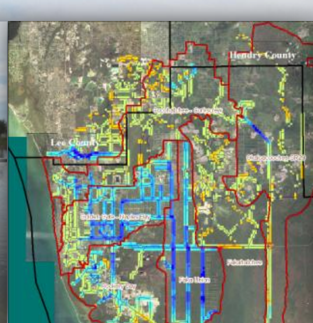
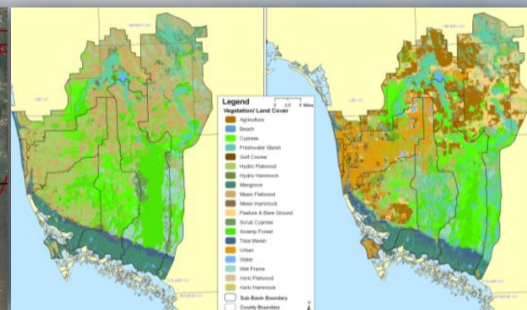
Collier County Watershed Model Update and Plan Development



Volume 4
Technical Report
Assessment of Existing Conditions and Performance Measures
Part B

Collier County

Prepared by ATKINS

August 2011

Document No. 110082
Job No. 100013237

DRAFT

COLLIER COUNTY WATERSHED MANAGEMENT PLAN COLLIER COUNTY, FLORIDA

Volume 4: Technical Report for Literature Review and Assessment of Existing Conditions

Prepared for:

Collier County
3301 East Tamiami Trail
Naples, Florida 34112

Prepared by:

Atkins
4030 Boy Scout Boulevard
Suite 700
Tampa, Florida 33607

August 2011

Contents of Volume 4

Volume 4 is a compilation of the individual technical memoranda completed to describe results of the existing conditions analysis in the watersheds and estuaries of Collier County, as well as the performance measures utilized to assess the benefit of proposed structural projects. The technical memoranda are presented as individual chapters and sections in this document and address the following items in the project's scope of work:

- Literature Review
- Element 1: Assessment of Existing Conditions – Watersheds
- Element 2: Assessment of Existing Conditions – Estuaries
- Element 3: Development of Performance Measures

Contents of Volume 4

Figures

Figures, cont'd

Figures, cont'd

Figures, cont'd

Figures, cont'd

Figures, cont'd

Tables

Tables, cont'd

Tables, cont'd

Tables, cont'd

Tables, cont'd

Tables, cont'd

Page

Acronyms and Abbreviations

ACSC	Area of Critical State Concern
ACSC-ST	Area of Critical State Concern – Special Treatment
BCB	Big Cypress Basin
BCC	Board of County Commissioners
BCE	Black, Crow, and Eidsness
BCNP	Big Cypress National Preserve
BMAP	Basin Management Action Plan
BMP	Best Management Practices
BOD-5	5-Day Biochemical Oxygen Demand
CC	Cocohatchee-Corkscrew Watershed
CCME	Conservation Coastal Management Element
CCPC	Collier County Planning Commission
CCWMP	Collier County Watershed Management Plan
CDU	Community Development Unit
CERP	Comprehensive Everglades Restoration Plan
cfs	Cubic feet per second
CN	Curve Number
Cu	Copper
DCIA	Directly Connected Impervious Area
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EAC	Environmental Advisory Council
ECM	Existing Conditions Model
EDDMapS	Early Detection and Distribution Mapping System
EMC	Event Mean Concentration
ENP	Everglades National Park
EPA	Environmental Protection Agency
ERD	Environmental Research and Design
ERP	Environmental Resource Permit
ERU	Equivalent Residential Unit
ET	Evapotranspiration
F.A.C.	Florida Administrative Code
FAS	Floridan Aquifer System
FCM	Future Conditions Model
FDEP	Florida Department of Environmental Protection
FDoH	Florida Department of Health
FLInv	Florida Invasive Plants Geodatabase
FLUCCS	Florida Land Use, Land Cover Classification System
FLUE	Future Land Use Element
FLUM	Future Land Use Map

FNAI	Florida Natural Areas Inventory
FPLOS	Flood Protection Level of Service
FRESP	Florida Ranchlands Environmental Services Project
FUFHOK	Faka Union, Fakahatchee, and Okaloacoochee-SR29 Watersheds
FWRI	Fish and Wildlife Research Institute
GGAMP	Golden Gate Area Master Plan
GGNB	Golden Gate-Naples Bay Watershed
GIS	Geographic Information Systems
GMP	Growth Management Plan
H&H	Hydraulic and Hydrologic
HOA	Homeowners Association
IAS	Intermediate Aquifer System
IWR	Impaired Waters Rule
JEI	Janicki Environmental Inc.
LASIP	Lely Area Stormwater Improvement Plan
LDC	Land Development Code
LID	Low Impact Development
LSI	Landscape Suitability Index
MAL	Minimum Aquifer Level
mg/l	milligrams/liter
MPN	Most Probable Number
MSL	Mean Sea Level
MSTU	Municipal Services Taxing Unit
NAVD	North American Vertical Datum
NEXRAD	High Resolution Radar
NGGE	Northern Golden Gates Estates
NGGEFRA	North Golden Gate Estates Flowway Restoration Area
NGGEFRP	North Golden Gate Estates Flowway Restoration Program
NGVD	National Geodetic Vertical Datum
NOx	Nitrate + Nitrite
NSG	Natural Systems Group
NSM	Natural Systems Model
OFW	Outstanding Florida Water
OL	Overland
Pb	Lead
PBS&J	Post Buckley Schuh and Jernigan
PCU	Platinum Cobalt Units
PDVM	Pre-Development Vegetation Map
PIR	Project Implementation Report
PSRP	Picayune Strand Restoration Project
PUD	Planned Unit Development
RB	Rookery Bay Watershed

RFMU	Rural Fringe Mixed Use
RIDS	Regional Irrigation Distribution System
RLSA	Rural Lands Stewardship Area
ROMA	Regional Offsite Mitigation Area
RSF	Residential Single Family
RWCA	Recyclable Water Containment Areas
SAS	Surficial Aquifer System
SCS	Soil Conservation Service
SFWMD	South Florida Water Management District
SGGE	Southern Golden Gate Estates
SOW	Scope of Work
S.R.	State Road
ST	Special Treatment
SWFFS	Southwest Florida Feasibility Study
SWIM	Surface Water Improvement and Management
SZ	Saturated Zone
TDR	Transfer of Development Rights
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TKN	Total Kjeldahl Nitrogen
TM	Technical Memorandum
TP	Total Phosphorus
TSS	Total Suspended Solids
TTI	Ten Thousand Islands
ug/l	micrograms/liter
UMAM	Uniform Mitigation Assessment Method
URF	Urban Residential Fringe
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geologic Survey
UZ	Unsaturated Zone
WBID	Water body Identification Number
WMD	Water Management District
WMPs	Watershed Management Plans
Zn	Zinc

INTRODUCTION

Collier County is developing Watershed Management Plans (WMPs) with the purpose of protecting the County's estuarine and wetland systems, consistent with Florida Statute (Subsection 163.3177 (5)(d)). Under the statute, a Conservation Element that addresses "the conservation, use, and protection of natural resources in the area, including air, water, water recharge areas, wetlands, water wells, estuarine marshes, soils, beaches, shores, flood plains, rivers, bays, lakes, harbors, forests, fisheries and wildlife, marine habitat, minerals, and other natural and environmental resources" is required as part of Local Government Comprehensive Plans.

This volume of the CCWMP provides a historical perspective and summary of previously completed studies. This volume also presents a detailed assessment of existing conditions in Collier County and performance measures that were used to evaluate the projects described in Volume 2.

DOCUMENT ORGANIZATION

This volume of the WMP describes the link between water quality, water quantity, and natural systems issues in Collier County watersheds and estuaries. This volume is presented in four (4) chapters, consistent with the work elements outlined in the County's Scope of Work.

Chapter 1: Literature Review and Preliminary Assessment Based on Review of Previously Developed Models. This section provides a historical perspective on water resource issues in Collier County. This chapter also describes other models previously applied for in BCB and compares model results in order to lay the groundwater necessary to fully understand the evaluation of existing conditions

Chapter 2: Assessment of Existing Conditions – Watersheds. Surface water, ground water, and natural systems conditions in the Cocohatchee-Corkscrew, Golden Gate, and Rookery Bay watersheds, and the rural Faka Union/Okaloacoochee/Fakahatchee basins combined are presented and assessed against performance measures to evaluate historical habitat loss.

Chapter 3: Assessment of Existing Conditions – Estuaries. Freshwater inflows, water quality of inflows and receiving waters, and coastal habitat conditions in Wiggins Pass, Naples Bay, Rookery Bay, and Ten Thousand Islands estuaries will be characterized and evaluated in terms of performance measures developed for the estuaries.

Chapter 4: Development of Performance Measures. Performance measures used for assessing watershed and estuary conditions are described in this chapter.

Chapter 5: References.

3.0 ASSESSMENT OF EXISTING CONDITIONS: ESTUARIES

3.1 VOLUME AND TIMING OF FRESHWATER INFLOWS/FRESHWATER

Historic fresh water flow patterns in Collier County have changed over the years due to increased development. The changes in flow have impacted the environmental integrity of many of the County's estuaries due to changes in salinity patterns (Browder et al. 1998, Shirley et al. 2005). In addition, the changes in flow patterns have resulted in the introduction into some estuaries of large quantities of organic-rich sediment from accelerated rates of freshwater inflow (Locker 2005). In fact, much of the scientific literature conducted in the TTI estuary has focused primarily on the issue of altered hydrology and the need for a more natural pattern of freshwater inflow (e.g., Browder et al. 1988, Shirley et al. 2005).

As watershed restoration activities must consider the restoration of historic flows, it was necessary as part of this project to assess existing conditions in the volume and timing of fresh water discharges to each estuary system from the contributing watersheds by comparing them to a baseline, which in this case is represented by the predevelopment condition.

The method consisted of comparing the results of the MIKE SHE MIKE 11 ECM to those of the NSM to define the monthly water surplus or deficit that should be targeted for restoration purposes. The ECM is the model updated specifically for this project to support preparation of the County's Watershed Management Plans, whereas the NSM, or pre-development model, was developed as part of the USACE SWFFS. A full description of the NSM can be found in the report titled "Final Report, Natural Systems Model (NSM) Scenario Southwest Florida Feasibility Study" (SDI, 2007).

As part of the watershed management planning process, it is necessary to establish basis for comparing existing conditions to both the natural system and a master plan conditions. That was achieved through the use of a performance measure, which is a quantitative indicator of the characteristics of the system under a given condition. A numerical scoring method was identified to reflect existing and proposed system conditions in terms of volume and timing of fresh water discharges into the receiving estuaries. This chapter includes a description of the scoring method and results.

3.1.1 Description of the Hydrologic / Hydraulic Models

As indicated above, model results from the Natural Systems MIKE SHE model (NSM) were compared to the Existing Conditions MIKE SHE model (ECM). The ECM represents the 2007 land use condition in Collier County and was calibrated against measured flow and stage data in the canal network, as well as measured groundwater head elevation data. The simulation period for this model is 2002–October 2007. The primary drainage system and most of the secondary drainage system is explicitly represented in the model input.

The NSM was developed as part of the USCOE SWFFS by modifying the original SFWMD Big Cypress basin (BCB) model in terms of land use and conveyance systems to represent pre-development conditions. The NSM simulation period extended from 1976 to 1986.

It should be noted that the ECM and NSM computer models provide an estimate of the simulated conditions. However, comparisons must consider differences in model characteristics including:

a) The ECM model domain includes the area within Collier County west of, and including, the Okaloacoochee-S.R. 29 basins, and all the way to the coastline. The NSM encompasses the entire SWFFS area, including the Caloosahatchee and Estero River Basins.
b) The ECM includes all the entire main conveyance system, as well as the main secondary canals. In the Collier County portion of the NSM, flow to the estuarine systems is predicted as overland flow. Natural drainage systems such as the Gordon River and Henderson Creek are not explicitly represented.
c) The ECM and NSM simulation periods are not the same. As indicated above, the ECM was used to conduct simulations from 2002–October 2007, whereas the NSM simulation period extended from 1976 to 1986.
d) The input data, particularly the topographic data source, for the ECM and NSM are not the same and differences in terrain elevations are noticeable.

In spite of the model differences, it was determined that the comparisons between the two models provide valid information to setup flow restoration targets because a) flow estimates for comparison were obtained at specific locations within each watershed, which minimized the effect of differences in the extent of the model domain, and b) both models included simulation periods that on the average can be considered representative of hydrologic conditions.

To further validate the model comparisons results, it was considered necessary to compare them to those from an alternative method. As such, they were compared to those from the salinity analysis described in a technical memorandum previously prepared as part of this project. Results of those comparisons are also described later in this report.

3.1.2 Flow Estimation Methods

This section describes the method used to calculate the total water discharged to each estuary system from the NSM and the ECM.

3.1.2.1 Natural Systems Model (NSM) Flow Estimates

The NSM uses overland flow to predict the movement of water across the ground surface and into the estuaries. In order to extract overland flow results from specific locations in the model, a tool was developed to extract the required information. This tool, called FlowthruLine, was used to extract a time series of flow data from one set of cells to an adjacent set of cells along a line.

Figures 3-1 through 3-4 show the locations of the "Flow through" lines specified for each watershed. These lines are generally drawn along the US 41 corridor and it is assumed that all water that flows across this line will enter the downstream estuary.

The tool was applied to each of the six watersheds. The calculated times series of flow for each watershed was then converted to daily discharge volume and summed by month for the period of the simulation (1976–1986). The monthly values generated for each year were then averaged to estimate the period of record average monthly flow volume from each watershed. The flows from the Faka Union, Fakahatchee, and Okaloacoochee-SR29 watersheds were combined to estimate total flows into the TTI estuary.

3.1.2.2 Existing Conditions Model (ECM) Flow Estimates

The ECM utilizes both channel and overland flow to predict total watershed discharge. However, in Collier County US 41 generally restricts overland flow before it can reach the estuaries and flow is routed through a series of culverts, bridges, or control structures. Therefore, only flows in the conveyance system were used in the calculations.

Discharge to the estuaries was measured by extracting time series of flow data from specified locations in the MIKE 11 river network. These locations are also shown in **Figures 3-1 through 3-4**. The flow data from each station were converted from discharge rate (cubic feet per second) to discharge volume (inches) for each time step. Flow data was extracted every three hours for the duration of the simulation. As indicated previously, the simulation covers the period from January 1, 2002–October 31, 2007.

The following steps were used to calculate the seasonal fresh water discharges for each watershed.

- The individual times series of discharge for each watershed were summed to estimate the total volume to the estuary for each time step.
- The volumes for each time step were then summed by month and by year. The results for the Faka Union, Fakahatchee, and Okaloacoochee-SR29 watersheds were consolidated to represent the total flow to the TTI Estuary. This resulted in a table of monthly volume by year for the period of the simulation. An example calculated for the Wiggins Pass Estuary is shown in Table 3-1.
- The monthly values generated for each year were then averaged to estimate a period of simulation average monthly water volume discharged from each watershed.
- The monthly average values were then consolidated by season to arrive at predicted wet season and dry season discharges into each of the receiving estuaries.

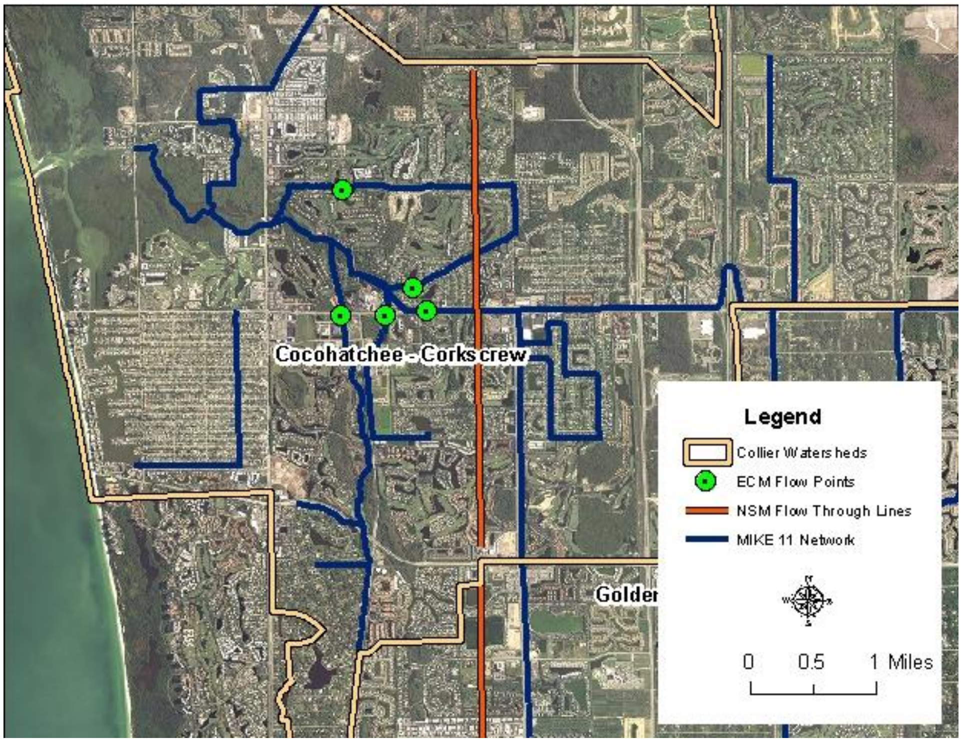


Figure 3-1
NSM Flow Through Line and ECM Flow Data Points,
Cocohatchee–Corkscrew Watershed

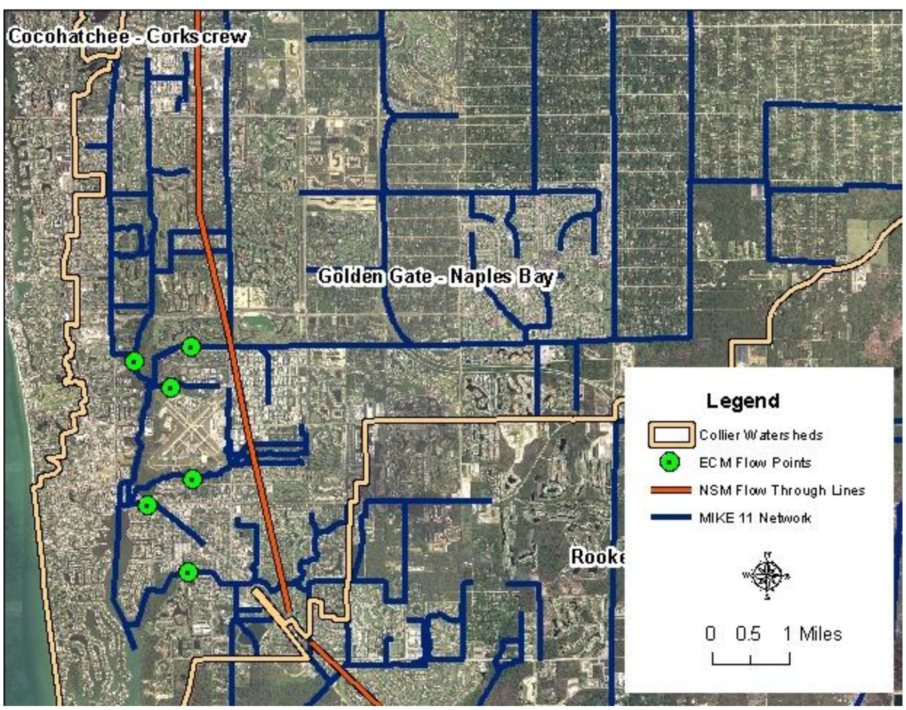


Figure 3-2
NSM Flow Through Line and ECM Flow Data Points,
Golden Gate-Naples Bay Watershed

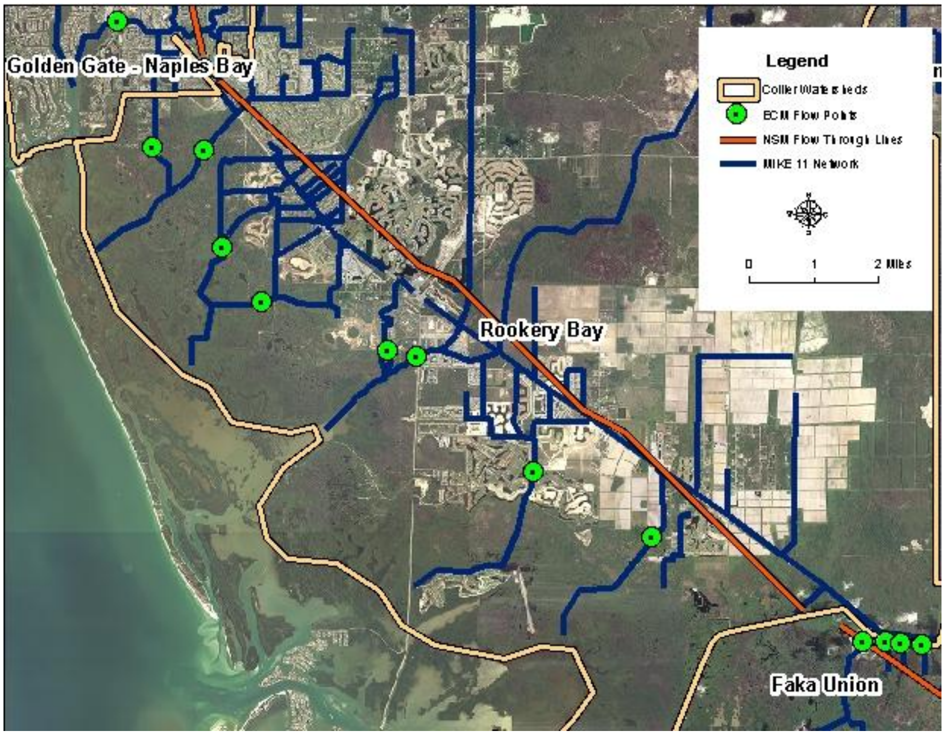


Figure 3-3
NSM Flow Through Line and ECM Flow Data Points, Rookery Bay Watershed

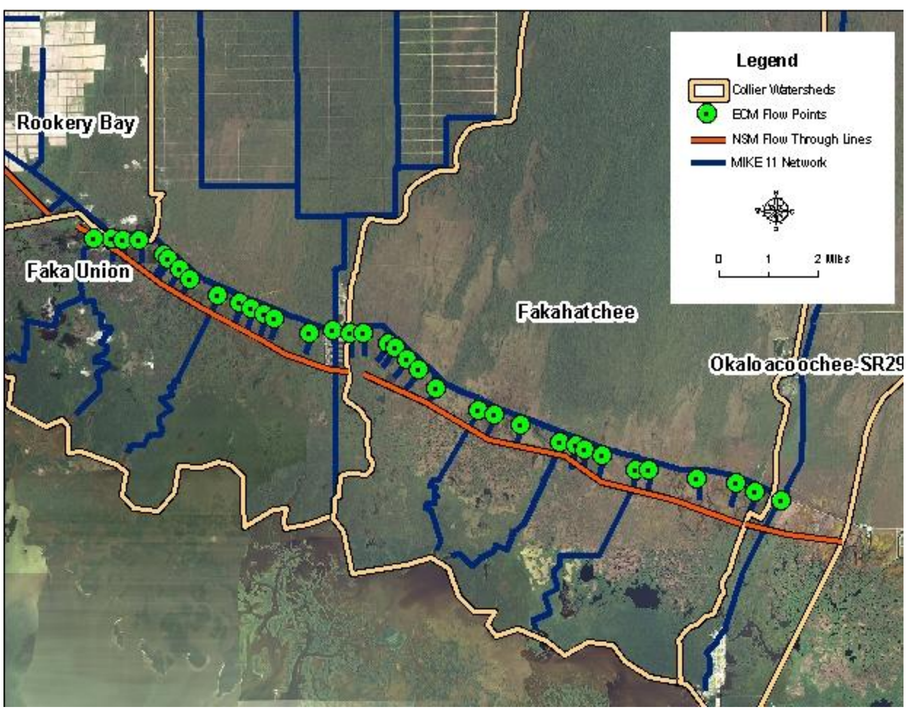


Figure 3-4
NSM Flow Through Line and ECM Flow Data Points, Faka Union, Fakahatchee and Okaloacoochee-SR29 Watersheds

Table 3-1
Calculated ECM Fresh Water Discharge to the Wiggins Bay Estuary
from the Cocohatchee-Corkscrew Watershed

Discharge to Wiggins Bay Estuary (inches)							
Month	2002	2003	2004	2005	2006	2007	Average Month
January	0.02	0.17	0.10	0.05	0.12	0.03	0.08
February	0.01	0.10	0.11	0.04	0.08	0.02	0.06
March	0.01	0.06	0.12	0.11	0.07	0.01	0.06
April	0.01	0.04	0.07	0.07	0.02	0.01	0.03
May	0.01	0.03	0.06	0.05	0.01	0.01	0.03
June	0.03	0.65	0.03	1.12	-0.10	0.01	0.29
July	0.10	0.66	0.12	1.59	0.20	0.01	0.44
August	0.09	1.44	2.21	1.04	0.61	0.01	0.90
September	0.54	1.75	1.72	0.50	1.52	0.06	1.02
October	0.22	0.73	0.45	1.36	0.20	0.13	0.51
November	0.13	0.21	0.07	0.48	0.04		0.19
December	0.15	0.15	0.06	0.21	0.03		0.12
Annual Total	1.32	5.98	5.11	6.61	2.79		3.73

3.1.3 Fresh Water Discharge Comparison

For each of the four estuaries in Collier County, the predicted fresh water discharges from the NSM was compared to those predicted from the ECM. This was completed by subtracting the average monthly flows over the simulation period. Below is a description of the results for each of the estuaries.

3.1.3.1 Wiggins Pass Estuary

As shown in **Figure 3-5**, results indicate that the total fresh water discharges into Wiggins Pass have increased from pre-development conditions, particularly in the wet season. In addition, flow increases start earlier in the year and continue longer than in the NSM conditions. The difference in total fresh water volume discharged in the wet season (July–October) was expected, as were the comparable discharges for most of the dry season.

The relative large discharge increase in June was unexpected and suggests a change in the timing of flows to the estuary. This increase may also be attributable to the rainfall volume difference in the simulation periods for each model for the month of June. The surplus flow in November and December are likely associated with groundwater recharge to the canal system and delayed runoff from above average rainfall in 2003 and 2005.

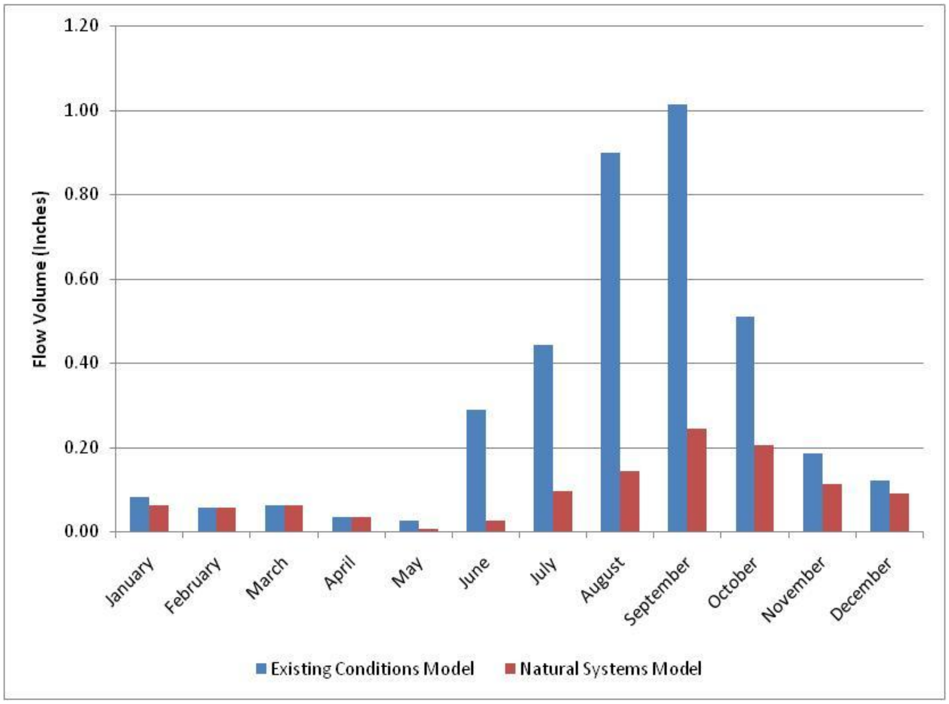


Figure 3-5
Comparison of the NSM vs. ECM Average Monthly Discharge,
Cocohatchee-Corkscrew Watershed to Wiggins Pass Estuary

3.1.3.2 Naples Bay Estuary

Figure 3-6 shows a comparison of the period of simulation average monthly volume of fresh water discharge to the Naples Bay Estuary from the Golden Gate-Naples Bay Watershed. The results indicate a year-round increase in the magnitude of water volume released to the estuary. The results do not indicate a significant change in the timing of discharges. These results were expected and consistent with previous studies (Black, Crow, and Eidsness, 1974; SFWMD, 2007). The increased discharges are attributed to construction of the Golden Gate Main Canal that resulted in effectively increasing the extent of the watershed's drainage area from approximately 50 square miles to approximately 135 square miles.

3.1.3.3 Rookery Bay Estuary

The period of simulation average monthly comparison results for the NSM vs. ECM predicted fresh water discharges into the Rookery Bay estuary is shown in **Figure 3-7**. These results show a flow deficit during the months of October through May, and a flow surplus during the months of June through September. The total average annual predicted volume discharged to the estuary is very similar for both models, indicating that the primary challenge in this estuary is related to the timing of discharges.

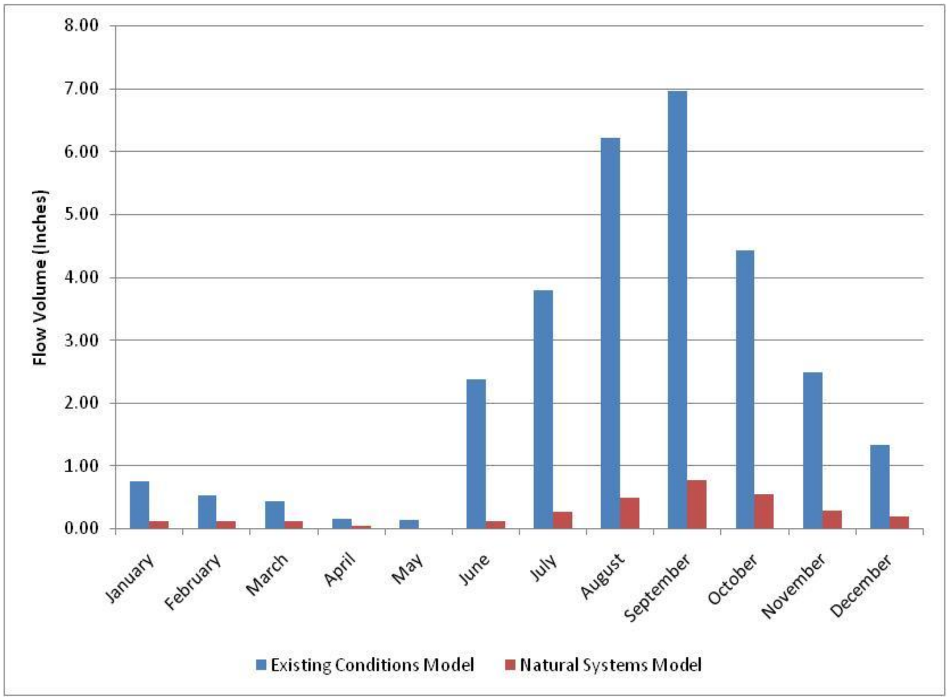


Figure 3-6
Comparison of the NSM vs. ECM Average Monthly Discharge,
Golden Gate-Naples Bay Watershed to Naples Bay Estuary

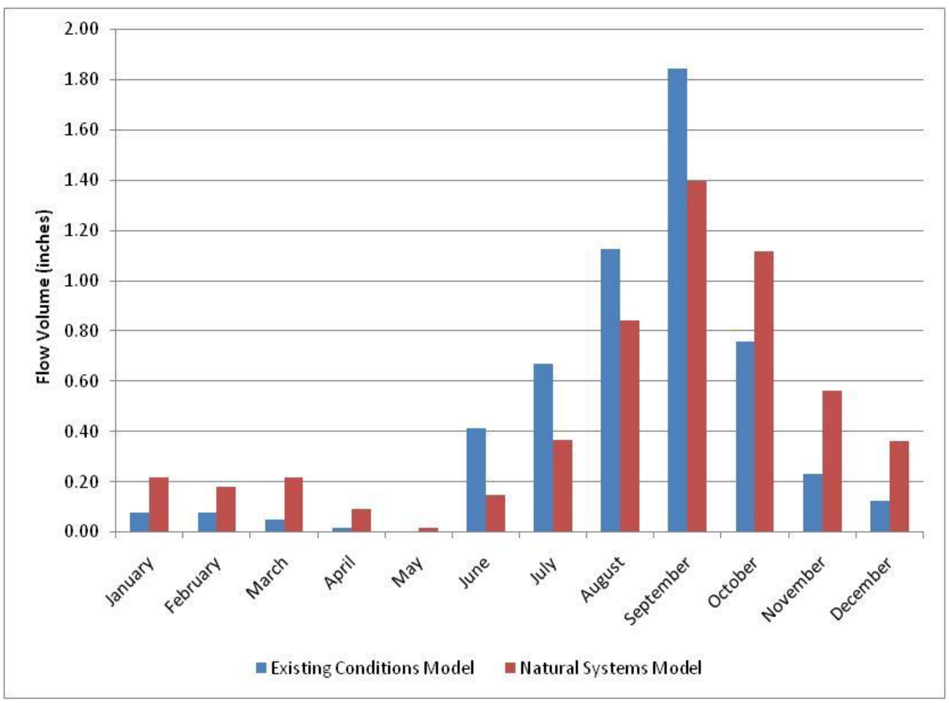


Figure 3-7
Comparison of the NSM vs. ECM Average Monthly Discharge,
Rookery Bay Watershed to the Rookery Bay Estuary

3.1.3.4 Ten Thousand Islands Estuary

The TTI Estuary receives fresh water discharge from three watersheds; Faka Union, Fakahatchee, and Okaloacoochee-SR29. Control structures are used to manage discharge from the Faka Union and SR29 canals into the estuary system. The results in **Figure 3-8** indicate that excess fresh water discharge to the estuary occurs primarily during the wet season. The volume of wet season excess discharge is approximately 10 inches. The data suggests that the wet season excess flow contribution comes primarily from the Faka Union watershed that is drained by Miller, Faka Union and Merritt Canals.

