Captiva Water Quality Assessment Project
Final Report

Prepared by the SCCF Marine Laboratory, Sanibel, FL 33957

For the Lee County Tourist Development Council (TDC)

And

The Captiva Community Panel (CCP)

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By:
Mark Thompson
Loren Coen
Eric Milbrandt
Alex Rybak
Richard Bartleson

Sanibel-Captiva Conservation Foundation

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Executive Summary

In the fall 2007, elevated bacteria levels caused the temporary closure of two Sanibel, Florida beaches. Engaged residents of Sanibel and neighboring Captiva Islands lobbied to investigate the conditions of their nearshore waters and the potential problems contributing to local water quality. Due to the perceived decline in water quality around the islands, the Captiva Community Panel (CCP), an advisory group to Lee County on land use and zoning issues and the Sanibel-Captiva Conservation Foundation (SCCF) applied to the Lee County's Tourist Development Council (TDC) for funding to conduct a two-year water quality study to better understand existing conditions around the barrier islands. TDC funded the project through the CCP from October 2008 through March 2011.

The specific goals of this study include: (1) establish a water-quality baseline from data collected during 1st year of the study; (2) identify and confirm potential pollution sources through periodic seasonal and "event-related" monitoring and more intensive "source tracking" approaches on both the Gulf of Mexico and estuary (Pine Island Sound) sides of the islands; (3) identify areas of degraded water quality and time periods when these ocurred; (4) coordinate above efforts with other concurrent studies and environmental assessment efforts by SCCF and others to provide a more thorough analysis of current conditions and dynamics affecting water quality; and finally (6) recommend a variety of potential responses to the above findings, including Best Management Practices (BMPs).

A detailed summary of the baseline monitoring findings is available in the Year 1 report previously provided to the CCP. To summarize, the parameters of greatest interest and the primary focus were the indicator <u>bacteria</u> *Enterococcus*, <u>nutrients</u> (nitrogen and phosphorus), <u>chlorophyll *a*</u> and <u>dissolved oxygen</u> (DO). Findings were grouped into the following locations: (a) samples from nearshore waters of Captiva Island; (b) samples around northern Sanibel Island; (c) samples taken in the J.N. "Ding" Darling National Wildlife Refuge (henceforth referred to as NWR); and (d) samples taken on the Pine Island Sound Estuary side of the islands compared to samples taken on the Gulf of Mexico coast. Categories of water quality ("poor", "moderate", "good") were assigned based upon Florida Water Quality Criteria (FDEP 2008) and the proportion of samples in the "poor" category were presented for each parameter and group.

Year One results demonstrated that the study area had elevated levels of the *Enterococcus* indicator bacteria after rainfall events, especially on the estuary side of Captiva and Northern Sanibel. "Poor" results for indicator bacteria occurred proximate to stormwater outfalls, around resorts and residential-golf course developments, and where rainwater runoff volumes were the greatest. Some of those areas also exhibited "poor" results for nitrogen and chlorophyll *a*. The various bayous (e.g., Clam and Dinkins) located on the northern portion of Sanibel had relatively higher nitrogen levels, most likely caused by poor tidal flushing and their close proximity to residential development. Dissolved oxygen levels were often classified as "Poor" at Captiva, Sanibel and the NWR stations. When analyzed using the Florida Department of Environmental Protection (FDEP) Impaired Waters Rule (IWR) the estuary stations around Captiva and northern Sanibel would be classified as "Impaired". This finding may be an indicator of one or more of the following: nutrient enrichment; organic loading; 'high' color concentrations; or potentially natural causes. A number of ongoing studies are documenting the natural occurrence of low dissolved oxygen in coastal plain watersheds which have large organic deposits (e.g. mangrove habitats) with low light penetration and dark-colored water which combine to produce prevailing hypoxic conditions (UGA 2011).

Gulf of Mexico sites (beaches) for Captiva and Sanibel generally exhibited "good" water quality with only a few instances of "moderate" conditions caused by elevated indicator bacteria levels. Phosphorus at Gulf stations was relatively high, as compared to the estuarine stations or overall mean Florida coastal values (see Dorfman and Rosselot 2009). One potential cause of elevated phosphorus on the Gulf-side is that it may be transported into the study area from other phosphorus-rich watersheds such as Charlotte Harbor or Tampa Bay which contain large natural phosphorus deposits (USF 2011). Additionally, nutrients may be passing through the inlets into Gulf waters from upstream sources such as the Caloosahatchee watershed.

Confounding influences on water quality during the 2008-09 baseline assessment period included: a very dry period with no hurricanes or significant tropical storms; the closing of the Sanibel Bayous wastewater treatment plant early in 2008 and filling its storage pond (located on northern Sanibel Island near Clam Bayou) by the City of Sanibel; and the dredging and opening of Blind Pass in August 2009. The potential impact of these events on water quality in the study area were not the focus of this study and have complex, unpredictable effects on water quality. This should be kept in mind before drawing conclusions from the assessment results.

Concentrations and sources of nitrogen and enterococci indicator bacteria in near shore surface waters, groundwater, and rainwater runoff were the primary focus of the second year of this study. Half of the properties on Captiva Island are on septic system and half are connected to a 0.264 MGD wastewater treatment plant, as determined from property appraisal data and GIS tools. We were able to compare nitrogen and indicator bacteria between these areas and to reference sites on undeveloped sites on Sanibel Island. Nitrogen in groundwater beneath the non-sewered portion of Captiva was elevated compared to reference sites and the sewered part of Captiva. We also found greater mean of nitrogen concentrations in surface water (estuary sites) proximate to the non-sewered portion of Captiva compared to the sewered portion. In addition, rainwater and irrigation water runoff from Captiva had relatively high levels of nitrogen compared to estuary or gulf locations. *Enterococcus* bacteria were low in all of Captiva's groundwater but were high in rainwater runoff and were elevated at estuary and gulf sites after a significant rain event (>0.5 inches). Groundwater from the non-sewered portion of Captiva contributes nitrogen to near shore surface waters especially on the estuary side of Captiva. Nitrogen in Captiva's groundwater most likely originates from septic systems which do not typically remove nitrogen from domestic waste. Rain event runoff increases indicator bacteria concentrations near Captiva and adds significantly to nitrogen loads.

To address these water quality concerns, the Captiva community can focus upon two broad strategies; the reduction in storm and irrigation runoff volume and the reduction in nitrogen discharges from septic systems. Storm event runoff can most effectively be reduced by encouraging multi-layered vegetation in place of turfgrass and impervious surfaces. The use of widely accepted stormwater management practices such as constructed/reclaimed wetlands, swales, bioretention areas, cisterns, green roofs and roof filters can also decrease the volume of stormwater runoff and thus the slow the delivery of bacteria and nitrogen to surface water. Reducing nitrogen from septic systems may be accomplished through separation and treatment of waste streams through the replacement of conventional toilets with composting and incinerating toilets. Nitrogen can also be removed from septic system waste through the installation of advanced wastewater treatment units in place of conventional septic systems. Florida DOH promotes these nitrogen reduction technologies and provides an informational website at www.doh.state.fl.us/environment/ostds/index.html.

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Introduction

Tourism is one of the largest economic industries in Florida, with approximately 82.4 million travelers visiting the Sunshine State in 2007. In 2003, 23 of the 25 most densely populated U.S. counties were coastally-located, with Florida leading the nation in coastal population growth (75%), normalized to percent change, from 1980 to 2003. Tourism employs one out of every five people in Southwest Florida's Lee County (Lee County VCB 2011). Approximately 5 million visitors a year come to the area generating approximately $3 billion in economic impact. Just this past year, the Tourist Tax collection generated $23.1 million dollars. The Charlotte Harbor National Estuary is a unique land and water resource providing about $1.8 billion per year in net value to recreationist and Florida households, and is used to produce about $3.2 billion per year in income to the area (CHNEP 1998). The areas' recreational fishing and other water-related recreation account for $916 million per year, and commercial fisheries are worth over $38 million each year based on a 1998 estimate (CHNEP 1998). The shallow waters of Pine Island Sound are world renowned for snook, tarpon, redfish, trout, snapper, grouper, sharks, and flounder which utilize the Sound's extensive seagrass and mangrove habitats. Estuarine and marine habitats such as marshes, oyster reefs, mangroves, mudflats, and seagrasses function as sites for breeding, feeding, and shelter for economically and ecologically valuable plants and animals. In addition to direct tourism value, they also have significant economic value through their ecological "services" derived from healthy ecosystems (Costanza et al. 1997). These include the importance to society in general (e.g., goods and services, such as health, social, cultural, and economic well being) that these ecosystems provide, either through their preservation or restoration.

The Pine Island Sound Estuary in Lee County is home to subtropical habitats such as mangroves, seagrasses, and intertidal oysters, cumulatively supporting diverse communities of aquatic and land-based vertebrates such as birds, mammals, reptiles, amphibians, fishes, along with numerous marine and estuarine-living invertebrates (FDEP 2009a). One of the attractions to SW Florida is world-class shelling, which is highly-dependant on sustainable populations of invertebrates in the surrounding coastal waters. In addition, these waters (including the Pine Island Sound Aquatic Preserve) are used extensively by people for recreational fishing, boating, and eco-tourism, all together making water quality a critical issue for local residents, property owners and visitors alike.

Captiva Island is an 800 acre barrier island located in Lee County just north of the larger 11,000 acre Sanibel Island (Figure 1). Development on Captiva consists of single family homes, estate-zoned properties, condominiums, tourist-based commercial development and numerous vacation destinations ranging from single units to large self-contained resorts with golf courses, marinas and shopping facilities. Captiva's 1088 housing units are primarily served by on-site wastewater treatment and disposal systems (OSTDS or septic systems) of varying ages and efficiencies, while the larger resorts typically have wastewater treatment systems with drain fields or reclaim water systems. About 55% of Captiva relies upon OSTDs, while about 45% of the island is served by the South Seas Plantation (SSP) wastewater treatment facility. The effluent from this wastewater facility is stored and mixed with well water to provide irrigation for the SSP golf course. Through a contracted NELAC certified lab, SSP monitors nutrients, bacteria and several other parameters in groundwater from three monitoring wells on its property as required by FDEP in its reclaim water reuse permit.

The population of Captiva and Sanibel Islands fluctuates greatly, with seasonal residents present mainly from January through April (Figure 2, Sanibel-Captiva Chamber of Commerce 2009). The 2000 US census database lists 83% of homes on Captiva as unoccupied by permanent resident. Of the unoccupied homes, 64% of the homes are occupied seasonally or rented. The Sanibel-Captiva Chamber of Commerce defines the "high" season as January through April and "low" season as May through December. During high season Captiva Island may support 1,800 or more people, while during "low season" the population is at its lowest at between 400 and 500. The larger, adjacent Sanibel Island has similar seasonal population fluctuations between 6,300 and 23,000 residents and visitors.

Previous studies have linked land use and 'impervious surface' area within a watershed to water quality (Mallin et al. 2000, Brabec et al. 2002, Holland et al. 2004, Luckenbach et al. 2008). As of 2003, approximately 25% of land on Captiva (Table 1) and 19% of land on Sanibel Island was classified as impervious due to urban development (Stys et al. 2004). About 35.2% of Captiva (Table 1) is classified as forest, swamp, beach or other undeveloped area, while 70% of Sanibel was undeveloped. On Sanibel, the Sanibel-Captiva Conservation Foundation (SCCF), J.N. “Ding” Darling National Wildlife Refuge (henceforth referred to as NWR only), the Sanibel Audubon Society and the City of Sanibel have, for the past four decades, set aside land for conservation. In contrast, available statistics suggest that greater development activity has occurred on Captiva as compared to Sanibel (Stys et al. 2004).

In addition to development, soil types can be important when looking at surface water runoff and groundwater recharge. Captiva soils are primarily sandy soils which have been modified by fill to allow construction and landscaping. The National Resources Conservation Service (NRCS) lists the hydrologic groups for the soils on Captiva as primarily group “C” with a small amount of group “D” soils. Group “C” and “D” soils are characterized by low to very low infiltration rates caused by a partially impervious layer or permanent high water table. In the case of Captiva the soils are given this classification due to the permanently high water table.

Recently, poor water quality has been documented during periods of above-average rainfall and hurricane activity (especially 2006-2008), resulting in the degradation of habitats in the Aquatic Preserve and nearby Caloosahatchee River watershed (DeGrove 1981; Doering 2005). Beach closures have been noted recently (2007) in and around Captiva and Sanibel islands, along with significant coastal accumulations of macroalgae (2006-2007) and harmful algae bloom (HAB) events (Loh et al. 2011). No single source is thought to have caused the declines in water quality, but the effects include, low dissolved oxygen levels, large salinity fluctuations and diminished water clarity impacting seagrass habitats. Additionally, increased sedimentation and lower salinities from runoff and upstream discharges have caused significant oyster mortalities (Volety 2008), prompting island residents to seek help in ascertaining whether their activities are having significant affects on the surrounding waters, in conjunction with watershed and upstream influences.

Increased awareness of changing water quality conditions has generated much interest in determining the locations contributing most significantly to the problem. Areas with well-designed storm-water treatment structures would be expected to contribute a relatively smaller load of nutrients and suspended sediments from terrestrial runoff compared to those without stormwater management practices in place, but due to lack of significant planning, stormwater treatment on Captiva Island is currently minimal. A detailed study of water quality conditions surrounding Captiva Island was necessary to identify potential problem areas, sources of pollution and transport mechanisms to provide recommendations for improving local nearshore water quality. Clear, clean water is Captiva and Sanibel Islands' most essential resource and protection of these natural resources is critical for a healthy tourism market and protecting property values.

A two-year study started by SCCF in October 2008 and supported by funds from the Lee County Tourist Development Council (TDC) through the Captiva Community Panel (CCP), characterized Captiva's nearshore water quality identified areas of concern for a variety of pollutants.

<u>The goals of this two-year study were to:</u>

1. *Establish a water quality baseline (including the creation of a relational database) for the Island's nearshore waters which can be applied to future studies;*
2. *Identify and confirm as many as possible most potential pollution sources through more general, seasonal and "event-related" monitoring and more intensive "source tracking" approaches at preselected stations on both the beach (Gulf of Mexico) and Sound sides of Captiva Island;*
3. *Identify degraded water quality locations and time periods;*
4. *Survey of critical habitats (oysters and seagrasses) using mapping techniques around Captiva and northern Sanibel;*
5. *Quantify the effect of stormwater runoff on water quality;*
6. *Coordinate the above, along with other concurrent local studies and environmental assessment efforts to provide a more thorough analysis of current conditions and dynamics affecting water quality; and finally*
7. *Recommend potential responses to the above findings, including Best Management Practices (BMPs) based on available information.*

Additional Background Information for Water Quality Monitoring Efforts

Bacteria of the *Enterococcus* genus are used by state and federal regulatory agencies to monitor the hygienic quality of water bodies and drinking water sources. The presence of these bacteria in water in significant numbers can be an indicator of contamination by human or animal waste. These bacteria are characteristically found in high concentrations in human and animal fecal matter and domestic and agricultural wastewaters. The higher the concentration of *Enterococcus* in a water body, the more likely the water body contains disease-causing agents. This group of bacteria is thought to be a better indicator for monitoring estuarine and marine waters (as opposed to fresh water) due to their reported better viability in higher salinities than other indicators, such as the fecal coliform group (US Environmental Protection Agency 2009).

The genus *Enterococcus* is also associated with fecal matter of non-human animals, including mammals and birds, creating challenges for water quality managers trying to identify specific sources (human versus animal). Techniques using DNA and Antibiotic Resistance Analysis (ARA) are an area of active research and development to better assess the original source of bacterial contamination (Whitlock et al. 2002).

The concentration of chlorophyll *a* in a water body is an indicator of the amount of phytoplankton and single-celled algae present in the water column. When phytoplankton or microalgae concentrations are high (blooms), other water quality parameters such as dissolved oxygen and water clarity are compromised and estuarine habitats (seagrass and coral reef) can be detrimentally affected. Algae blooms, and high chlorophyll *a* levels are positively correlated with nutrient enrichment (nitrogen and phosphorus). Florida DEP has established water quality criteria based upon mean levels of chlorophyll *a* for determining if a water body is impaired due to nutrient enrichment. If an estuarine water body has an annual mean chlorophyll *a* concentration greater than 11 µg/L, it is classified as “Impaired” due to nutrients. FDEP then looks at the ratio of nitrogen to phosphorus to determine which nutrient (or both) is limiting in the water body.

Excessive amounts of nutrients in estuarine water bodies can cause water quality problems such as algae blooms, decreases in water clarity, decreases in dissolved oxygen, deterioration of habitats, and even fish kills. Nitrogen is typically the limiting nutrient in estuarine waters surrounding Captiva and addition of more nitrogen to the water body can lead to additional algae growth. The application of fertilizer to terrestrial habitats can result in stormwater runoff containing high concentrations of nitrogen. Nitrogen is transported by storm events from the land to waterbodies where it will have detrimental effects. Total nitrogen is the summation of several forms of nitrogen (organic nitrogen, nitrate, nitrite and ammonia nitrogen) which can be present in water bodies. The inorganic forms (ammonia, nitrite and nitrate) of nitrogen are usually more easily available to algae and thus more susceptible to causing algae blooms.

There are presently no numeric criteria for nitrogen in estuary waters, although the USEPA has issued criteria for fresh waterbodies in Florida and is now in the process of developing numeric criteria for estuarine and marine waters in Florida. Chlorophyll *a* concentrations are currently used by the state to determine whether an estuary has problem-causing levels of nutrients (nitrogen and phosphorus).

Nitrogen in the form of ammonia (or "ammonium") is used more readily by plants and algae in the aquatic environment than other forms of nitrogen so it is often present in very low concentrations and often undetectable. When ammonia nitrogen levels are elevated it may be an indicator of recent discharges from domestic wastewater or septic tanks which contain nitrogen in this form. Monitoring ammonia concentrations can determine the presence of anthropogenic sources within an area.

Like nitrogen, increased levels of phosphorus in estuarine waters may lead to eutrophication resulting in increased phytoplankton concentrations, reduced water clarity, lower dissolved oxygen and other problems. Though nitrogen is the limiting nutrient in the local estuary (Loh et al. 2011), there are conditions in which phosphorus becomes the controlling factor and any increase phosphorus can result in immediate problems. The most common anthropogenic sources of phosphorus are fertilizer, wastewater, animal wastes, and waste from mining operations.

There are no numeric criteria for phosphorus in estuarine or marine waters, although the US EPA is now in the process of developing criteria. Chlorophyll *a* concentrations are currently used by the state for determining whether an estuary has problem-causing levels of nutrients (nitrogen and phosphorus).

Low dissolved oxygen (DO) concentrations in estuary waters can limit the survival and distribution of aquatic life, especially if they exist over any extended period of time. Hypoxia is the term for waters having oxygen concentrations of 2 mg/L or less. These waters will typically not support life, and can be a symptom of eutrophication caused by increased levels of nutrients or organic material in the water. In extreme conditions surface waters may become anoxic, or completely void of dissolved oxygen at some depth or area.

Dissolved oxygen levels typically fluctuate during a 24 hour period (diurnal cycle) due to varying rates of plant photosynthetic and respiratory activity based upon light availability. In the early morning hours, DO is typically at its lowest level of the day after having been consumed by the respiration of plants and algae during the night. Photosynthetic activity during the daylight hours causes increases in water column oxygen levels. Warm water temperatures and high salinity can also reduce the amount of DO.

Turbidity is a measure of water clarity which can directly affect the health of essential estuarine habitats such as seagrass. Turbidity is also an indicator of the amount of sediment in the water column and suspended sediment loads can affect the health of many organisms such as fish, oysters and other invertebrates. Land use changes and increased nutrient loadings are the primary causes of increased turbidity in our local estuaries.

High levels of dissolved organic material in an estuary can cause the water column to exhibit significant color (yellow-brown) which we term CDOM. High CDOM levels can lead to decreased light penetration and detrimental effects on light-dependent seagrass habitat.

Salinity is one of the most important water column characteristics influencing the health and distribution of aquatic plant and animal life. Large fluctuations in salinity can be very stressful to organisms when they occur over short periods of time. Land use changes (development, deforestation), canals, and stormwater drainage systems are major reasons why salinity in local estuaries now vary greatly compared to undeveloped lands with layers of vegetation (original natural conditions).

