0.025	0.004	5.4
Pomello Fine Sand	Moderately Well Drained	A	22.40	0.43	0.073	0.029	5.4
		E1\E2	27.93	0.38	0.037	0.006	5.4
		Bh1	15.80	0.37	0.036	0.007	5.4
		Bh2	11.85	0.42	0.100	0.029	5.4
		BC1	24.35	0.38	0.056	0.014	5.4
		BC2	22.40	0.36	0.038	0.008	5.4
		C	25.00	0.32	0.022	0.003	5.4
Paola Fine Sand	Excessively Drained	A	62.45	0.44	0.039	0.013	5.4
		E	70.35	0.36	0.018	0.013	5.4
		Bw	65.75	0.35	0.020	0.009	5.4
		BA	70.30	0.30	0.021	0.007	5.4
		Bw/E/Bh	53.25	0.33	0.024	0.008	5.4
		C	53.20	0.33	0.023	0.008	5.4

Notes:

Ksat (cm/hr) = Saturated Hydraulic Conductivity
θ_{sat} = Volumetric water content at effective saturation
θ_{fc} = Volumetric water content at field capacity, estimated as the water content at a negative pressure of -1/3 bar
θ_{wp} = Volumetric water content at wilting point, estimated as the water content at a negative pressure of -15 bar

The relationship between moisture content and negative capillary pressure is specified in MIKE SHE using tabulated values. **Figures 44** – **46** illustrate the different moisture retention characteristics for Satellite Fine Sand (a somewhat poorly drained sand), Pomello Fine Sand (a moderately well drained sand), and Paola Fine Sand (an excessively drained sand).

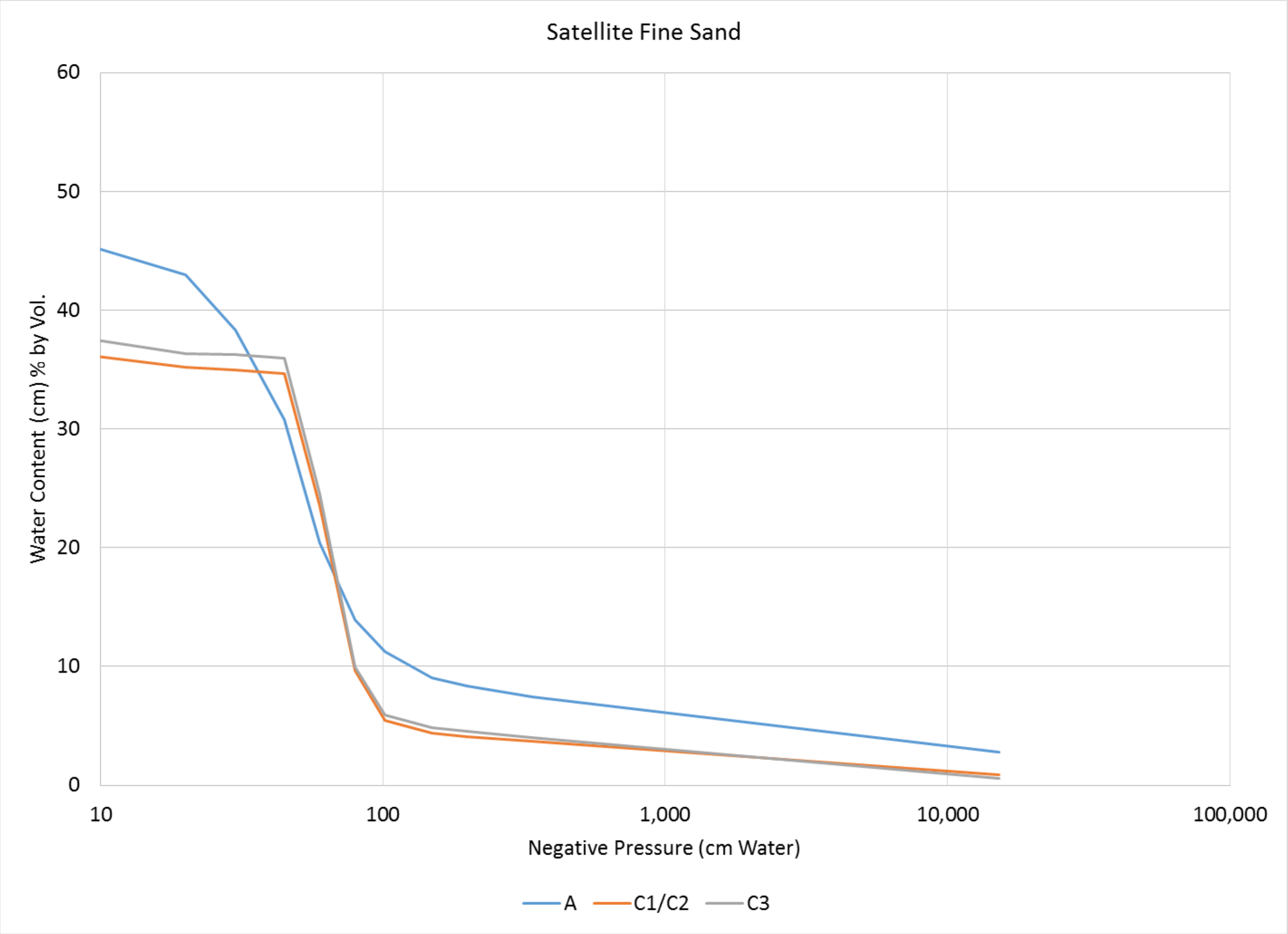


Figure 44. Water Retention Curves for a Somewhat Poorly Drained Soil

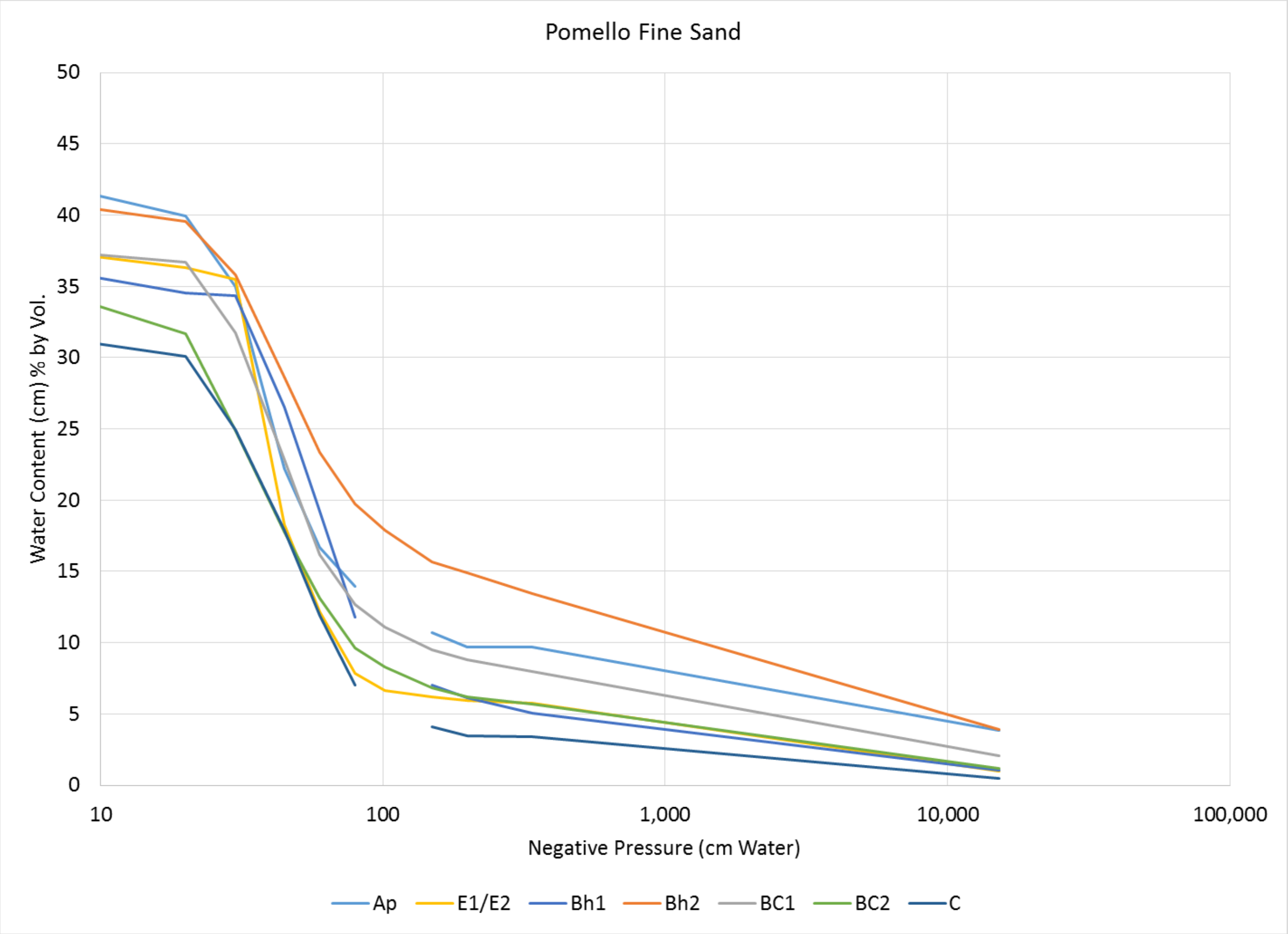


Figure 45. Water Retention Curves for a Moderately Well Drained Soil

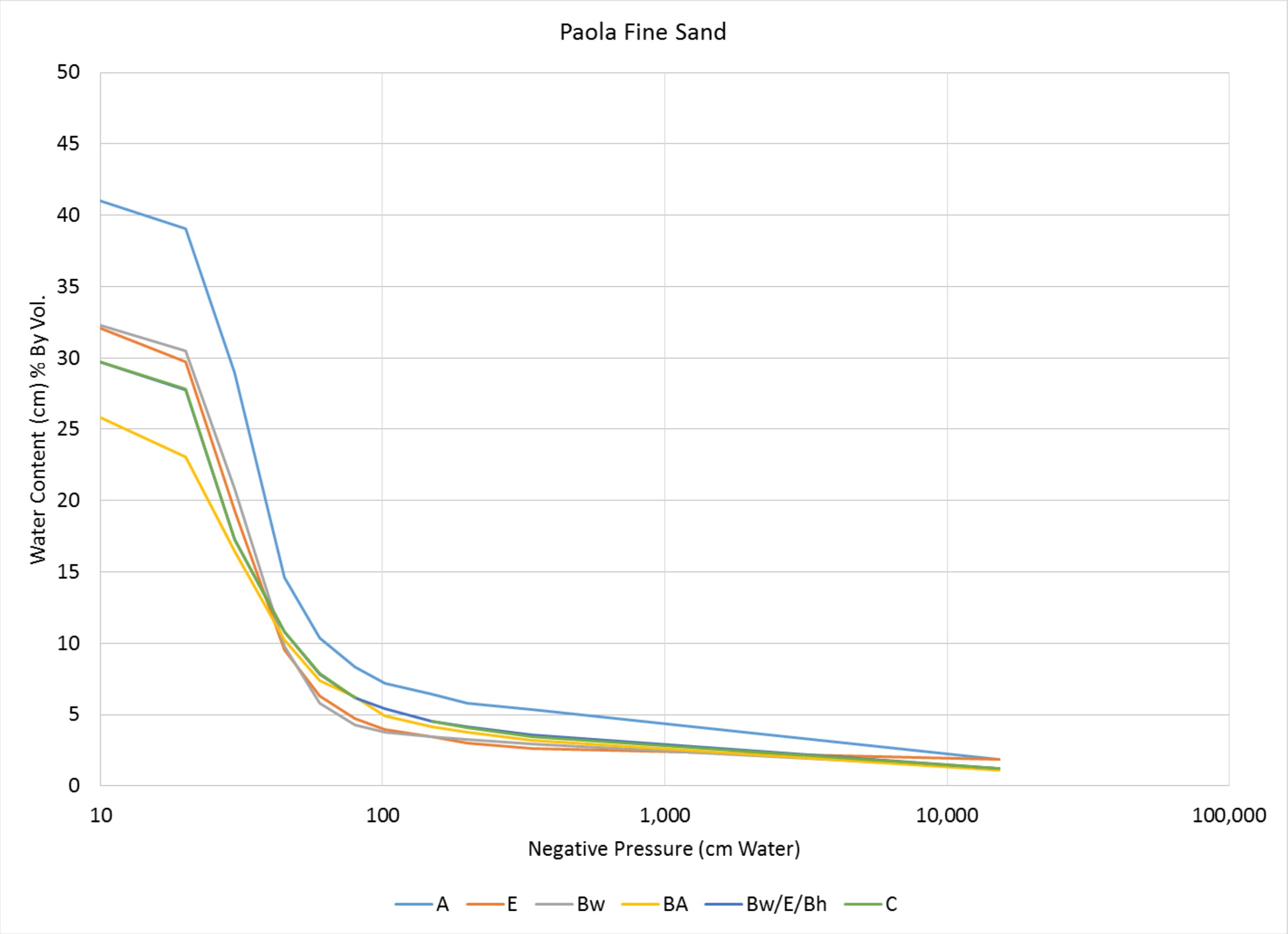


Figure 46. Water Retention Curves for an Excessively Well Drained Soil

As shown in the previous figures and tables, the soils data within the Existing-LSM domain are highly variable with respect to the spatial position and hydraulic properties (saturated/unsaturated) of each soil. Due to the complexity of the unsaturated zone within a watershed, the benefits of using an integrated model with the ability to capture the fluctuations within the saturated and unsaturated zones are numerous. MIKE SHE provides users with the ability to simulate the hydrologic response of each zone (saturated/unsaturated), is an important tool in understanding the hydrologic cycle of a watershed, and provides the necessary data for the simulation and determination of each component individually and as a whole.

3.1.11 Saturated Zone

When refining a model grid from 1500-ft to 375-ft, every layer in the model has to be accounted for with the refined grid over the entire model domain. This means that file sizes become larger and as a consequence, the model run times also increase with reduced or refined grid cell sizes. The MIKE SHE saturated zone was revised to contain four layers to reduce computational burdens and simulation run times. The Existing-LSM Saturated Zone consists of the following layers:

- Surficial Aquifer
- Tamiami Confining Unit (CU)
- Lower Tamiami Aquifer
- Upper Hawthorn Confining Unit (CU)

The hydraulic properties of each layer (aquifer or confining unit) were not changed from the CC-ECMv2 model, only the total number of computational layers reduced. This is scientifically appropriate, as the purpose of the model is not to account for water supply from the Sandstone or other deep aquifers, but rather to account for the volume and timing of surface water flows to the Rookery Bay Estuary. While surficial aquifer and other "shallow" aquifers may contribute to the water flowing through Henderson Creek or other streams within the Existing-LSM domain, water from the deeper aquifers (i.e., Sandstone) is not a primary source of surface water runoff. As such, the explicit simulation of these water supply aquifers and associated confining units was not necessary. MIKE SHE allows the user to define the computational layers within the saturated zone parameterization, and from the calculation layers a boundary condition was applied to the Upper Hawthorn (CU) (The deepest layer in the Existing-LSM). This boundary condition was chosen as the Upper Hawthorn (CU) was shown to be the most hydraulically restrictive layer in the model. As such, a time series .DFS2 file of groundwater elevations was extracted from the CC-ECMv2 model and applied as a variable head boundary at the Upper Hawthorn CU to allow for the variability and fluctuations of the overlying aquifers to be simulated appropriately with respect to the water elevations of the deeper layers. For example if an inappropriate boundary condition was applied to the lower aquifers, surface water runoff could be over or under simulated depending on the elevation of the water at the boundary condition with respect to the overlying aquifer. If the boundary condition is artificially higher or lower than reality, the water will stack up and create higher runoff depths or drain to the deeper aquifer and lead to lower runoff depths. Additionally, all pumping wells at a depth below the Upper Hawthorn CU have been removed from the model domain. Thus the only remaining pumping wells within the Existing-LSM domain are Collier County wells C-26 and C-27, both of which withdraws water from the Lower Tamiami aquifer and are part of SFWMD Water Use Permit 11-00249-W. The average daily withdrawal from C-26 and C-27 from 2001 through 2013 is 0.56 and 0.53 MGD or 206 and 194 MGY respectively.

3.1.11.1 Drainage Depth

The purpose of the saturated zone drainage routine is to account for the effects of sub-grid scale drainage ditches, swales, and underdrains that are too small to represent explicitly in the MIKE-11 network. The saturated zone drainage component is used to route shallow groundwater to a surface water feature such as a stream, ditch, or canal based upon grid codes known as "Drain Codes." Drain Codes were not altered from the CC-ECMv2 model, as such no discussion will be made regarding this model parameter. However, the drain codes provide a sub-surface routing mechanism to the MIKE-11 network, where each grid code connected to a like-numbered code will route water to the surface water feature touching each unique grid code. The drainage depth specification allows the model to calculate the drainage from MIKE SHE to MIKE-11 based upon the head difference between the groundwater, and associated MIKE-11 branch, as well as determining from which saturated zone layer (aquifer) groundwater will drain.

Drainage depths are only associated with agriculture and urban land use categories, as such all other natural land uses such as forest, wetland, or marsh will not have a drainage depth associated with the area. **Table 20** lists the drainage depth in feet used for each land use category in the Existing-LSM domain. The CC-ECMv2 model used a maximum drainage depth of 1-ft for residential areas, as noted in the "HESM Internal Review of BCB – Collier County MIKE SHE/MIKE-11 Model." This maximum drainage depth was set due to the 1500-ft grid cell resolution over the CC-ECMv2 domain and the resolution leading to lower than average house pad elevations, thus a lower drainage depth was chosen to account for this discrepancy. The Existing-LSM grid-cell refinement allows for a more in depth discretization of the drainage depth grid over the domain, as can be seen in **Table 20,** residential drainage depths range from 2 to 3 ft below ground surface. **Figure 47** presents the spatial distribution of drainage depths across the Existing-LSM domain, as can be seen these values are negative while the values in **Table 20** are positive. This discrepancy is explained by the MIKE SHE model requiring a negative value to calculate drainage depths (levels) below ground surface.

Table 20. Existing-LSM Drainage Depth

Hydrologic Land Use	Drainage Depth (feet)
Citrus	4
Pasture	1
Sugar Cane/Sod	1
Truck Crops	2
Golf Course	1
Bare Ground	0
Mesic Flatwood	0
Mesic Hammock	0
Xeric Hammock	0
Hydric Flatwood	0
Hydric Hammock	0
Wet Prairie	0
Marsh	0
Cypress	0
Swamp Forest	0
Mangrove	0
Water	0
Urban Low Density	2
Urban Medium Density	2.5
Urban High Density	3

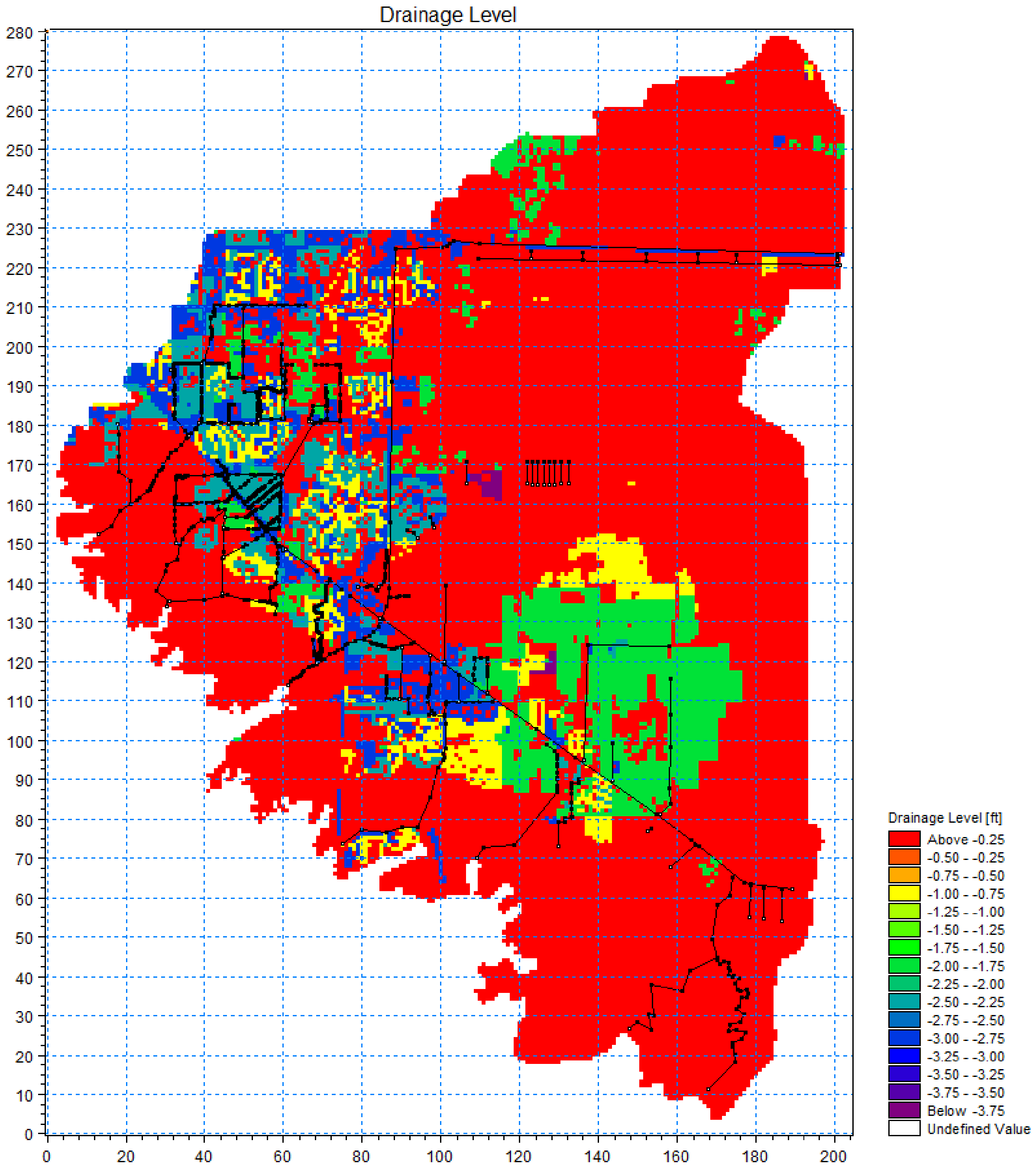


Figure 47. Existing-LSM Drainage Depth

3.1.11.2 Drainage Time Constant

The drainage time constant describes a leakage factor from the saturated zone drainage feature to the associated MIKE-11 feature. The drainage time constant of the model was updated based upon the revised soils data described in section 3.1.10. Interflow Engineering conducted a peer review of the CC-ECMv2 model and noted that the saturated drainage time constants were considerably higher (0.25 to 0.5 day^{-1}) than typical values used in similar modeling studies or the general range of values given in the MIKE SHE reference manual (0.01 to 0.1 day^{-1}). As a result of the peer review, the Existing-LSM utilizes a saturated drainage time constant based upon the revised soils distribution and drainage class. Please refer to **Section 3.7** Unsaturated Zone for a complete description of the soils data. As mentioned, the saturated zone drainage time constant is based upon the drainage classification of each soil group, from Very Poorly Drained to Excessively Well Drained. Note that the Soil Drainage Class of “Water” has a drain time constant of 0. This is because water is not drained, meaning that water is not a porous media and any fluctuations will be calculated in open channels, detention storage, or other surface water feature. As such, drainage of “Water” is determined by other calculations (infiltration, recharge, open channel flow etc.) within MIKE SHE/MIKE-11. **Table 21** presents the range of values for the Saturated Zone Drainage Time Constant used in the Existing-LSM development, as shown the values used are an order of magnitude (or more) less than those used in the CC-ECMv2 model. The SZ Drainage Time Constants have been derived from other projects using the same method, where the drainage time constant is a function of Soil Drainage Class. **Figure 48** presents the spatial distribution of the SZ Drainage Time Constant of the Existing-LSM domain, and is a replica of the Hydrologic Soil group definition as presented in Section 3.7. This is because the SZ Drainage Time Constant of the model was derived from the soil drainage class, which is how MIKE SHE delivers water from SZ Drainage to the MIKE-11 network. In other words, the SZ communicates with the Unsaturated Zone to compute the amount of SZ drainage water entering the MIKE-11 network.

Table 21. Existing-LSM SZ Drainage Time Constants

Soil Drainage Class	SZ Drain Time Constant (1/day)
Excessively Well Drained	0.01
Moderately Well Drained	0.001125
Somewhat Poorly Drained	0.00075
Poorly Drained	0.0005
Very Poorly Drained	0.00025
Water	0

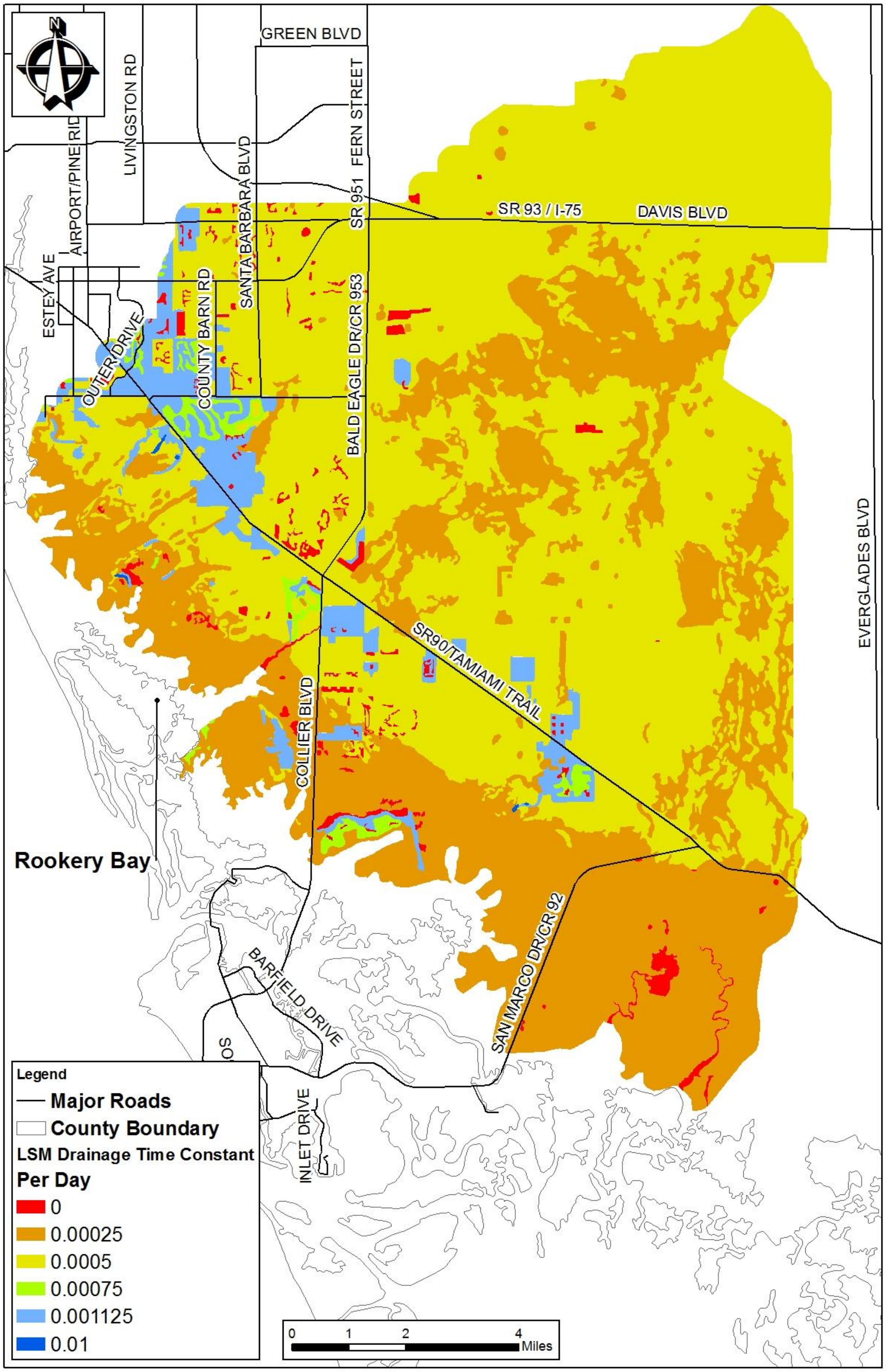


Figure 48. Existing-LSM Drainage Time Constant

3.1.12 Irrigation

MIKE SHE employs a grid (.DFS2) file of unique grid codes to represent irrigated lands, these grid codes are known as “Irrigation Command Areas” (ICA). Whether the irrigation is used for agriculture, golf courses, or urban land use categories, irrigation will not be applied to the area unless an ICA is present within the model domain. Each ICA defines how the irrigation is applied and the source of irrigation water (groundwater/surface water). MIKE SHE utilizes four ways to determine when it is appropriate to apply irrigation known as irrigation demand. For an in-depth discussion of irrigation demand please see MIKE SHE User Manual Vol. 2 Reference Guide (DHI, 2011b). The CC-ECMv2 and Existing-LSM models both use the “Maximum Allowed Deficit” method. Meaning, the model calculates the soil moisture characteristics and based upon a specified soil moisture deficit, will apply irrigation water until a specified deficit threshold is met. The Maximum Allowed Deficit for the Existing-LSM irrigation is variable for each vegetation type and related to the field capacity of the soil. It is not feasible to provide a table or discussion of each irrigated vegetation within this report, but should one choose, an in-depth review of the irrigation moisture deficit can be accessed within the MIKE SHE framework.

However, we supply this example: suppose a maximum deficit of 0.1 is chosen, and the deficit is related to the field capacity of the specific soil within each irrigation command area. That irrigation is applied when the moisture content drops below 0.1, or 10% of the assigned value of the field capacity of the soil. Irrigation ceases when the moisture deficit has been calculated to be the assigned moisture deficit stop value (usually zero), or the moisture content of the soil has been returned to field capacity (the moisture deficit stop also ranges from 0 to 1). In simple terms, if the user selects a moisture deficit stop value of 0, then the model will apply irrigation until 100% of the field capacity moisture content of the soil is reached. Field capacity is defined as the moisture content of the soil due to gravitational forces, or the moisture content within the soil after gravity drainage has occurred. An in-depth definition of field capacity is provided herein:

“Field Capacity

> ***The field capacity is the amount of water remaining in the soil a few days after having been wetted and after free drainage has ceased. The matric potential at this soil moisture condition is around - 1/10 to – 1/3 bar. In equilibrium, this potential would be exerted on the soil capillaries at the soil surface when the water table is between 3 to about 10 feet below the soil surface, respectively. The larger pores drain first so gravity drainage, if not restricted, may only take hours, whereas in clay soils (without macropores); gravity drainage may take two to three days. The volumetric soil moisture content remaining at field capacity is about 15 to 25% for sandy soils, 35 to 45% for loam soils, and 45 to 55% for clay soils.”*** **From: http://nrcca.cals.cornell.edu/soil/CA2/CA0212.1-3.php**

As this study was not designed to investigate water supply, but rather to quantify the volume and timing of fresh water deliveries to the Rookery Bay, only limited efforts were applied in refining and checking the irrigation component of the model. It has been generally assumed the CC-ECMv2 irrigation command areas and other previously-developed irrigation parameters were appropriate. For an in-depth discussion on the CC-ECMv2 irrigation parameters, refer to “Collier County Watershed Model

Update: Element 3 Task 6, ECM Agricultural Irrigation." It is understood that irrigation can represent a major component of the water budget in a watershed; as mentioned in **Section 3.1.11**, the aquifers pumped for water supply and irrigation have been removed, additional irrigation command areas (32, 42, 52, 62, 72) are outside of the Existing-LSM domain and have been removed.

The irrigation component of the model was adjusted to reflect the grid-cell refinement and associated ICA boundary changes when refining each area. The CC-ECMv2 was parameterized using a 1500-ft grid resolution which, when refined to 375-ft cell size, created a blocky shape that did not always provide an accurate representation of an irrigated area. For example, the grid-cell refinement created irrigation command areas that were applying water to streams, ponds, roadways, rooftops, and other impervious surfaces. Care was taken to adjust the irrigation command area boundaries to reflect lands actually receiving irrigation. This was accomplished by reviewing aerial photographs and the SFWMD Water Use Permit polygons in concert. **Figures 49** and **50** present the ICAs in two configurations, both have a 375-ft grid-cell resolution and cover the Existing-LSM domain, where **Figure 50** presents the ICAs after refinements were made. Additionally, the maximum rate of irrigation was adjusted to 0.25ft^3/s for ICA codes 02, 12, and 22, which are largely reflective of golf courses and other agricultural crops. This was done in reference to the same SFWMD/HESM review mentioned in Section 3.8.1 to allow for a maximum rate of about 1 in/day to these land use categories (0.25ft^3/s = 1.84 in/day when applied to the Existing-LSM 375ft grid cell).

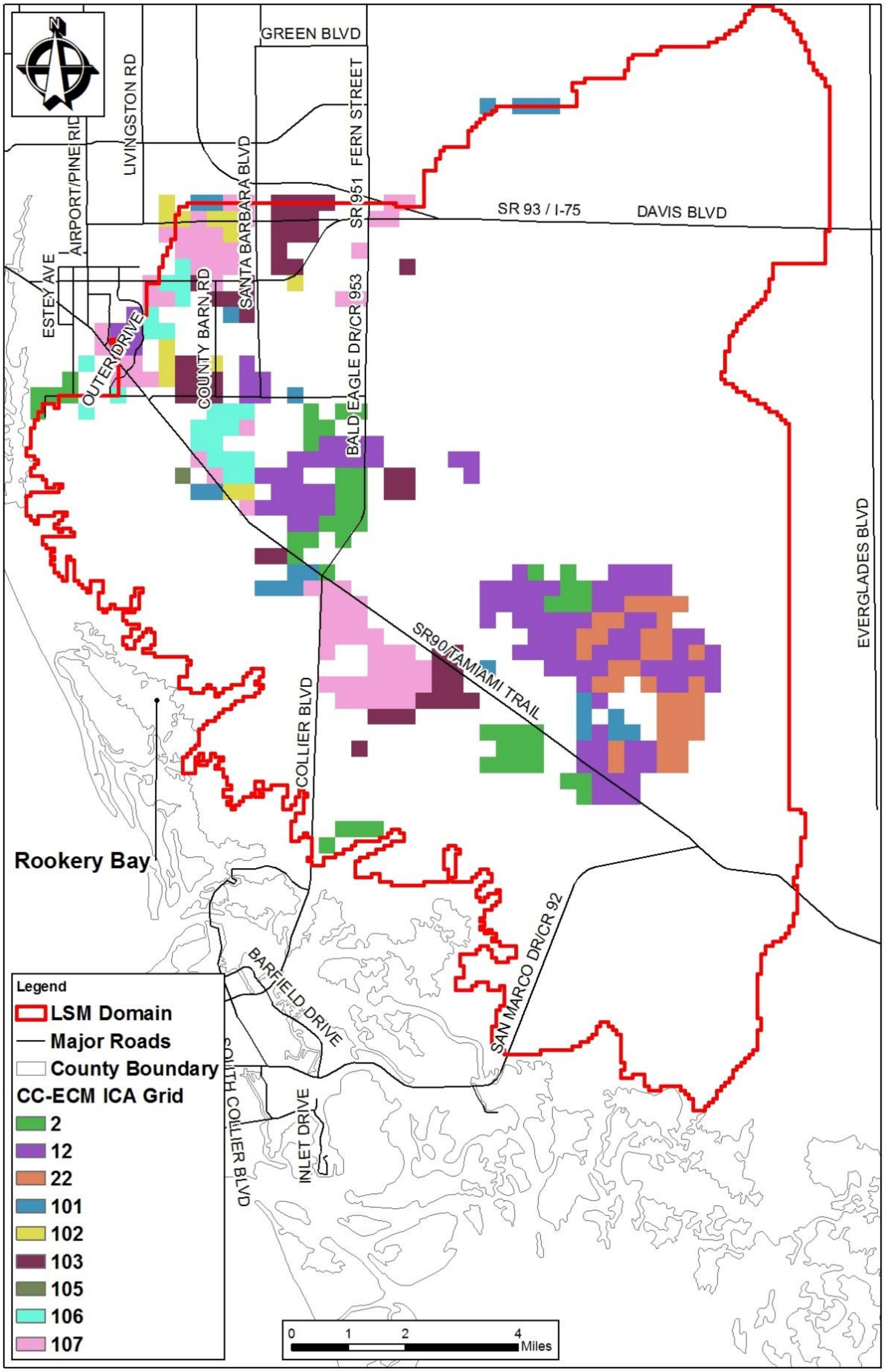


Figure 49. CC-ECMv2 ICA within Existing-LSM Converted From 1500-ft to 375-ft Grid Cells Without Refinement

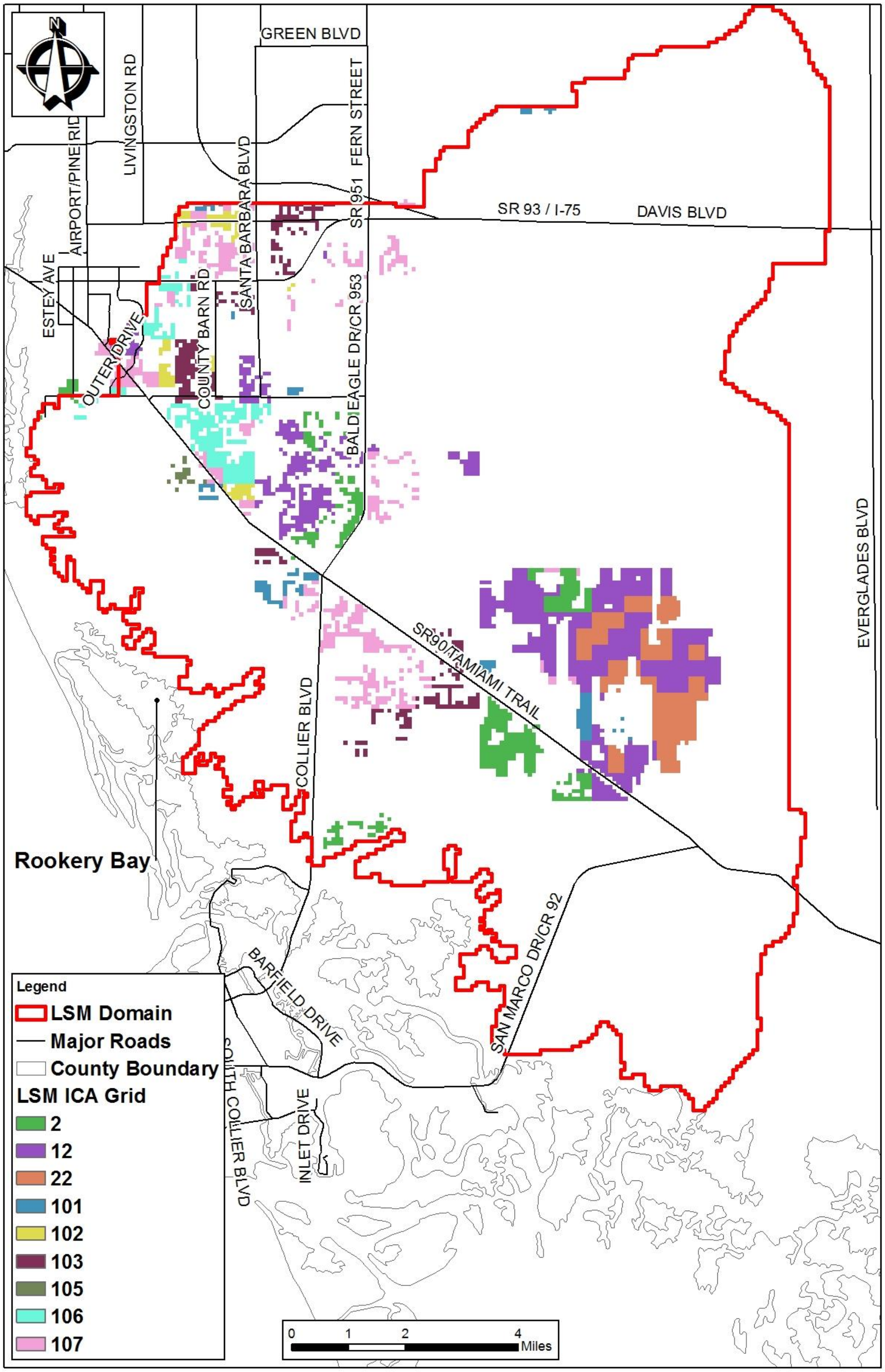


Figure 50. Existing-LSM ICA Converted From CC-ECMv2 1500-ft to 375-ft Grid Cells With Refinement

3.2 Task 2.3. MIKE-11 Updates and Revisions

As detailed in Task 2.2, the CC-ECMv2 was developed to create boundary conditions for the Existing-LSM. Time series files of stage from selected locations were applied to the MIKE-11 portion of the model. The entire MIKE-11 network (streams, canals, hydraulic control structures) was revised to account for the Existing-LSM domain, where any section of a MIKE-11 branch (stream, ditch, canal, etc.) not within the domain were removed. Additionally, all control structures (weir, culvert, gate, etc.) were also removed from the network if outside of the Existing-LSM domain. Careful consideration was paid to the location of natural or man-made watershed divides; for example, the northwestern boundary was shown to be at the weir at Haldeman Creek, providing a stage dependent boundary condition that allows water to flow south and remain within the Existing-LSM domain or exit over the top of the weir and flow west via Haldeman Creek and ultimately to Naples Bay (north of Rookery Bay).

3.2.1 MIKE-11 Boundary Locations and Conditions

The MIKE-11 time series boundary locations derived from the CC-ECMv2 model are presented in **Figure 51**. As shown, there are four points (yellow circles) where the Existing-LSM model has a time varying .DFS0 file of water levels from the CC-ECMv2. All other channels (Lely Main, Lely Manor, Henderson Creek Main Branch, Henderson Creek East Branch, Belle Meade, US 41 Outfall Swale), have the same boundary condition of the average tidal elevation from the Naples Tide Gage used in the CC-ECMv2 model. From these boundary locations, water is allowed to flow out of the model domain through the surface water network.

Table 22. Average Annual Flow from CC-ECMv2 at Existing-LSM Boundary Locations

Boundary Location (MIKE-11 Branch, Chainage)	Average Annual Flow
Northeastern Boundary (I75N-1, 33603.32)	12.20
Northeastern Boundary (I75S-1, 30675.85)	0.20
Northwestern Boundary (HALDEMAN_CREEK-00, 3280.84	2.19
Southeastern Boundary (TAMIAMI1, 47695.21)	1.15

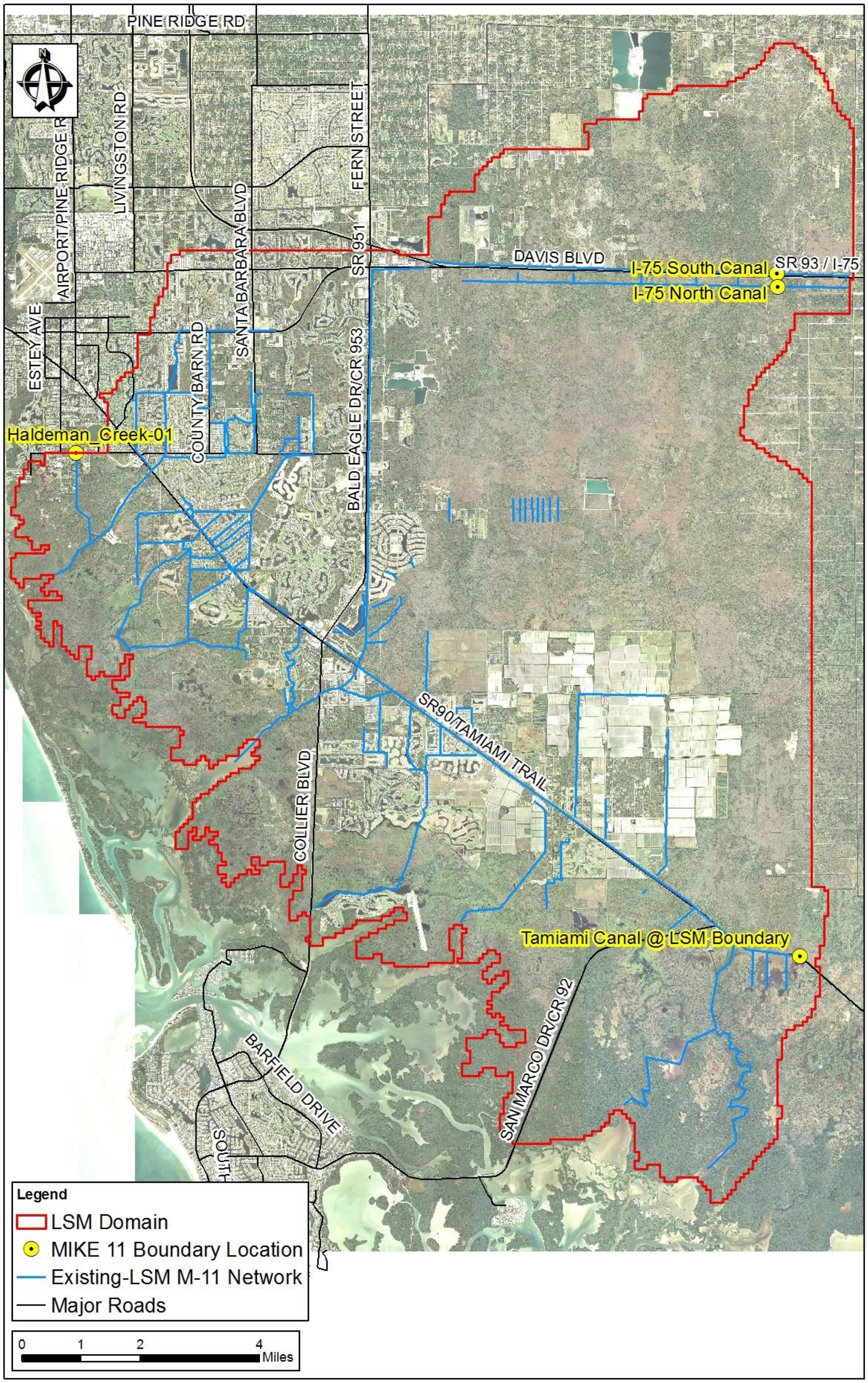


Figure 27. MIKE-11 Boundary Conditions from CC-ECMv2

3.2.2 Surface Water Network

The surface water network was modified based upon recent developments that would affect the volume and timing of fresh water deliveries to Rookery Bay, or other notable changes in the drainage characteristics within Collier County. The following sections detail the revisions and updates to the MIKE-11 network. **Table 23** lists a comparison of the components of the MIKE-11 network for the CC-ECMv2 and Existing-LSM models. As shown, the hydraulic network was reduced substantially, which is not unexpected due to the reduction in area of the model domain between the Existing-LSM and previous model.

Table 23. Existing-LSM Comparison of MIKE-11 Components to CC-ECMv2 Model

Model	Branches	Operable Gates	Culverts	Bridges	Weirs	MIKE SHE Links
CC-ECMv2	289	83	261	31	168	235
Existing-LSM	83	18	75	0	29	59

3.2.2.1 Winding Cypress Subdivision

The Winding Cypress Subdivision is a large residential/commercial development including provisions for golf courses, and is located off C.R. 953 about 1 mile south of Rattlesnake Hammock Road. **Figure 52** presents the location of the Winding Cypress development within the Existing-LSM domain. The development has many detention areas (lakes), and currently only the northern portion of the development has been built. As such, only the areas associated with the storage and already developed areas have been included in the MIKE-11 network. According to the permit (11-021312-P), these two areas are known as Drainage Area 1 (DA-1) and Drainage Area 2 (DA-2) and are modeled as a single MIKE-11 branch. **Figure 53** presents the master site plan, where the two aforementioned drainage areas are shown. The permit provides information on all drainage features within the Winding Cypress development, including lake areas, typical cross sections and control structure details for the site. Along with control structure (weir and WQ "notch") outfalls, culverts with tide-flex one way flow valves allow water to flow from the Bell Meade Flow-way or slough system back into the Winding Cypress water management system. The culverts were parameterized in MIKE-11 by placing a one-way flow valve on each culvert and increasing the entrance and exit loss coefficients to account for hydraulic restriction associated with the tide-flex valves. Tide-flex valves provide a directional control where the upstream water levels must exceed downstream water levels by a specified gradient before flow in a positive direction will occur. This is vastly different for an "un-valved" culvert where water will flow freely (either direction) based on gradients. **Table 24** lists the details of each drainage area within the development as parameterized in the MIKE-11 network.

Table 24.Winding Cypress Drainage Details

Drainage Facility	Cumulative Storage (ac)	Weir Notch FT-NAVD88	Weir Notch Width (ft)	Weir Crest FT-NAVD88	Weir Width (ft)	Tide-Flex Invert FT-NAVD88
DA-1	112	5.5	3.34	6.1	5.6	-1.5
DA-2	78	6.2	2.17	6.7	3.5	-0.8

Note: Each DA has a broad crested weir and associated "notch" or bleeder providing attenuation and water quality treatment exceeding the required 1.5 inches over the entire development. Each Tide-Flex culvert is placed on a 4-ft x 4-ft culvert.

Based on the cross section provided in the permit file, DA-1 and DA-2 have been standardized to be 7-ft deep and 750-ft wide with variable lengths to account for the cumulative storage provided in each. The upstream and downstream boundary conditions are set as closed to allow for the accounting of surface water storage and runoff due to precipitation and groundwater inputs and ET outputs.