The southern portion of the Faka Union watershed is the location of the Picayune Strand Restoration Project. This project will remove the road system and install ditch blocks throughout the canal network. The project is expected to provide wet season storage, restore wetlands, and decrease the volume of discharge to the estuary, which is consistent with estuary restoration goals.

Predicted dry season discharges from the watersheds are essentially equal for the ECM and NSM during the months of January through May. Excess flows in November and December are likely the result of delayed runoff during 2003 and 2005. The average runoff volume is 1.97 inches in November 2003 and November 2005. The average runoff volume is 0.70 in the other years of the ECM simulation, which compares favorably with the average NSM November discharge of 0.6 inch.

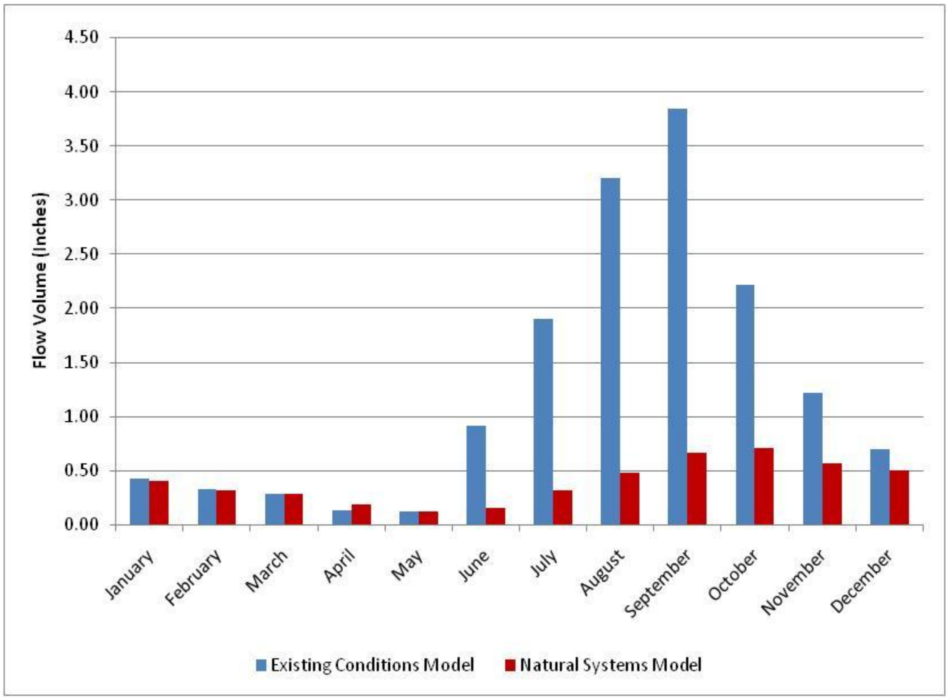


Figure 3-8
Comparison of the NSM vs. ECM Average Monthly Discharge, Faka Union, Fakahatchee and Okaloacoochee Watersheds to the Ten Thousand Islands Estuary

3.1.3.5 Seasonal Discharge Comparison Summary

Figure 3-9 shows the seasonal fresh water deficit or surplus estimated by subtracting NSM predicted discharges from ECM predicted discharges. As shown, pre-development water discharges during the wet season have increased for all estuaries due to the construction of drainage canals as well as the increased impervious areas associated with urban development. During the dry season, discharges have increased to all estuaries, except Rookery Bay, which has experienced a fresh water flow reduction because of the re-routing of watershed discharges into the Golden Gate Canal.

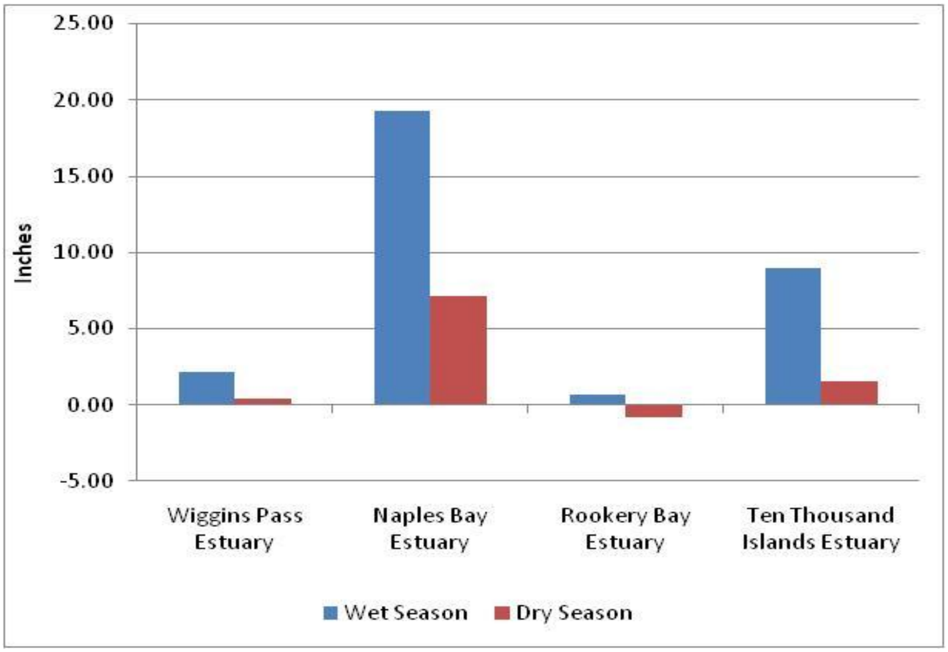


Figure 3-9
Seasonal Fresh Water Surplus and Deficit by Estuary

3.1.4 Results Validation with Salinity Analysis

The salinity:flow analysis method is described in detail in the Technical Memorandum submitted for Phase 1, Element 4, Task 2. The analytical method was applied to areas drained by the four primary canals listed below that discharge to the County estuaries. The location of those canals is shown in **Figure 3-10**.

- The Cocohatchee Canal that discharges to the Wiggins Pass Estuary,
- The Golden Gate Main Canal that discharges to the Naples Bay Estuary,
- The Henderson Creek Canal that discharges to the Rookery Bay Estuary, and
- The Faka Union Canal that discharges to the TTI Estuary

The analysis included the following steps:

- Obtain estimates of salinity at an estuarine area that can be considered unaffected by changes in fresh water discharge patterns due to development. This salinity value was assumed to be the target representing restored conditions at other locations.
- Based on available salinity and flow data, develop salinity:flow relationships representing conditions at the four estuaries of concern for this study, Wiggins Pass, Naples Bay, Rookery Bay, and TTI. The location of the salinity and flow stations used in the analysis are also shown in **Figure 3-10**.
- Estimate the flow deficit or surplus at each of the monitoring stations that is required to reach the salinity target.

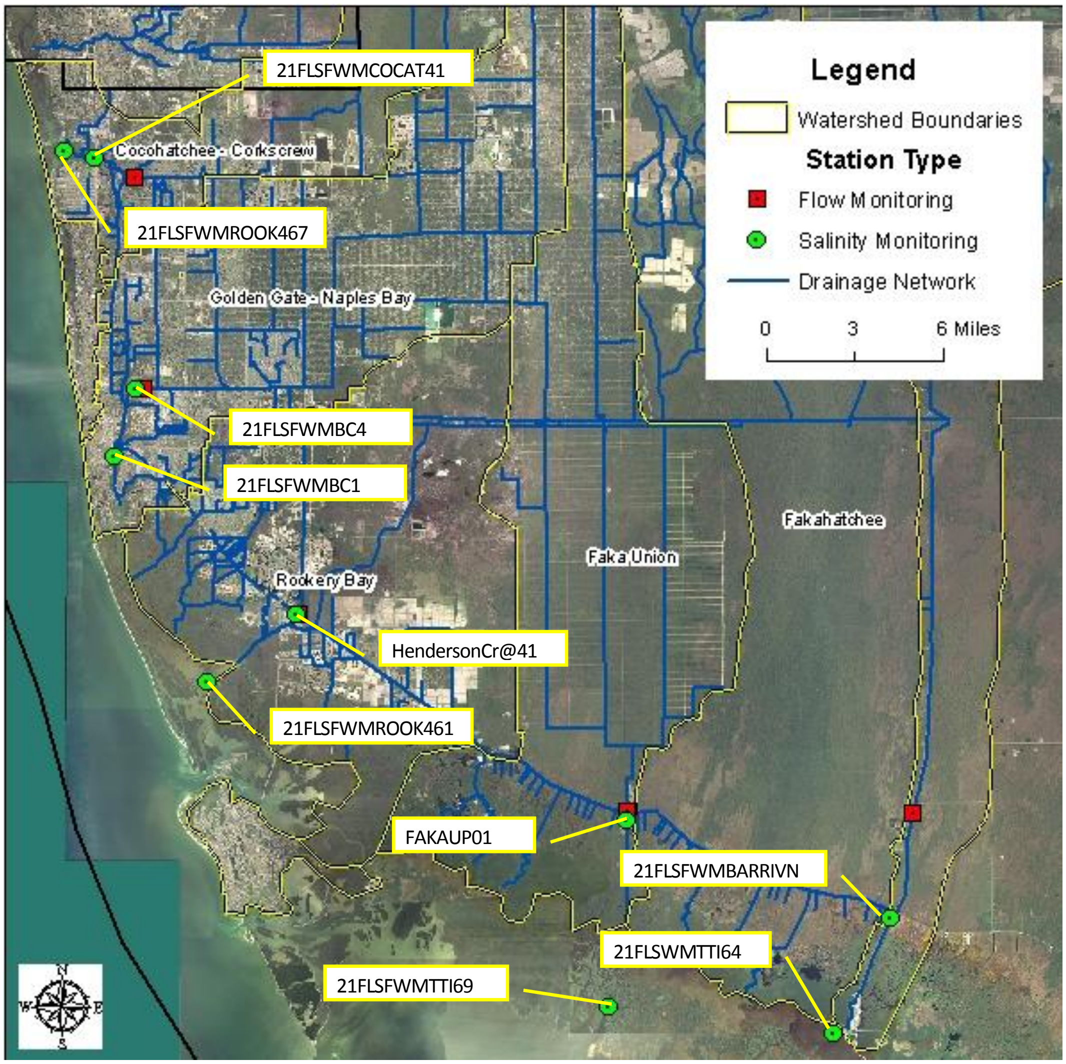


Figure 3-10
Monitoring Stations Considered in the Salinity:Flow Analysis

It must be noted that flow estimates in the salinity analysis are based solely on a single point of discharge to each estuary. In some watersheds, such as Rookery Bay, additional fresh water flows enter the estuaries through other canals that are not monitored for flow or salinity and could not be included in the analysis.

Figure 3-11 shows results of the model comparison and salinity analysis methods for the wet and dry seasons, respectively. During the wet season, the predicted excess flow to the Wiggins Pass and Naples Bay estuaries are very similar in both methods. This indicates that wet season flows to the estuary are dominated by discharge from the Cocohatchee and Golden Gate Main Canals to the Wiggins Pass and Naples Bay estuaries; respectively.

Both methods also predict similar discharge to the TTI Estuary during the wet season. The salinity analysis uses only measured flows from the Faka Union watershed. The similarity of the ECM vs. NSM results suggest that the excess wet season flow to the TTI estuary is dominated by discharges from the largely impacted Faka Union watershed and not from the Fakahatchee and Okaloacoochee/SR 29 watersheds, which have been impacted by development to a much small degree.

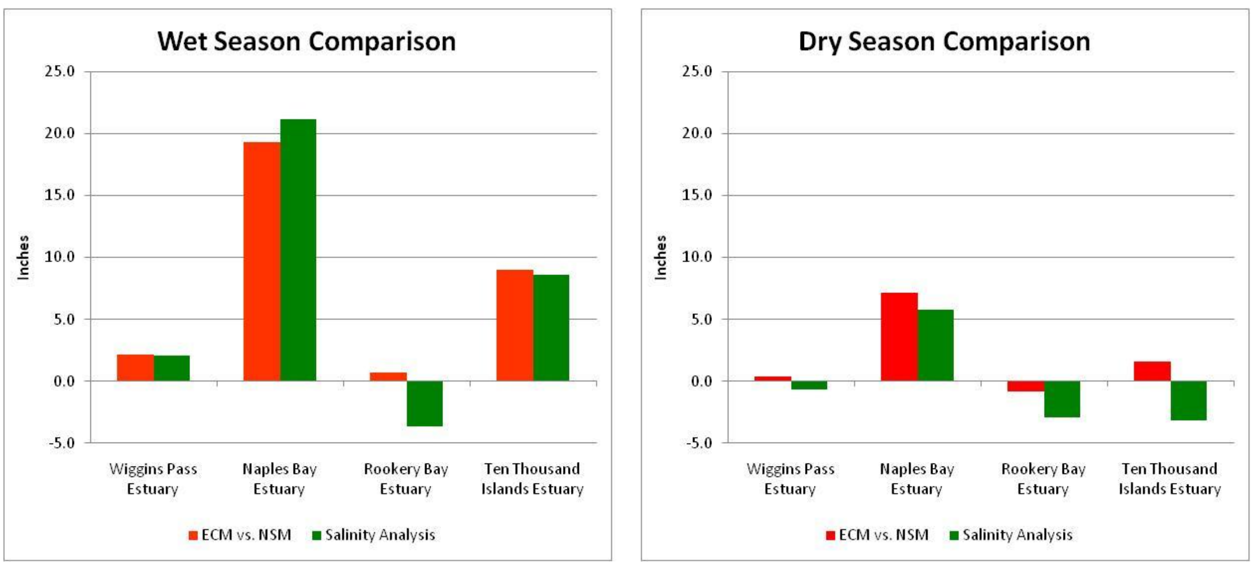


Figure 3-11
Results of the Model Comparison and Salinity Analysis Methods

For the Rookery Bay estuary, the Salinity Analysis indicates a wet season deficit from the Henderson Creek Canal to the estuary. The ECM vs. NSM comparison indicates a wet season surplus. The difference is that the Salinity Analysis only considers flows from the Henderson Creek Canal that drains approximately 40 percent of the watershed. The ECM vs. NSM analysis considers flows from the entire watershed and includes the urbanized Lely Area in the western portion of the watershed and the agricultural areas in the southeastern portion of the watershed.

During the dry season, the Salinity Analysis indicates that there is a flow deficit from the primary canals to the Wiggins Pass, Rookery Bay, and TTI estuaries. This is expected since the most downstream control structures in the Cocohatchee, Henderson Creek, and Faka Union Canals often prevent flow from occurring during the dry season. In the ECM vs. NSM results, a flow surplus, or a smaller flow deficit, can be attributed to the flow contributions from the secondary and uncontrolled releases to the estuary systems.

In the Naples Bay Estuary, the dry season results indicate a surplus using both calculation methods. This indicates that the Golden Gate Main Canal remains the primary source of discharge to the estuary; however, it is likely that flows from the smaller tributaries make up a larger percentage of the total flow to the estuary during the dry season.

3.1.5 Conclusions on the Application of the Analysis Methods

The following conclusions can be drawn from the results of this analysis:

In spite of the limitations of both methods applied to define fresh water discharge targets for the Collier County estuaries, the runoff surplus or deficit results are comparable. This validates the use of the ECM to evaluate potential proposed projects that will be incorporated in the Watershed Management Plans.

The primary environmental protection issue associated with the Wiggins Pass, Naples Bay, and TTI estuaries is excess runoff during the wet season.

For the Rookery Bay Estuary, the primary issue appears to be the timing of flow to the estuary. The system receives too much water during the wet season and too little water during the dry season.

3.2 QUALITY OF DISCHARGE

This Chapter addresses Element 2, Task 2: Quality of Discharge. The objective of this task is to characterize the water quality of fresh water discharges delivered to the following four estuaries in Collier County:

- Wiggins Pass
- Naples Bay
- Rookery Bay
- TTI

Six watersheds were evaluated that discharge fresh water to these four estuaries (**Figure 3-12**). The Wiggins Pass estuary receives runoff from the Cocohatchee-Corkscrew watershed. The Golden Gate-Naples Bay and Rookery Bay watersheds discharge into Naples Bay and Rookery Bay estuaries, respectively. Three watersheds make up the drainage area to the TTI estuary: Faka Union, Fakahatchee, and Okaloacoochee-SR29.

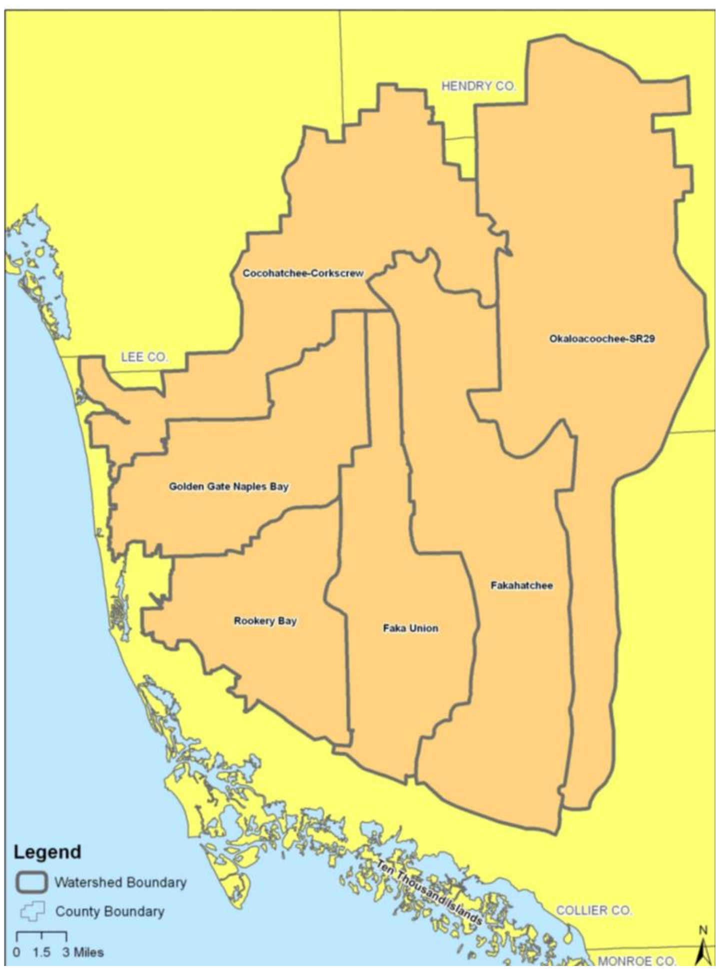


Figure 3-12. Collier County Watersheds

3.2.1 Water Quality Data

To accurately characterize the water quality of the discharge waters from priority watersheds in Collier County, in addition to the review of the available reports, Atkins analyzed available water quality data for Cocohatchee-Corkscrew, Golden Gate–Naples Bay, Rookery Bay, Faka Union, Okaloacoochee–SR29, and Fakahatchee watersheds. The data used for the analyses included the IWR Run 39 data (supplied by FDEP), as well as data from Florida STORET, Collier County, City of Naples, and the Rookery Bay National Estuarine Research Reserve. This resulted in an updated and comprehensive database of water quality data.

All available water quality data were subject to a quality assurance / quality control procedure. It should be noted that the analyses were conducted using data from the most recent ten year time period (2000 to 2009) to minimize the effect of temporal variations. Also, it was determined that the majority of water quality data available was collected during this ten year period.

As all water quality stations retrieved from the IWR database or Florida STORET were previously assigned to a WBID by FDEP, water quality station data provided by Collier County, City of Naples, or Rookery Bay National Estuarine Research Reserve were assigned to a WBID and watershed based on location coordinates.

3.2.2 Analysis Method

To focus on the assessment of watershed discharges in the receiving estuaries, only the most downstream water quality stations in each watershed were included in the analysis. **Table 3-2** lists the stations by watershed. As described later in more detail, the data was analyzed for the TMDL planning and verified periods. Data from all stations were used for the verified period analysis, whereas the planning period analysis included all stations except 21FLNAPLGORDJOE and Gord60, both in the Golden Gate / Naples watershed.

An important factor considered in the analysis was that many of the sampling stations are subject to tidal effects, especially during the dry season, Effects extend as far inland as the Tamiami Trail. This situation creates two data analysis problems: a) data does not reflect watershed conditions because the discharges are diluted by estuarine waters, and b) the chemistry of the discharges fluctuates from freshwater to marine conditions.

Table 3-2. Sampling Stations by Watershed

Watershed	Sampling Station
Cocohatchee–Corkscrew	28030036
Golden Gate / Naples Bay	21FLNAPLGORDJOE
	HC@Bayshore
	BC2
	Gord60
Rookery Bay	21FLSWMLELY
	HendersonCrk at US41
Faka Union	21FLSFWMFAKA
	FAKAUPOI
Fakahatchee	21FLSFWMBC21
	21FLSFWMBC19
	21FLSFWMBC18
Okaloacoochee-SR 29	BARRIVN

To control for this situation, water quality data from the selected stations was queried so that data analysis was restricted to those times when specific conductance (μmhos / cm at 25°C) was below 4,700 (equivalent to FDEP's threshold for marine waters of 1,500 mg chloride / liter). Samples representing the "freshwater" condition were thus considered representative of the surface water quality discharging into the estuaries.

The subsequent analysis method included the following steps:

1. The water quality data sets were compared to existing water quality criteria for the impairment parameters associated with each estuary.
2. The mean, minimum, maximum and percent exceedances of such criteria were quantified and displayed for each station within each watershed.
3. A review of data from the Planning Period was conducted, with data restricted to between January 1995 and December 2004.
   a. For inclusion on the Planning List, impairments for dissolved oxygen and metals concentrations would have to occur in at least 10 percent of samples, with an 80 percent confidence level using a binomial distribution.
      i. For samples of 10 to 15, this requires 3 exceedances.
      ii. For samples from 16 to 23, this requires 4 exceedances.
      iii. For samples from 24 to 31, this requires 5 exceedances
      iv. For samples from 32 to 39, this requires 6 exceedances
      v. For samples from 40 to 47, this requires 7 exceedances.

4. A review of data from the Verified Period was conducted, with data restricted to between January 2000 and June 30, 2007.
   a. For inclusion on the Verified List, impairments for dissolved oxygen and metals would have to occur in at least 10 percent of samples, with a 90 percent confidence level using a binomial distribution.
      i. For samples of 20 to 25, this requires 5 exceedances.
      ii. For samples from 26 to 32, this requires 6 exceedances.
      iii. For samples from 33 to 40, this requires 7 exceedances
      iv. For samples from 41 to 47, this requires 8 exceedances
      v. For samples from 48 to 55, this requires 9 exceedances.
5. For nutrient concentrations, discharge data were compared to two separate potential criteria.
   a. FDEP's screening criteria for streams uses the 75th percentile of values in STORET. These values are 1.6 mg total nitrogen (TN) / liter and 0.22 mg total phosphorus (TP) / liter
   b. FDEP's Hendry Creek TMDL used target TN and TP values of 0.74 and 0.04 mg / liter, respectively.

3.2.3 Analysis Results

This section presents the results and discussion of the water quality characterization of the watershed discharges into each of the estuary systems in Collier County based on the identified sampling stations. **Tables 3-3 through 3-10** show data statistics, as well as percent exceedance of the water quality/ screening criteria for dissolved oxygen, total phosphorus, total nitrogen, and fecal coliform concentration associated with the TMDL planning and verified periods. Following are descriptions of the results by watershed and estuary.

3.2.3.1 Wiggins Pass

Wiggins Pass is the receiving water for the Cocohatchee-Corkscrew watershed. It is located within WBID 3259A (Cocohatchee River) and is presently listed as impaired for three water quality parameters; dissolved oxygen, fecal coliforms and iron. As shown in **Tables 3-3 through 3-10**, the data available at Station 28030036 is very limited. Therefore, definite statistical conclusions are not possible, but general conclusions have been derived for this analysis for each impairment parameter.

Table 3-3. Data Analysis–Dissolved Oxygen Concentration, Planning Period (January 1995–December 2004)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (< 5 mg / L)
Cocohatchee–Corkscrew	28030036	2	6.00	4.70	7.30	50
Golden Gate / Naples Bay	BC2	28	4.05	2.74	5.56	80
	HC@Bayshore	14	3.82	2.34	5.40	86
Rookery Bay	21FLSWMLEY	42	4.98	1.41	8.37	52
	HendersonCrk@41	13	6.13	4.73	0.28	15
Faka Union	21FLSFWMFAKA	48	6.46	2.92	9.83	25
	FAKAUPOI	29	6.12	3.60	8.92	24
Fakahatchee	21FLSFWMBC21	34	4.41	0.84	8.80	71
	21FLSFWMBC19	34	2.82	0.24	7.98	88
	21FLSFWMBC18	37	3.02	0.60	8.06	86
Okaloacoochee-SR 29	BARRIVN	28	4.24	2.72	7.87	82

Table 3-4. Data Analysis–Dissolved Oxygen Concentration, Verified period (January 2000–June 30, 2007)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (< 5 mg / L)
Cocohatchee–Corkscrew	28030036	1	3.36	3.36	3.36	100
Golden Gate / Naples Bay	21FLNAPLGORDJOE	1	3.90	3.90	3.90	100
	HC@Bayshore	19	3.80	2.34	5.40	89
	BC2	15	3.89	2.74	5.56	87
	Gord60	2	4.31	4.20	4.41	100
Rookery Bay	21FLSWMLELY	59	4.77	1.41	8.37	54
	HendersonCrk@41	19	5.87	3.64	9.28	21
Faka Union	21FLSFWMFAKA	64	6.53	2.92	10.39	27
	FAKAUPOI	35	6.01	3.60	8.92	29
Fakahatchee	21FLSFWMBC21	42	4.20	0.84	8.80	74
	21FLSFWMBC19	44	2.85	0.24	7.98	84
	21FLSFWMBC18	48	3.05	0.30	8.06	85
Okaloacoochee-SR 29	BARRIVN	36	4.12	2.38	7.87	83

Table 3-5. Data Analysis–Total Phosphorus, Planning Period
(January 1995–December 2004)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (> 0.04 mg/L)[1]	Percent exceedance (>0.22 mg/L)[2]
Cocohatchee–Corkscrew	28030036	2	0.05	0.03	0.07	50	0
Golden Gate / Naples Bay	HC@Bayshore	15	0.06	0.04	0.08	93	0
	BC2	10	0.06	0.03	0.09	80	0
Rookery Bay	21FLSWMLELY	39	0.03	0.01	0.09	13	0
	HendersonCrk@41	10	0.01	0.01	0.03	0	0
Faka Union	21FLSFWMFAKA	44	0.01	0.00	0.03	0	0
	FAKAUPOI	23	0.03	0.00	0.34	9	0
Fakahatchee	21FLSFWMBC21	30	0.01	0.00	0.04	0	0
	21FLSFWMBC19	31	0.02	0.01	0.06	6	0
	21FLSFWMBC18	32	0.01	0.00	0.04	3	0
Okaloacoochee-SR 29	BARRIVN	26	0.02	0.01	0.05	4	0

1 Hendry Creek TMDL Criteria

2 Florida Streams Screening Criteria

Table 3-6. Data Analysis–Total Phosphorus, Verified period
(January 2000–June 30, 2007)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (> 0.04 mg/L)[1]	Percent exceedance (>0.22 mg/L)[2]
Cocohatchee–Corkscrew	28030036	1	0.07	0.07	0.07	100	0
Golden Gate / Naples Bay	21FLNAPLGORDJOE	1	0.04	0.04	0.04	0	0
	HC@Bayshore	18	0.06	0.04	0.11	89	0
	BC2	13	0.05	0.03	0.09	85	0
	Gord60	2	0.04	0.03	0.06	50	0
Rookery Bay	21FLSWMLELY	51	0.03	0.01	0.09	18	0
	HendersonCrk@41	16	0.02	0.01	0.05	6	0
Faka Union	21FLSFWMFAKA	56	0.01	0.00	0.03	0	0
	FAKAUPOI	28	0.01	0.00	0.06	4	0
Fakahatchee	21FLSFWMBC21	36	0.01	0.00	0.06	3	0
	21FLSFWMBC19	38	0.02	0.00	0.06	5	0
	21FLSFWMBC18	39	0.01	0.00	0.04	3	0
Okaloacoochee-SR 29	BARRIVN	32	0.02	0.01	0.05	3	0

1 Hendry Creek TMDL Criteria

2 Florida Streams Screening Criteria

Table 3-7. Data Analysis–Total Nitrogen, Planning period (January 1995–December 2004)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (> 0.74 mg/L)[1]	Percent exceedance (>1.6 mg/L)[2]
Cocohatchee–Corkscrew	28030036	2	1.26	0.75	1.78	100	50
Golden Gate / Naples Bay	HC@Bayshore	13	1.05	0.04	5.98	46	8
	BC2	9	0.86	0.27	1.08	78	0
Rookery Bay	21FLSWMLELY	40	1.68	0.01	4.30	35	2
	HendersonCrk@41	11	0.78	0.58	1.02	55	0
Faka Union	21FLSFWMFAKA	44	0.38	0.01	1.22	5	0
	FAKAUPOI	27	0.36	0.01	0.71	0	0
Fakahatchee	21FLSFWMBC21	32	0.80	0.01	2.70	56	3
	21FLSFWMBC19	32	0.82	0.01	1.50	56	0
	21FLSFWMBC18	36	0.62	0.01	1.30	31	0
Okaloacoochee-SR 29	BARRIVN	26	0.57	0.02	1.02	15	0

1 Hendry Creek TMDL Criteria

2 Florida Streams Screening Criteria

Table 3-8. Data Analysis–Total Nitrogen, Verified period (January 2000–June 30, 2007)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (> 0.74 mg/L)[1]	Percent exceedance (>1.6 mg/L)[2]
Cocohatchee–Corkscrew	28030036	1	1.00	1.00	1.00	100	0
Golden Gate / Naples Bay	21FLNAPLGORDJOE	1	1.03	1.03	1.03	100	0
	HC@Bayshore	17	0.93	0.03	5.98	47	6
	BC2	13	0.70	0.04	1.08	54	0
	Gord60	2	1.23	1.11	1.34	100	0
Rookery Bay	21FLSWMLELY	52	0.65	0.01	4.30	33	2
	HendersonCrk@41	16	0.63	0.06	1.02	38	0
Faka Union	21FLSFWMFAKA	55	0.36	0.01	1.22	4	0
	FAKAUPOI	31	0.32	0.01	0.71	0	0
Fakahatchee	21FLSFWMBC21	38	0.72	0.01	2.70	50	3
	21FLSFWMBC19	40	0.78	0.01	1.64	52	2
	21FLSFWMBC18	43	0.59	0.01	1.65	28	2
Okaloacoochee-SR 29	BARRIVN	32	0.49	0.01	1.02	12	0

1 Hendry Creek TMDL Criteria

2 Florida Streams Screening Criteria

Table 3-9. Data Analysis–Fecal Coliform, Planning period
(January 2000–June 30, 2007)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (> 43/100 mL)
Cocohatchee–Corkscrew	28030036	2	140.00	10.00	270.00	50
Golden Gate / Naples Bay	HC@Bayshore	15	829.00	142.00	3,627.00	100
	BC2	9	573.33	70.00	3,200.00	10
Rookery Bay	21FLSWMLELY	40	191.78	11.00	2,600.00	65
	HendersonCrk@41	11	172.82	17.00	440.00	73
Faka Union	21FLSFWMFAKA	45	104.98	1.00	560.00	51
	FAKAUPOI	25	27.36	1.00	340.00	12
Fakahatchee	21FLSFWMBC21	32	421.41	6.00	5,300.00	47
	21FLSFWMBC19	33	324.48	3.00	1,386.00	73
	21FLSFWMBC18	36	289.69	9.00	5,450.00	61
Okaloacoochee-SR 29	BARRIVN	28	371.00	33.00	2,300.00	93

Table 3-10. Data Analysis–Fecal Coliform, Verified period
(January 2000–June 30, 2007)

Watershed	Station	Sample Size	Mean	Min.	Max.	Percent exceedance (> 43/100 mL)
Cocohatchee–Corkscrew	28030036	1	200.00	20.00	200.00	100
Golden Gate / Naples Bay	21FLNAPLGORDJOE	1	1.00	1.00	1.00	0
	HC@Bayshore	18	856.83	61.00	3,627.00	100
	BC2	14	402.86	40.00	3,200.00	93
	Gord60	2	76.00	72.00	80.00	100
Rookery Bay	21FLSWMLELY	52	159.96	11.00	2,600.00	63
	HendersonCrk@41	16	186.81	17.00	576.00	75
Faka Union	21FLSFWMFAKA	47	101.38	1.00	560.00	49
	FAKAUPOI	27	25.96	1.00	340.00	11
Fakahatchee	21FLSFWMBC21	37	369.41	6.00	5,300.00	46
	21FLSFWMBC19	42	282.86	3.00	1,386.00	69
	21FLSFWMBC18	41	277.12	9.00	5,450.00	59
Okaloacoochee-SR 29	BARRIVN	36	321.86	20.00	2,300.00	89

Dissolved Oxygen

Data collected in Wiggins Pass itself has indicated that low dissolved oxygen levels appear to be evident in the estuary's upstream portions of Wiggins Pass. This supports the notion that watershed discharges may affect that portion of the estuary. The limited data available shows that the dissolved oxygen concentration in the watershed discharge does not meet the 4 mg/L standard for the estuary. The cause of the depleted oxygen level may be attributed to excessive nutrient concentrations. The available data shows that the measured concentration of TN in the two discharge samples exceeds the Hendry Creek TMDL target for both the planning and verified periods. However, only one of the samples exceeds the screening criteria for Florida streams. The available data also shows that TP exceeds the Hendry Creek TMDL target in one of the samples, but never exceeds the Florida streams criteria.