During the study period, there were a number of noteworthy occurrences having significant impacts on local water quality conditions. First, the Sanibel Bayous wastewater treatment plant, which served a residential area of northern Sanibel, was taken over by the City of Sanibel and its operation ceased in the spring of 2008. The Sanibel Bayous' sewer system was diverted and connected to the City's treatment system (Donax Wastewater Treatment Plant). A large wastewater treatment/holding pond associated with the plant that was long suspected of leaking pollutants into the immediate environment and likely contributed to elevated bacteria and nutrient levels in nearby waters. By August 2009, the wastewater holding pond was filled with sand obtained from the dredging of Blind Pass (Figure 3). Blind Pass formerly formed a narrow tidal inlet separating Sanibel Island from Captiva Island to the north. The Pass has historically opened and closed depending on hurricane activity and longshore sediment transport. Additionally, sedimentation kept this pass closed until recently when a navigation project was undertaken by Lee County, the Captiva Erosion Control District (CEPD) and FDEP to dredge open Blind Pass, and reconnect Pine Island Sound to the Gulf of Mexico (Figure 4). On August 1st, 2009 tidal exchange was reestablished at Blind Pass with the completion of dredging. This renewed tidal exchange was expected to have significant impact to the local water quality especially in the immediate area of the pass (Roosevelt Channel, Sunset Bay, Dinkins Bayou, and Wulfert Channel).

The nationwide economic recession of 2008-2010 may have indirectly impacted the area's water quality by affecting such things as the number of people (volume of waste) visiting this tourism-dependent area, decreasing the amount of vehicle and boat traffic, slowing the rate of land use change and the altering the management of existing land uses (i.e. fertilizers). These events occurred during the period of this study and must be taken into account when evaluating the data collected. The report is subdivided by subheadings into activities and results related to the baseline assessment portion of this study and those related to the focused monitoring. The baseline assessment was performed from October 2008 through December 2009. Focused monitoring was performed from November 2009 until March 2011. Although many additional water quality parameters were monitored than described within this document, we report here only those parameters which best characterize the overall water quality conditions. Additional information and data are available from SCCF Marine Lab upon request.

Methods

This study was conducted between October 2008 and March 2011. The study was broken into two components: year 1 water quality baseline assessment; year 2 focused monitoring and source tracking. The study area was defined as nearshore waters (within 50 m of shore) surrounding Captiva Island south to the Bayous areas of northern Sanibel Island (Figure 5). In the second year we expanded the scope of the study to include the uppermost groundwater aquifer (freshwater lens) which is present on both Captiva and Sanibel Islands. We used an adaptive monitoring strategy to take advantage of the findings from the first year to better utilize resources and direct our efforts during the second year of the study.

To assist in understanding and identifying informational needs, a water quality relational (MS Access) database was created which included all available historical data from ten independent municipal, county, state and local agencies and other organizations. These data were initially analyzed and used as the foundation for developing a monitoring plan that would concentrate on filling in both spatial (sampling sites) and temporal (e.g., seasonal) gaps in the region's water quality data. Possible pollutant sources were identified through field surveys of the study area, conversations with local and state government utilities and environmental protection agencies, and GIS-based land use mapping. The potential sources were plotted on a map of the study area. Study area watershed boundaries were estimated and plotted using GIS software and Light Detection and Ranging (LIDAR) elevation data (Figure 6).

Year One Baseline Assessment

Year 1 water quality monitoring sites were selected for this study based upon: (1) location of possible pollutant sources, (2) information gained from analyzing historical water quality data from the area, (3) accessibility (from land or water); and (4) producing the best combination of temporal and spatial coverage within the funding and resource constraints of this project.

The Year 1 monitoring schedule was developed with three components: (a) storm-water "event" sampling; (b) periodic "sentinel" site sampling; and (c) additional beach (sand and water) sampling. The sampling specifically for this study included 22 sites (Figure 3) after at least three, 0.5 inch or greater "rain events" in each of the two seasons (wet and dry). We also sampled nine "sentinel" sites, at least three times, in each of the two seasons based upon optimal tidal conditions (late ebb tide), and four to five beach sites, at least four times each season, based upon optimal beach tidal stage (early ebb tide). Thirty three monitoring events were completed specifically for this part of the study through January of 2009.

Data on the following water quality (WQ) parameters were collected in the field for each monitoring event: dissolved oxygen (DO, mg/l), turbidity (NTU), pH, salinity, air and water temperatures (in ^{o}C), secchi depth (meters), photosynthetically-active-radiation (PAR, $\mu mol \cdot s^{-1} \cdot m^{-2}$) and total depth (meters). Depending on the focus of a particular sampling event, the following additional laboratory analyses may have been conducted at either the Lee Co. Environmental Lab or SCCF Lab: total nitrogen (TKN Kjeldahl, mg/L), nitrate plus nitrite-nitrogen (mg/L), ammonia/ammonium-nitrogen (NH_3, mg/L), total nitrogen (TN, mg/L), turbidity (NTUs), chlorophyll *a* (μg/L), pheophytin (μg/L) , total phosphorus (TP, mg/L), fecal coliform bacteria (colonies/100 ml), *Enterococcus* bacteria (colonies/100 ml), optical brighteners (raw fluorescence) and Colored Dissolved Organic Matter (CDOM, QSE).

Sampling was conducted using Florida DEP Standard Operating Procedures (SOP) FS2001 (Surface Water Sampling Protocol) as a guideline for processing and QA/QC. All water "grab samples" were collected by placing the appropriate bottles at the end of a 1.8-2.7 meter (6-9 foot) extendable pole and sampling approximately 0.1 meter below the water surface and about 1-10 meters from shore. Water samples were collected in 500 ml capacity HPDE (Daniels Scientific BPC3016) for nutrient samples; 500 ml polypropylene (Wide-mouth Nalgene bottles) for chlorophyll; turbidity, CDOM and optical brighteners; and 100 ml sterile polyethylene bottles for bacteriological samples (IDEXX, WB120SVST). Nutrient samples were preserved using 2 ml of concentrated sulfuric acid per liter of sample. Bacteriological, chlorophyll *a*, CDOM, and optical brightener samples were immediately preserved on ice at $<4^{o}C$.

Turbidity, water temperature, pH, salinity, and dissolved oxygen data were collected in the field using a calibrated Hydrolab Quanta multi-probe sonde. The sonde was calibrated before each monitoring trip. All data was recorded on standardized water quality field logsheets. At each site, the following additional information was collected: current direction, tidal stage, wind direction and speed, wave height, number of people in area, number of animals in area, macroalgae presence, percent wrack on the beach and rainfall in past 48 hours. In general, rainfall data was collected from the J.N. "Ding" Darling National Wildlife Refuge (NWR) weather station located on Sanibel Island (ROMAN 2009). This weather station was installed in December 2008. Any rainfall information preceding that date came from Lee County's Ft. Meyers Beach rainfall station located at the corner of Summerlin and San Carlos Boulevard in Ft. Myers (Lee County 2009).

Samples collected for *Enterococcus* bacteria analysis were delivered to Lee County Lab or SCCF Marine Lab within the 6 hours of collection (maximum holding time). Lee County Lab used EPA Method 1600, "Enterococci in Water by Membrane Filtration to assess *Enterococcus* in samples," (USEPA 2002). When samples were analyzed by the SCCF Lab, EPA-approved method 9230D was used (see Standard Methods for the Examination of Water and Wastewater).

For this method, (Enterolert®) fluorogenic media are used with 100 ml of the water sample. The media is mixed in a sterile, 100 ml sample container (IDEXX, catalogue no. WB120SVST) and the samples are then poured into either a 51 or 98 well Quanti-Tray® and sealed using a Enterolert® sealer from IDEXX (Westbrook, Maine). The sample trays are then incubated at 41±2°C. At the end of 24 hours, trays are removed from the incubator and *Enterococcus* bacteria colonies were enumerated by observing the number of tray wells that fluoresce (indicating enterococci present) under a 365 nm UV light. Total fluorescing wells are then summed and a most probable number (MPN) table from IDEXX is used to determine the number of colonies per 100 milliliter (cfu/100ml) sample.

Confirmation tests were performed on samples after the Enterolert® analysis was completed. Confirmation tests were necessary due to the possibility of false positive results. If the Enterolert® method produced results of 25 cfu/100 ml or greater, the results were confirmed using bile esculin azide agar (BE) plates and then brain heart infusion (BHI) broth. Confirmation tests were performed by wiping the back of the Enterolert® Quanti-Tray with an alcohol pad and piercing the back of each positive well with a sharpened and sterilized wire. A sample is removed from each positive well using a 1 or 10 μl loop and placed onto a separate BE plate and spread over the plate. The plates are incubated for 24 hours at 35°C and those colonies with a black precipitate are transferred into BHI-6.5% NaCl broth and incubated at 35°C and to BHI broth and incubated at 45°C for 24-48 hours. Samples that are turbid confirm the presence of enterococci. To better understand the limitations of this methodology, we categorized all samples by type (estuary, Gulf, groundwater, runoff) and calculated the percentage of samples which were erroneously identified as positive (false positive) using the Enterolert® method.

During beach monitoring efforts, we sampled nearshore water at our beach sites (for bacteria and nutrients) and occasionally tested for indicator bacteria in beach sand, beach interstitial water and wrack material. When sampling beach sand, 10 subsamples were combined into a composite sample for the location we were focusing on. Approximately 10 grams of the well mixed composite sample would be transferred into a sterile container and extracted with 100 ml sterilized, deionized (DI) water by shaking the sample and water together for about 90 seconds. The water would then be decanted into another sterile container and analyzed for *Enterococcus* bacteria using methods described above. Beach sand samples were taken from locations above the wrack line and also in the intertidal area of the beach. Interstitial water samples were collected by digging (about 0.5-1 m deep) through the sand near the top of the intertidal zone down to the water level. Once water filled the hole, a sample was collected in a sterilized bottle and transported on ice to the lab for enterococci analysis. Composite wrack samples (3-5 subsamples) were taken from the wrack line using forceps sterilized in alcohol to transfer samples into sterile bottles. Wrack samples were extracted into sterilized water using the same methods as described for sand. The composition of beach wrack was typically seagrass or macroalgae. When both were present we would separate the different types of wrack into individual samples.

Samples were analyzed for chlorophyll *a* at the SCCF Marine Laboratory using EPA Method 445, determination of chlorophyll *a* and pheophytin in marine and freshwater algae by fluorescence with acidification. Between 100-200 ml of water sample is filtered through a Whatman GF/F, 0.7 µm borosilicate glass fiber filter. The filter is then placed within a 15 ml capped centrifuge tube and transferred to a minus 20^{o}C freezer. Within 21 days the frozen filters were extracted using 10 ml of 90% acetone. To aid in extraction (especially cyanobacteria), the filters were ground within the acetone solution using a tissue grinder (Kontes 22 with IKA RW20 homogenizer) and tube until filters are transformed into smaller particles. The ground samples in 10 ml of 90% acetone are transferred to a refrigerator and extracted for 12-24 hours. After samples are extracted, they are centrifuged at 3000 rpm for 10 minutes to separate solid particles from acetone. The acetone supernatant is then decanted into a 5 ml borosilicate glass culture tube and inserted into a Turner Trilogy® fluorometer fitted with chlorophyll *a* head (for acidification method). The fluorometer was calibrated annually with a known chlorophyll *a* standard from Turner (Part # 10-850) and displayed as chlorophyll *a* and pheophytin *a* (in ppb or µg/L) of pigment.

CDOM samples were analyzed at SCCF Marine Lab using the Turner Trilogy® fluorometer fitted with a UV-CDOM head. Samples were preserved on ice and warmed to room temperature. Approximately 5 ml were syringe-filtered through a 0.22 µm Millex®GP filter into a 12 x 75 mm borosilicate glass cuvette culture tube. The tube with sample was then read in the fluorometer calibrated to quinine sulfate standards ranging from 0 to 500 ppb. The fluorometer's results for CDOM are reported in units of Quinine Sulfate Equivalents (QSE).

Optical brightener samples were analyzed at SCCF Marine Lab using the Turner Trilogy® fluorometer fitted with a UV-optical brightener head. Samples were preserved on ice and warmed to room temperature before analyzing. Approximately 5 ml was then transferred to a borosilicate glass cuvette culture tube. The sample was then read in the fluorometer and raw fluorescence readings recorded.

Lee County Environmental Laboratory performed all nutrient analyses. The following EPA approved methods were used by the NELAC-certified laboratory: Total Kjeldahl Nitrogen by EPA Method 351.2; Nitrate plus Nitrite Nitrogen by EPA Method 353.1; Ammonia nitrogen by EPA Method 350.1; Total Phosphorus by EPA Method 365.1. A chain of custody sheet accompanied all samples taken to Lee County Environmental Lab. The chain of custody includes a description of the samples, where and when they were taken, the temperature of the sample when delivered, the analyses to be performed on each sample and the signature of each person in possession of the sample from the time it was taken until it was delivered to the laboratory.

Results from the first year of this project were summarized parameter by parameter and then compared to relevant regulatory criteria or relevant guidelines. In Year 1, data were grouped so that results from Captiva nearshore waters could be compared to data collected around Sanibel Island, the NWR, and pooled data from the entire state of Florida (FDEP 2008) for each parameter. The Captiva grouping contained data from 113 sites located between Redfish Pass to the north and the middle of Blind Pass to the south (Figure 7), while Sanibel had 62 sites and the NWR had 16 sites. These analyses were presented in our first year report entitled Captiva Water Quality Assessment Project Year One: Summary and Findings (Thompson and Coen 2010).

In the Year 1 report, a general assessment of water quality based on the data collected in this study was made by comparing the percentage of samples which met or exceeded Florida DEP Water Quality Criteria for Marine Waters (Florida DEP) for each parameter of concern. In cases where there were no water quality criteria already established for a parameter, comparisons were made to the 70th and 90th percentile levels of all samples taken in Florida Estuaries for that parameter. During this analysis we refer to “good” as values that are less than 70th percentile value, “moderate” as between 70th and 90th percentile values and “poor” as greater than the 90th percentile value (Table 2).

Statistical Analyses

For this study, “high” season is defined as the period from January through April each year when the Captiva and Sanibel Islands are at their peak seasonal populations, while “low season” is designated as the remainder of the year (May–December). The “wet” (or “rainy”) season is defined as May-October each year, the “dry” season as November through April. Comparisons were made between results obtained during dry season (November-April) versus wet season results (May-October), between “high” season (January-April) versus. “low” season (May-December), and between rain events (0.45 inches of rain or greater in previous 48 hours) versus dry periods (at least three days no rain). Comparative analyses were also performed between results from sites near sewered portions of Captiva compared to non-sewered portions (Figure 8). All box-plot and bar graph comparisons are shown with standard error of the mean bars. Parametric and non-parametric statistical methods (Minitab® Version 13.20) were used for comparisons of means and medians. The type of test along with its test value and significance value (p) are reported for each analysis in the results section. An alpha value of $\alpha = 0.05$ for the type 1 error was used for all analyses in this report.

Year Two Focused Monitoring

Groundwater

We monitored groundwater April 2010 through March 2011. Monitoring wells were installed per Florida DEP monitoring well specifications (FDEP 2008c) at 18 sites on the Island of Captiva (Figure 9). Three additional wells were installed for comparative purposes on undeveloped natural preserve land owned by SCCF on Sanibel Island. Wells were installed using a 3.25 inch diameter soil auger with 10’ extension (Ben Meadows Part 220872). The auger was used bore into the soil until 100% saturated soil was found. At this point we continued boring for another 0.5-1.0 meters or until well wall collapsed and prevented further boring. A 1.25” Pipelife Jet Stream blue tip well point was attached to a sufficient length of 1.25” diameter, schedule 40 PVC to reach the saturated soil (Figure 10). The well point and PVC extension was then driven by mallet another 0.2-0.5 meters. The well installation was then leveled, backfilled, tamped, capped and labeled. Each well was then “developed” per FDEP recommendations

(FDEP 2008c). Wells were pumped using a Masterflex® Easy Load tubing pump (model 7518-10) connected to a Cole Parmer model 7533-50 DC motor until 20-30 volumes were displaced within the well. Each well was then left undisturbed for at least one week before samples were taken. Before each sampling event, at least 4-5 volumes were pumped from each well to assure the sample was being taken from groundwater and not water which had accumulated in the well casing. Each individual well was assigned a unique 15 foot long section of #18 Masterflex® tubing that would be used to obtain samples. The tubing resided in a 5 gallon bucket of 50% household bleach solution between each sampling events. This assured no bacteriological contamination of samples by the tubing. After samples were collected, a graduated monitoring rod was inserted into the well and a depth to water surface was measured. This depth was then converted to an elevation to obtain aquifer water level. The rod was decontaminated with a 50% bleach solution between each site. Additionally, negative control samples were routinely run to check for cross contamination. To better understand the relationship between aquifer level and tidal phase, we installed an Onset® level logger in six different wells for time periods ranging from 12 to 48 hours.

We also obtained permission to monitor two wells on northern Captiva within South Seas Plantation Resort which are part of the monitoring well array required by FDEP for spray irrigation of their reclaim water. South Seas Plantation resort is required by FDEP to monitor these wells quarterly for nitrates, bacteria and other parameters. We obtained that monitoring data from FDEP for use in this study.

To determine groundwater flow direction we converted the depth of aquifer measurements to an elevation based on ground surface elevations at the well obtained from 2007 LIDAR surveys of Captiva Island (Florida DEM, 2007). The elevations were then plotted together with distance from the Gulf coast to obtain the general groundwater elevation gradient. The flow direction was estimated from the change in elevation (flow from higher to lower).

The results from surface water monitoring in the first year of the study were used to determine those parameters which would be monitored in groundwater. Nitrogen and bacteria were the two parameters found to be of primary concern in surface waters during the first year of study. Only these two parameters (along with conductivity and salinity) were monitored in groundwater to make the best use of funds remaining.

Regional Water Quality Analyses

To give a regional perspective to our findings, we analyzed Lee County water quality monitoring data collected during the same period of this study for the area from lower tidal Caloosahatchee River to upper Pine Island Sound and from Pine Island to Captiva Island. Data were grouped into strata based on distance from the lower Caloosahatchee River (Figure 11 and 12) and descriptive statistics were calculated for several parameters. Comparisons between strata were made using the nonparametric Kruskal-Wallis test.

An estimate of nutrient limitation was made using regional water quality results from Lee County. For the period October 2008 through January 2011 water quality data collected by Lee County in the area between Pine Island and Captiva was analyzed for nutrient limitation using the molar ratio of IN:IP (inorganic nitrogen to inorganic phosphorus). Following Florida DEP guidelines for evaluating impaired waters, a ratio of less than 10 molar was classified as nitrogen limited while a ratio of greater than 30 molar was reported as phosphorus limited. Ratios between 10 and 30 molar were classified as co-limited by N and P.

Using Florida DOH data mean *Enterococcus* bacteria concentrations were calculated for Lee County Beaches for the period of February, 2006 through December, 2009. This analysis was used to compare bacteria in Captiva Gulf waters to similar beaches in the region after rain events and dry periods.

Loading Estimates

The second year of this study focused primarily on bacteria and nitrogen in surface and ground water. To estimate loadings of nitrogen from different land use types on Captiva Island, we applied methods described in the CHNEP Draft Water Quality Target Refinement Project documents (Janicki Environmental 2010) and used in previous loadings estimates for southwest Florida (Janicki et al. 2001). The SFWMD 2004-2005 GIS land use coverage was used to estimate the area of each land use classification (based on Florida DOT's FLUCCS system) on the island. Runoff coefficients for each land use were obtained from previous studies (Janicki 2010; Gao 2008) and modified when appropriate based upon local knowledge of actual development on Captiva Island. Buck Key was not considered a part of Captiva Island and was not included in the calculations performed for this study. Nitrogen concentrations for runoff from different land uses were estimated from actual sampling results and from previous loading estimates for southern Florida (Janicki 2010; Graves et al. 2004). Loading estimates were also made for discharges from OSTDs following methods outlined in CHNEP Draft Water Quality Target Refinement Project documents and other studies (Janicki 2010; Anderson et al. 2006, Hazen and Sawyer 2009). Captiva population estimates were obtained from US Census data (US Census 2010) and used for calculating septic system loading estimates. The seasonal population was estimated from analyzing trends in traffic data across Sanibel causeway (Lee County 2008) and evaluating census data on seasonal occupancy. A nitrogen removal efficiency of 10% was used for septic tanks and a removal/dilution factor of 25% was used for unsaturated soil in the drainfield (Janicki 2010; Anderson et al. 2006; Hazen and Sawyer 2009; Harden et al. 2010). A 10% failure rate for septic systems was estimated from FDOH information (FDOH 2007) and previous estimates for SW Florida (Janicki 2010). Septic tank failure is defined as the percentage of septic systems which are discharging to surface water due to inability to percolate through drainfield system (due to high water table, improper installation, improper maintenance, etc.). Other than the estimates for failure, all loadings from septic systems were assumed to go to groundwater. Most septic system drainfields on Captiva are located within 200 meters of surface water and it is hypothesized that most of the nitrogen discharged into the upper aquifer will be capable of affecting surface water before any significant denitrification occurs.