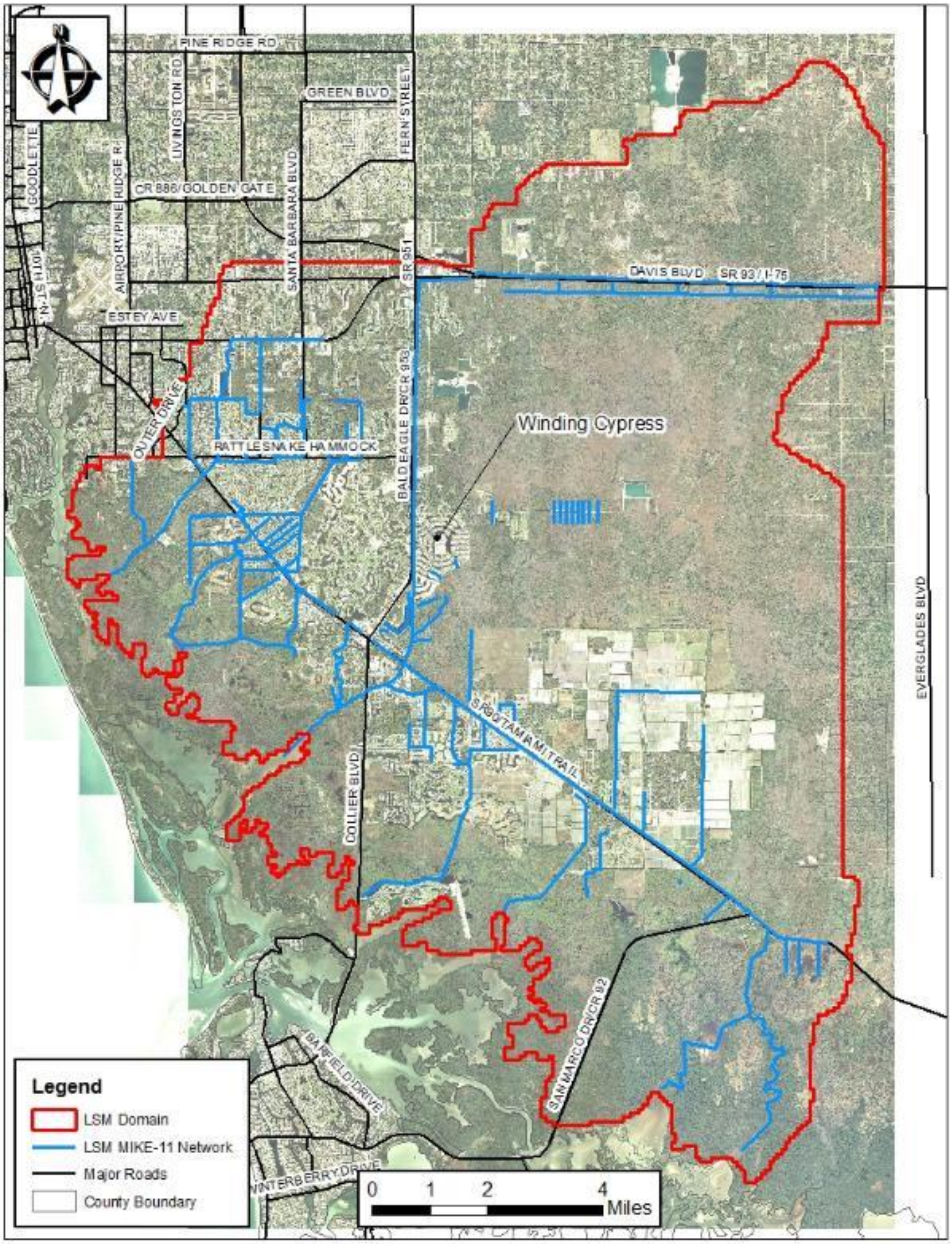


Figure 52. Location of Winding Cypress Development within Existing-LSM Domain

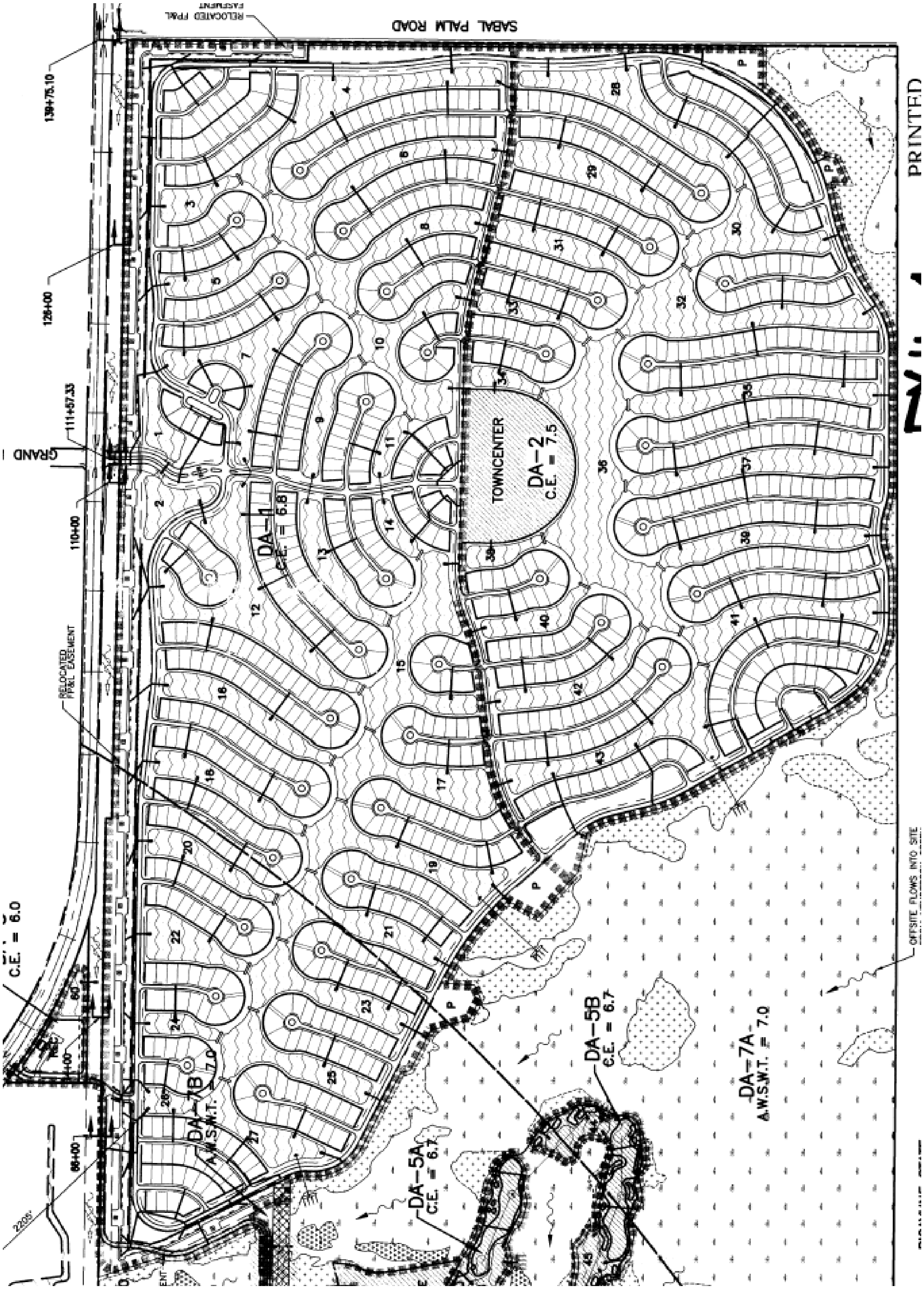


Figure 28. Winding Cypress Master Site Plan (From Permit File 000201-12_PermitFileHistoryMaps_498695)

In association with the conceptualization of the Winding Cypress development was the addition of three branches, representing the conveyance from the Belle Meade Flow-way to Henderson Creek. These branches were added after reviewing the available LiDAR data in conjunction with the Winding Cypress permit plans and noting over 34 culverts allow water to flow from east to west under an FP&L easement, which has been re-aligned through the Winding Cypress Development. Conversations with SFWMD staff indicate that this connection to Henderson Creek can provide a large amount of flow from the Belle Meade Flow-way to Henderson Creek. Both the culverts and the weir have been represented in the model as the top of the FP&L road surface. **Figure 54** presents the alignment of the FP&L easement, and addition of three branches representing the conveyance features between theBelle Meade Flow-way andHenderson Creekbranch within the Existing-LSM domain. As shown, the FP&L branch runs north-south and bisects the connection of the Belle Meade Flow-way to Henderson Creek.

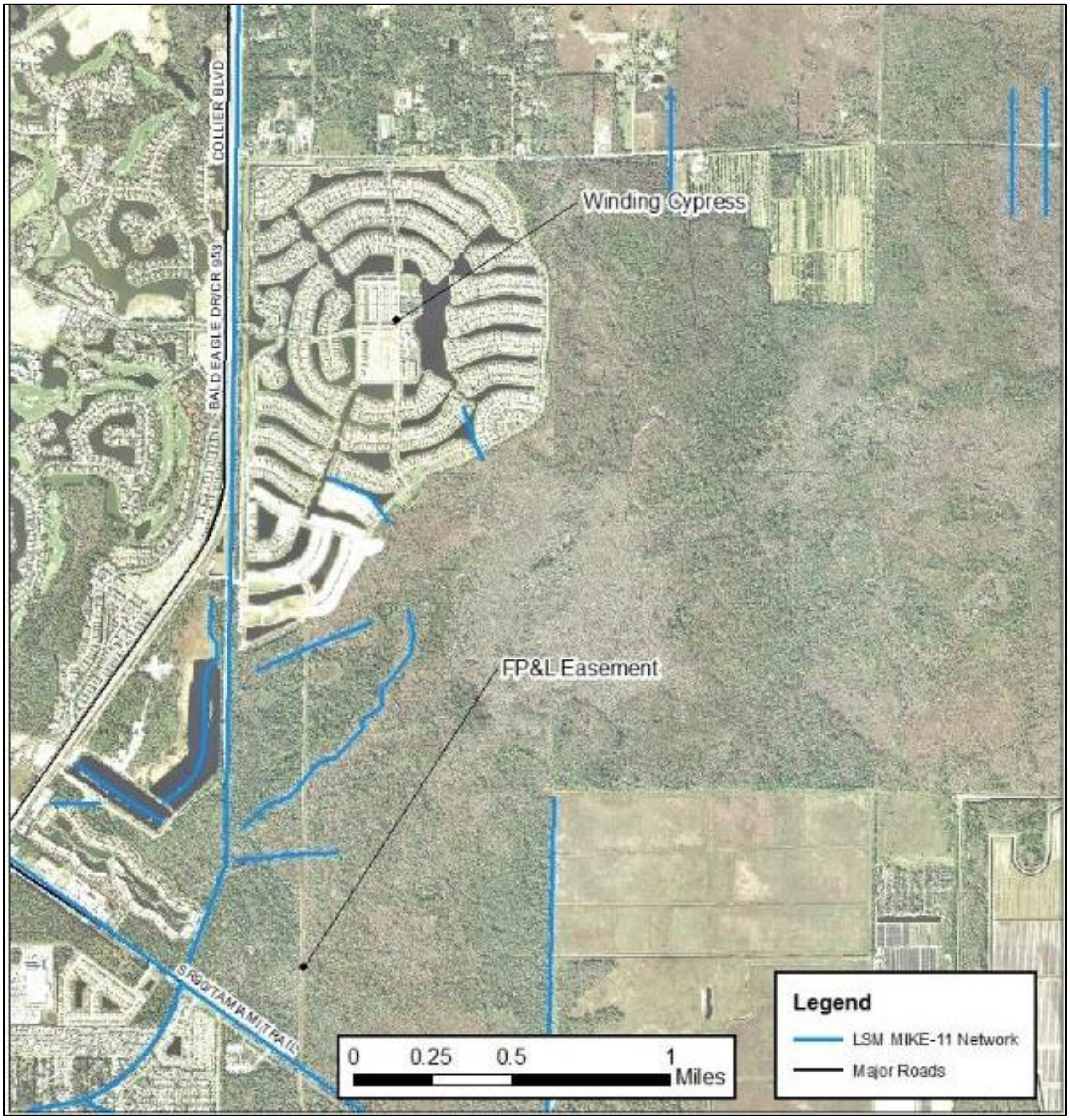


Figure 54. FP&L Easement and RevisedBelleMeadeto Henderson Creek Connections

While 30 culverts exist under the FP&L easement, 8 are represented in the Existing-LSM MIKE-11 parameterization, of which 2 are 18-inch diameter culverts and the remaining 6 are 36-inch diameter culverts (all set to an assumed invert of 3.5 FT-NAVD88 as no inverts were provided in the plan set). **Figure 55** presents the alignment of the eight culverts placed in the MIKE-11 network: culverts 21 and 25 (18-in dia.), 22 – 24, and 26 – 28 (36-in dia.). FP&L culverts 21 – 28 were included in the model due to the proximity along the easement, and corresponding cross sections were developed for the branches determined to be tributary to Henderson Creek from depressions within the Belle Meade Flow-way.

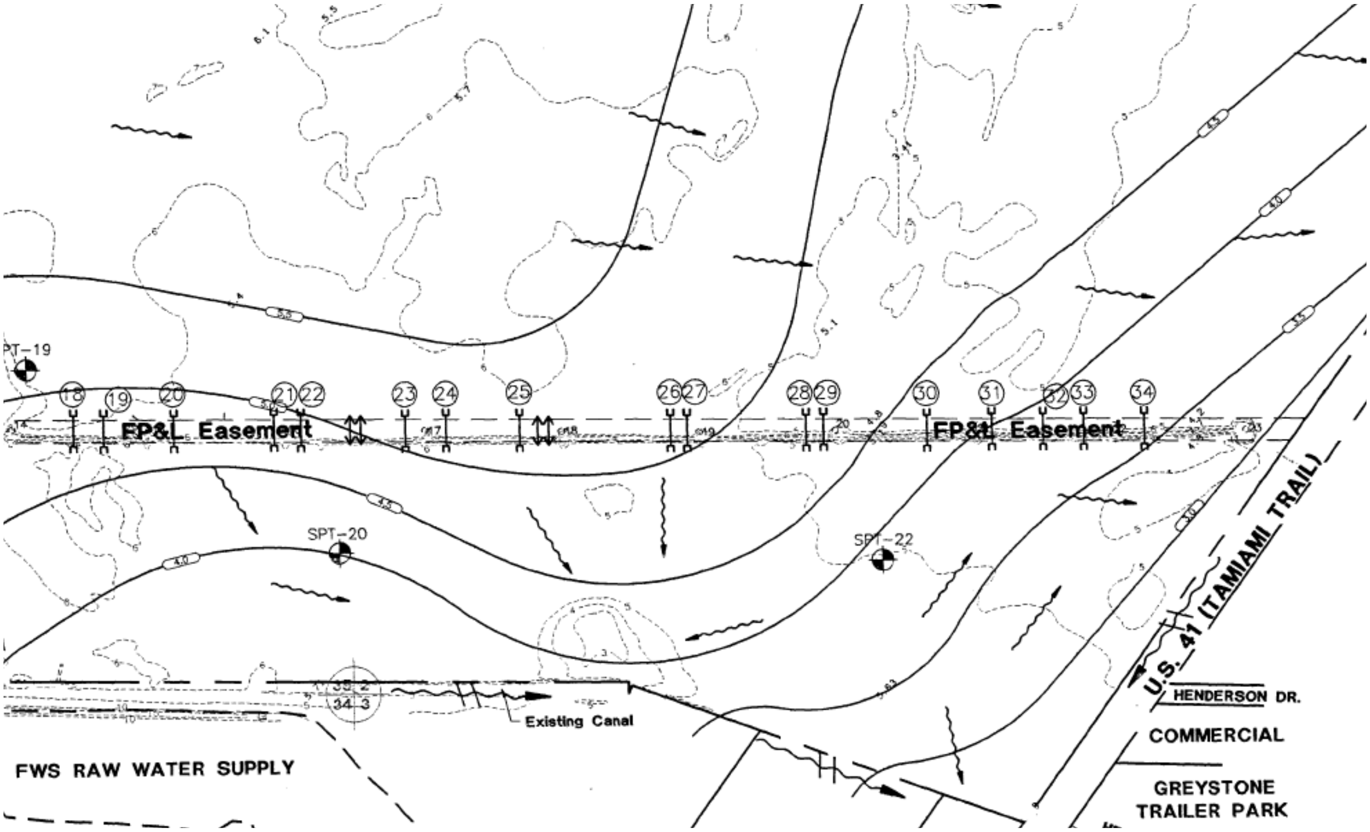


Figure 29.FP&L Easement and Culvert Locations Near Connection to Henderson Creek (Modified From: 000201-12_PermitFileHistoryMaps_590581: p.9/22)

The addition of the Winding Cypress Development, and conveyance features from the Belle Meade Flow-way to Henderson Creek MIKE-11 branch, and culverts associated with the FP&L easement have improved the Existing-LSM's representation of the surface water system.

3.2.2.2 Sabal Palm Road Culverts

As mentioned in **Section 3.6.2**, the Separated Overland Flow area file was revised over the entire Existing-LSM domain, and notably for the area north of Sabal Palm Road (Between the I-75 Canal system and Sabal Palm Road). This allows the MIKE SHE model to calculate the area north of Sabal Palm Road separately from other areas in the model with respect to overland flow. Creating this separated flow area essentially creates a "glass wall" where surface water can flow to each separated flow area boundary. Once water reaches the boundary of each separated overland flow area, it will stack up unless there is a MIKE-11 branch to convey to surface water to other portions of the model (adjacent separated flow areas), or another method of outflow is calculated for water to be removed from a separated flow area such as infiltration to the unsaturated zone with eventual transfer to the saturated zone, or losses to ET.

It was important to create a separated flow area for Sabal Palm Road, because the top of roadway is about 1 – 1.5 ft higher than the surrounding land (based on survey data in the plan and LiDAR). The previous CC-ECMv2 model had a long branch allowing water to flow from the I-75 canal system to the US-41/Tamiami Canal. This branch was removed from the Existing-LSM model because review of available LiDAR and aerial photograph data does not indicate a defined channel in the area. **Figure 56** presents the MIKE-11 network (CC-ECMv2 and Existing-LSM) and LiDAR data for the area north of Sabal Palm road. The figure indicates that the area is a patchwork of depressions and interspersed upland mounds with a central depression about 1.5 miles east of the Winding Cypress development. The flow of water north of Sabal Palm Road is largely south to southwest through very dense vegetation. The modeling team believes most of the flow north of Sabal Palm Road accumulates at the depression shown in **Figure 56**, and either over-tops the road or flows through the newly constructed culverts. Consequently, most of the culverts under Sabal Palm Road lie in the depression shown in **Figure 56**.

As evidenced from **Figures 51, 52, and 54,** as compared to **Figure 17** in **Section 2.2.2,** it is apparent that the Belle Meade Flow-way is not represented in the 1-D portion (MIKE-11) of the model. Rather, the Belle Meade Flow-way is being represented in the 2-D portion of the model as overland flow. This representation of the Belle Meade Flow-way explicitly in the 2-D portion of the model was accomplished by the finer grid-cell resolution of 375-ft for the LSM simulations, allowing for accurate calculations of sheet flow across the flow plane of the Belle Meade Flow-way.

Figure 57 presents the CC-ECMv2 and Existing-LSM MIKE-11 networks along with aerial photographs to give the reader an idea of the total length of the branch that was removed from the previous model and to compare with the current Existing-LSM MIKE-11 set up. As evidenced, each new MIKE-11 branch in the Existing-LSM allows water to drain from upstream of Sabal Palm Road to downstream. In other words, each branch is long enough to convey water from the separated flow area north of Sabal Palm Road, to the separated flow area south of Sabal Palm Road, thus negating the glass wall effect described earlier in this section.

In total, 12 culverts have been placed in nine separate MIKE-11 branches (**Figures 56** and **57**), where three of the branches contain 2 culverts and the remaining six contain 1. The Existing-LSM was set up this way based on the plans from the SFWMD entitled "Sabal Palm Road Culverts Site Improvement Plans" dated Nov. 2012, revised March 2013. These plans are part of SFWMD Permit # 11-03312-P "Hacienda Lakes," and are provided in the permit as wetland mitigation requirements. The plans call for an FDOT three-grate Type H inlet and outlet structure on each culvert. The modeling team determined that this was to prevent sedimentation of the culverts and has elected not to model these inlets individually because they do not reduce the total conveyance at each structure and to improve model stability. Therefore, only the culvert at each structure location has been included in the Existing-LSM as a 48inch diameter reinforced concrete pipe (RCP). **Table 25** lists the top of grate elevation for each inlet and invert of each culvert. Please note all inverts in the MIKE-11 model are in FT-NAVD88, while the plans are in FT-NGVD29.

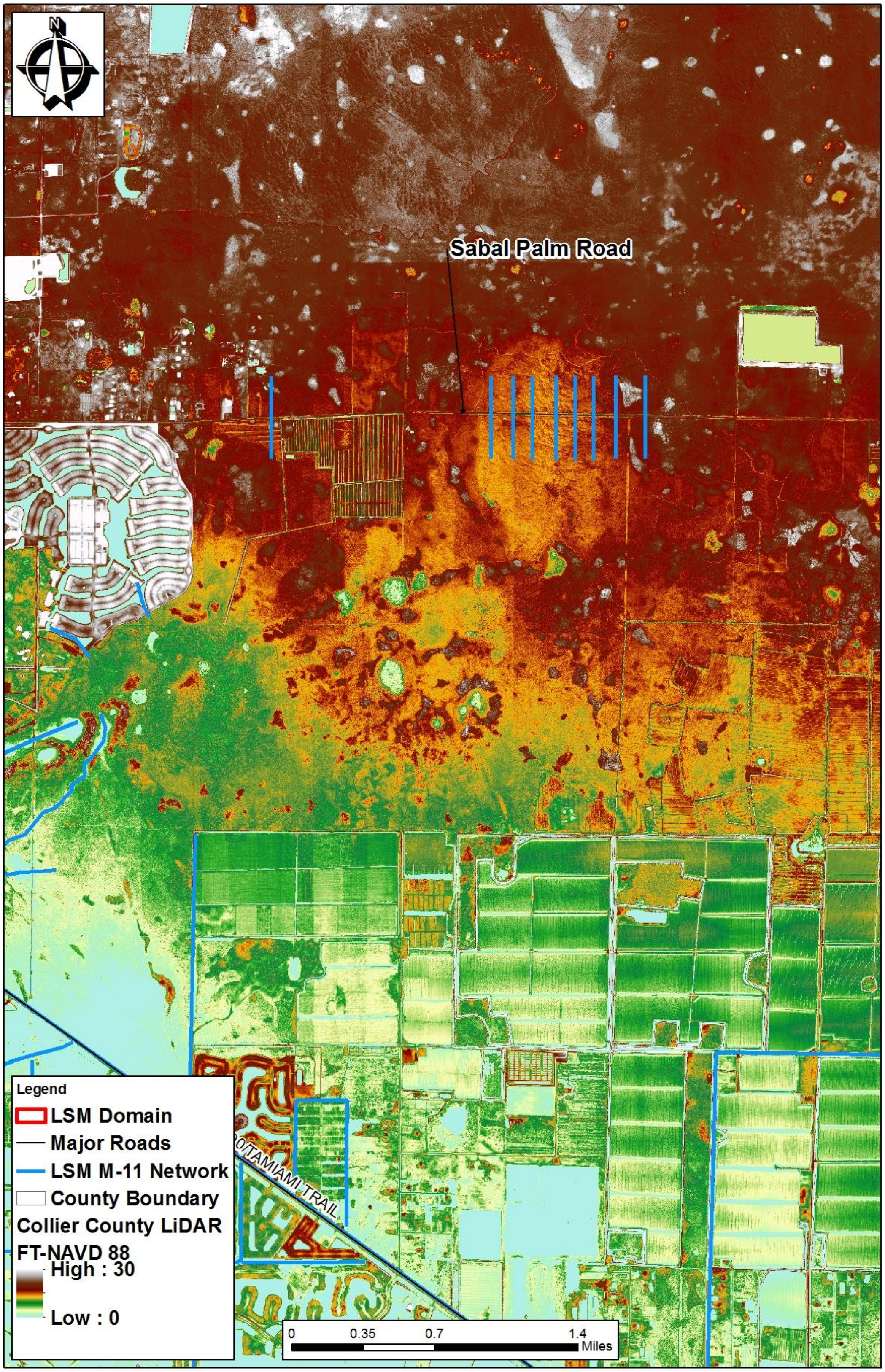


Figure 56. Topography near Sabal Palm Road (Note: Most Culverts Located in Central Depression)

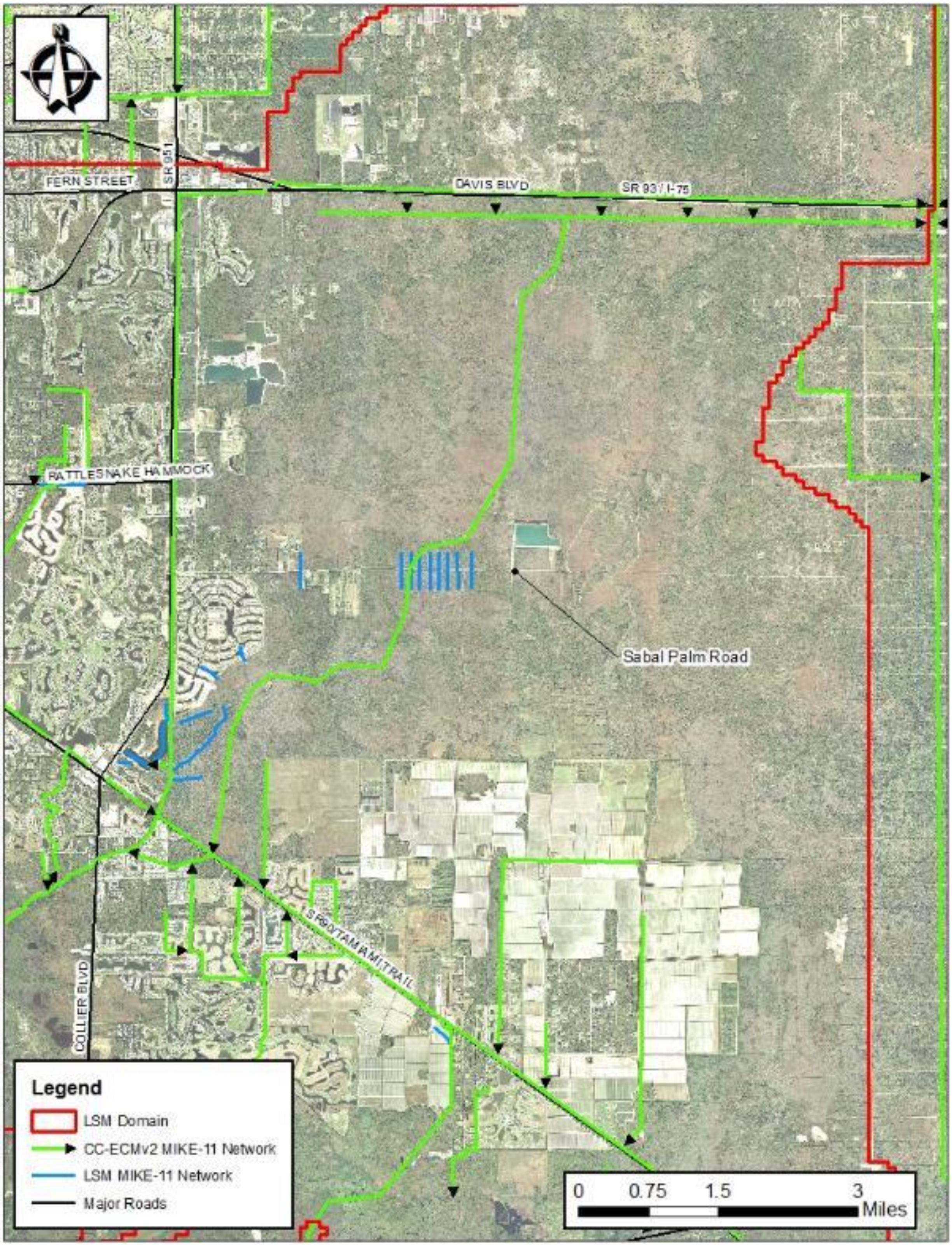


Figure 57. MIKE-11 Configuration Differences (CC-ECMv2 vs Existing-LSM)

Table 25. Sabal Palm Road Structure Details

SP#	FT-NGVD29		FT-NAVD88		Diameter (ft)	Roughness Coefficient (Manning's n)
	Grate Inlet	Culvert Invert	Grate Inlet	Culvert Invert		
1	7.2	0.54	5.904	-0.756	4	0.013
2	7	0.54	5.704	-0.756		
3	7.3	1.18	6.004	-0.116		
4	7.3	1.18	6.004	-0.116		
5	7.3	1.18	6.004	-0.116		
6	7.3	1.18	6.004	-0.116		
7	7.1	1.18	5.804	-0.116		
8	7.1	1.18	5.804	-0.116		
9	7.3	1.18	6.004	-0.116		
10	7.1	1.18	5.804	-0.116		
11	7.4	1.28	6.104	-0.016		
12	7.2	1.28	5.904	-0.016		
13	7.4	1.28	6.104	-0.016		
14	7.2	1.28	5.904	-0.016		
15	6.4	0.28	5.104	-1.016		
16	6.2	0.28	4.904	-1.016		
17	5.8	-0.32	4.504	-1.616		
18	5.6	-0.32	4.304	-1.616		
19	5.9	-0.22	4.604	-1.516		
20	5.7	-0.22	4.404	-1.516		
21	6.3	0.18	5.004	-1.116		
22	6.1	0.18	4.804	-1.116		
23	7	0.88	5.704	-0.416		
24	6.8	0.88	5.504	-0.416		

Note: SP# refers to the structure # located on the plan set from SFWMD Permit # 11-03312-P

Culvert locations were determined by georeferencing (incorporating the image of the plans to GIS and referencing to known geographical locations common to the plans and GIS) the permitted plans and digitizing the MIKE-11 branches for each "SP" structure or group of structures. It was not feasible to place the plan sheets within this document because they would not be legible at this scale. However, **Figure 58** presents an excerpt of the plans. The plans are available through the SFWMD's ePermitting website and can be accessed by searching for Permit # 11-03312-P, where page 33/35 contains the culvert location details.

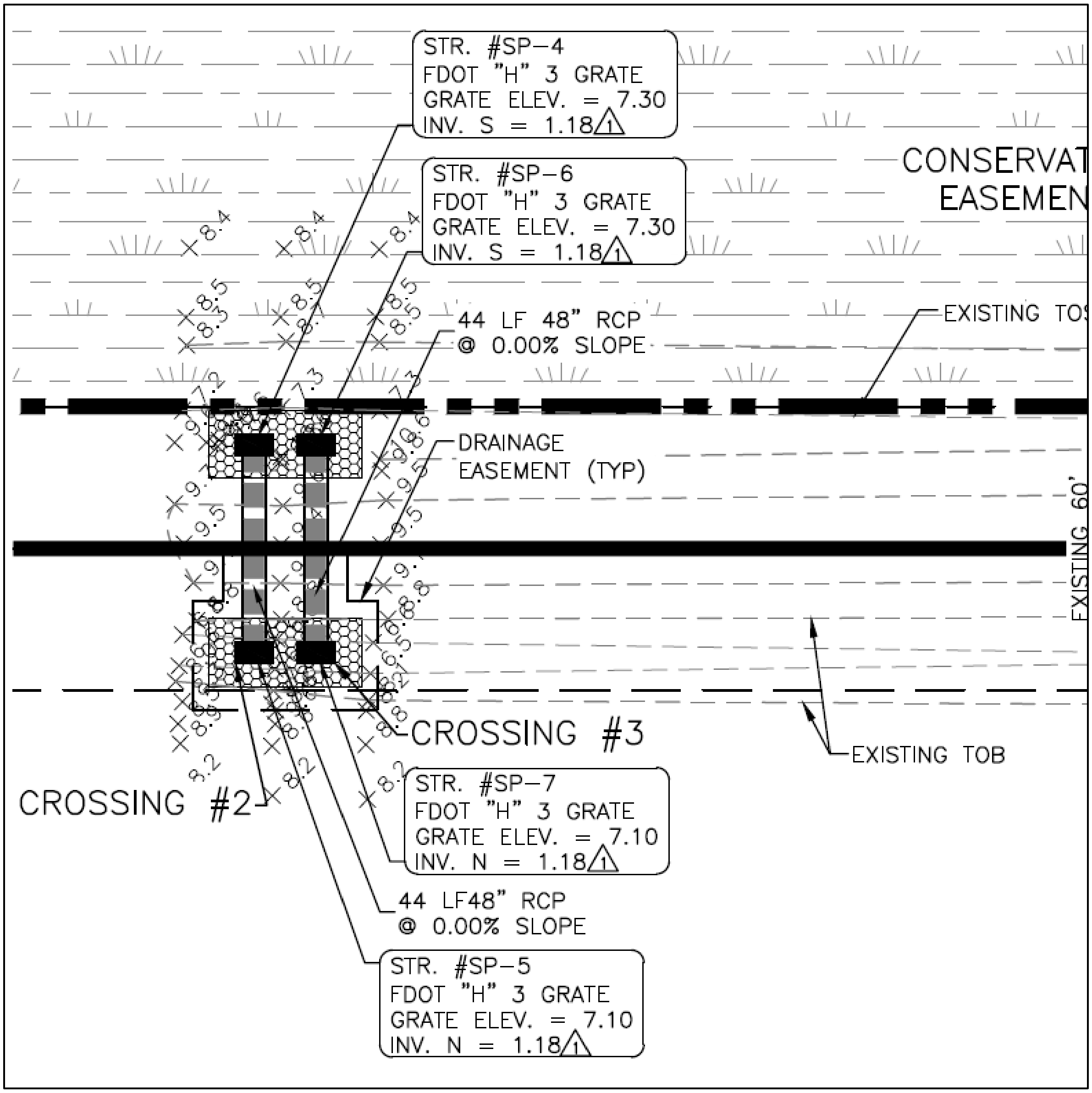


Figure 58. Representative Sabal Palms Road Crossing (#2) Image Modified From Hacienda Lakes Permit Plans.

3.2.3 Marco Island Utilities

Marco Island Utilities (MIU) provided measured withdrawals from Marco Lakes from 2002 through 2012. The measured data was the cumulative monthly withdrawal from the Marco Lakes for water sent to Marco Island for water supply and that sent to the Aquifer Storage and Recovery (ASR) system for recovery at a later time. The monthly data was processed to a daily average in Million Gallons per Day (MGD). **Figure 59** presents a graph of the average daily withdrawals from Marco Lakes A&B, representing the water sent to Marco Island for treatment to potable water supply and water delivered to the ASR system for recovery at a later date. **Table 26** lists the comparison of cumulative yearly withdrawal in Million Gallons per Year (MGY), between permitted and measured withdrawals from Marco Lakes.

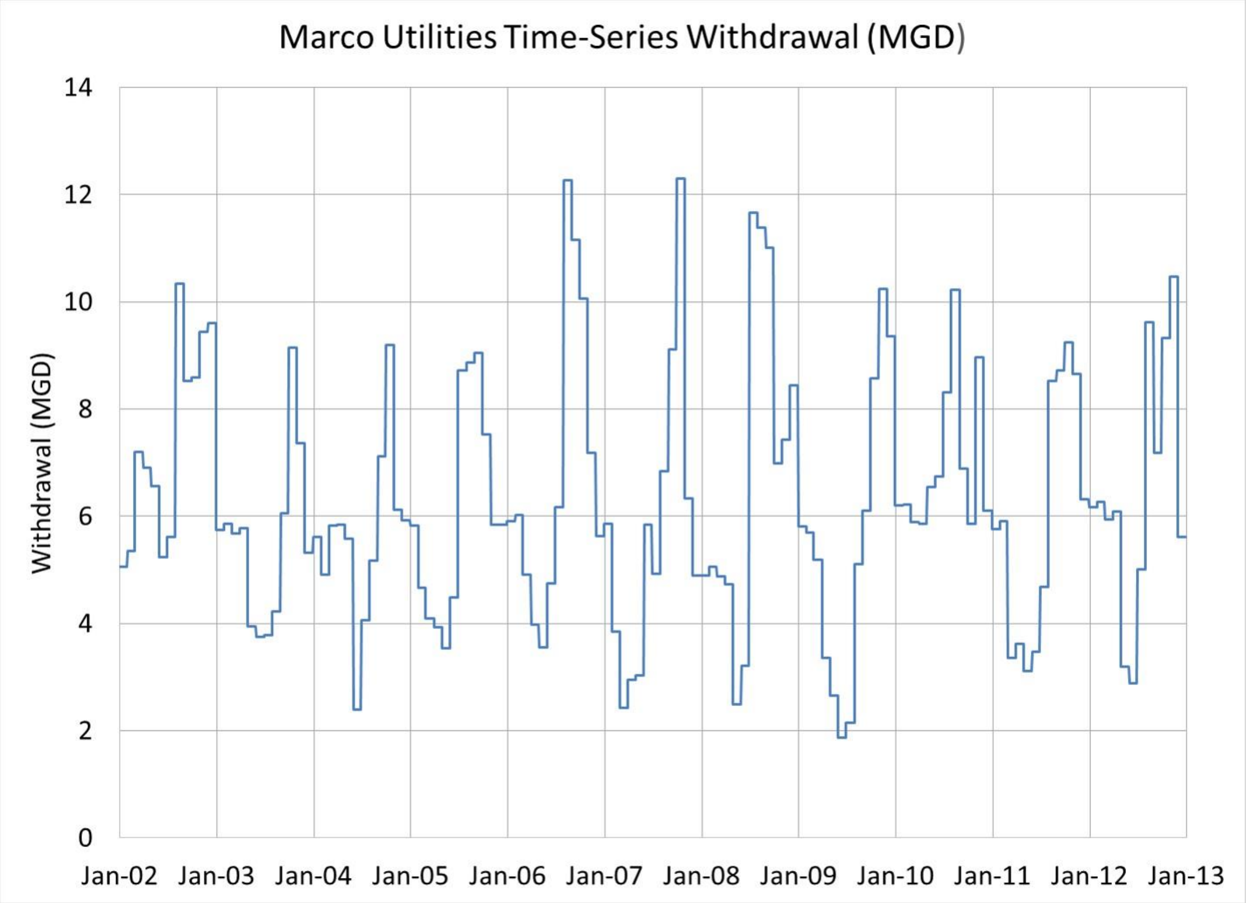


Figure 30. Average Daily Withdrawal From Marco Lakes A&B

Table 26. MIU Yearly Withdrawal From Marco Lakes A&B

Marco Lakes (A&B) Allocation	Permitted Withdrawal	Measured Data (From: MIU)
	MGY	
To ASR	1,600	533
To Treatment	1,935	1,754
Total From Marco Lakes	3,535	2,287

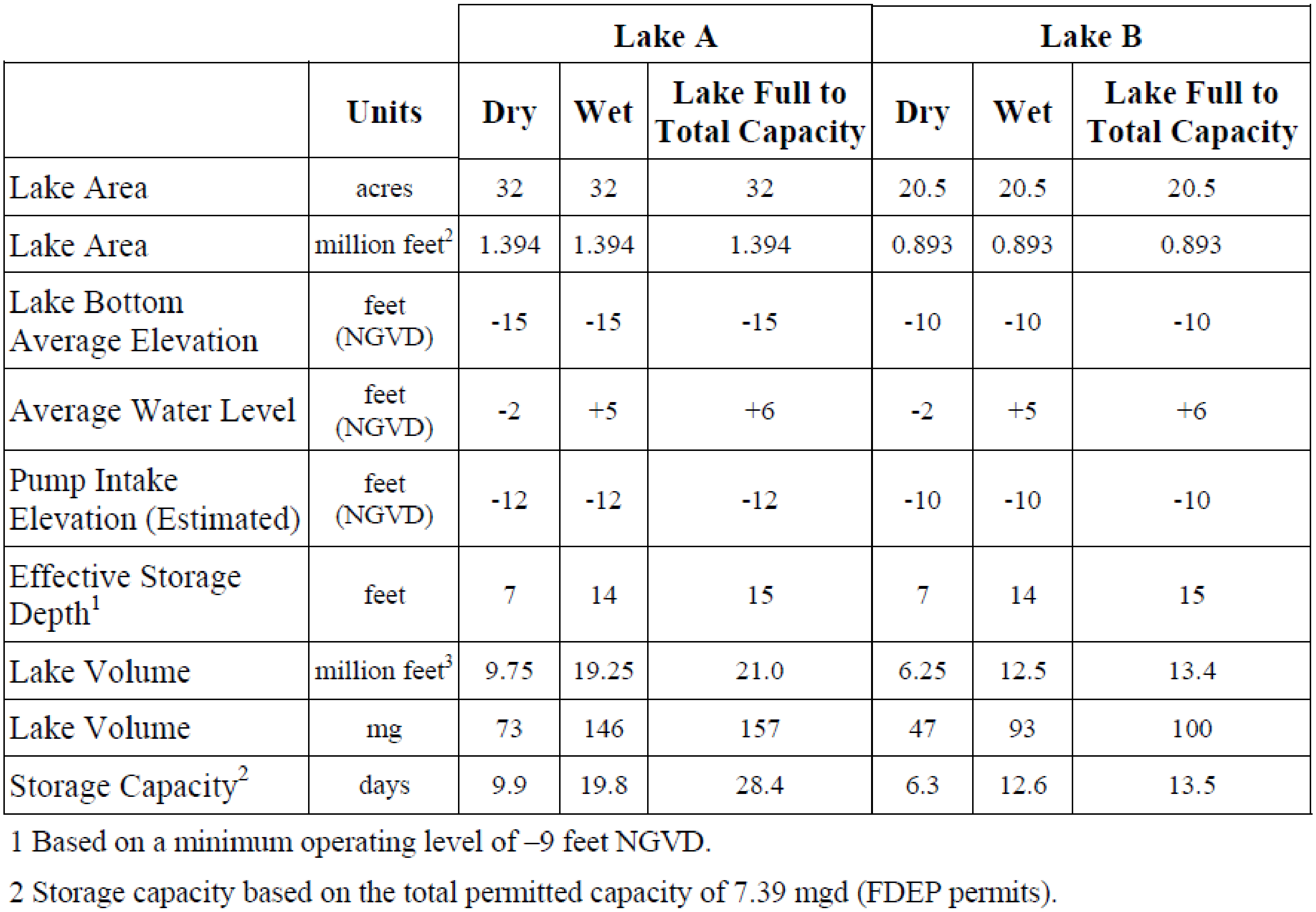
Notes: Permitted Annual Withdrawal was obtained from SFWMD App. # 041027-12.

A comparison of the average withdrawals (from Marco Lakes A&B) between the measured data from MIU and SFWMD permitted allocations show that the actual withdrawal from Marco Lakes A&B is about 6.3 MGD versus 9.68 MGD, or 3.4 MGD less than permitted.

Additional detail was added to the MIKE-11 network where the physical representation of MIU Lakes A&B were refined to account for the storage volume and groundwater interactions associated with the lakes. The CC-ECMv2 parameterization did not include branches or associated cross sections (storage) for the lakes. The Existing-LSM now accounts for the storage and groundwater interactions of the lakes by incorporating two distinct branches for the lakes, which are connected to each other, as well as Henderson Creek via the "interconnect structure." **Figure 60** presents the alignment of MIU Lakes and the interconnection with Henderson Creek. While the interconnect structure is in the model, it is set to be closed throughout the entire simulation.

Figure 60. Marco Lakes General Location Map: Modified from: Figure 2-1, from 2005 MUI-UMP

The 2005 MIU Utilities Master Plan (UMP) details the storage capacity of each lake as well as the average lake bottom elevation (MWH, 2005). From the UMP, the average lake bottom elevation was incorporated into the MIKE-11 domain and cross-sectional widths and bank height for each lake were assumed based upon aerial photograph measurements and LiDAR topography within GIS. Lake A was assumed to be 500-ft wide with an average bottom elevation of-16.3 FT-NAVD88, while Lake B was assumed to be 430-ft wide with an average bottom elevation of -11.3 FT-NAVD88. **Figure 61** presents the estimates of lake volumes and storage capacity based on season from the UMP, and was used for the average lake bottom elevation for each lake.



		Lake A			Lake B		
	Units	Dry	Wet	Lake Full to Total Capacity	Dry	Wet	Lake Full to Total Capacity
Lake Area	acres	32	32	32	20.5	20.5	20.5
Lake Area	million feet^2	1.394	1.394	1.394	0.893	0.893	0.893
Lake Bottom Average Elevation	feet (NGVD)	-15	-15	-15	-10	-10	-10
Average Water Level	feet (NGVD)	-2	+5	+6	-2	+5	+6
Pump Intake Elevation (Estimated)	feet (NGVD)	-12	-12	-12	-10	-10	-10
Effective Storage Depth[1]	feet	7	14	15	7	14	15
Lake Volume	million feet^3	9.75	19.25	21.0	6.25	12.5	13.4
Lake Volume	mg	73	146	157	47	93	100
Storage Capacity[2]	days	9.9	19.8	28.4	6.3	12.6	13.5

1 Based on a minimum operating level of –9 feet NGVD.

2 Storage capacity based on the total permitted capacity of 7.39 mgd (FDEP permits).

Figure 61. Table 2-1From: MIU Utilities Master Plan (MWH, 2005).

Figure 62 presents the MIKE-11 network near the MIU Lakes (Lake alignment in **Figure 62** follows that of **Figure 60**) and provides detail of the locations of the lakes, interconnect structure, and outflow pump. The outflow pump uses the measured data provided by MIU and the pumped volumes are removed from the model domain. All water pumped out of the MIU lakes is considered lost from the model domain as the Existing-LSM does not explicitly model Marco Island or the Aquifers associated with ASR injection/recovery.

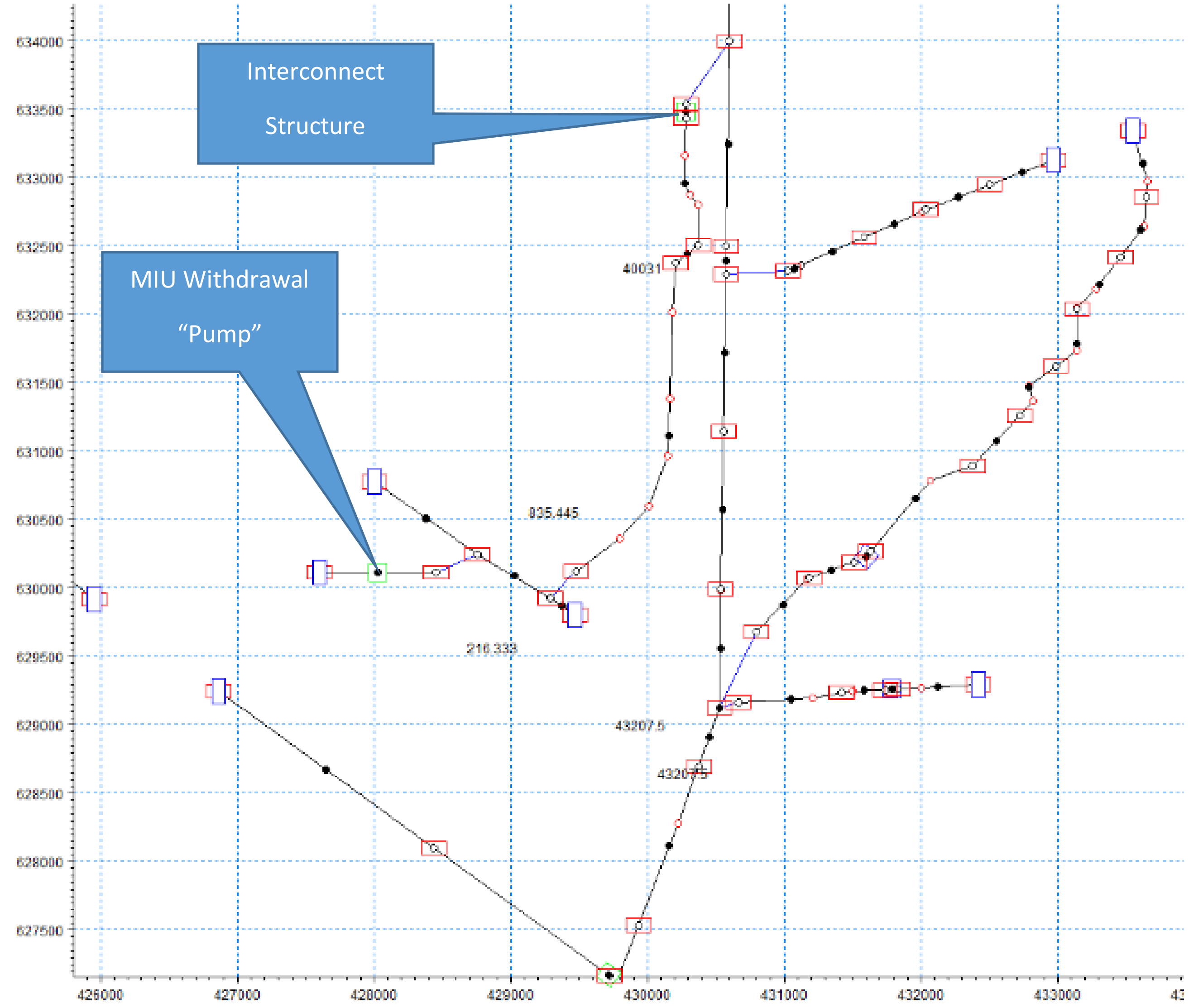


Figure 62. MIKE-11 Network Showing MIU Lakes, MIU Withdrawal Pump and Henderson Creek

3.2.4 Fiddlers Creek

Fiddlers Creek is a large development and golf course community east of Collier Boulevard and south/southwest of US 41. After extensive desktop review, field reconnaissance, GIS, and SFWMD permit review, it was determined that the CC-ECM MIKE-11 network near Fiddler's Creek was outdated. The network was deemed such, due to a channel connection that allowed water to flow from north of Fiddlers Creek north into the east branch of Henderson Creek. While the existing north/south canal shown in **Figure 63** is still in service, the east/west connection just north of Fiddlers Creek (ditch in reference) has been removed. **Figure 63** presents the Collier County stormwater channel network, obtained from the county database. The figure indicates drainage from the east, which flows north. Fiddler's Creek collects surface runoff internally via the Fiddler's Creek stormwater system, and drains to the east and south through the Collier County maintained stormwater system. This drainage network was confirmed after reviewing SFWMD Permit #11-00685-S "Fiddler's Creek" as well as past aerial photograph review from 1995 to 2007. Review of aerial photographs indicates a drainage swale/channel connection allowing water to drain either north or east was present until 2006, when the channel was cut off sometime between 2005 and 2006 leaving the current drainage network shown in **Figure 63**. This revision is not anticipated to affect flows at the "HENDTAMI" structure, but will rather represent the drainage network as currently defined.