Another potential cause of low dissolved oxygen concentrations in the watershed discharge is the groundwater contribution to the canal flow. As described for the stream water quality analysis, the annual average groundwater contribution from WBID 3278D - Cocohatchee (Inland Segment), to flow in the Cocohatchee Canal is about 40 percent of the total contributions and increases to 65 percent during the dry season.

The results of the analysis suggest that groundwater discharges may have a larger impact on dissolved oxygen levels than nutrient concentrations in the Wiggins Pass estuary. However, more data coupled with in-stream water quality modeling are necessary to determine the cause of the low dissolved oxygen levels in the estuary.

Fecal Coliform

One of the two samples analyzed for the planning period evaluation exceeds the water quality criteria for the estuary. So does the only sample that is included in the verified period analysis. Therefore it can be concluded that there is the possibility that the estuary is affected by watershed discharges of fecal coliform bacteria. Bacteria source evaluations are necessary to confirm the condition.

Iron

No data for iron is available at the sampling stations considered for data analysis. Although sources have not been confirmed, it is possible that groundwater discharges through the canal system as described for dissolved oxygen is an important cause of the elevated iron levels. Other human activities such as mine drainage, sewage treatment plant outfalls, or landfill leachate from industrial scrap yards (e.g., junkyards for cars) are also potential sources of the elevated iron levels in this case.

3.2.3.2 Naples Bay Estuary

Naples Bay is located within WBID 3278R (Naples Bay-Coastal Segment) and is presently listed as impaired for four parameters; dissolved oxygen, fecal coliforms, copper and iron. Naples Bay is the receiving water for the Golden Gate-Naples Bay and Gordon River Extension watersheds.

Dissolved Oxygen

Data available at the two stations analyzed for planning period conditions and the four stations with data available for the verified period analysis show that the dissolved oxygen concentration in the watershed discharges do not meet the estuary water quality standard. As indicated for Wiggins Pass, the cause of the depleted oxygen levels could be attributed to excessive nutrient concentrations. The analytical data indicates that neither TN nor TP concentrations in the watershed discharges exceed the Florida stream screening standards; however in most cases they exceed the Hendry Creek TMDL target for both the planning and verified periods. In summary, from the available data it is not clear if TN and TP discharges from the watershed are causing the lower dissolved oxygen levels. More data collection and analysis may be required to determine the effect of discharged nutrients on the estuary.

Another potential cause of low dissolved oxygen concentrations may be the discharge of groundwater to the dredged canal network. Low dissolved oxygen levels appear to be most evident in the upstream portions of the estuary that are most affected by watershed discharges. As described for the stream water quality analysis, measured DO concentrations in groundwater are less than 3.0 mg/L and the annual average baseflow contribution to the flow in the Golden Gate Canal is about 55 percent of the total flow and increases to more than 70 percent during the dry season. This information suggests that watershed discharges may have a larger impact on dissolved oxygen levels in the estuary than nutrient loading in the upper reaches of the estuary. More data is required to determine the cause of low measured DO levels in the estuary.

Fecal Coliform

The data analyzed indicate that fecal coliform concentrations exceed the standard at most discharge locations. Therefore it can be concluded that there is the possibility that the estuary is affected by watershed discharges of fecal coliform bacteria. However, significant more bacteria source evaluations are necessary to confirm this condition.

Iron and Copper

No sources of iron contribution to the canal network have been identified. Based on the predicted groundwater concentrations for iron in the Golden Gate – Naples Bay watershed and the level of baseflow contributions to the drainage network, it is possible that groundwater discharges to the canal system are an important cause of the elevated iron levels. Other potential sources include human activities such as mine drainage, sewage treatment plant outfalls, or landfill leachate from industrial scrap yards (e.g., junkyards for cars).

Data for copper at the discharge stations were not analyzed, but discharges of copper into the estuary could be from anthropogenic sources, such as its use as an algaecide to prevent algae growth. High measured concentrations could also result from site characteristics of the sampling locations, such as effects of leaching from boardwalks and pilings that are constructed from pressure-treated lumber.

3.2.3.3 Rookery Bay Estuary

Rookery Bay is the receiving water for the Rookery Bay watershed. The estuary is located within WBID 3278U (Rookery Bay-Coastal Segment) and, similar to the other previously described two estuaries, is presently listed impaired for dissolved oxygen and fecal coliforms. However, this estuary is also listed impaired for nutrients, which are potential causes for the low dissolved oxygen concentrations.

Dissolved Oxygen and Nutrients

Data available at the two stations analyzed for planning period conditions and the four stations with data available for the verified period analysis show that the dissolved oxygen concentration in the discharges do not meet the estuary water quality standard. Causes of the depleted oxygen level could be attributed to excessive nutrient concentrations, as well as groundwater inflows. In spite of the estuary being listed for nutrient impairment, data at the watershed discharge point indicate that TN and TP concentrations are below the Florida screening criteria for streams for both the planning and verified period analysis. In addition, total phosphorus exceeds the Hendry Creek TMDL criterion less than 20 percent of the time. The exceedance of the Hendry Canal standard for total nitrogen ranges between 35 and 55 percent for the planning period and 33 and 38 percent for the verified period.

As mentioned previously, another cause of low dissolved oxygen concentrations may be the discharge of groundwater. The groundwater quality analysis predicts that DO concentrations are less than 2.0 mg/L in the Rookery Bay watershed and the stream water quantity analysis showed that the annual average groundwater contribution to the estuary is about 45 percent of the total flow and increases to approximately 70 percent during the dry season. This information suggests that the groundwater contribution is likely an important factor effecting DO concentrations in the estuary.

It is also possible that nitrogen runoff is contributing to the lower dissolved oxygen concentration in the estuary, although the measured concentrations are generally low. Additional monitoring is required to assess the causes of the DO impairment in the Rookery Bay estuary.

Fecal Coliform

The estuary fecal coliform water quality criterion at the watershed discharge point is exceeded between approximately 60 and 75 percent of the time. Therefore it is likely that the estuary is affected by watershed discharges. Additional bacteria source evaluations are necessary to confirm this condition.

3.2.3.4 Ten Thousand Islands Estuary

The TTI is the receiving water for the Faka Union, Fakahatchee, and Okaloacoochee/SR29 watersheds. It is located within WBID 3259M (TTI) and is presently not listed as impaired for any parameter. The watersheds largely remain in undeveloped conditions.

No detailed water quality evaluation of the discharge characteristics was conducted. However, per the data provided in Tables 3-3 through 3-10, the percent of time dissolved oxygen concentrations in the watershed discharges are below the standard range from 24 to 85 percent during the planning and verified periods. This is likely the result of discharges from the wetland systems present in the watersheds coupled with groundwater contributions to the total flow in the canals. Total phosphorus and total nitrogen concentrations are below the screening criteria for Florida streams, but nitrogen levels exceed the Hendry Creek criteria in the Fakahatchee watershed. Fecal coliform data also shows values above the estuarine criterion around 60 percent of the time.

3.2.4 Conclusions

The Collier County estuaries are impaired primarily for dissolved oxygen and fecal coliforms. Rookery Bay is also impaired for nutrients. Data show that the watershed discharges do not meet the water quality standards for dissolved oxygen and fecal coliforms either. Therefore, it is likely that the watershed conditions are impacting the receiving estuaries. However, causative parameters for the observed low oxygen levels are not clear. Nutrient concentrations in the discharges are commonly below the screening criteria for Florida streams and only exceed the TMDL target established for Hendry Creek. Fecal coliforms are indicators of pathogenic organisms and are used to identify potential health threats. However, as described in other technical memos, fecal coliform bacteria may not be an appropriate indicator for pathogenic diseases in sub-tropical climates. Further source identification efforts are warranted.

Other parameters of impairment concern are iron and copper. Iron appears to be caused by the groundwater discharges through the canal network, although other sources are possible. High copper concentrations may be the result of anthropogenic impacts such as the use of copper sulfate as an algaecide to prevent algae growth in ponds or for leaching from boardwalks and pilings that are constructed from pressure-treated lumber.

3.3 QUALITY OF RECEIVING WATERS

This Chapter will address Element 2, Task 3: Quality of Receiving Waters. The objective of this task is to characterize the water quality conditions in the receiving waters of the four primary estuaries in Collier County:

- Wiggins Pass
- Naples Bay
- Rookery Bay
- Ten Thousand Islands (TTI)

Six watersheds were identified as the headwaters to the four estuaries of interest for this project (**Figure 3-13**). The Wiggins Pass estuary is located at the outfall from the Cocohatchee-Corkscrew watershed. Naples Bay estuary receives discharge from the Golden Gate-Naples Bay watershed and Gordon River Extension, while the Rookery Bay watershed discharges into the Rookery Bay estuary. The TTI estuary is the receiving water body for three main watersheds: Faka Union, Fakahatchee, and Okaloacoochee-SR29.

This section focused on the downstream, estuarine portions of the above-listed watersheds in Collier County. These estuaries are influenced by the quantity, timing, and quality of inflow from their associated watersheds. Characterization of the quality of water within the watersheds was the focus of the technical memorandum prepared for Phase 2, Element 2, Task 2.

The main impact to the Collier County estuaries has resulted from changes in historic fresh water flow patterns over the years due to increased development. These hydrologic changes have adversely impacted the environmental integrity of many of the estuaries, mostly in terms of widely varying salinity patterns (Browder et al. 1998, Shirley et al. 2005). Specifically about TTI, much of the scientific literature focused on the issue of altered hydrology and the need for a more natural pattern of freshwater inflow (e.g., Browder et al. 1988, Shirley et al. 2005).

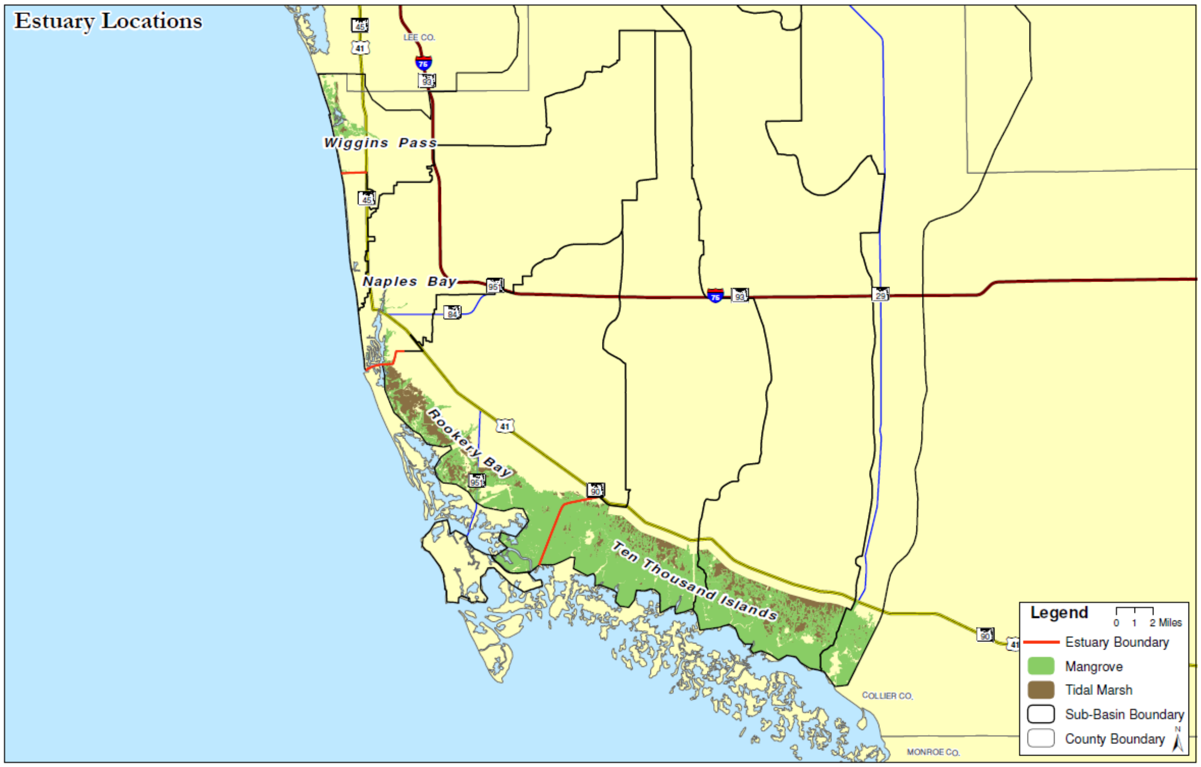


Figure 3-13. Collier County Estuaries and Major Features

3.3.1 Methods

In order to accurately characterize the receiving waters of the Collier County estuaries, Atkins completed a review of the existing impaired water bodies as defined by Florida Department of Environmental Protection (FDEP) and compared these results to available water quality data within the estuarine portion of each watershed: Cocohatchee-Corkscrew, Golden Gate–Naples Bay, Rookery Bay, Faka Union, Okaloacoochee–SR29, and Fakahatchee. A discussion of the analysis conducted is presented below.

3.3.1.1 FDEP Impaired WBIDs

For implementation of the statewide TMDL program, the FDEP has divided the state into five groups. Each group is comprised of multiple basins. All water bodies within Collier County are located within the Everglades West Coast Group 1 Basin. Per TMDL guidelines, every five years each WBID is evaluated to determine whether available water quality parameters exceed the limits defined by FDEP in the IWR. The verified impaired list of WBIDs for each group and cycle is available on the FDEP website. After the compilation of all impaired WBIDs from Cycle 1 and 2, a total of ten impairments have been designated by FDEP for the four WBIDs representing the estuaries. Those WBIDs are listed in **Table 3-11**.

Table 3-11. WBID Name and corresponding estuarine receiving water

WBID#	WBID Name	Receiving Water
3259A	Cocohatchee River	Wiggins Pass
3278R	Naples Bay (Coastal Segment)	Naples Bay
3278U	Rookery Bay (Coastal Segment)	Rookery Bay
3259M	Ten Thousand Islands	Ten Thousand Islands

3.3.1.2 Water Quality Analysis

As was done for characterizing the quality of water discharging into the estuaries, the IWR Run 39 dataset was supplemented with data from Florida STORET, Collier County, City of Naples, and the Rookery Bay National Estuarine Research Reserve to create a comprehensive water quality database. To eliminate potential errors due to apparent data duplications for water quality stations (possibly due to multiple agencies uploading the same data, a single agency loading the data more than once with slight variations like rounding errors, etc.), median values were calculated by station, date, and parameter. For field parameters such as water temperature and dissolved oxygen, all data with water depths greater than one meter were analyzed no further. Daily median values were calculated for water quality stations in which datasondes collected data at 15-minute intervals. This ensured that any comparisons of field parameters to lab parameters (i.e., nutrients) were from samples taken at the same water depth.

Using GIS and the station descriptions, the location of water quality stations were reviewed in order to identify locations where multiple stations were sampled. Data were merged when more than one water quality station was sampled at a location and a unique merged station name was assigned to that location. **Appendix 4-B** lists all water quality stations and assigned merged station names. Each parameter in the database was screened to identify outliers or entry errors due to unit inconsistencies. Identified inconsistencies were reviewed and corrected. When Total Nitrogen (TN) species were not listed, TN was calculated through the addition of Total Kjeldahl Nitrogen (TKN) and Nitrate + Nitrite (NOx). For chlorophyll *a* data consistent with IWR, corrected chlorophyll *a* was preferentially used over uncorrected chlorophyll *a* when available for samples collected in 2006 and earlier. After 2006, only corrected chlorophyll *a* data were used. All statistical analysis was completed using the most recent ten year time period (2000 to 2009) to characterize each watershed.

All water quality stations retrieved from the IWR database or Florida STORET were previously assigned to a WBID by FDEP. Water quality station data provided by Collier County, City of Naples, or Rookery Bay National Estuarine Research Reserve were assigned to a WBID based on location coordinates (**Figure 3-14**). A list of the parameters analyzed for each station and receiving water is provided in **Table 3-12**.

Table 3-12. List of Water Quality Parameters

Parameter	Unit	Parameter	Unit
Salinity	ppt	Conductivity	µmhos/cm
Total Nitrogen	mg/l	Nitrate-Nitrite	mg/l
Total Phosphorus	mg/l	Orthophosphate	mg/l
Total Kjeldahl Nitrogen (TKN)	mg/l	Un-ionized Ammonia	mg/l
Chlorophyll a	µg/L	Fecal Coliform	#/100 mL
Color	PCU	Copper	µg/L
Total Suspended Solids (TSS)	mg/l	Turbidity	NTU
Dissolved Oxygen (DO)	mg/l	Biochemical Oxygen Demand (BOD)	mg/l
Iron	µg/L	Hardness	mg/l
Secchi Depth	m		

Summary data for each estuary were compared to the Criteria for Surface Water Quality Classifications (F.A.C. 62-302.530) for water quality parameters based on water body classification. All of the receiving waters are Class II water bodies, i.e. their designated use is shellfish propagation and harvesting. In addition, FDEP's anti-degradation policy (62-302.300 FAC) allows for protection of water quality above the minimum required for a classification and Class II water bodies, i.e. "water quality sufficient for the protection and propagation of fish, shellfish, and wildlife, as well as for recreation in and on the water, is an interim goal to be sought whenever attainable." **Table 3-13** lists the regulatory standards for a Class 2 water body for the selected parameters previously identified by the FDEP TMDL program as verified parameter. Regulatory standards have been vetted by the scientific community and provide a biologically relevant basis for comparison.

To further evaluate potential water quality impairments for chemical parameters for which no numeric water quality standard currently exist, the data were compared to screening level standards, which can provide an indication of potential water quality concerns but do not necessarily constitute an impairment problem. Screening level standards are available for TN and TP based on the 70th percentile of all available data, as in Friedman and Hand (1989). Using IWR Run 39, a similar screening level was calculated by water body type for color, total suspended solids, and Secchi depth, in which the 70th percentile of all data available from 2000 to 2009 by water body type was calculated. **Table 3-14** shows the screening level standard for selected parameters by water body type (estuary).

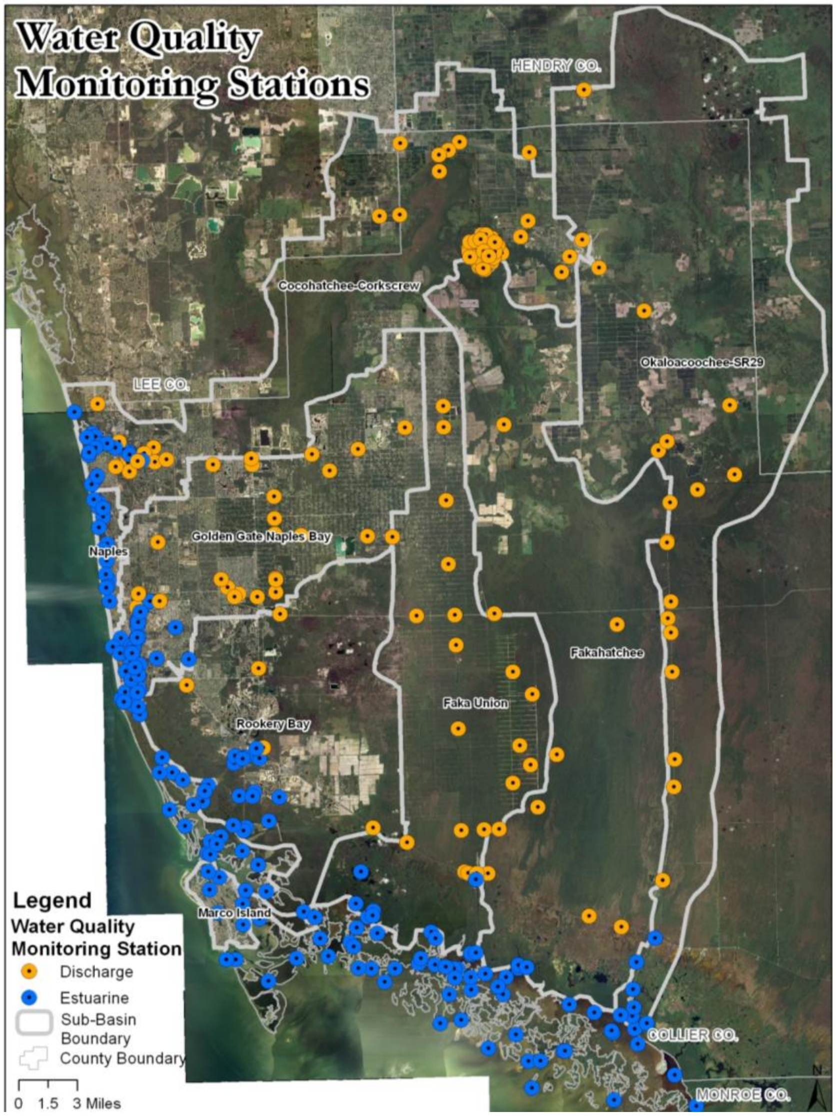


Figure 3-14. Water quality monitoring station location map

Table 3-13. List of regulatory standards for selected water quality parameters

Parameter	Class 2
Dissolved Oxygen (mg/l)	4
Fecal Coliform (#/100 mL)	43
Chlorophyll a (µg/L)	11
Iron (µg/L)	300
Copper (µg/L)	3.7

Table 3-14. List of screening levels for selected water quality parameters

Parameter	Estuary
Color (PCU)	40
SD (m)	1.38
TSS (mg/l)	17
TN (mg/l)	1
TP (mg/l)	0.19

Another screening tool that was used to assess nutrient concentrations in the Collier County estuaries was the Hendry Creek TMDL (located on the Everglades West Coast in northern Estero Bay; this is the only estuarine WBID with a nutrient TMDL in the EWC group), which addresses dissolved oxygen impairments, established TN and TP targets using an estuarine reference site, Estero Bay Wetlands (FDEP, 2008). The TN and TP targets were calculated based on the unique characteristics of the Estero Bay Wetlands to develop an empirical relationship between nutrients (especially TN) and dissolved oxygen. Similarly, the TMDLs developed for the Gordon and Imperial Rivers were established based on assumptions specific to those particular watersheds. These TN and TP targets could be used as a screening tool but should not be accepted as representative of the potential response found in watersheds other than those themselves.

3.3.1.3 Impaired WBID Comparison

Using methods similar to FDEP IWR, Atkins analyzed the water quality data for each WBID All analyses were conducted using the most recent ten year time period (2000 to 2009) to minimize the effect of temporal variations. Also, it was determined that the majority of water quality data available was collected during this ten year period. All data collected for each WBID during that period were used to evaluate the parameters previously declared "verified impaired" by FDEP. Dissolved oxygen, iron, fecal coliforms, nutrients (chlorophyll *a*), and copper concentrations were compared to the appropriate state regulatory standard (**Table 3-13**) to determine impairment status. A modification to the FDEP method for determining chlorophyll *a* impairments was utilized because it provides a more realistic assessment of the frequency of exceedances. Each chlorophyll *a* value was compared to the state regulatory standard and the percent exceedance was calculated. In contrast, FDEP calculates an annual average using data from each quarter for comparison with the regulatory standard. The results of Atkins WBID analysis were compared to the FDEP impaired WBID list for those water bodies in the study area.

Results of the impairment analysis was also compared to the work conducted by Janicki Environmental, Inc as part of a review of the County's water quality data in the context of Florida's Impaired Water Rule (Janicki Environmental, Inc. 2010). A preliminary review of annual chlorophyll *a* values for each WBID indicated one basin which exceeded the threshold (Cocohatchee River). Annual chlorophyll *a* values exceeded the 11 µg/L threshold in one year only (2001).

Results of the FDEP impairment status for nutrients were compared to the two other methods (Atkins and Janicki) to identify potentially impaired WBIDs **(Table 3-15)**. Rookery Bay (Coastal Segment) is the only WBID identified as impaired for nutrients by FDEP. Atkins identified two additional WBIDs which may be impaired. Janicki Environmental identified one potentially impaired segment, but that conclusion is not supported by the current analysis.

Table 3-15. Comparison of methods to identify
WBIDs potentially impaired for nutrients

WBID	WBID Name	Watershed	FDEP	Atkins	Janicki
3278U	Rookery Bay (Coastal Segment)	Rookery Bay	Impaired	Potential	
3278R	Naples Bay (Coastal Segment)	Golden Gate Naples Bay		Potential	
3259A	Cocohatchee River	Cocohatchee-Corkscrew			Potential
3278Q	Naples			Potential	

3.3.1.4 Critical Parameters

Four critical parameters were further evaluated for the estuaries to identify those estuaries of concern: chlorophyll *a*, dissolved oxygen, transparency (Secchi depth), and bacteria. In addition, parameters of concern for individual estuaries such as iron and copper were evaluated.

Potential areas of concern within the estuaries by water quality station were identified for each of the critical parameters. Water quality stations data were used if the sample size was greater than or equal to 12 to preclude the use of data with irregular sampling frequency over short time periods. Data from each of the water quality stations were categorized based on the percent of data values that exceeded the appropriate regulatory standard or screening level. Stations which have data with less than 10 percent of the total samples greater than the regulatory standard were shaded green. Data from stations with values that exceed the appropriate regulatory standard or screening level in 10-49 percent of the total samples were shaded yellow. Stations with values that exceed the appropriate regulatory standard or screening level in 50 percent or more of the total samples were shaded red.

Several factors can be responsible for elevated chlorophyll *a* or depressed dissolved oxygen values, including nutrient loading and/or low flushing rates within an estuary. Additionally, Boyer (2008) reported that "localized naturally low DO conditions are common due to stratification and inputs of large amounts of organic material from natural mangrove forests" (as cited in FDEP 2010). In regards to transparency, sediment loading or resuspension, algal blooms and/or elevated color values can cause a decline in Secchi depth values. Bacterial loads can be attributed to either human, pets or wildlife from point or non-point discharges. Iron discharges can be the results of natural groundwater discharges or could result from anthropogenic pollution, same as copper.

3.3.2 Results and Discussion

This section presents the results and a discussion of the FDEP impaired WBIDs, a water quality characterization for each estuary, and an evaluation of critical water quality parameters. The water quality characterization results and discussion are discussed separately for Wiggins Pass, Naples Bay, Rookery Bay, and the TTI estuaries.

The impairments identified by FDEP in the estuaries include dissolved oxygen, fecal coliform, iron, nutrients, and copper (**Figures 3-15 to 3-19).** Three (Wiggins Pass, Naples Bay and Rookery Bay) of the four estuarine receiving waters are verified impaired for both dissolved oxygen and fecal coliform bacteria by FDEP. Only the TTI is presently not listed as impaired for any water quality parameters. It is the only estuary in which average dissolved oxygen concentrations have remained above the regulatory standard of 4.0 mg/L for marine waters and fecal coliform concentrations have remained below 43 #/100 mL for a Class 2 water bodies. Rookery Bay was shown to be the only receiving water to have elevated chlorophyll *a* concentrations attributed to nutrient loads. Naples Bay is presently verified impaired for copper (>3.7 µg/L) and iron (>300 µg/L). The Wiggins Pass estuary has also been verified impaired for iron.

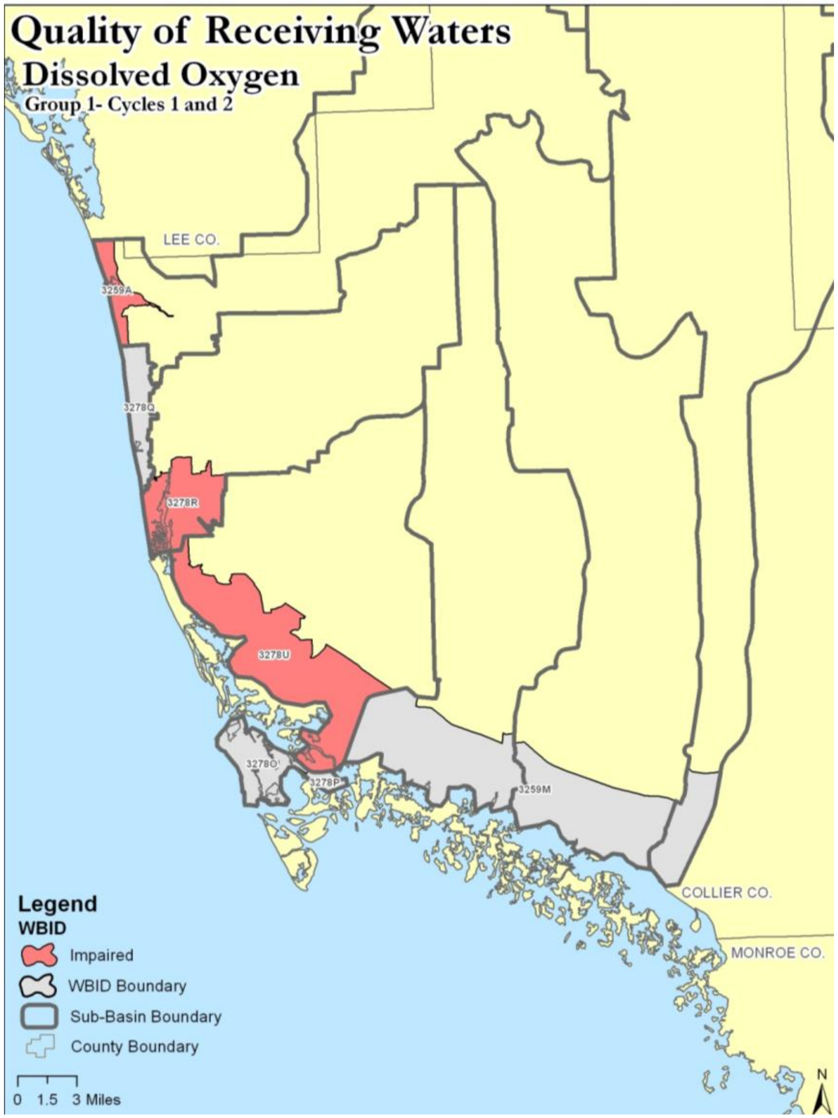


Figure 3-15. WBIDS verified impaired for Dissolved Oxygen in the estuarine receiving waters of the study area by FDEP

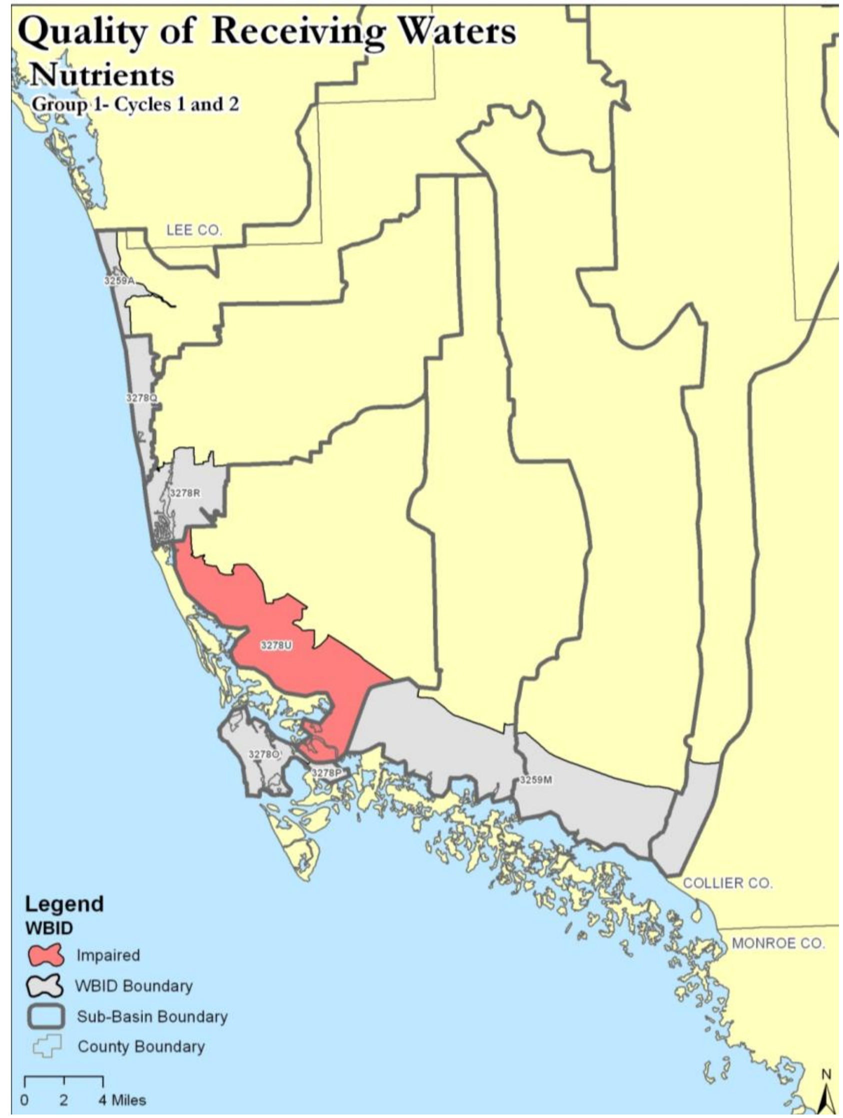


Figure 3-16. WBIDS verified impaired for Nutrients in the estuarine receiving waters of the study area by FDEP