Loadings for *Enterococcus* bacteria were made by estimating septic system flows as described above and using the mean groundwater concentration for these bacteria found in this study multiplied by the estimated septic system flow. This gives an estimated loading to surface water assuming all groundwater flow caused by septic systems discharges to surface waters. *Enterococcus* loading associated with stormwater and irrigation runoff was estimated using the total estimated annual runoff volume from Captiva multiplied by the mean verified *Enterococcus* concentration for runoff samples obtained in this study (1050 CFU/100ml).

Source Identification Efforts

During the second year of this study, we developed a bacteriological source tracking approach to better define the source of indicator bacteria which increase in surface and ground waters after rainfall events. The approach involved 3 or 4 steps including the Enterolert test, BE and BHI confirmation tests, speciation using the Biolog carbon source utilization system and DNA analyses using a human biomarker for confirmation of human source (Figure 13). The the source tracking approach was used in attempts to characterize the relative importance of humans as a source of indicator bacteria concentrations in our surface and ground waters. The Enterolert test was used as a course screening for the presence of *Enterococcus* bacteria. Positive results using this system were then transferred to confirmation tests on BE azide plates and BHI broth to confirm the presence of enterococci in the samples. After confirmation with these two steps, samples testing positive were sent to INX Labs in Groveland FL for analyses using the Biolog GEN III carbon substrate utilization assay. The Biolog GEN III system uses a 94 well media tray containing 71 carbon source media and 23 chemical sensitivity assays. All 94 wells are inoculated with sample and incubated for 48 hours. After 48 hours the plates are read by a computerized spectrophotometer which determines the wells that are positive for growth or reactivity. A computer program then matches the pattern of growth and reactivity to a library of known bacteria species. These analyses provide a 95% confidence level identification for the *Enterococcus* bacteria species present in the sample. Previous studies have shown that human fecal waste contains primarily *Enterococcus faecalis* and *Enterococcus faecium* species (Manero et al. 2002; Blanch et al. 2003; Bonilla et al. 2006). Samples testing positive for the genus *Enterococcus* but which contain species other than *faecalis* or *faecium* are most likely from sources other than human. However if a sample contains primarily species *faecalis* or *faecium,* this does not necessarily mean the source is human, as these two *Enterococcus* species have been found to be associated with many other organisms, including plants (Hagedorn et al. 2003; Bonilla et al. 2006). The Biolog carbon source utilization data was analyzed using a discriminate analysis approach similar to Hagedorn et al. (2003) as well as analyzed using multi dimensional scaling (Minitab® Version 13.20; Primer v5). Variables for the analyses were the classification of carbon substrate containing wells as to their condition after incubation (positive or negative). For our analyses a number of known feces samples were obtained including raccoon, bobcat, opossum, shorebirds, pelicans and humans. The results of the Biolog analyses for the known samples were analyzed using discriminate analyses setting their classification group as “human” or “non-human”. Biolog results from unknown surface and groundwater samples were then compared to these ‘known” categories and a classification obtained as to likely grouping (Hagedorn et al. 2003). A multi-dimension scaling (MDS) plot was also made of all unknown samples to compare to the known human and non-human groups.

A few samples which were confirmed positive for *Enterococcus* bacteria and then found to have either *E. faecalis* or *E. faecium* species present by the Biolog analyses were shipped to Source Molecular Company in Miami, Florida for additional analyses. At Source Molecular, the samples were analyzed for the presence of *E. faecium* containing a human biomarker. If the sample was confirmed to have this species with the human biomarker, it was considered confirmation that the sample was contaminated with human fecal matter. Due to the very expensive nature of these DNA based analyses, only 10 samples were processed during this study.

Macroalgae and Enterococci Mini-Study

As part of this study, a concurrent study was initiated by a SCCF Marine Lab intern during the first year of this study to examine the relationship between algae on the beach and enterococci bacteria. The goal of this study was to determine if enterococci-free macroalgae placed on the beach would be inoculated with enterococci from the environment and become a growth media and to determine if there was a difference in concentrations of macroalgae at beaches which have higher historical levels of enterococci. This study was initiated after high concentrations of enterococci were observed in areas with high macro algae concentrations. Samples of water, macroalgae, and sand were collected from Sanibel and Captiva and nearby beaches in order to determine the abundance of enterococci in each of these media. Samples were collected with tweezers or gloves cleaned between samples with ethanol, placed in sterile 100 ml vials, and held on ice and in the dark until tested. Subsamples of sand and macroalgae were extracted with 100 ml of sterile water and the vials were vigorously shaken in for one minute order to extract enterococci from the samples. Marine and estuarine water samples were diluted 1:10 to kill *Bacillus spp.* bacteria, which can produce false positive results when using the Enterolert® system. *Bacillus spp.* bacteria do not survive well in low salinity solutions. The Enterolert® media was added to the water, mixed thoroughly, and the solution was sealed in an Enterolert® tray. After 24 hours of incubation at 41° C, the number of wells that glow blue under an ultraviolet light (positive) were recorded and the most probable number (MPN) of enterococci was determined using the Enterolert® MPN chart. Sand and macroalgae samples were weighed and dried in order to determine both wet and dry weights which were necessary for determination of the MPN per gram of sample.

Samples collected included water, macroalgae in the water, damp wrack macroalgae, desiccated wrack macroalgae, and both intertidal and dry sand. Samples of a second type of wrack comprised of a mixture of small leaves, sticks, and seeds were collected to determine if macroalgae was the only wrack substrate that was conducive to the growth of enterococci.

In addition, macroalgae was collected from two sites of the SCCF drift algae research project. Site 03 (26.41583, -82.11079) was a nearshore site with a depth of 5.7m and site 12 (26.55452, -82.28576) was an offshore site at a depth of 13.5 m. Macroalgae was placed in a sterilized mesh bag and transported in sterile jars and a cooler back to the lab where the samples were extracted and the Enterolert® system was used to determine the bacterial levels contained on the surfaces of the macroalgae.

It was been determined that if boiling water is poured on enterococci -containing macroalgae, the bacteria will be killed and the macroalgae will test negative for enterococci (Thompson and Kovacs, unpublished). Cages made from plastic fencing material approximately 25 x 25 x 5 cm in size were filled with macroalgae of the genera *Acanthophora*, *Agarghiella*, and *Gracilaria* and deployed at 4 beach sites just below the wrack line using a piece of pvc pipe and zip ties. The sites were Bowman's Beach, Blind Pass beach on Sanibel Island, and 'Tween Waters, and Alison Hagerup beach (also referenced as South Seas Plantation) on Captiva Island. All cage and deployment materials were sterilized prior to use via heat or bleach and were handled while wearing ethanol sterilized gloves.

Past data from the Florida Department of Health showed that Bowman's Beach and Blind Pass have significantly higher levels of enterococci than Captiva Beach, which has not had any closures within the past few years. It was predicted that the macroalgae would become inoculated with enterococci from elements in the beach environment and the bacteria would grow and reproduce within the nutritious habitat of the macroalgae. In addition, enterococci levels were expected to be higher in the macroalgae at Bowman's Beach and Blind Pass, where more enterococci would be present. At Bowman's beach an addition set of macroalgae cages were placed above tidal range to act as a control in order to discern if the enterococci inoculating the macroalgae was coming primarily from the ocean or if there was an additional source. As an additional control, macroalgae was sterilized via boiling water, tested for enterococci and allowed to sit in a sealed jar for five days, then tested again. Controls to test for sterility of the process were also run, in which sterilized water was tested according to the Enterolert process.

The cages remained on the beach for eight days, with testing for enterococci occurring after days one, four, six, and eight. The cages were moved periodically in order to ensure that they were affected by the tides enough to keep them damp but not so much as to wash away the macroalgae. During each day of testing, macroalgae sub-samples were returned to the lab and the Enterolert® system was used to determine enterococci levels.

Results

Potential Pollutant Sources and Land Use

The results of surveys used to identify and map potential sources of pollution are shown in Table 3 and Figure 14. Stormwater outfalls, golf course runoff, areas with dense concentrations of septic systems, high density developments, and wastewater treatment plants were initially identified as potential sources. The results of estimating local watersheds (drainage basins) using ARCGIS® (Version 9.3) software is shown in Figure 6. Watershed delineation on an area of such minor variation in relief is difficult. In general, surface water flows from the highest part of Captiva (the primary dune) toward Pine Island Sound to the east and toward the Gulf to the west. Areas with large amounts of impervious surface often do not conform to natural flow paths and GIS derived watersheds may be imperfect.

Compilation and Review of Existing Data

Over 15,000 water quality monitoring events by various agencies and organizations were collected in the vicinity of the study area since 2003. Upon further review a smaller set of data contained water quality data with parameters of interest in the immediate vicinity of Captiva and northern Sanibel Islands. There were only a small number of historical samples collected within the near shore shallow waters of Captiva. Most water quality sampling in the area takes place within Pine Island Sound greater than 50 meters offshore of Captiva. The City of Sanibel does monthly water quality monitoring in the Blind Pass area which was useful for examining water quality which affects lower Captiva. Lee County collects monthly water quality data from random sites in Pine Island Sound which are sometimes located in Captiva near shore waters.

Historical water quality data showing elevated levels of nutrients, chlorophyll *a*, or bacteria are plotted in Figure 15. Most of the elevated levels of nutrients occurred within the northern Sanibel bayous area (Dinkin's and Clam Bayou). The Florida DOH monitors two Captiva beaches weekly for indicator bacteria in the near-shore water. Since 2006, there have been 8 instances of elevated enterococci levels at Turner (Blind Pass) Beach and 1 occurrence at Allison Hagerup beach. All elevated bacteria events came after significant storm events within the preceding 48 hours. The Florida DOH also monitors near-shore water at 3 of Sanibel Island's beaches. Historical data for these Sanibel beaches were similar to the Captiva beach data with from 4-8 instances of elevated indicator bacteria all occurring after significant rain events.

Rainfall

During the period of study (October 2008 through February 2011), annual rainfall was significantly less than the 40 year annual average. Nearby Fort Meyers recorded a -16.4 inch rainfall anomaly in 2008 and a -19 inch anomaly from the 40 year mean in 2009. Total precipitation in 2010 was at the 40 year average of 54 inches (Weatherbase 2011). The dry seasons (November – April) of 2007-08 and 2008-09 were exceptionally dry at 5.5 and 3.3 inches compared to the 40 year average of 11.4. The 2009-2010 dry season had greater rainfall at 21.7 inches and a drier than average wet season.

Year One (2008-2009) Baseline Assessment Results by Parameter

Enterococci Bacteria

During the baseline assessment portion of this study we found that concentrations of *Enterococcus* bacteria in local waterbodies were significantly greater (Mann-Whitney: $P<0.0001$; $n=273$) following a rainfall event (0.5 inches or greater in past 48 hours) than levels present after at least 48 hours of no rainfall (Figure 16). There were also significantly higher enterococci levels during the wet season as compared to the dry season (Mann-Whitney: $P<0.0001$; $n= 391$) and during "low season" compared to "high season" (Mann-Whitney: $P\leq 0.001$; $n= 325$).

The percentage of Captiva Island nearshore Gulf samples exceeding water quality criteria during the period of our study was low with only 4% falling within the moderate category and 1% within the "poor" category (Figure 17). This is comparable to the results from Sanibel Island stations and better than the overall data for Florida and U.S. beaches (Dorfman and Roselot 2009).

For Captiva Island estuary stations, the percentage of samples having enterococci greater than the state water quality criteria was higher than Gulf side results with 15% exceeding the single sample limit of 105 colonies/100 ml and 14 % exceeding the "moderate" level of 35 colonies/100 ml (Figure 18). This was comparable to Sanibel stations, while the NWR stations were considerably lower in enterococci for the period.

The mean enterococci concentration for all interstitial beach water samples collected in our study was 10.1 colonies per 100ml sample, while means for all beach sand and wrack samples were 25.1 and 2,364 colonies per gram dry weight of sample respectively (Table 4). The standard deviations were great for all three types of samples due to large variation in results.

Chlorophyll a

Results of chlorophyll *a* monitoring demonstrate significantly higher mean levels at estuary stations during the wet season when compared to the dry season (Figure 19, Mann-Whitney, $p < 0.0001$, n = 218). Significantly higher mean chlorophyll *a* concentrations were also observed during "low season" compared to "high season" (Figure 19, Mann-Whitney: $p < 0.0001$; n = 232) and after rain events versus dry periods (Figure 19, Mann-Whitney: $p = 0.005$; n=112). Results from Gulf stations monitored during the study period revealed little difference between Captiva, northern Sanibel and Florida historical data for the same period (Figure 20). Results (*see* Figure 21) from estuarine (Pine Island Sound) stations revealed the proportion of samples exceeding criteria near Captiva Island (12%) was similar to the NWR and Florida estuaries as a whole (10%) but less than the results from stations on northern Sanibel Island (25%).

The mean chlorophyll *a* concentration for pooled estuary station data (6.21 mg/L) was found to be significantly greater than the mean chlorophyll *a* concentration for pooled Gulf station data (3.61 mg/L) (Unequal Variance t-Test, $t = 6.09$, $p < 0.0001$; n= 65).

Total Nitrogen

For purposes of this study, we defined "poor" water quality as any value above the 90th percentile (1.2 mg/L) of all Florida estuary results for TN (DEP 2008) and "moderate" water quality as any value between the 70th (0.93 mg/L) and 90th percentile for all Florida data (Table 2). Assessment of data collected during this study to date shows that total nitrogen at estuary stations is significantly higher during the wet season than the dry season (Figure 22, Mann-Whitney: $p = 0.020$; n = 153). However, no significant difference could be found between TN during "high" season compared to "low" season (Mann-Whitney, $p = 0.08$, n=126) nor after a rainfall event compared to a dry period (Figure 22, Mann-Whitney, $p = 0.060$; n=83).

Total nitrogen results from Gulf stations monitored during the study period revealed little difference between Captiva (0% "poor") and northern Sanibel (0% "poor") data for the study period (Figure 23). Both areas appeared slightly less degraded than the Florida overall data (10% "poor") for Gulf stations. Results from estuary stations revealed the proportion of samples exceeding criteria near Captiva Island (0%) was similar to the NWR (3%) while poor results from stations on northern Sanibel Island (15%) and all other Florida estuaries as a whole (10%) were more frequent (Figure 24). The mean TN concentration for pooled estuary station data (0.546 mg/L) was found to be significantly greater than the mean TN concentration for pooled Gulf station data (0.204 mg/L) (Unequal Variance *t*-Test: $t = 8.6$; $p < 0.0001$, n=36).

Ammonia/Ammonium

For the purposes of this study, we defined "poor" water quality as any value above the 90th percentile (0.087 mg/L) of all Florida estuary results for ammonia/ammonium (FDEP 2008b) and "moderate" water quality as any value between the 70th (0.0.05 mg/L) and 90th percentile for all Florida data (see Table 2).

Ammonia at estuary stations is significantly higher after a rain event versus a dry period (Mann-Whitney: $p = 0.004$; n=96), and also during "low" season compared to "high" season (Mann-Whitney: $p = 0.027$; n=107). No significant difference in ammonia could be found between wet season versus dry season (Figure 25, Mann-Whitney: $p = 0.249$; n=109).

Ammonia from Gulf water samples collected during the study period demonstrated both Captiva (28% in "poor" category) and northern Sanibel (17% "poor" category) had relatively higher proportions of “poor” ammonia concentrations compared to all Florida coastal stations (Figure 26). Results from estuarine stations revealed the proportion of samples with high levels of ammonia near northern Sanibel (23% “poor”) was relatively higher than Captiva Island (13% poor), the Wildlife Refuge (8% “poor”) and Florida estuarine stations overall (10% “poor”) (Figure 27).

The mean ammonia concentration for pooled estuarine station data (0.0542 mg/L) was found to be significantly greater than the mean ammonia concentration for pooled Gulf station data (0.0308 mg/L; Unequal Variance *t*-Test: $t = 5.5$, $p < 0.0001$; n=35).

Total Phosphorus

For purposes of this study, we defined “poor” water quality as any value above the 90th percentile (0.23 mg/L) of all Florida estuary results for TP (DEP 2008b) and “moderate” water quality as any value between the 70th (0.133 mg/L) and 90th percentile for all Florida data (see Table 2).

Assessment of data collected during this study to date shows TP at estuary stations is significantly higher after a rain event versus a dry period (Figure 27, Mann-Whitney: $p = 0.006$, n = 113), however no significant difference in TP could be found between wet season versus dry season (Figure 27, Mann-Whitney: $p = 0.06$; n=155) or “high” season compared to “low” season (Figure 28, Mann-Whitney: $p = 0.18$; n=156).

Results for total phosphorus from Gulf stations monitored during the study period demonstrated both Captiva (30% “poor” category) and northern Sanibel (50% “poor”) had relatively high TP concentrations for Gulf stations compared to all Florida coastal stations (Figure 29). Results from estuary stations revealed the proportion of samples with high levels of TP near Captiva Island (1% “poor”), Northern Sanibel (0% “poor”) and the NWR (0% “poor”) were low when compared to data from all Florida estuaries (10% in “poor” category) (Figure 30).

The mean TP concentration for pooled nearshore Gulf of Mexico station data (0.10 mg/L) was significantly greater than the mean TP concentration (0.043 mg/L) for pooled estuarine station data (Unequal Variance *t*-Test: t=-2.17; $p = 0.035$; n = 43).

Dissolved Oxygen

Assessment of data collected during this study to date shows DO at estuary stations is significantly lower during wet season compared to dry season (Figure 31, Mann-Whitney: $p < 0.0001$; n=334), lower during "low" season compared to the "high" season (Figure 31, Mann-Whitney: $p = 0.002$; n=334) and lower after rain events compared to dry periods (Figure 31, Mann-Whitney: $p < 0.0001$; n=219).

Dissolved oxygen results from gulf stations monitored during the study period (*see* Figure 32) showed Captiva (6% "poor") and northern Sanibel (6% "poor") had very similar proportions of low DO levels when compared to all Florida coastal stations (6%). Results from estuarine stations revealed that the proportion of samples with low DO levels near Captiva Island (19% "poor"), northern Sanibel (41% "poor") and the NWR (18% "poor") were much higher compared to data from all Florida estuaries (9% "poor") (Figure 33).

The mean DO concentration for pooled Gulf station data (5.81 mg/L) was found to be significantly greater than the mean DO concentration for pooled estuarine station data (5.26 mg/L) (Unequal Variance *t*-Test: t=5.37, p <0.0001; n=126).

Turbidity

Mean turbidity levels at estuary stations were greater in dry season versus wet season, "high" season versus "low" season and during a period of no rain compared to after a rainfall event (Figure 34). Mean turbidity values for pooled ocean station data (9.6 NTU) was also greater than the mean value for pooled estuary station data (6.3 NTU) (Unequal Variance T-Test: $t = 2.71$, $p = 0.008$).

Colored Dissolved Organic Matter (CDOM)

Mean CDOM levels were greater in "wet" season versus "dry" season and "low" season versus "high" season, while no significant difference could be detected for samples taken after a rain "event" compared to samples taken during a period of no rain. Mean CDOM values for pooled estuary station data (30.8 QSE) was also greater than the mean value for pooled ocean station data (10.0 QSE) (Figure 35, Unequal Variance *T*-Test: $t = 17.64$, $p < 0.0001$, n=100).

Salinity

The mean salinity (PSU) for pooled data from Gulf stations (35.98) was greater than the mean salinity for pooled data from estuary stations (34.07) in our study. Salinities at the 20 stations showing the most variability had a maximum range of 33.5 to a minimum range of 9 during the study period (Table 5).

Year Two (2009-2010) Focused Monitoring

Groundwater

The flow direction of groundwater in the upper aquifer beneath Captiva was found to be from the middle of the primary dune eastward to the estuary with a smaller portion traveling westward toward the Gulf (Figure 36). All water table elevation data taken from cross-island well transects showed this general pattern. Due to tidal effects, the aquifer surface was also found to vary as much as 0.5 m in elevation during a tidal cycle depending on location and tidal phase (Figure 37). The mean distance from soil surface to water table surface for the wells in this study was 0.98 meters.