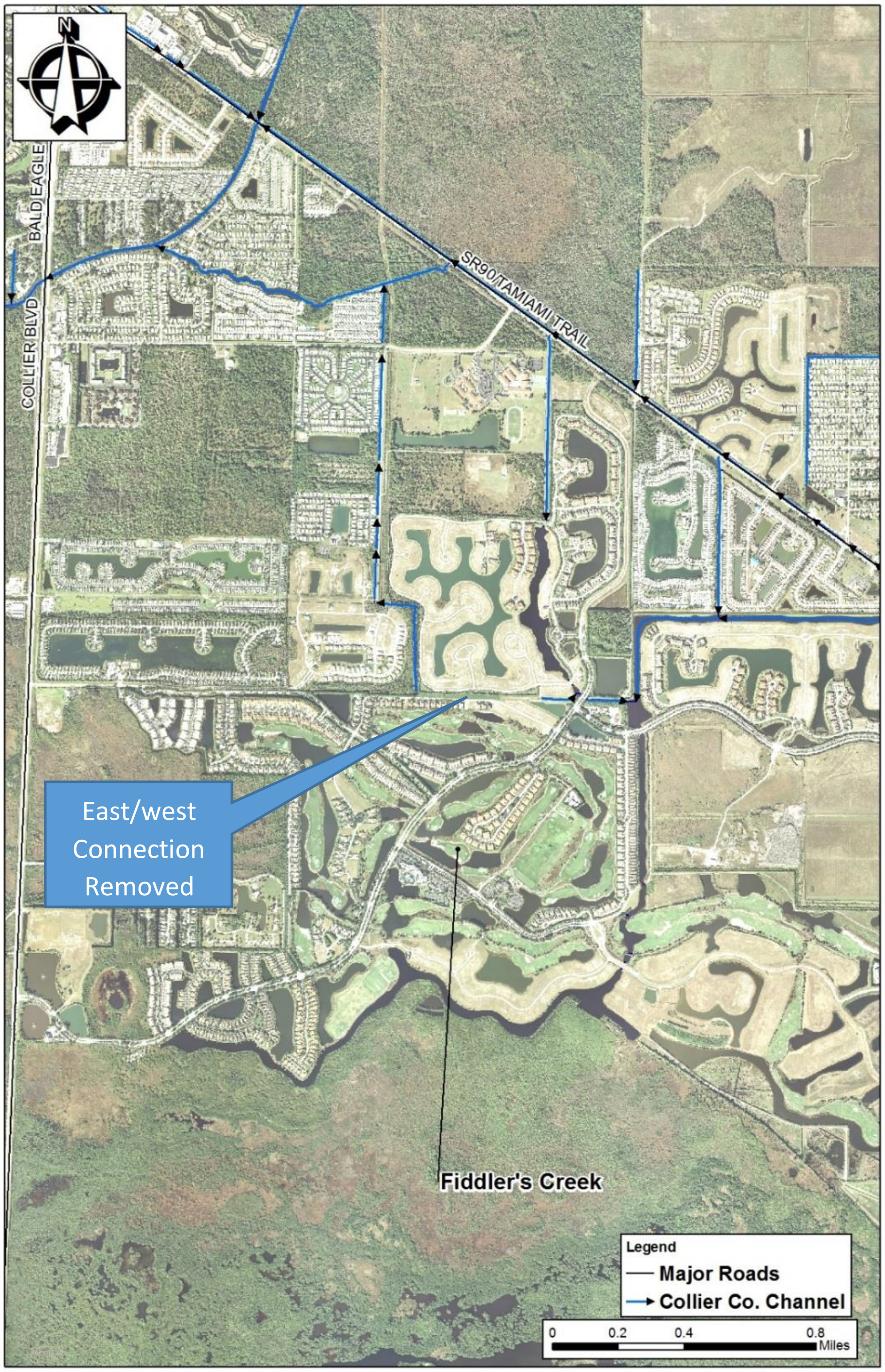


Figure 63. Collier County Stormwater Channel Network Near Fiddlers Creek

3.2.5 Flood Codes

Flood codes help define the interaction of the 2D Overland Flow (OL) plain and the 1D MIKE-11 channel network, where a head-dependent exchange between the OL and MIKE-11 network is defined based upon a unique grid code that must touch a portion of the associated channel. That is, for over-bank spilling to occur from the MIKE-11 network, stage in the channel must be higher than the surrounding topography and ponded water on the OL plain, where the opposite would be true with respect to OL water entering the MIKE-11 network. Flood codes are defined in a .DFS2 file and flooding/OL exchanges are specified in the MIKE-11 setup. Not every MIKE-11 branch will be allowed to flood due to the presence of a berm on either side of the channel or other surface feature that would restrict water from moving to or from the MIKE-11 network from the OL plain. This does not affect direct rainfall to the MIKE-11 branch.

The Flood Codes defined in the 1500-ft grid of the CC-ECMv2 were very rough with respect to the Existing-LSM grid-cell distribution. As such, refinements were made for flood codes on all channels within the Existing-LSM network, and to the extent practicable were applied to both sides of all MIKE-11 branches. This was brought up in the “HESM Internal Review of BCB – Collier County MIKE SHE/MIKE-11 Model,” where portions of the Henderson Creek Canal had flood codes representing one side of the channel. **Figure 64** presents the Flood Codes converted from the CC-ECMv2 1500-ft grid cell within the Existing-LSM Domain before refinement. **Figure 65** presents the Flood Codes within the Existing-LSM domain after refinement. (Note both **Figures 64** and **65** are at the same grid cell resolution of 375-ft.)

The process of the Flood Code refinements was similar to that of the Irrigation Command Areas presented in **Section 3.9**, where the placement and orientation of each grid code should reflect field conditions. As shown, **Figure 65** provides a more realistic and detailed representation of the flood codes in the Existing-LSM model domain. Additionally, flood codes were added to all branches associated with the Sabal Palms Road culverts, to allow for individual OL/MIKE-11 exchanges on each branch.

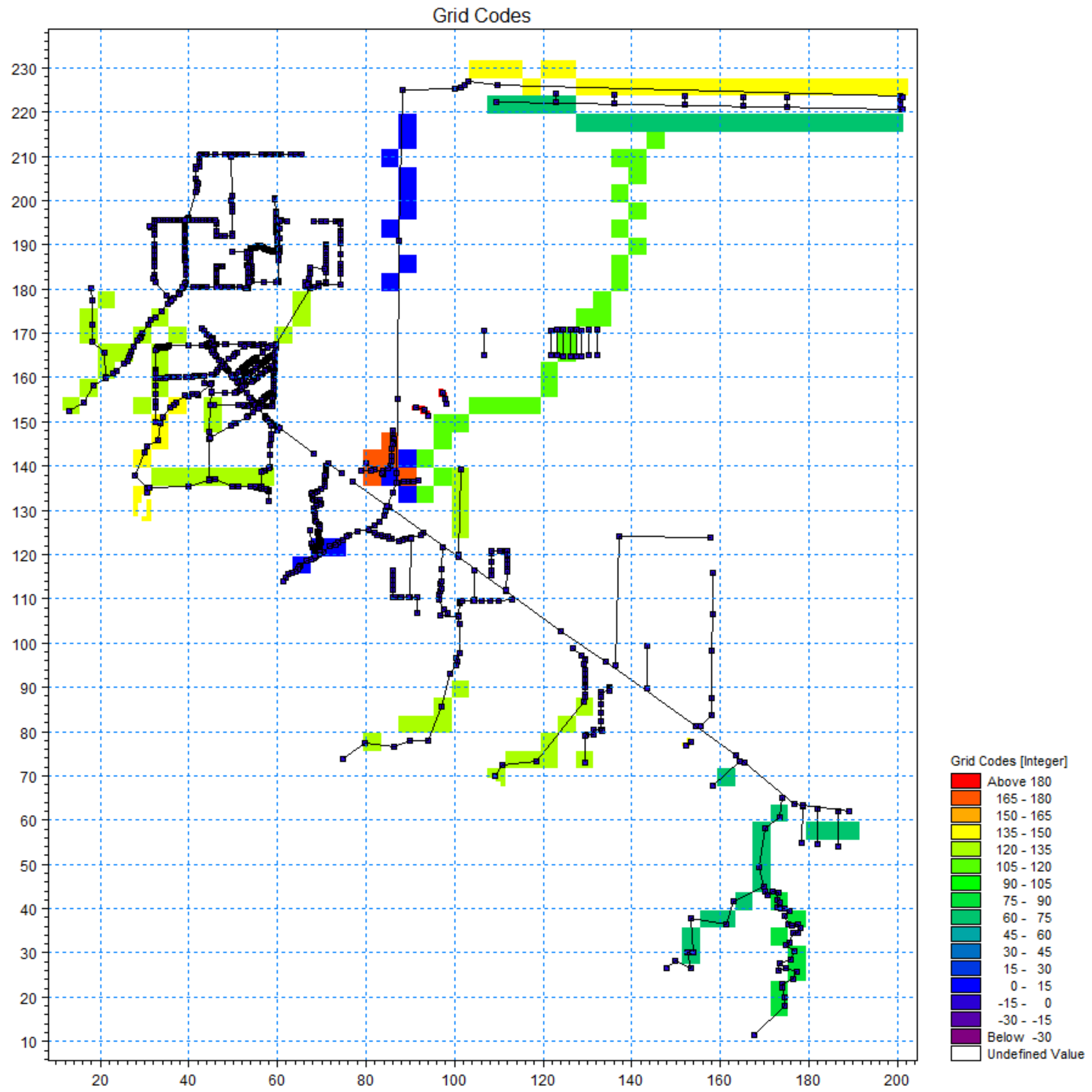


Figure 64. Existing-LSM Flood Codes Processed From CC-ECMv2 before Refinement

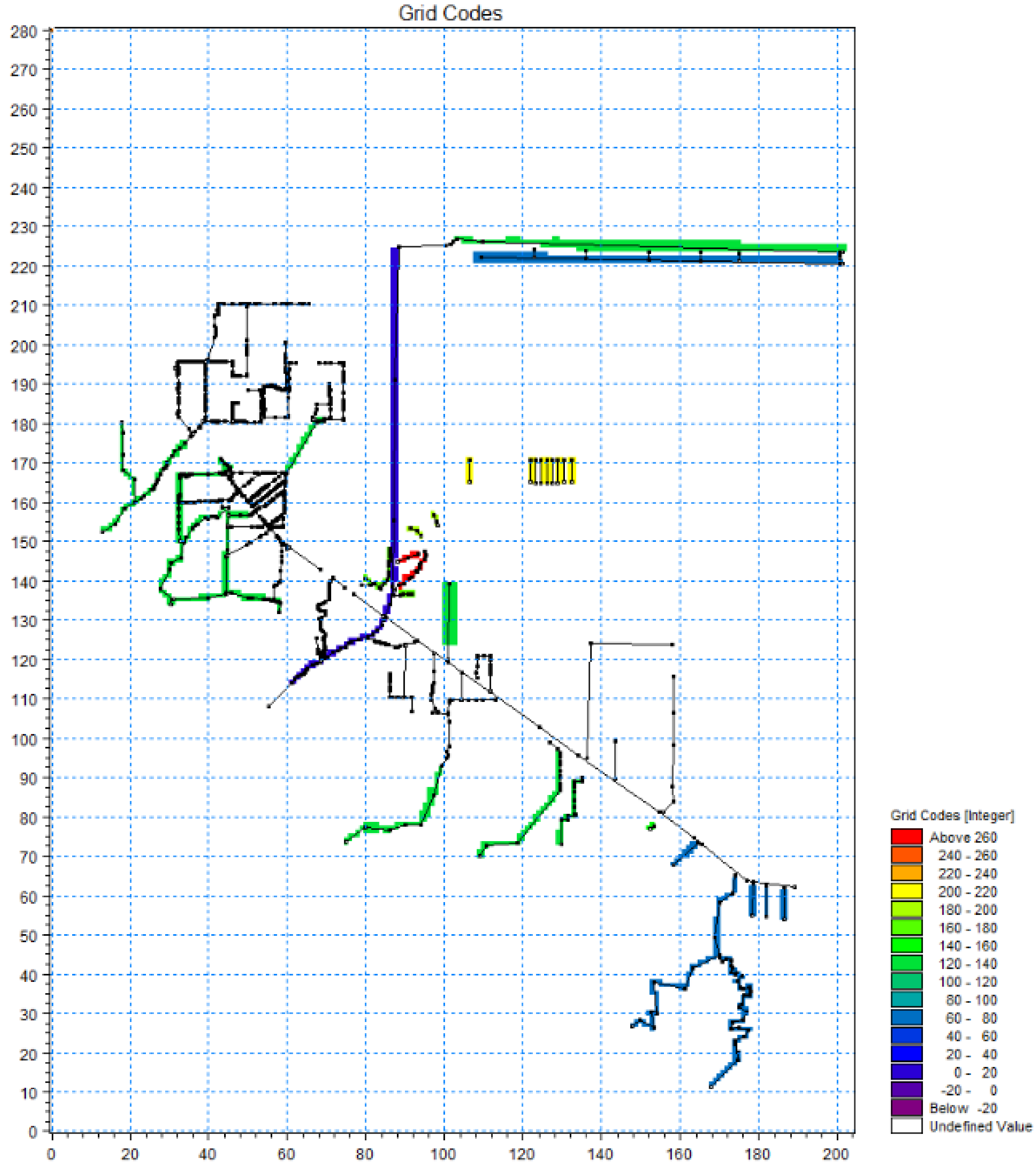


Figure 65. Existing-LSM Flood Codes Processed From CC-ECMv2 After Refinement

3.3 Task 2.3. Existing-LSM Results and Discussion

As detailed in “Task 2.2 Recalibrate Existing BCB Model,” MIKE SHE can provide detailed results from the post-processing routines within the software package. The results are available for the groundwater/overland flow (MIKE SHE) and 1D surface water (MIKE-11) portions of the model. These results are compared against measured data when specified, and MIKE SHE has the ability to calculate simulation statistics for each station being compared.

While the overall goal of this study is to better understand and quantify the freshwater deliveries to Rookery Bay estuary, with respect to volume and seasonality. The only flow calibration point within the model domain is the "HENDTAMI" structure, and as such, a significant effort was put forth during this study to improve the calibration and match seasonal trends within the surface water flow at the "HENDTAMI" gaging station along Henderson Creek at US-41 through 2012. **Figure 66** presents the overall water balance for the existing conditions LSM, in cumulative totals (inch) for the 10-year period of 1/1/2003 to 12/31/2012. This period was chosen as the calibration period of the local-scale models to allow for a 1-yr spin up period as detailed in **Section 4.1** of this report.

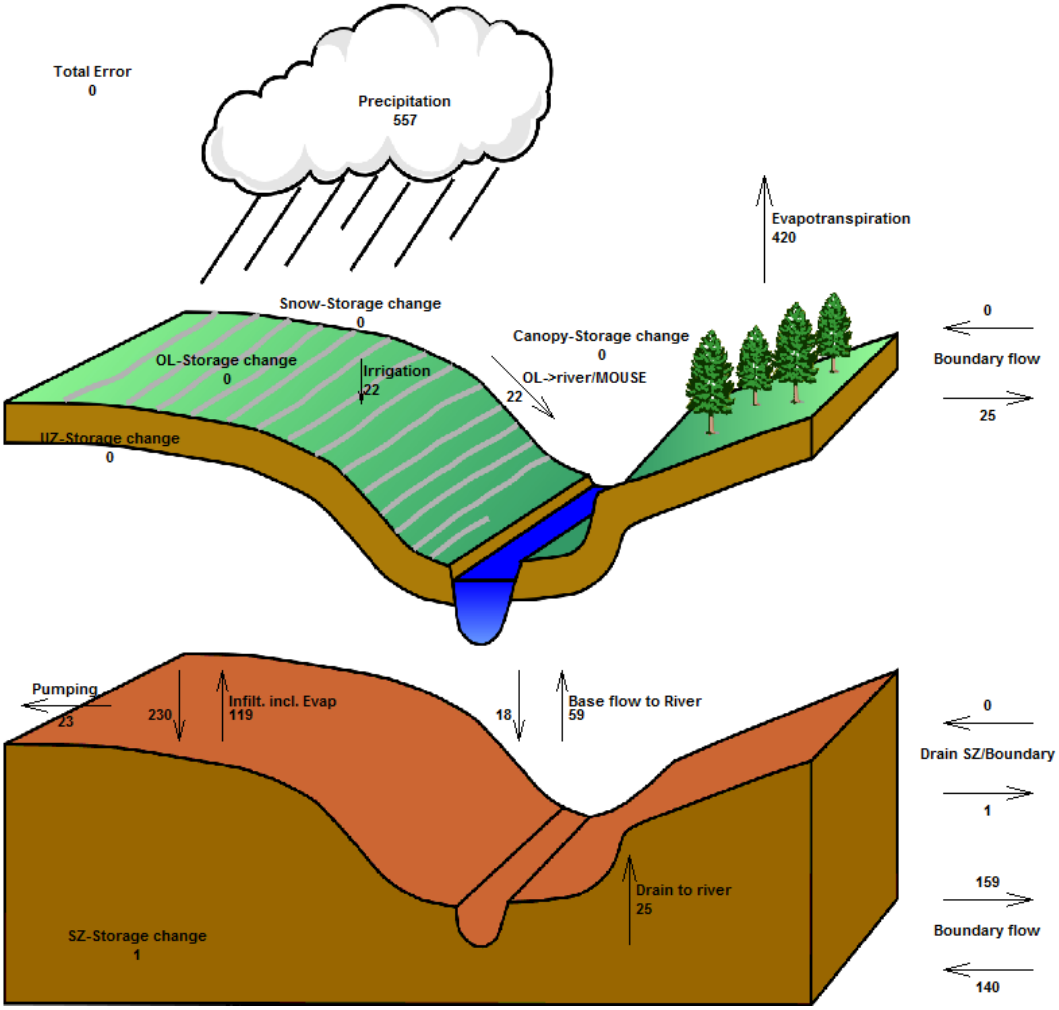


Figure 66. Total Water Balance (in inches) for Existing-LSM Domain, 2003-2012

3.3.1 MIKE SHE Results

The MIKE SHE results provide a comparison of simulated to observed groundwater levels at selected stations from the Existing-LSM-simulation. As shown in the **Table 27**, the Existing-LSM groundwater simulation results overall are a reasonable fit with the observed data. An exception is well C-968, with ME and MAE of over 1-ft, which is a departure from previous modeling studies in the watershed. While there has been a deterioration in calibration statistics at well C-968, well C-1225 (the closest well in proximity to C-968) shows an improvement in the calibration statistics for the limited period of available data (2002 through 2004) with which to make this comparison. Furthermore, the model is still overall well calibrated at the remaining wells within the model domain, indicating that no major instabilities or other inappropriate model assumptions were used when making revisions to the Existing-LSM. One of the goals of Task 2.3 within the modeling effort was to better represent the surface water flows at the Henderson Creek Gage, while ensuring that the groundwater results did not become far removed from reality. The results presented here fall within acceptable levels when considering the overall goal of the model. The fact that the Existing-LSM model was reduced to four SZ layers from seven, and the deeper aquifers (lower SZ layers) were not as well calibrated within the CC-ECMv2 simulation, in conjunction with the results from well C-1225, the modeling team believes the model represents the groundwater portion reasonably well within the model domain.

Table 27. MIKE SHE Calibration Statistics

Well	ME	MAE	RMSE	STDres	R(Correlation)
C-968	1.44	1.44	1.62	0.74	0.86
C-1225	0.39	0.96	1.25	1.18	0.73
SGT1W1	-1.43	1.46	1.58	0.66	0.92
SGT2W1	-0.17	0.48	0.75	0.73	0.92
SGT3W1	-1.74	1.75	1.81	0.50	0.95
SGT4W1	-0.22	0.50	0.68	0.64	0.91

ME: Mean Error; **MAE**: Mean Absolute Error; **RMSE**: Root Mean Square Error, **STDres**: Standard Deviation of Residuals; **R:** Correlation Coefficient

3.3.2 MIKE-11 Results

The MIKE-11 results provide a comparison of simulated stage or flow to observed stage or flow depending on the station. **Figure 27** of **"Task 2.2 Recalibrate Existing BCB Model"** shows the locations of the SFWMD stage monitoring stations within the Rookery Bay Watershed, with available data used for comparisons with simulation results. The Existing-LSM model presents a comparison of all stage monitoring stations with the exception of "HALDEMAN_H," which is now the location of a boundary condition within the model domain. **Table 28** presents the calibration statistics for the available surface water gaging stations within the model domain, as shown the stations are all within acceptable ranges (Less than 0.5 ft. ME and less than 0.75 ft. MAE).

Table 28. MIKE-11 Calibration Statistics

MIKE-11 Station	Simulation	ME	MAE	RMSE	STDres	R(Correlation)
HEND84	LS-ECM	-0.29	0.73	0.87	0.82	0.86
HENDTAMI_H	LS-ECM	0.13	0.54	0.75	0.74	0.84
LELYUS41	LS-ECM	-0.28	0.43	0.73	0.67	0.54
TAMITOM	LS-ECM	-0.34	0.61	0.74	0.65	0.83
TAMIHEND_H	LS-ECM	-0.13	0.63	0.87	0.89	0.40

MIKE-11 Station	Simulation	ME	MAE	RMSE	STDres	R(Correlation)
TOWER	LS-ECM	0.36	0.51	0.61	0.49	0.57

ME: Mean Error; **MAE**: Mean Absolute Error; **RMSE**: Root Mean Square Error, **STDres**: Standard Deviation of Residuals; **R:** Correlation Coefficient.

As previously stated, during the completion of **Task 2.3,** a significant effort was made during this study to represent the flows at the Henderson Creek gage at US-41, while the overall goal of the project is to better understand and quantify the freshwater deliveries to Rookery Bay Estuary, with respect to volume and seasonality. The current model simulates flow at Henderson Creek remarkably well and also provides reasonable results when comparing both seasonal trends (monthly average flow volume) and flow duration curves for the period of 2003 to 2012.

Figures 67-69 present the cumulative flow, average monthly flow ,and flow duration curve comparisons (Observed vs. Simulated) for the SFWMD "HENDTAMI" gage at US-41.

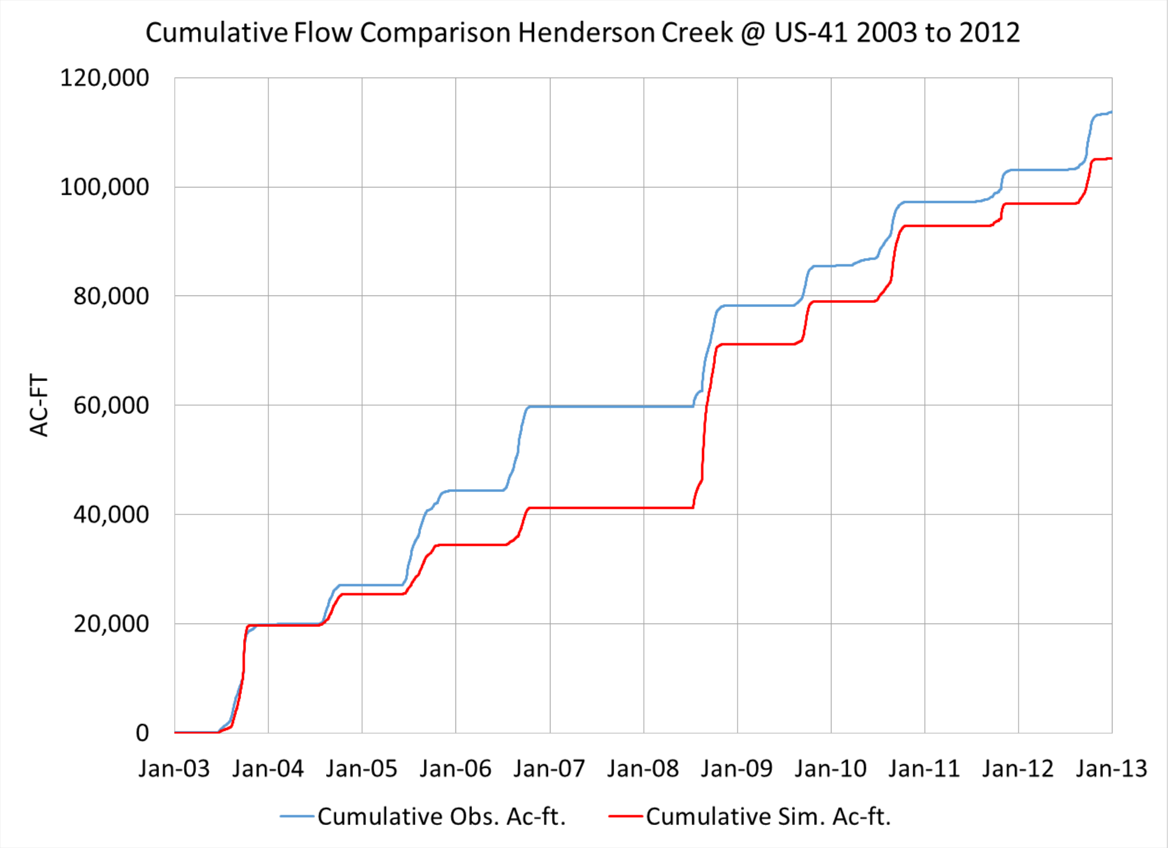


Figure 67. Observed vs Simulated Cumulative Flow - Henderson Creek @ US-41 (2003 to 2012)

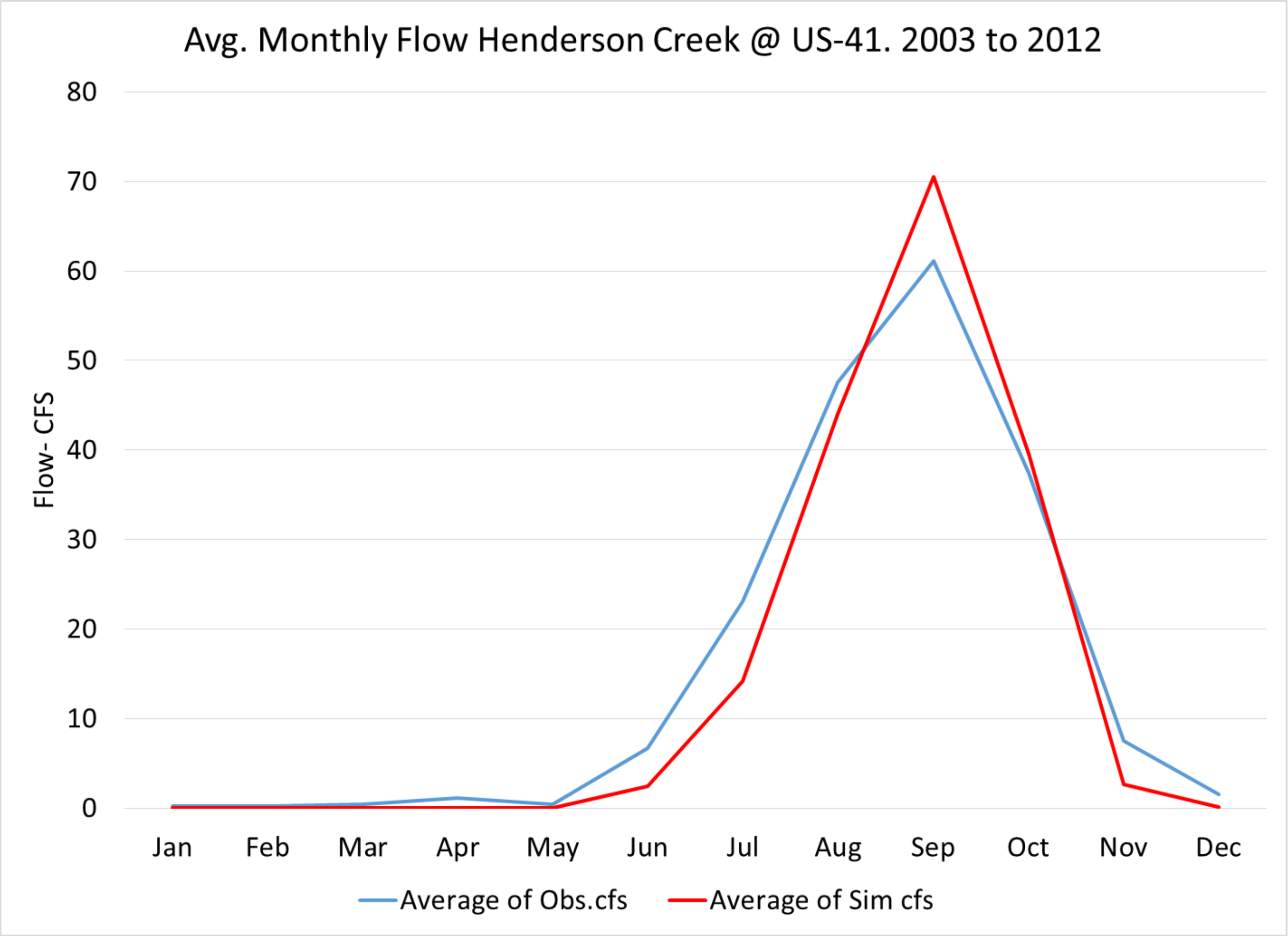


Figure 68. Observed vs Simulated Avg. Monthly Flow - Henderson Creek @ US-41 (2003 to 2012)

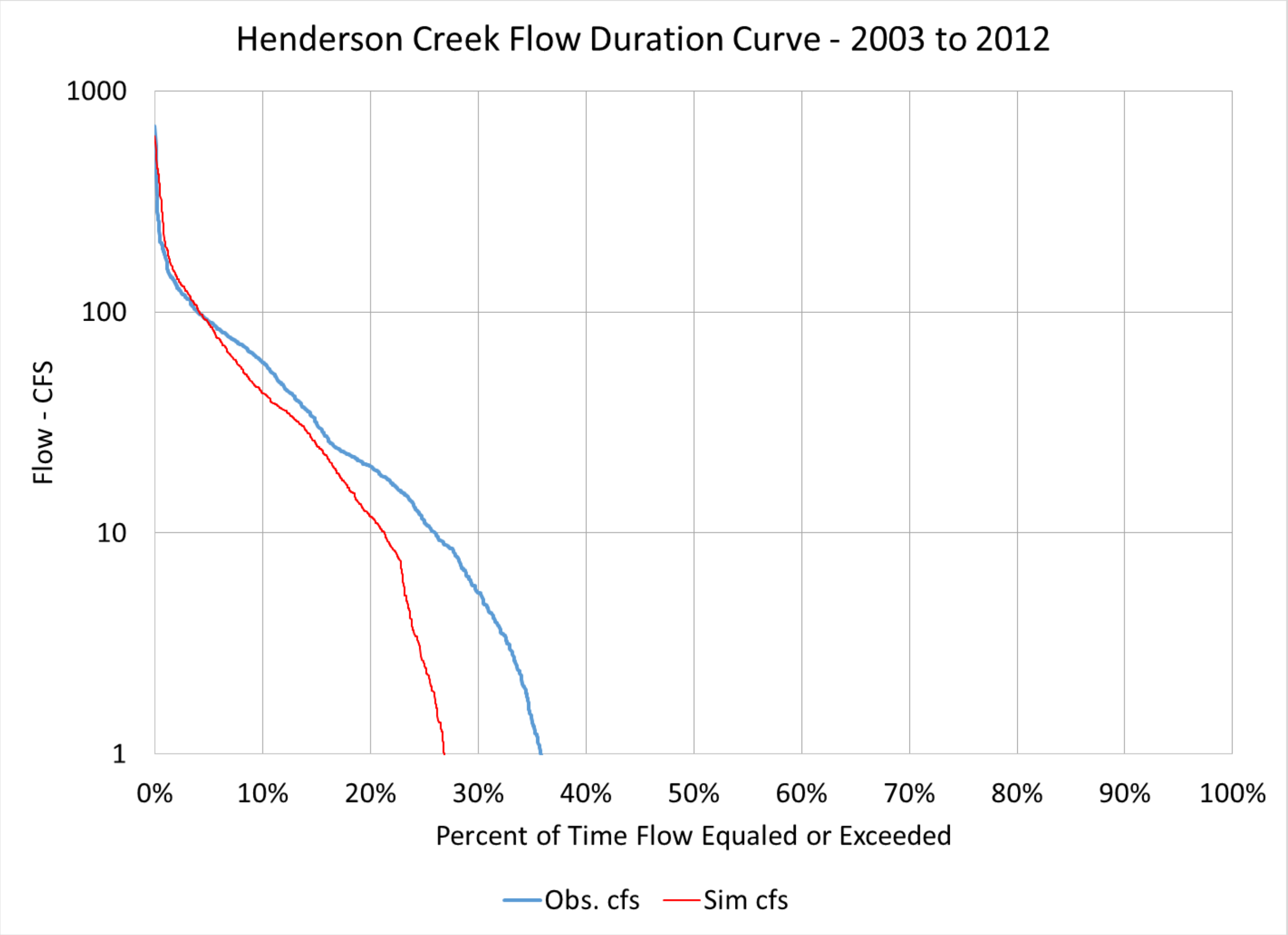


Figure 69. Observed vs Simulated Flow Duration Curve - Henderson Creek @ US-41 (2003 to 2012)

The period of 2003 to 2012 is relatively well calibrated from a cumulative flow comparison, in that the total volume of water delivered to Rookery Bay from Henderson Creek is about 7.5% less than the observed data for the same time period. This is a major improvement over the CC-ECM results, and it meets the calibration target for this parameter of 10% total error. The model error primarily occurs over three single events occurring in or around June of 2005, September 2006, and August 2008. As shown in **Figure 67,** these events are the main deviation points between observed and simulated flows. However, it should be noted that the overall pattern over the time period of 2003 to 2012 is very well matched.

Additionally, **Figure 68** shows that on average the monthly flows at Henderson Creek compare very well, with the exception of slight over predictions in the months of September and October, and slight under predictions in June through August as well as in November and December. Another way of reporting seasonal trends are with flow duration curves (FDCs), which show the percent of time a specific flow is met or exceeded, with a lower percentage being a higher flow. Thus, extreme events are on the order of 0 – 5% exceedance, meaning a flow with an exceedance percentage of 3% has a likelihood of a 3% chance of occurring (or a 97% probability of not occurring). While more common flows have exceedance percentages of 50% or higher, where the opposite is true, in that these flows are likely to occur at least 50% of the time or more (or a 50% probability of occurring). **Figure 69** shows the model under-predicts the most extreme event while providing reasonable results for almost every other events for the comparison period.

The time period of 2003 to 2012 was chosen to represent how the model simulated stage and flow, as this period excludes the first year "spin-up" period (to remove any 'model memory' of the assumed initial conditions), and to provide a full 10-year period for evaluation, which includes several wet and dry years. However, with the inclusion of various LASIP and other projects detailed in **Task 2.2**, the model is more representative of conditions after 2009 and more emphasis should be given to the model results for the post-2008 period.

As such, the same comparisons previously presented (**Figures 67-69)** were also conducted from 2009 through 2012 and presented in **Figures 70-72**. The figures indicate that the cumulative difference between observed and simulated has been reduced to about 4%. As was the case for the same analysis from 2003 through 2012, the model represents the seasonal trends very well.

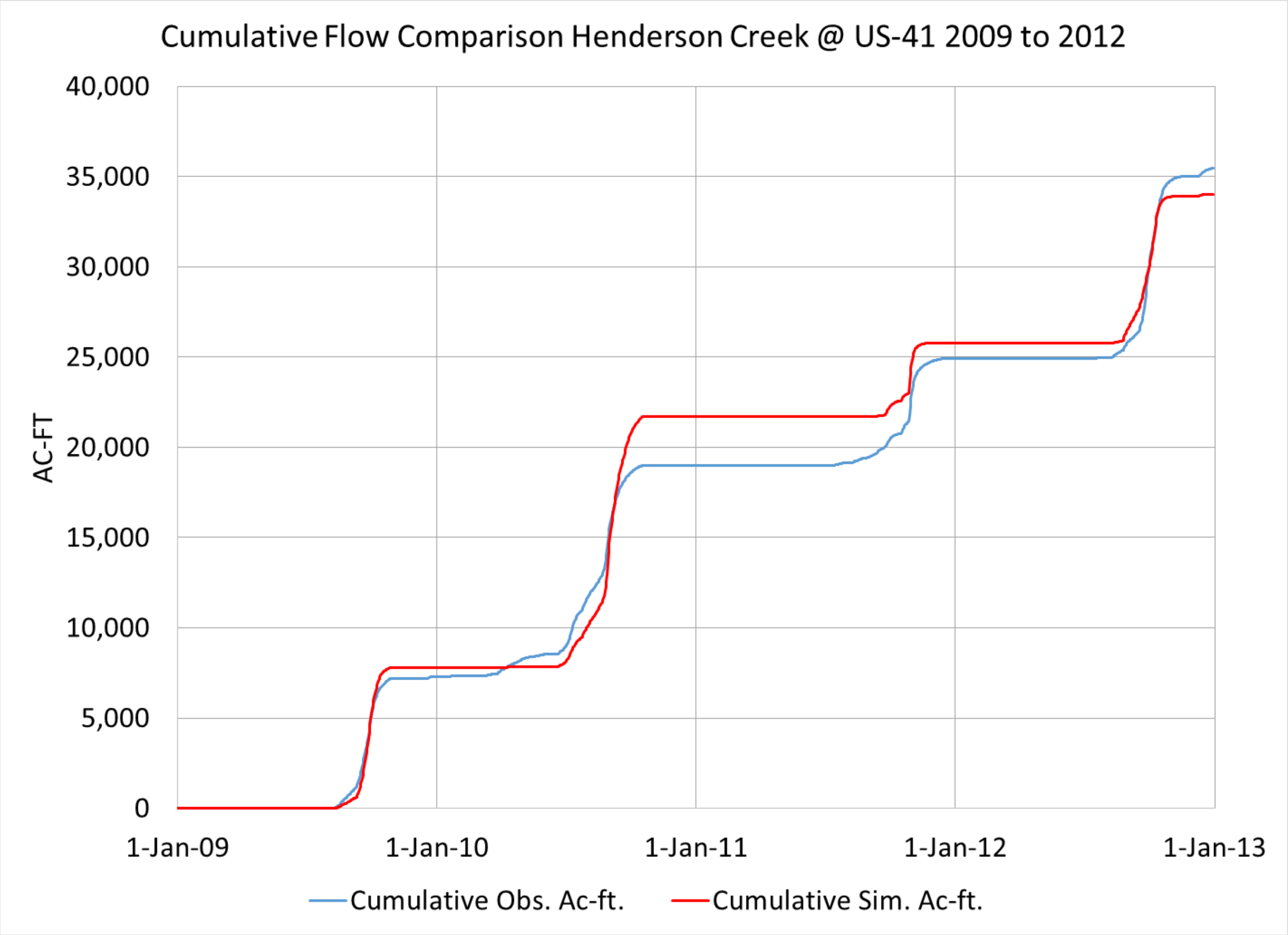


Figure 70. Observed vs Simulated Cumulative Flow - Henderson Creek @ US-41 (2009 to 2012)

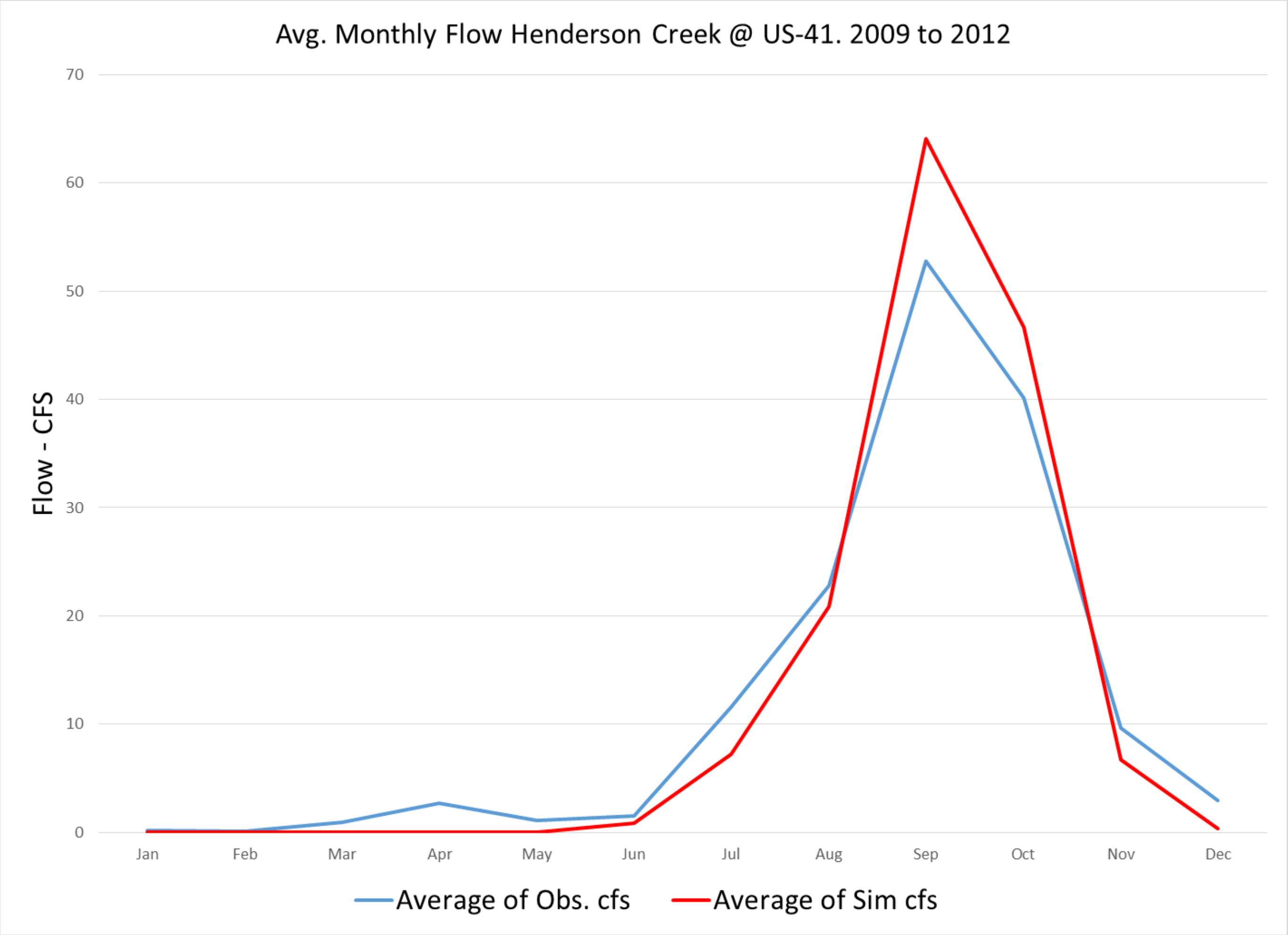


Figure 71. Observed vs Simulated Avg. Monthly Flow - Henderson Creek @ US-41 (2009 to 2012)

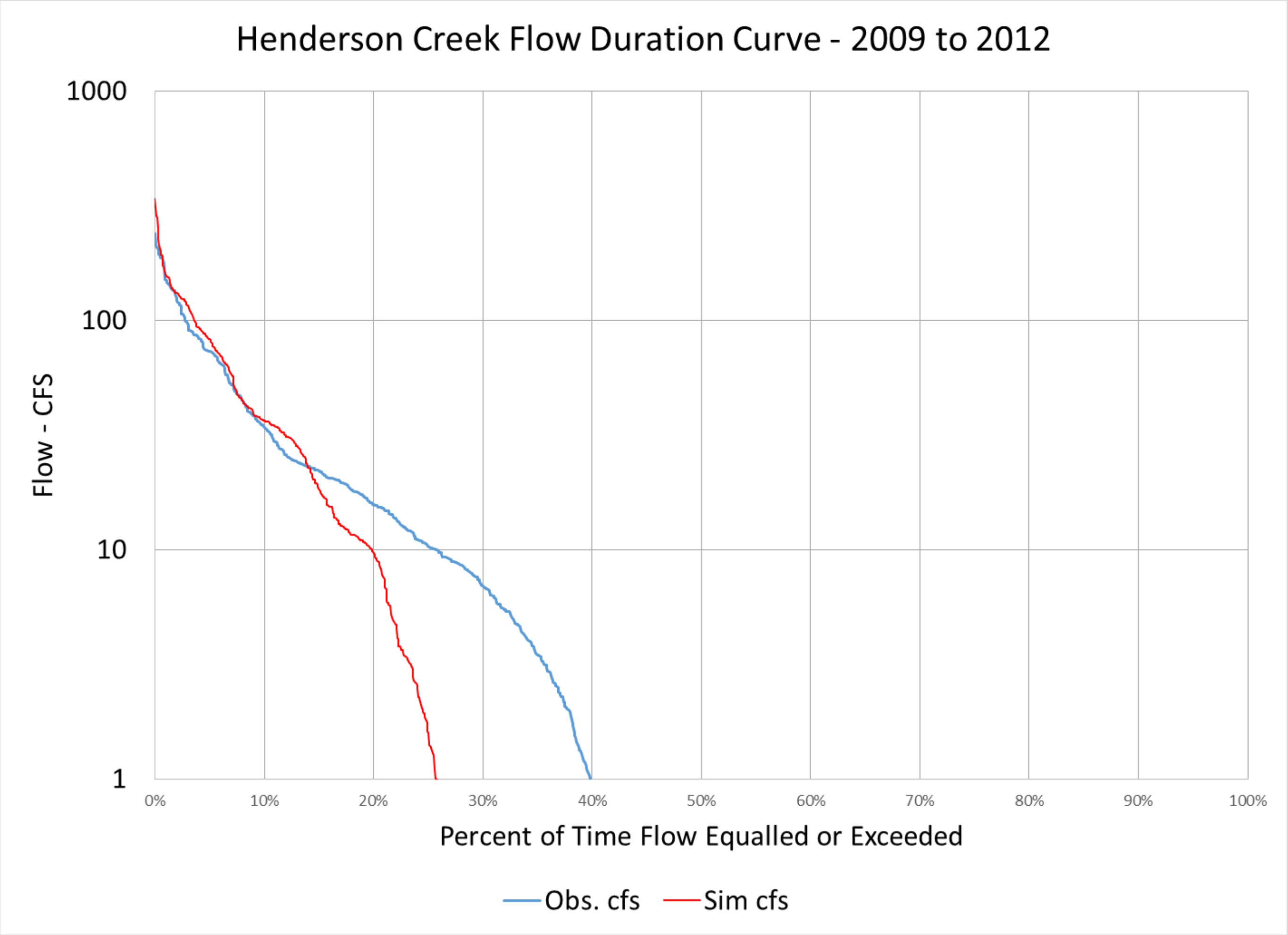


Figure 72. Observed vs Simulated Flow Duration Curve - Henderson Creek @ US-41 (2009 to 2012)

As evidenced in **Figures 70-74**, the model simulates Henderson Creek cumulative flows and seasonal trends as well or better for the time period of 2009 – 2012. This is not surprising as the physical representation (control structures, etc.) within the MIKE-11 portion of the model is more representative of this time period as most major projects within the watershed have been in place since 2009. This is further supported by the data presented in **Table 29**, where all statistical measures show improvement when comparing flows from 2003 to 2012 against flows from 2009 to 2012.

Table 29. Statistical Comparisons of Flow at SFWMD Gage HENDTAMI

	Simulation Period	**ME**	**MAE**	**RMSE**	**STDres**	**R(Correlation)**
HENDTAMI	2003-2012	1.2	8.02	22.38	42.13	0.75
	2009-2012	0.51	5.46	13.69	31.30	0.83

ME: Mean Error; **MAE**: Mean Absolute Error; **RMSE**: Root Mean Square Error, **STDres**: Standard Deviation of Residuals; **R:** Correlation Coefficient. (Note: Values in cfs)

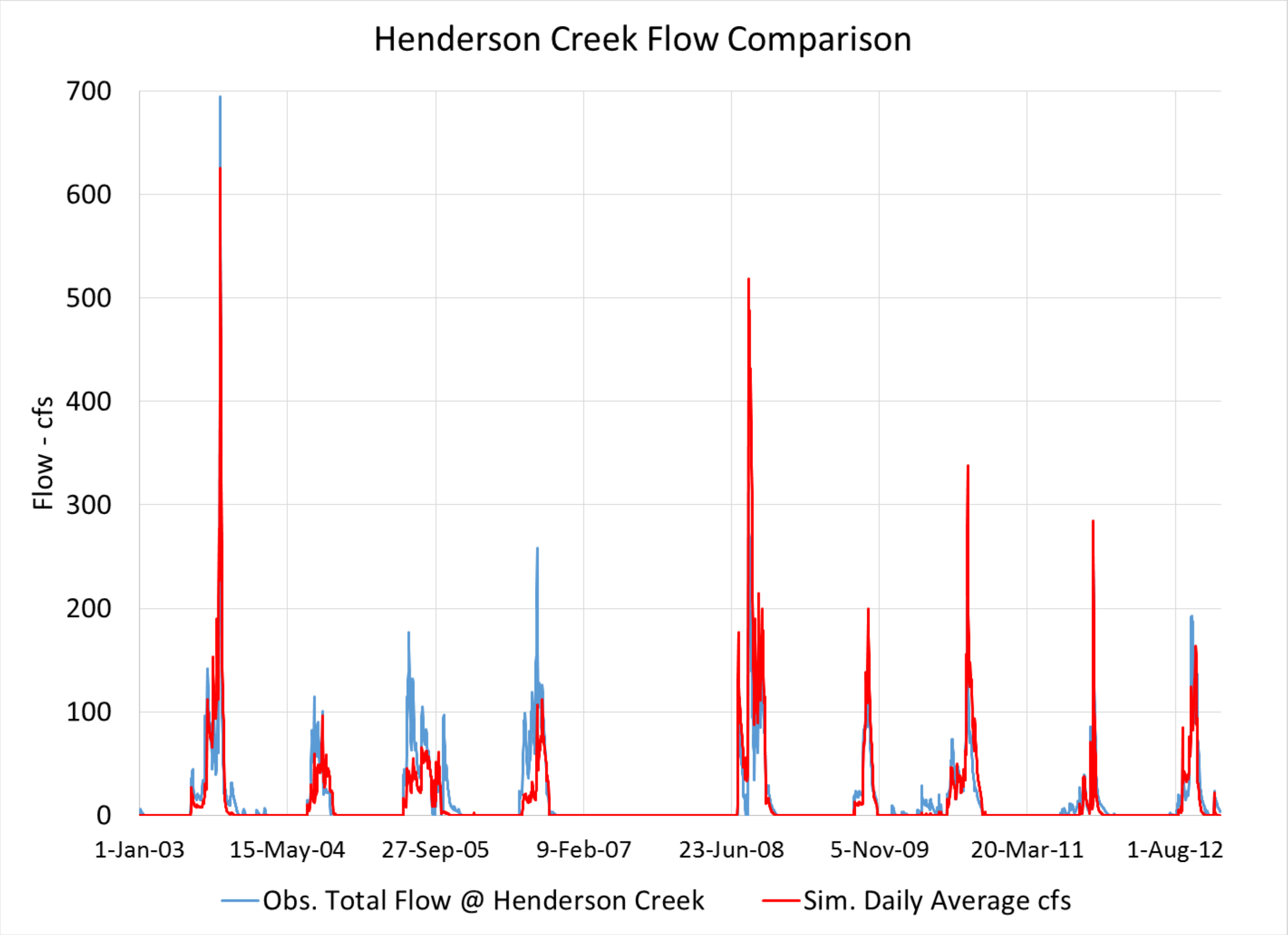


Figure 73. Daily Flow Comparisons SFWMD HENTAMI 2003 to 2012

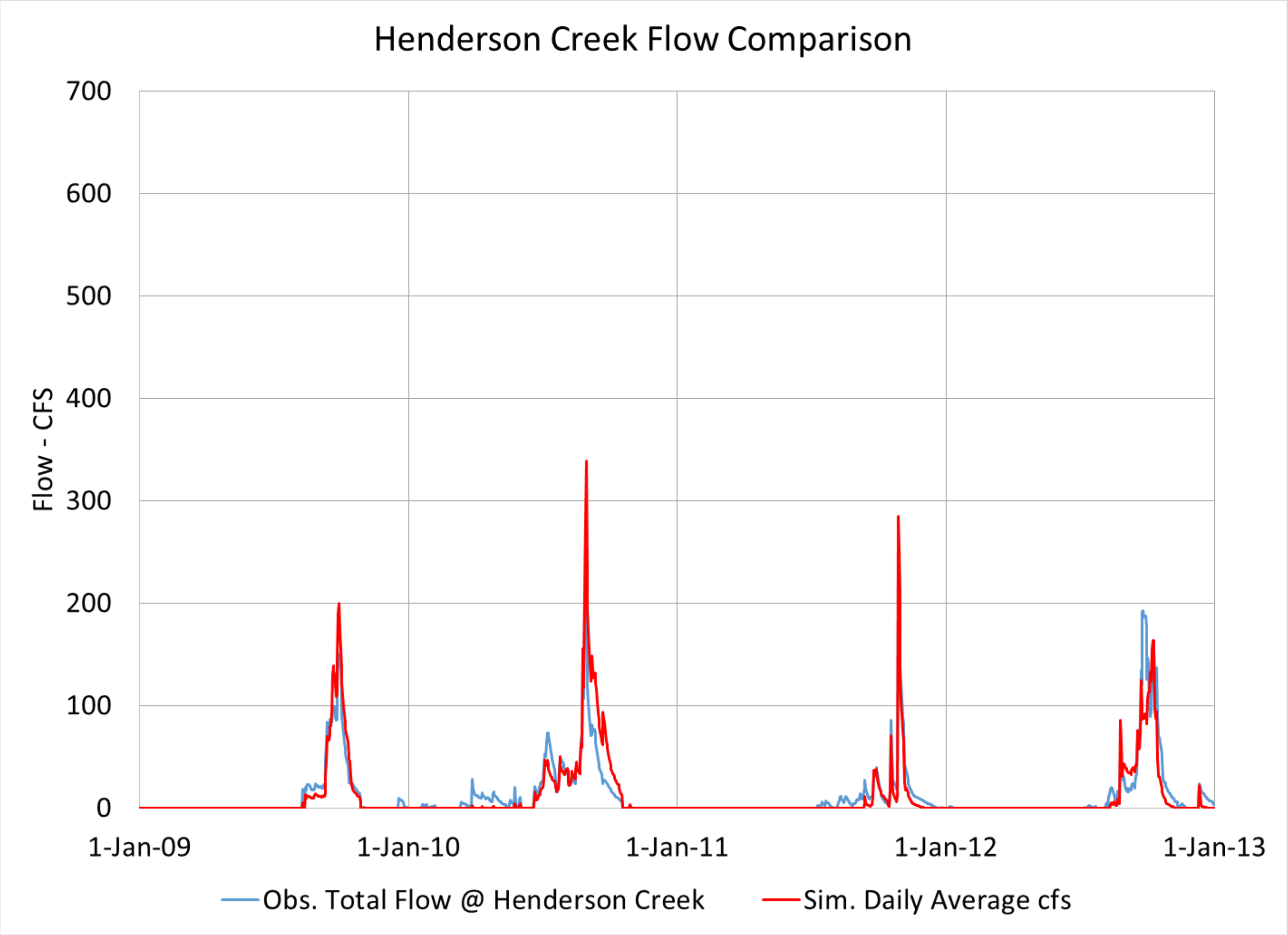


Figure 74. Daily Flow Comparisons SFWMD HENTAMI 2009 to 2012

3.4 Task 2.3. Existing-LSM Conclusions and Recommendations

The Existing-LSM model has been run for 2002 through 2012, with analysis periods of 2003 – 2012 and 2009 – 2012. As presented in the preceding section, the model calibration has been improved in terms of surface water flows and stages.