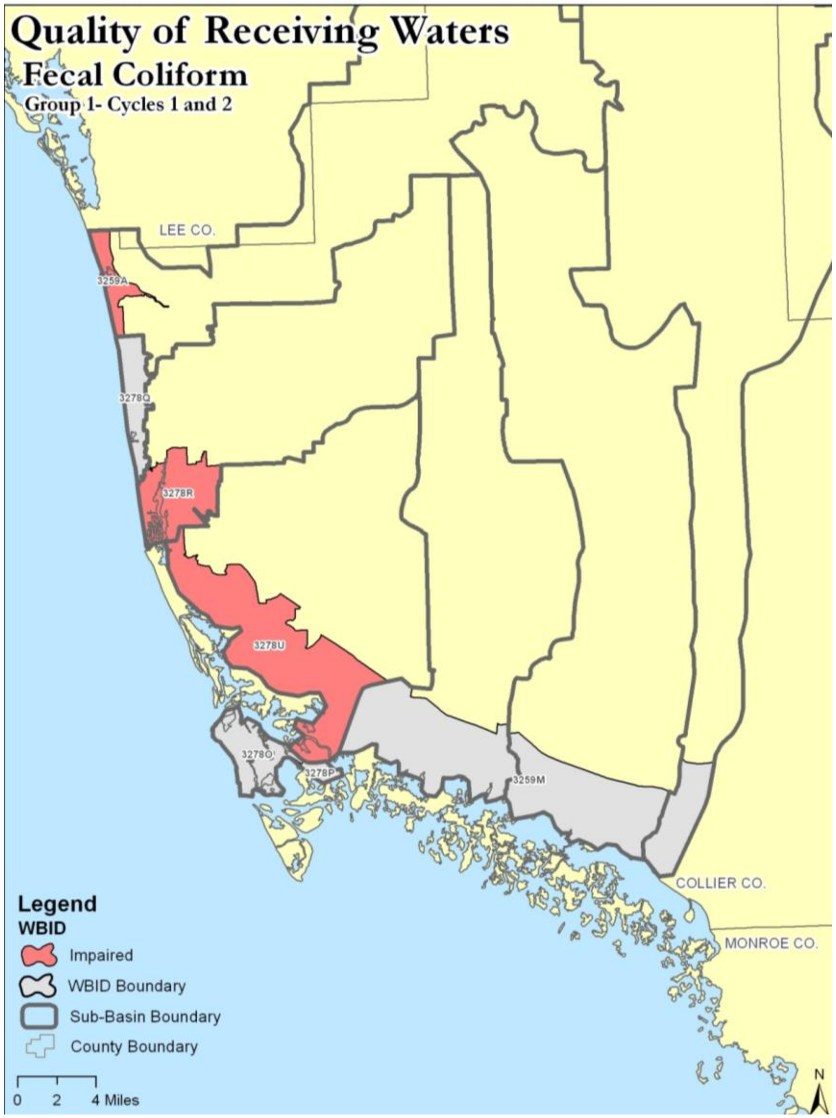


Figure 3-17. WBIDS verified impaired for Fecal Coliform in the estuarine receiving waters of the study area by FDEP

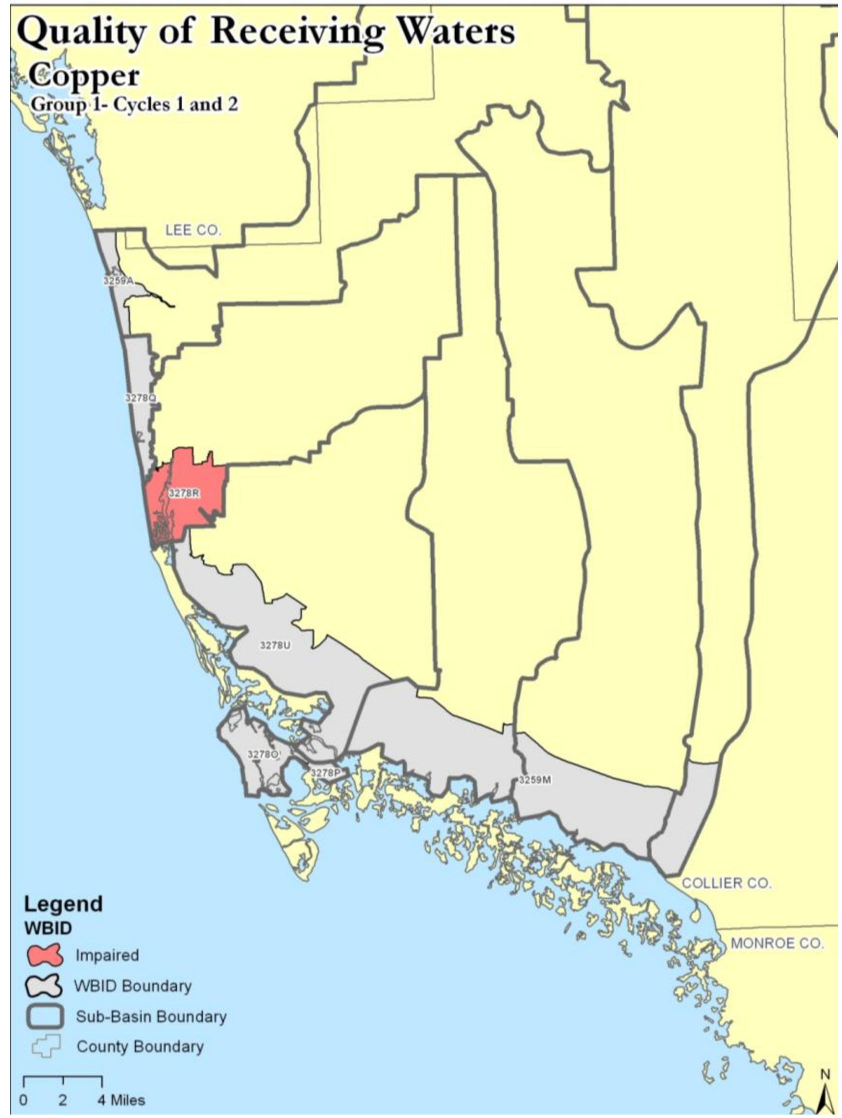


Figure 3-18. WBIDS verified impaired for Copper in the estuarine receiving waters of the study area by FDEP

Figure 3-19. WBIDS verified impaired for Iron in the estuarine receiving waters of the study area by FDEP

Summary statistics for each water quality parameter, by station and watershed, were calculated for the four estuarine receiving water bodies. Four critical water quality parameters were identified to evaluate the estuarine water quality condition:

- chlorophyll-*a*
- dissolved oxygen
- transparency and
- Fecal coliform bacteria

The maps shows as **Figures 3-20 though 3-23** show water quality conditions by sampling station for each of the parameters. Secchi depth was used as the measure of transparency in the water body.

3.3.2.1 Wiggins Pass Estuary

Wiggins Pass is located within WBID 3259A (Cocohatchee River) and is presently listed as impaired for three water quality parameters; dissolved oxygen, fecal coliforms and iron. Wiggins Pass is the receiving water for the Cocohatchee-Corkscrew watershed. A total of eighteen water quality stations contain data for the parameters reviewed from 2000 to 2009 (**Table 3-16**). Summary statistics by station are available in **Appendix 4-D**. The water quality summary statistics for Wiggins Pass are presented in **Table 3-17.**

Table 3-16. List of stations with water quality data from 2000 to 2009 in Wiggins Pass (WBID 3259A)

Name	Name
21FLFTM 28030071FTM	28030036
21FLFTM EVRGWC0024FTM	BFBSP
21FLFTM EVRGWC0026FTM	COCEOF31
21FLFTM EVRGWC0041FTM	COCOR1
21FLFTM EVRGWC0042FTM	COCOR2
21FLFTM EVRGWC0081FTM	COCORVW
21FLSFWMROOK467	Canal@99thAve
28030009	Coco @ Collier Reserve
TURKBAY	Coco at SR 865

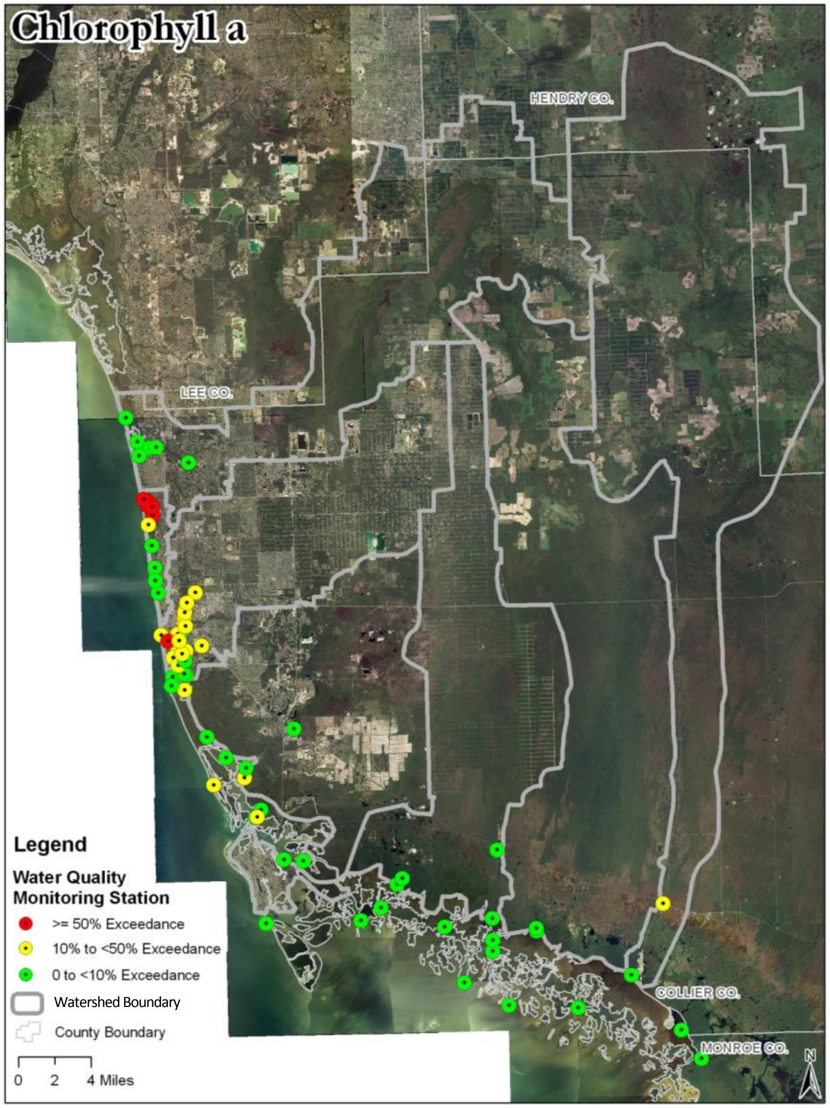


Figure 3-20. Chlorophyll *a* potential areas of concern by water quality station

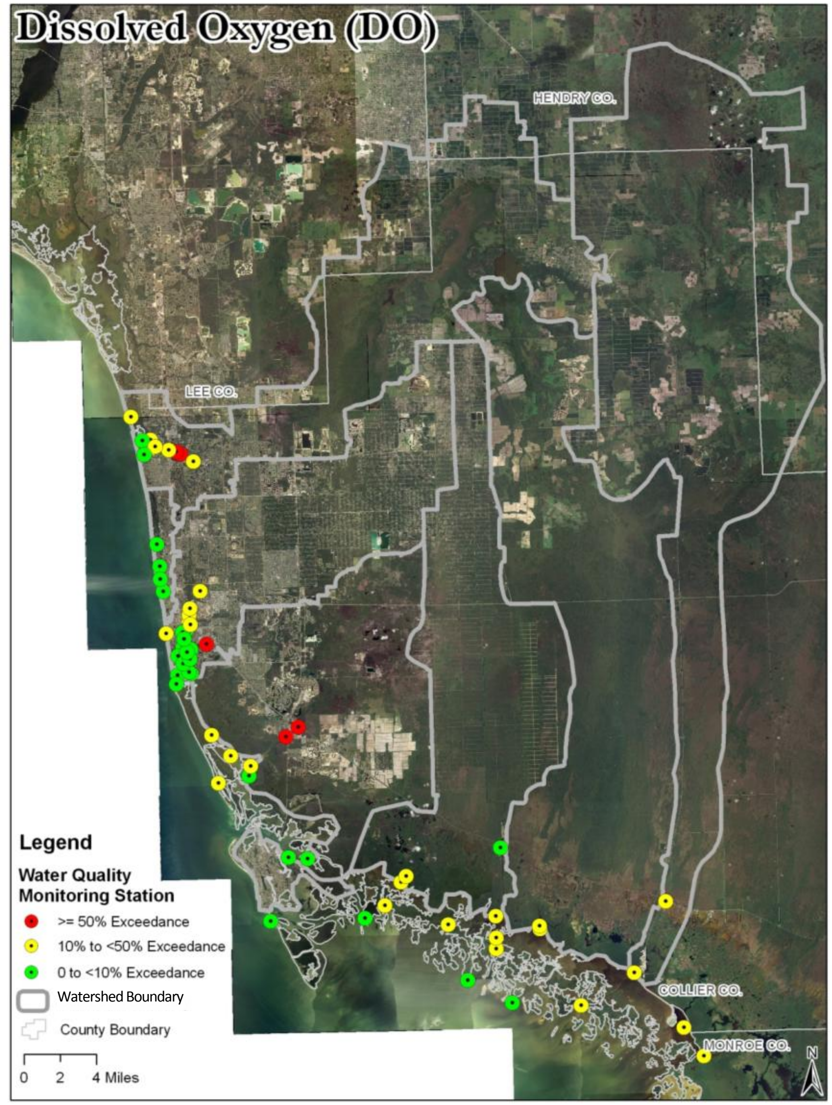


Figure 3-21. Dissolved Oxygen potential areas of concern by water quality station

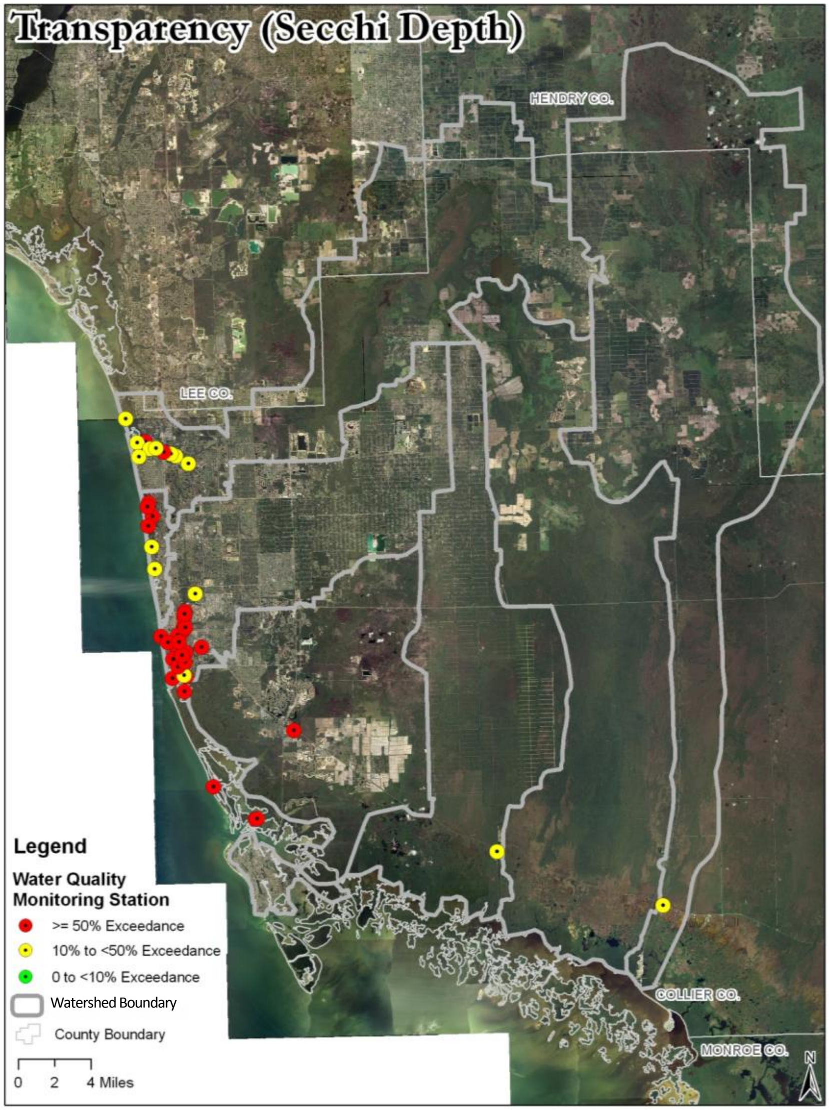


Figure 3-22. Transparency (Secchi Depth) potential areas of concern by water quality station

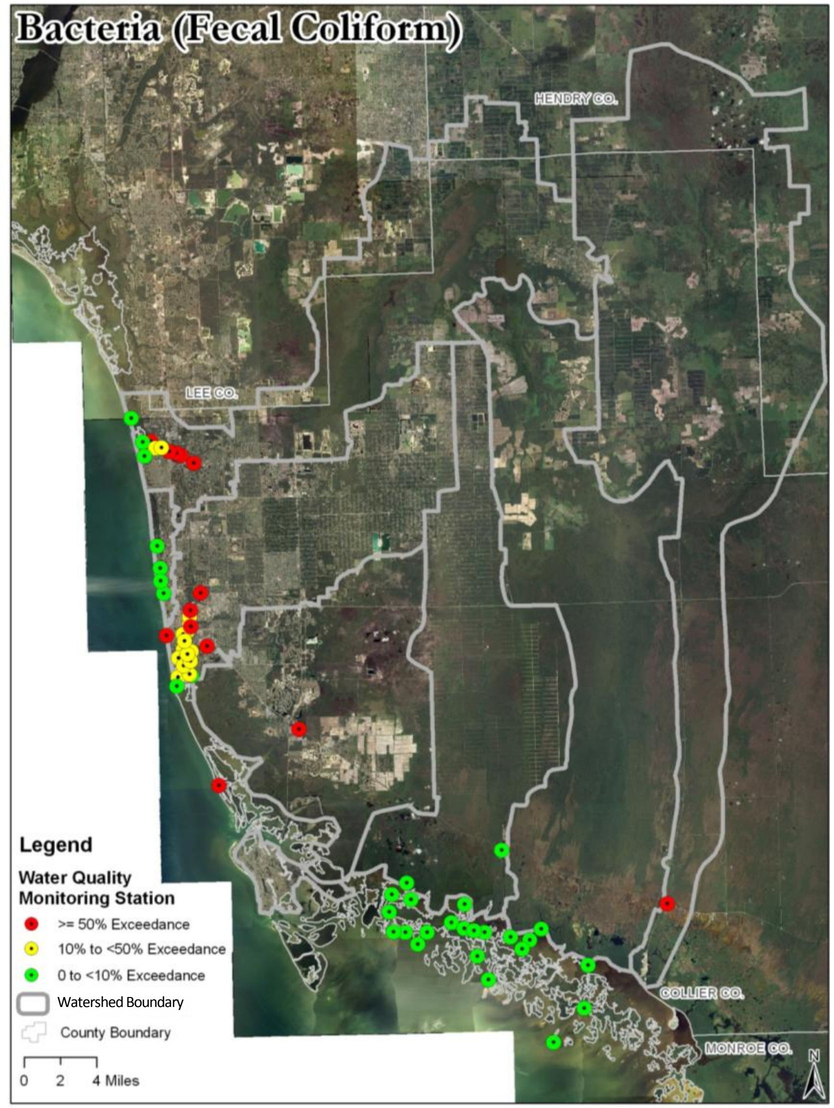


Figure 3-23. Bacteria (Fecal Coliform) potential areas of concern by water quality station

Table 3-17. Water quality summary statistics from 2000 to 2009 in Wiggins Pass (WBID 3259A)

Parameter	N	Min	Mean	Median	Max	Percent Exceed
BOD, mg/l	108	1.0	2.2	2.0	8.1	-
Chlorophyll-*a*, ug/l	209	1.0	4.5	3.0	70.0	6
Color, PCU	149	5	51	50	200	8
Conductivity, umhos/cm	282	305	28135	33990	57059	-
Copper, ug/l	75	0.51	1.95	1.65	7.60	4
DO, mg/l	340	0.1	5.1	4.9	19.4	29
Fecal Coliform, #/100 mL	260	1	187	62	5700	57
Iron, ug/l	72	35	290	239	840	40
Nitrate-Nitrite, mg/l	213	0.002	0.508	0.027	99	-
Orthophosphate as P, mg/l	122	0.004	0.018	0.012	0.140	-
Salinity, ppt	167	0.0	22.3	29.0	66.9	-
Secchi Depth, m	268	0.10	0.92	1.00	3.50	45
TKN, mg/l	150	0.08	0.74	0.78	2.00	-
Total Nitrogen, mg/l	181	0.05	0.72	0.74	2.09	1
Total Phosphorus, mg/l	210	0.004	0.046	0.036	0.310	0
TSS, mg/l	90	2.0	10.1	7.5	62.0	50
Turbidity, NTU	210	0.1	3.5	2.8	18.1	
Unionized Ammonia, mg/l	34	0.0001	0.0008	0.0008	0.0022	

Impaired WBID comparison

Using all of the water quality data for each WBID, Atkins confirmed the impairment status determined by FDEP for parameters identified in the Wiggins Pass Estuary (WBID 3259A) (**Table 3-18**).

Table 3-18. Impaired WBID comparison for Wiggins Pass estuary

WBID#	Water Segment Name	FDEP Impaired Parameter	PBSJ Analysis
3259A	Cocohatchee River	Dissolved Oxygen	Confirm FDEP assessment
3259A	Cocohatchee River	Fecal Coliform	Confirm FDEP assessment
3259A	Cocohatchee River	Iron	Confirm FDEP assessment

Chlorophyll a

Overall, chlorophyll *a* concentrations exceeded the regulatory 11 µg/L standard in 6 percent of the collected samples. The median chlorophyll *a* concentration was 3 µg/L with the maximum measuring 70 µg/L. These concentrations are within the allowable range for a marine water body and have remained consistently below the regulatory standard throughout the estuary (**Figure 3-20**).

Dissolved Oxygen

Dissolved oxygen values were less than 4.0 mg/L in 29 percent of the samples. The median DO concentration was 4.9 mg/L with a minimum value of 0.1 mg/L. Low dissolved oxygen levels appear to be evident in the upstream portions of Wiggins Pass, where stations were below 4 mg/L in more than 50 percent of samples reviewed. Depressed dissolved oxygen continued mid-estuary but less consistently with stations reporting values below the standard in 10-49 percent of samples (**Figure 3-21**). From this analysis it was confirmed that Wiggins Pass is impaired for dissolved oxygen (**Table 3-18**), although those stations with the most interaction with the Gulf of Mexico consistently met regulatory standards for dissolved oxygen.

The DO impairment could be attributed to decomposition of organic material from the adjacent wetlands and upstream landscapes (McCormick, 1997); however, elevated color and high total suspended solid concentrations were not observed in the downstream portion of these watersheds.

A causative factor for the low DO concentration could also be the presence of high concentrations of TN and TP. The median TN and TP concentrations in Wiggins Pass (0.74 and 0.05 mg/L, respectively) are lower than the screening levels per **Table 3-18**. In addition, although the TN concentration is slightly higher than the Estero Bay Wetland TN target (0.60 mg/L), the median TP concentration is below the 0.05 mg/L TP target from the Hendry Creek TMDL.

Based on the findings described above, further analyses may be necessary to identify the cause of the low dissolved oxygen concentrations.

Transparency (Secchi Depth)

Forty-five percent of the Secchi depth measurements were below the calculated screening level of 1.38 m indicating low visibility. The median Secchi depth was 1.00 m with a minimum of 0.10 m. No water quality station had consistent Secchi depth values greater than the screening level (**Figure 3-22**). Low Secchi depth values indicate poor light penetration which could lead to degradation of seagrass communities and other photosynthetic biota. Atkins believes that that the measured Secchi depth values may be low due to the limited flushing characteristics of the estuary and potentially the resuspension of bottom material.

Fecal Coliform Bacteria

Wiggins Pass is impaired by FDEP for fecal coliforms (**Table 3-18**). Fecal coliform concentrations in Wiggins Pass exceed the 43 #/100 mL regulatory standard for Class II waters in 57 percent of the samples. The median bacteria concentration was 62 #/100 mL and a maximum value of 5,700 #/100 mL. The water quality stations within the upper estuary exceeded 43 #/100 mL in >=50 percent of all samples reviewed (**Figure 3-23**). The frequency of elevated values decreases with proximity to the Gulf of Mexico. The decrease in frequency of elevated bacterial concentration is possibly due to the high inactivation ("die-off") rate of both fecal coliforms and *E. coli* in saline waters (Anderson et al. 2005).

Though values exceed the regulatory standard, it should be considered that fecal coliform bacteria may not be an appropriate indicator for pathogenic diseases in sub-tropical environments such as South Florida where the specificity of the fecal coliform test is compromised by the more constant and warmer ambient water temperatures. The inability to specifically identify humans as a source of bacteria using traditional indicator testing protocols has been noted by Fujioka (2001) and Fujioka et al. (1999) for various tropical locations. Source identification studies are recommended to determine whether anthropogenic factors cause of the elevated bacteria concentrations. This is particularly important because uses of the Collier County estuaries are shellfish propagation and harvesting and monitoring for the presence of bacteria is important for public health concerns.

Iron

Computer model simulations indicate that groundwater represents almost 40 percent of the average annual flow in the Cocohatchee Canal and range between 30 percent in the wet season to65 percent in the dry season. Therefore, groundwater contributions to Wiggins Pass are significant and could be the cause for the elevated iron concentrations. However, because iron may also be of anthropogenic origin, more detailed source-identification studies may be warranted.

3.3.2.2 Naples Bay Estuary

Naples Bay is located within WBID 3278R (Naples Bay-Coastal Segment) and is presently listed as impaired for four parameters; dissolved oxygen, fecal coliforms, copper and iron. Naples Bay is the receiving water for the Golden Gate-Naples Bay watershed and Gordon River Extension A total of forty water quality stations are available which contain data for the parameters reviewed for the period 2000 to 2009 (**Table 3-19**). Summary statistics by station are available in **Appendix 4-D**. The water quality summary statistics for Naples Bay are presented in **Table 3-20.**

Table 3-19. List of stations with water quality data from 2000 to 2009 in Naples Bay (WBID 3278R)

Name	Name	Name
21FLBRA 3259G-B	21FLSFWMBC4	21FLNAPLNBAYBV
21FLBRA 3259G-C	AQS8-1	21FLNAPLNBAYCC
21FLBRA 3259G-D	BC2	21FLNAPLNBAYLLO
21FLBRA 3259G-E	Bay20	21FLNAPLNBAYNL
21FLFMRINTK200120	COL8	21FLSFWMBC1
21FLFTM 28030069FTM	COL9	ROOK464
21FLFTM28030031	ESBAY	Haldeman Bay
21FLGW14160	GORD10	JayceePark
21FLGW21751	GORD30	NaplesBay22
21FLGW22543	GORD31	NaplesBay24
21FLNAPLGORDJOE	GORD70	NaplesBay41
21FLNAPLGORDPK	Gord60	NaplesBay50
21FLNAPLNBAY13	Gord80	HC@Bayshore
21FLNAPLNBAY29		

Table 3-20. Water quality summary statistics from 2000 to 2009 in Naples Bay (WBID 3278R)

Parameter	N	Min	Mean	Median	Max	Percent Exceed
BOD, mg/l	500	0.3	2.1	2.0	12.0	-
Chlorophyll-*a*, ug/l	842	0.9	6.6	3.7	110.0	14
Color, PCU	719	5	45	40	200	41
Conductivity, umhos/cm	729	449	34163	42751	57220	-
Copper, ug/l	513	0.15	3.43	2.90	25.30	30
DO, mg/l	714	0.6	5.6	5.7	14.0	16
Fecal Coliform, #/100 mL	682	1	148	29	4700	43
Iron, ug/l	306	29	419	390	2530	65
Nitrate-Nitrite, mg/l	712	0.00	0.05	0.04	0.26	-
Orthophosphate as P, mg/l	596	0.004	0.021	0.018	0.081	-
Salinity, ppt	660	0.2	22.7	27.9	38.2	-
Secchi Depth, m	746	0.15	1.13	1.10	3.90	78
TKN, mg/l	683	0.04	0.60	0.60	5.90	-
Total Nitrogen, mg/l	766	0.01	0.63	0.63	17.00	10
Total Phosphorus, mg/l	823	0.004	0.046	0.040	0.310	0
TSS, mg/l	577	2.0	10.4	6.0	270.0	14
Turbidity, NTU	618	0.1	2.7	2.1	63.0	-
Unionized Ammonia, mg/l	0	-	-	-	-	-

Impaired WBID comparison

The current analysis confirmed the impairment status determined by FDEP for parameters identified in the Naples Bay Estuary WBID 3278R (**Table 3-21**).

Table 3-21. Impaired WBID comparison for Naples Bay estuary

WBID#	Water Segment Name	FDEP Impaired Parameter	Atkins Analysis
3278R	Naples Bay Coastal	Copper	Confirm FDEP assessment
3278R	Naples Bay Coastal	Dissolved Oxygen	Confirm FDEP assessment
3278R	Naples Bay Coastal	Fecal Coliform	Confirm FDEP assessment
3278R	Naples Bay Coastal	Iron	Confirm FDEP assessment

Chlorophyll a

Overall, chlorophyll *a* concentrations exceeded the 11 µg/L standard in 14 percent of the collected samples. The median chlorophyll *a* concentration was 3.7 µg/L, with the maximum measured value equal to 110 µg/L. The chlorophyll *a* data do not show evidence of excess phytoplankton production in Naples Bay (**Figure 3-20**).

Dissolved Oxygen

Naples Bay is impaired for dissolved oxygen by FDEP (Table 2-21). Concentrations in the Atkins data set were less than 4.0 mg/L in 16 percent of the samples. The median DO concentration was 5.7 mg/L with a minimum value of 0.6 mg/L. Low dissolved oxygen levels appear to be evident in the upstream portions Naples Bay where stations were below 4 mg/L in more than 50 percent of samples reviewed. Depressed dissolved oxygen levels continued mid-estuary but less consistently with stations reporting values below the standard in 10-49 percent of samples (**Figure 3-21**). Those stations with the most interaction with the Gulf of Mexico consistently met regulatory standards for dissolved oxygen.

TN and TP are potential causative parameters for low DO level. The median TN and TP concentrations in Naples Bay are lower than the screening criteria and lower than the targets established to address the DO impairment in Hendry Creek using the Estero Bay Wetlands (FDEP 2008). Therefore nutrient concentrations are likely not the cause for the DO impairment.

Another potential cause for the low DO levels could be related to the elevated total suspended solids (TSS) concentrations measured in the estuary. The measured results exceed water quality criteria 14% of the time. TSS may contribute to decreased DO concentrations if sufficient organic material is available for decomposition. The stratification caused by stormwater discharges and limited circulation in dead end canals may also contribute to depressed DO concentrations. More detailed evaluations are necessary to assess the cause of the DO impairment.

Transparency (Secchi Depth)

Transparency in the Naples Bay estuary appears to be the lowest of the Collier County estuaries. Seventy-eight percent of the Secchi depth measurements were below the calculated screening level of 1.38 m. The median Secchi depth was 1.10 m with a minimum of 0.15 m. No water quality station had consistent Secchi depth values greater than the screening level (**Figure 3-22**). As previously mentioned, Atkins believes that total suspended solid loads may be a concern for the Naples Bay estuary. High suspended solids loads may result in reduced water clarity and decreased Secchi depth values.

Fecal Coliform Bacteria

Naples Bay estuary was declared impaired by FDEP for fecal coliform concentrations. They exceed the regulatory standard of 43 #/100 mL in 53 percent of the samples (**Figure 3-23**). The median bacteria concentration was 29 #/100 mL and the maximum value was 4,700 #/100 mL. The majority of consistent exceedances occurred in the upper portion of each estuary. The frequency of elevated values decreases with proximity to the Gulf of Mexico. As with the other estuaries, the decrease in frequency of elevated bacteria concentrations is possibly due to the high inactivation ("die-off") rate of both fecal coliforms and *E. coli* in saline waters (Anderson et al. 2005).

Impairment for fecal coliform bacteria may not necessarily mean that there is an anthropogenic impact (Fujioka 2001, Fujioka et al. 1999). Bacterial loads from the watershed would provide a source of contamination to the estuary. However, none of the WBIDs discharging into Naples Bay have been declared impaired for fecal coliforms. Historically, elevated bacterial concentrations in Naples Bay may have been attributed to discharge from stormwater pipes (Staats, 1999).

Given the uncertainty as of the nature of the impairment, further source identification efforts are warranted.

Iron and Copper

Computer model simulations indicate that groundwater represents 43 and 24 percent of the average annual flow in the Golden Gate North canal and the Gordon River Extension, respectively. During the dry season, the groundwater contribution at those same locations increases to 52 and 32 percent, respectively. Therefore, groundwater contributions to Naples Bay are significant and could be the cause for the elevated iron concentrations. However, because iron may also be of anthropogenic origin, more detailed source-identification studies may be warranted.

Discharges of copper into the estuary could be from anthropogenic sources, such as its use as an algaecide to prevent algae growth. High measured concentrations could also result from the effects of copper leaching from boardwalks and pilings that are constructed from pressure-treated lumber. Detailed site-specific studies are also warranted.

3.3.2.3 Rookery Bay Estuary

Rookery Bay is located within WBID 3278U (Rookery Bay-Coastal Segment) and is presently listed as impaired for three parameters; dissolved oxygen, fecal coliforms, and nutrients. Rookery Bay is the receiving water for the Rookery Bay watershed. A total of thirty-nine water quality stations contain data for the parameters reviewed for the sampling period 2000 to 2009 (**Table 3-22**). Summary statistics by station are available in **Appendix 4-D**. The water quality summary statistics for Rookery Bay are presented in **Table 3-23.**

Table 3-22. List of stations with water quality data from
2000 to 2009 in Rookery Bay (WBID 3278U)

Name	Name	Name
21FLFMRINTK200121	21FLFTM EVRGWC0061FTM	HendersonCreek
21FLFMRINTK200122	21FLFTM EVRGWC0062FTM	HendersonCrk@41
21FLFMRINTK200123	21FLFTM EVRGWC0063FTM	JohnsonBay1
21FLFMRINTK200124	21FLGW13733	JohnsonBay2
21FLFMRINTK200129	21FLGW15163	JohnsonBay3
21FLFTM EVRGWC0027FTM	21FLSFWMHALDCRK	NTK200125
21FLFTM EVRGWC0028FTM	21FLSFWMROOK461	NTK200126
21FLFTM EVRGWC0029FTM	21FLSFWMROOK462	NTK200130
21FLFTM EVRGWC0030FTM	21FLSFWMROOK463	PORTAUPR5
21FLFTM EVRGWC0031FTM	BigMarcoRiver	ROOK458
21FLFTM EVRGWC0059FTM	COL10	ROOK459
21FLFTM EVRGWC0060FTM	DollarBay15	ROOK460
TarponBay1	UH	TarponBay

Impaired WBID Comparison

Using water quality data for each WBID, Atkins confirmed the impairment status determined by FDEP for two parameters identified in the Rookery Bay Estuary (WBID 3278U), dissolved oxygen and fecal coliforms (**Table 3-24**). The evaluation of chlorophyll *a* data indicated that values were not elevated frequently enough to classify the water body as impaired. The discrepancy in impairment classification could be due to the modified technique used to evaluate chlorophyll a, the data used or time period examined. However, Atkins also identified Rookery Bay estuary as potentially impaired for copper and iron.