Overall, mean *Enterococcus* concentrations in Captiva groundwater were below Florida DOH criteria values for healthy beaches. Table 6 summarizes the data collected for each monitoring well. Mean *Enterococcus* concentrations ranged from 1 to 43 cfu/100ml while nitrate concentrations ranged from 0.01 to 2.48 mg/l. Mean salinity values were related to the distance from the estuary or Gulf with those sites closer to the water having higher salinity. The mean groundwater *Enterococcus* concentration for samples from monitoring wells within the non-sewered portion of Captiva (11.5 cfu/100ml) was not significantly different than that of the sewered portion of Captiva (10.2 cfu/100ml) or the three reference wells (16.4 cfu/100ml) on Sanibel undeveloped preserve lands (Kruskall-Wallis, $z = 0.43$, $p = 0.664$; Figure 38). The mean nitrate concentration (1.11 mg/l, $n = 67$) for Captiva wells within the non-sewered area was significantly greater than the wells within the sewered area (0.1 mg/l, $n = 37$) and the reference wells (0.2 mg/l, $n = 7$) (Kruskall-Wallis, $z = 5.2$, $p < 0.01$; Figure 39). Nitrate concentrations (1.3 mg/l, $n = 17$) in the high (human) population season were significantly greater compared to the low season (1.0 mg/l, $n = 50$; Kruskall-Wallis, $z = 1.9$, $p = 0.05$), while *Enterococcus* concentrations were not found to be different between seasons (Kruskall-Wallis, z = 0.58, p = 0.564).

After rain events we found significantly higher concentrations of enterococci in wells (Kruskall-Wallis, z = 1.5, p = 0.05), but no significant change in groundwater nitrates (Kruskall-Wallis, z = 0.93, p = 0.352). Comparison of mean *Enterococcus* concentrations in wells with mean water levels less than 1.1 meters from the ground surface to those with deeper water tables revealed no significant difference in values although mean concentrations were higher in shallower wells (shallow well = 16.1 cfu/100ml, n = 74; deeper wells = 11.9 cfu/100ml, n = 43).

Groundwater/Runoff/Surface Water Relationships

Groundwater from Captiva discharges to Pine Island Sound and the Gulf of Mexico provide a link between surface and groundwater quality (Figure 36). No significant difference could be found between mean *Enterococcus* concentrations in estuary waters compared to groundwater or Gulf side waters during a period with no rainfall reported in the preceding 48 hours (Kruskall-Wallis, z = 1.07, p = 0.564; Figure 40). Results from the Year 1 baseline assessment showed significantly greater *Enterococcus* concentrations in estuary and Gulf waters after rainfall events. Comparing estuary to Gulf and groundwater after rain events we found significantly greater enterococci levels in the estuary (mean = 75.3 cfu/100ml, n = 127) compared to the Gulf (mean = 17 cfu/100ml, n = 94) or groundwater (25.1 cfu/100ml, n = 53) (Kruskall-Wallis, z = 4.4, $p < 0.01$; Figure 40). *Enterococcus* bacteria in stormwater runoff was significantly greater than Gulf, estuary or groundwater concentrations after a rainfall event (Kruskall-Wallis, z = 9.5, $p < 0.01$; Figure 41). When we compared sewered to non-sewered areas of Captiva we found no significant difference in *Enterococcus* levels after rain events for either estuary or gulf samples (Kruskall-Wallis, z = 0.25, p = 0.803).

Mean total nitrogen (TN) concentrations were significantly greater in groundwater (1.91 mg/l) and runoff (2.80 mg/l) compared to estuary (0.45 mg/l) or Gulf (0.34 mg/l) (Kruskall-Wallis, z = 11.9, $p < 0.01$; see Figure 42). Mean TN concentrations for estuary sites within the non-sewered portion (0.46 mg/l) of Captiva were significantly greater than for sites within the sewered portion (0.38 mg/l) of Captiva (Kruskall-Wallis, z = 2.09, p = 0.037; see Figure 43). No difference could be found when comparing TN for sewered (0.36 mg/l) versus non-sewered (0.33 mg/l) in Gulf side samples (Kruskall-Wallis, z = 1.29, p = 0.198; see Figure 43). Mean TN concentrations for estuary samples were greater during the wet season (0.51 mg/l) than during the dry season (0.39 mg/l) (Kruskall-Wallis, z = 3.32, $p = 0.04$; see Figure 44) but no significant difference could be seen for Gulf samples in wet season. When comparing mean Gulf and estuary TN after rain events to a no-rain period we were not able to detect significant differences (Kruskall-Wallis, z = 0.41, $p = 0.82$).

Regional Water Quality Comparisons

Using Lee County monitoring data from stations at least 0.5 km offshore for the period October 15, 2008 through January 1, 2011 we evaluated mean TN concentrations for distance strata from the lower Caloosahatchee Estuary to upper Pine Island Sound and found a general decreasing trend in TN as you move farther away from the Caloosahatchee (or closer to the Gulf) (Figure 45). This same general trend is evident for total organic carbon, total phosphorus and KdPAR (Figure 46). There was no apparent trend in *Enterococcus* concentrations as mean values were near detection levels (Figure 47). Mean chlorophyll *a* concentrations were greatest near mid Pine Island Sound and lower toward the mouth of the Caloosahatchee or Charlotte Harbor (Figure 48).

An analysis was also performed on Lee County data from the same period combined with data from this study on a transect from Pine Island to Captiva. In general mean TN, TP and TOC values were greater near Pine Island and Captiva Island and lesser toward the middle of Pine Island Sound (Figure 49). Chlorophyll *a* concentrations were greater near Captiva Island than in Pine Island Sound or near Pine Island (Figure 50). No pattern could be seen for *Enterococcus* concentrations as the variability of the results was high and most results were at the detection limit for the method (Figure 51).

In a large majority (87%) of samples nitrogen was the limiting nutrient with phosphorus limiting in only 5 % of the samples taken (Figure 52), based upon Redfield ratio calculations.

From Florida DOH data it was found that near-shore waters of more urbanized Lee County beaches showed a greater concentration of *Enterococcus* bacteria after rainfall events compared to beaches with less urbanized watersheds (Figure 53). Water quality for Captiva was typical of the more urbanized watersheds with large increases in enterococci concentrations after rain events.

Source Identification Efforts

Samples of golf course turf grass, grass blades from residential lawns, macroalgae from various gulf and estuary locations, beach wrack, floating wrack, wild animal feces, soil, marine sediment, and seagrass blades were obtained and tested for the presence of *Enterococcus* indicator bacteria. In most cases, these samples had relatively high concentrations of the indicator bacteria (Figure 54).

Mean percent false positives using the Enterolert® system varied significantly between sample types with over half of the groundwater samples being erroneously identified as containing enterococci (Figure 55). Using the results from Biolog speciation analyses, the percentage of samples (by sample type) found to contain at least one of the two *Enterococcus* bacteria most commonly associated with humans was between 7 and 50% (Table 7).

Due to a cost per sample greater than $400.00, only 13 total samples were processed using the *Enterococcus* human DNA biomarker technique during this study, but based on this limited sample size the estimated percentage of samples (by type) confirmed to have human *Enterococcus* present was between less than 7 and less than 47 % (Table 7).

Loading Estimates

Runoff coefficients and mean nitrogen concentrations used during this analysis are shown in Table 8. The total estimated nitrogen loading due to stormwater and irrigation runoff from Captiva Island was 2,800 kg/year (Table 8) or 8.84 kg/ha/yr (7.87 lbs/acre/yr). Of the total anthropogenic nitrogen loading from runoff, the large low-density residential area at the south end of the island, high density residential in South Seas Plantation (SSP), roads and the SSP golf course were the largest contributors.

The total number of septic tanks on Captiva was estimated to be 303 by counting the number of land parcels having structures in the non-sewered portion of the island. From U.S. census data the total number of continuously occupied septic systems was estimated to be 121, with 78 systems seasonally occupied. Each system was estimated to have 1.95 users with a total of just over 100,000 people-days of use annually for all systems on Captiva ([365days/yr x 1.95 people/household x 121 continuous households] + [91.3 days/yr x 1.95 people household x 78 seasonal households]). A mean total nitrogen loading of 11.2 grams per person per day was used

(USEPA 1980) for the input to the septic systems with an estimated 10% reduction for TN (Hazen Sawyer 2002) in the septic tank. An estimated 10% system failure rate was used for Captiva based upon Florida DOH data (DOH 2010). Nitrogen reduction in the unsaturated drainfield zone was estimated at 25% (Hazen Sawyer 2006). Using these values, an estimated TN loading to the environment from Captiva septic tanks of 1,550 kg/year was calculated. Total nitrogen input from Captiva based upon septic tank loading and runoff is estimated to be 4,344 kg/year of which 36% originates from septic systems and 64% can be attributed to stormwater and irrigation runoff (Figure 56).

The enterococci bacteriological loading from Captiva was estimated by using runoff data provided in Table 8 and a mean concentration 1,050 cfu/100 ml for enterococci in stormwater (results from this study). Annual infiltration (2,148,474 m^3) was estimated by subtracting total annual runoff volume (Table 8) from total rainfall volume on Captiva. Loading due to infiltration to groundwater was estimated by multiplying infiltration flow by mean groundwater enterococci concentration of 12.1 cfu/100 ml. Septic system loading was estimated from the product of annual septic system flow (47877 m^3) and mean groundwater *Enterococcus* concentration of 12.1 cfu/100ml. Due to the sandy composition of Captiva soils and close proximity to surface waters, it is assumed that all infiltration and septic tank flow eventually discharges into the near shore surface waters through groundwater flow. The total estimated annual enterococci loading from Captiva Island is 12651 billion colony forming units. Of this total about 98% is estimated to be from stormwater and irrigation runoff while about 2 % is discharge from groundwater flow into surface waters (Figure 57).

Macroalgae and Enterococci Study

At all study sites *Enterococcus* bacteria colonized the experiment's sterilized macroalgae after only 24 hours exposure on the beach. After 8 days, significantly greater concentrations of *Enterococcus* bacteria were found compared to day 1 (Mann-Whitney pooled data, W= 15, p = 0.0122; see Figure 58). ANOVA performed on log transformed data did not reveal significant differences in enterococci concentrations between sites (f= 0.76, p = 0.557, n = 9) Daily sampling of near shore waters at each site revealed no detectable concentrations of *Enterococcus* bacteria existed during the 8 days of the study. No measurable precipitation was recorded during the study period.

Discussion

Related Events

The evaluation of results from this study must be interpreted in the context that several unusual events likely affected water quality in the study area during this period. First, the Bayous wastewater treatment plant and holding pond was taken offline and decommissioned in the spring of 2008, a few months before the start of this project. The plant's wastewater holding pond was suspected of discharging to the surrounding environment through surface and groundwater transport and was cited by Florida DEP several times. Secondly, the tidal connection between Pine Island Sound and the Gulf of Mexico at the boundary of Sanibel and Captiva Islands (Blind Pass) was reestablished in August, 2009 after 10+ years of closure caused by coastal accretion and sedimentation. Gulf waters which are lower in nutrients, turbidity, color and chlorophyll *a* are now mixing with estuarine waters in areas of Captiva where tidal exchange was previously minimal. In a study recently completed by SCCF Marine Lab in cooperation with Bayous Preservation Association (BPA), the reopening of Blind Pass was found to have measurable effects on several water quality parameters within 1.7 kilometers of the pass (Milbrandt et al. 2011). CDOM and chlorophyll *a* were found to be significantly lower within 1.7 km of blind pass while turbidity was found to be higher. These changes were caused by dilution effects along with increased flow rates and resuspension of fine organics. No measurable changes in nitrogen, phosphorus or indicator bacteria were found to be associated with the opening of Blind Pass.

Year One Baseline Assessment Discussion

Please refer to the year one report (Thompson and Coen 2010) for a more detailed discussion of findings during the baseline assessment. A summary of the first year findings are presented here as a starting point to provide context for discussing the second year's efforts.

Results from the first year of this study were based upon only a single year of data, whereas water quality trend assessment typically requires 10 or more years of data (Elsdon and Connell 2009). During the 2008-2009 study period, water quality around Captiva was fairly good during dry periods and slightly impacted by nutrient enrichment and bacterial contamination during wet periods and after rain events. During the first year of this study we had significantly less rainfall than average, no hurricanes, no macroalgae stranding events and no beach closures due to elevated bacteria concentrations in the water.

The results from the first year of this study also suggest that in general the Gulf waters of Captiva and northern Sanibel Islands had average or above average water quality when compared to all Florida data taken as a whole (FDEP 2008b). Bacteria concentrations were noted to be higher after rain events and significantly greater nitrogen concentrations were found during the wet season suggesting that further investigation into the probable sources was warranted. We found high concentrations of TP at coastal (Gulf) sites but low concentrations at estuary sites suggesting a regional source of phosphorus such as Charlotte Harbor (Peace River watershed) or Tampa Bay discharges travel here through prevailing longshore currents.

In the first year of the study we found that Captiva waters do not have significantly greater concentrations of nitrogen than other Florida estuaries. However, this does not put proper perspective on the fact that Captiva Island is in an oligotrophic, very low nutrient environment and local loadings may be enough to trigger detrimental water quality issues such as hard bottom mortality or macroalgae blooms. In general offshore hard bottom areas and barrier island habitats are more sensitive to slight increases in nutrient concentrations than estuarine habitats (Lapointe 1997). A study of the causes of macroalgae blooms in the Sanibel and Captiva area confirmed that local macroalgae uses terrestrially-derived nitrogen (from stormwater runoff) to fuel its propagation (Milbrandt et al. in Loh et al. 2011).

Year Two Focused Monitoring Discussion

Groundwater/Surface Water Relationships

The groundwater monitored in this study is actually a freshwater lens underlain by denser salt water. Captiva groundwater flow direction is perpendicular to the long axis of the island with the axis centered beneath the primary dune, a pattern consistent with findings for other barrier islands in Florida (Ruppel et al. 2000). Variation in groundwater level due to tidal influence is well documented for barrier islands such as Captiva (Corbett et al. 2000). The tidal signals observed by water level sensors in our study wells were offset from the local (Pine Island Sound or Gulf) tides between 15 minutes to 3 hours, depending on the distance the well was located from the coast. These findings were coupled with the fact that Captiva soils are merely sandy deposits from the Gulf. Therefore, we can extrapolate that groundwater in the freshwater lens below Captiva can travel rapidly through the soil and is predicted to discharge to estuarine and Gulf waters as other studies have found for Gulf barrier islands (Corbett et al. 2000).

The mean distance between soil surface and groundwater surface (water table) for all 21 wells monitored on Captiva was 0.9 m (Table 6). Florida DOH regulations require a minimum of 1.1m unsaturated soil over the highest annual water table to install a septic system (Florida DOH 2010). Over 60% of the locations (wells) monitored had water table levels at greater elevations than a conventional septic system could be legally installed in 2011 and operate properly. The Florida DOH regulations were put into effect after a majority of the known septic systems on Captiva were installed which leaves the possibility that many (or most) septic systems on Captiva were not installed to today's codes and standards protective of water quality. The Florida Department of Health has just over 100 records of septic systems on Captiva (FDOH 2011 personal communication) and there are over 300 parcels with housing units on septic systems (GIS analysis; Figure 8). Properly operating septic systems require a minimum of 24 inches of unsaturated soil beneath the drainfield to allow removal of organics and pathogens from wastewater (USEPA 1999; FDOH 2008). Nitrogen is primarily in the form of ammonia coming from a septic tank, and the unsaturated soil layer converts the ammonia to nitrate, the first step in denitrification, which is the removal of nitrogen from the groundwater. Most areas of Captiva do not meet the minimum unsaturated soil layer requirements and septic systems installed within these areas have reduced wastewater treatment effectiveness and are not protective of good water quality.

Findings from this study indicate that Captiva septic systems are not contributing significant numbers of *Enterococcus* bacteria to groundwater. Bacteria concentrations were low and similar to reference sites and wells on the portion of Captiva with a sewer system. This is contrary to the idea that many septic systems on Captiva are improperly installed and may be less effective in removing pathogens and organics. Septic systems and drainfields on Captiva appear to be removing these indicator bacteria. Low concentrations of enterococci may also be attributable to the inability of these indicator bacteria to survive in subsurface environments which are partially aerated, partially anaerobic, changing in salinity and are flowing through a sand media. Most households discharge chemicals, drug by products, disinfecting agents, hormones and other compounds which may make the waste stream and subsurface environment too harsh for these indicator bacteria.

Findings from this study also indicate that concentrations of nitrate in the groundwater beneath Captiva are elevated relative to reference wells, relative to estuary and Gulf surface water samples and relative to groundwater samples on the portions of Captiva with sewer system. During the high season when Captiva's population triples, nitrate concentrations in the groundwater were significantly greater than during the low population season. In addition, surface water monitoring results for the non-sewered portion of Captiva demonstrated that surface water sites near septic systems on Captiva have greater nitrogen concentrations. Together, these findings support the case that septic systems are not adding indicator bacteria but are in fact adding nitrogen to the groundwater beneath Captiva.

These findings do not necessarily suggest a significant number of septic systems on Captiva are malfunctioning or operating less effectively than other conventional septic system. Properly operating conventional septic systems generally remove a very small portion of the nitrogen in the waste while removing organics and pathogens. Of the septic systems on record for Captiva, a large proportion are advanced wastewater treatment systems which are capable of removing nitrogen from wastewater.

The presence of elevated groundwater nitrogen in areas using septic systems is a common occurrence (Cantor 1996; Corbett et al. 2002; Anderson 2006) and does not indicate that septic systems are malfunctioning, but instead highlights the fact that conventional septic systems remove only a very small portion of nitrogen from the waste stream (USEPA 1999). Over 70% of the nitrogen in domestic wastewater is contained in liquid form as urine (FDOH 2010b). In the first stage of a septic system, the tank removes solids and partially digests the organics contained within the solids (USEPA 1999). In this step, only about 10% of the nitrogen is removed with the solids, a majority is discharged from the tank and flows into the drainfield. The purpose of the drainfield is to disperse the waste stream over a large area of aerated subsurface soil on which microbes have colonized. As the waste flows over the unsaturated soil pathogens are killed and the microbes remove organics.

Nitrogen contained in the waste is primarily in the form of ammonia when it enters the drainfield. If the drainfield is unsaturated the ammonia-nitrogen is converted to nitrate nitrogen but not removed from the waste. Nitrate nitrogen is very soluble in water and is easily transported by groundwater flow (Shukla et al. 2006). Anaerobic denitrifying bacteria are required in order to remove the nitrate nitrogen from the waste stream (Shukla et al. 2006). These bacteria are found in wetlands and saturated soils but require a long contact time with the waste stream for efficient nitrate removal. Unless the contaminated groundwater flows into a wetland with saturated soils and denitrifying bacteria, very little nitrogen removal occurs prior to discharging to surface water. Because Captiva is a very narrow barrier island and many of its natural wetlands have been filled, groundwater is near to surface water (estuary or Gulf) at all locations and there is little nitrogen removal in wetlands or saturated soil before discharging to surface waters.

One additional natural method for removal of nitrogen from waste streams is uptake by plants, especially trees (Hazen Sawyer 2009; Center for Watershed Protection 2011). Trees and other plants have extensive root systems which specialize in removing needed nutrients including nitrogen from the soil and incorporating it into plant material. Because septic system drainfields are kept free of deep rooted vegetation because of potential interference with hydraulic flow, trees are removed from drainfields. In addition, the conversion of forested areas to turfgrass decreases the natural removal of nitrogen from subsurface waste streams.

Elevated levels of nitrogen in groundwater beneath the non-sewered portion of Captiva are typical of developed lands without centralized sewer. The combination of insignificant removal by septic systems, conversion of forested areas to turfgrass or impervious surfaces and the removal of natural wetlands contribute to the current conditions. The finding that estuarine waters near these non-sewered portions of Captiva also have elevated nitrogen concentrations compared to the non-sewered portions of Captiva is realistic since the groundwater is located within a few hundred meters of surface water and resides in a very porous medium (sand) with characteristically high transmissivity allowing rapid movement.

Runoff/Surface Water Relationships/Source Identification

Enterococcus concentrations in Captiva near shore waters were found to increase significantly after rainfall events. Often, bacteria levels were above Florida DOH criteria. During dry periods these indicator bacteria were shown to be consistently at low levels. Groundwater concentrations were also consistently low. *Enterococcus* concentrations were significantly greater in runoff compared to estuary, Gulf or groundwater samples. Stormwater and irrigation runoff are the primary transport mechanism for these bacteria and the source is terrestrial.

Source tracking efforts undertaken in this study revealed extremely high concentrations of bacteria on lawns, golf courses, urban soils, macroalgae in near shore waters; wrack on the beach, and in feces from shorebirds and resident mammals. These bacteria were also found in all domestic waste streams which contain human waste.