The main objective of Task 2.3 was to construct a detailed local-scale model of the Henderson Creek / Rookery Bay Watershed, while improving the flow calibration at Henderson Creek. This has been accomplished where flows are shown to be over-predicted by only about 4% for the time period of 2009 through 2012. The seasonal flows at Henderson Creek have been shown to relate well to observed data. Additionally, the system is well represented with specific interested paid to the LASIP projects incorporated and how the Belle Meade Flow-way is represented and interacts with Henderson Creek.

As developed and represented herein, the Existing-LSM model is useful in characterizing the existing volumes and timing of freshwater flows into Rookery Bay. The Existing-LSM was also deemed a useful and valid starting point for the development of a Historical Conditions LSM, described in the following sections.

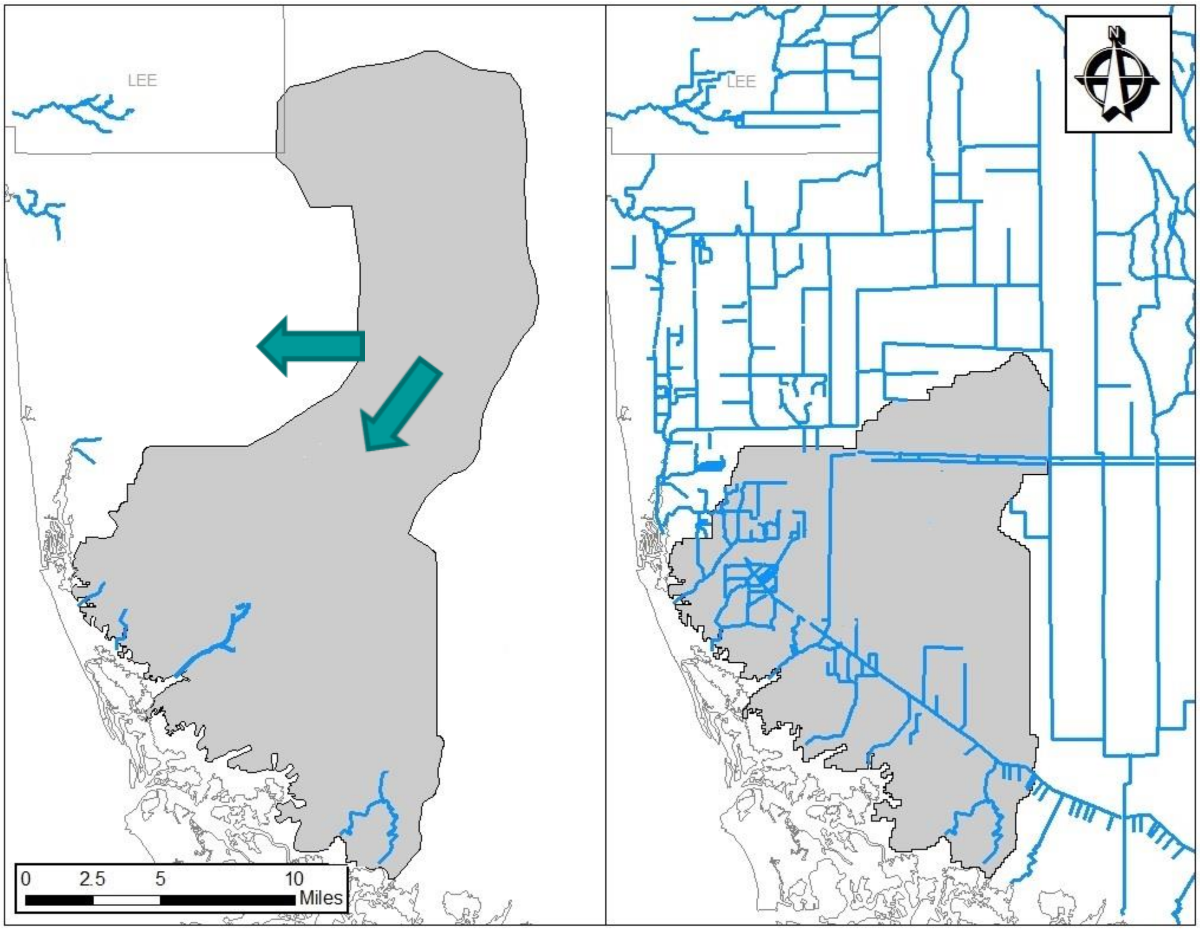
4.0 Task 2.4. Historical-LSM Introduction

A local-scale historical conditions model (Historical-LSM) was prepared for the Henderson Creek / Rookery Bay watershed to estimate the changes in volumes and timing of freshwater inflows to Rookery Bay that have occurred over the past several decades due to anthropogenic impacts. These changes in flow can be estimated by comparing the results of the Existing-LSM with the results of the Historical-LSM. Development of the Historical-LSM utilized components of the Existing-LSM model in conjunction with the BCB NSM model (Regional-NSM) provided by the SFWMD (District). As per the District, this model also known as the PSRP NSM, was developed in 2003 and run from 1988 to 2000, to make long-term comparisons between historical and existing conditions. The Regional-NSM model was used to provide boundary condition inputs to the Historical-LSM for this project.

The Historical-LSM provides results for the analysis of the watershed in a pre-development or historical condition against conditions as they are today (existing conditions). Important aspects of the model setup, including saturated zone layering and parameters, rainfall and potential evapotranspiration, soils and land-use dependent parameters, etc. were held constant between the Existing and Historical conditions LSM models to provide scientifically defensible comparisons between Existing and Historical Conditions. Care was taken to ensure that differences in model inputs and outputs between the two models are solely attributable to anthropogenic changes in the watershed.

For historical conditions, all man-made features from ditches/canals and control structures, to detention/retention ponds and mining operations have been removed from the network of both NSM simulations (Regional and Local Scale). As a result, the model simulates the flow of water in a natural manner to an outfall based upon the topography and other physical properties within the watershed.

Figure 75 provides a comparison between the Historical- and Existing-LSM domains. The Historical-LSM includes a large area to the north of the current Golden Gate Canal that historically could have contributed flow at times to the Henderson Creek / Rookery Bay system. However, due to the flat topography in this area, overland flows could also have contributed to Naples Bay and therefore the significance of the additional contributing area is uncertain. One of the most notable characteristics of the Historical watershed is an absence of defined stream channels. A review of 1940 aerial topography indicated that Henderson Creek did not exist as a defined stream channel north of present-day US 41. This suggests that the primary mechanisms for lateral water movement in the watershed were sheet flow and shallow subsurface flow.



Historical Domain *Existing Domain*

Figure 75. Comparison of Historical and Existing LSM Domains

The following sections and sub-sections are included in describing the comprehensive work accomplished for the NSM Model.

- NSM Utilization
- MIKE SHE Revisions
  - Climate
  - Topography
  - Land Use
  - Unsaturated Zone
  - Saturated Zone
- MIKE-11 Revisions

4.1 Task 2.4. Historical-LSM Utilization

The intent of the Regional-NSM simulation was to provide boundary conditions in a manner similar to that of the aforementioned CC-ECM simulation. As such, it was necessary to run the NSM model for the same period as the previous CC-ECM and Existing-LSM simulations, to facilitate comparisons over a fixed temporal scale. The revised NSM model has been updated to run from 2002 through 2012, with the year 2002 representing a spin up period (allowing the model to equalize and remove any ‘model memory’ of assumed initial conditions) while the period of 2003 through 2012 has been selected for analysis and model comparisons. As mentioned earlier (Section 8), the BCB-NSM was received from the SFWMD and has subsequently been revised to allow for an “apples to apples” comparison between the Existing Conditions and Natural Systems Models. It was important to 1) run the models for similar time periods and 2) ensure both models had as much in common as possible. For example, the meteorological component of each model is exactly the same. Additionally, the land-use based parameters (such as Manning’s M) and unsaturated and saturated zone parameters are common between both models. However, the spatial distribution of land-use based parameters have changed to represent the historical land use coverage.

4.2 MIKE SHE Revisions: Regional and Local Scale Historical Models

This report combines two model simulations where the Regional-NSM has been modified to use the exact same meteorological, overland calculation, and saturated zone parameters as the CC-ECMv2 simulation. This ensures that a fair comparison is made between the Existing and Historical Conditions LSM simulations. The Historical-LSM was changed substantially from the Regional-NSM, in that all topographic, vegetative, unsaturated, and saturated Zone parameter files were created specifically as part of this task. For example a new topographic file was developed as well as a refined representation of the historical land use within the model domain.

4.2.1 Climate

All meteorological components of the NSM models (Regional and Local Scale) are identical to that used in the CC-ECM and Existing-LSM models respectively. NEXRAD Rainfall data was distributed in a 1km x 1km spatially/temporally varying “.DFS2” grid file for the CC-ECM and Regional-NSM simulations while individual NEXRAD pixels and time varying “.DFS0” files were used for the Existing and Historical LSM development. Additionally, USGS GOES Satellite RET was distributed by the NEXRAD pixel spacing, and time-varying .DFS0 files were utilized as forcing conditions. As both of these files have been thoroughly checked in earlier memos (See Task 2.2 “Recalibrate Existing BCB Model” and Sections 3.1.1 and 3.1.2 of this report), additional discussion of the climate data is not provided here but can be reviewed in the aforementioned sections of this report. **Figure 76** presents the Historical-LSM model domain with the NEXRAD Rainfall pixel distribution overlain on the domain. As was the case in the Existing-LSM model development, USGS GOES RET was distributed over the same pixels shown in **Figure 76**.

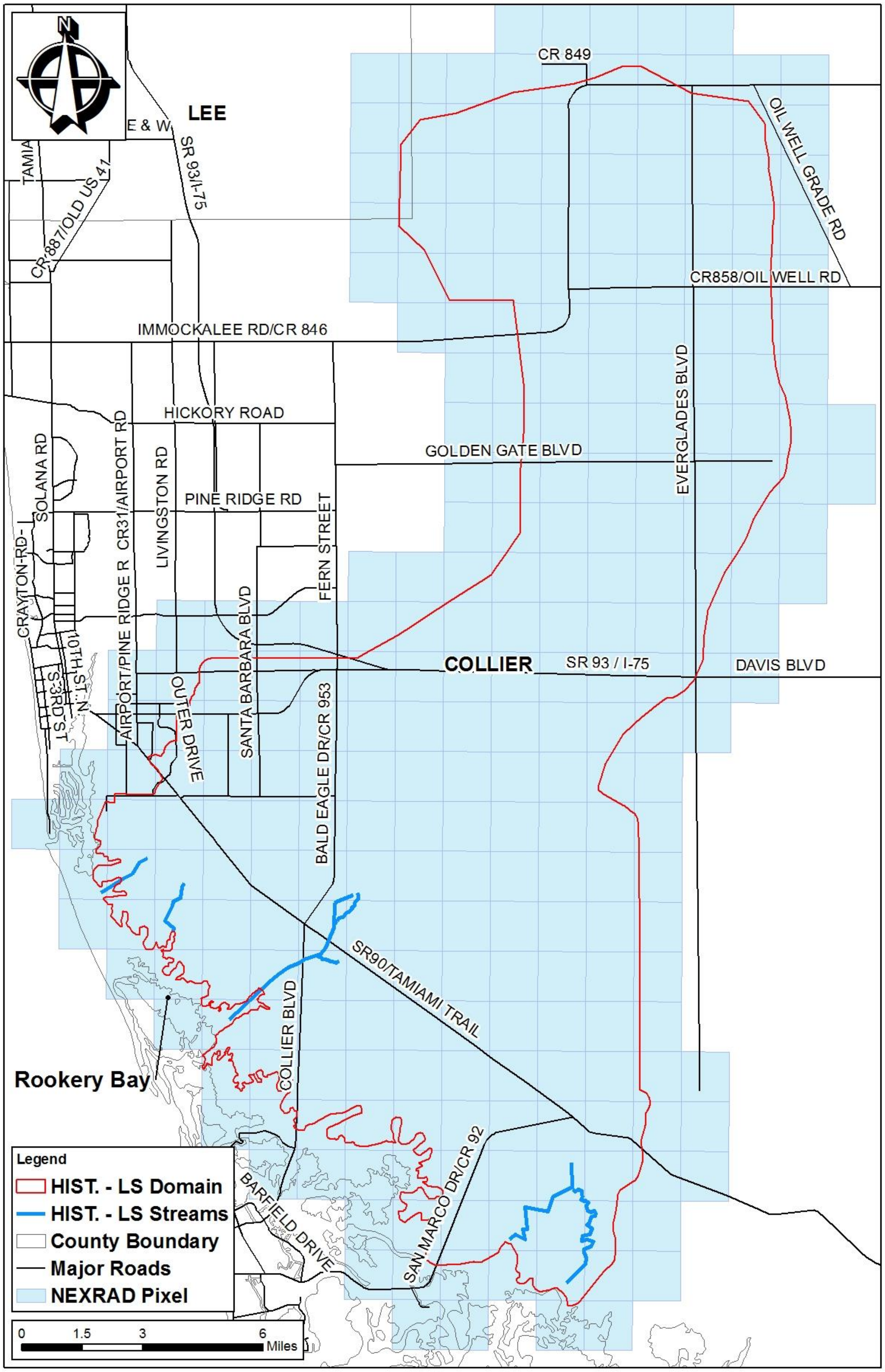


Figure 31. Historical-LSM Domain, NEXRAD Rainfall Pixel and USGS GOES RET Distribution

4.2.2 Topography

The Historical-LSM utilized a DEM developed by Interflow Engineering, LLC. The DEM, herein known as the "NSM Topography," was developed by many processes in ArcGIS using the advanced functions available within ArcToolBox.

The process started with the existing Collier County LiDAR (CC-LiDAR), flown in 2008, referenced in **Section 3.4** of this report. At the time of LSM (both Existing and Historical Conditions) development and the writing of this report, the 2008 CC-LiDAR data was the best and most recent available data. From the CC-LiDAR, areas of disturbance or manmade activity were identified and marked for removal. Examples of manmade disturbances are listed below.

- Developments/Urbanization
- Ditching/Draining/Canal Implementation
- Ponds (Retention/Detention)
- Mining
- Major Roadways
- Other activity judged to be un-natural (Examples include: Agricultural or Industrial)

Figure 77 presents the 2008 CC-LiDAR data in an unedited state, as well as the areas of disturbance identified as part of developing the NSM topography. As shown, there are many areas where the topographic data was removed and replaced. These areas were removed and replaced with data from the previously developed Regional Natural Systems Model (Regional-NSM). A few key areas of interest are I-75 and associated ditches on either side of the highway, as well as a few mining areas and large-scale developments generally located within the Lely Canal and Lely Manor basins as well as the Winding Cypress development in the Henderson Creek basin. Other areas shown in the northern portion of the Historical-LSM domain include mining, agricultural/industrial activity, and several large linear features, which are drainage canals and associated interconnections that were deemed appropriate for removal. These features were removed to ensure that the data would not influence calculations of the final NSM topography, which will represent the watershed in a "natural state." Through a combination of familiarity with the Henderson Creek watershed along with experience relating to DEM development and aerial photograph interpretation, as many disturbance features were removed as possible. The natural state DEM developed as the final product of this process was accomplished from the documentation provided here.

Once the disturbances were identified and deemed appropriate (i.e., not a natural topographic feature) these areas were eliminated from the CC-LiDAR DEM, creating a void or area of "No Data." From this newly created DEM, the topography used in the previously developed Regional NSM was used to fill in the gaps thus creating a new file which is a combination of the Collier County DEM with "No Data" and these "No Data" gaps partially filled with the Regional-NSM pre-development elevation data. **Figure 78** presents the LiDAR data with all areas of disturbance removed and the Regional NSM data inserted to be combined using a processes known as Focal Statistics, and is subsequently described later in this section.

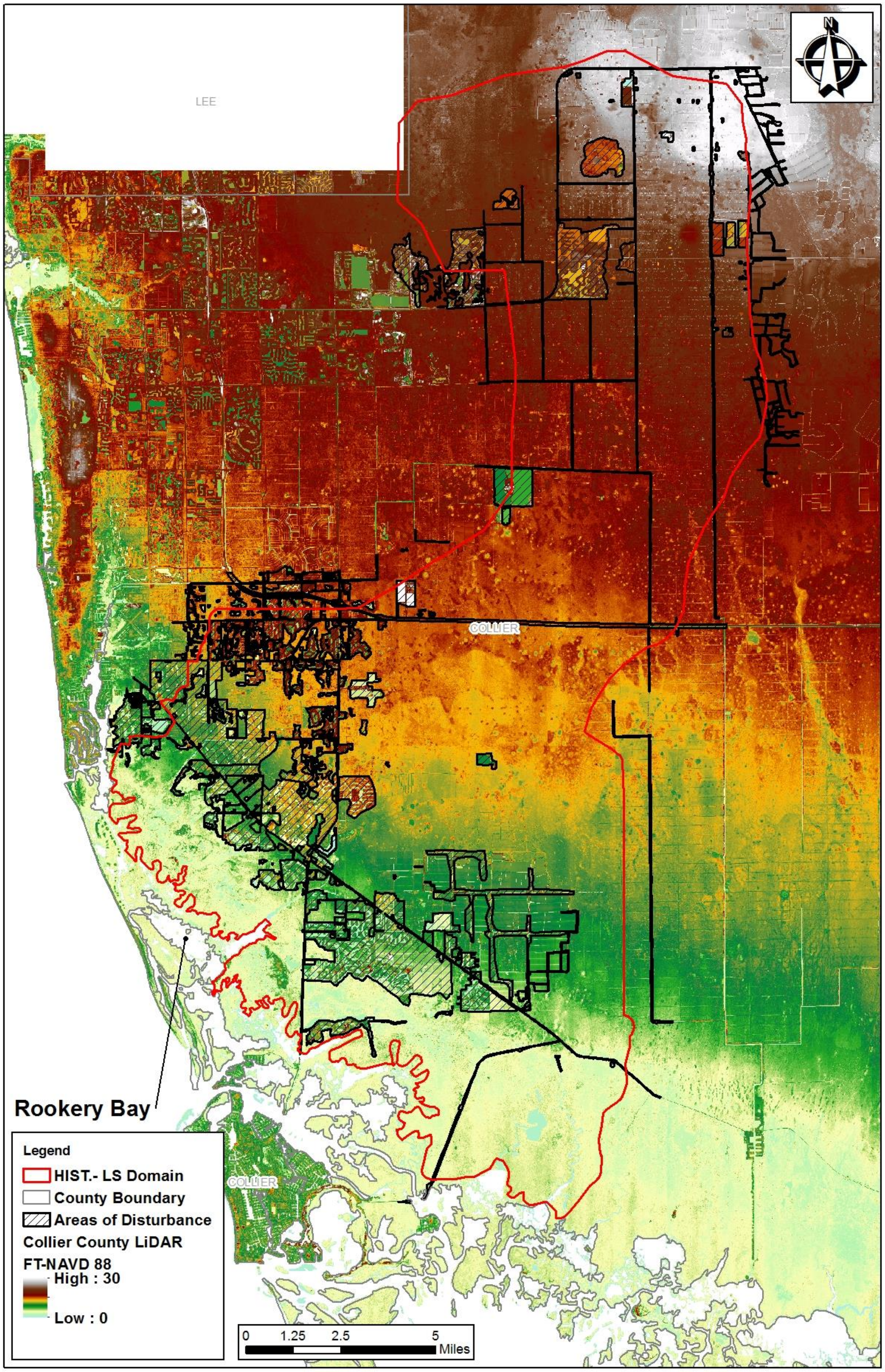


Figure 77. Areas of Disturbance Identified From2008 Collier County LiDAR

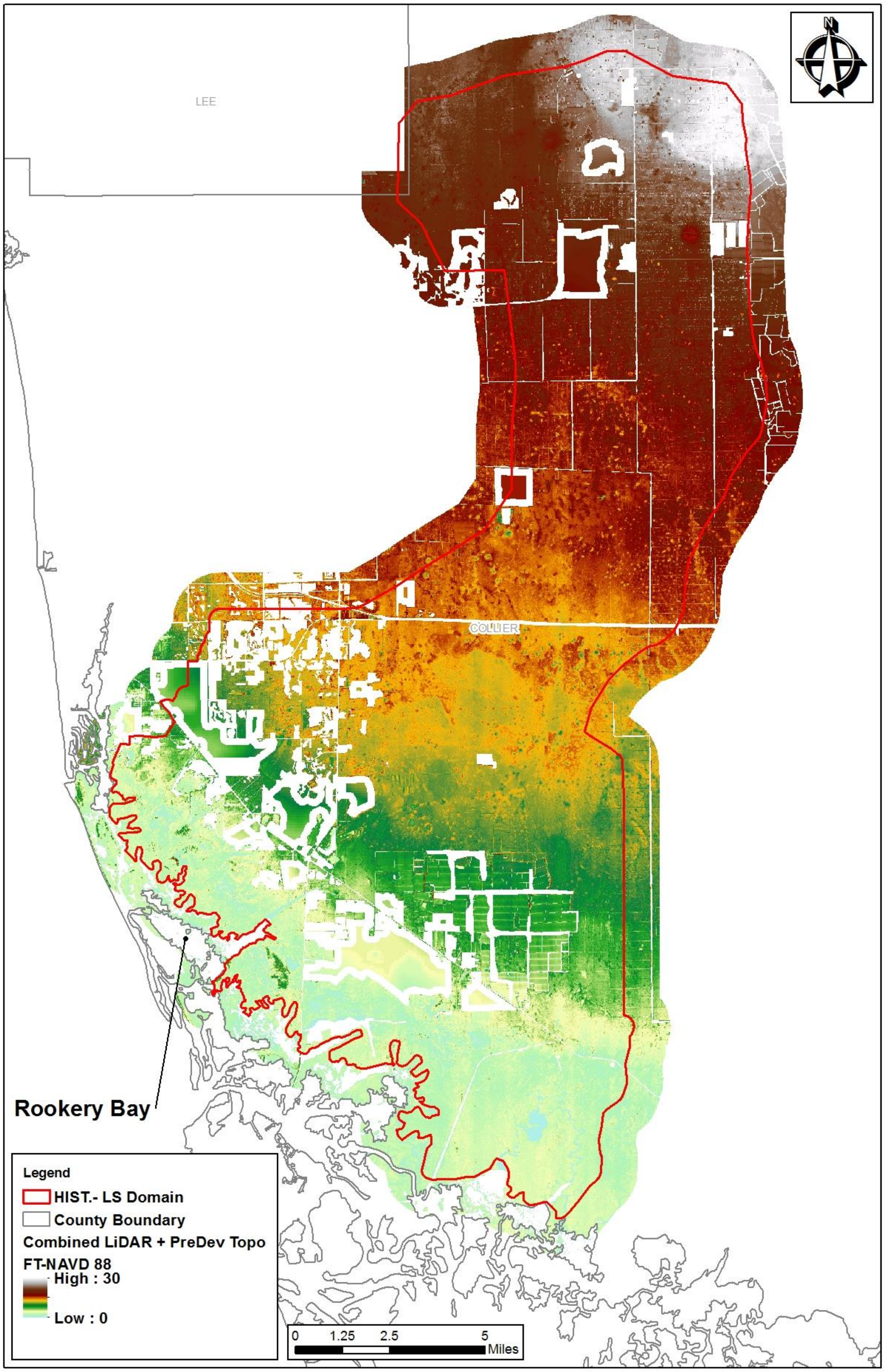


Figure 78. 2008 Collier County LiDAR Combined With 1500-ft Pre-Development Topography From The Regional-NSM

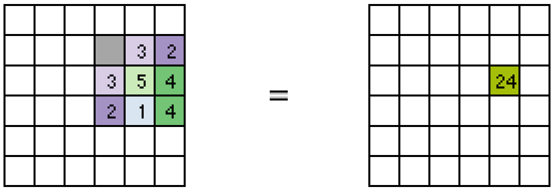
As shown in **Figure 78**, only interior portions of the "No Data" areas have been filled with the Pre-Development topography used in the Regional-NSM model at a 1500-ft grid resolution. The fact that these areas of "No Data" were partially filled is by design, allowing ArcGIS to process (via Focal Statistics) a smooth transition between the CC-LiDAR and the Regional-NSM predevelopment elevations. This transition was used to fill the gaps shown as white space in **Figure 37**.

Focal Statistics is a tool available in ArcToolbox, where a neighborhood operation computes an output raster with the value of each output cell a function of the values of all the input cells within a specified neighborhood around the cell location (ESRI, 2014 website accessed January, 2014).

From ESRI's website:

"Example

To illustrate the neighborhood processing for Focal Statistics calculating a Sum statistic, consider the processing cell with a value of 5 in the following diagram. A rectangular 3 by 3 cell neighborhood shape is specified. The sum of the values of the neighboring cells (3 + 2 + 3 + 4 + 2 + 1 + 4 = 19) plus the value of the processing cell (5) equals 24 (19 + 5 = 24). So a value of 24 is given to the cell in the output raster in the same location as the processing cell in the input raster.



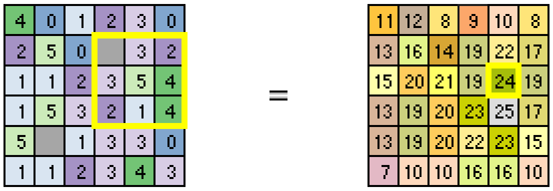
				3	2
			3	5	4
			2	1	4

Input processing raster

				24	

Output raster

The above diagram demonstrates how the calculations are performed on a single cell in the input raster. In the following diagram, the results for all the input cells are shown. The cells highlighted in yellow identify the same processing cell and neighborhood as in the example above.



4	0	1	2	3	0
2	5	0		3	2
1	1	2	3	5	4
1	5	3	2	1	4
5		1	3	3	0
1	1	2	3	4	3

Input processing raster

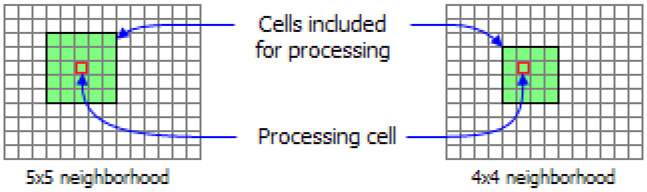
11	12	8	9	10	8
13	16	14	19	22	17
15	20	21	19	24	19
13	19	20	23	25	17
13	19	20	22	23	15
7	10	10	16	16	10

Output raster

- *Rectangle*
  - *The rectangle neighborhood is specified by providing a width and a height in either cells or map units.*
  - *Only the cells whose centers fall within the defined object are processed as part of the rectangle neighborhood.*
  - *The default rectangle neighborhood is a square with a height and width of three cells.*

- *The x,y position for the processing cell within the neighborhood, with respect to the upper left corner of the neighborhood, is determined by the following equations:*
  - *x = (width of the neighborhood + 1)/2*
    y = (height of the neighborhood + 1)/2
    If the input number of cells is even, the x,y coordinates are computed using truncation. For example, in a 5 by 5 cell neighborhood, the x- and y-values are 3,3. In a 4 by 4 neighborhood, the x- and y-values are 2,2.

- *Example illustrations of two rectangle neighborhoods follow:*



Focal statistics with rectangle neighborhood illustration

(Previous Examples:http://resources.arcgis.com/en/help/main/10.1/index.html#//009z000000r7000000)

The Focal Statistics tool provides four options to define the neighborhood. These options are user defined and chosen on a case-by-case basis. As such, the following options are presented here.

- Annulus (doughnut)
- Circle
- Rectangle
- Wedge

As the name implies, Focal Statistics calculates a statistical value for a specified distance (search neighborhood) where the user has control over which statistic is calculated within the neighborhood cells. Focal Statistics provides a statistical computation from the following calculation options: Mean, Majority, Maximum, Median, Minimum, Minority, Range, Standard Deviation, Sum, and Variety.

The currently developed Historical-LSM topography was developed employing Focal Statistics with a specification that calculation only occurred is areas of “No Data”, with the Rectangle Neighborhood method to calculate the mean statistic at a 10-ft resolution. **Figure 79** presents the 10-ft DEM with the mean statistic calculated for areas of “No Data” removed from the LiDAR.

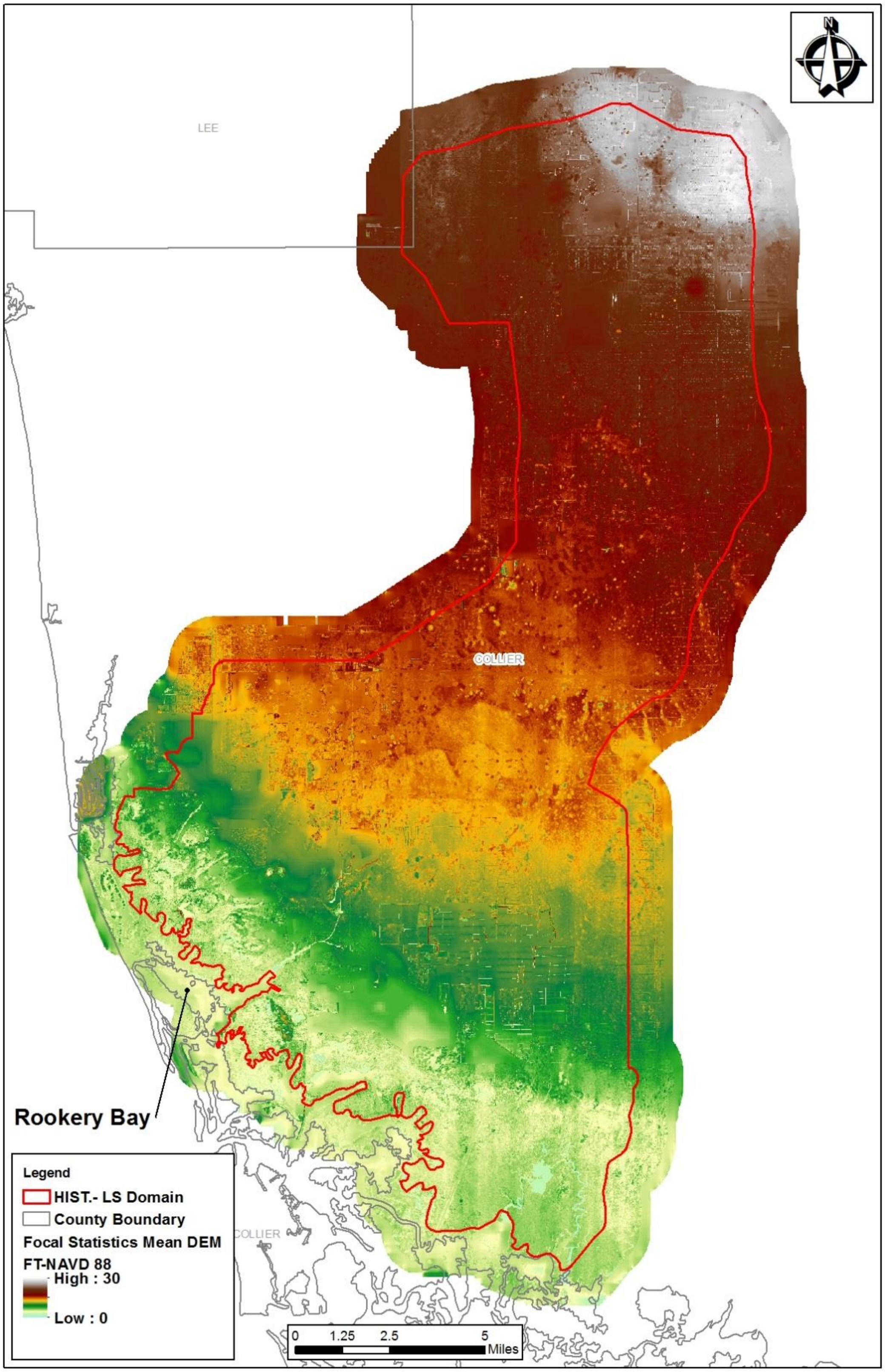


Figure 79. Combined CC-LiDAR+1,500ft Predevelopment DEM with Mean Focal Statistics Calculated for Areas of "No Data"

Figure 79 shows a seamless DEM representing the NSM-Topography from the stand point that no man-made disturbances are present and in general the topographic relief is south to southwest. The transition from the "No Data" areas to the existing CC-LiDAR is slightly evident, while the overall "natural topography" is well represented and no major flaws within the data are present. A major flaw would be a linear high or low feature within the DEM that would artificially influence overland flow or other processes within MIKE SHE.

Figure 80 presents a comparison of the DEM used in the Historical-LSM (Right Frame) against the raw or unedited CC-LiDAR (Left Frame). As noted in **Figure 80** with a zoomed-in view of a mined area, the mining pit shown has been removed from the Historical-LSM topography. This figure captures how the area was removed and a seamless transition has been developed where no disturbance is present and the topography represents a natural gently sloping terrain.

The newly developed topography represents the relief of the watershed as a whole (**Figures 79 and 80**); the DEM was further processed for use in the MIKE SHE model. Using zonal statistics, the median value was calculated from the combined DEM at a 10-ft grid cell resolution, to create a DEM with the previously defined grid-cell spacing of 375-ft. This grid cell size of 375 ft was chosen for the Historical-LSM because the previously developed Existing-LSM utilizes the same resolution on a similar land area (167-sq. mi for Existing-LSM and 255-sq. mi for Historical-LSM). Not only does this give the model the ability to accurately predict overland flow and other processes within the watershed, it also allows for a reasonable comparison between the LSM simulations (Existing vs. Historical) based on model grid-cell size and similarity in almost every other aspect of the model parameterization (see previous sections on: simulation period, climate, land use, unsaturated and saturated zone parameters).

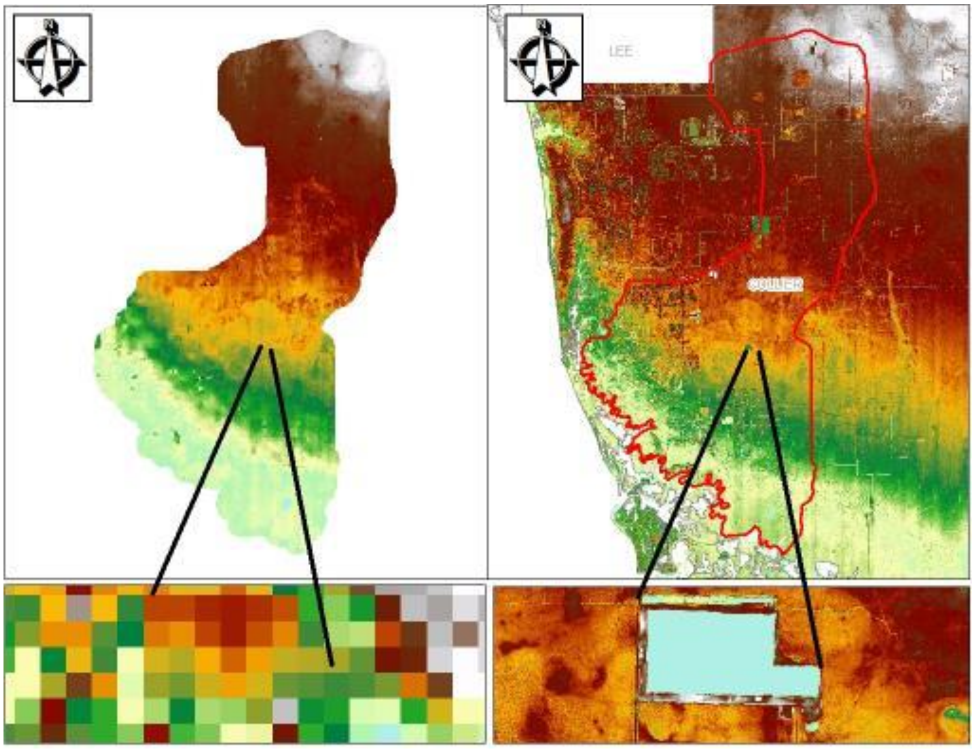


Figure 80. Comparison of the Historical Conditions DEM to Raw CC-LiDAR Data, With Call Out of Mining Area

Figure 81 presents the calculated median 375-ft resolution DEM developed as part of this current effort "Task 2.4," and used in the Historical-LSM. The figure clearly indicates that all manmade disturbances have been removed and a very detailed topography representing the watershed in a natural state has been developed for use in the MIKE SHE model.

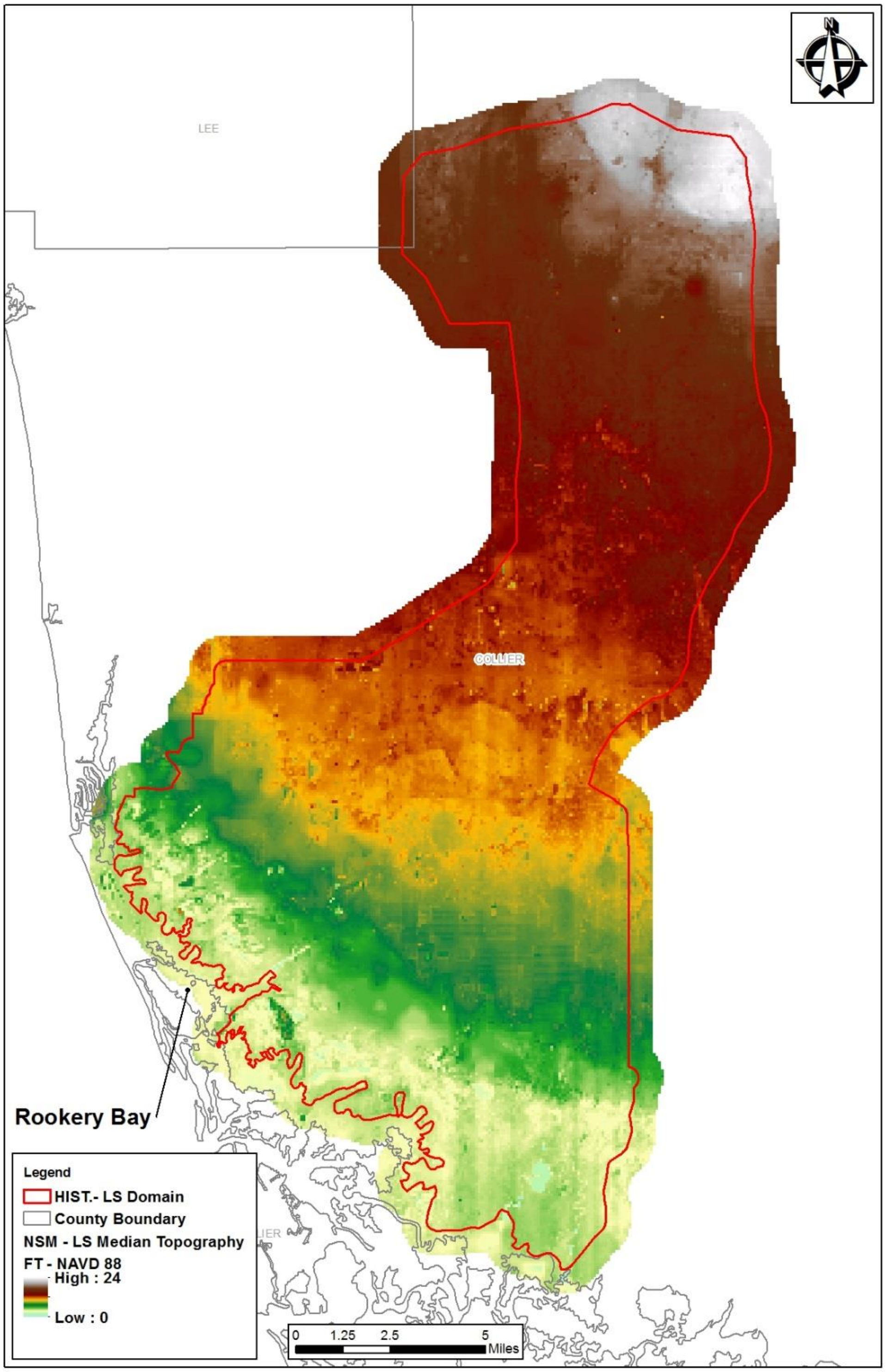


Figure 81. Historical Conditions Median Topography

4.2.3 Land Use

Land use parameters were updated for the Historical-LSM, where all vegetative files reflect the same coefficients as described in the LSM-Existing Conditions model set up (**Section 3.6.1**). The difference in land use lies in the aerial extent of the land use classifications, where all man-made classifications such as "Low Density Residential" or "Mining" are not present in the NSM model. The vegetation presented here was provided by the SFWMD (Duever, 2002) and has been accepted for use in modeling applications and other studies with the aim of determining the water budget or other aspects of the hydrologic cycle from a historic or unaltered/natural system. **Figure 82** presents the areal extent of land use for the Historical-LSM domain, while **Table 30** presents each land use classification and associated area and percentage of the watershed. As can be seen in **Figure 82** and **Table 30**, the majority of the model domain is characterized by Hydric Flatwood with Mesic Flatwood, Swamp Forest, Mangrove, and Cypress covering a large percentage of the remaining area within the watershed. In other words, over 76% of the Historical-LSM watershed is characterized by wetlands or other Hydric Forest land use types. This fact, combined with the vegetative arrangement evidenced in **Figure 82**, lends to the idea that this watershed was a low-velocity system (low slope, and high Manning's Roughness Coefficients) of interconnected sloughs and wetlands. Additionally, the Historical-LSM does not include a paved runoff coefficient because no development exists within the watershed under these conditions.

Figure 83 details the areal extent of land use types between the Historical- and Existing-LSM simulations, where the largest land use types in terms of individual percentages (33 and 22 % see **Table 30**) of the Historical Watershed are Hydric and Mesic Flatwoods respectively. The Existing-LSM shows more urbanization within the Lely Canal and Lely Manor Basins with other pockets of urbanization near US-41. Other major changes were conversion of Hydric Flatwoods to agricultural operations, the largest example of which is the 6-L's ranch just north of US-41.

Table 30. Historical-LSM Land Use Parameters, Associated Area, and Associated Overland Manning's M

LU Description	Area (acres)	Percentage of Watershed
Hydric Flatwood	55,313.08	33.87%
Mesic Flatwood	36,604.95	22.41%
Swamp Forest	24,088.89	14.75%
Mangrove	19,902.71	12.19%
Cypress	18,227.25	11.16%
Marsh	4,065.32	2.49%
Mesic Hammock	2,689.45	1.65%
Wet Prairie	942.07	0.58%
Water	779.02	0.48%
Xeric Hammock	591.06	0.36%
Scrub Cypress	113.94	0.07%

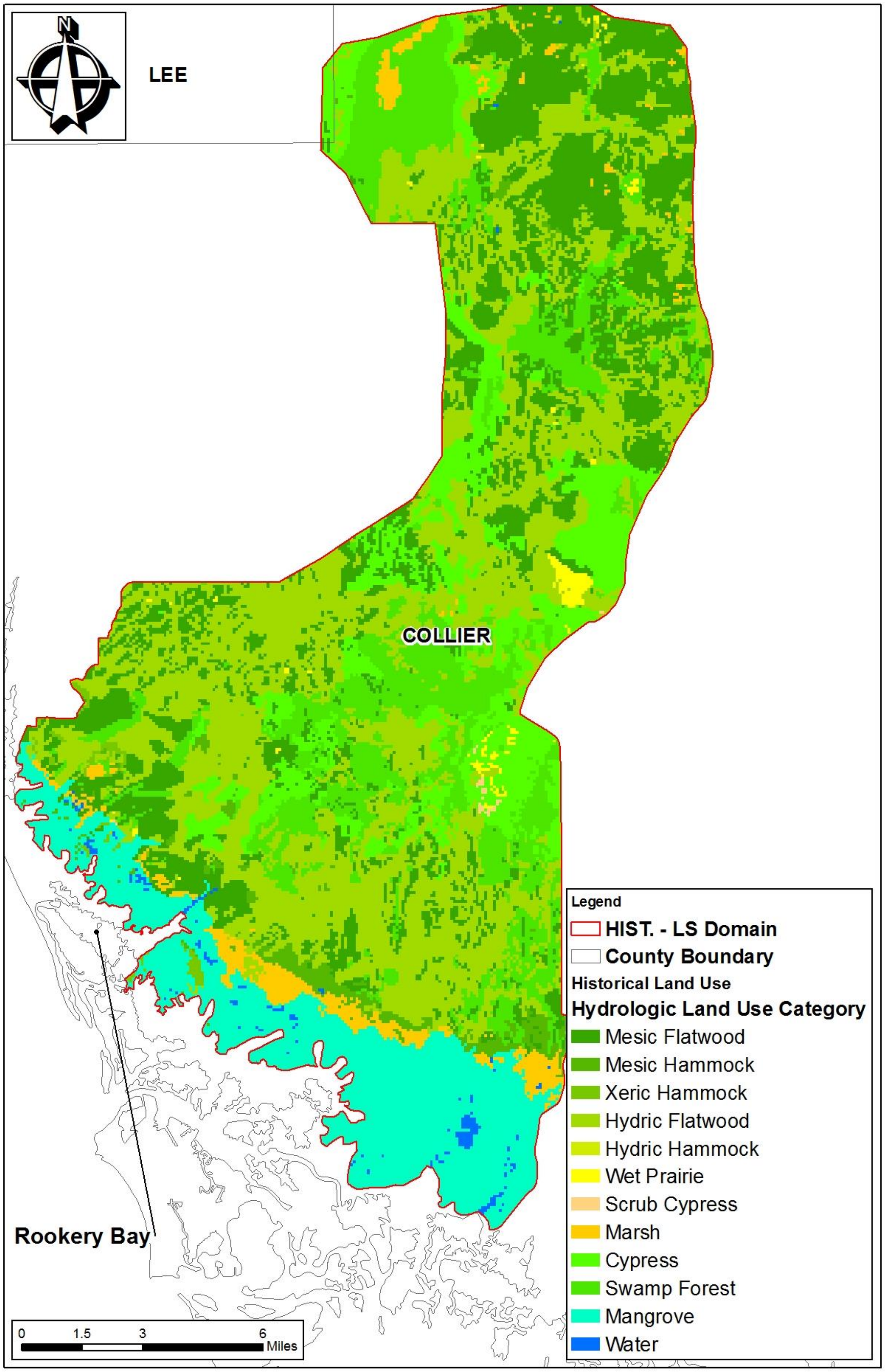


Figure 82. NSM-LS Domain and Vegetative Cover

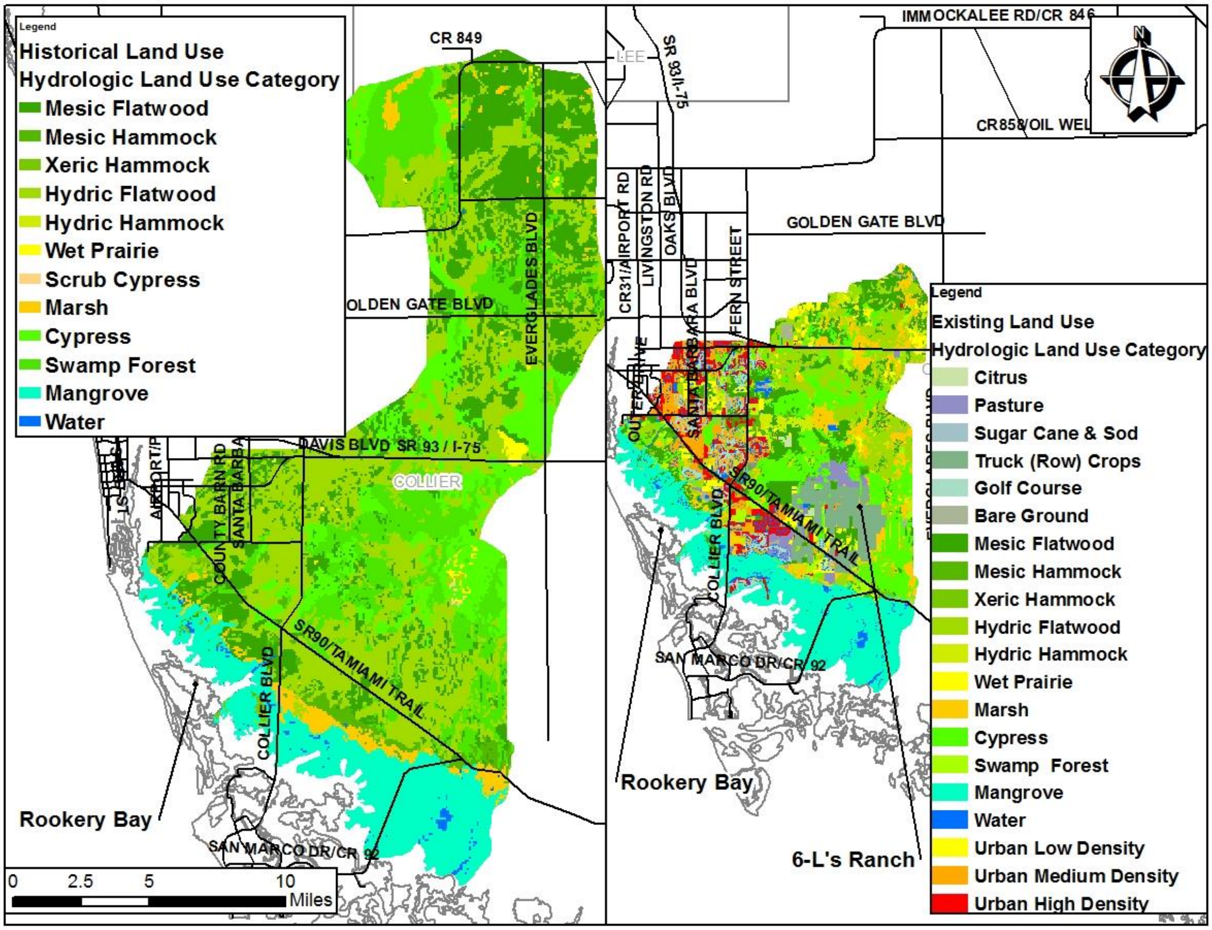


Figure 83. Comparison of Historical and Existing LSM Land Use Distributions

4.2.4 Overland Flow

The overland flow parameters were adopted from the Existing-LSM simulation. For the Historical Conditions models (Regional and Local Scale), the Manning's M overland parameterization were the same between all models for natural systems land use types. All Urban Land grid codes were removed as shown in **Figures 82 and 83,** as discussed in **Section 4.2.3- Land Use**. **Table 31** presents the Overland Manning's M Coefficient of roughness as a function of land use type, as well as the percentage of the watershed covered by the respective roughness coefficient. As shown, the most restrictive land use is "Marsh" with a roughness coefficient of 2.33 or a Manning's n (1/M) roughness coefficient of 0.43. These values fall within the range of roughness coefficients for the varying land use types and have remained consistent between all simulations presented in this Report.