Table 3-23. Water quality summary statistics from 2000 to 2009 in Rookery Bay (WBID 3278U)

Parameter	N	Min	Mean	Median	Max	Percent Exceed
BOD, mg/l	66	0.8	2.2	2.0	5.8	-
Chlorophyll-a, ug/l	691	0.8	5.9	4.3	74.0	10
Color, PCU	192	15	71	60	277	83
Conductivity, umhos/cm	521	125	29777	36345	60964	-
Copper, ug/l	84	0.25	5.94	1.71	51.00	38
DO, mg/l	771	0.6	4.9	4.8	20.6	31
Fecal Coliform, #/100 mL	166	1	136	80	1143	62
Iron, ug/l	79	16	340	240	1440	43
Nitrate-Nitrite, mg/l	453	0.0003	0.0170	0.0094	0.1440	-
Orthophosphate as P, mg/l	315	0.002	0.012	0.008	0.126	-
Salinity, ppt	779	0.1	24.3	27.7	41.4	-
Secchi Depth, m	267	0.15	1.06	1.04	2.59	82
TKN, mg/l	167	0.19	0.83	0.75	2.90	-
Total Nitrogen, mg/l	418	0.01	0.50	0.39	2.91	11
Total Phosphorus, mg/l	542	0.002	0.043	0.038	0.206	0
TSS, mg/l	127	2.0	5.5	2.0	70.0	6
Turbidity, NTU	670	-1.0	5.1	4.1	70.5	-
Unionized Ammonia, mg/l	0	-	-	-	-	-

Table 3-24. Impaired WBID comparison for Rookery Bay estuary

WBID#	Water Segment Name	FDEP Impaired Parameter	PBSJ Analysis
3278U	Rookery Bay Coastal	Dissolved Oxygen	Confirm FDEP assessment
3278U	Rookery Bay Coastal	Fecal Coliform	Confirm FDEP assessment
3278U	Rookery Bay Coastal	Nutrients (Chlorophyll a)	Not confirmed
3278U	Rookery Bay Coastal	Copper	Potential Impairment
3278U	Rookery Bay Coastal	Iron	Potential Impairment

Chlorophyll a

Overall, chlorophyll a concentrations exceeded the 11 µg/L regulatory standard in 10 percent of the collected samples (**Figure 3-20**) and no impairment was identified. . The median chlorophyll a concentration was 4.3 µg/L, with a maximum reported value of 74 µg/L. Some of these stations are landlocked or strongly affected by stormwater treatment systems. In those cases, they may have poor water quality but are not representative of the open waters of Rookery Bay or a significant source of nutrients to the estuary.

Dissolved Oxygen

As indicated previously, the estuary was declared impaired for low dissolved oxygen values by FDEP. The Atkins data set showed that dissolved oxygen concentrations were less than 4.0 mg/L in 31 percent of the samples. The median DO concentration was 4.8 mg/L, with a minimum reported value of 0.6 mg/L. Low dissolved oxygen levels appear to be evident in the upstream portions of Rookery Bay where stations were below 4 mg/L in more than 50 percent of samples reviewed (**Figure 3-21**). Depressed dissolved oxygen continued in the northern section of the estuary but less consistently with stations reporting values below the standard in 10-49 percent of samples. Those stations with the most interaction with the Gulf of Mexico consistently met regulatory standards for dissolved oxygen.

As DO concentrations may be affected by nutrient concentrations, TN and TP concentrations were compared to screening levels. The median TN and TP concentrations in Rookery Bay were found to be below the established screening values for Florida as well as those established for Hendry Creek using the Estero Bay Wetlands (FDEP 2008). The results of the comparative analysis suggest that nutrients do not appear to be the cause for the depressed DO levels.

Atkins believes that another cause for the low DO levels could be the stratification caused by stormwater discharges from the watershed. Given the uncertainty regarding the cause of the DO impairment, more detailed evaluations are necessary.

Transparency (Secchi Depth)

Eighty-two percent of the Secchi depth measurements were below the calculated screening level of 1.38 m. The median Secchi depth was 1.04 m with a minimum of 0.15 m. No water quality station had consistent Secchi depth values greater than the screening level (**Figure 3-22**). It is unclear what is causing the low secchi depth values. Atkins believes that the low values may be due to the low flushing characteristics of the estuary and resuspension of bottom material deposited in the discharge canals. In Addition, mangrove forests are abundant in Rookery Bay which may result in increased color which would be expected to diminish Secchi disk depths.

Fecal Coliform Bacteria

Rookery Bay is designated impaired by FDEP for elevated fecal coliform levels. For this analysis, the median bacteria concentration was 80 #/100 mL, with a maximum value of 1,143 #/100 mL. Sixty-two percent of all samples were greater than the regulatory standard of 43 #/100 mL for Class II water bodies. Both water quality stations examined within this estuary exceeded 43 #/100 mL in >=50 percent of all samples reviewed (**Figure 3-23**).

Bacterial loads from the watershed could be a source of the elevated concentration of fecal coliforms in the estuary. However, low bacterial loads are expected from the watershed (see TM

3.1: Quality of Discharge). As impairment for fecal coliform bacteria may not necessarily mean that it is caused by an anthropogenic impact (Fujioka 2001, Fujioka et al. 1999), source identification studies are warranted.

3.3.2.4 Ten Thousand Islands Estuary

The TTI is the receiving water for the Faka-Union, Fakahatchee, and Okaloacoochee/SR29 watersheds, which largely remain in undeveloped conditions. It is located within WBID 3259M (TTI) and is presently not listed as impaired for any parameter. The watershed largely remains in undeveloped conditions; therefore, no significant human activities affect the estuary system. A total of sixty-three water quality stations are available for the parameters reviewed from 2000 to 2009 (**Table 3-25**). Summary statistics by station are available in **Appendix 4-D**. The water quality summary statistics for TTI estuary are presented in **Table 3-26.**

Impaired WBID Comparison

No WBIDs were declared impaired by FDEP in the Ten Thousand Island estuary. Results of the analysis conducted herein for the critical water quality parameters are described below.

Chlorophyll a

Overall, chlorophyll *a* concentrations exceeded the 11 µg/L standard in 3 percent of the collected samples. The median chlorophyll a concentration was 3.0 µg/L with a maximum reported value of 47.5 µg/L. Only one station in the eastern portion of the estuary near the Tamiami Trail indicated values in exceedance of the standard in 10 to 49 percent of the samples (**Figure 3-20**). In general, chlorophyll a concentrations have remained consistently below the regulatory standard throughout the estuary.

Table 3-25. List of stations with water quality data from 2000 to 2009 in Ten Thousand Islands (WBID 3259M)

Name	Name	Name
187_Fakahatchee	21FLSFWMTTI53	SEAS007_Ferguson
21FLA 66011SEAS	21FLSFWMTTI65	SEAS010_IndianKey
21FLA 66038SEAS	21FLSFWMTTI67	SEAS028_Turtle
21FLFMRISTK200201	21FLSFWMTTI68	SEAS029_SnagShoal
21FLFMRISTK200205	21FLSFWMTTI69	SEAS034_DismalKey
21FLFMRISTK200208	21FLSFWMTTI70	SEAS035_SantinaBay
21FLFMRISTK200210	21FLSFWMTTI72	SEAS036_Pumpkin
21FLFMRISTK200211	21FLSFWMTTI74	SEAS037_Santina
21FLFMRISTK200212	21FLSFWMTTI75	SEAS111_Fakahatchee
21FLFMRISTK200214	21FLSFWMTTI76	SEAS112_Fakahatchee
21FLFMRISTK200216	BARRIVN	SEAS113_Fakahatchee
21FLFTM EVRGWC0001FTM	BL_Kwater	SEAS114_Fakahatchee
21FLFTM EVRGWC0002FTM	BRMouth	SEAS281_FishHawk
21FLFTM EVRGWC0003FTM	Bridge030122	SEAS299_Blackwater
21FLFTM EVRGWC0004FTM	COL14	SEAS300_Blackwater
21FLGW13734	COL15	SEAS301_ShellKey
21FLGW15173	COL16	SEAS302_SnagShoal
21FLSFWMROOK451	FAKAUPOI	SEAS303_Buttonwood
21FLSFWMTTI51	FU	SEAS401_FakaUnion
Fa-Aunion	STK200206	SEAS771_FakaUnion
FakahatcheeBay	PumpkinBay	Seas077

Table 3-26. Water quality summary statistics from 2000 to 2009 in the Ten Thousand Islands (WBID 3259M)

Parameter	N	Min	Mean	Median	Max	Percent Exceed
BOD, mg/l	52	0.6	1.9	2.0	8.3	-
Chlorophyll-a, ug/l	1113	0.5	4.0	3.0	47.5	3
Color, PCU	167	10	60	50	200	68
Conductivity, umhos/cm	9150	306	43007	48013	64190	-
Copper, ug/l	63	0.26	1.33	1.00	5.13	5
DO, mg/l	7593	0.2	5.0	5.0	20.3	24
Fecal Coliform, #/100 mL	431	1	56	1	2300	17
Iron, ug/l	66	65	233	180	980	15
Nitrate-Nitrite, mg/l	918	0.0005	0.0162	0.0108	0.1100	-
Orthophosphate as P, mg/l	319	0.002	0.012	0.009	0.054	-
Salinity, ppt	10132	0.2	28.1	31.4	43.4	-
Secchi Depth, m	190	0.20	1.52	1.55	2.90	41
TKN, mg/l	152	0.04	0.63	0.58	2.26	-
Total Nitrogen, mg/l	769	0.01	0.43	0.38	2.27	5
Total Phosphorus, mg/l	926	0.001	0.144	0.033	99	0
TSS, mg/l	130	2.0	6.9	2.0	113.0	8
Turbidity, NTU	9735	0.3	9.4	8.0	249.0	-
Unionized Ammonia, mg/l	0	-	-	-	-	-

Dissolved Oxygen

Dissolved oxygen concentrations were less than 4.0 mg/L in 24 percent of the samples. The median DO concentration was 5.0 mg/L with a minimum value of 0.2 mg/L. Low dissolved oxygen levels appear to be evident in the mid-estuary with stations reporting values below the standard in 10-49 percent of samples (**Figure 3-21**). While FDEP has not declared the WBID impaired for dissolved oxygen, the analysis completed by Atkins indicates that during the time period examined dissolved oxygen is a parameter of potential concern for the estuary. The elevated color and total suspended solids discharged from the contributing watersheds are likely responsible for the depressed dissolved oxygen values. However, as discussed in technical memorandum 1.2: In-stream water quality, low dissolved oxygen concentrations in this region are likely due to natural conditions (Diaz, 2011) associated with the extensive forested wetlands found in the adjacent watershed.

Transparency (Secchi Depth)

Forty-one percent of the Secchi depth measurements were below the calculated screening level of 1.38 m. The median Secchi depth was 1.55 m with a minimum of 0.2 m. Although limited data were available, those stations with sufficient data show values less than 1.38 m in 10-49 percent of all samples (**Figure 3-22**). Total suspended solid and color loads from the adjacent watersheds contribute to the reduced water clarity in the TTI estuary.

Fecal Coliform Bacteria

Fecal coliform concentrations exceed the regulatory standard of 43 #/100 mL in 17 percent of the samples. The median bacteria concentration was 1 #/100 mL with a maximum value of 2,300 #/100 mL. While FDEP has not declared the WBID impaired for fecal coliforms, the analysis completed by Atkins indicates that one water quality station in the eastern portion of the estuary exceeded 43 #/100 mL in >=50 percent of all samples reviewed (**Figure 3-23**). The remainders of the water quality stations were consistently below the regulatory standard. If the fecal coliform concentration results in water quality impairment in the future, additional water quality sampling to identify the potential bacteria sources to the estuary would be warranted. In addition, impairment for fecal coliform bacteria may not necessarily mean that there is an anthropogenic impact as the cause (Fujioka 2001, Fujioka et al. 1999).

3.3.3 Conclusions

Water quality impairments identified by FDEP were generally confirmed by results of analyses completed for the estuaries water quality evaluation. Only one discrepancy was identified in a comparison of the FDEP and Atkins derived impaired WBIDs. FDEP verified Rookery Bay estuary (WBID 3278U) as impaired for chlorophyll a; however, Atkins did not reach the same conclusion. The discrepancy is likely due to the modified method utilized by Atkins as well as the data set and time period analyzed. A more extensive review of this impairment is recommended.

Recommendations were developed based on the results of this evaluation to address dissolved oxygen and chlorophyll *a* impairments and source identification for fecal coliforms in some cases. It is recommended that Collier County work with FDEP to determine whether the impairment for dissolved oxygen in Wiggins Pass, Naples Bay and Rookery Bay is naturally occurring due to wetland influences, or due to groundwater contributions from the extensive canal system, or whether low dissolved oxygen levels are due to anthropogenic pollutant loads. While these three estuaries have been declared verified impaired by FDEP for dissolved oxygen, it is important to note that many of the “reference sites” used by FDEP to establish background levels of nitrogen and phosphorus also “fail” FDEP’s default dissolved oxygen standard. In addition, levels of the potentially causative nutrients TN and TP are only infrequently above relevant screening criteria. In Atkins’ opinion, it is likely that factors other than nutrient enrichment alone influence concentrations of chlorophyll *a* and levels of dissolved oxygen.

Site specific alternative criteria might be a useful tool to address chlorophyll *a* and dissolved oxygen impairment conditions if it is proven that the problem is not caused by anthropogenic pollutant loads.

Additionally, Collier County should work with FDEP to develop a directed sampling effort focusing on identifying potential sources (including non-anthropogenic ones) of fecal coliform bacteria in Wiggins Pass, Naples Bay, and Rookery Bay, perhaps as part of FDEP’s TMDL and/or Basin Management Action Plan (BMAP) programs. Further assessments are needed to determine whether or not levels of iron and copper are indicative of anthropogenic influences in Collier County’s estuaries. Given the extent of groundwater contributions to the estuaries, iron concentrations may reflect groundwater sources rather than anthropogenic contamination.

3.4 COASTAL HABITATS

The loss of natural functions in Wiggins Pass, Naples Bay, Rookery Bay, and the Ten Thousand Islands estuaries (**Figure 3-24)** that has occurred over time due to hydrologic alterations is addressed in this section of the CCWMP. Specifically, the historical (i.e. natural) timing and volume of freshwater discharges to these four estuaries have been altered due to excess freshwater deliveries to the systems. The result of these alterations includes the reduced areal extent (acres) of oyster bars, seagrass beds, mangrove forests and salt marshes in the estuaries. This section specifically addresses Element 2, Task 4 in the CCWMP SOW.

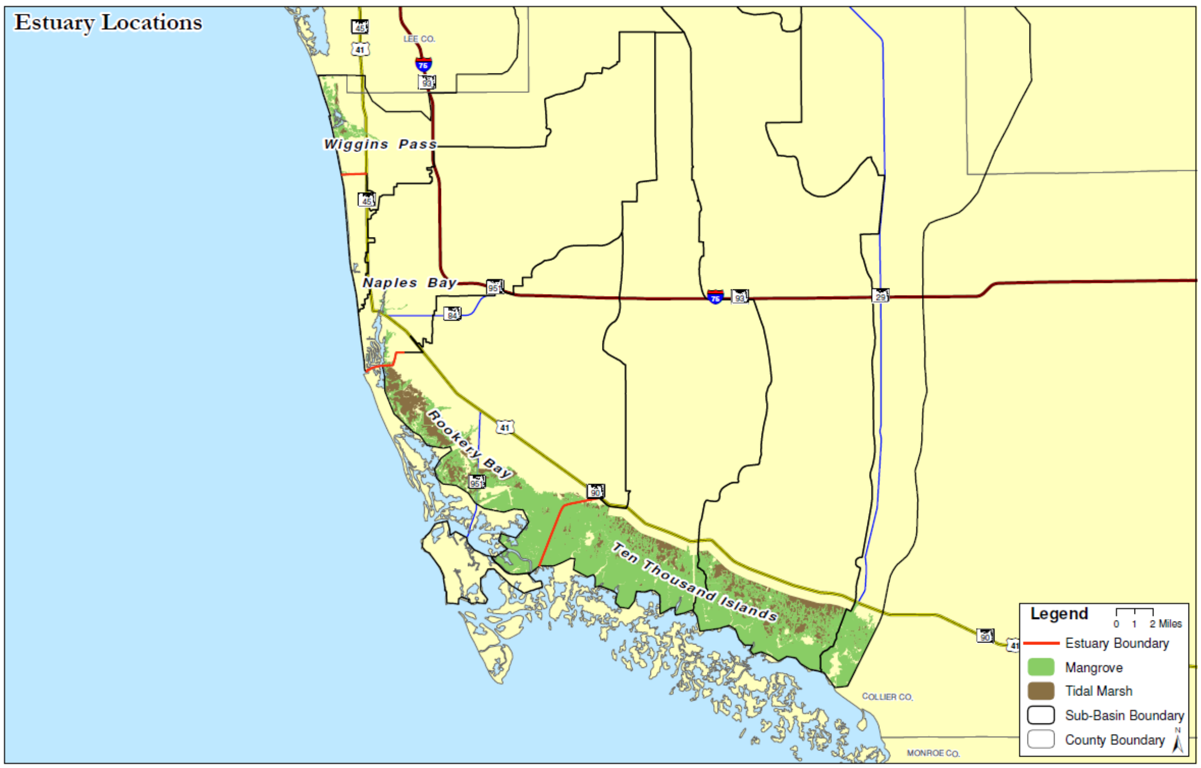


Figure 3-24. Estuary Locations

3.4.1 Introduction and Objective

Estuaries provide many ecosystem functions, including shoreline stabilization, nutrient recycling, and habitat for a diverse assemblage of plants and animals. Within Collier County, coastal ecosystems have been impacted by altered timing and volumes of freshwater inflow (e.g., Browder et al. 1988, Shirley et al. 1997, Shirley et al. 2005, Popowski 2006, etc.) and direct physical destruction (Shirley et al. 1997). A less frequently mentioned impact is degradation due to nutrient enrichment, a topic discussed by Shirley et al. (1997).

Many of the large-scale hydrologic alterations in Collier County began in the early 1950s. Dredge-and-fill became the established method to meet the post-World War II demand for housing. Canals were used to create waterfront property, increase access for boating, and provided fill material needed for buildable lots (Antonini et al 2002). Increased impermeable surfaces due to coastal development have subsequently increased freshwater inputs from the watershed. Changes to the timing and volume of freshwater discharges to the estuaries have been dramatic when compared with historical conditions, the primary problem being the delivery of too much fresh water during the wet season and too little during the dry season (e.g., Browder et al. 1988, Shirley et al. 1997). As a result, the historical areal extents of oyster bars and seagrass beds have been reduced by salinity alterations, increased shading due to decreased water clarity, and increased sediment deposition in communities. The tidal mangrove habitat has also been directly affected by coastal development and hydrologic alterations to the salinity regime (Doyle et al 2003, Popowski 2006).

3.4.2 Methods

Several GIS databases were queried, and relevant data compiled, to quantify the changes, if any, in the spatial extent of oyster bars, seagrass beds, mangrove forests, and salt marshes in Wiggins Pass, Naples Bay, Rookery Bay, and the TTI estuaries. GIS databases searched included those from the SWFWMD (i.e., Duever 2004 and others) and the Florida Freshwater Fish and Wildlife Conservation Commission. The data available differed among the four estuaries examined.

Wiggins Pass GIS data were available for 1999 for oysters, seagrass data were found for 2006, tidal marsh data were available for pre-development and current (2007) time periods, and mangrove data were available for both pre-development and 2007 time periods.

In Naples Bay, GIS data were acquired for both oysters and seagrass for the years 1953 and 2005. Data on both tidal marshes and mangrove forests were available for both pre-development and 2007 time periods.

For Rookery Bay, GIS data were available for both tidal marshes and mangrove forests for both pre-development and 2007 time periods. No GIS data on the spatial extent of oysters and seagrasses were found, although reports in which locations of oyster reefs and seagrass beds that had been encountered were found, although these sources were insufficient for a GIS-based analysis of spatial trends.

In the TTI, GIS data for both tidal marshes and mangrove forests for both pre-development and 2007 time periods were found. As in Rookery Bay, no GIS data were found that would allow for a detailed assessment of the changes (if any) in the spatial extent of oysters and seagrasses, although reports were found that referenced locations at which oyster reefs and seagrass beds had been encountered.

The report *Seagrass Status and Trends in the Northern Gulf of Mexico* (Handley et al. 2007) identifies the coastal waters of Collier County as the only region on both east and west coasts of Florida without seagrass acreage estimates. In general, the lack of GIS data for seagrasses and oysters in much of Collier County may be due to the reduced water clarity in many coastal waters, making delineation of features from aerial photography a difficult task to accomplish.

Trend analysis in the estuaries depends on the availability of an accurate assessment of the spatial extent of various landscape features at the earliest time possible. For Collier County, the previously described PDVMs developed by Duever (2004) allow for a comparison of more recent landscapes with a "pre-development" condition. However, that pre-development conditions mapping effort did not include the islands south and west of the mainland of Collier County, particularly in the region of the TTI. Therefore, GIS comparisons are limited to those regions along the mainland portion of Collier County. While this is unfortunate, most of the alterations in natural system features over time have occurred along the mainland shoreline in response to coastal development, not on the offshore islands of the TTI estuary, with the exception of the large-scale development of Marco Island.

3.4.3 Results and Discussion

This section presents the results of the GIS-based land cover analysis conducted as part of this project for each of the four estuaries, Wiggins Pass, Naples Bay, Rookery Bay and the TTI.

3.4.3.1 Wiggins Pass

Wiggins Pass was first officially dredged in 1952, and dredging continues in the inlet and along the inland waterway south of Bonita Beach and north of Naples Park. Coastal development surrounding Wiggins pass began in the early 1950s and included creation of residential canals that subsequently altered natural sheet flow of stormwater runoff into the estuary. As shown in **Figure 3-25,** the area adjacent to Wiggins pass has shifted from a mangrove dominated system to both tidal marsh and mangroves and an overall decrease in the mangrove community has occurred due to direct loss due to coastal development.

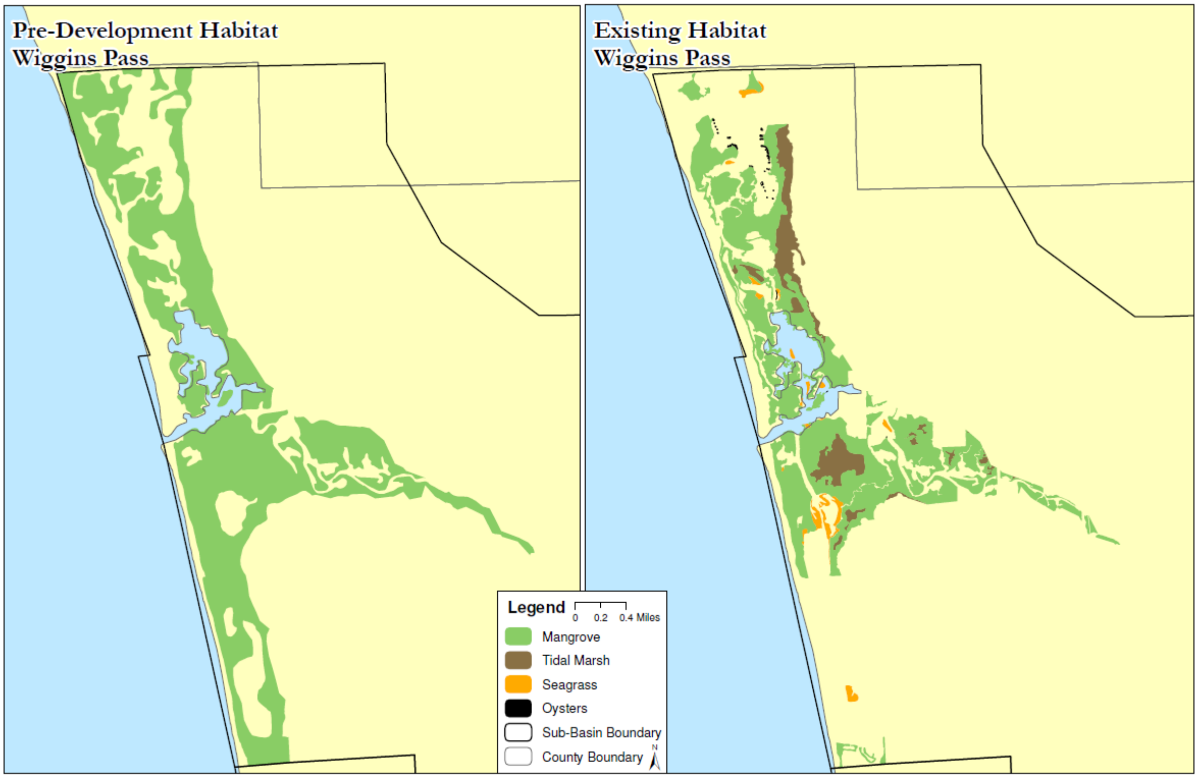


Figure 3-25. Wiggins Pass Estuarine Communities
(GIS data from SFWMD and the FWRI)

Areal extent (acres) of mangroves in the Wiggins Pass estuary boundaries decreased from 1,660 in pre-development times (Duever 2004) to 999 acres in 2007, a decline of approximately 40 percent (**Table 3-27**). Tidal marsh habitat was not mapped for pre-development conditions in the Wiggins Pass estuary boundaries, but it accounted for 183 acres in 2007 (**Table 3-27**). Due to natural succession shifts between mangroves and salt marshes (Lewis and Streever, 2000); analysis was focused on examining the combined acreage of the two communities, rather than each one separately. With this approach, a decrease from 1,660 acres in pre-development years to 1,182 in 2007, a decline of 29 percent, occurred in mangroves and tidal marshes in the Wiggins Pass estuary.

Table 3-27
Wiggins Pass Estuarine Communities Changes (Acres)

<table>
<tr><th>Community</th><th>Pre-Development</th><th>Current</th><th>Acres Lost</th><th>Percent Loss</th></tr>
<tr><td>Oyster (1999)</td><td>No Data</td><td>5</td><td>NA*</td><td>NA</td></tr>
<tr><td>Seagrass (2006)</td><td>No Data</td><td>39</td><td>NA</td><td>NA</td></tr>
<tr><td>Tidal Marsh (Pre-Dev vs. 2007)</td><td>0</td><td>183</td><td rowspan="2">477</td><td rowspan="2">29</td></tr>
<tr><td>Mangrove (Pre-Dev vs. 2007)</td><td>1,660</td><td>999</td></tr>
<tr><td colspan="5">NA=not applicable due to missing data</td></tr>
</table>

No GIS data sources of oyster resources were located other than a 1999 coverage obtained from the Fish and Wildlife Research Institute (FWRI). **Figure 3-25** depicts several small patches of oysters in the northern portion of Wiggins Bay in 1999. **Figure 3-25** also shows the location of seagrasses from a data layer compiled in 2006 by the FWRI. These limited oyster and seagrass data provide a potential baseline of information for identifying future changes in estuarine conditions.

3.4.3.2 Naples Bay

Historic maps and records indicate that Naples Bay was a shallow estuarine system with mangrove islands surrounded by oysters and seagrass beds (Antonini et al. 2002, Schmid et al. 2006). Historically, extensive oyster bars occurred along the shorelines and at the mouth of Naples Bay's many tidal creeks. Seagrass beds were also noted in the historical record (Schmid et al 2006).

Dredging activities conducted to create the system of residential development dramatically altered the tidal flushing patterns and the overall function of the bay (Schmid et al 2006). The length of shoreline associated with Naples Bay increased by nearly 50 percent between 1927 and 1965, followed by an additional increase of 11 percent between 1965 and 1978. The increase in shoreline length is directly related to the construction of residential canal systems. In addition, Schmid et al. (2006) documented a 91 percent loss in seagrass habitat and 82 percent loss in oyster habitat since the 1950s.

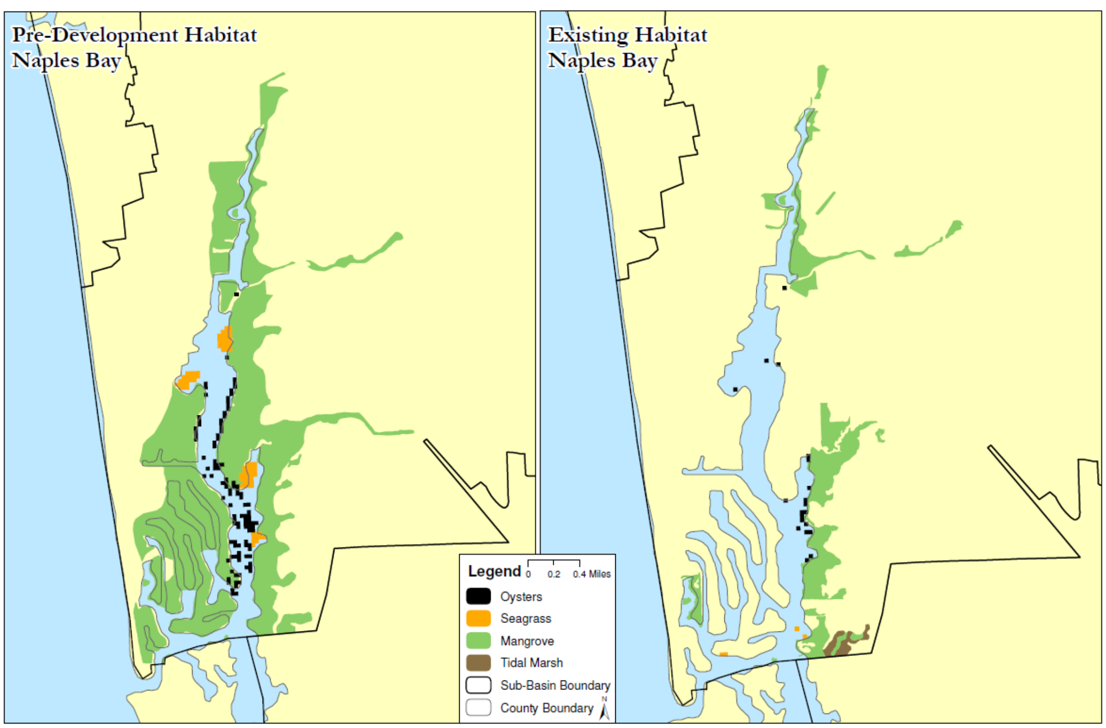


Figure 3-26. Naples Bay Habitat Changes
(GIS data from SFWMD and the FWRI)

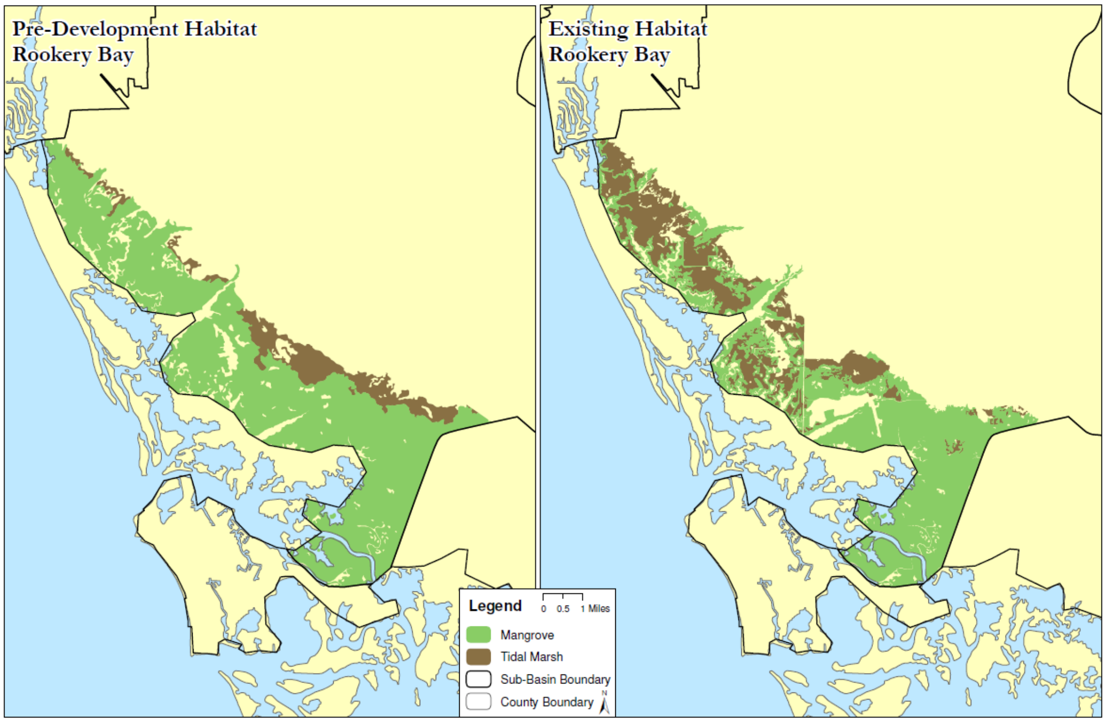


Figure 3-27. Rookery Bay Mangroves and Salt Marshes
(GIS data from SFWMD)

The loss of oyster coverage is mapped in **Figure 3-26** and illustrates past widespread distribution of oysters in 1953, now restricted to scattered locations along the eastern shoreline south of Haldeman Creek. **Figure 3-26** also shows the decrease in natural shoreline vegetation, particularly the mangrove fringe. Schmidt et al. (2006) reported that 70 percent of the fringing mangrove shoreline of Naples Bay has been converted to residential developments. This is consistent with the GIS analysis results listed in **Table 3-28**, in which a 76 percent decline in combined mangrove and tidal marsh acreage was estimated between the pre-development and 2007 time periods (1,549 and 367 acres, respectively) in the Naples Bay estuary.