Enterococcus bacteria are currently the regulatory agencies' primary indicator used for detecting fecal contamination in public estuary waters. Enterococci from wastewater discharges are more persistent in marine waters than the coliform group of bacteria frequently used as indicators in fresh water (US EPA 1986). Florida DOH uses the presence or absence of these bacteria to determine if beach advisories should be issued for Florida (and Captiva) beaches. It was once thought that this group of bacteria was usually traceable to human origins, however, studies now indicate many animals and even some plant species have these bacteria associated with them (Muller et al. 2001, Bonilla et al. 2006). Enterococci were originally thought unable to persist long in environments outside of their animal host. However, studies are now finding that these bacteria persist in sands, wrack, storm sewers and even in natural marsh habitats to name a few (Yamahara et al. 2007, Lee et al. 2006, USGS 2008). Beach sands and wrack material can act as a growth media for indicator bacteria. Beach sands can be inoculated with bacteria from external sources (humans, animals, stormwater runoff) which then find suitable conditions amongst the sand and wrack to grow and divide. This results in high enough concentrations to contaminate waters near the beach (Shibata et al. 2004). Current research suggests the occurrence of enterococci in our waters is partially natural and partially human derived. This leaves some uncertainty of the true source whenever an elevated level of *Enterococcus* bacteria is found in public waters.

We now believe that *Enterococcus* bacteria are present throughout our environment. They can colonize diverse natural terrestrial and marine media and remain viable for days to weeks or longer (Hartz et al. 2008). When a significant rain event occurs, the indicator bacteria are transported by runoff from the many different locations which they have colonized and increase the concentrations in the receiving waters. Increases of bacteria in any area may be a function of increased runoff due to land use changes (development), an increase in acceptable media for colonization (such as macroalgae blooms), or failing wastewater systems which periodically discharge directly to surface waters, or terrestrial areas.

Source identification efforts undertaken in this study show that a relatively small percentage of estuary, Gulf or groundwater samples contained *Enterococcus* bacteria from a possible human source (Table 7). The data also suggest that stormwater runoff has a much higher probability of containing these bacteria (from human or non-human source) than groundwater or surface waters. Decreasing the amount of runoff from any land area will decrease the probability of bacteriological contamination in Captiva's near shore waters.

Nitrogen was also significantly greater in runoff than estuary or Gulf samples and significantly greater in surface water during the wet season. Plus, when we analyzed data from a transect crossing Pine Island Sound, there were significantly lower concentrations of nitrogen in middle Pine Island Sound compared to the near shore waters of Captiva, even though Captiva is closer to the diluting effects of the Gulf of Mexico. These findings imply terrestrial sources of nitrogen from Captiva do, in fact, enrich near shore waters.

Nutrient enrichment of waterbodies by non point sources is currently one of the biggest issues in water quality management (FDEP 2011). Conversion of natural landscapes into agriculture, industrial and urbanized land use is the main cause of this world-wide problem. Captiva Island is typical of any developing area in the world. In its natural condition Captiva Island consisted of well-vegetated wetlands and uplands having multiple layers of vegetation and dense underbrush. During a significant rainfall event, the naturally-vegetated island would have had little to no runoff. Rain is intercepted by canopy, trapped by detritus, evapotranspired by vegetation and collected by wetlands (Center for Watershed Protection 2011). Captiva's natural landscape has been converted to tracts of lands with large homes, impervious roads and driveways and turfgrass lawns. The portion of rainfall which runs directly off of the land surface has significantly increased.

Other studies have shown a direct link between urban development and degraded estuarine water quality (Holland et al. 2004). Our GIS land use analyses for Captiva estimates that as much as 25% of Captiva may now be impervious surface. The natural condition would have been near zero. Runoff has increased to nearly one quarter of the annual rainfall volume. This stormwater runoff carries with it bacteria as described previously and nutrients such as nitrogen. There are many natural sources of nitrogen (plant material, animal wastes, etc.) but modern day runoff also carries fertilizers and other anthropogenic nitrogen sources. As we convert natural areas to lawns and managed landscapes, we rely upon fertilization and irrigation to maintain ground cover (Holland et al. 2004; Center for Watershed Protection 2011). This practice adds nitrogen to runoff as well as increasing runoff volume – leading to nutrient-enriched near shore waters favoring algae blooms, decreased water clarity, seagrass reduction, harmful algae blooms, hypoxic conditions and mortality of fish and other aquatic life (Holland et al. 2004; FDEP 2011). This condition is one reason that chlorophyll *a* concentrations are significantly greater near Captiva than they are near Pine Island or in mid-Pine Island Sound. SCCF Marine Lab played a significant role in a recent study in which investigated the cause of large macroalgae (drift algae) deposits which covered area beaches in 2006-2007. One of the findings revealed local drift algae used nitrogen from terrestrial runoff in the area to fuel its growth (Milbrandt et al. in Loh et al. 2011).

Loading Estimates

Loading estimates are calculations of the mass of a substance which is discharged into a water body. Through estimates of Captiva's nitrogen loads from runoff and septic systems we can better develop strategies which would reduce local impacts to our near shore waters. Table 8 shows the distribution of nitrogen loading between land use types and areas on Captiva. Compared to the mean of 4.9% for the Caloosahatchee/Charlotte Harbor (CHNEP) watershed (Janicki Environmental 2010), the proportion of nitrogen inputs from septic systems on Captiva is very high at 36% (Figure 56). The load per unit area for Captiva was 7.9 lbs/acre/yr compared to other CHNEP watersheds between 0.5 to nearly 10 lbs/acre/yr. The Captiva unit area load is high and more typical of loadings from large river watershed segments such as the Caloosahatchee (Janicki Environmental 2010). Per unit area, we estimate discharges from Captiva contain more nitrogen than most other watersheds, due to development and high density of septic systems. Of special note here, most other loadings estimates done in this region have relied upon Florida DOH data for septic tank density (Janicki Environmental 2010). Florida DOH estimates nearly 75% of septic systems in Florida are not in their records (FDOH 2007) and are not counted in most studies. Estimates which rely upon DOH data will significantly underestimate septic system inputs. Our estimates were made by actual GIS analyses of existing structures in the non-sewered portion of Captiva. The current study presents a more accurate analysis of loads contributed by septic systems than previous studies estimating loads in this area.

Enterococcus bacteria loads were determined to be primarily (98%) of stormwater runoff origin. There were no beach advisories during the study period due to elevated bacteria levels, even though there were many rain events which did elevate bacteria levels above state advisory criteria. Florida DOH samples near shore water from Captiva beaches one time each week on a set schedule. Commonly, the sampling event will miss runoff from any recent rain events. Although indicator bacteria concentrations in near shore waters are likely to be high during and just after a rain event, our experience indicates bacteria levels drop quickly within a day or two.

The sampling protocol used by Florida DOH will usually miss periods of elevated bacteria levels. Near Captiva, this may not be such a serious situation since our study shows that a high proportion of the indicator bacteria in near shore waters is not of human origin and thus not an indicator of the presence of human-associated pathogens. Until agencies charged with protecting beach-goer health can use more accurate methods of determining true bacteriological health concerns in our waters, we cannot know whether an actual health risk exists when a beach advisory is posted; or whether a health risk exists in the period between sampling efforts. We can say for certain that an increase in stormwater runoff provides an increased chance that health risks will exist in our near shore waters. Therefore, a reduction in stormwater runoff will reduce health risks.

Given that a significant portion of nitrogen loading from Captiva originates from septic system discharges and that stormwater runoff contributes to both nitrogen enrichment and bacteria in near shore waters, a logical strategy to reducing these discharges is to reduce, wherever practical and cost effective, the impact from both sources. Stormwater runoff may be reduced through re-vegetating native landscapes, reducing impervious surfaces, restoring wetlands, installing swales, retention ponds, cisterns and many other widely accepted methods. Strategies for reduction of nitrogen from septic system discharges include; installation of nitrogen-removing onsite wastewater treatment systems in place of conventional septic systems, separation of waste streams by use of composting or incinerating toilets and reduction of waste flow through water conservation. All of these strategies require cost/benefit analyses and can be next steps for CCP.

Summary and Recommendations

The findings of this study demonstrate that lower Captiva Island has elevated levels of nitrogen in its groundwater which likely originate from septic systems. The northern half of the island, which is connected to the South Seas Plantation sewer system, did not exhibit this condition. Concentrations of the indicator bacteria *Enterococcus* were generally low in Captiva's groundwater. Therefore, septic systems did not appear to be contaminating the island's groundwater with these bacteria. Comparison of surface water samples from non-sewered portions of Captiva with locations which have sewer indicated greater nitrogen exists in the non-sewered areas. This is additional indication that septic systems are having an impact on local water quality.

After rain events, *Enterococcus* bacteria were commonly found in Captiva's near shore Gulf and estuary at levels above state health criteria. The indicator bacteria were transported into these waterbodies by stormwater runoff from terrestrial sources. Stormwater runoff was also shown to transport nitrogen from terrestrial sources into Captiva's surface waters. Of the parameters monitored, *Enterococcus* bacteria and nitrogen in stormwater/irrigation runoff and high nitrogen concentrations in septic system discharges were found to be the two primary water quality concerns originating from Captiva Island. These concerns can be addressed through activities of the CCP.

We suggest the local community focus their energies on two main strategies:

1. Reduction in the amount of stormwater and irrigation runoff that enters the surface water.
2. Reduction of the concentration and flow of nitrogen containing wastes originating from septic systems.

There is a vast assortment of activities which can adequately address these issues, however economic ability and social acceptance of the practices often limit their implementation.

To decrease the amount of nitrogen discharged to the environment, several approaches may be taken: water conservation efforts in each household can reduce waste flow discharged; separation of the most concentrated wastes such as urine into separate streams which are then recycled as fertilizer or disposed in a more environmentally acceptable manner; use of wetlands to remove nitrogen from waste streams; conversion of conventional septic systems to nitrogen removal systems; and connection of non-sewered areas to centralized wastewater treatment with nitrogen removal capability.

The use of Florida DOH-approved composting toilet systems or incinerating toilet systems (FDOH 2011) reduces the volume and concentration of nitrogen discharge by separating and treating the most concentrated waste streams. The concentrated, dry waste produced by these units can then be used as compost or disposed of as solid waste instead of being discharged into Captiva ground and surface waters.

Advanced nitrogen removal septic systems are approved by the state of Florida and available for installation by local contractors (FDOH 2011). These systems are more expensive than conventional systems and require more maintenance to operate properly but they do help to keep local waters clean.

Providing centralized collection and wastewater treatment to Captiva would be a large undertaking with its own set of impacts on the environment and economic impacts on local residents. Centralized wastewater treatment can reduce nitrogen concentrations and reduce the volume of wastewater discharged into the environment; however the cost-effectiveness and environmental impacts of this alternative would need to be thoroughly investigated. Many homes could be completely retrofitted with composting toilets for the cost of centralized wastewater treatment and sewer with similar potential environmental benefits. Florida DOH provides a very helpful website which outlines onsite nitrogen reduction technologies and trade-offs and costs at www.**doh**.state.**fl**.us/environment/**ostds**/index.html.

Before Captiva Island real estate became exceptionally valuable as waterfront property and was developed, it naturally consisted of a multitude of vegetative layers which kept runoff volumes to near nothing. Development has brought an increase in impervious surfaces and managed turfgrass lawns which result in an increase in the volume and concentration of nitrogen and indicator bacteria in stormwater runoff.

The easiest and most logical way to reduce stormwater and irrigation water runoff is to simulate natural land use as much as possible by encouraging growth of natural (or natural–like) layers of vegetation on all lands. Additionally, engineering solutions to runoff from impervious surfaces such as roads and house tops which cannot be easily vegetated will reduce runoff and the amount of nitrogen and bacteria discharged into Captiva's surface waters.

When visualizing groundcover impacts to water quality, the following general pattern can be remembered from greatest negative impact on water quality to least negative impact: blacktop roads, sidewalks or surfaces; concrete surfaces; rooftops; gravel, shell aggregate surfaces; turfgrass or other managed grassy surfaces; pervious pavers and concrete; mulch; managed natural vegetation with few layers; managed natural vegetation with understory and canopy; unmanaged island vegetation with many layers and forest canopy.

Practices which have direct negative impact on local water quality include; irrigation with fertilization, wetland removal, channelization of ditches, removal of trees and understory, planting turfgrass, installing impervious surfaces for driveways, sidewalks, large homes, etc, and excessive landscape management (trimming, detritus removal, herbicide spraying). In areas where a natural landscape cannot be recovered, engineered solutions to reduce runoff volumes and nitrogen concentrations are available such as; swales, cisterns, bioretention areas, green roofs, roof filters, and engineered wetlands. Vegetation and especially large canopy-forming trees reduce runoff volume and remove nitrogen.

Our analysis of Lee County water quality data from the lower Caloosahatchee Estuary to the northern Pine Island Sound shows a clear pattern of higher pollutant (nitrogen, phosphorus, total organic carbon, water clarity) concentrations in the Caloosahatchee which gradually decrease with the diluting effects of the Gulf in Pine Island Sound. This finding supports previous analyses which found similar patterns (DeGrove 1981, Doering 2005). The local input of pollutants from Captiva Island is significant enough to cause an impact to the regionally-impacted water quality of the area. To address local water quality impacts regional issues must also be of concern. The management of water flow and quality by South Florida Water Management District, the US Army Corps of Engineers and Florida DEP should become an important concern of the Captiva community and advocacy (SCCF 2011) for improved conditions through better management practices developed.

This report is meant to be used as input into the discussion of the future of local water quality for Captiva Island and the surrounding area. The focus of this study was an attempt to highlight problem issues to allow the local community to better plan any activities which may be appropriate based upon these findings. We think that the presentations associated with this project and this report address these goals thoroughly and in a manner that CCP and Captiva can proceed with addressing water quality concerns.

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Tables and Figures

Table 1. Distribution of Captiva Island land use and soils hydrological groups. Group "C" and "D" soils are characterized by low to very low infiltration rates caused by a partially impervious layer or permanent high water table.

Captiva Land Use Classification/Description	***Percent Impervious Surface Area***	***Area (Acres)***	***Percent Area***	***Soils Hydro Group***
Low Density Residential (South End Captiva)	17	216.1	27.6	C
Mangrove Forests (South Seas Plantation)	6	141.1	18.0	D
Recreational - Beach	0	120.6	15.4	C
High Density Residential (South Seas Plantation)	60	80.8	10.3	C
Medium Density Residential (Captiva Town)	30	55.3	7.0	C
SSP Golf Course	30	42.7	9.0	C
Roadways	90	30.7	3.9	C
Low Density Residential (South Seas Plantation)	25	26.5	3.4	C
Shrub and Brushland (Rauschenburg Estate Land)	10	14.4	1.8	C
Low Density Residential (Mid Captiva)	15	12.6	1.6	C
High Density Residential (Middle Captiva)	40	10.5	1.3	C
Tween Waters (Commercial)	85	9.6	1.2	C
High Density Residential (Captiva Town)	60	8.7	1.1	C
Low Density Residential (Captiva Town)	25	8.5	1.1	C
Commercial and Services (Souths Seas Entrance)	85	4.2	0.5	C
Totals	25%	782.3	100	

Table 2. Water quality guidelines used in this study for making a general water quality assessment.

Parameter	***Criteria: Good***	***Criteria: Moderate***	***Criteria: Poor***	***Criteria Source***
Enterococci Bacteria (colonies/100 ml)	< 35	35-104	>104	DEP WQ Criteria
Chlorophyll-a (µg/l)	< 7	7-11	≥11	DEP WQ Criteria
Total Nitrogen (mg/l)	<0.93	≥0.93,<1.2	≥1.2	70^{th} and 90^{th} percentile all Florida estuaries
Ammonia/Ammonium (mg/l)	<0.05	≥0.087,<0.05	≥0.087	70^{th} and 90^{th} percentile all Florida estuaries
Total Phosphorus (mg/l)	<0.133	≥0.133,<0.23	≥0.23	70^{th} and 90^{th} percentile all Florida estuaries
Dissolved Oxygen (mg/l)	≥ 5.0	4.0 - 5.0	< 4.0	DEP WQ Criteria

Table 3. List of potential local sources of bacterial and nutrient pollution in the study area.

Site	***Site Description***	***Issues***	***Pollutants of Concern***
SRC1	South Seas Plantation Golf Course	Spray Irrigation with WWTP effluent/Fertilization	Nutrients
SRC2	South Seas Plantation Stormwater System	Discharge from high density residential and golf course	Nutrients
SRC3	South Seas Plantation WWTP	Large WWTP	Bacteria, Nutrients
SRC4	Captiva Stormwater System	Drains area with high density of septic tanks	Bacteria, Nutrients,
SRC5	Captiva Septic Tanks	Possible incomplete wastewater treatment before reaching ground or surface water	Bacteria, Nutrients
SRC6	Tween Waters WWTP/Drainfield	WWTP with history of violations	Bacteria, Nutrients
SRC7	Sanctuary Golf Course	Spray Irrigation with WWTP effluent/Fertilization	Nutrients
SRC8	Wulfert WWTP	WWTP and treated wastewater staging area	Nutrients
SRC9	Bayous WWTP Treatment Pond	Leaking pond high in Bacteria	Bacteria, Nutrients
SRC10	Bayous Subdivison Sewer System	Study showed sewer system leaking.	Bacteria, Nutrients
SRC11	Discharge Weir Sanibel River	Managed like canal, possible large sudden releases.	Bacteria, Nutrients,
SRC12	Discharge Weir Sanibel River	Managed like canal, possible large sudden releases.	Bacteria, Nutrients,
SRC13	Captiva Beach at South Seas	People and animals on beach. Sand and algae media for bacteria	Bacteria
SRC14	Blind Pass Beach	People and animals on beach. Sand and algae media for bacteria	Bacteria
SRC15	Bowmans Beach	People and animals on beach. Sand and algae media for bacteria	Bacteria

Table 4. Summary statistics for samples of beach sand, wrack and interstitial water taken during the first year of this study.

Sample Type	***Number of Samples***	***Mean Enterococci***	***Range***	***Standard Deviation***
Enterococci in Interstitial Beach Water (Colonies/100ml)	20	10.1	Jan-37	12.2
Enterococci in Beach Sand (Colonies/gram dry wt.)	33	25.1	1-400	79.5
Enterococci in Wrack (Colonies/gram dry wt.)	39	2,364	1-46,549	8,195

Table 5. Stations in our study which had the greatest variability in salinity.

Station	**Station Mean Salinity**	**Salinity Standard Deviation**	**Range**	**Total Number of Samples**	**Location**
TDC14	32.4	8.1	33.5	15	Near Stormwater Outfall, Mid-Captiva
TDC07	34.6	5.7	10.26	3	Mouth Holloway Bayou, Sanibel
BPADink	35.5	5	18.3	35	Dinkins Bayou, Sanibel
BPAClam	36.1	4.7	16.8	35	Clam Bayou, Sanibel
NWR09	32.7	4.4	8.75	3	Flats, Sanibel
Scal_Spat17	32.2	4.4	14.7	14	Sanibel
Scal_Spat18	32.2	4.2	13.9	17	Tarpon Bay near Shallow Cut, Sanibel
Scal_Spat16	32.2	4.1	13.6	17	West of Shallow Cut outside, Sanibel
Scal_Spat11	32.2	4.1	13.8	15	Pine Island Sound near NWR Creek Discharge, Sanibel
BPASun	35.9	4.1	15.6	33	, Dinkins Bayou, Sanibel
Scal_Spat10	32.8	4	13.8	17	Nearshore NWR at mouth of Holloway Bayou, Sanibel

Table 6. Mean nitrate, *Enterococci*, salinity and depth to water table for wells monitored during this study.

Site	Ground Elevation	Mean Depth to WaterTable	Enterococci cfu/100ml			Nitrate mg/l			Salinity (PSU)		
			mean	stdev	n	mean	stdev	n	mean	stdev	n
GW02	2.57	2.11	1	0.0	8	2.40		1	5.1	1.0	7
GW03	0.84	0.17	35	55.7	8	0.04	0.04	2	1.3	0.6	6
GW04	1.35	0.53	4	6.3	10	0.07	0.11	3	0.6	0.2	9
GW05	1.07	0.55	3	3.6	10	0.95	1.14	4	0.4	0.1	9
GW06	0.93	0.51	5	5.5	8	0.02	0.01	2	0.3	0.1	8
GW07	0.99	0.23	2	4.3	10	0.20	0.32	3	0.4	0.1	10
GW08	1.08	0.69	2	3.2	8	2.37	1.50	3	14.8	11.7	8
GW09	2.37	1.66	1	0.0	10	2.07	2.03	2	1.6	0.9	9
GW10	2.38	1.95	2	2.8	10	1.55	0.92	5	0.4	0.2	10
GW11	1.08	0.91	13	15.0	12	1.11	1.10	5	1.9	1.3	12
GW12	0.64	0.32	6	7.9	6	0.27	0.34	2	10.4	5.4	6
GW13	1.15	1.9	1	0.6	8	2.48	0.42	4	1.2	0.2	8
GW14	0.96	0.42	43	112.8	11	1.80	0.98	4	0.5	0.2	11
GW15	1.86	1.09	39	83.8	12	0.12	0.02	3	0.9	0.3	12
GW16	0.89	0.7	23	55.1	7	0.77	0.26	2	1.4	0.1	7
GW17	0.69	0.46	8	8.0	6	0.01		1	2.9	0.3	5
GW18	0.59	0.36	18	34.9	10	0.01	0.01	2	3.1	0.8	10
GW19	0.94	0.565	8	16.0	7	0.05	0.02	2	1.1	0.5	7
GW20	1.97	1.68	9	13.0	6	0.01		1	0.8	0.1	6
GW21	1.39	1.59	1	0.7	5	2.40		1	0.8	0.1	5
SSP_1	1.8	0.5			0	0.03	0.03	12	3.2	0.2	8
SSP_3	0.48	0.41	1	0.0	2	0.02	0.01	12	20.7	22.9	8
SSP_5	1.65	0.87	16	20.3	3	0.23	0.28	14	1.3	0.1	8
Mean	1.3	0.9	10.9	20.4	7.7	0.8	0.5	3.9	3.3	2.1	8.2

Table 7. Percentage of samples in this study which were confirmed to have enterococci bacteria by sample type. The percentage of samples which were identified to possibly enterococci from human sources (*E. faecalis* or *E. faecium*) and the percentage of samples confirmed to have a bacteria from a human source are also shown.