Table 31. Overland Manning's M by Land Use

LU Description	Percentage of Watershed	Overland Manning's M
Hydric Flatwood	33.87%	4
Mesic Flatwood	22.41%	5
Swamp Forest	14.75%	2.5
Mangrove	12.19%	5
Cypress	11.16%	3.33
Marsh	2.49%	2.33
Mesic Hammock	1.65%	3.33
Wet Prairie	0.58%	3.33
Water	0.48%	16.67
Xeric Hammock	0.36%	5
Scrub Cypress	0.07%	3.33

The Historical-LSM uses a uniform value of 0.39 inches for detention storage and does not include individual separated flow areas because no berms or other man-made impoundments/restrictions existed in the natural condition. Rather, water is applied to the land surface and that which does not infiltrate into the unsaturated zone will build up and either pond or travel within the watershed as overland flow.

4.2.5 Unsaturated Zone (Soils)

Soils within the Historical-LSM domain were also developed from the "sosrunt" shapefile obtained from the SFWMD (See **Section 3.1.5** for a complete discussion on this data). The "sosrunt" shapefile is the same data used for the Existing-LSM, with the only differences being the spatial extent of the soils within the watershed as the Historical-LSM domain has been extended further north to capture the historic flows from the Henderson Creek watershed, and the fact that all "Urban Land Complex" soils and "Open Water" due to mines or ponds were determined to be similar to the adjacent soils near each specific area where the soil was modified. **Figure 84** presents an example of these aforementioned soils, which were changed as a part of the historic/natural systems model development, in addition to the area shown (a mining pit with industrial area surrounding) are the soils used in the Historical-LSM. As shown in **Figure 84,** these areas of urbanization and or mining operations are in pockets throughout the watershed and have been removed to ensure all man-made artifacts of the soil have been excluded from the MIKE SHE model. This allows the model to calculate the infiltration capacity and soil moisture characteristics of the soils across the land surface in an accurate manner due to the removal of said artifacts. For example: a retention pond will hold water on the land surface, allowing no infiltration thereby increasing the available water for evapotranspiration. Conversely, most urban areas and golf courses have been built up and soils have been altered to a point to increase infiltration. In addition to an accurate representation of the unsaturated zone, it was important to maintain consistency between the models to rule out any unsaturated zone effects when comparing the results of each simulation.

When comparing Existing to Historical Conditions, the soils distribution are largely the same (not including urban and other disturbed areas), come from the same source, and have been designed as such (to facilitate a fair comparison to the Existing-LSM). Therefore, a detailed discussion of soil parameters will not be given here, rather the aerial extent over the Historical-LSM watershed is presented in **Figure 85** and the percentage of the watershed covered by each soil classification presented in **Table 32.**

Table 32. LS-NSM Soil Summary

Soil Type -Drainage Class	Area (acres)	Percentage of Watershed
Pineda Sand - Poorly Drained	114,086.72	69.86%
Plantation Muck - Very Poorly Drained	47,111.32	28.85%
Satellite Fine Sand - Some What Poorly Drained	1,115.08	0.68%
Open Water	577.29	0.35%
Pomello Fine Sand - Moderately Well Drained	390.49	0.24%
Paola Fine Sand - Excessively Drained	36.85	0.02%

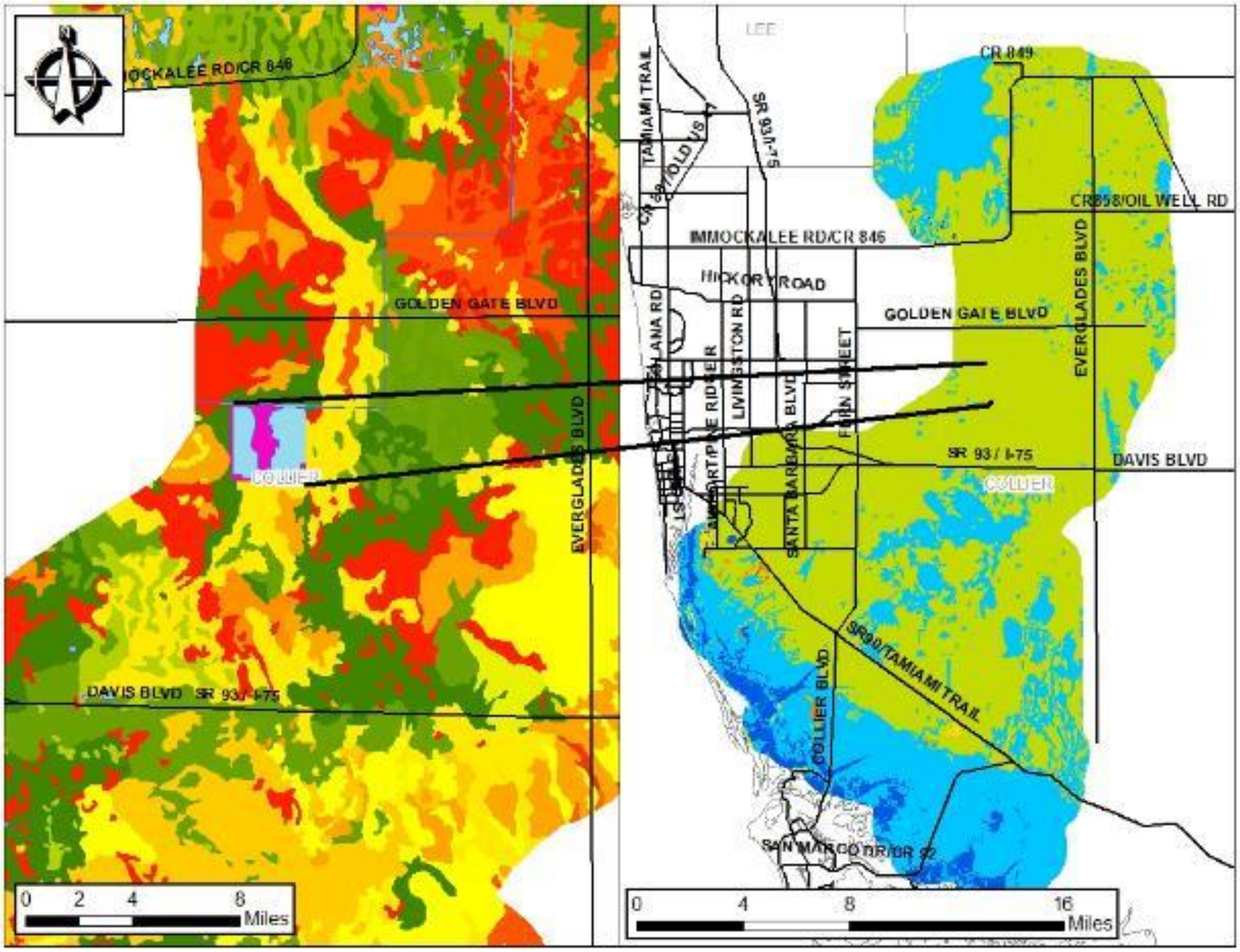


Figure 84. Soil Comparison Existing Conditions vs Historical (Note Mining Pit and Lateral Drainage Canals Removed From Historical Conditions Soil Definitions)

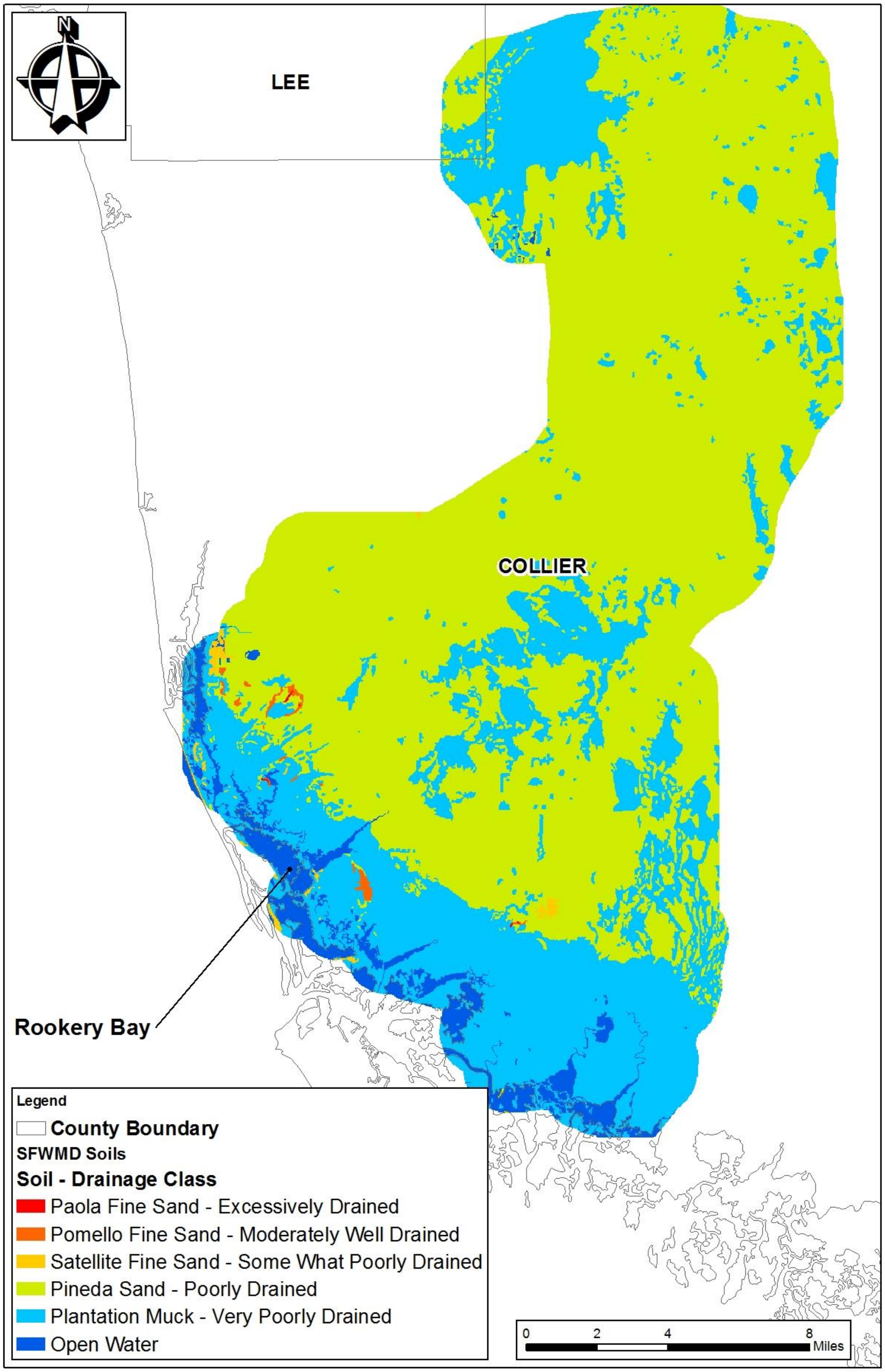


Figure 32. Historical Conditions Soil Distribution (Modified From SFWMD Soil Data)

As shown in **Figure 85** and **Table 32**, the watershed is dominated by Pineda Sand and Plantation Muck, classified as Poorly Drained and Very Poorly Drained respectively. This is not surprising as the LS-ECM has the same order in terms of soil type and drainage classification distributed throughout the watershed. The main difference between the historic and existing condition model parameterization for the unsaturated zone was the removal of urban land use and open water soil classifications to represent the historic condition.

4.2.6 Saturated Zone

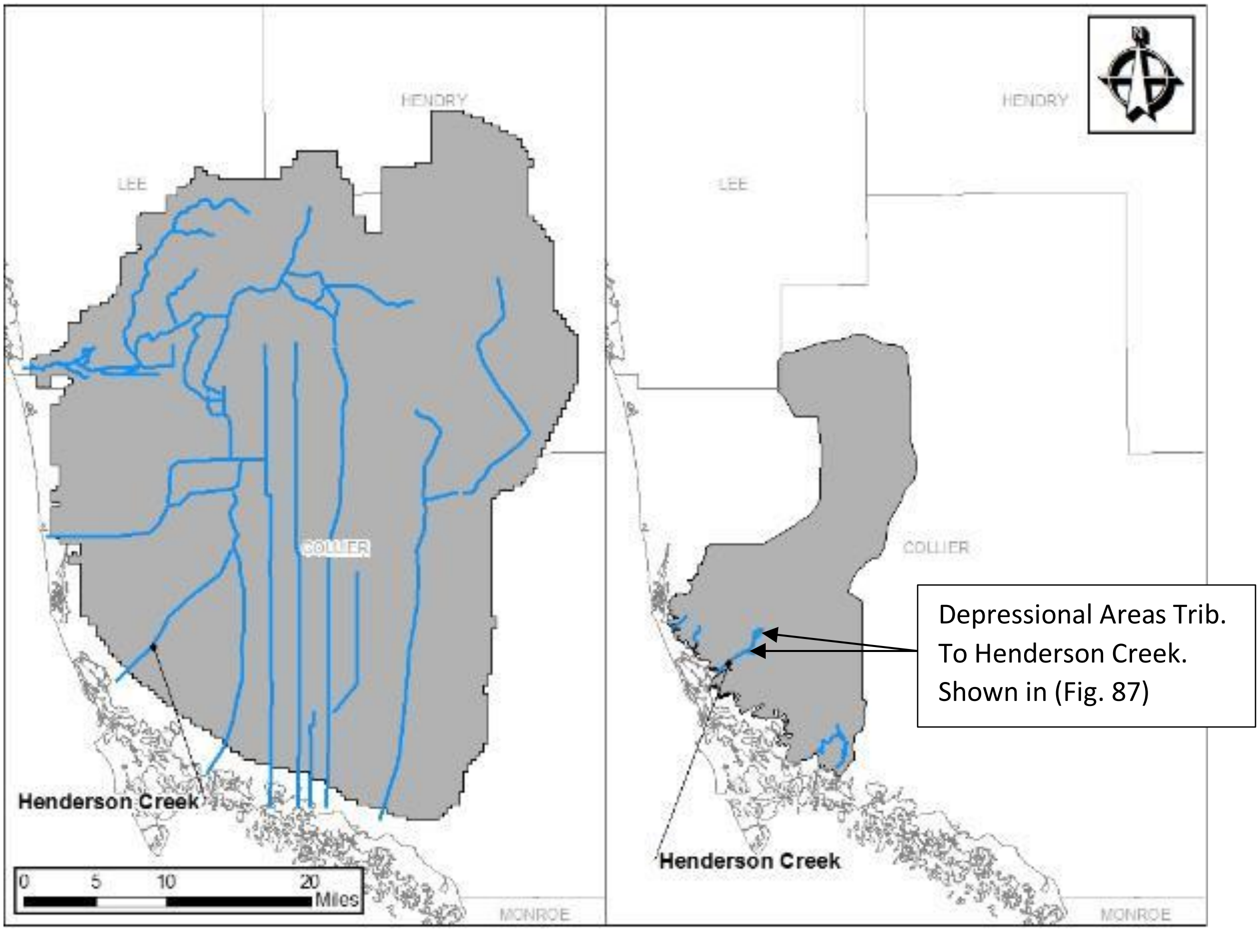
The BCB-NSM was previously developed with eight Geological Layers and has been refined for this current study to have the same saturated zone parameters as the CC-ECMv2 simulation as reported in **Section 2.1.4**. As was the case with the CC-ECMv2 model, the purpose of this BCB-NSM simulation was to provide boundary conditions for the LS-NSM. Therefore, the BCB-NSM simulation was run with the exact parameters and boundary conditions as the CC-ECMv2 (for a complete discussion on the saturated zone parameters please see **Section 2.1.4**. Because both Regional Scale models utilize the same parameters as discussed earlier, no new discussion of the saturated zone parameters within the BCB-NSM will be presented here. However, it should be noted that no well field withdrawals were included in either historical conditions model (BCB-NSM or LS-NSM) because this is a man-made occurrence to develop the groundwater resources.

Similar to the Existing-LSM development, the Historical-LSM, uses the same saturated zone parameters with the following exceptions (where the Existing-LSM contains the following features while the Historical-LSM does not):

- Wellfield withdrawals
- Saturated Zone Drainage
- Irrigation

4.3 Task 2.4. MIKE-11 Revisions: Regional and Historical-LSM Models

The MIKE-11 stream network of the BCB-NSM model, with a network of 34 streams, has been reduced to 7 streams for the Historical-LSM simulation. **Figure 86** presents a comparison of the stream networks for the BCB-NSM (Right Frame) and Historical-LSM (Left Frame), and as shown, the stream network has been vastly reduced. The only remaining stream from the BCB-NSM network is the “Henderson Creek,” with the addition of two tributaries shown to contribute to Henderson Creek as well as the tidal segments of the Lely Canal, Lely Manor, Bridge 39, and Bridge 39E from the Existing-LSM.



Depressional Areas Trib. To Henderson Creek. Shown in (Fig. 87)

Figure 86. BCB-NSM, Historical-LSM Stream Network Comparison

The tributary streams were noted after LiDAR and aerial photograph review, where these tributaries represent low points within the Belle Meade Flow-way with clear paths to Henderson Creek. **Figure 87** presents the alignment of Henderson Creek with the aforementioned tributaries shown where depressions within the topography are noted and thought to contribute flow to Henderson Creek. Please note that the linear feature running north/south is an FPL crossing, which does not show up in the DEM used in the Historical-LSM, rather the DEM shown in **Figure 87** was chosen to allow for enough detail to exemplify the depressions which convey water to Henderson Creek.

Furthermore, the additions of the Lely Canal, Lely Manor, Bridge 39 and Bridge 39E (**Figures 88 -89**) from the Existing Conditions Models, were included as the aerial photographs show a natural stream channel leading to the tidal/coastal boundary of the model for each of these channels. **Figure 88** presents the Lely Canal downstream of the “Lely Main Canal Spreader” (LCB-00-S0050), and the Lely Manor Canal downstream of the “Manor South Weir” (LMB-00-S0100), where both canals appear to be formed from natural processes (tidal fluctuations and bank scour from upstream runoff) draining to Dollar and Sand Hill Bays respectively.

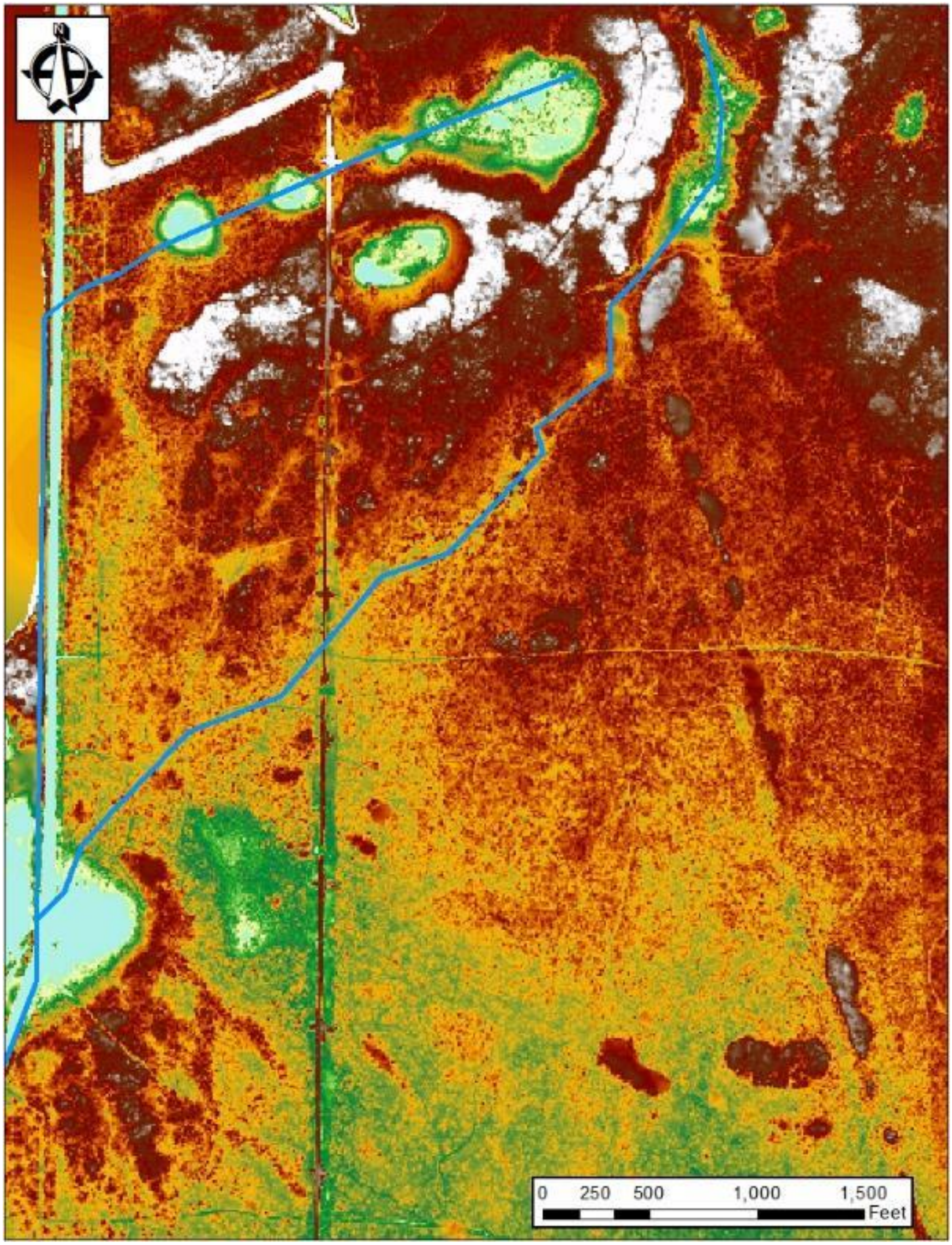


Figure 87. Depressional Areas Shown to be Tributary to Henderson Creek

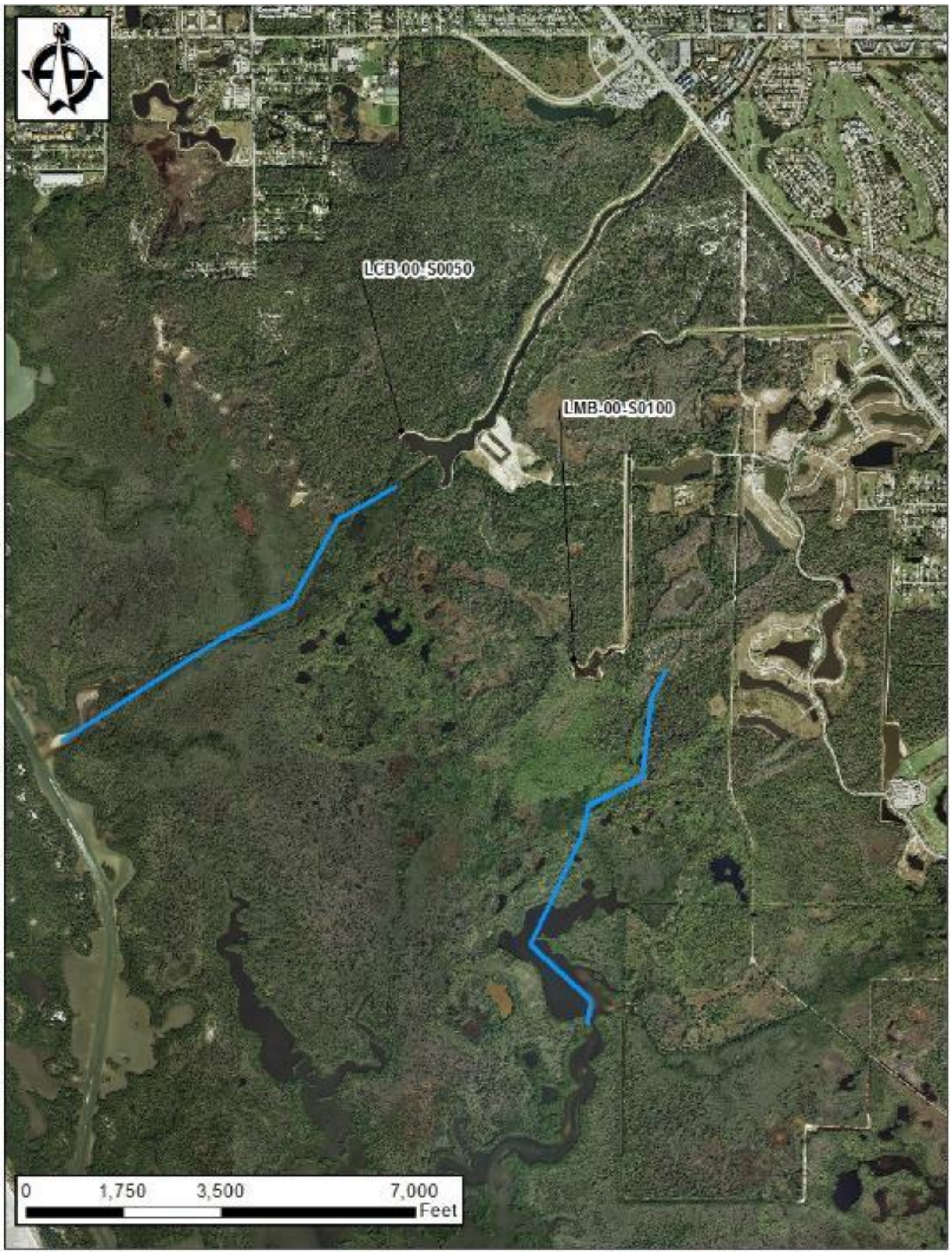


Figure 88. Tidal Streams Included in The Historical-LSM, Near Lely Canal and Lely Manor Basins

While the names “Bridge 39 and Bridge 39E” imply man-made canals, aerial photograph interpretation reveals that these streams are natural and have not been channelized (straightened) or dredged to a certain point. **Figure 89** presents the alignment of Bridge 39 and 39E stream segments, where Bridge 39 is shown to be a natural channel about 4,200 ft downstream of the Collier Seminole Boat Basin draining through Mud Bay, to Palm Bay while Bridge 39E is a branch of Bridge 39, conveying water south/south east to Blackwater Bay.

Figure 89. Tidal Portions of Bridge 39 and 39E

4.4 Task 2.4. Historical-LSM Results and Discussion

This section presents and compares results of the Historic-LSM with simulated flows and levels from the Existing-LSM at selected locations. The simulated comparisons here provide insight into how anthropogenic alterations may have changed the hydrology of the Henderson Creek/Rookery Bay watershed. The Historical-LSM was run for the same time period as the previously described Existing-LSM. As previously noted, important aspects of the model setup were held constant between the Existing and Historical conditions LSM models to provide scientifically defensible comparisons between Existing and Historical Conditions. Care was taken to ensure that differences in model outputs between the two models, as presented in this section, are solely attributable to anthropogenic changes in the watershed.

A model is our best representation of a system. While checks have been made to ensure that the rainfall and potential ET data is reasonably accurate, and that the physically based parameters are reasonable and within acceptable ranges of these parameters, the model has a level of uncertainty built in. Uncertainty is inherent in all models and comes from a number of sources including, but not limited to

- Measurement error in model forcing functions (e.g., rainfall, ET variables),
- Parameter estimation error, and
- Imperfect mathematical and numerical solutions representing complex hydrologic processes.

The Existing LSM has been compared to measured data in the recent past to assess the predictive capability of the model. However, there are no available measurements of flows and water levels pre-dating the major hydrologic alterations in the watershed. Considering the uncertainty inherent in the model development and the lack of historical flow data, the Historical-LSM model results should not be viewed as a record of past flows and levels. Rather, these results should be viewed as an informed but imperfect hindcast of the flows and levels that may have occurred historically under climatic conditions similar to those of the recent 10-year period of 2003 – 2012. It is therefore recommended to focus on the general trends of the hydrology to understand how the system responds to these anthropogenic changes.

4.4.1 Water Budget Comparisons

Total water budget and surface water comparisons were made between the two simulations (Existing vs Historic). **Figure 90** [figure number provides a graphical depiction of the Historic-LSM water budget over the period of 2003-2012, while **Table 33** provides a comparison with the corresponding results from the Existing LSM. The table indicates that the precipitation varies slightly when compared against the Existing-LSM, as is to be expected due to the differences in the geographic extent of each model domain. Additionally the Evapotranspiration (ET) was shown to be about 3 inches/year higher on average in the Historic-LSM, which shows about 45 inches/year of ET. This is also to be expected as the historic model domain is dominated by wetland and upland land use types. Furthermore, total runoff from the model was reduced by about 0.4 inches/year in the Historic-LSM, largely due reductions in both Baseflow and Drainage to river, while total Overland Flow (including boundary flow) was increased to 10.2inches/year or about 5.5inches/year more than existing conditions. These results are to be expected and considered reasonable as more water is thought to have been available to overland flow historically due to the absence of ditching and draining found throughout the watershed under existing conditions. Groundwater baseflow is higher in the Existing Conditions due to the presence of drainage canals, which penetrate into the highly permeable surficial aquifer.

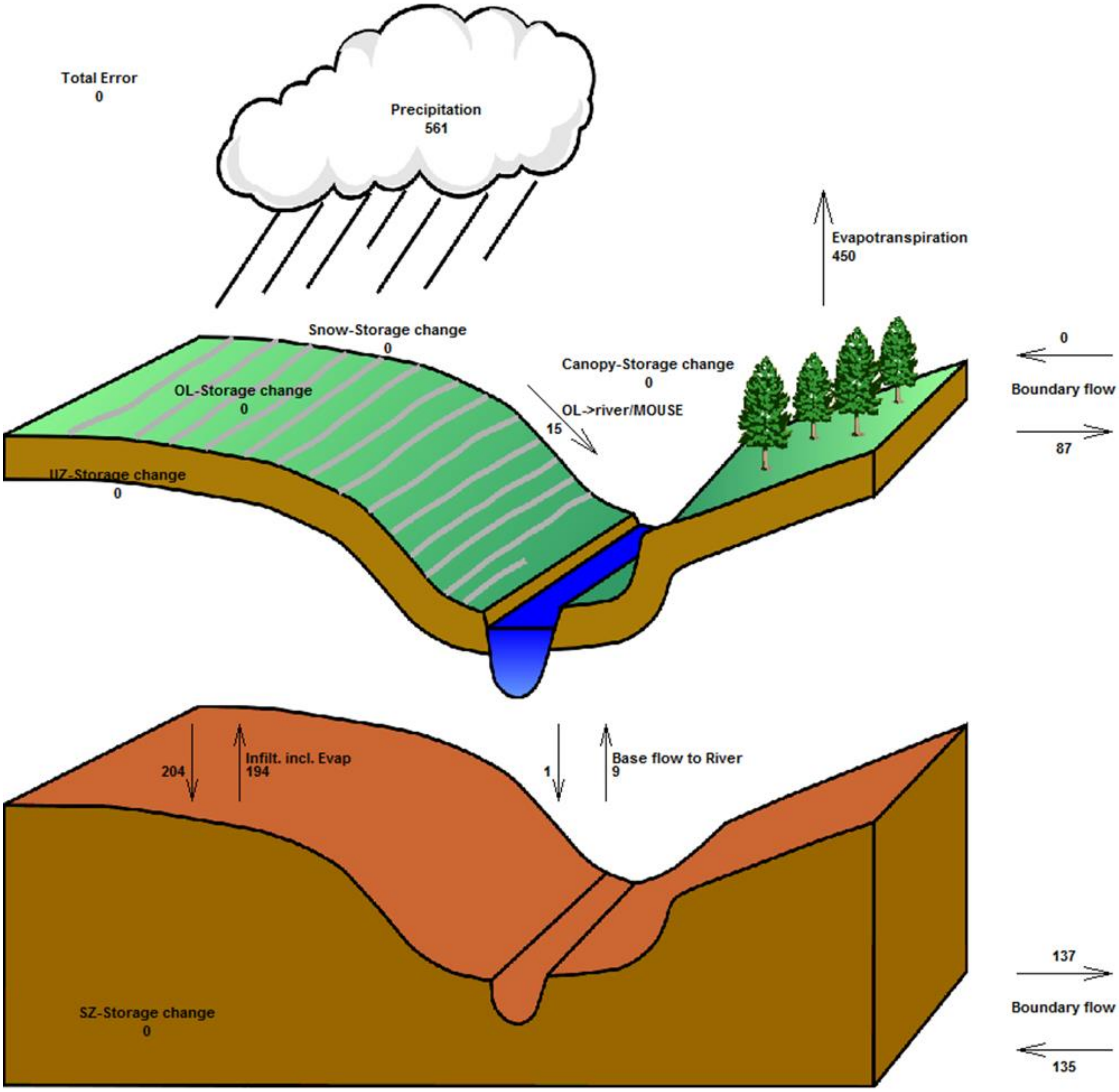


Figure 90. Total Water Balance Historic-LSM Domain (2003 through 2012)

Table 33. Water Budget Comparison, Existing and Historical Conditions

Water Budget Component	Existing Conditions (inches per year)	Historical Conditions (inches per year)
Rainfall	55.7	56.1*
Irrigation	2.2	0
Evapotranspiration	42.0	45.0
Overland flow to streams and canals	2.2	1.5
Groundwater baseflow to streams and canals	6.6	0.8
Overland flow to boundary	2.5	8.7
Pumping	2.3	0
Deep percolation	1.9	0.2

* Rainfall difference is due to contributing area in historical conditions

Comparisons of surface water flows to Rookery Bay and the surrounding estuarine waters were made for locations shown in **Figure 91,** where the results from the Existing-LSM are compared to the Historic-LSM simulations for the period of 2003 through 2012. **Figure 91** presents color-coded MIKE-11 inflow points as well as the alignment of their corresponding coastal transects based upon upstream contributing basins (Lely Main, Lely Manor, Henderson Creek, BelleMeade-9, US-41 Outfall Swale No-2, and Bridge 37). The combination of the MIKE-11 inflow points and their corresponding coastal transect is considered the total inflow to the estuarine areas. The MIKE-11 inflow locations provide point discharges. Distributed flows from the 2-D overland flow plane are determined at the coastal transect locations and added to the MIKE-11 flows to get the total flow into each of the six coastal basins.

The graphics presented here have been completed for each coastal basin as shown in **Figure 91,** and include graphical comparisons of the following flow statistics developed for the period of 2003 through 2012.

- Average Monthly Flows (average month-of-year flows for all 10 years)
- Flow Duration Curves (percent of time flows are equaled or exceeded)
- Cumulative Flow Plots
- Daily Flows

Water depth analyses were completed for locations of the green and red stars (**Figure 91**), which represent depressions within the northern and southern portions respectively, of the Belle Meade Flow-way. Analyses presented for the Belle Meade Flow-way include

- Time series plots of daily depths of overland water
- Depth-duration of overland water depth
- Stage-duration of water table aquifer elevation

The analyses were performed for the Belle Meade Flow-way to gain an understanding of the existing and historical water levels, which can provide a comparison of hydroperiods between the models for the selected points. This analysis can also provide insight to how this part of the watershed has responded to construction of hydrologically significant features such as I-75 and the Henderson Creek Canal.

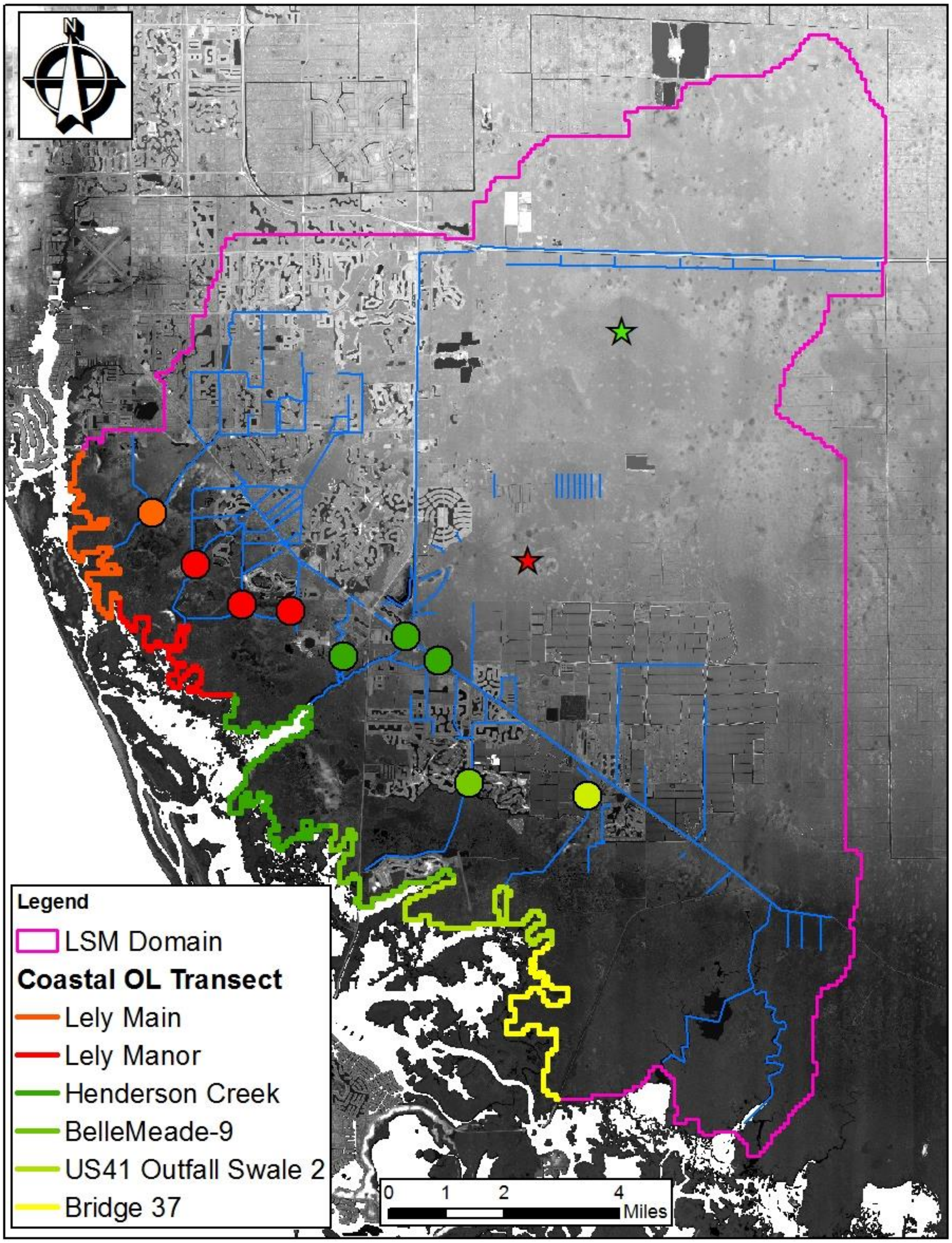


Figure 91. Model Comparison Locations

4.4.2 Comparisons of Surface Water Flows to the Estuary

4.4.2.1 Lely Main Flow Analysis

The Lely Main area is characterized by urban residential development and infrastructure associated with the City of Naples metro area. In the graphs that follow, the general trend that is evident is the increase in both low flows and high flows as a result of this urbanization (**Figures 92** and **94**). Urbanization tends to cause an overall increase in runoff volumes due to the construction of impervious surfaces, such as pavement and rooftops, which limit infiltration. Impervious surfaces can also cause decreases in ET (as compared to vegetated land covers). Reductions in ET may be manifested as higher flows, as the overall water balance must be maintained.

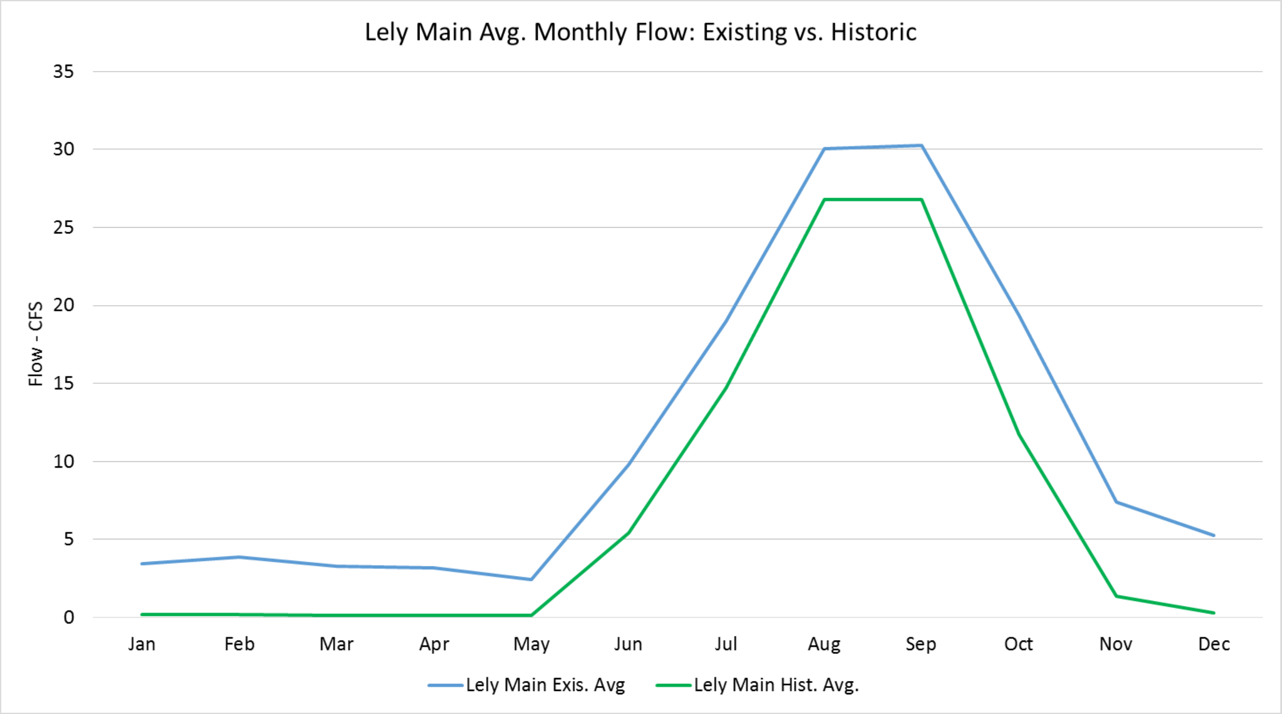


Figure 92. Lely Main Monthly Average Flows

Although the impervious surfaces are the most likely reason for the increase in flows, the increase in dry season flows could be partially an artifact of the channelization in the area, allowing drainage of the aquifer (via baseflow) over an extended period (**Figures 92** and **93**).

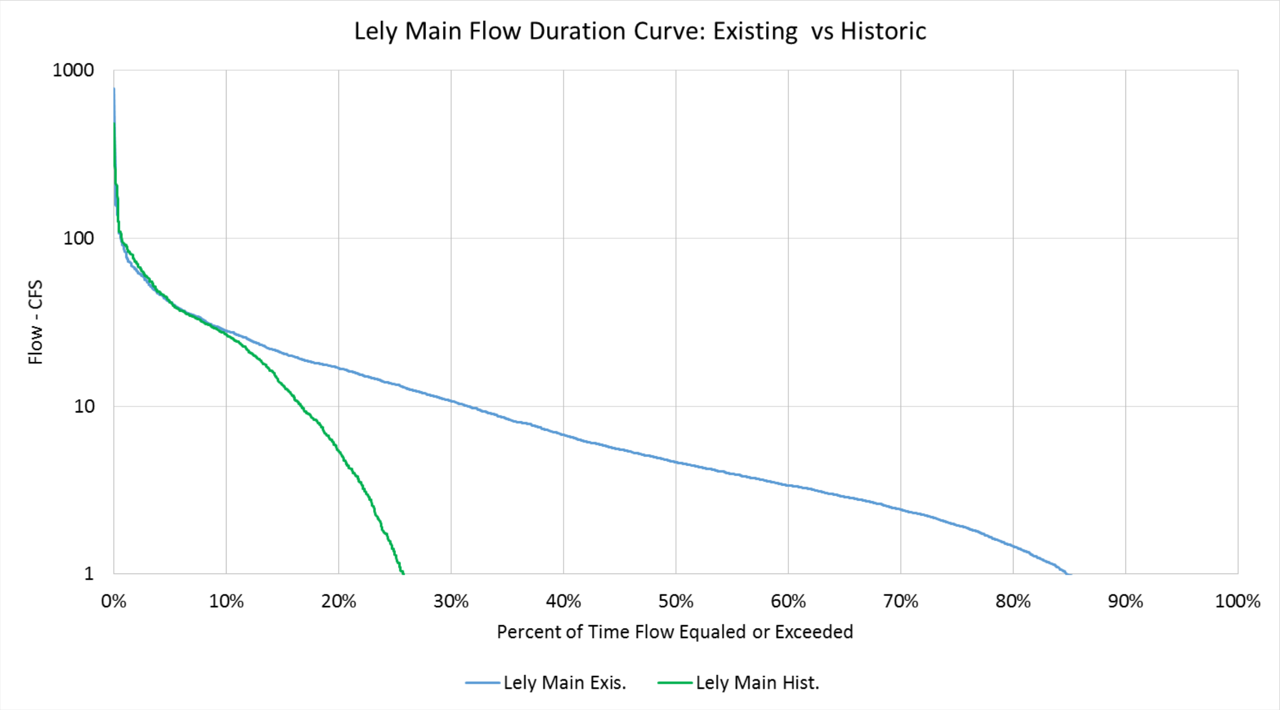


Figure 93. Lely Main Analysis Flow Durations

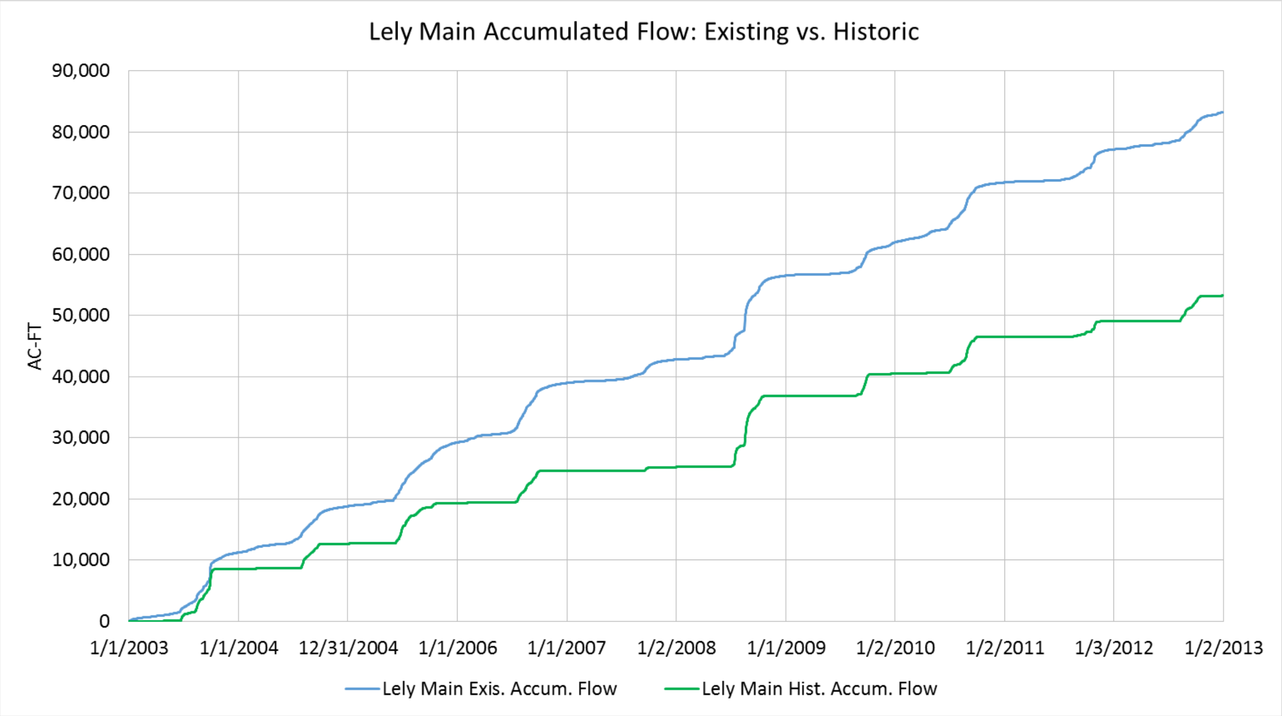


Figure 94. Lely Main Cumulative Flows

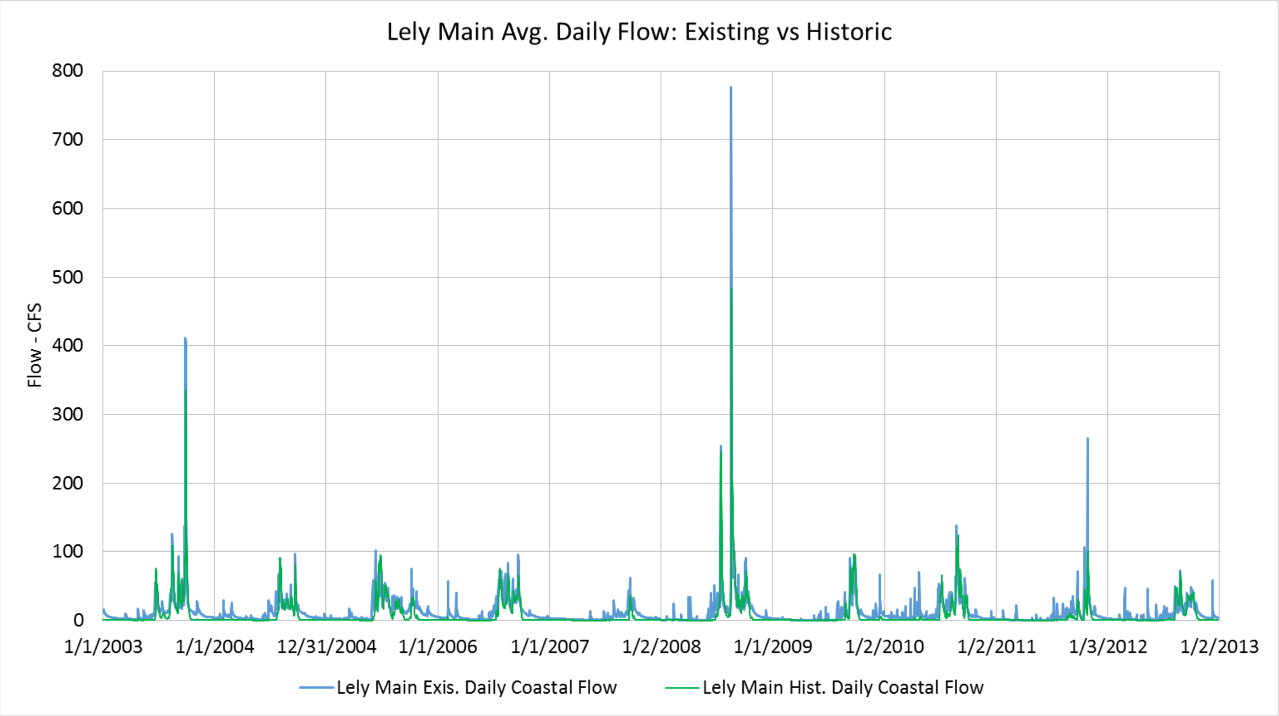


Figure 95. Lely Main Daily Flows 2003-2012

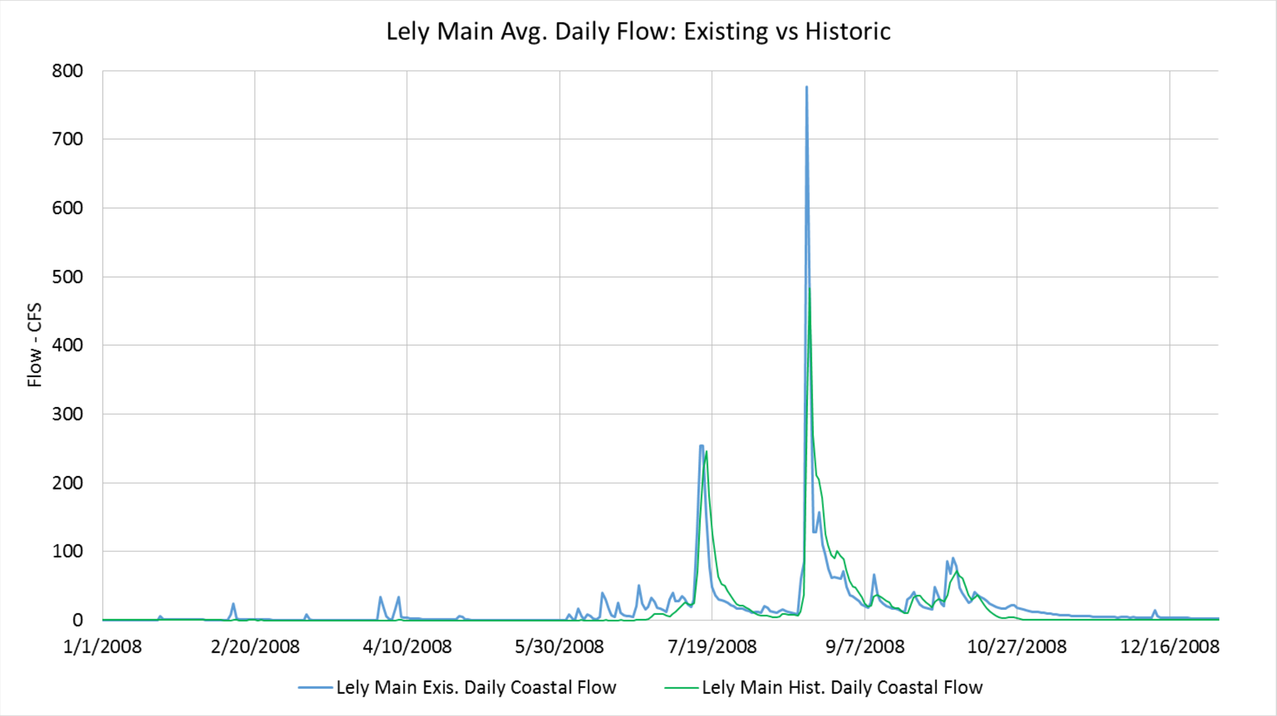


Figure 96. Lely Main Daily Flows 2008

As presented in the previous figures, freshwater flows from the Lely Main basin show a pattern that is consistent with an urbanized environment with an increase in flow both seasonally and in cumulative volume (**Figure 94**). Additionally, the system responds in a flashier manner to storm events (small and large), exemplified in Lely Main Analysis **Figure 96,** which provides a closer examination of simulated flows in 2008. The existing conditions streamflow response to small rainfall events in the drier months of January through June can be attributed to the increase in impervious surfaces that are directly connected to a stormwater collection system.