Table 3-28. Naples Bay Estuarine Community Changes (Acres)

Community	Pre-Development	Current	Acres Lost	Percent Loss
Seagrass (1953 vs. 2005)	51	2	48	95
Oyster (1953 vs. 2005)	68	12	55	82
Tidal Marsh (Pre-Dev vs. 2007)	0	20	1,182	76
Mangrove (Pre-Dev vs. 2007)	1,549	347		

3.4.3.3 Rookery Bay

The Rookery Bay watershed has also been altered by channel creation, and present estuarine salinity regimes are more strongly influenced by canal management than by tides or rainfall

(Shirley et al 2004). Resulting alterations to freshwater inflows have been identified as the most important threat to the natural biodiversity of this area (Shirley et al., 2004).

Based on the rates of vertical accretion in the mangrove communities in Rookery Bay, mangrove forest elevations have kept pace with sea level rise over approximately the past 70 years (Cahoon and Lynch 1997). This finding supports the importance of mangroves as a means of stabilizing shorelines and preventing erosion in coastal regions. **Figure 3-27** illustrates the transition of the mangrove community into salt marsh in some locations, a finding at odds with the pattern described by Popowski (2006). This transition could be the result of natural cycles of succession, or the "transition" could be a mapping artifact associated with delineating the boundaries of tidal marshes in the pre-development vegetation data layers (i.e. Duever 2004).

Overall, Rookery Bay has had a decrease in acres of mangrove and salt marsh habitat of within its estuary boundaries, from 17,866 acres in pre-development times to 15,697 in 2007, a decline of 12 percent (**Table 3-29**).

Table 3-29. Rookery Bay Estuarine Community Changes (Acres)

Community	Pre-Development	Current	Acres Lost	Percent Loss
Tidal Marsh (Pre-Dev vs. 2007)	2,131	5,122	2,170	12
Mangrove (Pre-Dev vs. 2007)	15,735	10,575		

3.4.3.4 Ten Thousand Islands

The spatial and temporal variation in salinities in the Ten Thousand Island estuary has been significantly and adversely affected by upstream water management practices (Browder et al. 1988, Shirley et al. 1997, Shirley et al. 2005, Popowski 2006). Two major examples of large-scale hydrologic alteration are the Tamiami Trail Canal, which intercepts inflows from the north and passes them through a fixed number of bridges and box culverts underneath Tamiami Trail (Popowski, 2006) and the Golden Gate Estates canal system, which discharges more than 10 times the volume of freshwater into Naples Bay during the wet season than prior to construction of the canal network (Section 3.1).

The TTI estuary consists of mangrove islands, oyster beds, and shallow lagoons (Wanless et al 1994). As depicted in **Figure 3-28**, the TTI mangrove system appears to have been slightly reduced in areal extent, but has also undergone an apparent transition into tidal marsh habitat when comparing the PDVM data to 2007 data. This finding is in contrast to the pattern of an increase in mangrove coverage, at the expense of tidal marsh, cited by Popowski (2006). As described previously, a shift from mangrove to salt marsh, or vice versa, could be due to natural succession, or it could be an artifact associated with the difficulty of accurately locating GIS based features in the pre-development vegetation data layer used for this analysis.

As with the other estuaries examined, the status and trends of the areal extent (acres) of salt marsh and mangroves (combined) was examined. These data (**Table 3-30**) indicate a decrease in combined salt marsh and mangrove extent from 40,405 acres in pre-development times to 38,490 acres in 2007, a decline of 5 percent (**Table 3-30**). North of Tamiami Trail, a more substantial loss in mangrove and salt marsh extent was identified — a 13 percent reduction from pre-development to current conditions.

Table 3-30. Ten Thousand Islands Estuarine Community Changes (Acres)

Community	Pre-Development	Current	Acres Lost	Percent Loss
Tidal Marsh (Pre-Dev vs. 2007)	2,711	7,737	1,916	5
Mangrove (Pre-Dev vs. 2007)	37,694	30,753		

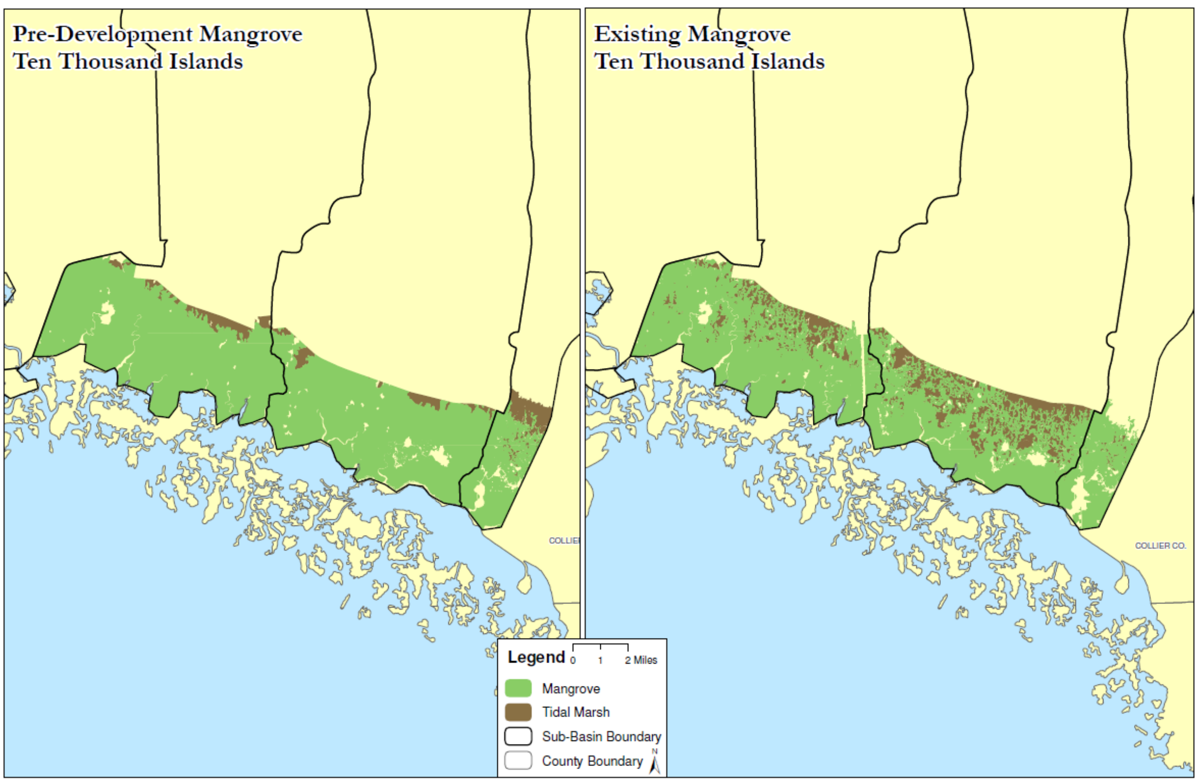


Figure 3-28. Ten Thousand Islands Mangroves and Tidal Marshes
(GIS data from SFWMD)

3.4.4 Conclusions

The extent of coastal habitats along the Collier County's coast line increases from north to south, commensurate with the decrease in coastal development. In Wiggins Pass, the most northern estuary, acres of salt marsh and mangroves have declined by 29 percent when compared with pre-development conditions. To the south, in Naples Bay, the extent of salt marsh and mangroves has declined by approximately 76 percent. In contrast, salt marshes and mangroves in the less developed estuaries of Rookery Bay declined by 12 and 5 percent, respectively, from pre-development to current conditions. Less development along the coastal reaches of the Rookery Bay estuary reflects the protection of this area through various land acquisition activities (e.g., the 110,000 acre Rookery Bay National Estuarine Research Reserve).

Documenting changes over time in the extent of oyster reefs and seagrass beds is more difficult due to the limited availability of data. The coastal waters of Collier County are mostly unique for the absence of any seagrass bed delineations and/or quantification compared with other coastal Florida waters (Handley et al. 2007). These data were available only for Wiggins Pass and Naples Bay, and historical data were available only found for Naples Bay. In Naples Bay, the areal extent of oyster reefs has declined by 82 percent from the 1950s, with seagrass coverage down by 95 percent. In Wiggins Pass, oysters and seagrass meadows are not wide-spread features of these estuaries, yet it is not known if their declines over time have been as substantial as that found in Naples Bay. Using side-scan sonar, Locker (2005) found substantial meadows of seagrass, mostly *Halophila decipiens*, in Fakahatchee Bay, but little evidence of anything other than small isolated patches of seagrass within Faka Union Bay. Locker (2005) also recorded "…anthropogenic mud layer blankets much of the bay due to flushing of organic-rich fines from the Faka Union Canal due to high-velocity freshwater inflows."

Based on this information, estuarine habitats in Collier County coastal areas have been impacted by alterations in the timing and quantity of freshwater inflows as well as direct physical impacts of increased development and shoreline disturbance/loss in the more urbanized estuaries (e.g., Wiggins Pass and Naples Bay. For Wiggins Pass and Naples Bay, re-creating more natural freshwater inflows may not be sufficient for restoring historical estuarine functions (i.e. habitats), since oyster reefs and seagrass meadows have been displaced by coastal development. In contrast, much of the historical extent of tidal marshes and mangroves remains intact in Rookery Bay and the TTI. Therefore, restoration of historical freshwater inflows for the less-developed Rookery Bay and TTI estuaries may provide a more effective management action to address the loss of coastal habitats in Collier County.

4.0 DEVELOPMENT OF PERFORMANCE MEASURES

Performance measures were developed for freshwater discharge to estuaries, pollutant loads, aquifer recharge, and natural systems using the same approach of comparing pre-development with existing conditions to establish a performance score against which to evaluate the success of proposed projects.

Performance measures are tools based on a set of indicators used in project planning to predict (or evaluate) the degree to which proposed alternative plans are likely to meet restoration objectives and to assess the success of implemented plans in meeting restoration objectives (CERP 2006). Most performance measures for the Everglades restoration projects were developed through conceptual models that identified key stressors and attributes of the natural system. Attributes are biological and resource protective indicators in the natural system that respond to effects of stressors. Performance measures for other water-related needs of the system, such as water supply and flood control to meet urban and agricultural needs, are derived from state and federal laws.

The intent of the performance measures developed for the CCWMP was to maintain consistency with this concept, as developed by the CERP program. Therefore, performance measures for freshwater discharge to the estuaries, aquifer recharge/yield, and natural systems were developed based on the concepts outlined below.

- The performance measure must address indicators that represent attributes or stressors of natural or human systems that (the proposed project or management action) is expected to affect
- The performance targets, e.g. improved water quality, must reflect the desired restoration condition, which is the maximum level of restoration possible given the existing development conditions
- The performance measure must provide an understanding of system-wide responses relative to how project implementation will meet improvement and/or restoration goals, while not being so unwieldy and costly that system-wide modeling and monitoring programs cannot be sustained over many years

The approach to developing the performance measures was based on “restoring” the system as close as possible to the original condition, within the constraints of existing development, and given the constraints of funding.

The maximum level of restoration, then, would be pre-development conditions. The NSM was used to provide the pre-development, or baseline condition. The County’s ECM was used to characterize existing conditions. The difference between the two gives the total restoration possible, without restraints of existing development and cost and provides a means of evaluating the improvement, or “lift” anticipated as a result of implementing a project.

Performance measures for each of the components examined, i.e. freshwater discharge, aquifer recharge, pollutant load, and natural systems, were developed using this approach. Development of individual performance measures are presented in the following sections.

4.1 NATURAL SYSTEMS WATER BUDGETS AND SEASONAL WATER LEVELS

Functional assessment scores, or performance measures, were calculated for the watersheds in Collier County. Average scores are lower for the Golden Gate-Naples Bay watershed due to extensive canals systems and development and suggest that hydrologic restoration may provide the greatest opportunity for measurable improvement in functional value in the County.

4.1.1 Introduction

The performance measure development the natural systems component of the CCWMP was accomplished as part of the *Functional Assessment*. Under this task, pre-development and current conditions were compared and losses and conversions of native plant communities in Collier County watersheds over the past 50–60 years were estimated via a change analysis of land use cover data. The 1942 Collier County soils map provided additional data to characterize pre-development characteristics in the watersheds. The vegetation and soils data are reported and analyzed for the first three watersheds individually and the other three watersheds collectively.

4.1.2 Methods

Results of an analysis of changes in areal extent of natural communities and the causes of those changes are reported here and used to evaluate current watershed functions for Element 1 Task 3.2 (Functional Assessment). The pre-development data serve as the reference period, or baseline index against which to evaluate current vegetation data in determining resource protective function. Performance measures were established prior to the development of proposed project alternatives and will be used to:

- Evaluate how well proposed alternatives meet specific project objectives.
- Examine the applicability and feasibility of specific alternative analyses.
- Address the issues identified in the assessment of existing conditions, including surface water, ground water, and natural systems.

Similar to performance measures developed for freshwater discharges and groundwater, performance scores were calculated that provide a baseline conditions against which the success of proposed projects can be measured.

Vegetation scores represent the resource protective function, or value, of the landscape based on the degree to which the pre-development vegetation persists under existing conditions. The difference in scores between pre-development and existing provides the baseline against which to evaluate the result of a project, such as removing a control structure or filling a canal. If the anticipated improvement, or "lift" score from the proposed project is greater than the performance score, one can conclude that the project will have a net benefit on the system. Hydrology and landscape (LSI) scores are developed similarly.

Dramatic conversions from pre-development wet prairie vegetation to a developed urban land use, for example, would be assigned low scores, while little or no change in vegetation cover (i.e. no change from pre-development, or shift to another natural vegetation classification) would be scored higher.

4.1.3 Results

Performance measures developed for this CCWMP are simply the hydrology and LSI scores developed for the functional assessment. The LSI and hydrology scores were developed as a means of characterizing existing baseline data (in numerical form) for natural conditions and, therefore, provide the conditions against which proposed projects can be measured. The vegetation score is not as applicable for evaluating the results of hydrological restoration projects because proposed projects will not focus on active vegetation management (although shifts in vegetation are expected to occur over time, commensurate with changes in hydrology).

The performance measures developed, i.e. the LSI and hydrology scores (refer to Element 1, Task 3 for further detail on development of scores), are suitable for small-scale site-level assessments (i.e., for projects that have little or no affect on the score of a 1500 X 1500 foot cell) or as modeled performance measures for larger-scale projects. The functional value of proposed projects will be assessed using the UMAM functional value calculation below.

Functional Value = [(Anticipated Score – Existing Score)/Maximum Score] X Number of Acres,

where:

Performance Measure = Functional Value
Anticipated Score = anticipated hydrology index or LSI
Existing Score = Hydrology score OR LSI based on existing conditions
Maximum Score = 10
Number of Acres = Acres of site being evaluated

As an example, consider a 500-acre proposed project area with a current hydrology score of 6. Rehydration of the site by filling a drainage ditch to the elevation of the surrounding area is reasonably expected to increase the hydrology score to 8. The hydrologic functional value of this proposed project would be 100 ((8-6)/10) X 500 acres). Likewise, LSI functional values would improve within, and adjacent to, projects that include restoration to more-natural conditions, conservation easements, transfers of development rights, or other similar means of improving the degree of resource protective support to adjacent areas.

4.1.4 Conclusions

Functional assessment scores, or performance measures, are presented in Table 4.1 for the watersheds in Collier County. Average scores are lower in the Golden Gate-Naples Bay watershed due to extensive canals systems and development and indicate that hydrologic restoration may provide the greatest opportunity for measurable improvement in functional value in Collier County.

Table 4-1. Functional Assessment Score for Watersheds in Collier County

Average Functional Values of Non-Urban Lands, by Watershed				
Watershed	**Non-Urban Acres**	**Average Vegetation Score**	**Average Hydrology Score**	**Average LSI Score**
Cocohatchee-Corkscrew	111,250	7	7	8
Golden Gate-Naples	36,627	5	6	6
Rookery Bay	83,105	8	6	9
Faka Union/ Okaloacoochee SR29/ Fakahatchee	431,414	9	6	9

4.2 FRESHWATER DISCHARGE TO ESTUARIES

4.2.1 Development of Performance Measures

This section summarizes the method that was used to assign a Discharge to Estuary score for each watershed based on a comparison to the pre-development condition. As indicated previously, the scoring method is defined as the Performance Measure and is used to assign a score to the characteristics of the system under existing conditions. It will also be used to benefits of alternative improvement projects that are being proposed for each watershed.

4.2.1.1 Scoring Methods

Scoring is based by comparing the timing and volume of discharge from the NSM developed by for the Southwest Florida Feasibility Study (SDI, 2007) to the ECM and each alternative scenario. As described previously, average monthly discharge volumes from the NSM and ECM models were used to define the baseline distribution and total volume of flow from each watershed. The alternative scenarios will be scored in the same fashion as the ECM.

The scoring process consisted of the following steps.

1. The monthly discharge from each watershed from the NSM model is considered the baseline condition. The NSM volume of flow for each month is assigned a score of 10.
2. Each monthly discharge from the ECM is assigned a score from one (1) to 10. The monthly score is calculated by dividing the NSM volume by the ECM volume and multiplying by 10.
3. In the event that the NSM volume is larger than the ECM volume, the monthly score is calculated by dividing the ECM volume by the NSM volume and multiplying by 10.
4. The average of the monthly scores determines the watershed score relative to the NSM.

4.2.1.2 Example

The following example illustrates the scoring process. It was applied to the Golden Gate-Naples Bay Watershed using data extracted from the ECM. The data is shown in **Table 4-2**.

Step 1. Calculate the absolute difference between the ECM volume and the NSM volume. The result of this calculation is shown in Column 4.

Step 2 Calculate the score for each month. For the month of January, the score would equal to two (2) based on the following equation:

Calculated Score = (NSM volume/ECM volume) x 10)

The calculated score is rounded to the nearest whole number.

Step 3 Average the monthly scores to determine the watershed score for the annual and seasonal conditions relative to the NSM.

Table 4-2
Golden Gate-Naples Bay Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.12	0.76	0.64	2
February	0.12	0.53	0.41	2
March	0.13	0.44	0.31	3
April	0.06	0.15	0.09	4
May	0.02	0.14	0.12	1
June	0.13	2.38	2.25	1
July	0.27	3.80	3.54	1
August	0.50	6.22	5.72	1
September	0.78	6.97	6.19	1
October	0.55	4.43	3.88	1
November	0.30	2.49	2.19	1
December	0.20	1.33	1.13	1
			Annual Score	1.6
			Dry Season Score:	1.9
			Wet Season Score:	1.0

4.2.1.3 Existing Conditions Scores for the Watersheds

Tables 4-3 through 4-5 provide the scoring matrices showing the score for each of the other watersheds. Of the four watersheds, the Golden Gate-Naples Bay Watershed received the lowest annual score of 1.6. The score is indicative of the year round flow surplus discharging into Naples Bay.

The scores for the Rookery Bay watershed indicate that the primary impairment occurs during the dry season due to freshwater deficits. This is likely due to the reduced size of the watershed caused by construction of the Golden Gate Main Canal. The model results indicate that the observed wet season surplus is due to stormwater runoff from the Lely area and from the agricultural lands in the southeast portion of the watershed.

In the Cocohatchee-Corkscrew, and Eastern (Faka Union, Fakahatchee, and Okaloacoochee-SR 29) watersheds, the scoring results indicate that the operational controls that are used to manage dry season flows are reasonably effective at matching pre-development flow conditions. This contributes to the higher monthly scores observed during the dry season. However, the wet season scores are low for all watersheds. This provides an indication of the effect of development on the natural drainage system.

Table 4-3
Cocohatchee–Corkscrew Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.06	0.08	0.02	8
February	0.06	0.06	0.00	10
March	0.06	0.06	0.00	10
April	0.03	0.03	0.00	10
May	0.01	0.03	0.02	3
June	0.03	0.29	0.26	1
July	0.10	0.44	0.35	2
August	0.14	0.90	0.76	2
September	0.24	1.02	0.77	2
October	0.21	0.51	0.31	4
November	0.11	0.19	0.08	6
December	0.09	0.12	0.03	7
			Annual Score	5.4
			Dry Season Score:	6.9
			Wet Season Score:	2.5

Table 4-4
Rookery Bay Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.22	0.08	-0.14	4
February	0.18	0.08	-0.10	4
March	0.22	0.05	-0.16	2
April	0.09	0.02	-0.08	2
May	0.01	0.00	-0.01	2
June	0.15	0.41	0.26	4
July	0.37	0.67	0.30	5
August	0.84	1.13	0.28	7
September	1.40	1.84	0.45	8
October	1.12	0.76	-0.36	7
November	0.56	0.23	-0.33	4
December	0.36	0.12	-0.24	3
			Annual Score	4.3
			Dry Season Score:	3.1
			Wet Season Score:	6.8

Table 4-5
Faka Union, Fakahatchee, and Okaloacoochee–SR 29 Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.40	0.43	0.02	9
February	0.31	0.33	0.02	9
March	0.29	0.29	0.00	10
April	0.19	0.14	-0.05	7
May	0.12	0.12	0.00	10
June	0.16	0.91	0.75	2
July	0.32	1.90	1.59	2
August	0.48	3.20	2.72	1
September	0.67	3.85	3.18	2
October	0.71	2.22	1.51	3
November	0.56	1.21	0.65	5
December	0.50	0.69	0.20	7
			Annual Score	5.6
			Dry Season Score:	7.4
			Wet Season Score:	2.0

In order to evaluate the alternative scenarios, a similar scoring method will be used. The calculated monthly flows for each scenario will be compared to the NSM calculated monthly flows.

For instance, for a project implemented in the Golden Gate-Naples Bay watershed that leads to a reduction in flow to the estuary, the calculated monthly flow for September might be 5.0 inches. In the ECM, the score for September is one (1), but for the alterative, the score would be two (2):

$$(0.78/5.0) \times 10 = 2$$

where:

0.78 = the NSM monthly flow for September, and
5.0 = the Alternative monthly flow for September

4.3 POLLUTANT LOAD

The methods described in this memorandum, will also be used as performance measures to evaluate proposed watershed improvement projects. Anthropogenic pollution load reductions will be used to evaluate potential benefits. An important criterion for assessing project feasibility will be the estimated cost per pound of pollution load removed.

4.3.1 Surface Water Pollution Loads Performance Measures

The magnitude of the estimated pollutant loads by cell becomes meaningful when compared to a data normalization factor. For this analysis, it was determined that the gross load from a medium density residential development not including treatment facilities was an appropriate normalization factor because it provides an easily understandable means of comparing the magnitude of the pollutant load from different model cells and watersheds. That normalization factor was developed by averaging the annual runoff from all cells having a predominant medium density residential land use, which was determined to be 8.3 inches, and multiplying it by the corresponding EMC associated with a chemical parameter. Subsequently the ratios of total load from a cell to the normalization factor were scored as shown in **Table 4-6**. The scoring system is consistent with the scoring used for the other analyses conducted as part of the overall study. A score of 10 indicates no anthropogenic pollution, whereas a score of 1 or less indicates areas (urban or agriculture) that exhibit pollutant loads equal to or larger than those from a typical residential development with no stormwater runoff treatment.

Table 4-6
Pollutant Load Scores and Ratios

Score	Ratio of Net Load to Normalization Factor Load
10	< 10% of Normalization Factor
9	10% < Normalization Factor < 20%
8	20% < Normalization Factor < 30%
7	30% < Normalization Factor < 40%
6	40% < Normalization Factor < 50%
5	50% < Normalization Factor < 60%
4	60% < Normalization Factor < 70%
3	70% < Normalization Factor < 80%
2	80% < Normalization Factor < 90%
1 or less	> 90% of Normalization Factor

Figures 4-1 through 4-7 show the distribution of pollution load scores in the study area. As shown the areas of low TSS scores are in the older urban developments located along the coast as TSS result from the resuspension of sediment accumulated on roads and drainage facilities. In terms of nutrient pollution, areas of interest are older developments, golf courses, and agriculture. The nutrient source is likely the excessive use of fertilizers. It must be noted that the largest EMC value used in the SWFFS analysis is for agricultural land uses. Further wet weather sampling is necessary to better define areas of agricultural nutrient concern.

Areas of concern for BOD-5 primarily those of low and medium density residential land uses that do not incorporate treatment facilities. In terms of heavy metals, lead tends to accumulate in soils and sediment and has remained in the environment because of its former use as an additive in gasoline and paints. Primary sources of copper in urban runoff have been determined to be vehicle brake pads and the use of copper-containing herbicides and chemicals for algae control. Zinc commonly occurs due to its industrial uses as a rust preventative in iron-containing metals. These metals are also associated with urban land uses with no stormwater treatment.