Sample Type	Percent Samples Enterococci Confirmed	Percent Samples With Possible Human Enterococci	Percent Samples Confirmed to have Human Enterococci
Estuary	53	27	13
Gulf	40	25	13
Runoff	100	47	< 47
Groundwater	16	7	< 7

Table 8. Estimated nitrogen loading from Captiva Island based upon study data and accepted literature values.

Captiva Island Land Use and Description	***Percent Impervious Surface Area***	***Area (Acres)***	***Percent Captiva Area***	***Soils Hydrologic Group***	***Dry Season Runoff Coefficient***	***Annual Dry Season Rain (m) Nov 08-Jan 11***	***Annual Dry Season Runoff (m^3)***	***Wet Season Runoff Coefficient***	***Annual Wet Season Rain (m) Nov 08-Jan 11***	***Annual Wet Season Runoff (m^3)***	***Total Runoff (m^3)***	***Percent Total Runoff***	***Runoff TN (mg/l)***	***Loading Nov08-Jan 11 (kg)***
Mangrove Forests (South Seas Plantation)	6	141.1	18.0	D	0.95	0.33	177498.2	0.95	0.73	394134.2	571632.4	33.3	1	571.6
Low Density Residential (South End Captiva)	17	216.1	27.6	C	0.25	0.33	71521.6	0.35	0.73	222338.9	661186.1	17.1	1.7	499.6
High Density Residential (South Seas Plantation)	60	80.8	10.3		0.5	0.33	53509.9	0.65	0.73	154464.1	467941.5	12.1	2.1	436.7
Roadways	90	30.7	3.9	C	1	0.33	40645.3	1	0.73	90253	294521	7.6	2.1	274.9
SSP Golf Course (Rainfall+Irrigation Runoff)	30	42.7	9.0	C	0.21/0.15	1.41	30748.7	0.28/0.16	2.45	67293	220595	5.7	2.32	227.1
Medium Density Residential (Captiva Town)	30	55.3	7.0	C	0.35	0.33	25608.0	0.45	0.73	73109	222113	5.8	2.1	207.3
Recreational - Beach	0	120.6	15.4	C	0.1	0.33	15965.8	0.31	0.73	109901	283200	7.3	1.4	176.2
Tween Waters (Commercial)	85	9.6	1.2	C	0.78	0.33	9946.1	0.97	0.73	27465	84175	2.2	2.81	105.1
Low Density Residential (South Seas Plantation)	25	26.5	3.4	C	0.35	0.33	12241.0	0.45	0.73	34958	106199	2.8	2.1	99.1
High Density Residential (Middle Captiva)	40	10.5	1.3	C	0.45	0.33	6272.0	0.55	0.73	17022	52411	1.4	2.1	48.9
High Density Residential Captiva Town)	60	8.7	1.1	C	0.5	0.33	5754.9	0.65	0.73	16612	50326	1.3	2.1	47.0
Low Density Residential (Mid Captiva)	15	12.6	1.6	C	0.21	0.33	3498.0	0.31	0.73	11466	33669	0.9	2.1	31.4
Commercial and Services (Souths Seas Entrance)	85	4.2	0.5	C	0.78	0.33	4306.0	0.97	0.73	11891	36442	0.9	1.7	27.5
Low Density Residential (Captiva Town)	25	8.5	1.1	C	0.25	0.33	2824.4	0.35	0.73	8780	26111	0.7	2.1	24.4
Shrub and Brushland (Rauschenburg Estate Land)	10	14.4	1.8	C	0.18	0.33	3437.0	0.26	0.73	11024	32537	0.8	1.4	20.2
Totals		**782.3**	**1**				**463777.1**			**1250711**	**3143059**	**1**		**2797.2**

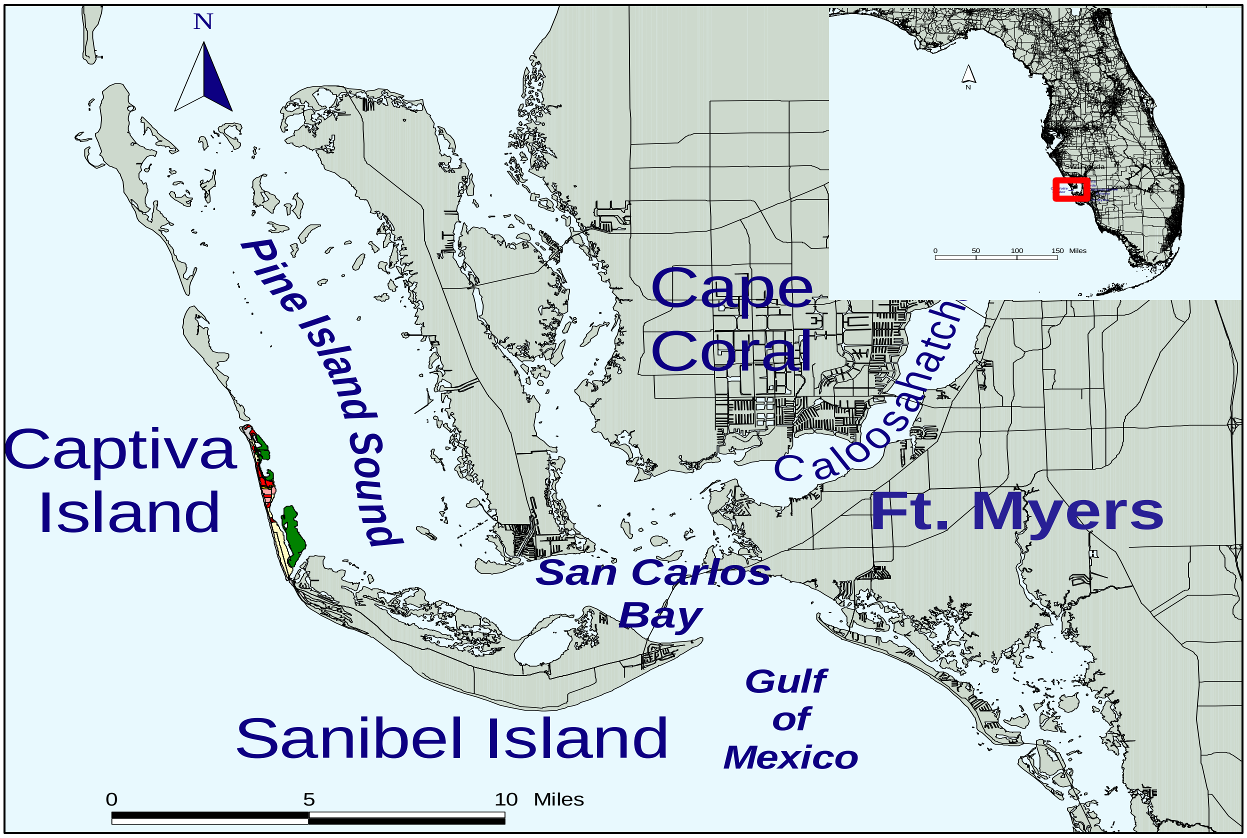

Figure 1. Area map showing Captiva and Sanibel Islands and nearby Ft. Myers and Cape Coral, Florida.

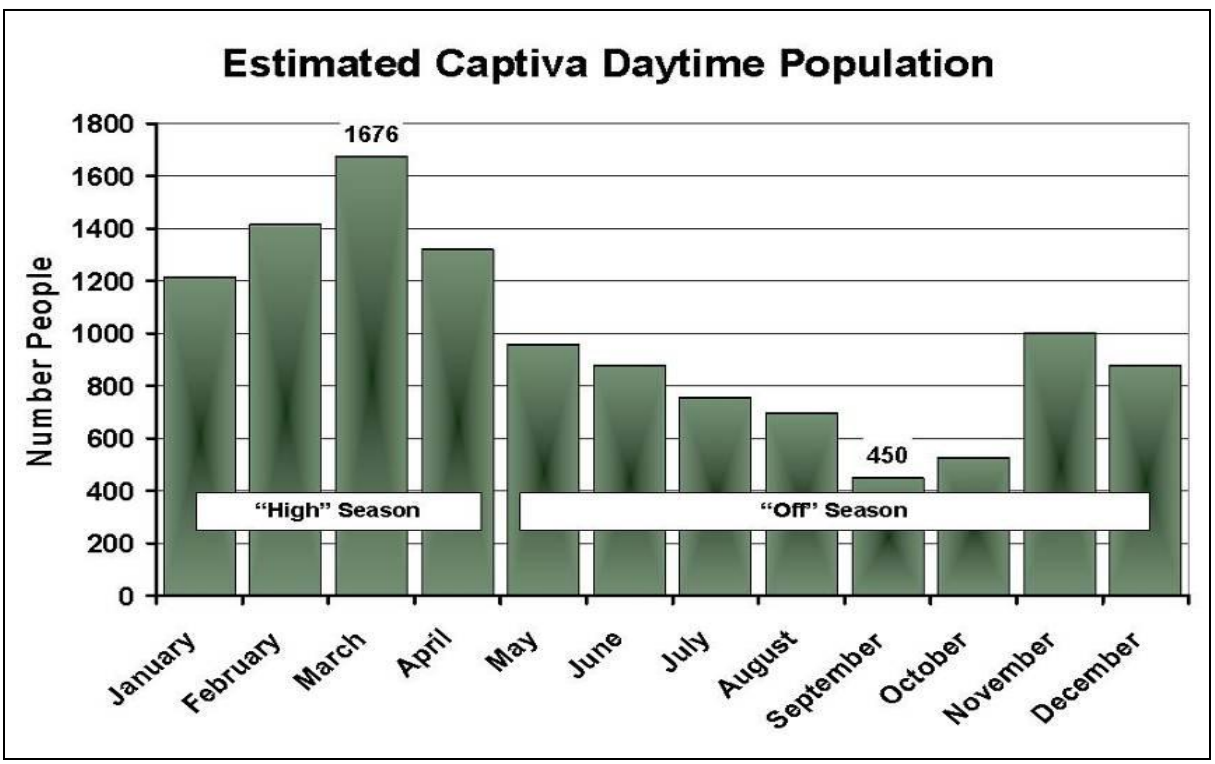

Figure 2. Population fluctuation on showing difference between "high" season and "low" season periods (derived from U.S. Census and Sanibel Captiva Chamber of Commerce).

Figure 3. Bayous wastewater treatment plant on northern Sanibel Island before (2008) and after (2009) the closure and filling of the holding pond. The holding pond was filled in 2009 with non-beach quality sediment from the Blind Pass dredging project.

Figure 4. Blind Pass separates Sanibel and Captiva Islands in 2008 before dredging work began (top) and in August, 2009 after dredging was completed (bottom).

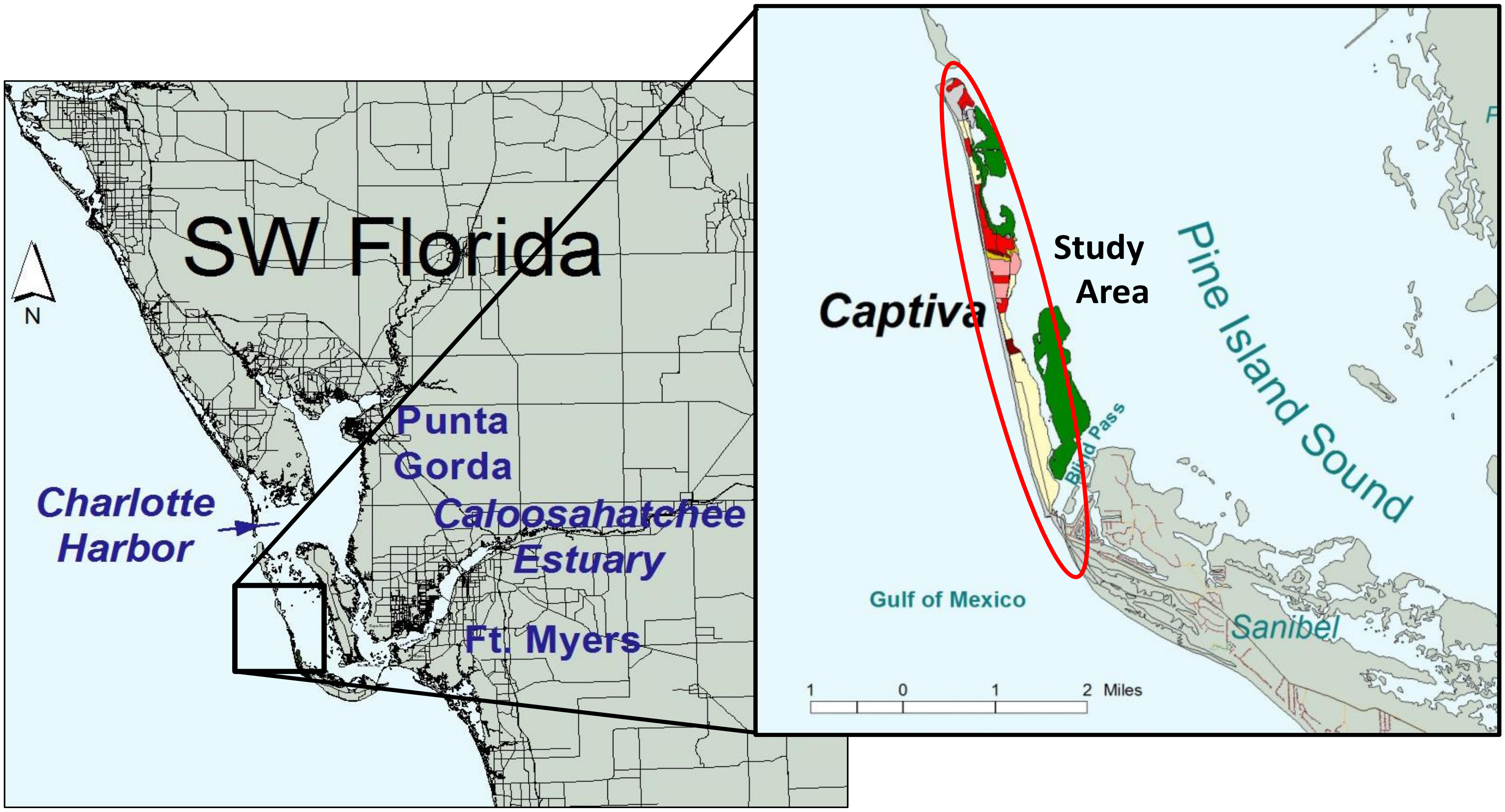

Figure 5. Study Area.

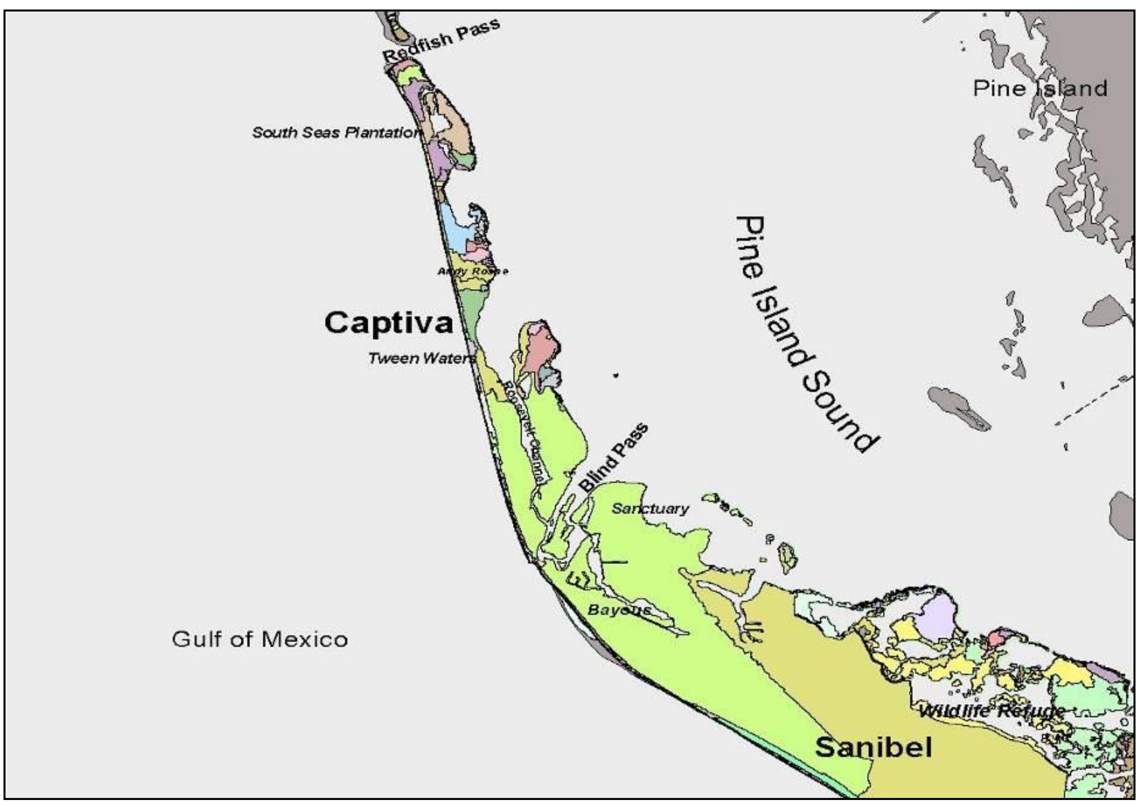

Figure 6. Watershed locations from estimated ARCGIS® 9. Each unique color represents a "predicted" drainage basin (*see* Methods).