4.4.2.2 Lely Manor Flow Analysis

Similar to the Lely Main comparison, the Lely Manor coastal basin appears to contribute more flow overall to the coast currently than it did historically, although to a smaller degree. The difference in overall flow to the coast is attributed to differences in the dry season (**Figure 97**) as the dry season and early wet season flows have increased slightly according to the model results. While the wet season averages are similar in terms of peak flow conditions (August-September), the monthly flow patterns have shown a shift, where dry season flows contribute higher flow rates over longer time periods (**Figure 98)**. These higher flows over time have led to a greater volume of cumulative freshwater deliveries to the bay according to model results (**Figure 99)**.

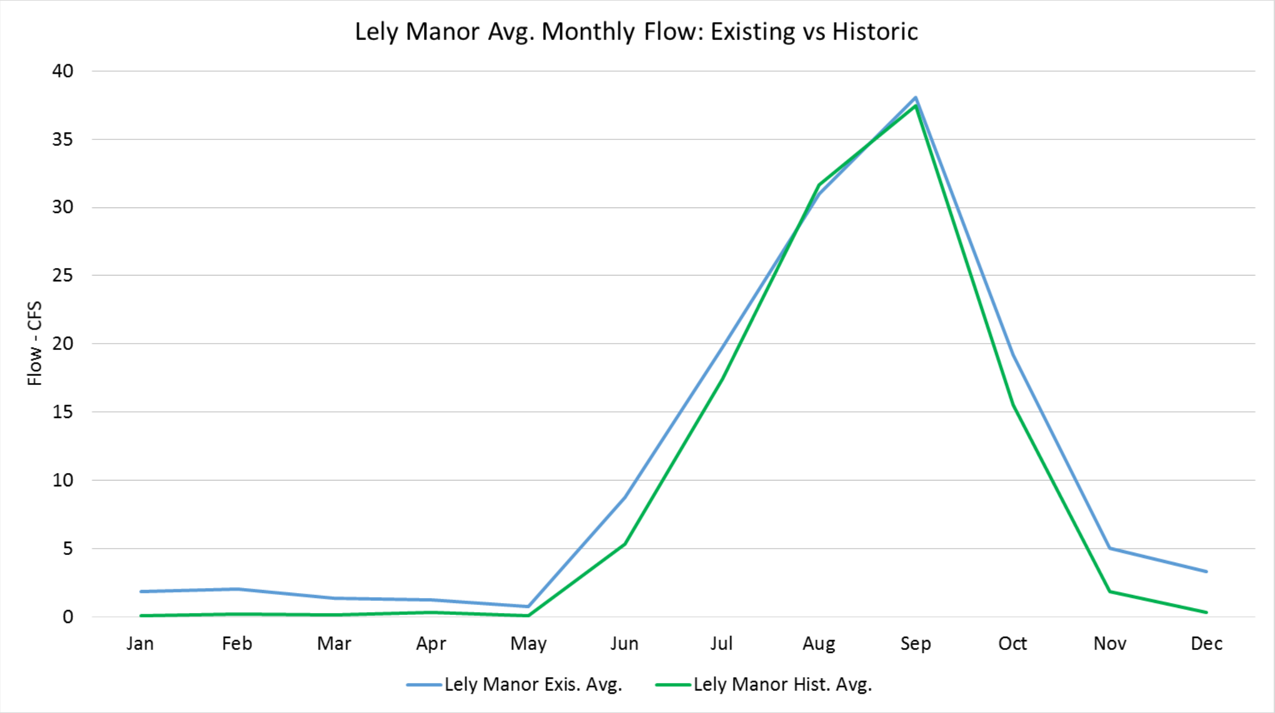


Figure 97. Lely Manor Average Monthly Flows

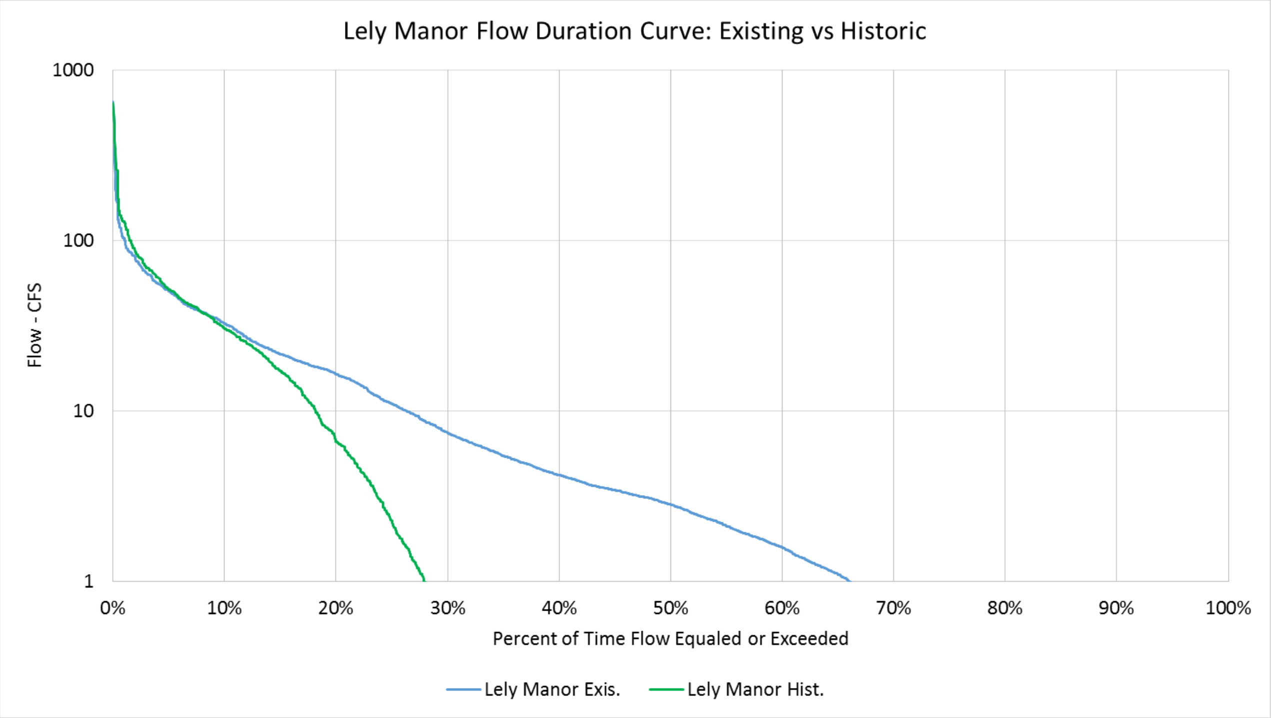


Figure 98, Lely Manor Flow Duration Curves

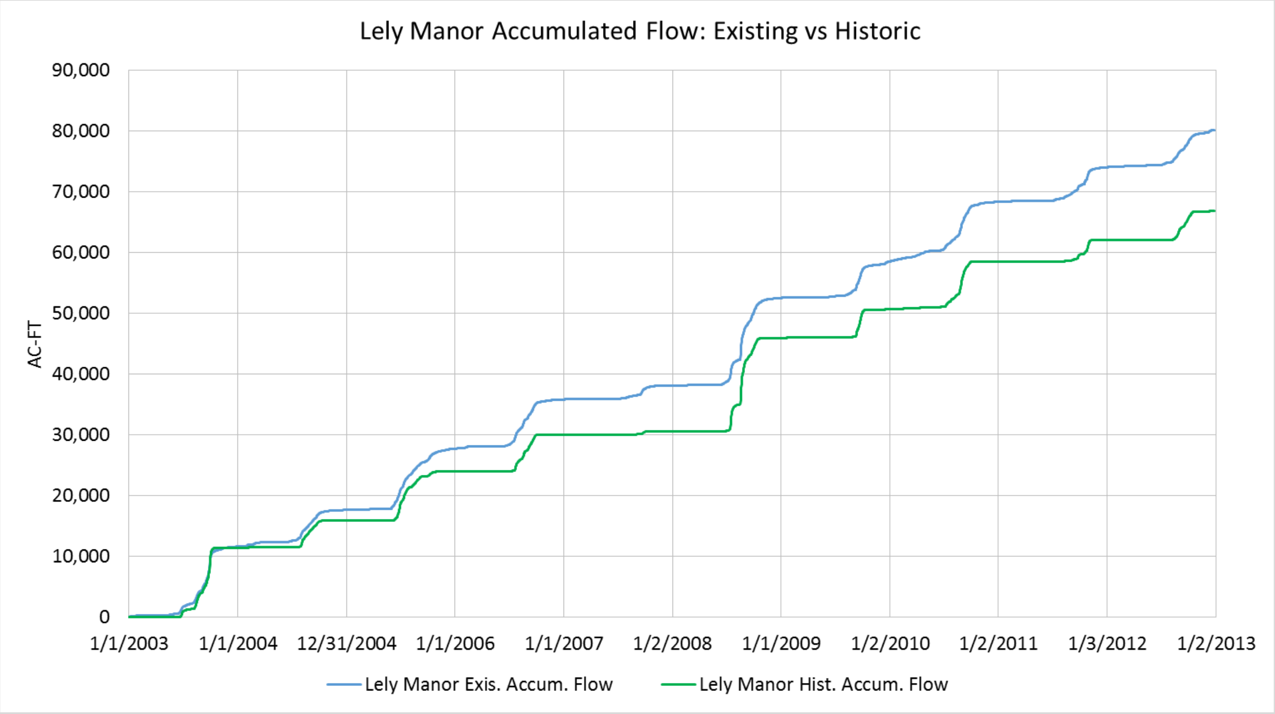


Figure 99, Lely Manor Cumulative Flow Volumes

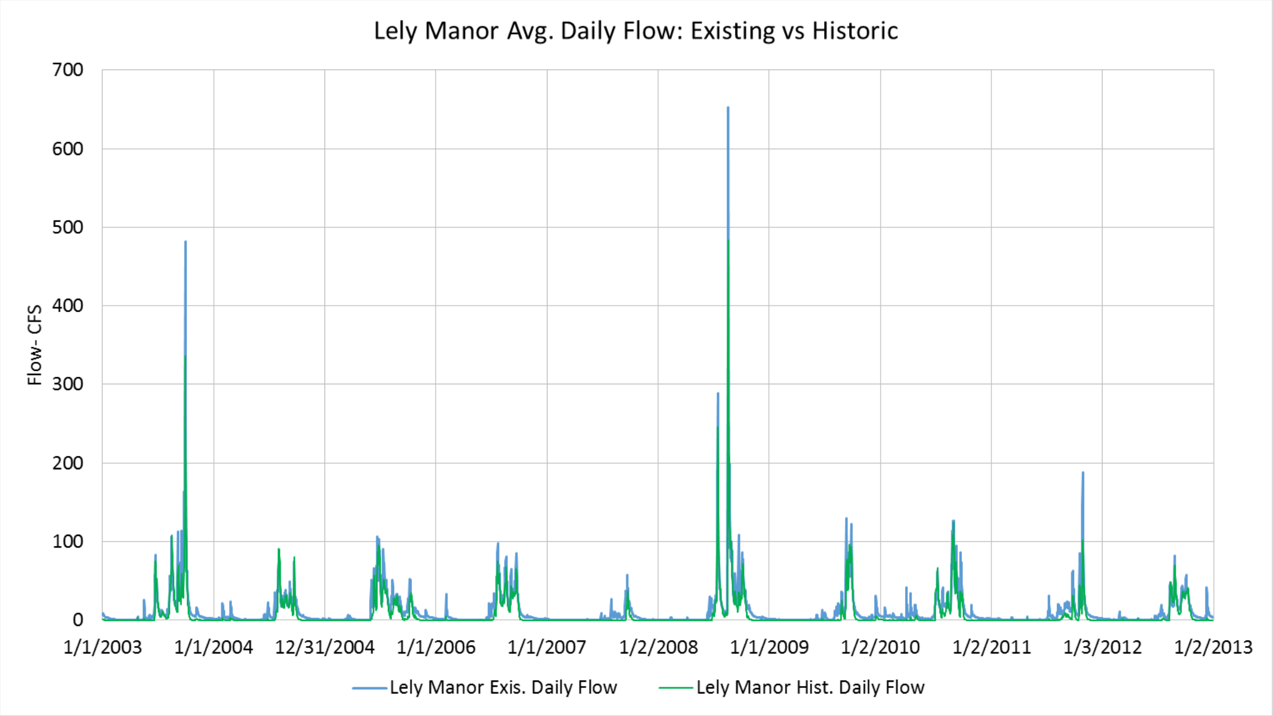


Figure 100. Lely Manor Daily Flows (2003-2012)

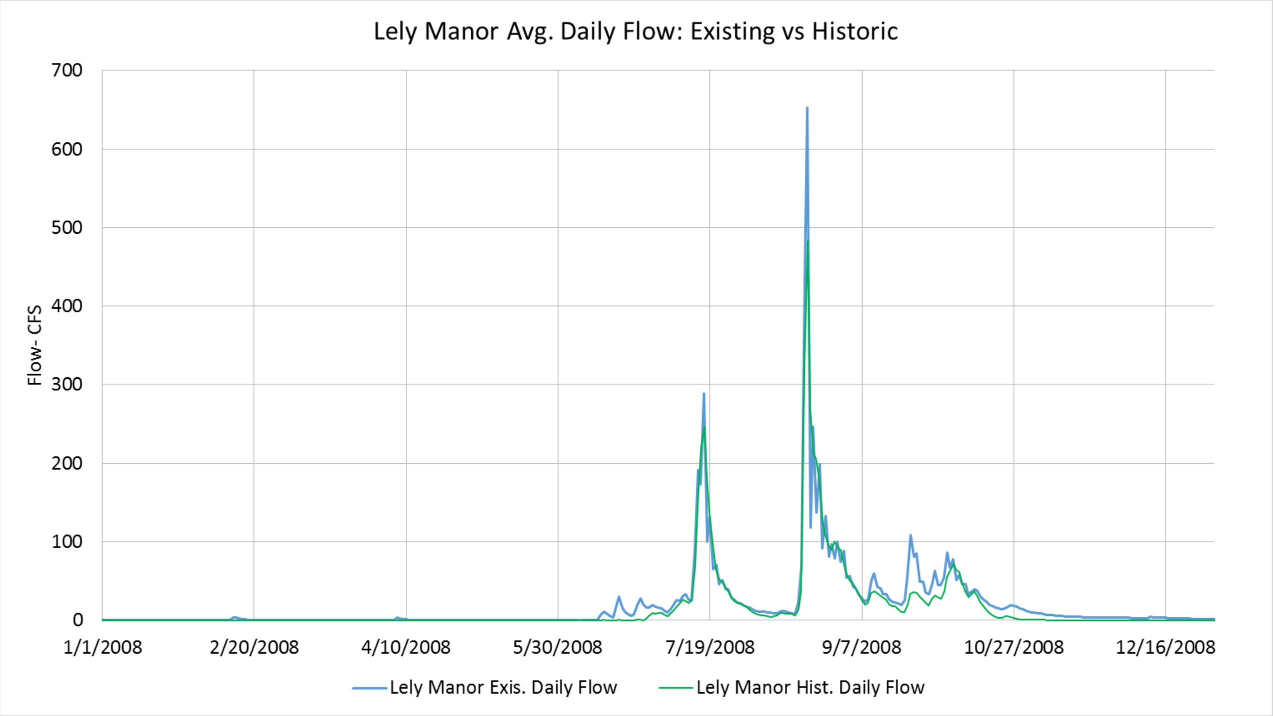


Figure 101. Lely Manor Daily Flows (2008)

Similar to the Lely Main area, The Lely Manor basin exhibits slightly longer flow durations at the low end of the flow curves (**Figure 98**). As was hypothesized in the Lely Main analysis, this may be due to the addition of impervious surfaces combined with the effects of channelization.

4.4.2.3 Henderson Creek Flow Analysis

In addition to the combined basin/transect analyses presented for the other coastal basins, The Historical-LSM was compared against the Existing-LSM at the Henderson Creek gage location upstream of US-41. This location was chosen as there is a reliable period of flow records corresponding to the simulation period. **Figure 102** presents a comparison between the Existing and Historic-LSM simulations of the average monthly flow in Henderson Creek, upstream of US-41.

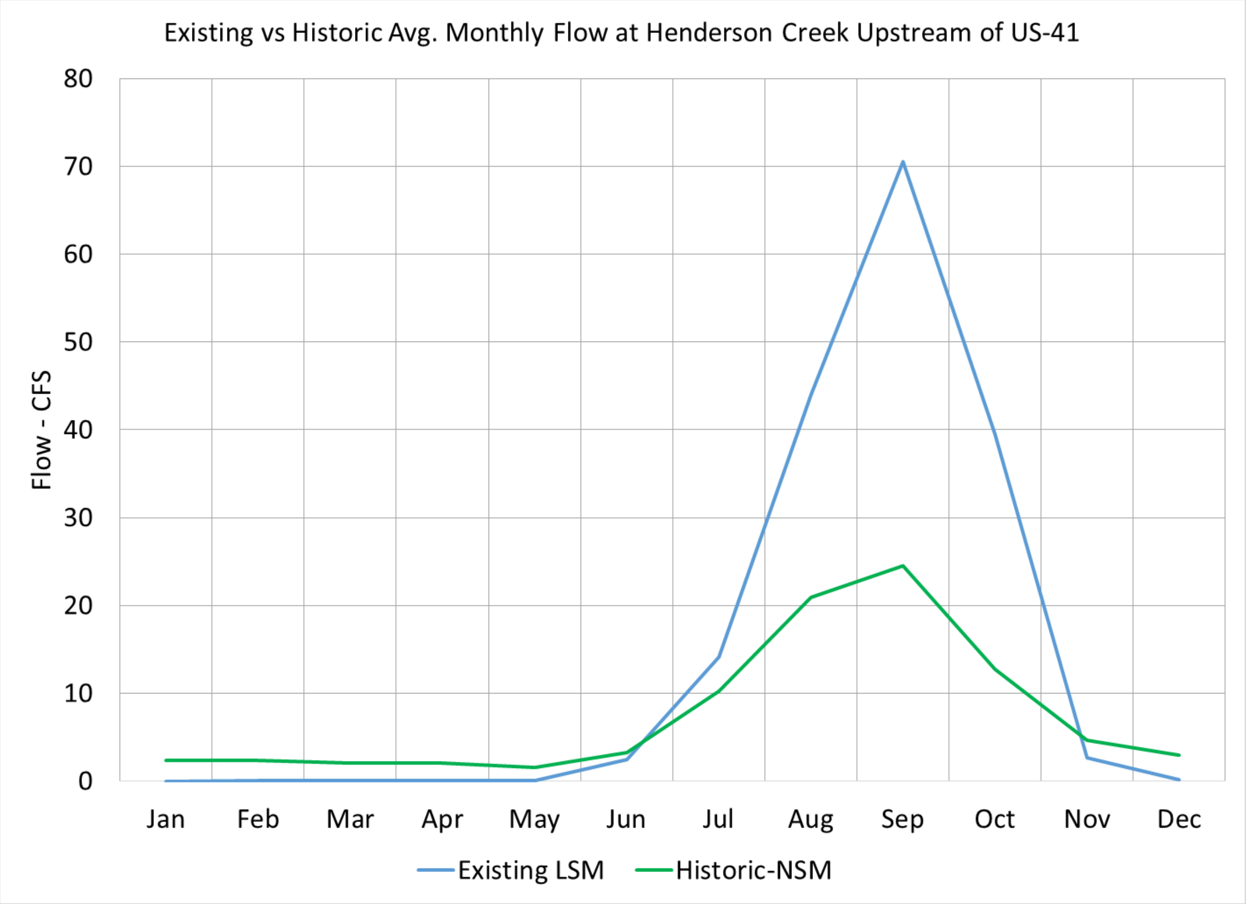


Figure 102. Henderson Creek at US-41 Canal Monthly Average Flows

As shown in **Figure 102**, the flows in Henderson Creek are slightly higher for the dry season months (January through June and November to December) for the Historic-LSM when compared against the Existing-LSM results at the same location. However, wet season flows are much larger today than they were historically. This is due largely to the channelization of and northern extension of Henderson Creek, which substantially increased the geographical contributing area of the historical creek. The current depth of the Henderson Creek Canal also penetrates into the upper portions of the Lower

Tamiami aquifer, allowing it to receive more baseflow than historically. Baseflow is not reflected in the months of December through May due to the operation of the HENDTAMI gate structure.

Figure 103 provides a comparison of flows in Henderson Creek at the coast. That is, the flows in the Henderson Creek Canal (**Figure 102)** have been added to flows in the Henderson Creek East Branch, the Eagle Creek branch to the north, and the 2-D flows across the coastal transect. In this figure, a similar trend in higher wet season flows is apparent, although not as pronounced. Evidently, some of the increases in wet season flows at the US 41 location have been offset by decreases in wet season flows in the other two branches and the coastal transect that comprise the remainder of the Henderson Creek basin flows. This result can be explained by the purpose and effect of the Henderson Creek Canal north of US 41, which was to collect and divert flows that historically went elsewhere.

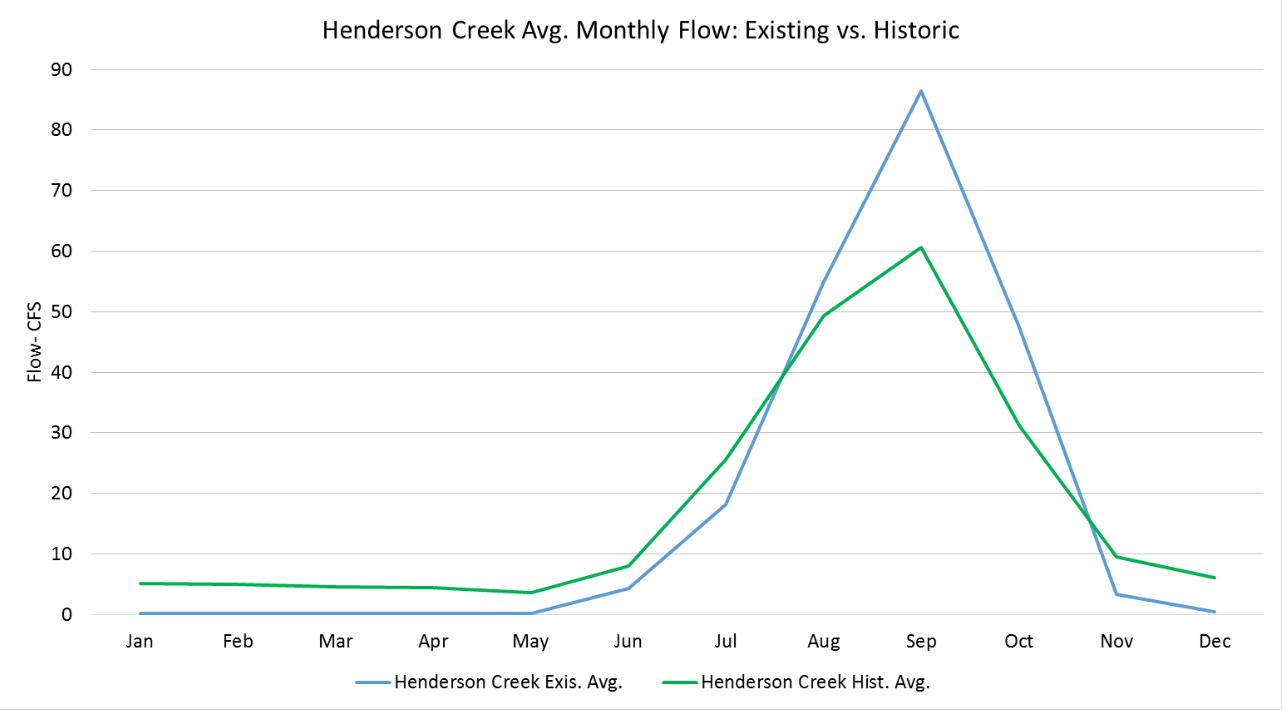


Figure 103. Henderson Creek Basin Combined Average Monthly Flows

The model results show more flow during the dry season months in the Historic condition (**Figures 103 and 104**). This could be explained by a regulation schedule at the "HENDTAMI" structure, which prevents flow until upstream stages reach a threshold for the gates to operate. The purpose of this structure is to prevent over-drainage of the system and to conserve water in the dry season.

The cumulative volume between simulations shows very little difference (**Figure 105**), indicating that under existing conditions the simulated freshwater deliveries from the Henderson Creek transect do not deviate substantially from historic conditions on an annual or long-term basis. However, from the other figures, it is apparent that the seasonality has changed.

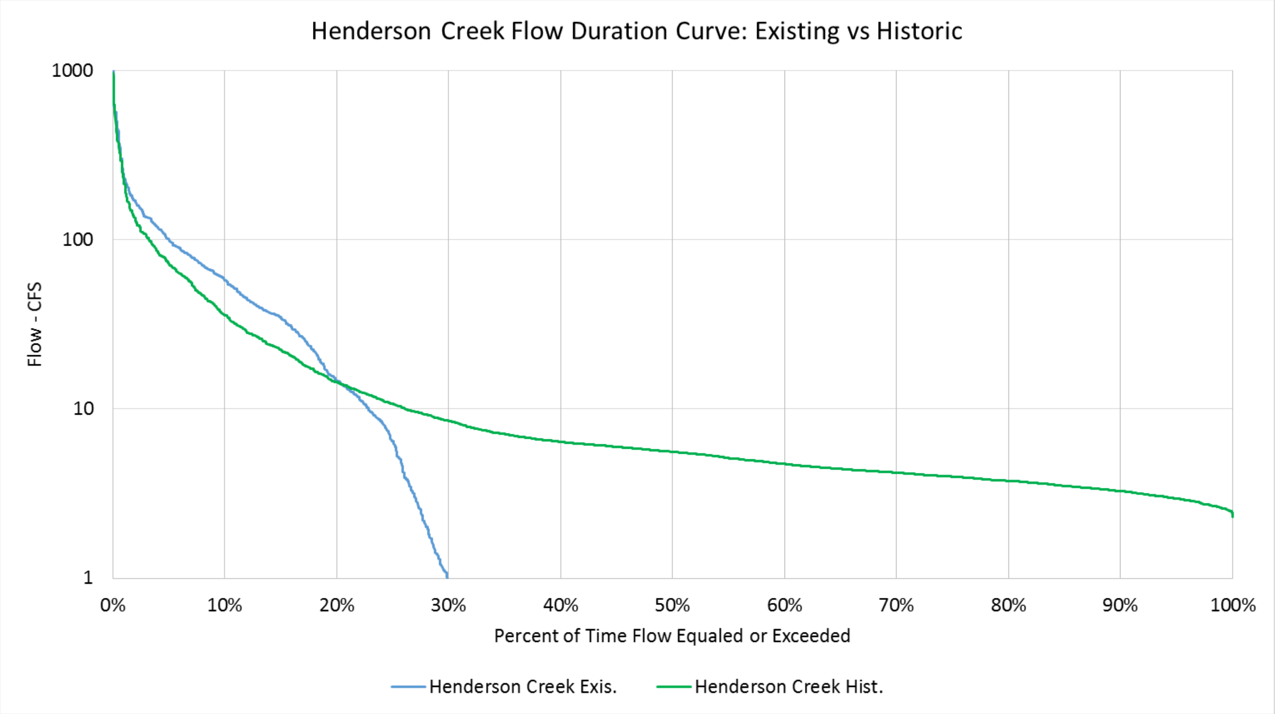


Figure 104. Henderson Creek Flow Duration Curves

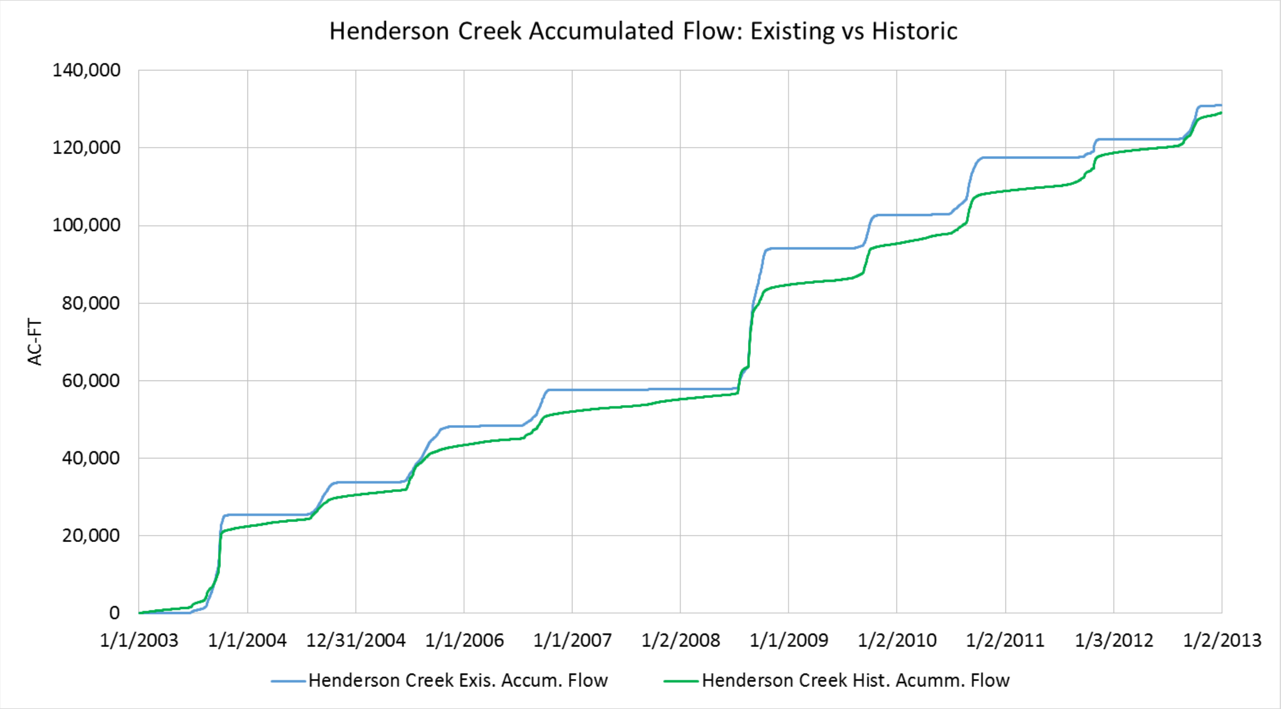


Figure 105. Henderson Creek Cumulative Flow

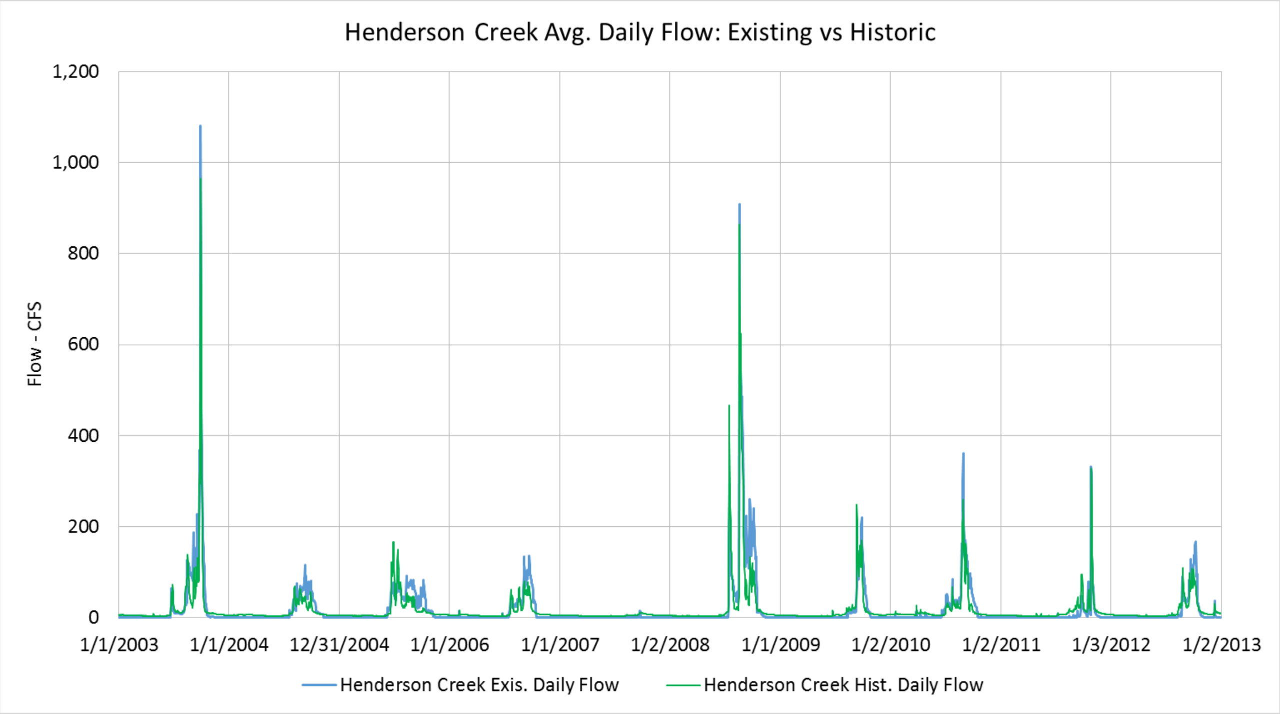


Figure 106. Henderson Creek Daily Flows (2003-2012)

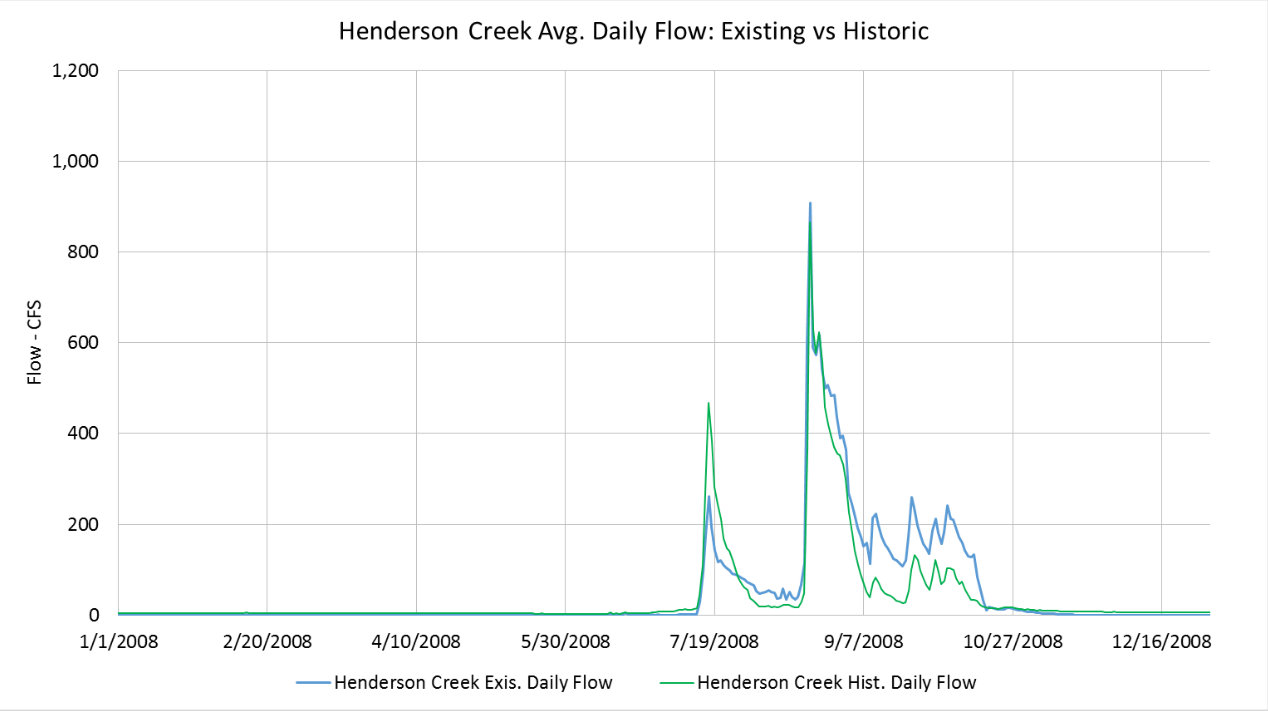


Figure 107. Henderson Creek Daily Flows (2008)

Figures 106 and **107** suggest that although peak flows in the Henderson Creek basin have not increased significantly, the duration of wet season flows in the 50 to 200 cfs range has increased from historical to existing conditions.

4.4.2.4 BelleMeade-9 Flow Analysis

The pattern of flow alterations in the BelleMeade-9 basin is similar to that seen in the Lely Manor basin. The decrease in wet season flows (from historic to existing conditions) shown on **Figure 108** may be an artifact of the construction of the Henderson Creek Canal and the I-75 borrow canals. These canals intercept groundwater and overland sheet flow which historically traversed the land in a south/southwest direction. Some of the wet season flow that historically flowed to the coast in the BelleMeade-9 transect might have been effectively diverted to the northwest in Henderson Creek.

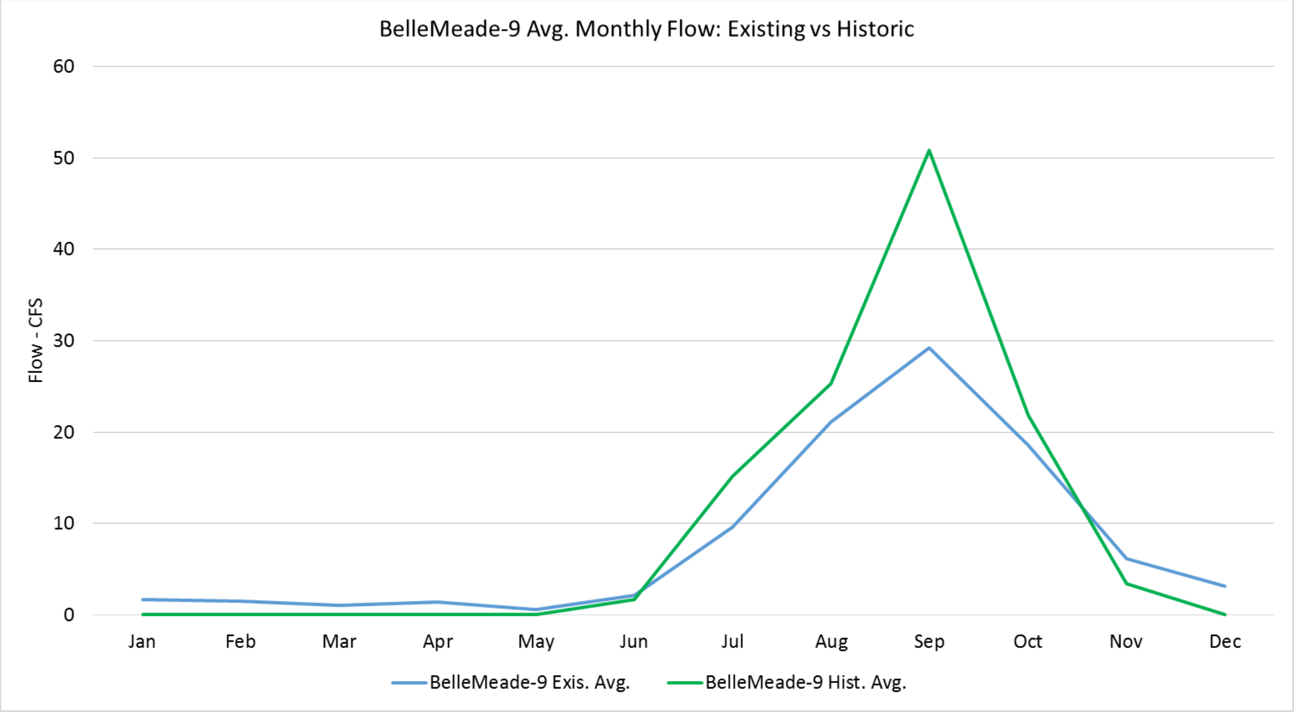


Figure 108. BelleMeade-9 Average Monthly Flows

Other factors within the watershed that may contribute to the reduction in flow could be attributed to groundwater/surface water withdrawals (withdrawals for irrigation or public water supply) or other storage areas (mining pits, detention/retention pond) that could potentially alter flows and cumulative volume at the BelleMeade-9 Transect. Despite the slight increase in dry season flows (**Figure 109**), the overall trend in this area is a decrease in flow volumes on a long-term annual basis (**Figure 110**).