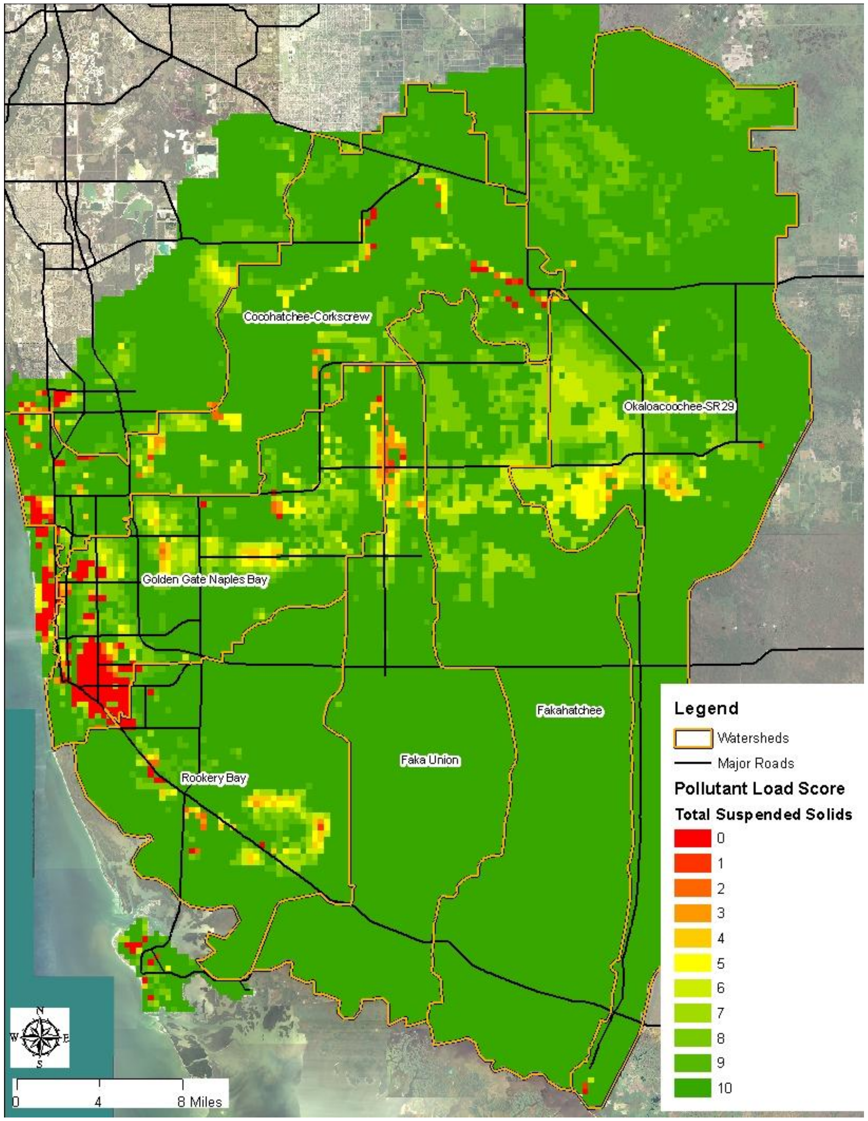


Figure 4-1. TSS Pollution Load Scores

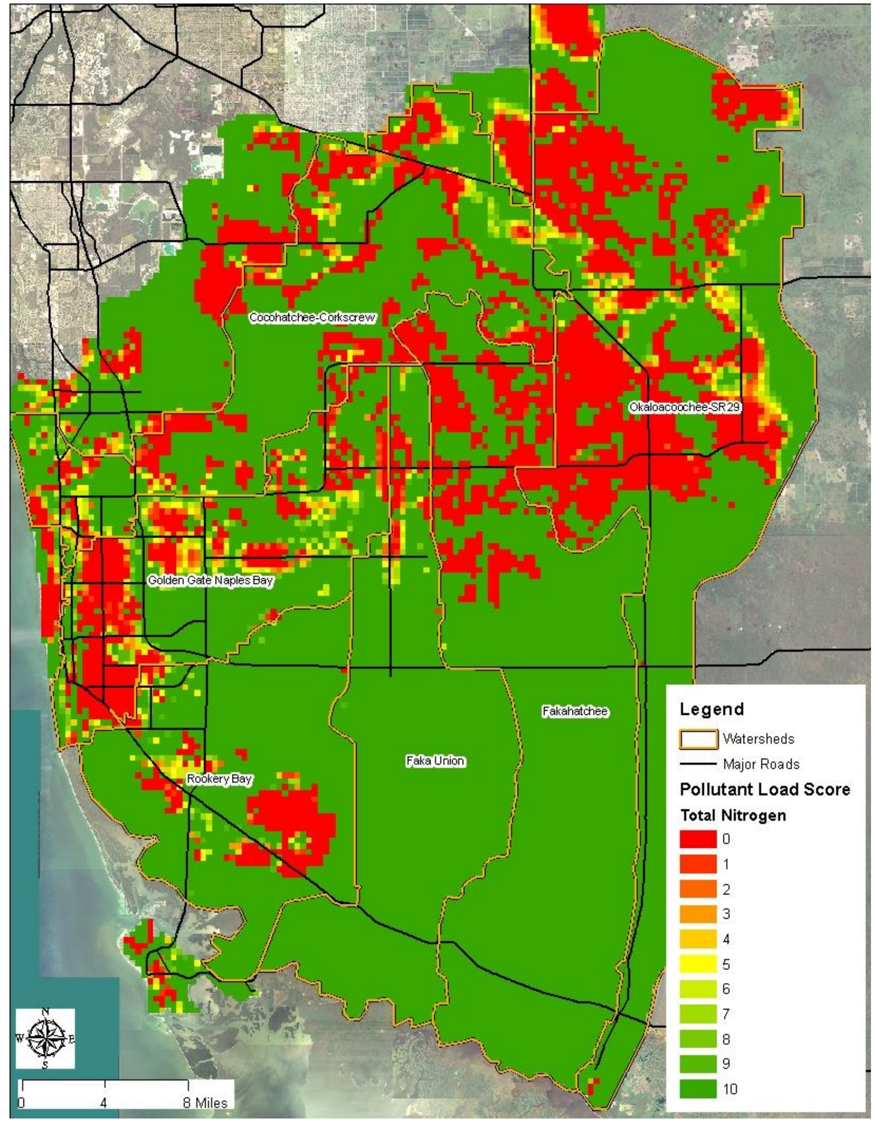


Figure 4-2. Total Nitrogen Pollution Load Scores

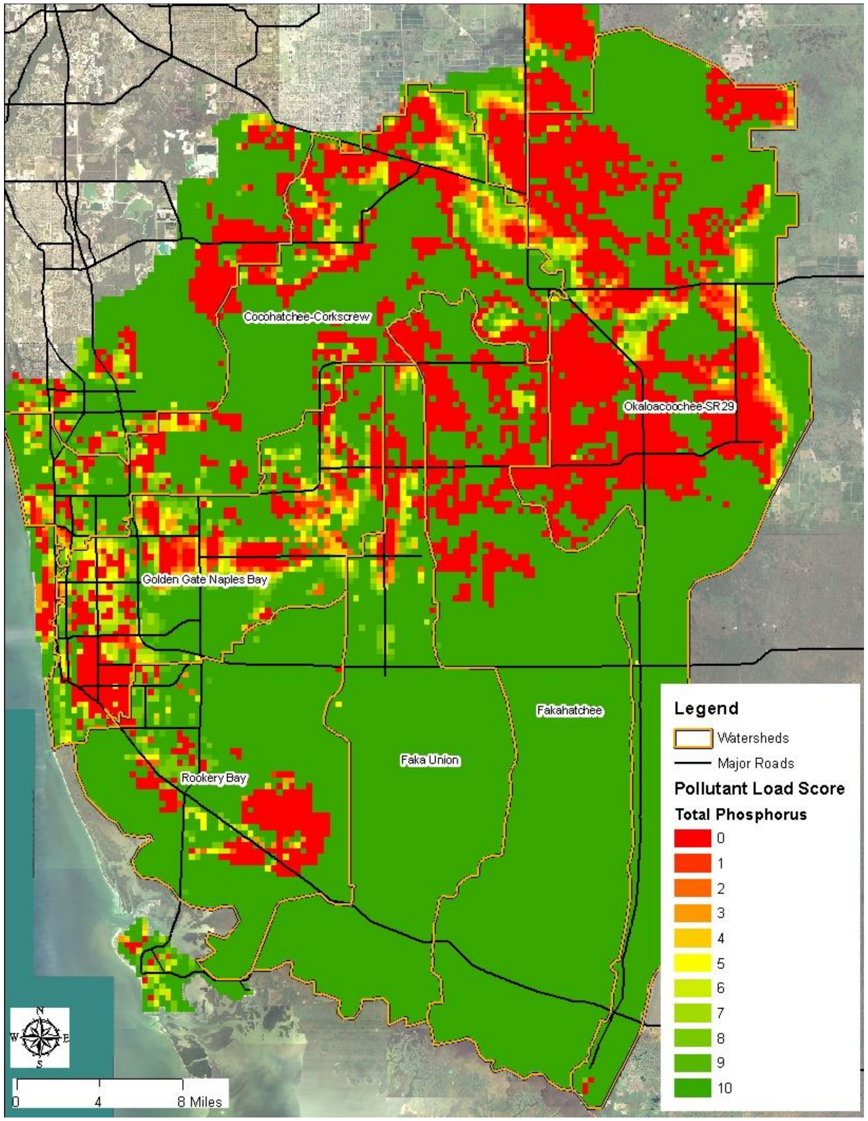


Figure 4-3. Total Phosphorus Pollution Load Scores

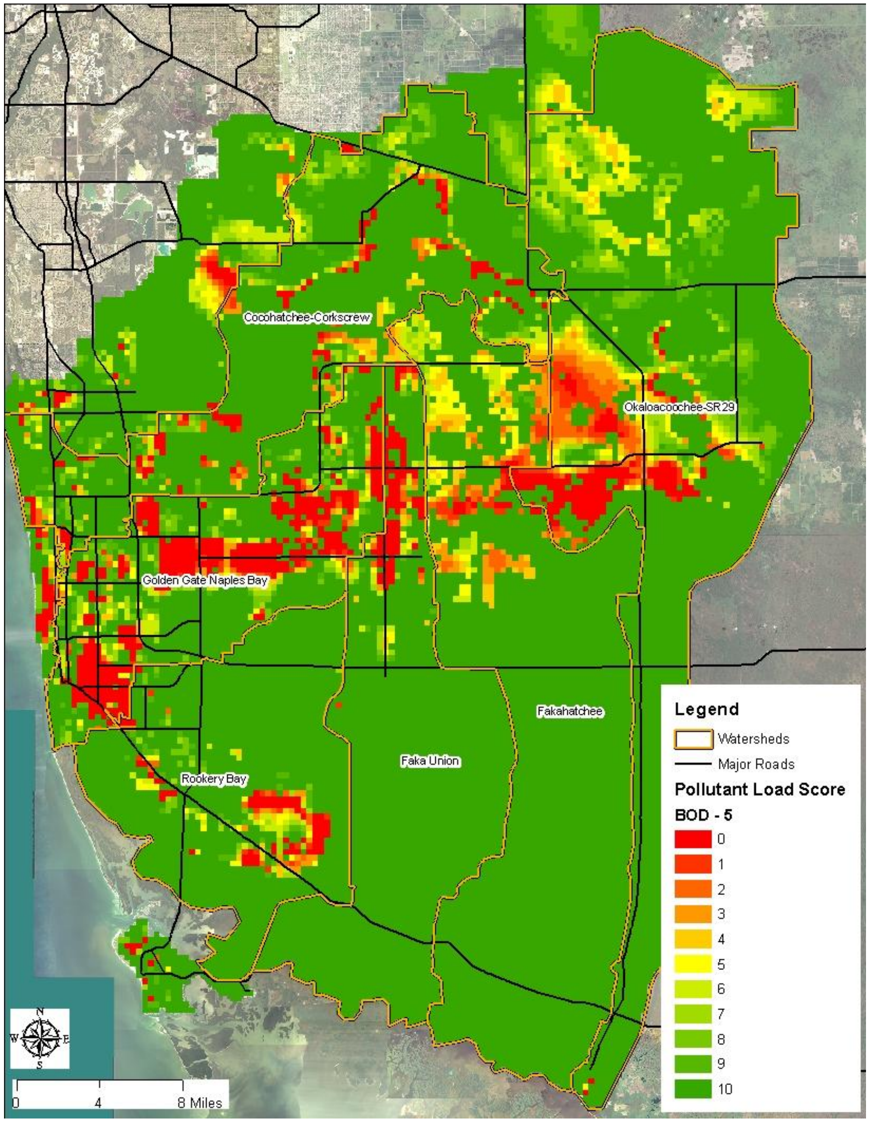


Figure 4-4. BOD-5 Pollution Load Scores

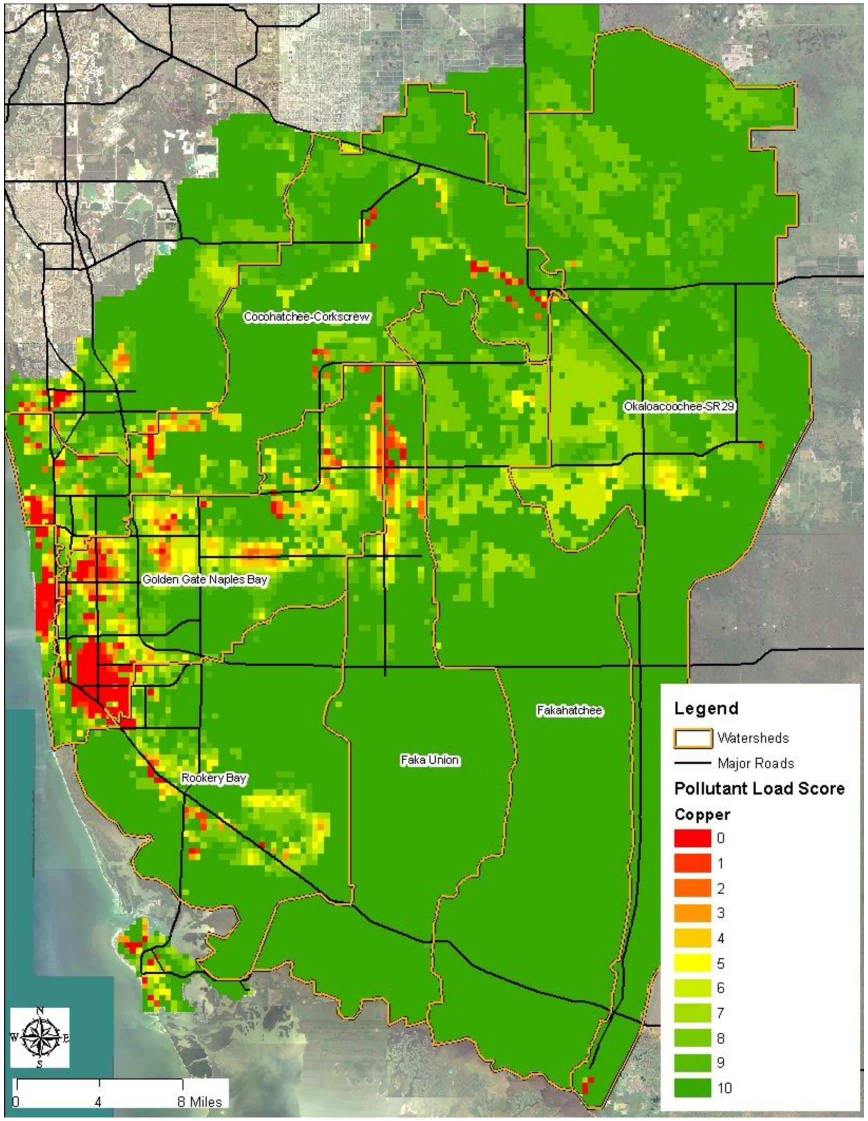


Figure 4-5. Copper (Cu) Pollution Load Scores

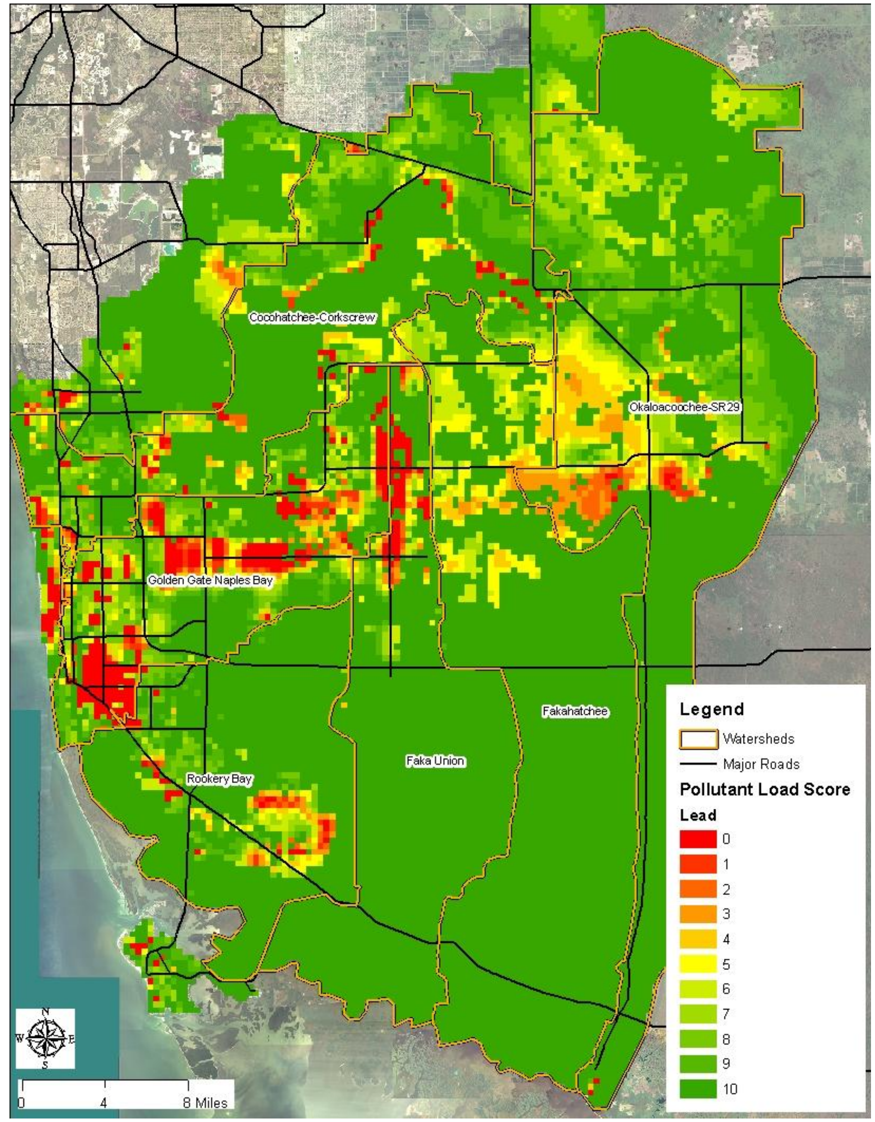


Figure 4-6. Lead (Pb) Pollution Load Scores

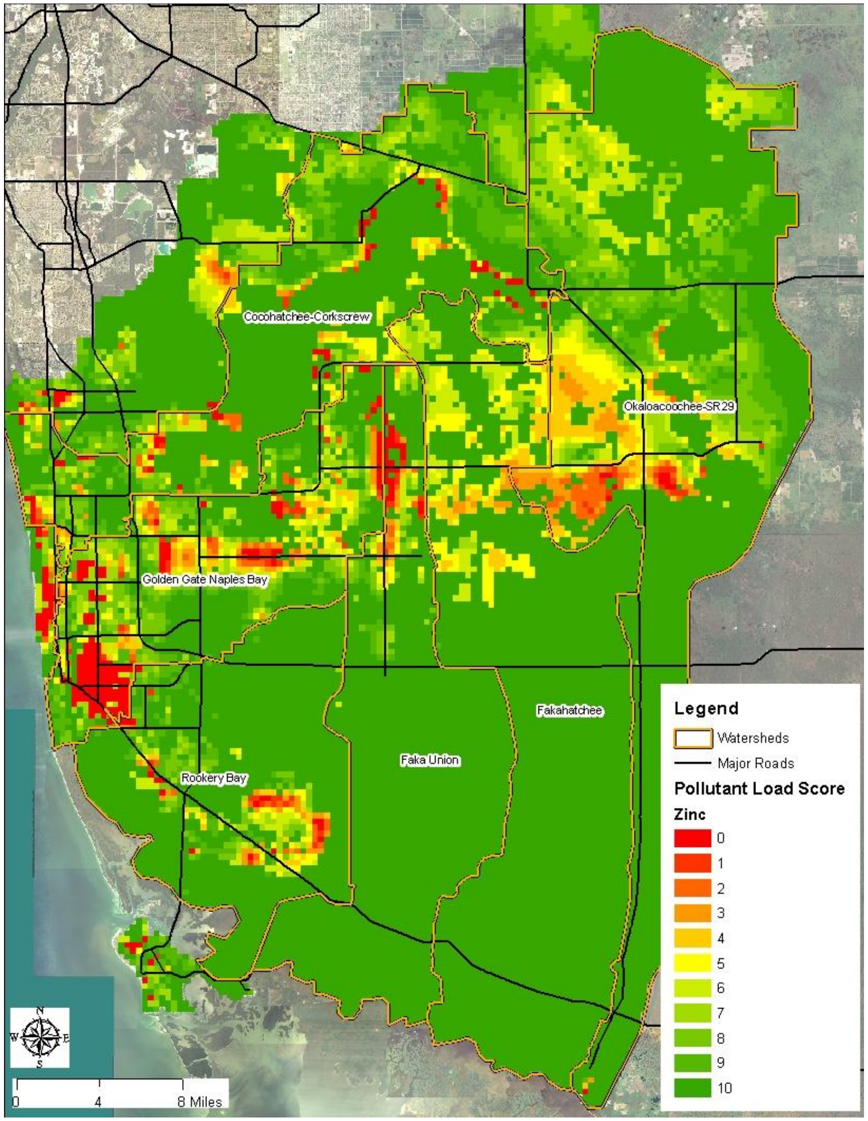


Figure 4-7. Zinc (Zn) Pollution Load Scores

4.4 AQUIFER RECHARGE/YIELD

The continued use of groundwater resources in Collier County has resulted in groundwater levels that fluctuate seasonally in response to the demand for withdrawals. During the wet season, sufficient rainfall and recharge typically result in higher aquifer storage and hydraulic heads. However, during the dry season, limited rainfall leads to additional groundwater pumping to meet seasonal population needs and increased demand for irrigation purposes.

In order to assess the relative yield or quantity of available water within each aquifer, the ECM-predicted hydraulic heads were compared to those obtained from the Natural Systems Model (NSM) that was developed for the SWFFS. The NSM was an approximation of the predevelopment hydrologic and hydrogeologic conditions of the region. The NSM did not include the Mid-Hawthorn Aquifer and so comparisons were completed for the Water Table, Lower Tamiami, and Sandstone aquifers.

The SFWMD has defined the Minimum Aquifer Level (MAL) for confined aquifers to be the structural top of each aquifer. The lower limit of the performance measure was therefore designated as the physical top of the aquifer unit. The upper limit of the Water Table Aquifer is defined by the simulated NSM results. For the water table, the lower limit was defined as the bottom of the aquifer.

A performance measure score (0 to 10) was calculated for the top three aquifers and each cell in the model grid. The NSM does not include the Mid-Hawthorn Aquifer so no performance score was been calculated for the Mid-Hawthorn. The score was defined as follows:

$$\text{Score} = ((\text{ECM Head Elevation} - \text{Structural Top of Aquifer}) / (\text{NSM Head Elevation} - \text{Structural Top of Aquifer})) \times 10$$

Figure 4-8 illustrates a theoretical aquifer condition representing performance scores for a confined aquifer system.

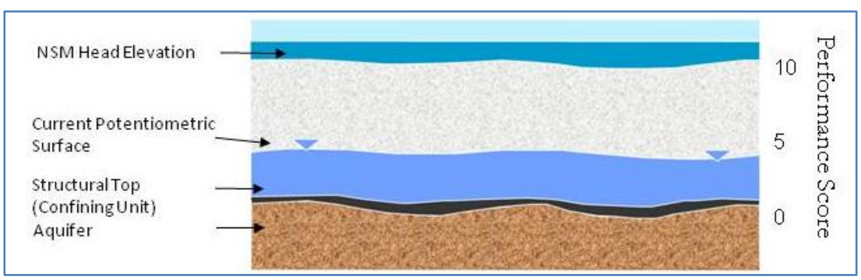


Figure 4-8. Theoretical Condition for Confined Aquifer Performance Score

Figures 4-9 through 4-11 show the difference between the average annual groundwater surface elevation for the NSM and ECM models for the Water Table, Lower Tamiami, and Sandstone aquifer systems. The results show that the most drawdown occurs near municipal wells fields and in areas where there is demand for irrigation or domestic self supply. These figures also indicate that boundary conditions can contribute to significant differences in predicted groundwater elevations. Negative values indicate that the ECM groundwater elevation is lower than the NSM groundwater elevation.

Aquifer performance measure scores were calculated for each aquifer on a cell-by-cell basis within the model area. The scores for each aquifer were then averaged within WBIDs and watersheds. Table 4-7 lists each WBID and the performance score for each aquifer. These scores are based on the average dry season water level for the ECM and the NSM. The relatively high performance scores averaged over WBID and watershed areas do not provide the resolution to evaluate local effects of groundwater drawdown. Figures 4-12 through 4-14 show the distribution of grid level performance scores within each watershed.

Figure 4-12 shows the cell by cell performance score in the Water Table Aquifer. The areas in green indicate high performance or relatively little change in dry season conditions from the NSM. Areas in red indicate locations where water demand to meet agricultural and potable water supply needs results in low performance scores relative to historic groundwater levels. Areas that score poorly tend to correspond to well field locations. This is most apparent in the Rookery Bay and Golden Gate watersheds. Other areas that correspond to well field locations include the area near Immokalee and in the northern portion of the Faka Union watershed. Another area that scores poorly is in the Okaloacoochee watershed and corresponds with agricultural areas with significant irrigation demands. Projects and policies that encourage additional recharge and reduce demand on the shallow aquifer systems would most likely lead to improved scores in these areas.

A final area that scores poorly is in the southern Faka Union watershed. This poor score is likely attributable to the canal network that has effectively drained this historic wetland area. Similar results are observed in portions of the Golden Gate-Naples Bay Watershed. The high level of baseflow in these areas influences the groundwater elevation and contributes to lower water table elevations. Changes in structure operations could have a positive influence on groundwater elevation and availability in the watershed.

The results for the Lower Tamiami Aquifer (Figure 4-13) show that poor scores correspond with similar locations in the Water Table Aquifer. This can be attributed to the significant interaction between the aquifer systems coupled with the high water demand.

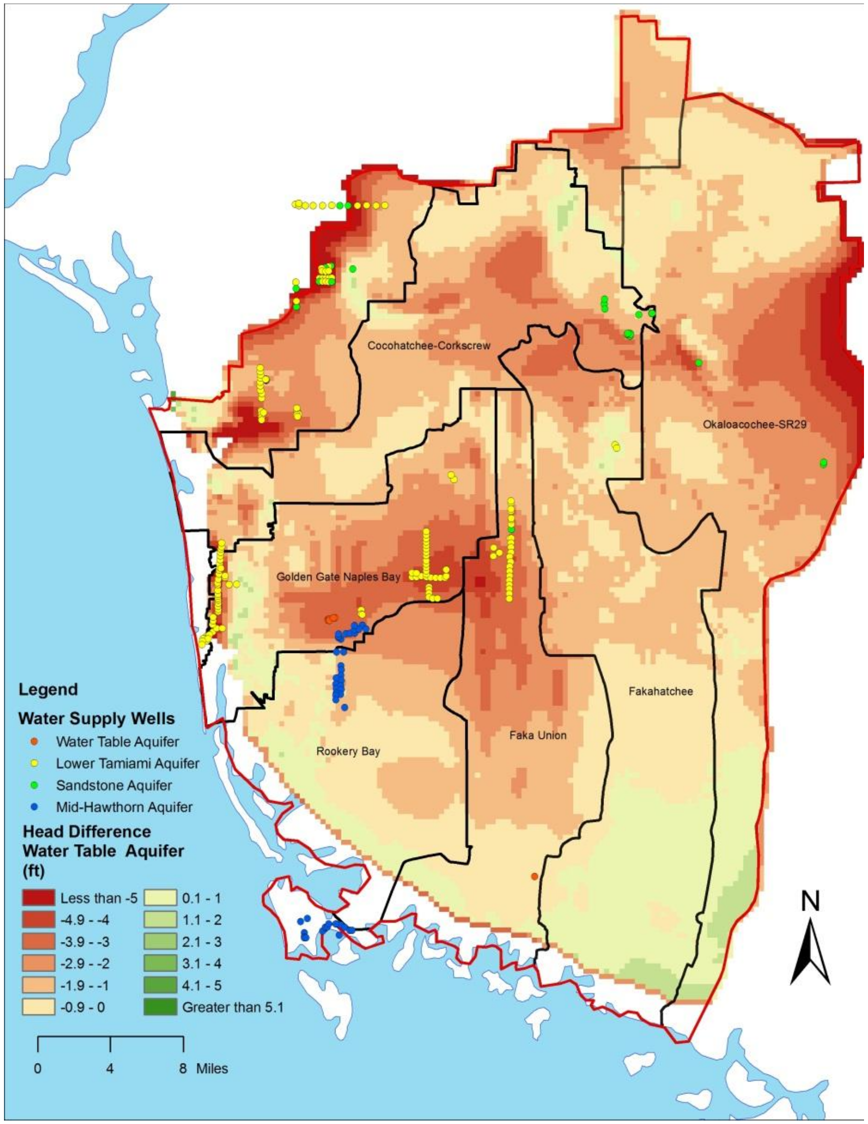


Figure 4-9. Water Table Aquifer, Average Annual Elevation Difference ECM–NSM

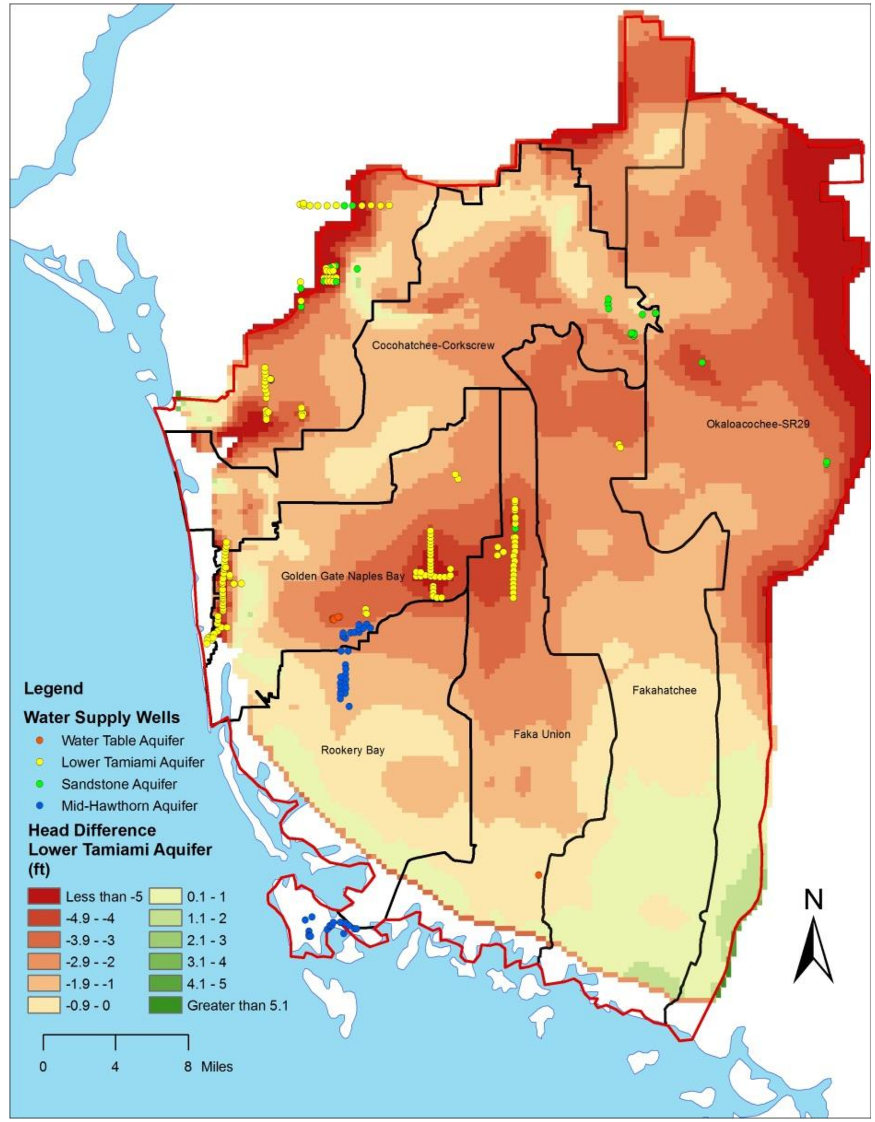


Figure 4-10. Lower Tamiami Aquifer, Average Annual Elevation Difference ECM–NSM

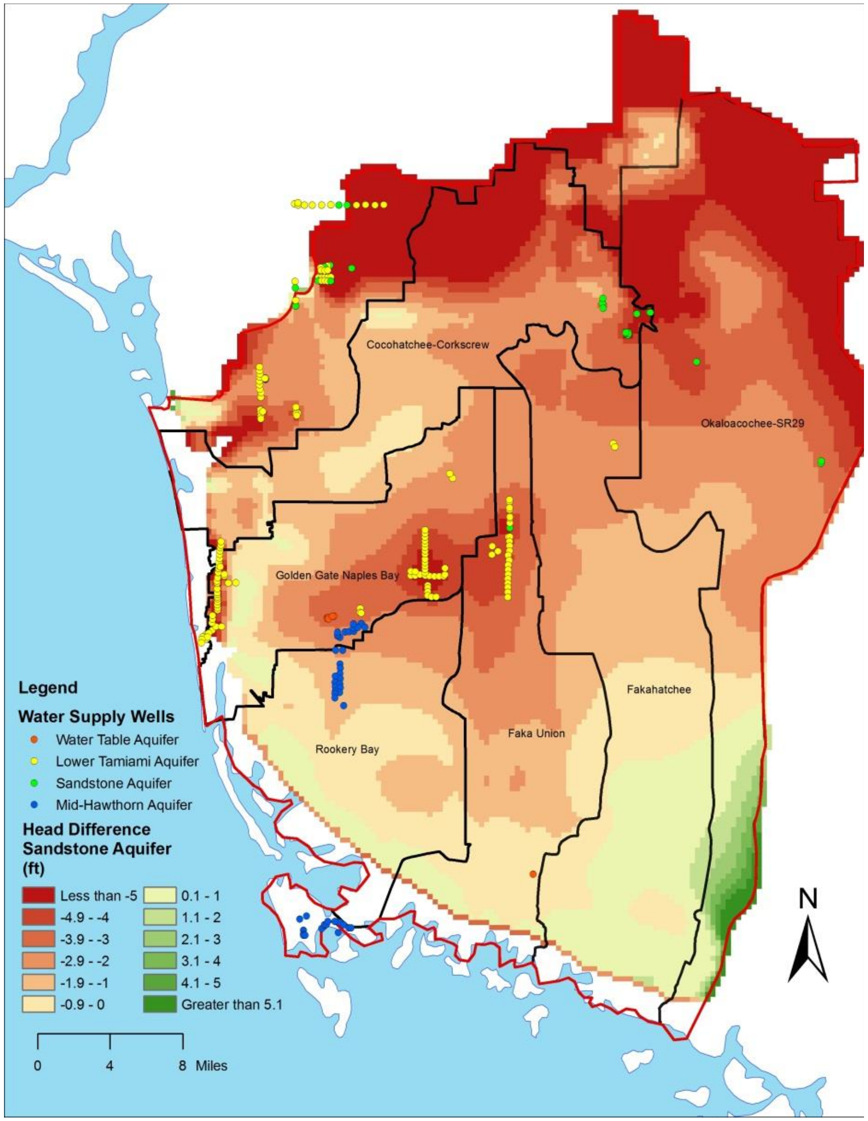


Figure 4-11. Sandstone Aquifer, Average Annual Elevation Difference ECM–NSM

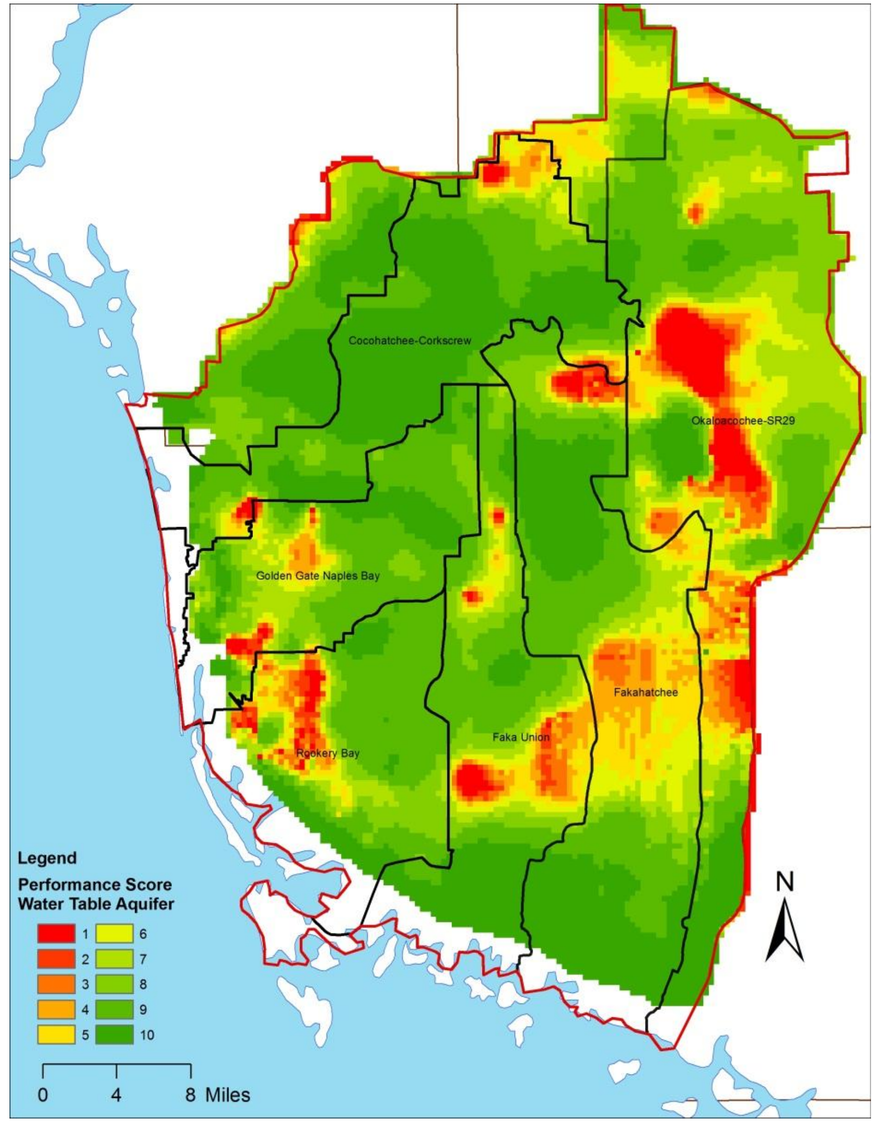


Figure 4-12. Water Table Aquifer, Average Dry Season Performance Score

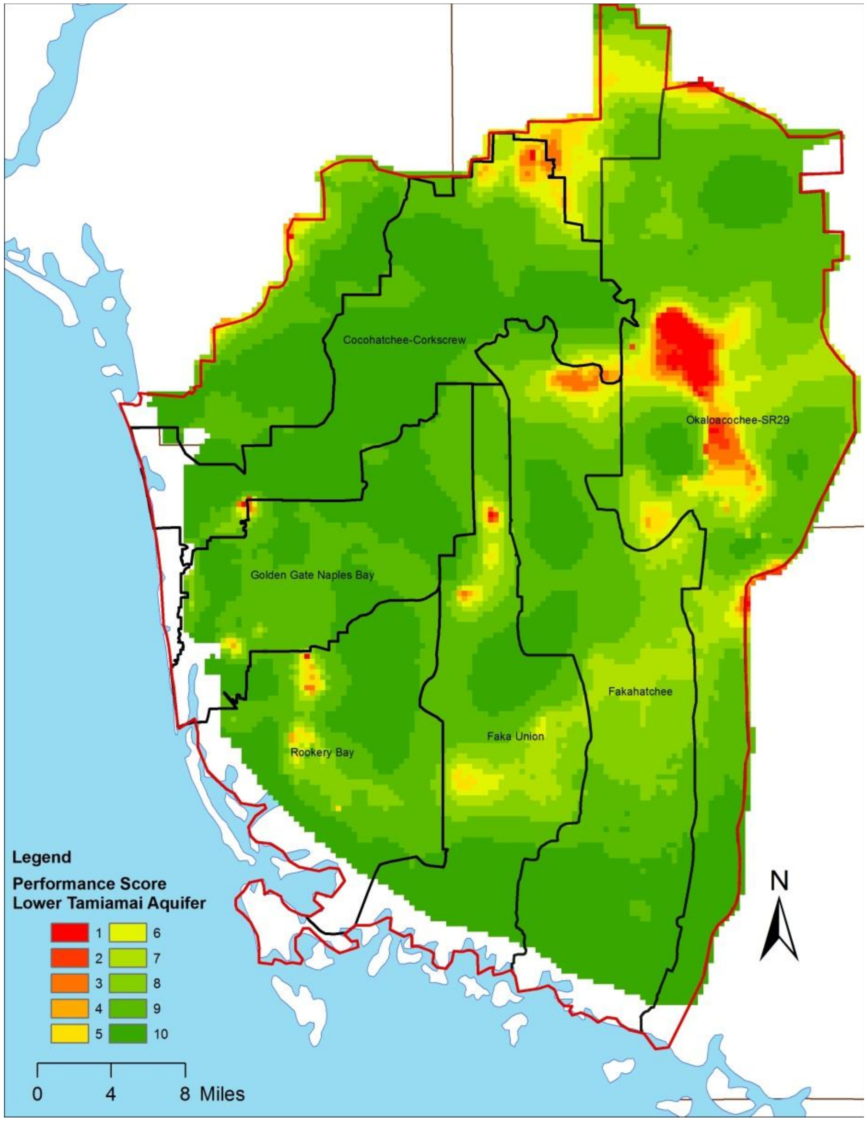


Figure 4-13. Lower Tamiami Aquifer, Average Dry Season Performance Score

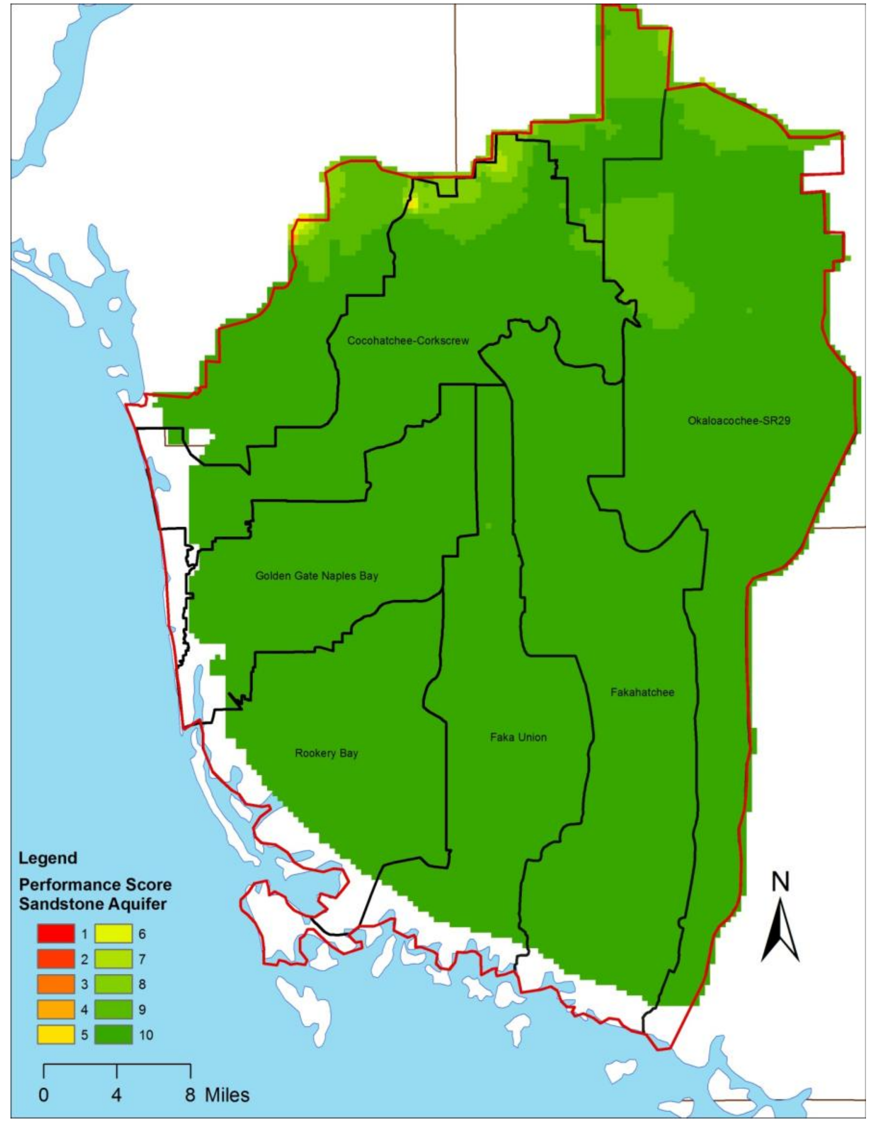


Figure 4-14. Sandstone Aquifer, Average Dry Season Performance Score

Table 4-7. Performance scores for each aquifer by WBID

Watershed	WBID	WBID Name	Water Table Aquifer	Lower Tamiami Aquifer	Sandstone Aquifer
Cocohatchee-Corkscrew	3278D	Cocohatchee (Inland Segment)	9.3	9.6	9.9
	3278C	Cocohatchee Golf Course Discharge	9.1	9.6	9.7
	3278F	Corkscrew Marsh	9.4	9.4	9.6
	3278E	Cow Slough	9.5	9.4	9.5
	3259B	Drainage to Corkscrew	9.5	9.6	9.5
	3278L	Immokalee Basin	9.1	9.2	9.5
	3259W	Lake Trafford	9.4	9.4	9.7
	3259Z	Little Hickory Bay	8.9	9.6	9.7
	Weighted Average		9.4	9.5	9.6
Golden Gate - Naples Bay	3278K	Gordon River Extension	9.3	9.5	9.8
	3278R	Naples Bay (Coastal Segment)	9.6	9.6	10.0
	3278S	North Golden Gate	8.9	9.3	9.8
	Weighted Average		9.0	9.3	9.8
Rookery Bay	3278U	Rookery Bay (Coastal Segment)	9.6	9.8	10.0
	3278V	Rookery Bay (Inland East Segment)	9.0	9.2	9.9
	3278Y	Rookery Bay (Inland West Segment)	7.2	9.1	9.9
	Weighted Average		8.7	9.3	9.9
Faka Union	3278H	Faka Union (North Segment)	8.5	8.8	9.7
	3278I	Faka Union (South Segment)	8.4	8.9	9.8
	Weighted Average		8.5	8.9	9.8
Fakahatchee	3259I	Camp Keais	9.3	9.2	9.8
	3278G	Fakahatchee Strand	8.7	9.0	9.9
	Weighted Average		8.9	9.1	9.8
Okaloacochee-SR29	3261C	Barron River Canal	8.4	8.8	10.0
	3278T	Okaloacoochee Slough	8.5	8.9	9.3
	3278W	Silver Strand	8.4	8.6	9.5
	Weighted Average		8.4	8.8	9.5

Areas in red along the model boundaries in both the Water Table and Lower Tamiami Aquifers are likely not real and caused by the differences in defined boundary conditions between the ECM and NSM.