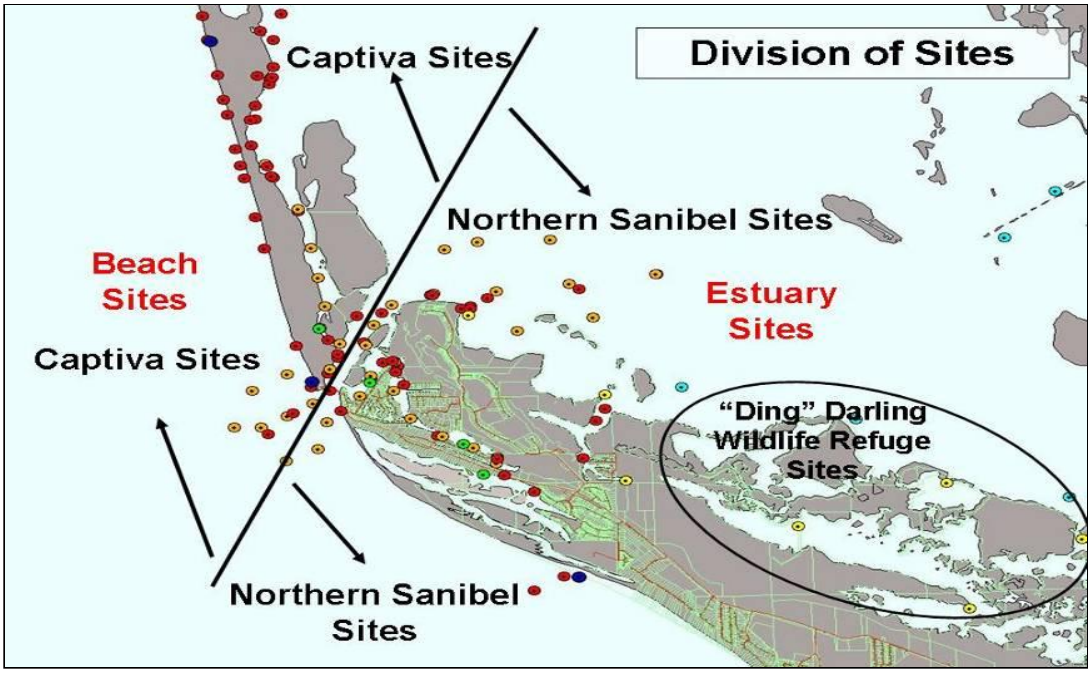

Figure 7. Distribution sampling locations used for group comparisons in Year 1 of this study**.**

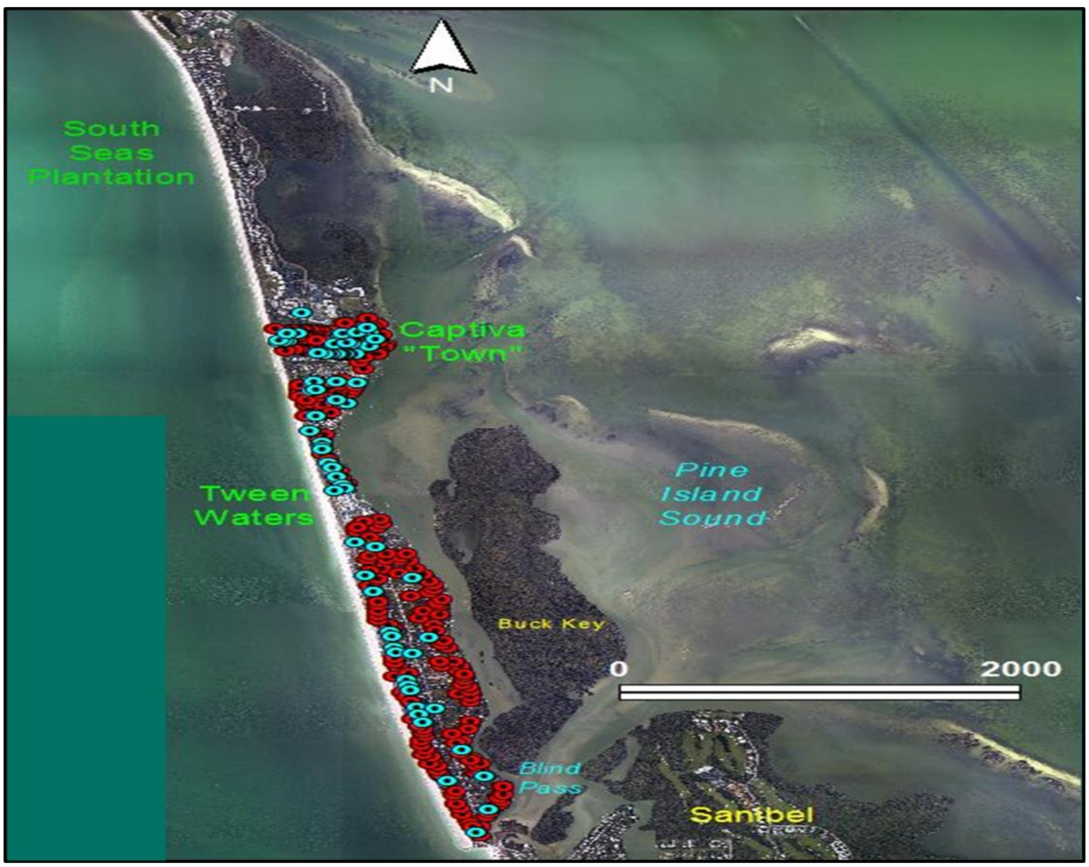

Figure 8. Captiva Island septic systems. Blue points indicate septic systems which were installed after Florida DOH septic system regulations became effective and are recorded in Florida DOH database. Red points indicate systems which are individual units not listed in FDOH records. These locations were installed before standardized septic system installation requirements existed. The northern portion of Captiva (South Seas Plantation) has a centralized treatment system with sewer. Scale in meters.

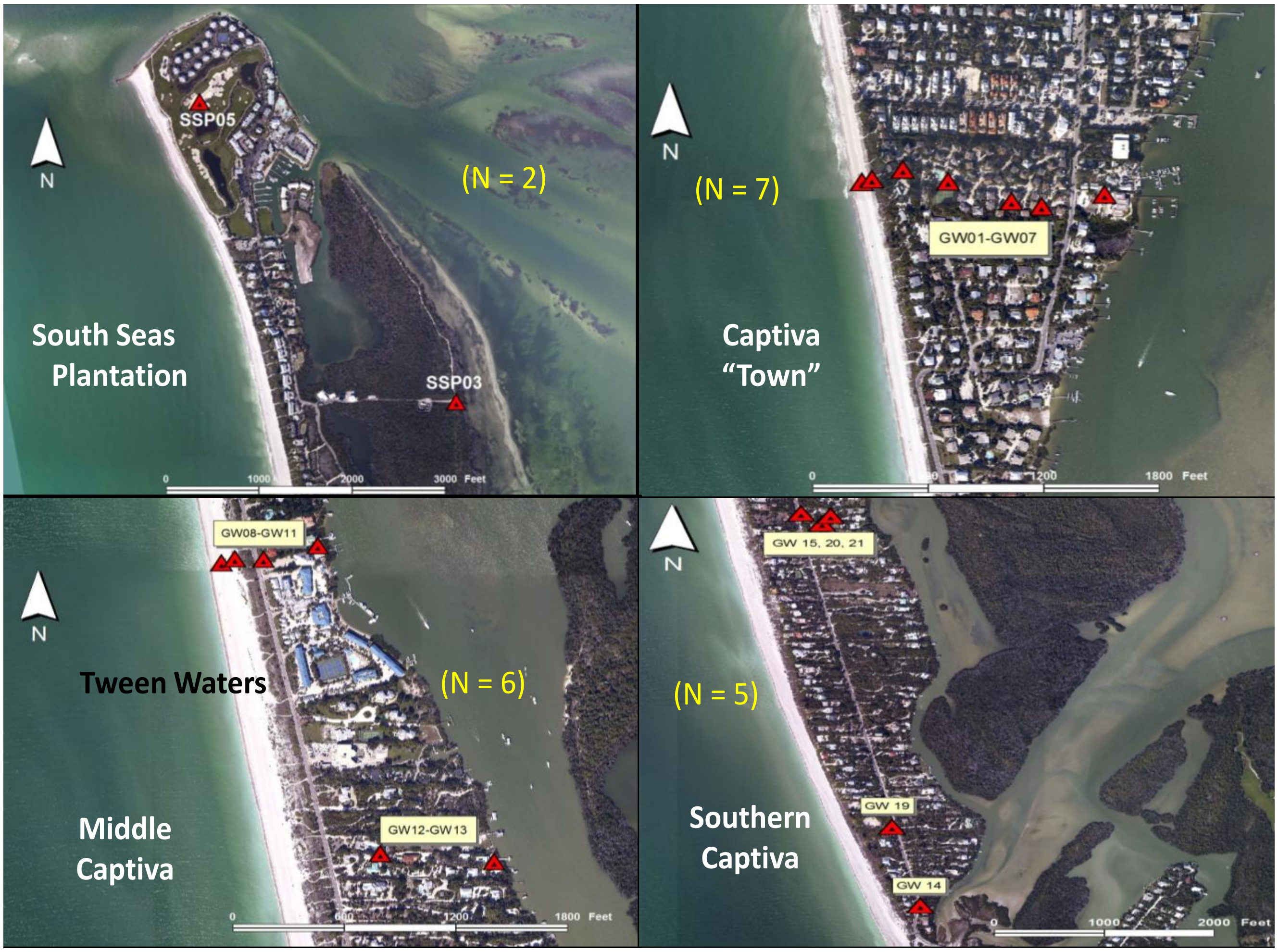

Figure 9. Location of Captiva groundwater monitoring wells used in this study. N represents the number of wells sampled in the area of each figure.

Figure 10. Wells were installed using 1.25” wellpoint with PVC extension placed into hole manually bored with auger.

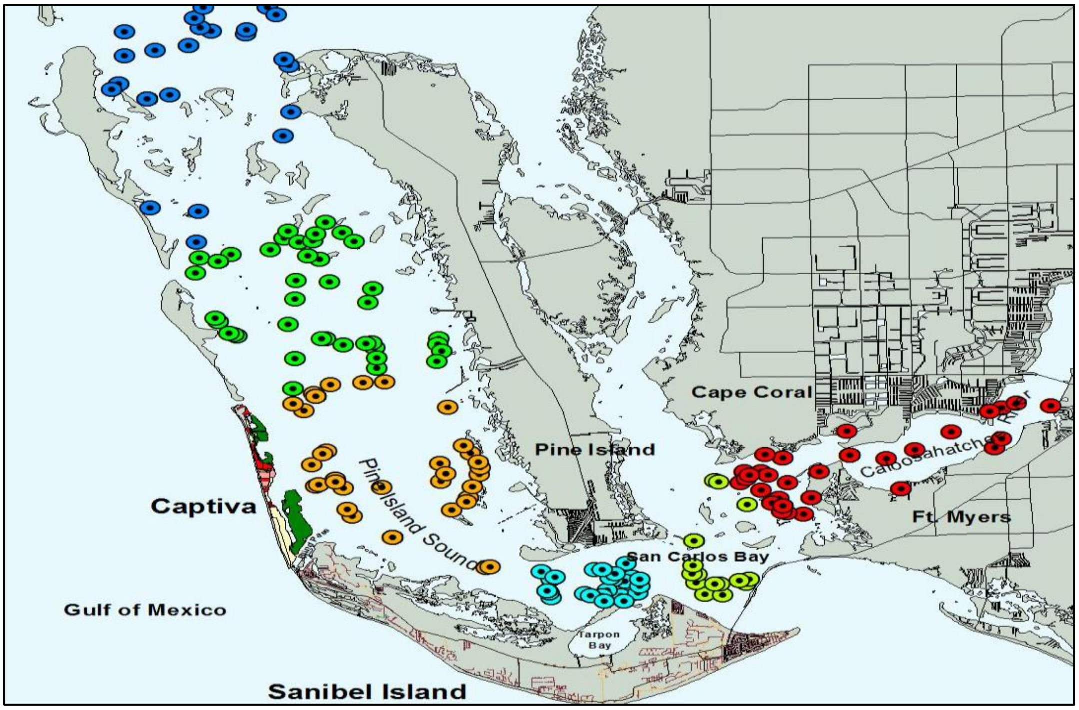

Figure 11. Distance strata for comparisons of WQ data more distant from the Caloosahatchee River/Estuary. Each distance class is represented by a different color. Data were obtained from the Lee County water quality database.

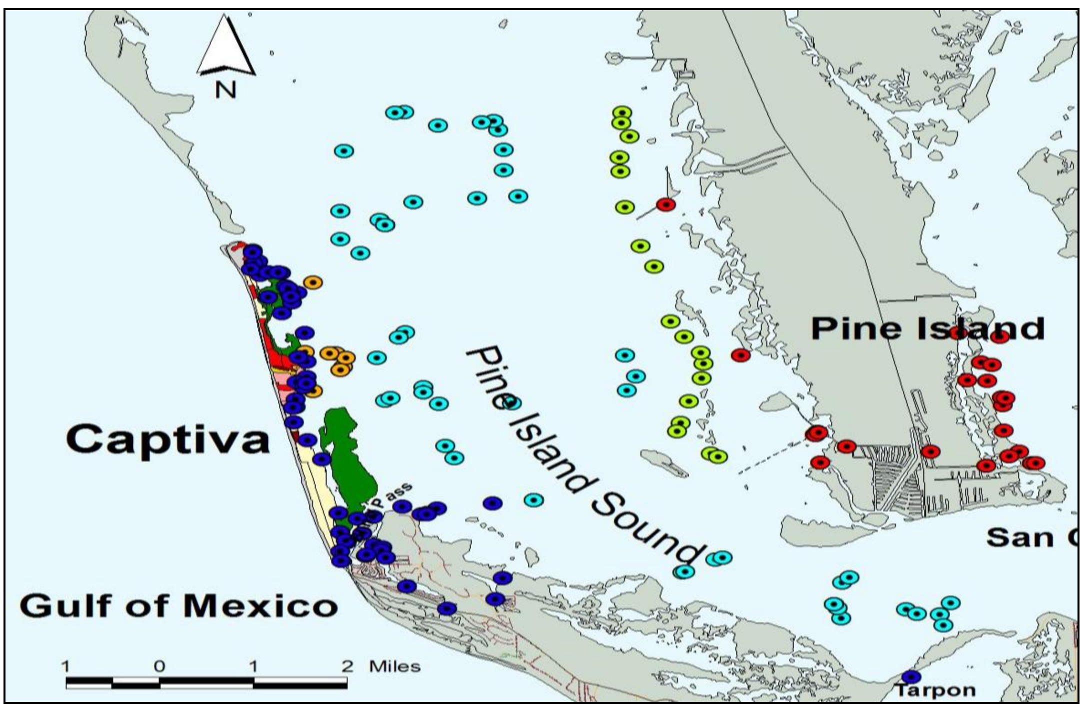

Figure 12. Distance strata for comparisons of WQ data across Pine Island Sound. Each grouping is represented by a different color. Data was obtained from the Lee County water quality database.

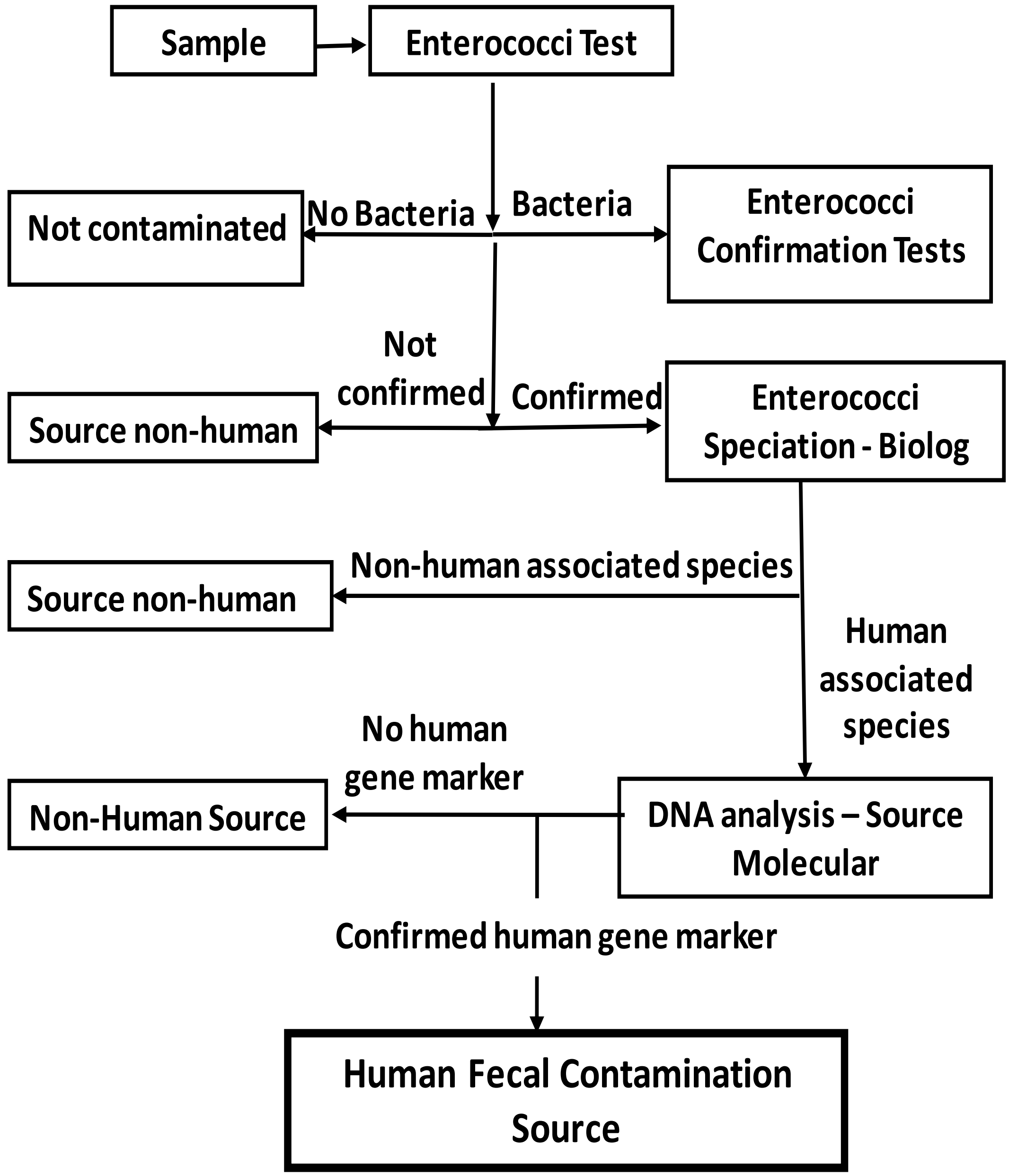

Figure 13. Multi-step approach used by SCCF Marine Lab in attempts to identify origin of *Enterococci* indicator bacteria**.** Note: The Florida DOH runs only the first *Enterococci* test in the series shown for their evaluation of beach health.

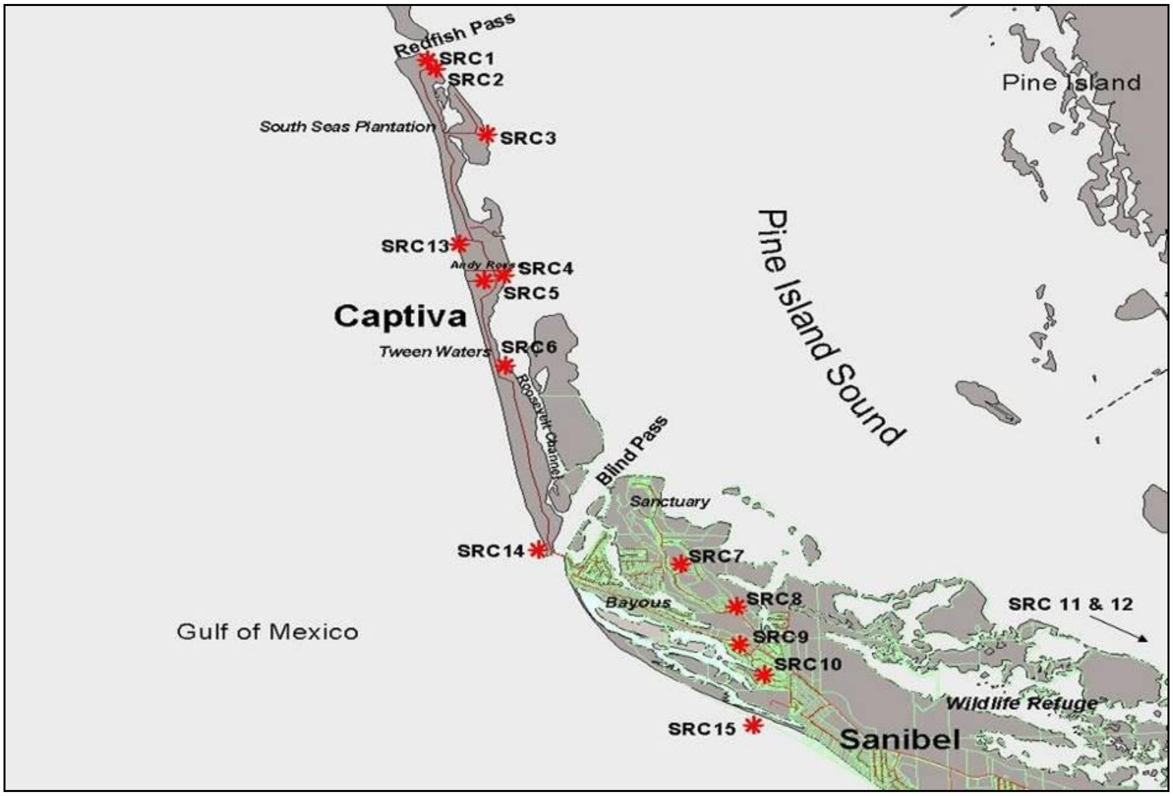

Figure 15. Location of possible pollutant sources (SRC) initially identified during study through review of Florida DEP records, optical surveys and local knowledge. Refer to Table 3.