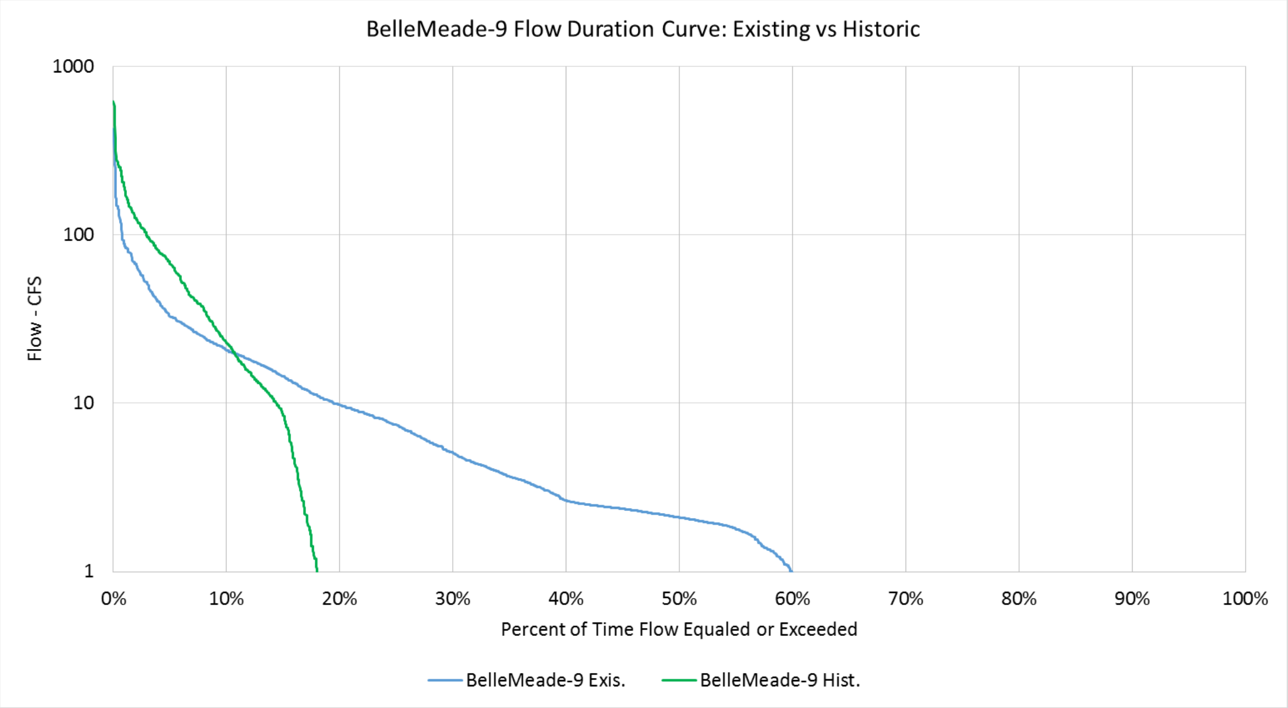


Figure 109. BelleMeade-9 Flow Duration Curves

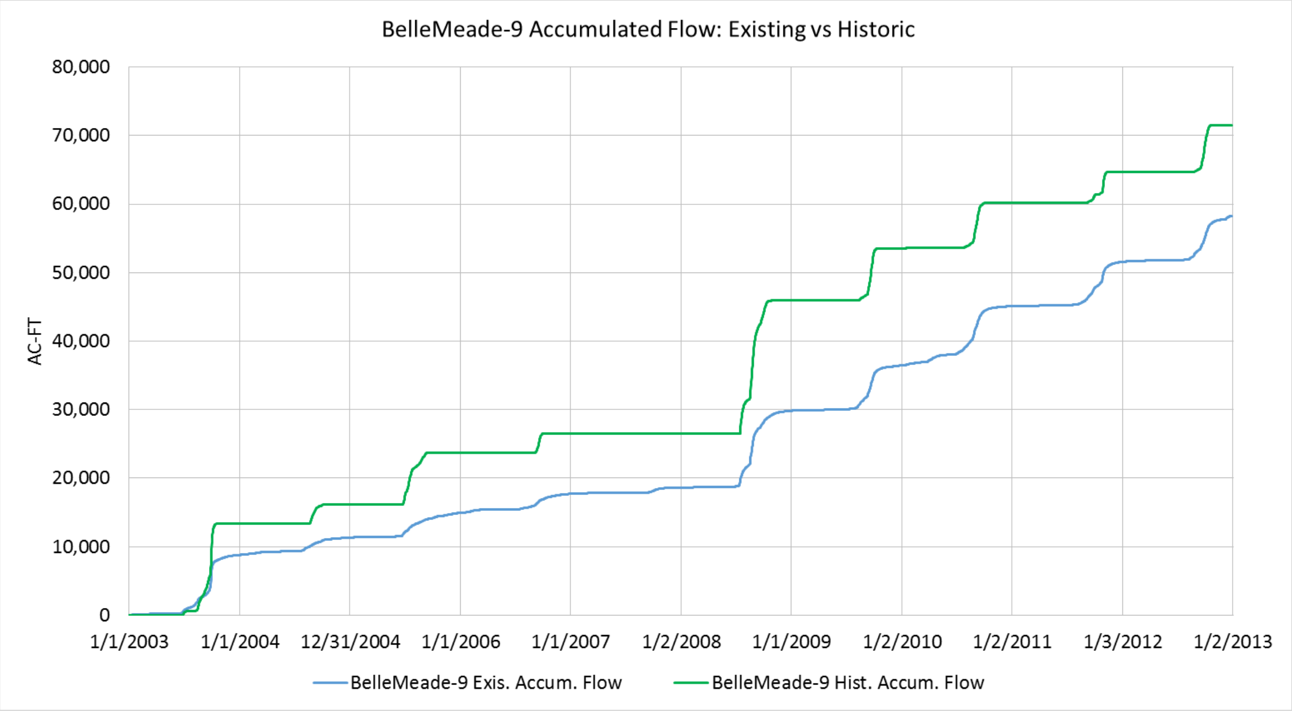


Figure 110. BelleMeade-9 Cumulative Flows

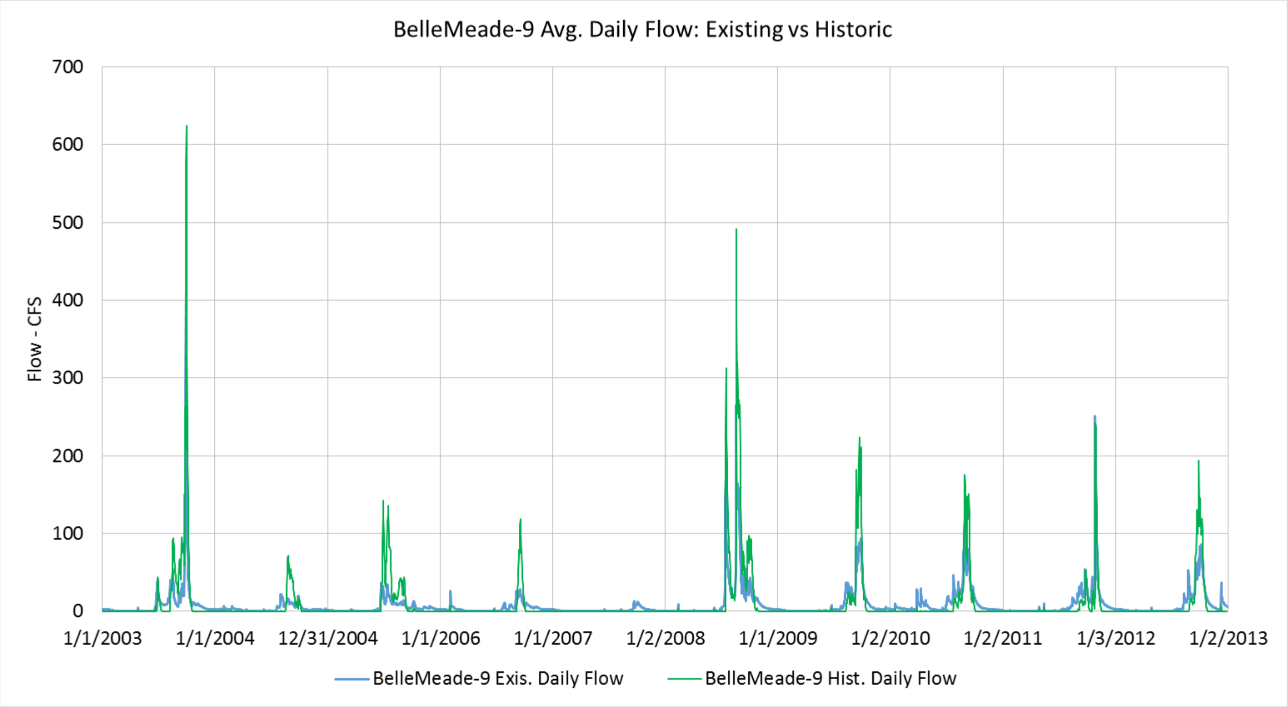


Figure 111. BelleMeade-9 Daily Flows (2003-2012)

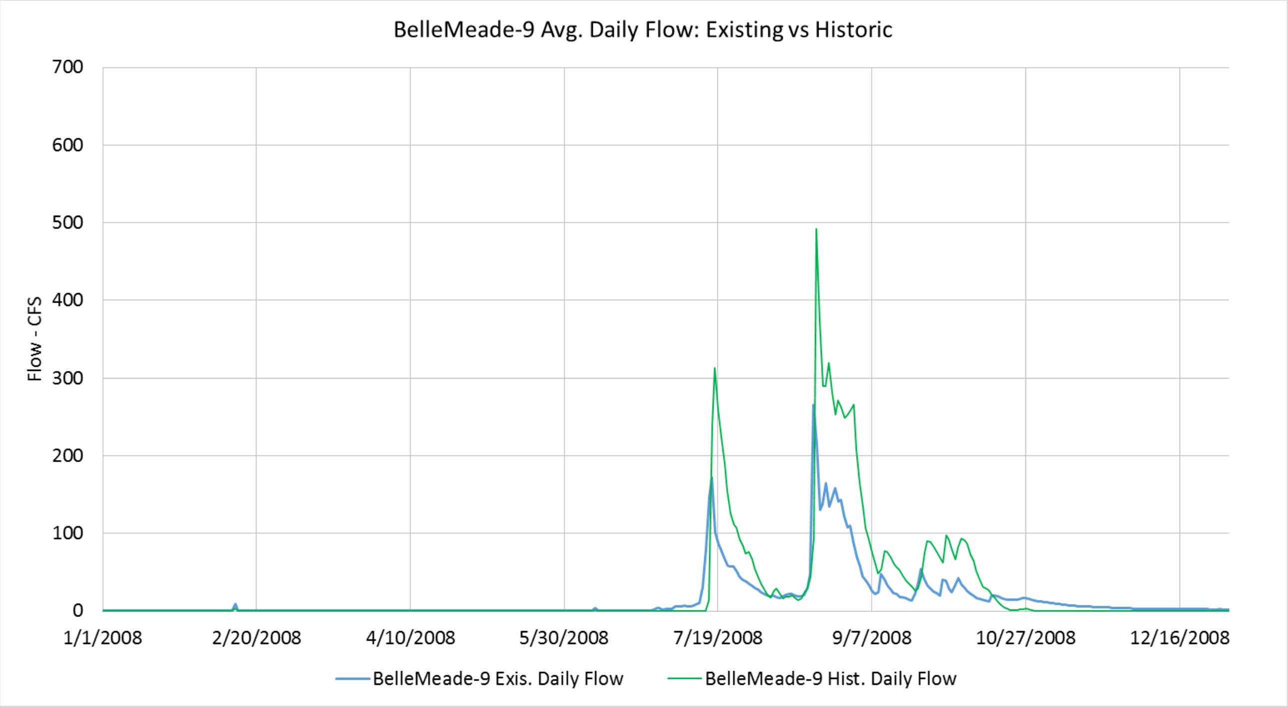


Figure 112. BelleMeade-9 Daily Flows (2008)

Figures 111 and **112** show daily flow comparisons, with **Figure 112** showing year 2008 for illustration. This graph is consistent with the others, showing an overall diminished streamflow response in this basin from historic to existing conditions, with a slightly longer duration of low flows in the current condition.

4.4.2.5 US41 Outfall Swale 2 Flow Analysis

As evident in **Figure 113** corresponding to the US41 Outfall Swale 2 transect, dry season existing condition flows are higher and the model results show slight increases in flows at the start of the wet season. The results also show a slight decrease in peak flows during September (the peak of the wet season). These results may be an indication of the US41 (Tamiami) canal acting to collect or intercept overland flow and distribute these flows east or west depending on stages within the canal. Another possible source of water are inflows from irrigation and drainage within the area, which may have contributed to an increase in dry season flows as well as an overall increase in the cumulative volume to the transect. An increase in flows at the beginning of the wet season is indicative of the effects of irrigation, which tends to fill the available soil storage, thus creating the potential for runoff to occur earlier in the wet season. Historically and in natural areas, a large fraction of rainfall occurring early in the wet season recharges the surficial aquifer and is not converted to runoff, due to typically low water table conditions at the end of the dry season.

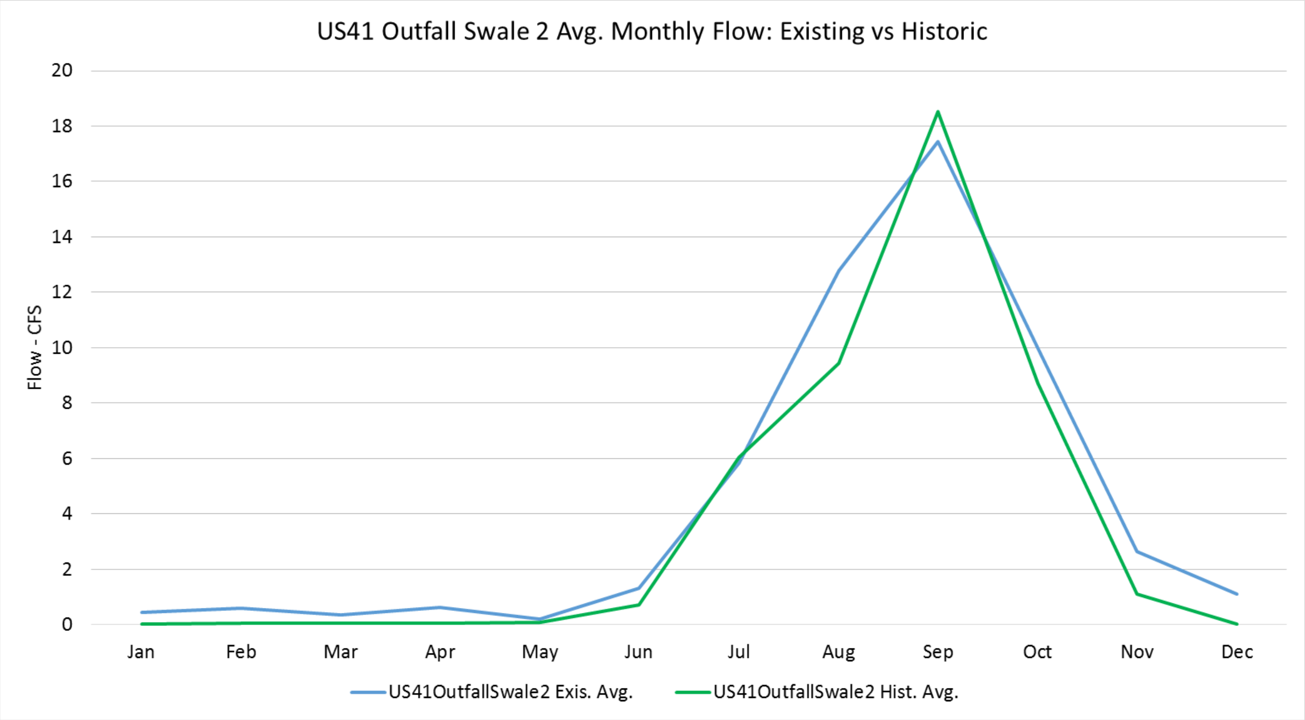


Figure 113. US41 Outfall Swale 2 Average Monthly Flows

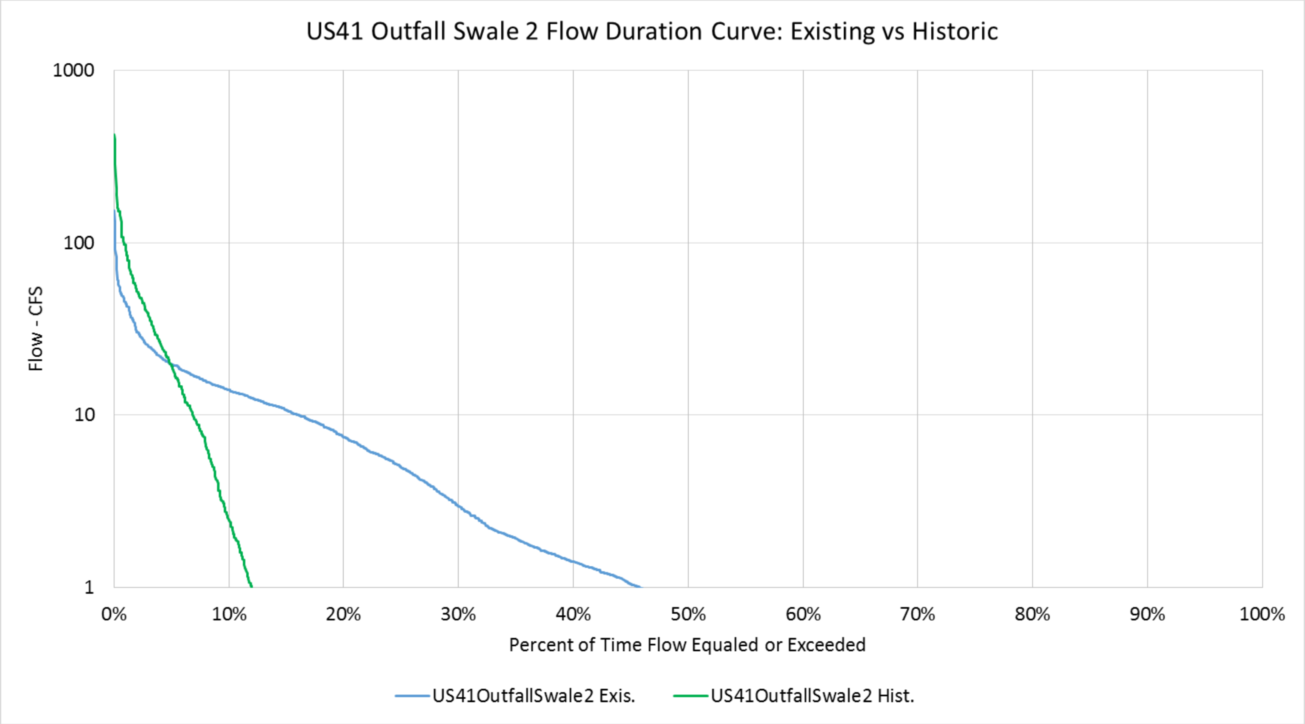


Figure 114. US41 Outfall Swale 2 Flow Duration Curves

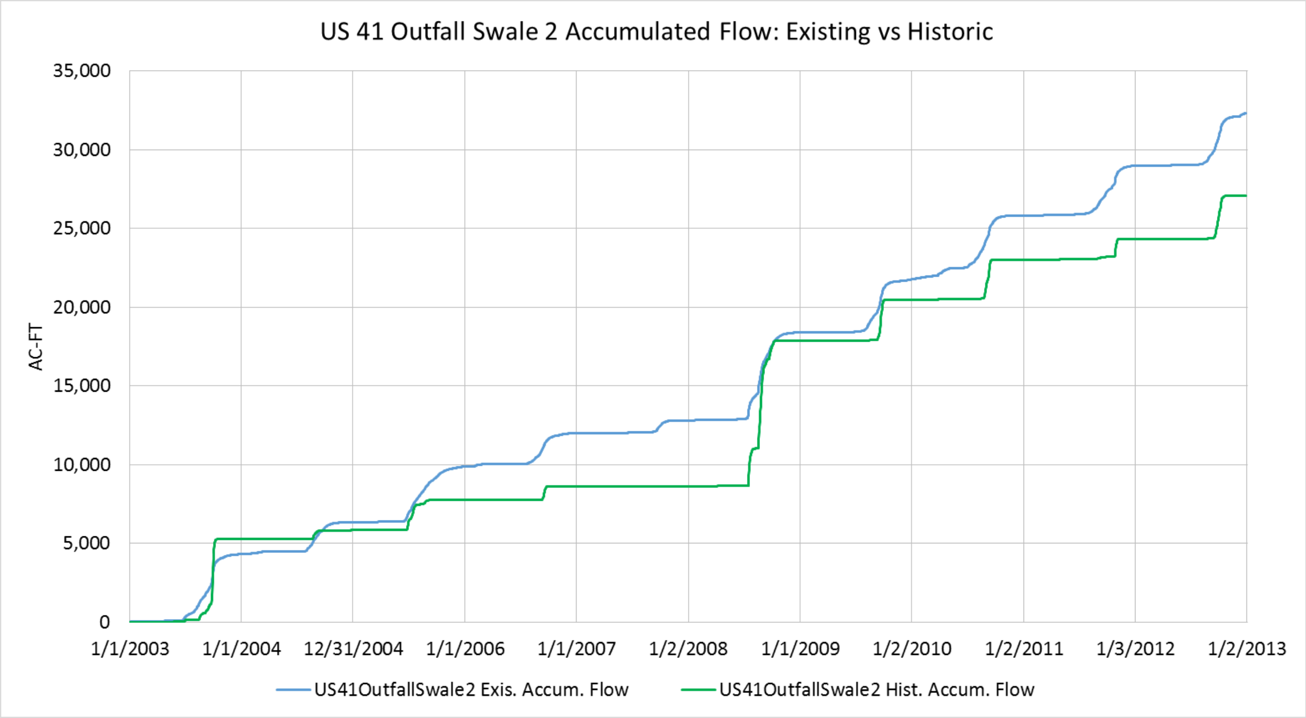


Figure 115. US41 Outfall Swale 2 Cumulative Flows

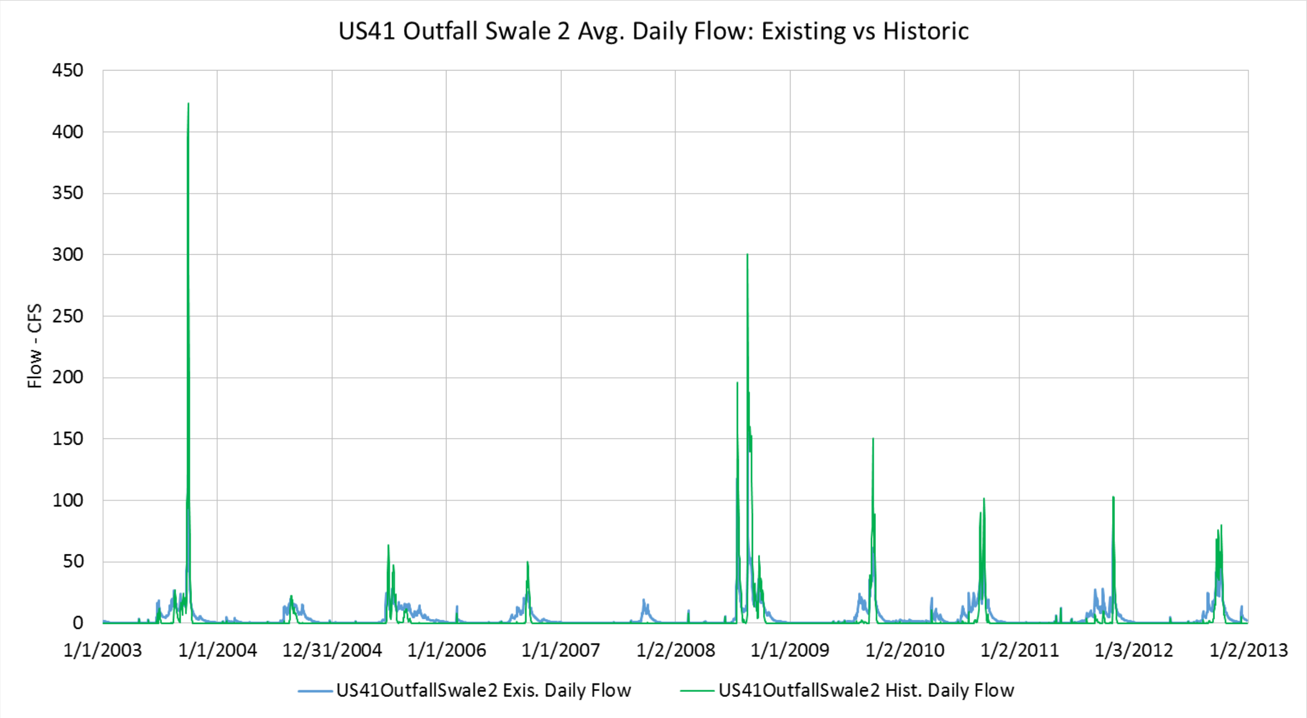


Figure 116. US41 Outfall Swale 2 Daily Flows (2003-2012)

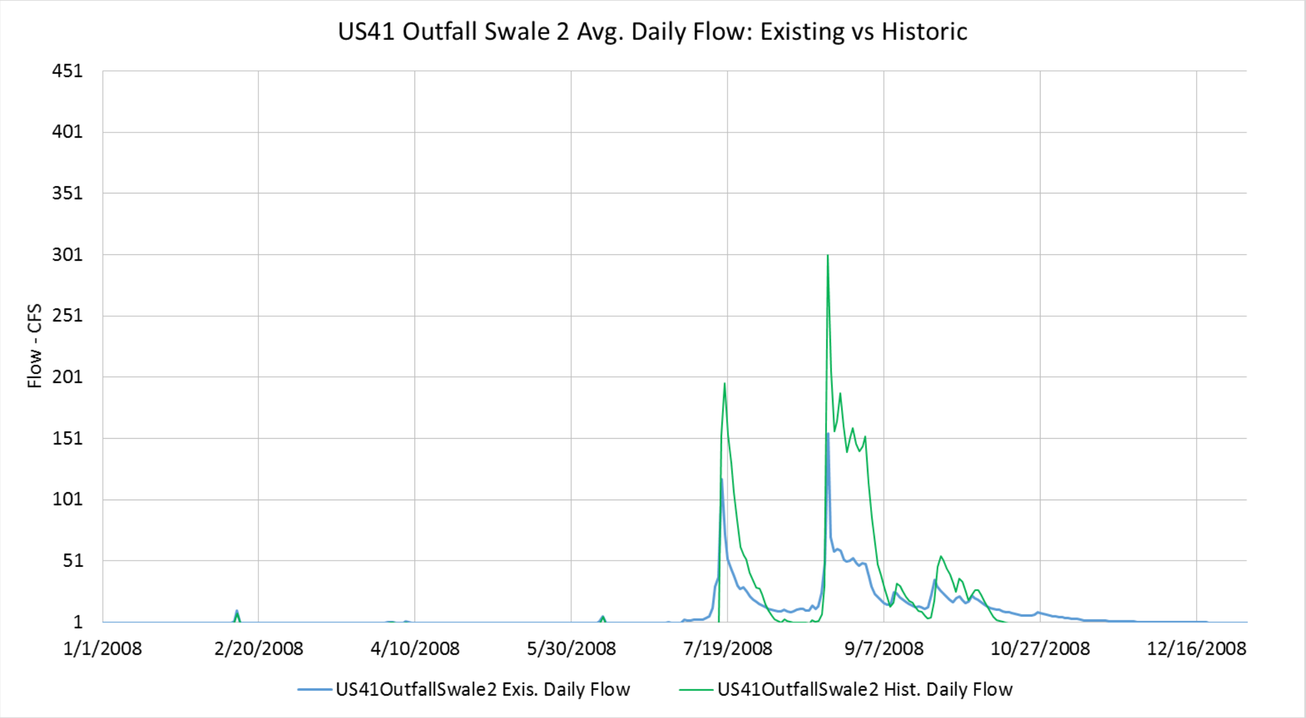


Figure 117. US41 Outfall Swale 2 (2008)

As shown in **Figures 116** and **117**, peak flows in this basin have decreased from historic conditions, according to the model results. The reason for the decrease in peak flows is not readily apparent.

However, this decrease appears to be more than offset by low and medium flows as evident in **Figures 114** and **116**, as the model shows an overall increase in annual and long-term flows.

4.4.2.6 Bridge 37 Analysis

As presented in the following figures, freshwater flows from the Bridge 37 transect show that the seasonal variation in flow from existing to historical are pronounced, where a large decrease during the wet season is evident in **Figure 118**. Additionally, under historic conditions the transect contributed a higher cumulative volume **Figure 120**, where redistribution of flows along the US-41/Tamiami Canal, localized ditching/draining, groundwater withdrawals, and potential contributing area reductions (impoundments, etc.) are thought to be the primary drivers of the flow differences at this location.

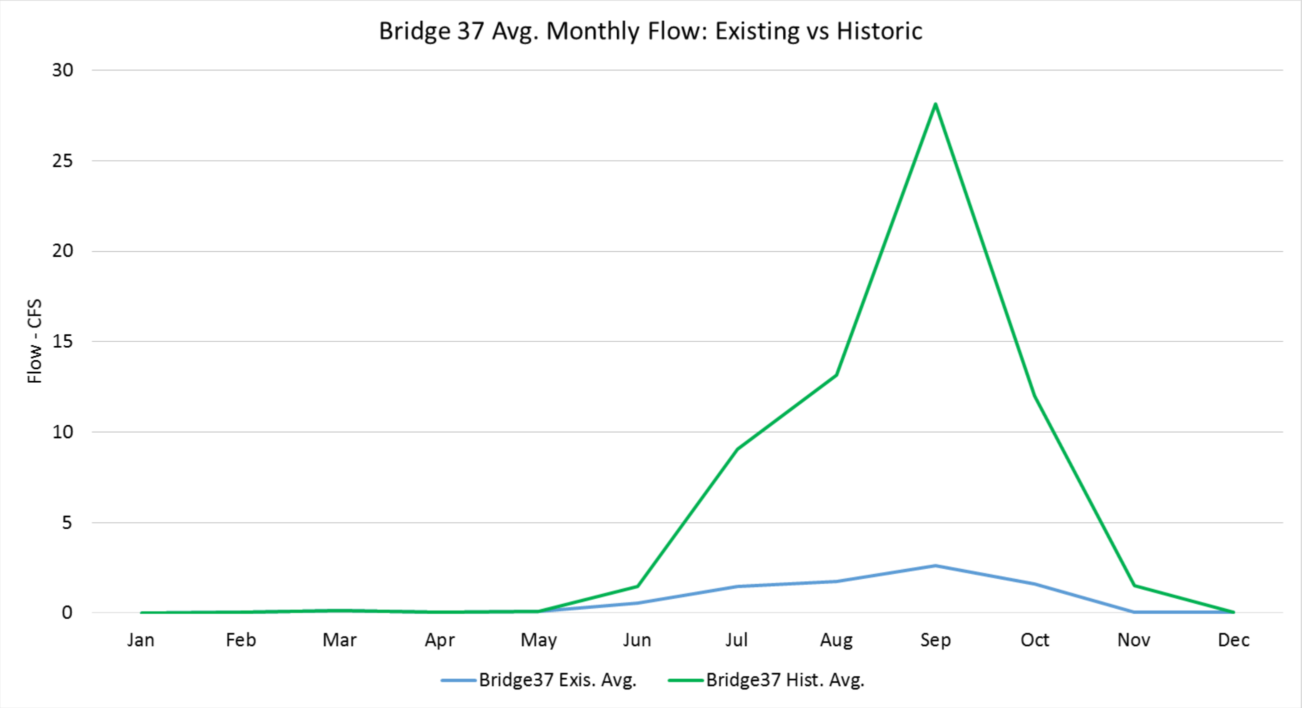


Figure 118. Bridge 37 Average Monthly Flows

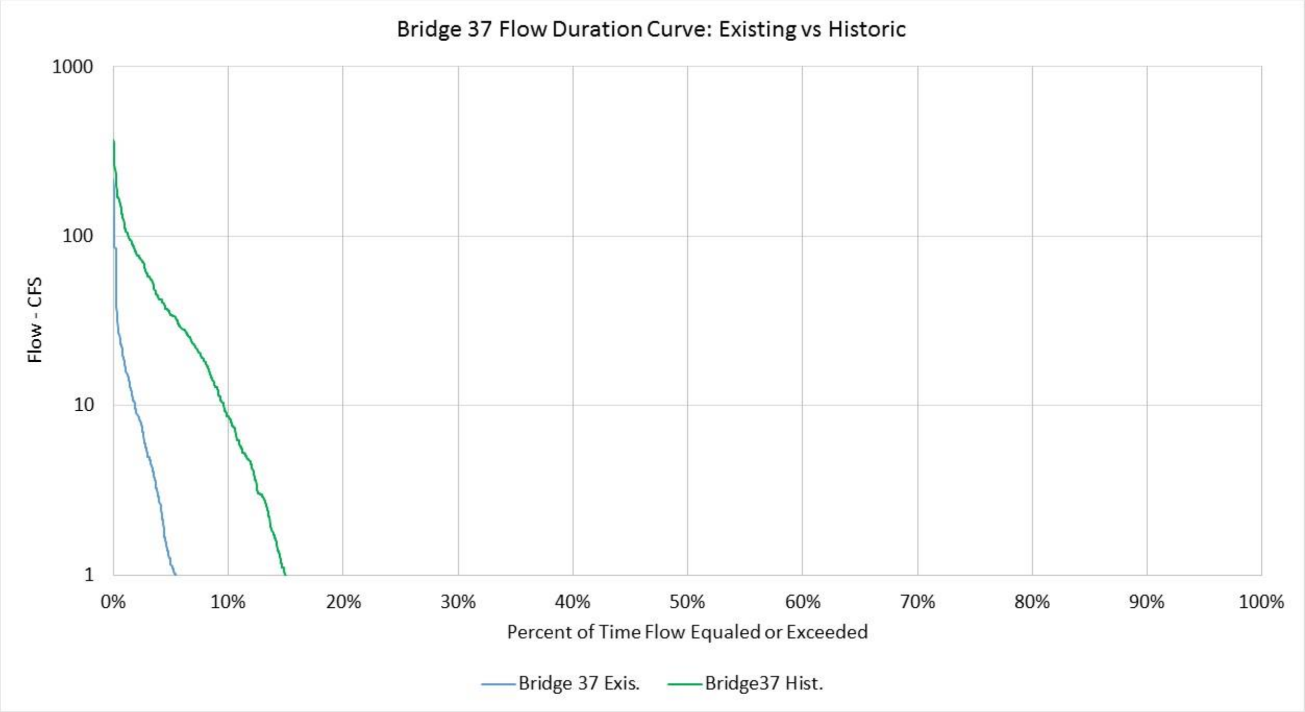


Figure 119. Bridge 37 Flow Duration Curves

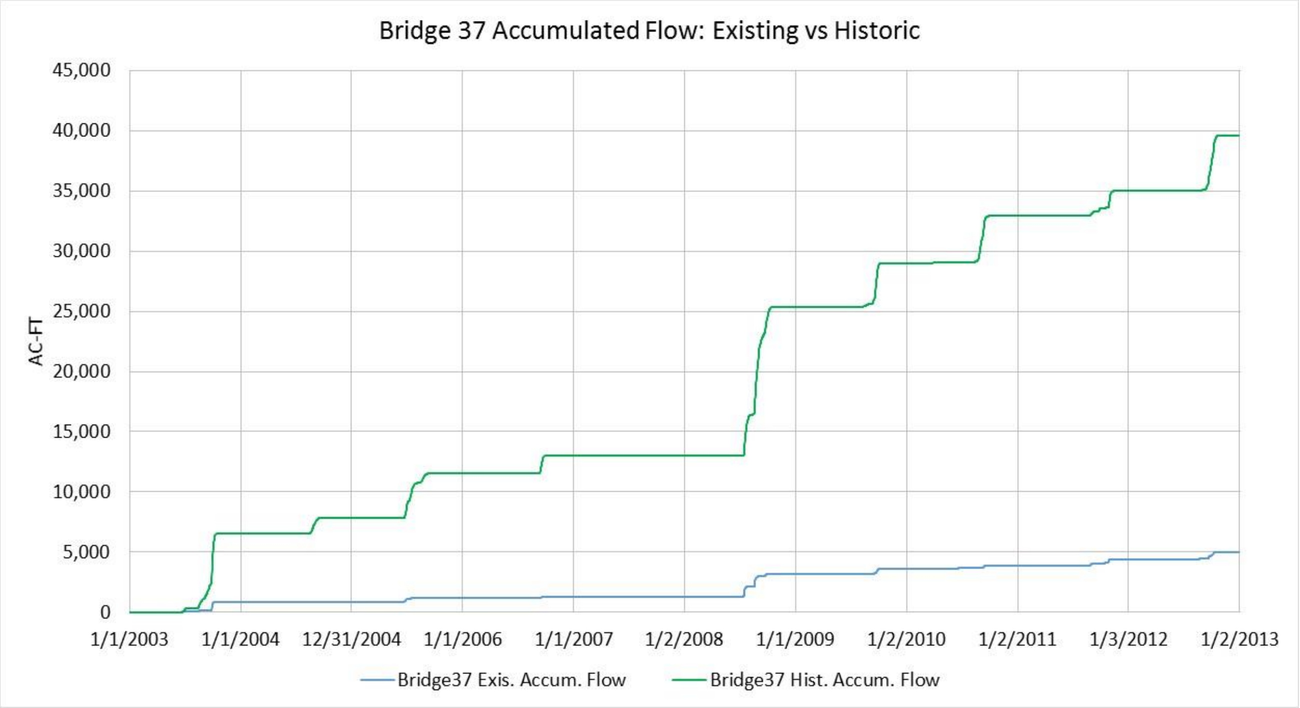


Figure 120. Bridge 37 Cumulative Flows

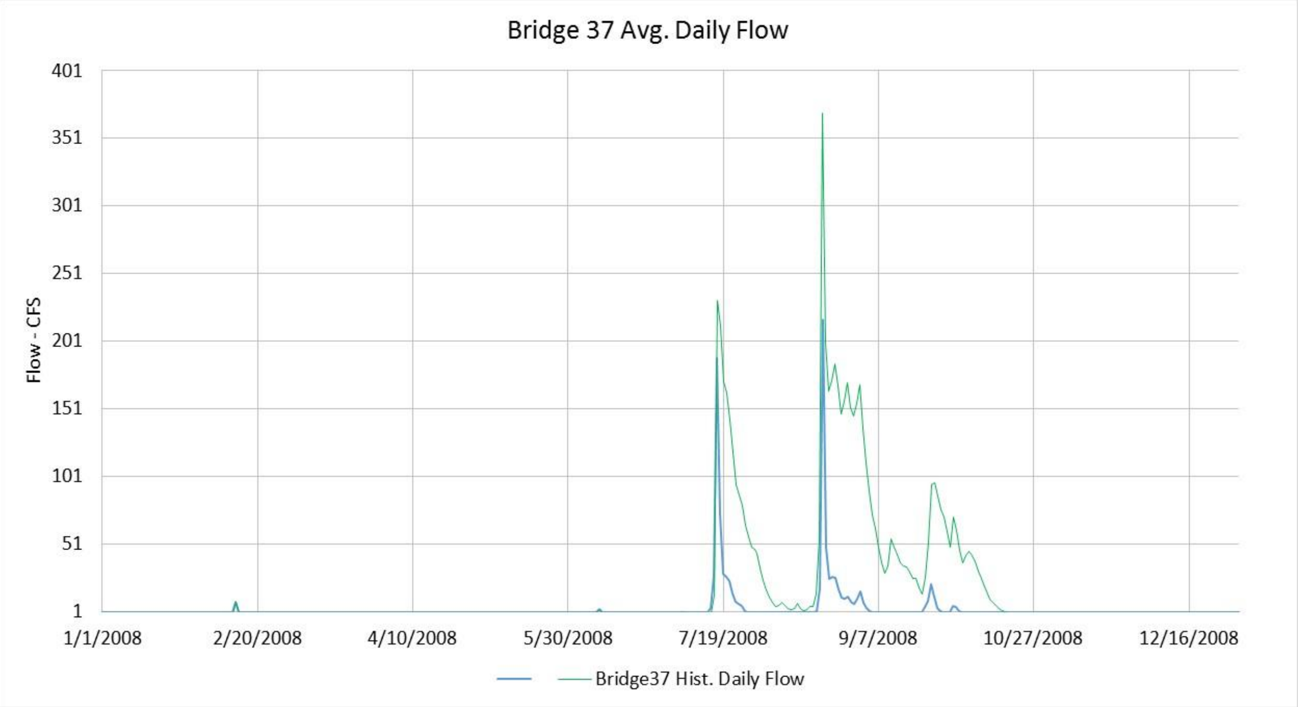


Figure 121. Bridge 37 Daily Flows (2003-2012)

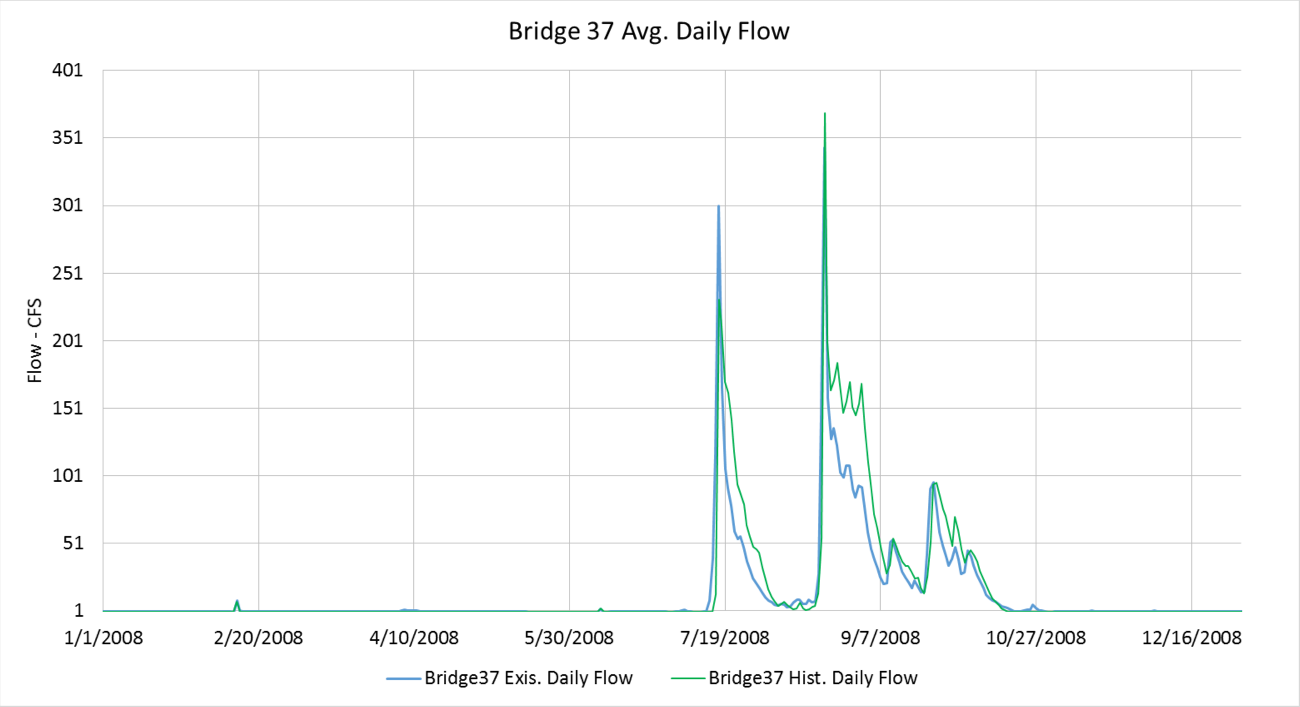


Figure 122. Bridge 37 Daily Flows (2008)

4.4.2.7 Total Coastal Flow to Rookery Bay

The following figures present the summed total coastal flow from all transect and MIKE-11 points as presented in **Figure 91.** As shown in **Figure 123**, the simulated seasonality in the summed coastal flows has shifted slightly from historical to existing conditions according to the model results. Slightly higher wet season flows occurred in the historical conditions model. Additionally, under existing conditions flows are higher for the 15% to 70% exceedance probabilities, meaning that for most mid-range flows, the existing conditions simulation showed a higher flow rate (**Figure 124)**. Although the slight shift in seasonal pattern shown in **Figure 123** is somewhat of unexpected result, the reduction in very low flow durations shown in **Figure 124** is characteristic of a drained system.

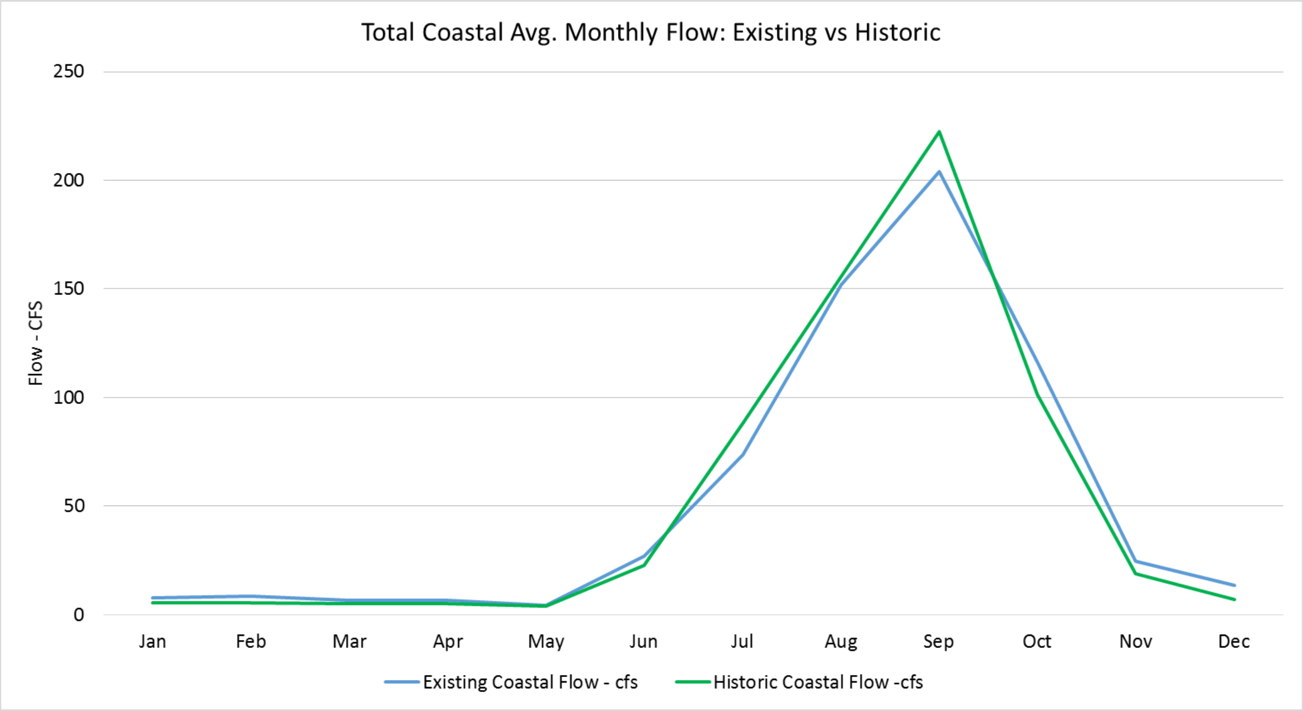


Figure 123. Monthly Average Freshwater Inflows from HCWERP Study Area

The results for the individual coastal inflows, presented separately for each basin/transect, suggests that the volume and timing differed spatially and seasonally. However, **Figure 125** shows that summed freshwater deliveries were predicted to be very similar overall under historical and existing conditions. This result is consistent with the water budget comparison (**Table 33**), which suggested that although the flow has shifted from a sheet flow dominated system to a groundwater dominated system (baseflow to canals), the overall flow volumes are similar on a unit basis. The combined result of the water budget analysis and the summation of the cumulative flows to the coast suggest that the area north of the current Henderson Creek / Rookery Bay Watershed that historically may have contributed flow at times (the NSM area north of the current Golden Gate Canal) to the Henderson Creek / Rookery Bay system was a relatively insignificant part of the overall water budget, but did contribute flow during extremely wet times.

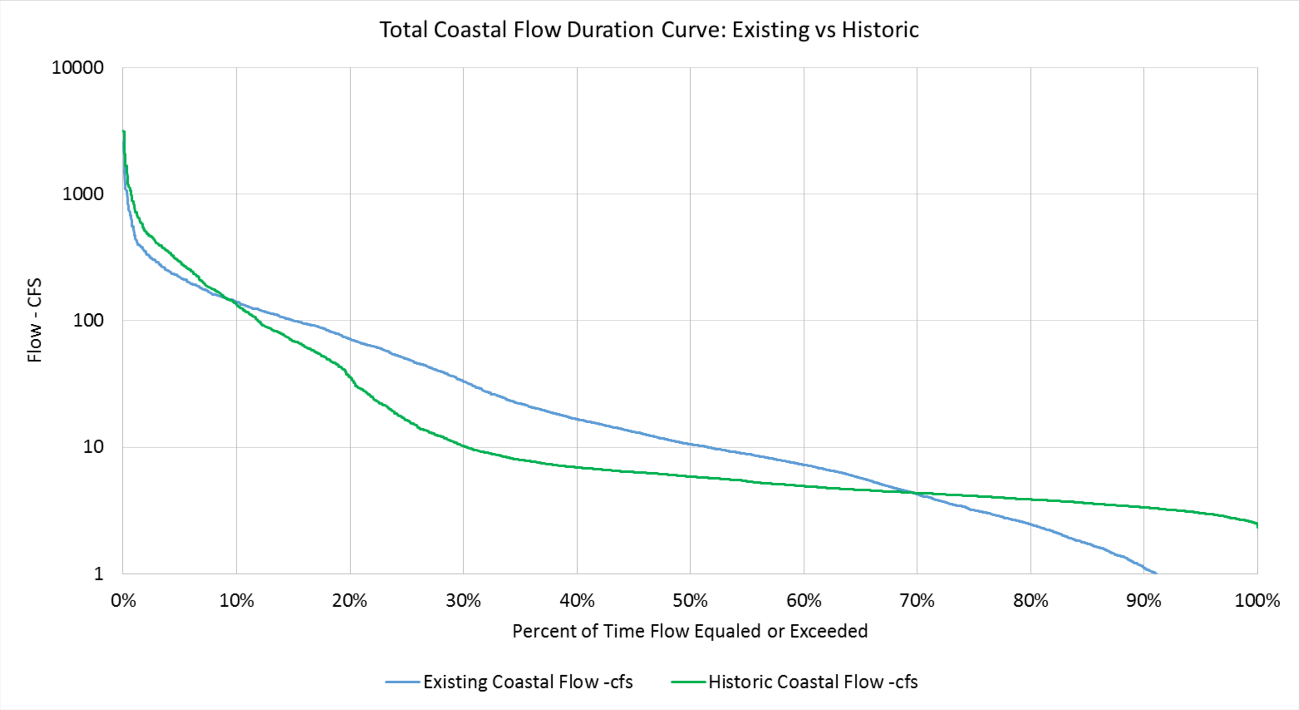


Figure 124. Freshwater Inflow Flow Duration Curves from HCWERP Study Area

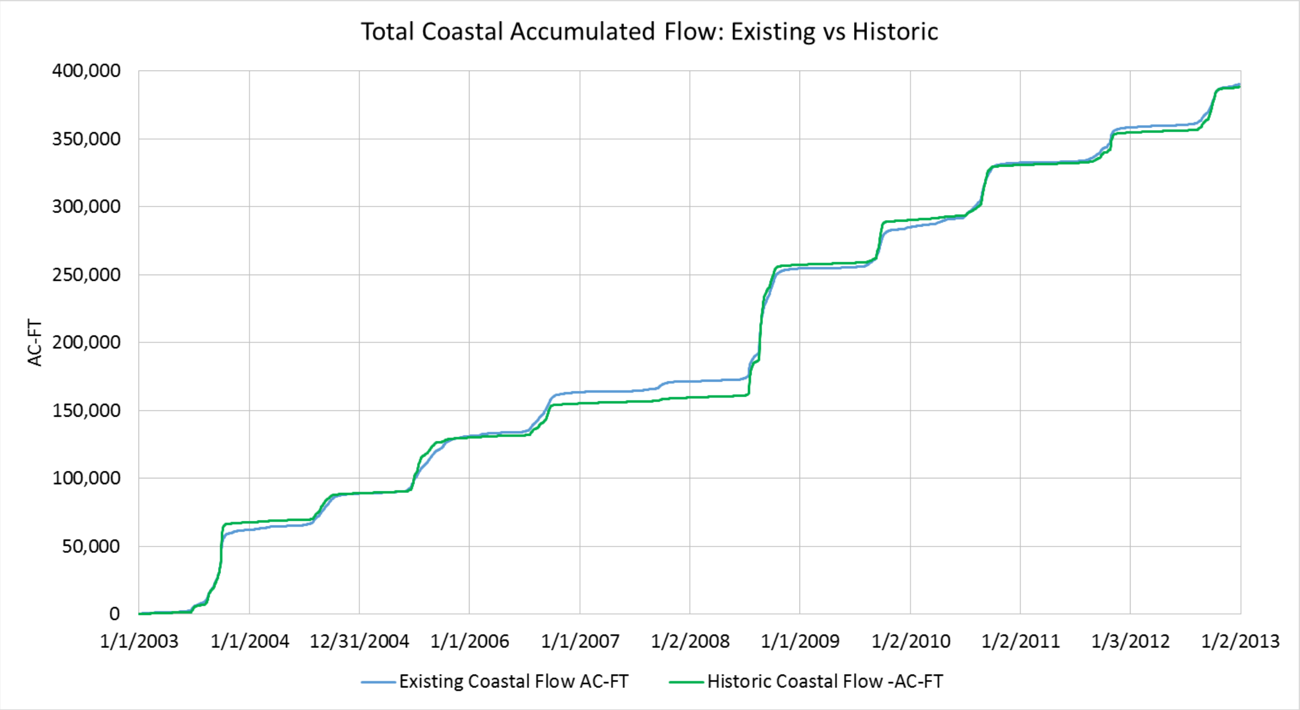


Figure 125. Cumulative Flows from HCWERP Study Area

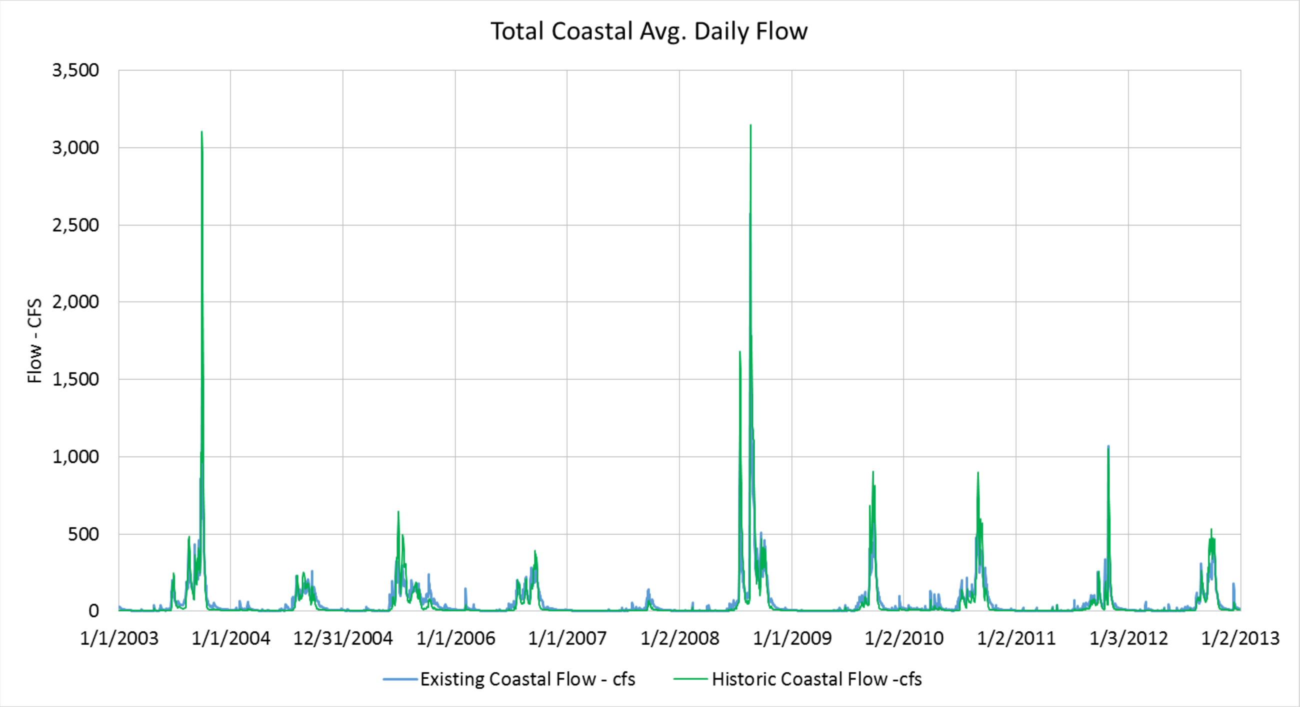


Figure 126. Daily Flows (2003 -2012) From HCWERP Study Area

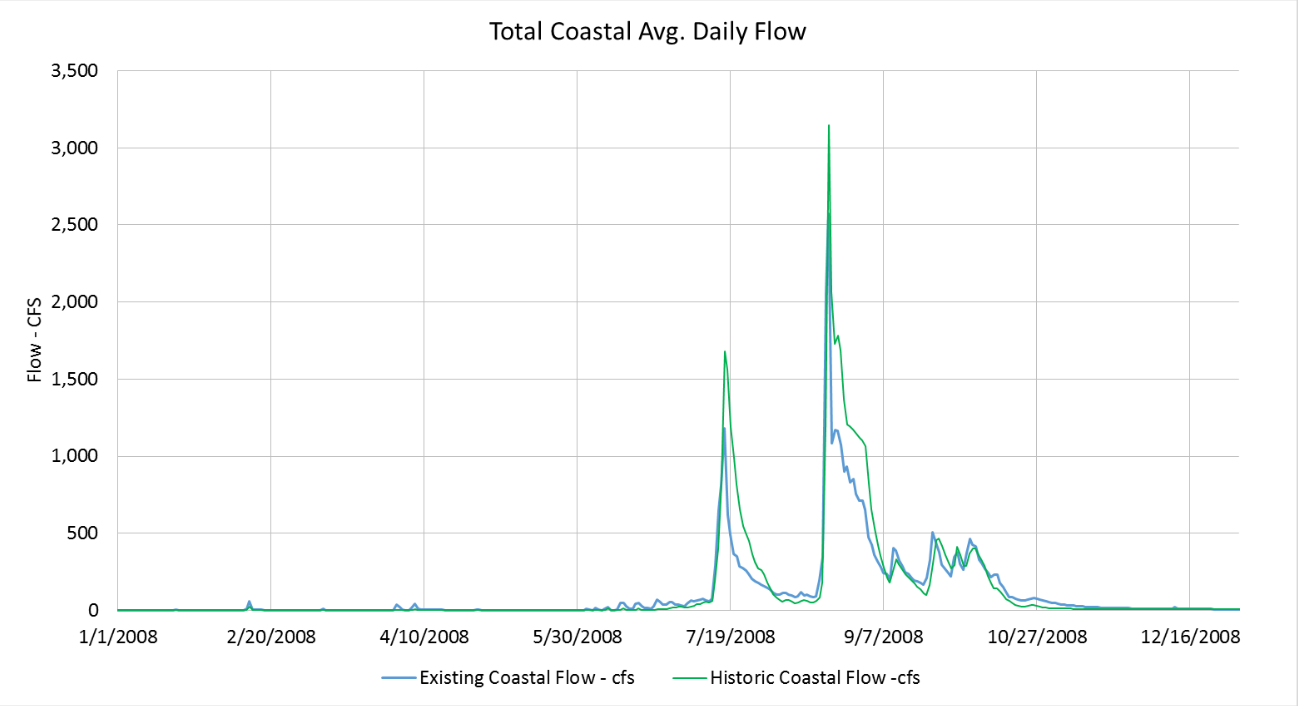


Figure 127. Daily Flows (2008) From HCWERP Study Area

4.4.3 Comparisons of Water Levels and Depths

The graphical comparisons within this subsection correspond to the north and south Belle Meade water level comparison points, represented by the green and red stars respectively, shown on **Figure 91** near the beginning of this Section. Analyses presented for the Belle Meade Flow-way include:

- Time series plots of daily depths of overland water
- Depth-Duration of Overland Water Depth
- Stage-Duration of Water Table Aquifer Elevation

The analyses were performed for the Belle Meade Flow-way to gain an understanding of the existing and historical water levels, which can provide a comparison of hydroperiods between the models for the selected points. This analysis can also provide insight to how this part of the watershed has responded to construction of hydrologically significant features such as I-75 and the Henderson Creek Canal.