5.0 REFERENCES

Abbott, G.C., and A.K. Nath. 1996. Hydrologic Restoration of Southern Golden Gate Estates Conceptual Plan. South Florida Water Management District, Naples, Florida. 206 pp. plus appendices.

Adamski, James C. and Leel Knowles, Jr. 2001. Ground-Water Quality of the Surficial Aquifer System and the Upper Floridan Aquifer, Ocala National Forest and Lake County, Florida, 1990 – 99. U.S. Department of the Interior, U.S. Geological Survey, Water-Resources Investigations Report 01-4008.

Agnoli Barber and Brundage. October 2004. Lely Area Stormwater Improvement Plan (LASIP), Collier County, FL.

Anderson, K.L., J.E. Whitlock, and V.J. Harwood. 2005. Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. Applied and Environmental Microbiology 71:3041-3048

Antonini, G.A., D. A. Fann, P. Roat, 2002. A Historical Geography of Southwest Florida Waterways. Volume 2 Placida Harbor to Marco Island. West Coast Inland Navigation District and Florida Sea Grant.

APHA (ed.). 1995. Standard Methods for the Examination of Water and Wastewater, Vol. American Public Health Association, Inc., Washington DC .

Bales, J.D., J.M. Fulford, and E.S. Swain. 1997. Review of Selected Features of the Natural System Model, and Suggestions for Applications in South Florida. U.S. Geological Survey Water-Resources Investigations Report 97-4039.

Bardi, E., M. T. Brown, K. C. Weiss, and M. J. Cohen. 2011 (last updated). Uniform Mitigation Assessment Method. Web-based training manual for Chapter 62-345, FAC for Wetlands Permitting. http://www.dep.state.fl.us/water/wetlands/mitigation/umam.htm.

Bartlett, Drew, FDEP Director, Division of Environmental Assessment and Restoration, 2010, Personal Communication

Black, Crow, and Eidsness, Inc. 1974. Hydrologic Study of the G. A. C. Canal Network. Gainesville, FL. Project no. 449-73-53.

Boyer, J.N., and H.O. Briceno. 2008. 2007 cumulative annual report for the Coastal Water Quality Monitoring Network. Southeast Environmental Research Center.

Browder, J.A., Tashiro, J., Coleman-Duffie, E., and A. Rosenthal. 1988. Comparison of Ichthyoplankton Immigration Rates into Three Bay Systems of the Ten Thousand Islands Affected by the Golden Gate Estates Canal System. Volume I. Final Report to the South Florida Water Management District.

Brown, M.T., and M.B. Vivas. 2005. Landscape Development Intensity Index. Environmental Monitoring and Assessment (2005) 101: 289–309.

Cahoon, D.R. and Lynch, J.C. 1997. Vertical accretion and shallow subsidence in a mangrove forest of Southwestern Florida, U.S.A. U.S. Geological Survey, National Wetlands Research Center, Lafayette, LA.

CDM. January 2007. Nutrient Load Assessment, Estero Bay and Caloosahatchee River Watershed. South Florida Water Management District.

CERP. 2007. "Development and Application of Comprehensive Everglades Restoration Plan System-wide Performance Measures." Restoration Coordination and Verification, Comprehensive Everglades Restoration Plan, Central and Southern Florida Project

CH2M Hill. February 1980. Gordon River Watershed Study: Engineering Report. South Florida Water Management District.

CMD. 2009. Southwest Florida Feasibility Study Water Quality Model Development, W912EP-06-D-0013-001. CMD, January 2009. Prepared for US Army Corps of Engineers Jacksonville District.

Collier County Ordinance Number 2007-11, http://www.colliergov.net/modules/ShowDocument.aspx?documentid=21529

Collier County Ordinance Number 90-10, http://www.colliergov.net/modules/ShowDocument.aspx?documentid=1843

Collier County. October 1997. Collier County Growth Management Plan – Public Facilities Element, Drainage Sub-Element.

Collier County, 2004. Land Development Code. Naples, Florida.

Collier County, 2010. Collier County Groundwater Database.xlsx.

Collier County, 2010. Wells in GRE WBID_DO_Data.xls.

Collier Soil and Water Conservation District. July 2008. Horsepen Strand Conservation Area Phase 1.

Conservation Research Institute. 2005. *Changing Cost Perceptions: An Analysis of Conservation Development*. Prepared for the Illinois Conservation Foundation and Chicago Wilderness. February. Retrieved October 26, 2007, from http://www.cdfinc.com/CDF_Resources/Cost Analysis – Part 1–Report–with ExecSummary.pdf

Davis, John H. October 1943. The Natural Features of Southern Florida, Especially the Vegetation, and the Everglades. Florida Geological Survey Bulletin No. 25.

Davis, S.M. and Ogden, J.C. 1994. Everglades: The Ecosystem and Its Restoration. St. Lucie Press: Delray Beach, Florida. 826 p.

Debra Childs Woithe, Inc. and Sherry Brandt-Williams. February 2006. Naples Bay Surface Water Improvement & Management Plan Reconnaissance Report.

DeGrove, Bruce. June 1979. Gordon River/Naples Bay Intensive Survey Documentation. Florida Department of Environmental Regulation.

DHI, Inc. January 2002. Big Cypress Basin Integrated Hydrologic-Hydraulic Model Final Report. South Florida Water Management District.

Diaz, Jennifer (FDEP spokeswoman). May 2011. Polluted-waters label for Clam Bay, Rookery Bay, under challenge. Naples News. http://www.naplesnews.com/news/2011/may/20/clam-bay-rookery-pollution-dep-epa-nutrient-water/

Dickson, Kevin G., William M. Helfferich, Michael Brady, and Sharon Hynes. May 1983. The Collier County Water Resource Mapping Program – Technical Report. South Florida Water Management District.

Doyle,T.W., Girod,G.F., and Books, M.A. 2003. Modeling Mangrove Forest Migration Along the Southwest Coast of Florida Under Climate Change. U.S. Geological Survey, National Wetlands Research Center, Lafayette, LA.

Duever, M. 2004 Southwest Florida Pre-Development Vegetation Map. South Florida Water Management District.

Dynamic Solutions, LLC, and Camp Dresser & McKee, Inc. January 2008. Task 2 – Model Development, Verification, and Preliminary Sensitivity Analysis, TMDL Data and Model Support Activities in the Caloosahatchee River Basin. Division of Water Resource Management, Watershed Assessment Section, Florida Department of Environmental Protection.

EcoNorthwest. 2007. The Economics of Low Impact Development: A literature Review.

Environmental Research and Design (ERD). 2007. Evaluation of Current Stormwater Design Criteria within the State of Florida. Orlando, Florida.

Fish and Wildlife Research Institute, http://research.myfwc.com/, downloaded May 2010.

Florida Department of Environmental Protection (FDEP). 2003. Evaluation of Alternative Stormwater Regulations for Southwest Florida, Harvey H. Harper, PhD., PE, and David M. Baker, PE. http://www.sarasota.wateratlas.usf.edu/upload/ documents/WERC, 2009-9-03.pdf

Florida Department of Environmental Protection (FDEP). 2007. Evaluation of Current Stormwater Design Criteria within the State of Florida, Harvey H. Harper, PhD., PE and David M. Baker, PE. http://www.dep.state.fl.us/water/nonpoint/ docs/nonpoint/SW_TreatmentReportFinal_71907.pdf

Florida Department of Environmental Protection (FDEP). 2004. Everglades Marsh Dissolved Oxygen Site Specific Alternative Criterion Technical Support Document. Final Report to Florida Department of Environmental Protection. Tallahassee, FL. 61 pp.

Florida Department of Environmental Protection (FDEP). 2008. Dissolved Oxygen TMDL for the Gordon River Extension, WBID 3278K (formerly 3259C). Final Report to Florida Department of Environmental Protection. Tallahassee, FL. 40 pp.

Florida Department of Environmental Protection (FDEP). 2008. Dissolved Oxygen TMDL for the Gordon River Extension, WBD 3278K (formerly 3259C). Final Report.

Florida Department of Environmental Protection (FDEP). 2008. Dissolved Oxygen TMDLs for Hendry Creek (WBIDs 3258B and 3258B1). Final Report.

Florida Department of Environmental Protection (FDEP). 2008. TMDL Report: Nutrient, Un-ionized Ammonia, and DO TMDLs for Lake Trafford (WBID 3259W). Final Report.

Florida Department of Environmental Protection (FDEP). 2010. Site-Specific Information in Support of Establishing Numeric Nutrient Criteria for the Southwest Coastal Estuaries, Including Naples Bay, Rookery Bay and the Ten Thousand Islands.

Florida Department of Environmental Protection (FDEP). 2010. Site-Specific Information in Support of Establishing Numeric Nutrient Criteria for the Southwest Coastal Estuaries, Including Naples Bay, Rookery Bay and the Ten Thousand Islands.

Florida Department of Environmental Protection (FDEP). 2010 Draft. Environmental Resource Permit. Stormwater Quality Applicant's Handbook.

Florida Department of Environmental Protection (FDEP). n.d. http://www.dep.state.fl.us/water/wetlands/ erp/rules/stormwater/background.htm

Florida Department of Environmental Protection (FDEP). http://www.dep.state.fl.us/water/wetlands/erp/rules/stormwater/background.htm.

Florida Department of Health. Kara Loewe, Personal communication. December 2009.

Foss, A. 2005. "Low Impact Development: An Alternative Approach to Site Design." *PAS Memo: May/June*. Retrieved October 26, 2007, from http://www.pathnet.org/si.asp?id=1592

Freiberger, H.J. 1972. Stream Flow Variation and Distribution in the Big Cypress Watershed during Wet and Dry Periods. Map Series 45. Bureau of Geology, Florida Dept. of Natural Resources, Tallahassee, FL.

Friedemann, M., and J. Hand, 1989, Typical water quality values for Florida's lakes, streams and estuaries: Florida Department of Environmental Regulation, Tallahassee, 31 p.

Fujioka, R.S. 2001. Monitoring coastal marine waters for spore-forming bacteria of fecal and soil origin to determine point from non-point source pollution. Water Science and Technology. 44: 181-188.

Fujioka, R.S., Stan-Denton, C., Borja, M., Castro, J., and K. Morphew. 1999. Soil, the environmental source of *Escherichia coli* and enterococci in Guam's streams. Journal of Applied Microbiology. (Symposium supplement) 85: 83S-89S.

Gentile, John H., Paul Montagna, Jeffrey M. Klopatek, and Michael Walters. July 2008. Scientific Peer Review of the Draft Technical Document to Support a Water Reservation Rule for Picayune Strand and Downstream Estuaries. South Florida Water Management District.

Google.com. 2009. Public Data – Population. Data Source is United States Census Bureau, Population Division.

Gregory, J. Stormwater Infiltration at the Scale of an Individual Residential Lot in North Central Florida. University of Central Florida. Orlando, Florida.

Grunwald, Michael. 2006. "The Swamp: Everglades, Florida and the Politics of Paradise." Simon and Schuster, New York, New York

H. W. Lochner, Inc. December 2004. Immokalee Storm Water Management Plan, Hydrologic and Hydraulic Water Quality Modeling, Collier County. South Florida Water Management District.

Handley, L., Altsman, D. and R. DeMay. 2007. Seagrass Status and Trends in the Northern Gulf of Mexico: 1940-2002. U.S. Geological Survey Scientific Investigations Report 2006-5287 and U.S. Environmental Protection Agency 855-R—4-003. 267 pp.

Hanlon, E.A. 2005. Using Recyclable Water Containment Areas (RWCAs) to Treat Agricultural Stormwater Runoff for Watersheds: A Concept Paper. EDIS document SL227. Soil and Water Science Department. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Hanlon, Edward A. n.d. Using Recyclable Water Containment Areas (RWCAs) to Treat Agricultural Stormwater Runoff For Watersheds: A Concept Paper, Fact Sheet SL227 of the Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Harwood V.J., J. Whitlock, and V. Withington. 2000. Classification of antibiotic resistance patterns of indicator bacteria by discriminant analysis: use in predicting the source of fecal contamination in subtropical waters. Applied and Environmental Microbiology 66:3698-3704.

Heald, Eric J. and Durbin C. Tabb. November 1973. Rookery Bay Land Use Studies, Environmental Planning Strategies for Development of a Mangrove Shoreline, Study No. 6 "Applicability of the Interceptor Waterway Concept to the Rookery Bay Area." The Conservation Foundation.

http://my.sfwmd.gov/gisapps/sfwmdxwebdc/dataview.asp?query=unq_id=296 "lscndclu88_POLYGON_meters_CC_URBAN.shp".

Hydrogeologic, Inc. August 2006. Hydrologic-Hydraulic and Environmental Assessment for the Camp Keais Strand Flowway. South Florida Water Management District.

Janicki Environmental, Inc., 2010. Collier County Surface Water Quality Annual Assessment and Trend Report. Draft Report Submitted to Collier County.

Johnson Engineering, Inc, Agnoli, Barber & Brundage, Inc., and Boylan Environmental Consultants, Inc. July 1999. South Lee County Watershed Management Plan. South Florida Water Management District.

Johnson Engineering, Inc. December 1981. Golden Gate Water Management Study. Big Cypress Basin Board, South Florida Water Management District.

Johnson Engineering. 1983. Hydrologic Effects of Storm of September 1-3, 1983 in Golden Gate City. Big Cypress Basin Board, South Florida Water Management District. September.

Jones, John. W. 2006. Creation of GIS-compatible, historic detailed soil data sets for Collier and Miami-Dade Counties of Florida. USGS, 13 pgs.

Kenner, W. E., 1966, "Runoff in Florida", Map Series No. 22, U.S. Geologic Survey.

Kimmerer, W. J. 2002. "Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary." Estuaries 25: 1275-1290.

Klein, H., W.J. Schneider, B.F. McPherson and T.J. Buchanan. May 1970. Some Hydrologic and Biologic Aspects of the Big Cypress Swamp Drainage Area, Southern Florida. United States Geologic Survey Open-file Report 70003.

Klein, Howard. 1980. Water-Resources Investigations, Collier County, FL. United States Department of the Interior, Geological Survey and South Florida Water Management District.

LaRoe, Edward T. January 1974. Rookery Bay Land Use Studies, Environmental Planning Strategies for Development of a Mangrove Shoreline, Study No. 8 "Environmental Considerations for Water Management District 6 of Collier County. Collier County Conservancy, Inc.

Larry Walker Associates. 2006. Copper Management Strategy Development Resources, Final.

Lewis, R.R., and B. Streever, 2000. Restoration of Mangrove Habitat. WRP Technical Notes Collection (ERDC TN-WRP-VN-RS-3.2), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Locker, S.D. 2005. Establishing Baseline Benthic Habitat Coverages in Faka Union and Fakahatchee Bays for Present and Future Environmental Studies. Final Report to South Florida Water Management District. Contract No. DG040614. 60 pp.

Locker, S.D. 2005. Establishing Baseline Benthic Habitat Coverages in Faka Union and Fakahatchee Bays for Present and Future Environmental Studies. Final Report to: South Florida Water Management District. Contract No. DG040614. 60 pp.

McCormick, P.V., Chimney, M.J. and D.R. Swift. 1997. Diel oxygen profiles and water column community metabolism in the Florida Everglades, U.S.A. *Archives die Hyrobiologie*. 140: 117-129.

McCoy, H. Jack. 1975. Summary of Hydrologic Conditions in Collier County, Florida, 1974. Open File Report FL-75007. United States Department of the Interior, Geologic Survey.

McCoy, Jack. 1972. Hydrology of Western Collier County, Florida. State of Florida, Department of Natural Resources, Division of Interior Resources, Bureau of Geology Report of Investigations No. 63.

McPherson, B.F., G.Y. Hendrix, Howard Klein, and H.M. Tyus. 1976. The Environment of South Florida, A Summary Report. Geologic Survey Professional Paper 1011. Department of the Interior, Resource and Land Investigations Program.

Metcalf & Eddy, AECOM. February 2006. Reconnaissance of Hydrology and Environmental Conditions in Central Big Cypress Basin, Final Report. South Florida Water Management District.

Metropolitan Washington Council of Governments. 1995. Site Planning for Urban Stream Protection. Washington D.C.

Minerals Management Service and Fish and Wildlife Service – U.S. Department of the Interior. September 1984. An Ecological Characterization of the Caloosahatchee River/Big Cypress Watershed.

Missimer and Associates, Inc. December 1982. Groundwater Resources of the Cocohatchee Watershed, Collier County, FL Phase II Geologic Model. Big Cypress Basin, South Florida Water Management District.

Myers, R.L. 1975. The Relationship of Site Conditions to the Invading Capability of *Melaleuca quinquenervia* in Southwest Florida. Masters Thesis, University of Florida.

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

PBS&J. December 10, 2010. Technical Memorandum submitted for Element 2, Task 3: Quality of Receiving Waters of the Collier County Watershed Model Update and Plan Development.

PBS&J. December 10, 2010. Technical Memorandum submitted for Element 1, Task 1.2: In-Stream Water Quality of the Collier County Watershed Model Update and Plan Development.

PBS&J. February 24, 2011. Technical Memorandum submitted for Element 1, Task 2.3: Groundwater Quality and Element 1, Task 2.4: Groundwater Loading to Canal Network of the Collier County Watershed Model Update and Plan Development.

PBS&J. 2009. Watershed Model Update and Plan Development Contract 08-5122, PO 4500106318, Element 4, Task 3 Water Quality and Ecological Assessment of Lake Trafford. Submitted To Collier County.

Popowski, R. Ten Thousand Islands Conceptual Ecological Model 22 May 2006, U.S. Fish and Wildlife Service, http://www.evergladesplan.org/pm/studies/study_docs/swfl/swffs_cems_10000islands.pdf

Post, Buckley, Schuh & Jernigan, Inc. 1990. Collier County Stormwater Management Program, Section 5, Level of Service Analysis.

Pritchard, D.W. 1967. What is an Estuary: Physical Viewpoint. In G.H. Lauff (ed). Estuaries. Washington, DC: American Association for the Advancement of Science.

Reiss, K.C., E. Hernandez, M. T. Brown, 2007. An Evaluation of the Effectiveness of Mitigation Banking in Florida: Ecological Success and Compliance with Permit Criteria. Final Report Submitted to the Florida Department of Environmental Protection Under Contract #WM881 and United States Environmental Protection Agency Region Four Under Contract #CD 96409404-0.

Reiss, K.C., M.T. Brown, C.R. Lane, 2009. Characteristic community structure of Florida's subtropical wetlands: the Florida wetland condition index for depressional marshes, depressional forested, and flowing water forested wetlands. Wetlands Ecol Manage DOI 10.1007/s11273-009-9132-z. Springer Science+Business Media B.V. 2009.

Rosendahl, Peter C. and David A. Sikkema. 1981. Water Management Plan: Turner River Restoration. South Florida Research Center Report M-621.

Schmid, J., K. Worley, D.S. Addison, A. R. Zimmerman, and A. Van Eaton, 2006. Naples Bay Past and Present: A Chronology of Disturbance to an Estuary. Final Report. City of Naples and South Florida Water Management District.

SDI Environmental Services, Inc. 2007. "Final Report, Natural Systems Model (NSM) Scenario Southwest Florida Feasibility Study"

SDI Environmental Services, Inc., BPC Group Inc. and DHI, Inc. January 2008. Southwest Florida Feasibility Study Integrated Hydrologic Model, Model Documentation Report. South Florida Water Management District, Ft. Myers, FL.

SFWMD. 2007. Naples Bay: Surface Water Improvement and Management Plan. South Florida Water Management District. 47 p.

Shirley, M., O'Donnell, P., McGee, V., and T. Jones. 2005. Nekton species composition as a biological indicator of altered freshwater inflow into estuaries. Pp. 351-364. In: S.A. Bortone (ed.). Estuarine Indicators. CRC Press, Boca Raton, FL.

Shirley, M.,J. Haner, H. Stoffel, and H. Flanagan. 1997. Estuarine Habitat Assessment: Rookery Bay National Estuarine Research Reserve and the Ten Thousand Islands Aquatic Preserve, Naples, FL. Report to the Florida Coastal Zone Management Program.

Simpson, B., R. Aaron, J. Betz, D. Hicks. J. van der Kreeke, B. Yokel. 1979. The Naples Bay Study. The Collier County Conservancy. Naples, Florida.

South Florida Water Management District. 2000. Basis of Review for Environmental Resource Permit Applications. West Palm Beach, Florida

South Florida Water Management District. 2005-2006 Update. Lower West Coast Water Supply Plan.

South Florida Water Management District. 2005-2006 Update. Lower West Coast Water Supply Plan - Appendices.

South Florida Water Management District. 2005-2006. Consolidated Water Supply Plan – Support Document.

South Florida Water Management District. 2010. Environmental Resource Permit Information Manual Volume IV, Water Resource Regulation Department.

South Florida Water Management District. December 2002. Master Plan for Regional Irrigation Distribution System (RIDS) for the Lower West Coast Region, Project C-12368.

South Florida Water Management District. January 1994. Big Cypress Basin, Five Year Plan – 1994 – 1998.

South Florida Water Management District. January 2007. Naples Bay Surface Water Improvement and Management Plan.

South Florida Water Management District. January 2010. Picayune Strand Restoration Fact Sheet.

South Florida Water Management District, GIS data provided via download: http://my.sfwmd.gov/gisapps/sfwmdxwebdc/dataview.asp?query=unq_id=296 "lscndclu88_POLYGON_meters_CC_URBAN.shp"

South Florida Water Management District, Big Cypress Basin and United States Department of Agriculture and Natural Resources Conservation Service. October 2003. Southern Golden Gate Estates Watershed Planning Assistance Cooperative Study

Southwest Florida Feasibility Study Water Quality Model Development, W912EP-06-D-0013-001. CMD, January 2009. Prepared for US Army Corps of Engineers Jacksonville District.

Southwest Florida Regional Planning Council. August 1976. Water Quality and Hydrodynamic Sampling Program Design.

Staats, Eric. 1999. Water monitoring may find solutions to pollution. Naples New. http://web.naplesnews.com/special/water/a30278o.htm

Starnes, Janet. 2009. Personal communication; SWFFS BAT Matrix dated March 30, 2008.

Taylor Engineering, Inc. June 2005. Evaluation of Naples Bay Water Quality and Hydrologic Data. South Florida Water Management District.

Tetra Tech, Inc., and Janicki Environmental, Inc. 2004. Compilation, Evaluation, and Archiving of Existing Water Quality Data for Southwest Florida. Contract No. DACW 17-02-D-0009. Final Report submitted to Department of Army, Jacksonville District Corps of Engineers.

U.S. Environmental Protection Agency. 2005. *Low-Impact Development Pays Off*. Nonpoint Source News-Notes. No. 75. May. Retrieved August 23, 2007, from http://www.epa.gov/NewsNotes/issue75/75issue.pdf

United States Army Corps of Engineers – Jacksonville District and South Florida Water Management District. April 1999. Central and Southern Florida Project Comprehensive Review Study; Final Integrated Feasibility Report and Programmatic Environmental Impact Assessment.

United States Army Corps of Engineers – Jacksonville District and Florida Department of Environmental Protection. August 2003. Comprehensive Water Quality Feasibility Study; Draft Project Management Plan.

United States Army Corps of Engineers – Jacksonville District and South Florida Water Management District. September 2004. Comprehensive Everglades Restoration Plan Picayune Strand Restoration (Formerly Southern Golden Gate Estates Ecosystem Restoration), Final Integrated Project Implementation Report and Environmental Impact Statement.

United States Army Corps of Engineers – Jacksonville District and CDM. February 2007. Southwest Florida Feasibility Study Water Quality Model Development.

United States Army Corps of Engineers – Jacksonville District. February 1986. Golden Gate Estates Collier County, Florida – Draft Feasibility Report.

University of Wisconsin. 2006. Water Action Volunteers, Volunteer Monitoring Factsheet Series, Dissolved Oxygen: Aquatic Life Depends on It.

Van Buskirk, Ryffel and Associates, Inc. September 2008. The Collier Interactive Growth Model (CIGM), Executive Summary. Prepared for The collier County Board of County Commissioners and the Collier County Comprehensive Planning Department.

Veri, Albert R., Arthur R. Marshall, Susan Uhl Wilson, James H. Hartwell, Peter Rosendahl and Thomas Mumford. October 1973. Rookery Bay Land Use Studies, Environmental Planning Strategies for Development of a Mangrove Shoreline, Study No. 2 The Resource Buffer Plan: A Conceptual Land Use Study Water Management District No. 6, Collier County, Florida. The Conservation Foundation.

Wanielista, Marty. August 2006. An Evaluation of Southwest Florida Basin Rule BMP Efficiencies.

Wanless, H.R., R.W. Parkinson, L.P. Tedesco, 1994. Sea Level Control on Stability of Everglades Wetlands. In Everglades: The Ecosystem and Its Restoration. St. Lucie Press.

Watkins, Rhonda. Collier County, Personal communication; January 6, 2011.

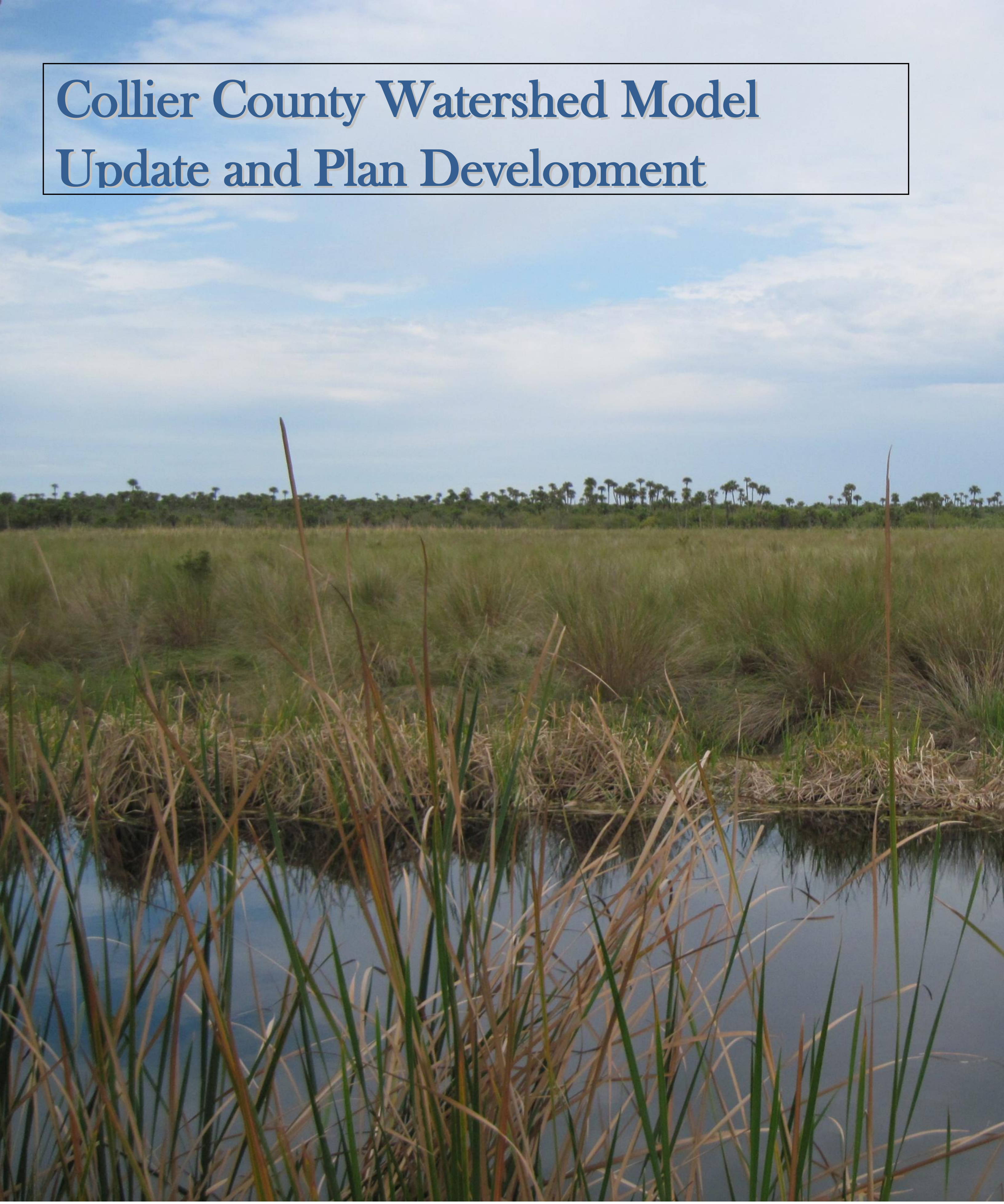
Weedman, Suzanne D., United States Geologic Survey, 2002, Hydrogeology of the Surficial Aquifer System in Southwest Florida, from http://sofia.usgs.gov/projects/surficial/surficialab1.html

Weisberg, Robert H. and Lianyuan Zheng, College of Marine Science, University of South Florida. September 2007. Estuarine Hydrodynamic Modeling of Rookery Bay, Final Report. Florida Department of Environmental Protection.

Weiss. R.F. 1970. The solubility of nitrogen, oxygen and argon in water and seawater. *Deep-Sea Research*. 17: 721-735.

Zickler, L. 2004. “Low-Impact Development Comes to Pierce County.” *Seattle Daily Journal of Commerce* July 29. Retrieved August 2, 2007, from http://www.djc.com/news/en/11159535.html

Collier County Watershed Model Update and Plan Development



Collier County

ATKINS