Figure 128 provides a comparison of the time series of daily water depths at the northern comparison point. From the figure, it is evident that the model results show significantly higher depths in the historic condition.

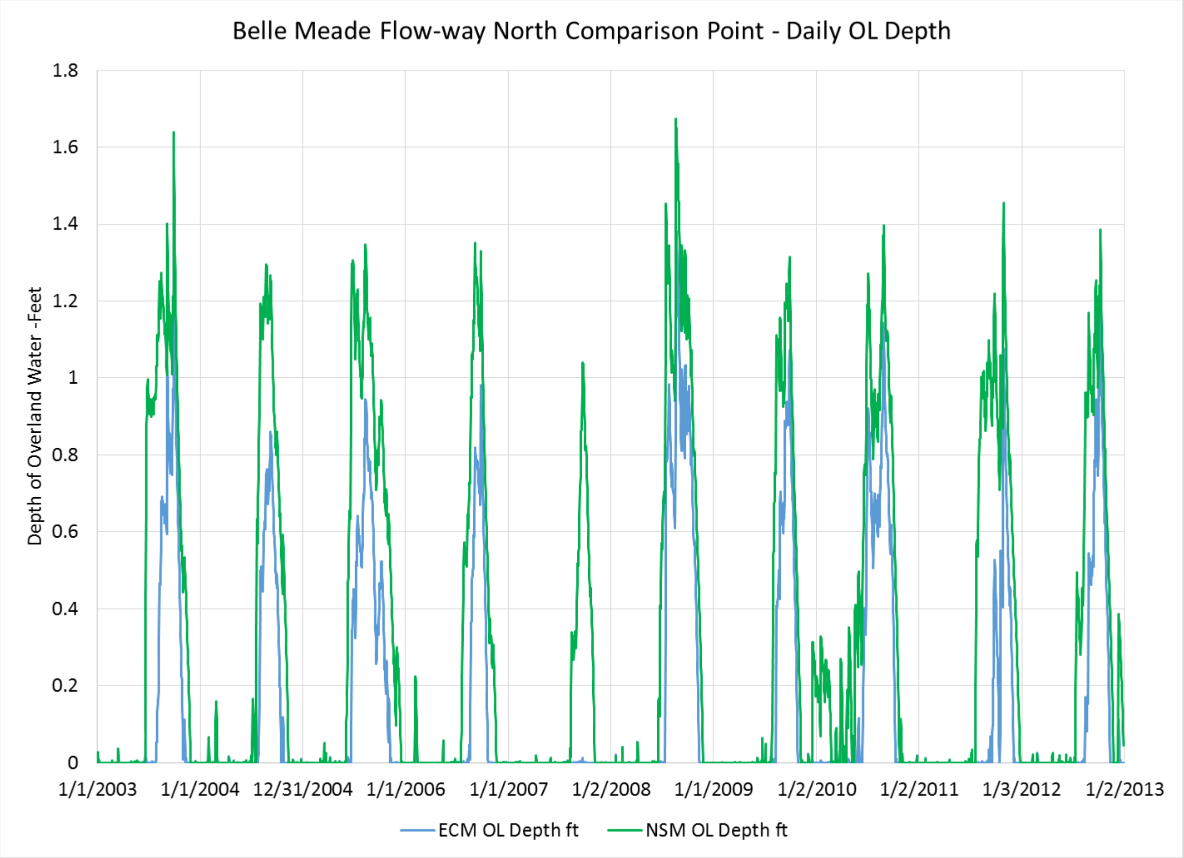


Figure 128. Belle Meade Flow-Way Overland Water Depth: North Comparison Point

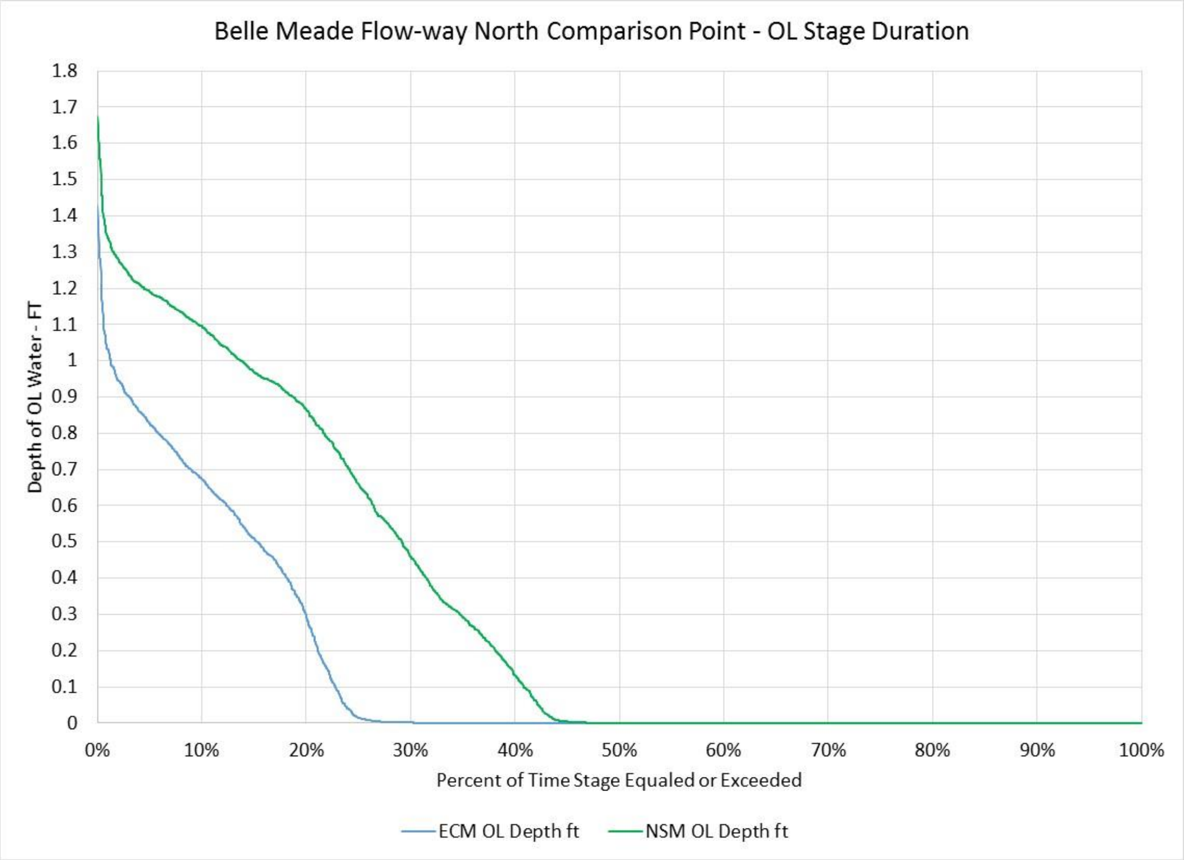


Figure 129. Belle Meade Flow-Way Depth-Duration: North Comparison Point

Figure 129 compares the statistical distributions of the daily depths from 2003 through 2012, in the form of depth-duration plots. From the comparison, it is evident that the percent of time water is ponded on the land surface has been reduced significantly. The 15-20% reduction in ponded water duration is approximately equivalent to 2 months of the year. That is, the duration of standing water has been reduced from about 5 months in the historical conditions to about 3 months in the existing condition.

Figure 130 provides a comparison of the time series of daily water depths at the southern comparison point. From the figure, it is evident that the model results show significantly higher depths in the historic condition, although the difference is slightly less pronounced than at the northern comparison point.

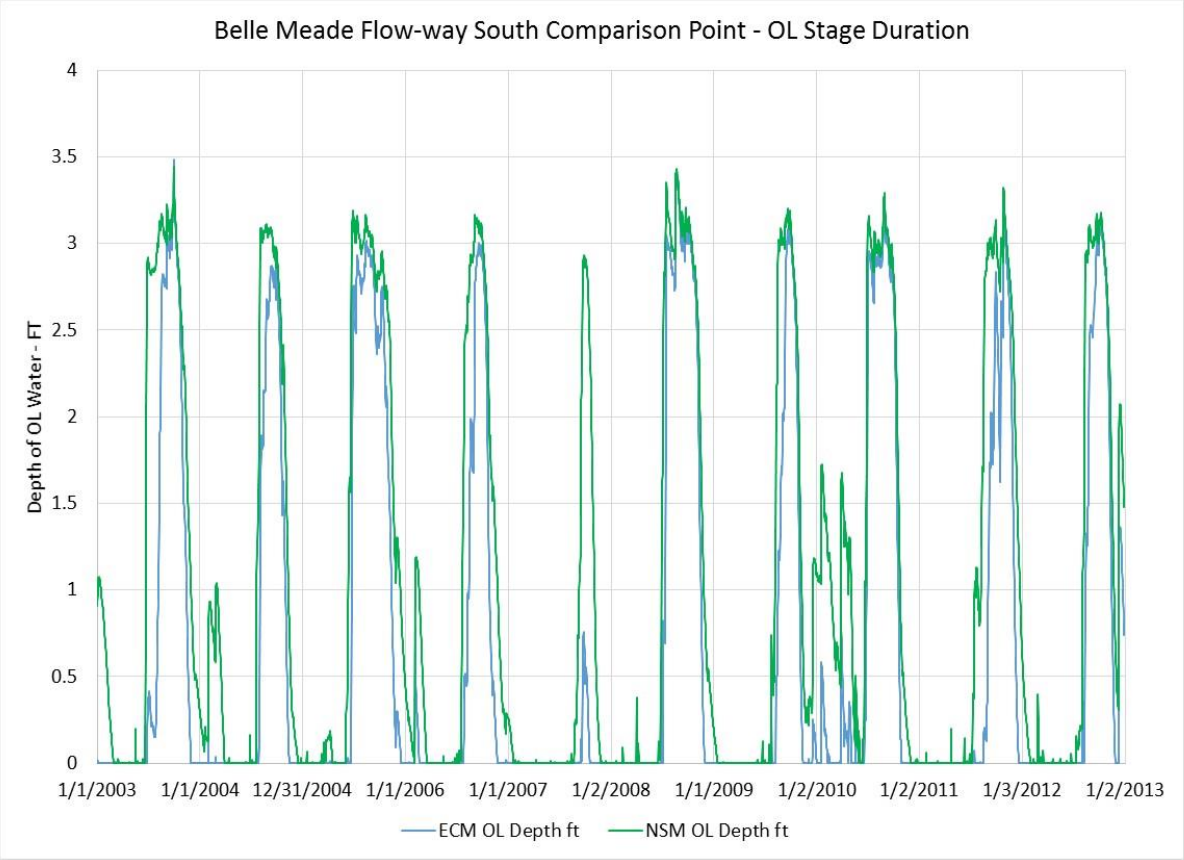


Figure 130. Belle Meade Flow-Way Overland Water Depth: South Comparison Point

Figure 131 compares the statistical distributions of the daily depths from 2003 through 2012 at the southern comparison point, in the form of depth-duration plots. From the comparison, it is evident that the percent of time water is ponded on the land surface has also been reduced significantly at the southern Belle Meade location. There appears to be a 15-20% reduction in ponded water duration, which is approximately equivalent to 2 months of the year. The duration of standing water has been reduced from about 7 months in the historical condition to about 5 months in the existing condition. At the higher water depths (above 1.5 feet), the reduction in duration is smaller (less than 10% of the time).

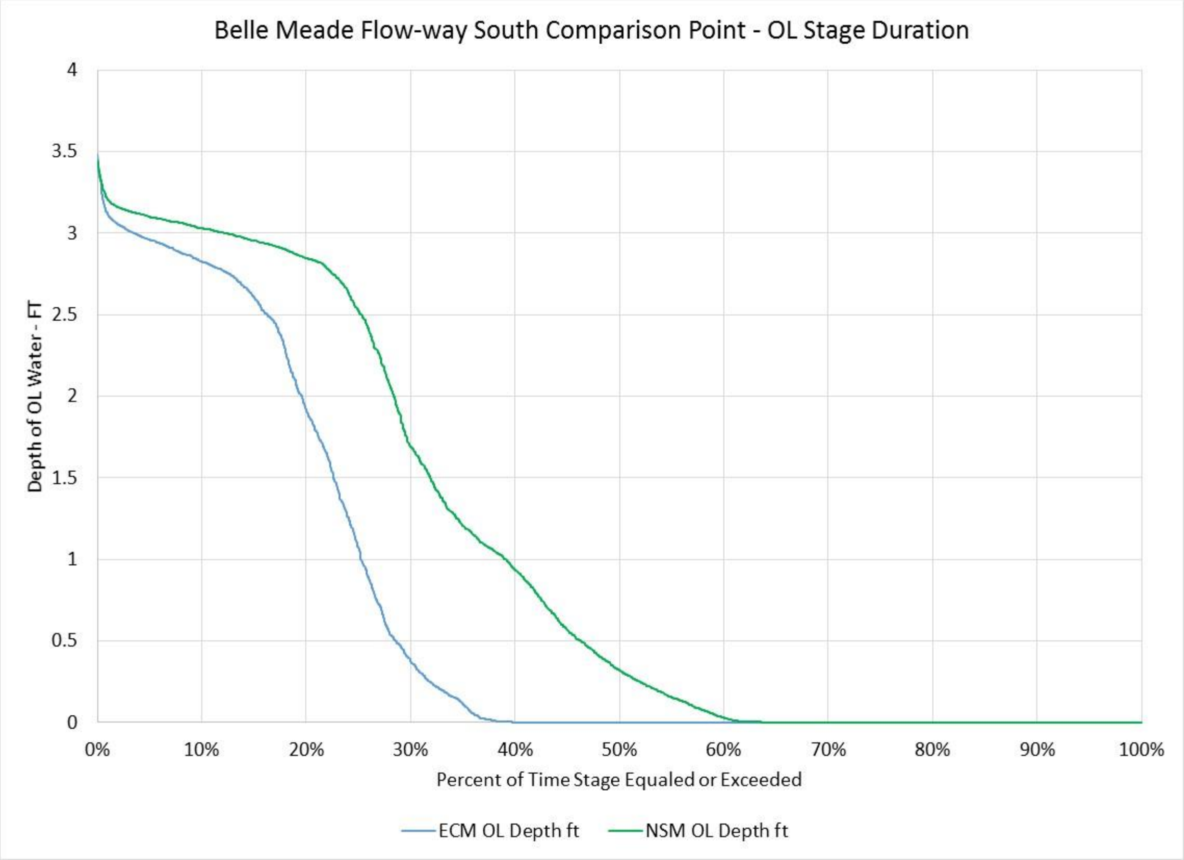


Figure 131. Belle Meade Flow-Way Depth-Duration: South Comparison Point

For both comparison points (north and south) within the Belle Meade Flow-way, the depth of overland water is deeper (higher relative to the ground surface elevation "GSE") for historic conditions. The recession in overland flow was slower for historic conditions as well, meaning that overland flow was deeper and remained on the overland flow plain longer than simulated existing conditions. The changes may be attributed to the I-75 canal system intercepting the southern flow of water, as well as Henderson Creek providing local drainage and acting as a sink for water.

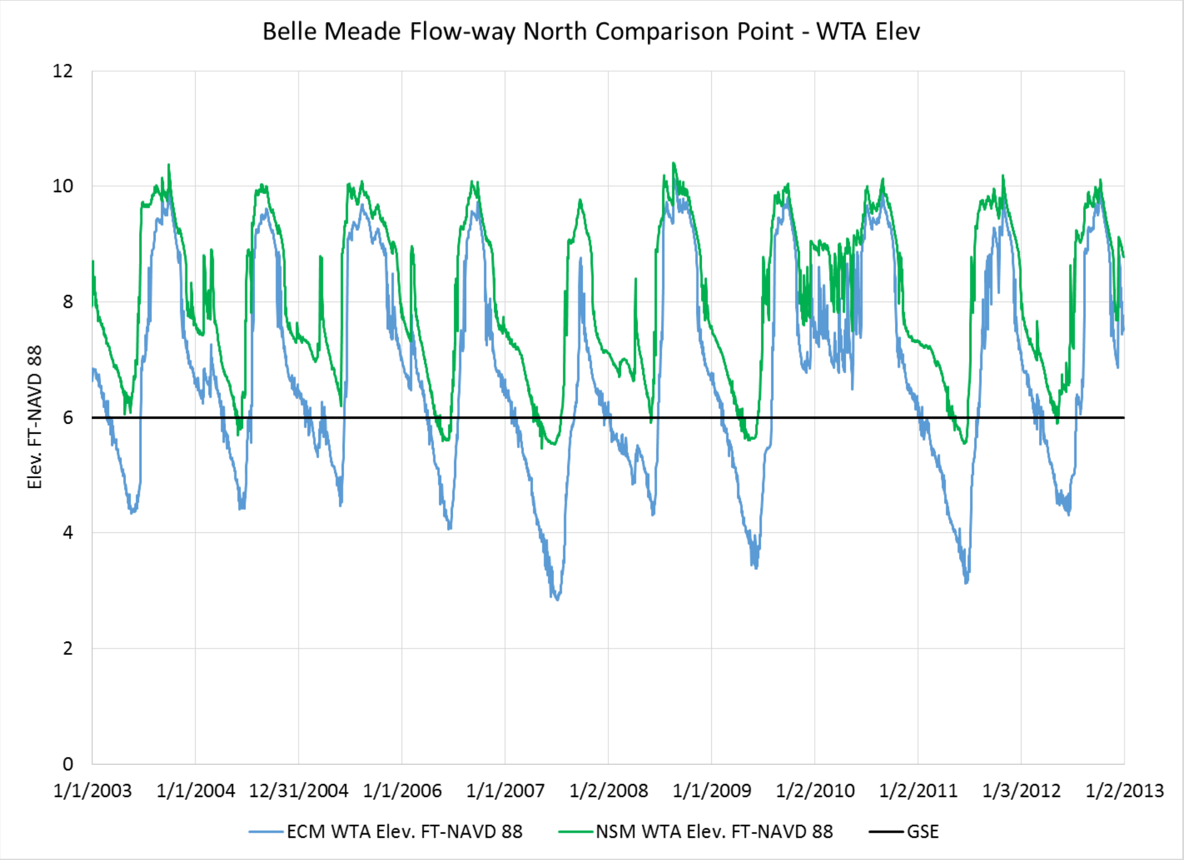


Figure 132. Belle Meade Flow-Way Water Table Elevation: North Comparison Point

Figure 132 provides a comparison of water table elevations relative to the NAVD88 datum, at the Belle Meade north comparison point, as well as to the GSE ascertained from the SFWMD LiDAR topography. From the comparison, the model results show the existing conditions water table falling to much lower levels during the drier months, compared to the historical conditions. This results in a water table that recovers later in the wet season than it did historically. The existing conditions water table also drops faster at the end of the wet season, which is likely a result of the drainage provided by the I-75 canals and the Henderson Creek canal.

Figure 133 compares the statistical distributions of the daily water table elevations from 2003 through 2012 at the Northern Belle Meade comparison point, in the form of stage-duration plots. From the comparison, it is evident that in the existing condition the percent of time the water table is more than about three feet below land surface (below approximately elevation 6 ft NAVD 88) has increased substantially over the historical condition simulation. Historically, the water table was below elevation 6.0 ft NAVD88 less than 10% of the time according to the model results. This has increased to more than 35% in the existing conditions, with the simulated water table dropping below elevation 4.0' for significant periods of time.

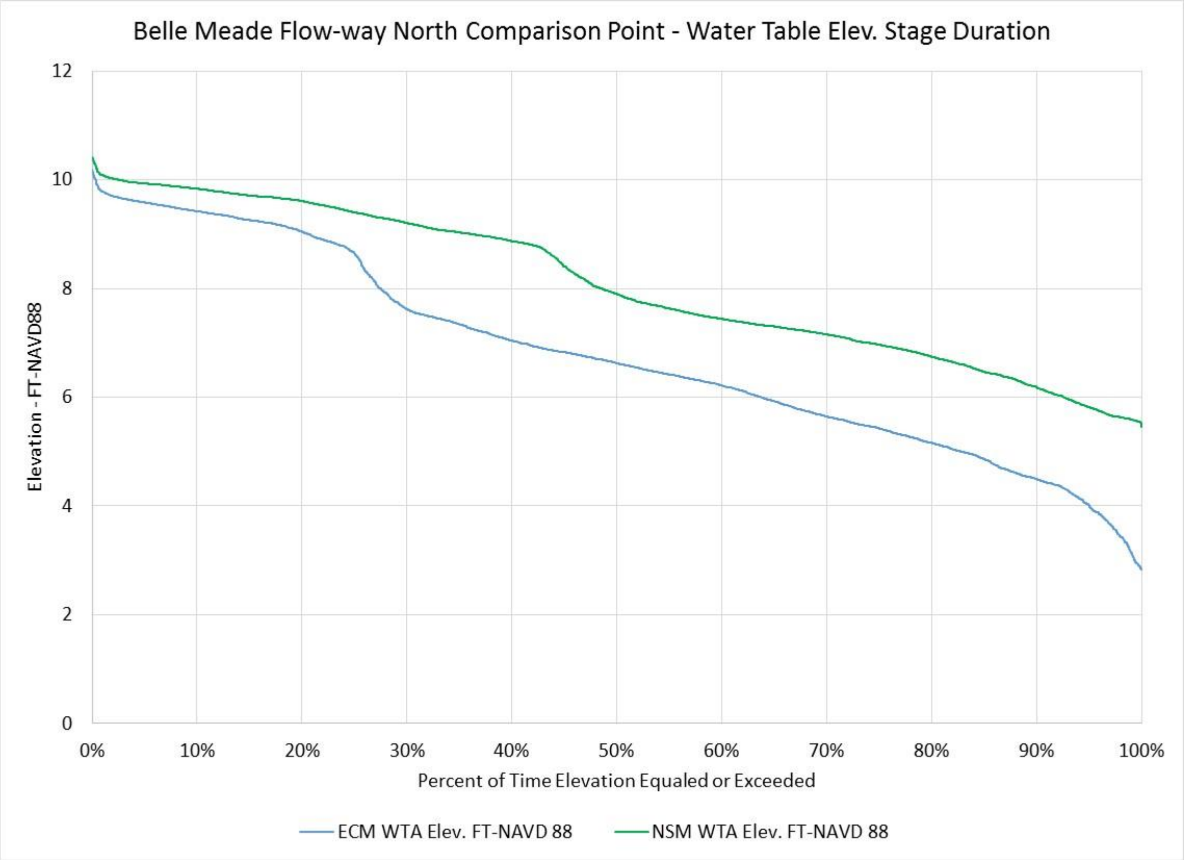


Figure 133. Belle Meade Flow-Way Water Table Stage-Duration: North Comparison Point

Figure 134 provides a comparison of water table elevations relative to the NAVD88 datum, at the Belle Meade south comparison point. The comparison shows a pattern similar to the one observed at the north comparison point. That is, the model results show the existing conditions water table falling to much lower levels during the drier months, compared to the historical conditions. This results in a water table that recovers later in the wet season than it did historically. The existing conditions water table also drops faster at the end of the wet season, which again is likely a result of the drainage provided by the I-75 canals and the Henderson Creek canal.

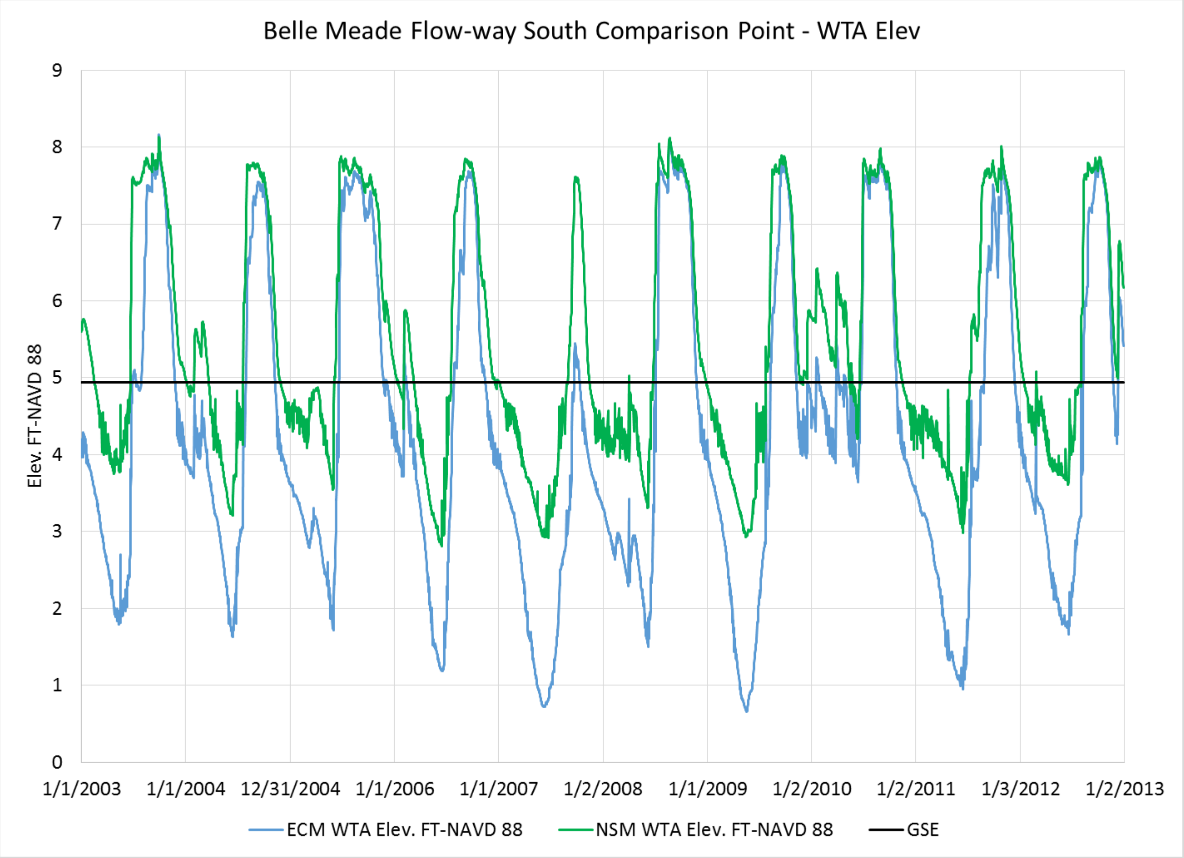


Figure 134. Belle Meade Flow-Way Water Table Elevation: South Comparison Point

Figure 135 compares the statistical distributions of the daily water table elevations from 2003 through 2012 at the Southern Belle Meade comparison point, in the form of stage-duration plots. From the comparison, it appears that historically, the water table rarely was more than two feet below land surface. In the existing condition, the water table is more than two feet below land surface more than 20% of the time and falls as low as three feet below land surface for significant percentage of the time, according to the model results.

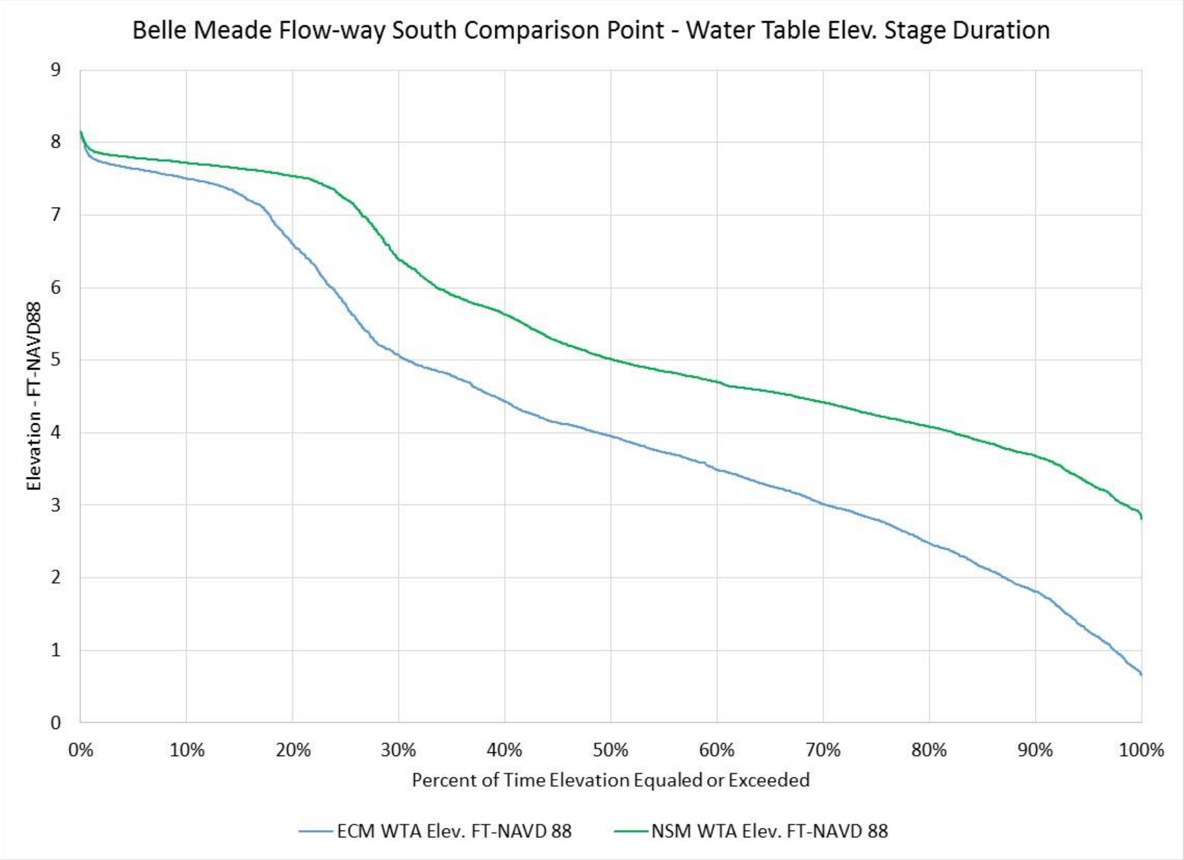


Figure 135. Belle Meade Flow-Way Water Table Stage-Duration: South Comparison Point

As seen in the preceding figures, the water table in the Belle Meade Flow Way responds similarly in both locations. Under historical conditions the elevation of the water table is higher and remains such for longer durations. This can be attributed to the aforementioned drainage of the I-75 and Henderson Creek canals, as well as other anthropogenic effects such as groundwater withdrawals and other surface water drainage, including localized drainage features (ditches, canals, etc.). Although the I-75 and Henderson Creek canals are several thousand feet away from these comparison points (**Figure 91**), the extremely permeable nature of the surficial and Lower Tamiami aquifers allow the effects of these canals to extend over large distances.

4.4.4 Depth of Overland Water Statistical Analysis

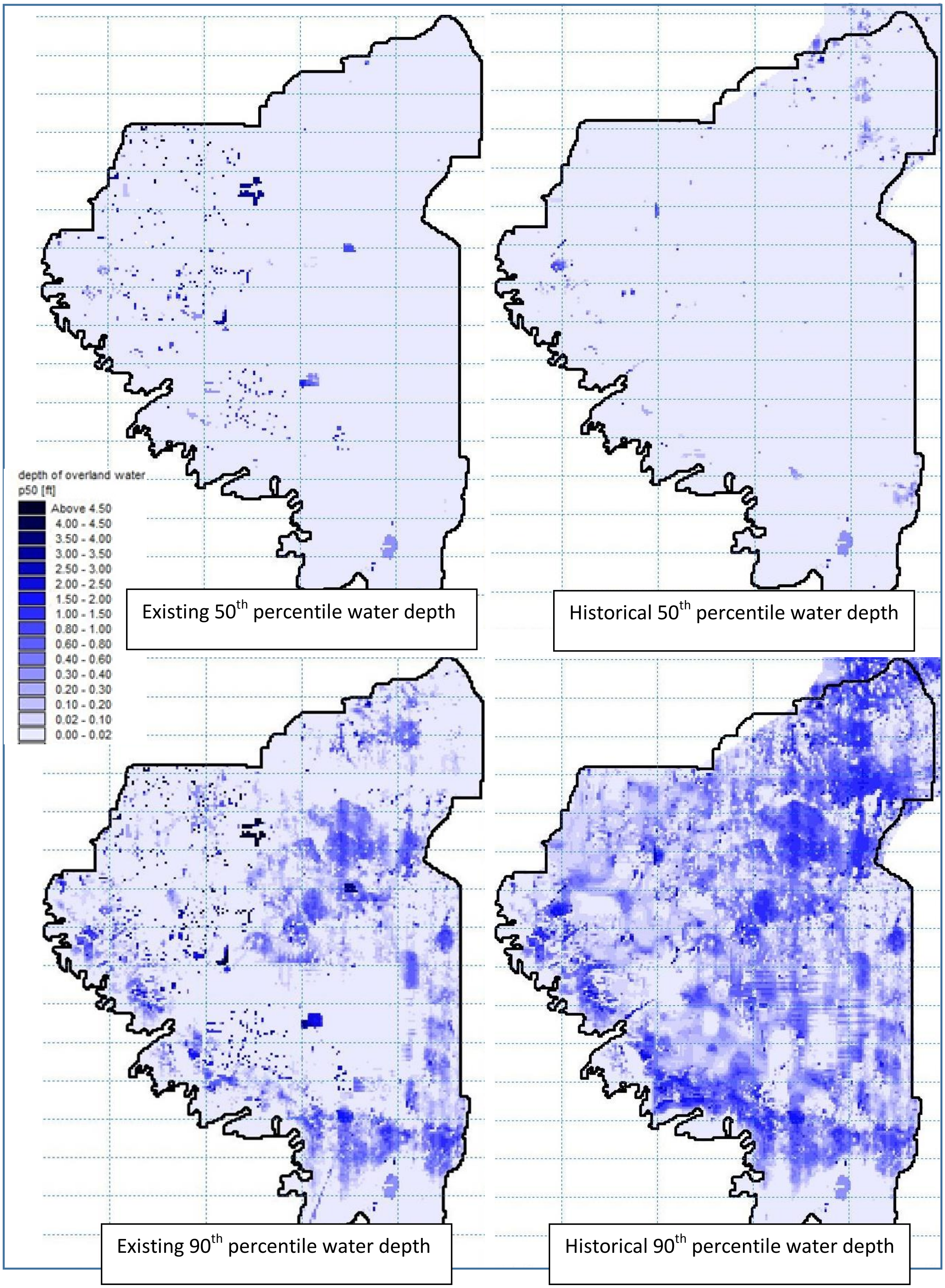
Figure 136 provides comparisons of the depth of overland water for the Existing-LSM (left) and Historic-LSM (right), where the spatial extent of each figure represents the model domain (black outline) used for the Existing-LSM. This analysis was completed to provide a view across the study area to facilitate discussions and possible management scenarios.

Statistical analysis represented by the figures are median water depths and 90th percentile water depths relative to land surface. Median water depths are those exceeded 50% of the simulation period of 2003 through 2012. The median depths are representative of relatively dry times of the year, considering that the wet season is typically about four months of the year and the other eight months tend to be fairly dry. The 90th percentile water depths are exceeded 10% of the time, and representative of wet season levels typically seen towards the end of the wet season (i.e., September).

These statistics are similar in some aspects to those represented by the Belle Meade Flow-way stage duration analyses (see previous section). However, the analysis presented here was accomplished for two discrete probabilities (50% and 10% probability of exceedance) over the entire study area, rather than the full spectrum of water depths (exceedance probabilities: 0% to 100%) for a selected point.

As evidenced by the 90th percentile statistical figures, the simulated overland water depths for the Historical-LSM show higher depths of overland water over a larger portion of the study area when compared to the Existing-LSM. The higher water depths generally predicted in the historical conditions can be attributed largely to the lack of a defined surface water drainage network in the historical conditions, and the presence of a network of canals and ditches in the existing conditions. Areas that have remained in a relatively natural state, such as the Belle Meade Flow-Way and the mangrove forests near the coast have retained a semblance of their pre-development hydrologic characteristics.

In the 50th percentile comparison, the scattered areas showing higher depths of overland water in the existing conditions correspond to retention ponds and other drainage features associated with urbanization, golf courses, mining, and agriculture.



Existing 50th percentile water depth

Historical 50th percentile water depth

Existing 90th percentile water depth

Historical 90th percentile water depth

Figure 136. Depth of Overland Water Comparisons

5.0 Conclusions and Recommendations

The Existing-LSM model is useful in characterizing the existing volumes and timing of freshwater flows into Rookery Bay. The Historical-LSM provides results for the analysis of the watershed in a pre-development or historical condition for comparison with existing conditions.

Important aspects of the model setup, including saturated zone layering and parameters, rainfall and potential evapotranspiration, soils and land-use dependent parameters, etc. were held constant between the Existing and Historical conditions LSM models in order to provide scientifically defensible comparisons between Existing and Historical Conditions. Care was taken to ensure that differences in model inputs and outputs between the two models are solely attributable to anthropogenic changes in the watershed.

The Existing LSM has been compared to measured data in the recent past to assess the predictive capability of the model. However, there are no available measurements of flows and water levels pre-dating the major hydrologic alterations in the watershed. Considering the uncertainty inherent in the model development and the lack of historical flow data, the Historical-LSM model results should not be viewed as a record of past flows and levels. Rather, these results should be viewed as an informed but imperfect hindcast of the flows and levels that may have occurred historically under climatic conditions similar to those of the recent 10-year period of 2003 –2012. It is therefore recommended to focus on the general trends of the hydrology to understand how the system responds to these anthropogenic changes.

From the comparisons of Historical and Existing Conditions water budgets, flows, and stages, a number of insights into the behavior of the system, and how it has changed in response to anthropogenic influences, can be inferred.

- Evapotranspiration (ET) was shown to have decreased by approximately 3 inches/year or on average from historical conditions to existing conditions. This is to be expected as the historical model domain is dominated by wetland and upland land use types. Urbanization and drainage tend to reduce ET. Furthermore, total surface water flows are similar on a unit area basis between the two scenarios. However, sheet flow has decreased considerably while baseflow to canals has increased. These results are to be expected as more water is thought to have been available to overland flow historically due to the absence of ditching and draining found throughout the watershed under existing conditions. Groundwater baseflow is higher in the Existing Conditions due to the presence of drainage canals which penetrate into the highly permeable surficial aquifer.
- Simulated seasonality in the summed coastal flows has shifted slightly from historical to existing conditions according to the model results. Slightly higher wet season flows occurred in the historical conditions model. Additionally, under existing conditions flows are higher for the 15% to 70% exceedance probabilities, meaning that for most mid-range flows, the existing conditions simulation showed a higher flow rate. Above the 90% exceedance probability, the existing

conditions flows were lower than historical or nonexistent. Overall, however, the simulated existing and historical average monthly and seasonal flows are surprisingly similar.

- Watershed-wide, the summed freshwater deliveries were predicted to be very similar overall under historical and existing conditions. This result is consistent with the water budget comparison, which suggested that although the flow has shifted from a sheet flow dominated system to a groundwater dominated system (baseflow to canals), the overall flow volumes are similar on a unit basis.
- The area north of the current Henderson Creek / Rookery Bay Watershed that historically would have contributed flow at times (i.e., the NSM area north of the current Golden Gate Canal) to the Henderson Creek / Rookery Bay system was a relatively insignificant part of the overall water budget, but did contribute some flow during extremely wet times.
- The results for the individual coastal inflows, presented separately for each basin/transect, suggest that the volume and timing differs spatially and seasonally between historical and existing conditions. Most notably, it appears the construction of the I-75 and Henderson Creek Canals have concentrated wet season flows in Henderson Creek at the expense of areas to the east, which have less flow now than historically. Other notable differences are related to the land use changes and associated drainage improvements. This result suggests that future management options that focus on spatial redistribution of flows, as opposed to projects that seek to change the timing of flows by storing freshwater for later releases, may have the greatest chances of success.

Several potential future scenarios are recommended for further study. The scenarios described below have been identified based upon the result comparisons between the LSM simulations (Existing vs Historical). Simulating these potential scenarios would provide insight into the ability of each alternative to better mimic historical hydrological conditions within the Rookery Bay watershed. Additionally, there have been recent discussions regarding the conversion of the Belle Meade Agricultural area to an urban land use through Collier County's Transfer of Development Rights (TDR) program. The RBNERR is interested in potential changes in freshwater flows that may result from such a conversion.

- Henderson Creek Weir Modifications – This scenario would simulate weir and gate operation scenarios for the Henderson Creek weir complex, and associated structures, including the Collier County structure on the east fork of Henderson Creek. Operational scenarios for these structures that have the potential to better mimic the historic conditions model results for Henderson Creek and the Rookery Bay Estuary will be identified and evaluated. This should include iterative model runs in an effort to develop ideal operational scenarios for timing, duration and flow results that would support restoration goals while minimizing potential negative upstream impacts.

- Belle Meade Agricultural Area Conversion – This scenario would simulate the potential conversion of the Belle Meade Agricultural Area to urban development, which may occur under the TDR program. This effort will require changing the topography and land use-related parameters in the model and to develop assumed conceptual stormwater routing, storage, and water control features to include in the model. The conversion from agriculture to urban land use would be simulated based on development standards and requirements such as the SFWMD or Collier county specified detention storage, and max allowable runoff for each area (i.e., Cubic Feet per Second per Square Mile CSM) required by development codes. Additionally, topographic changes associated with conversion to urban land use would be assumed consistent with other developments near the subject area. This scenario may also simulate one or more flow-ways through the developed areas to route offsite sheet flow from the north of the current agricultural area southward towards US 41. This scenario would not aim to provide a design level analysis from the land use conversion, rather answer the broader scale "what if?" question as to how the assumed differences in land use may affect run off to Rookery Bay.

- Belle Meade Flow-Way Hydrologic Restoration – The hydrology of the Belle Meade Flow-Way has clearly been impacted through the construction of the I-75 canals and the Henderson Creek Canal. This scenario would simulate a number of conceptual components that would work together to restore the regional hydrology of the Belle Meade Flow-Way. These include features to mitigate the groundwater drawdown effects of the I-75 canals and the Henderson Creek Canal, such as liners, slurry walls, and/or control weirs. Features that would facilitate restoration of north to south sheet flow across the present-day I-75 corridor should also be investigated. This may include construction of one or more pump stations and spreader canals. Another component of this alternative might include diversion of limited quantities of water from the Golden Gate Canal system. This alternative may be simulated independently and in conjunction with the Belle Meade Agricultural Area Conversion. Results would be evaluated with respect to restoring hydroperiods within the Belle Meade Flow Way and freshwater flows to Rookery Bay and adjacent estuarine waters.
- Tamiami Canal as Flow Re-distribution Canal – Based on the results of the distributed flow comparisons generated under Task 2.7, estuarine waters west of SR 951 generally receive more freshwater from the upland watershed today than under historical conditions. Conversely, estuarine waters east of SR 951 generally receive less freshwater inflow compared to historical conditions. Under this alternative, the modeling team would investigate the feasibility of using the existing Tamiami canal as a conveyance mechanism to re-distribute freshwater flows in a geographically and seasonally-appropriate manner. The general goal would be to move water in a southeasterly direction towards those areas that have experienced a decline in freshwater inflows.

6.0 References

Atkins, 2011. Collier County Watershed Management Plan Final Report Volume 1: Executive Summary Assessment of Existing Conditions and Performance Measures

Black, Crow & Eidsness, Inc., 1974. Master Plan for Water Management District No. 6.

Black, Crow & Eidsness, Inc., 1975. Master Plan - Water Management District No. 7.

Bruns & Bruns, Inc., 1982. A Report on the Henderson Creek Drainage Basin.

Assouline, S. and D.M. Tartakovsky. 2001. Unsaturated hydraulic conductivity function based on a soil fragmentation process. *Water Resources Research* 37(5): 1309-1312.

CH2M Hill Inc., 1980. Gordon River Watershed Study, Engineering Report.

CH2M Hill Inc., 1982. Belle Meade/Royal Palm Hammock Water Management Plan. Collier County, 2013. Stormwater Database: http://www.arcgis.com/explorer/?open=ff48f06d08754a53b8649ffd0b94f332

Dames and Moore, 1998. Big Cypress Basin Watershed Plan.

DHI, 2002. Big Cypress Basin Integrated Hydrologic-Hydraulic Model.

DHI, 2011a. Enhancement of Collier County Existing Condition MIKE SHE/MIKE-11 Model
PO# 4500061496

DHI, 2011a. MIKE SHE User Manual. Volume 1: User Guide.

DHI, 2011b. MIKE SHE User Manual. Volume 2: Reference Guide.

Duever, Mike, 2002. Southwest Florida Pre-Development Vegetation Map.

Cornell University Soil and Water Management. http://nrcca.cals.cornell.edu/soil/CA2/CA0212.1-3.php Website Accessed 2013

EPA, 2010. Stormwater Management Model User’s Manual Version 5.0. By Lewis A. Rossman.

Gee & Jenson, 1993. Corkscrew H & H Study.

HydroGeoLogic, Inc., 2006. Hydrologic-Hydraulic and Environmental Assessment For The Kamp Keais Strand Flow-way.

Johnson Engineering, Inc., 1981. Golden Gate Water Management Study.

Johnson Engineering, Inc., 1989. Watershed Analysis CR 951 Basin.

Johnson Engineering, Inc., 1991. Imperial River Watershed (Part of the Lee County Surface Water Management Plan, 1990 – 1991. Co-sponsored by Lee County and SFWMD).

Law Engineering and Environmental Services, 1993. Engineering and Environmental Studies Report for Lely and Lely Branch and Lely Manor Basins.

McCoy, Jack. 1972. Hydrology of Western Collier County, Florida. Report of Investigations No. 63. U.S. Geological Survey

MWH, 2005. City of Marco Island Utility Master Plan: Final March 2005.

NOAA, 2013. NOAA Tides and Currents: http://tidesandcurrents.noaa.gov/map/

NOAA, 2013. National Oceanic And Atmospheric Administration. http://oceanservice.noaa.gov/facts/lidar.html Website Accessed 2013.

Rawls, W.J., D.L. Brakensiek, and K.E. Saxton. 1982. Estimation of Soil Water Properties. In: *Transactions of the ASAE* 25: 1316-1320

PBS&J, 2011. Collier County Watershed Model Update *Model Development and Calibration Technical Memoranda:* Technical Memo Element 3 Task 10.

Parsons, 2006. Belle Meade Stormwater Management Master Plan. South Florida Water Management District.

Smally, Wellford & Nalven, 1961. Report on Water Management in Collier County, FL.

SFWMD, 1996. Hydrologic Restoration of Southern Golden Gate Estates (Conceptual Plan). SFWMD, 2013. DBHYDRO Environmental Database.
http://www.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu

USACE - Jacksonville District, 1986. Golden Gate Estates, Collier County, Florida – Draft Feasibility Study.

USGS, 2013. Florida Water Science Center, Evapotranspiration Data: http://fl.water.usgs.gov/et/

Waterman Industries, 2011. Company Website: http://watermanusa.com/products/water-control-equiptment/automatic-level-control/type-c-constant-upstream-level-guide