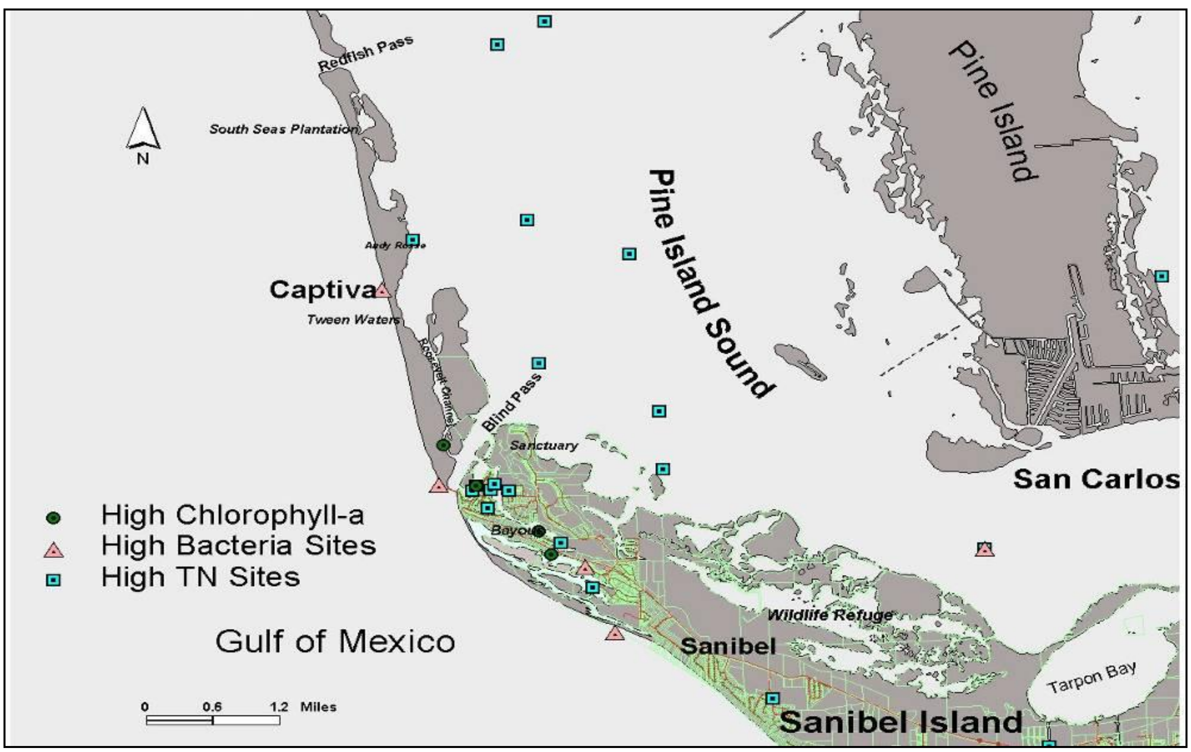

Figure 14. Locations which had historical record of elevated levels of a pollutant of concern during period January 2003 to October 2008. Data was obtained from the Lee County water quality database.

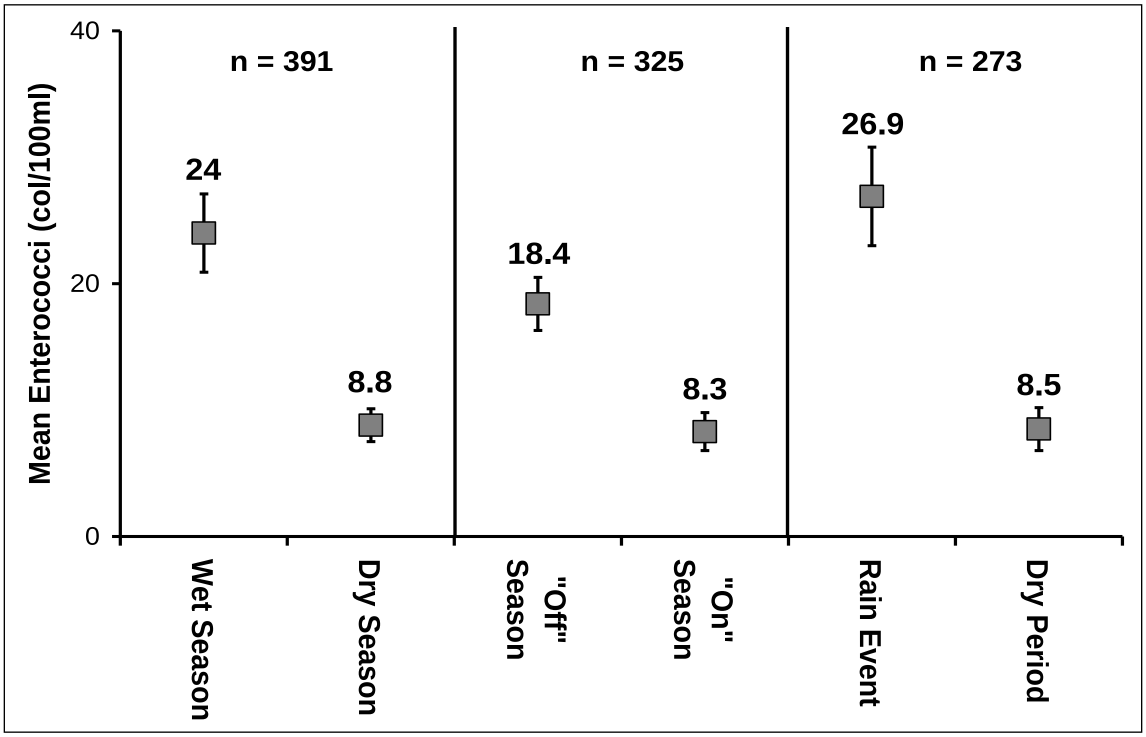

Figure 17. Comparison of mean *Enterococci* concentrations for estuary (Pine Island Sound) stations: wet season versus dry season; "low" ("off") season versus "high" ("on") season; and rain event versus dry events.

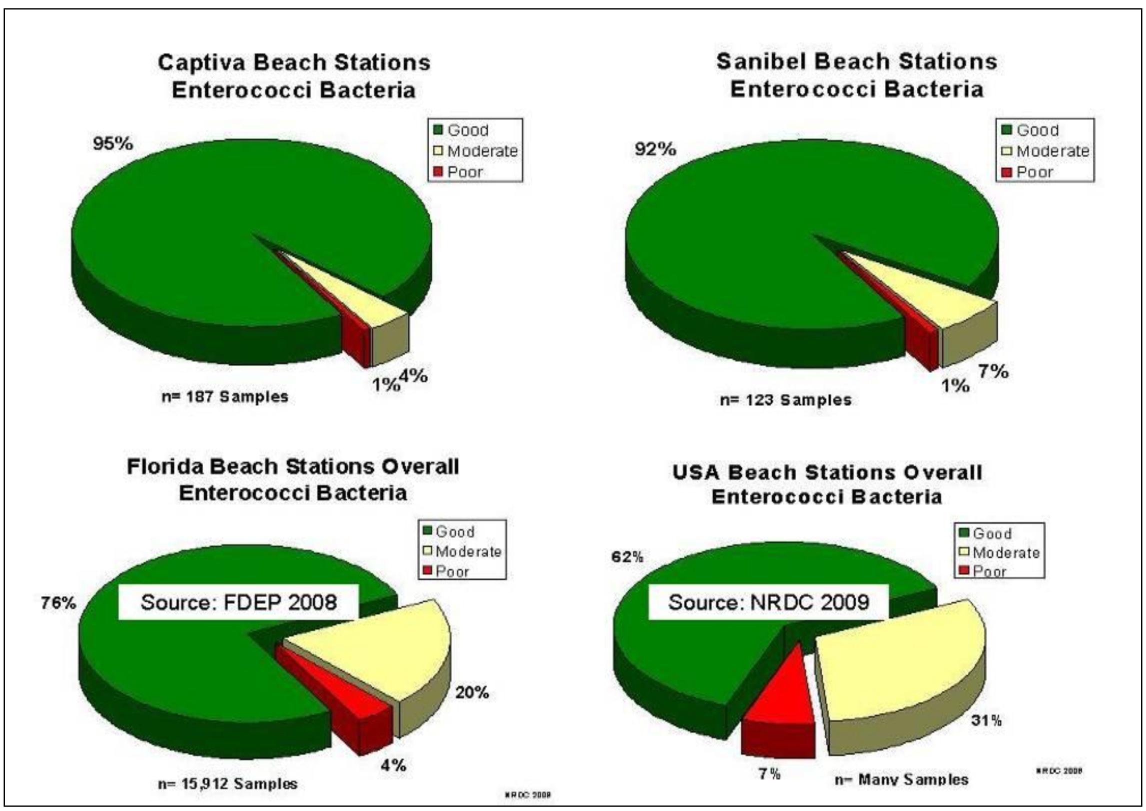

Figure 16. The proportion of samples within each water quality class for Captiva coastal (Gulf of Mexico) sites compared to northern Sanibel, Florida and USA overall data (Dorfman and Rosselot 2009).

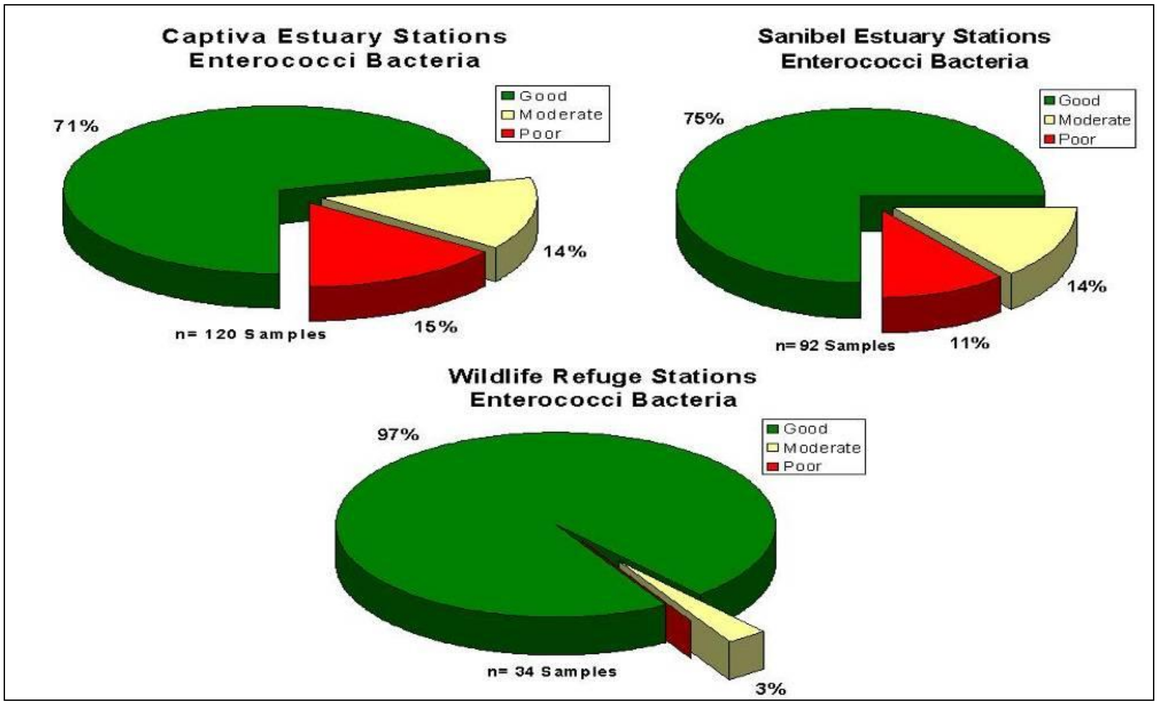

Figure 18. Results for *Enterococci* samples taken during the baseline assessment (2008-2010) for Captiva estuary (Pine Island Sound) stations compared to northern Sanibel and Pine Island Sound Inside the National Wildlife Refuge.

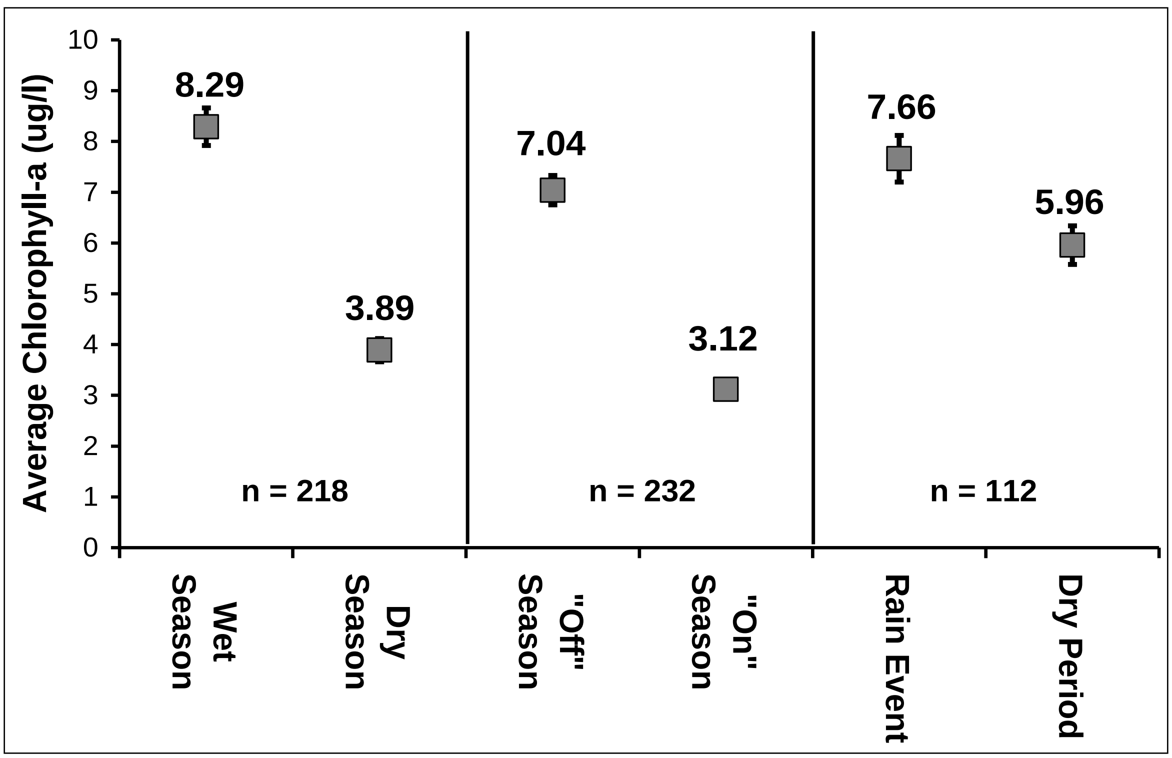

Figure 19. Comparison of mean chlorophyll a concentrations for estuary (Pine Island Sound) stations: wet season versus dry season; “low” (“off”) season versus “high” (“on”) season; rain event versus dry events.

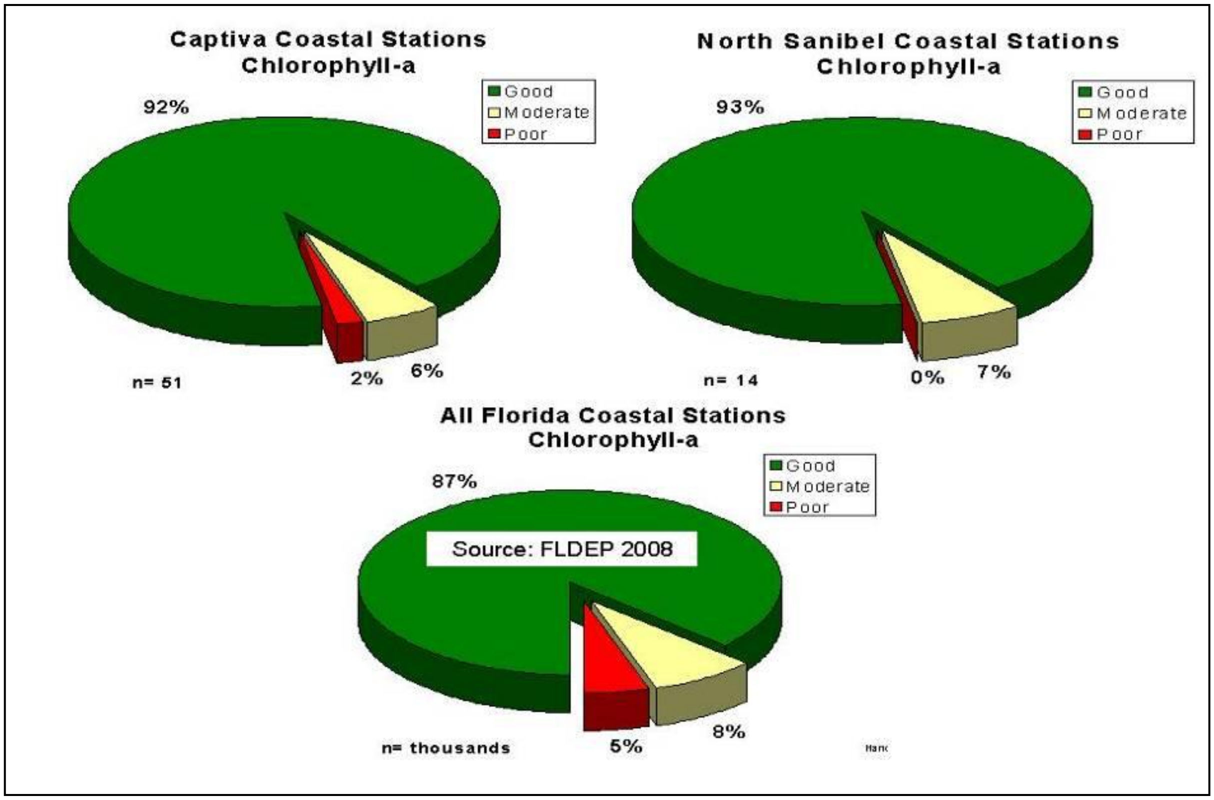

Figure 20. Results of chlorophyll *a* monitoring taken during the baseline assessment (2008-2010) for Captiva Island coastal (Gulf of Mexico) stations compared to northern Sanibel Island and Florida overall data (FDEP 2008b).

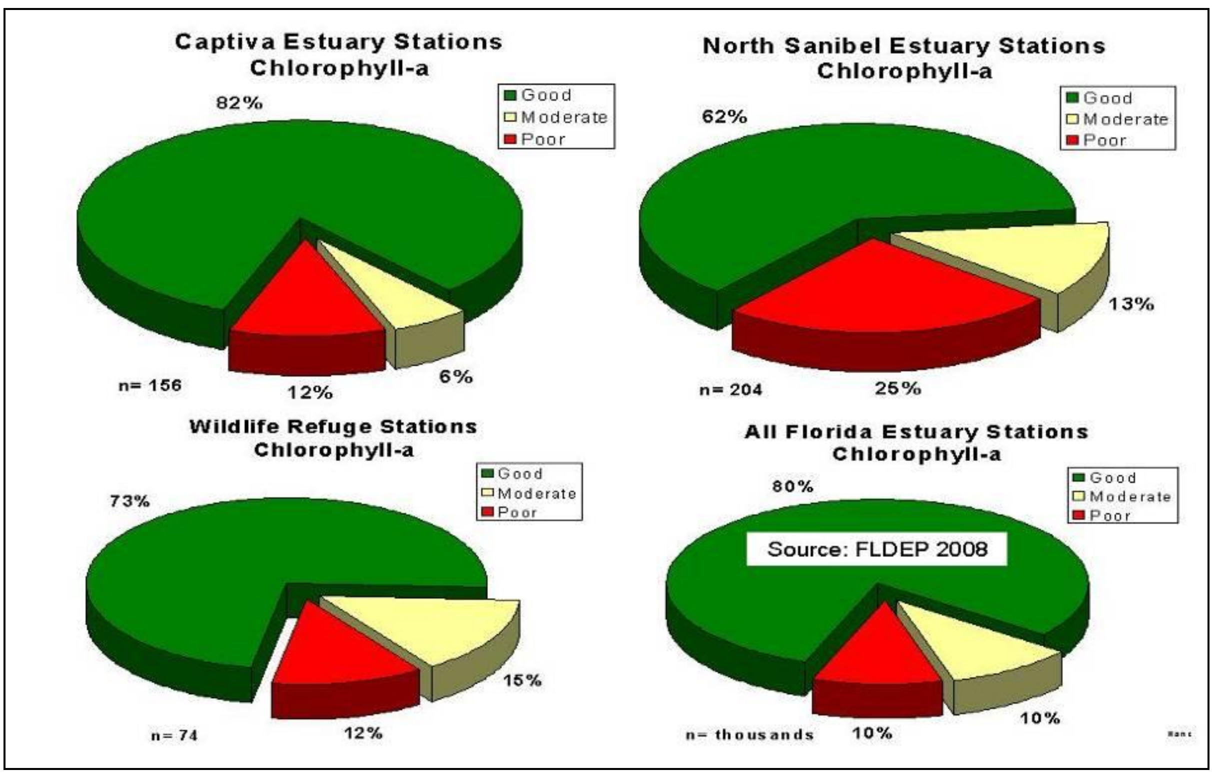

Figure 21. Results of chlorophyll *a* monitoring taken during the baseline assessment (2008-2010) for Captiva estuary (Pine Island Sound) stations compared to northern Sanibel, the National Wildlife Refuge and Florida overall data (FDEP 2008b).

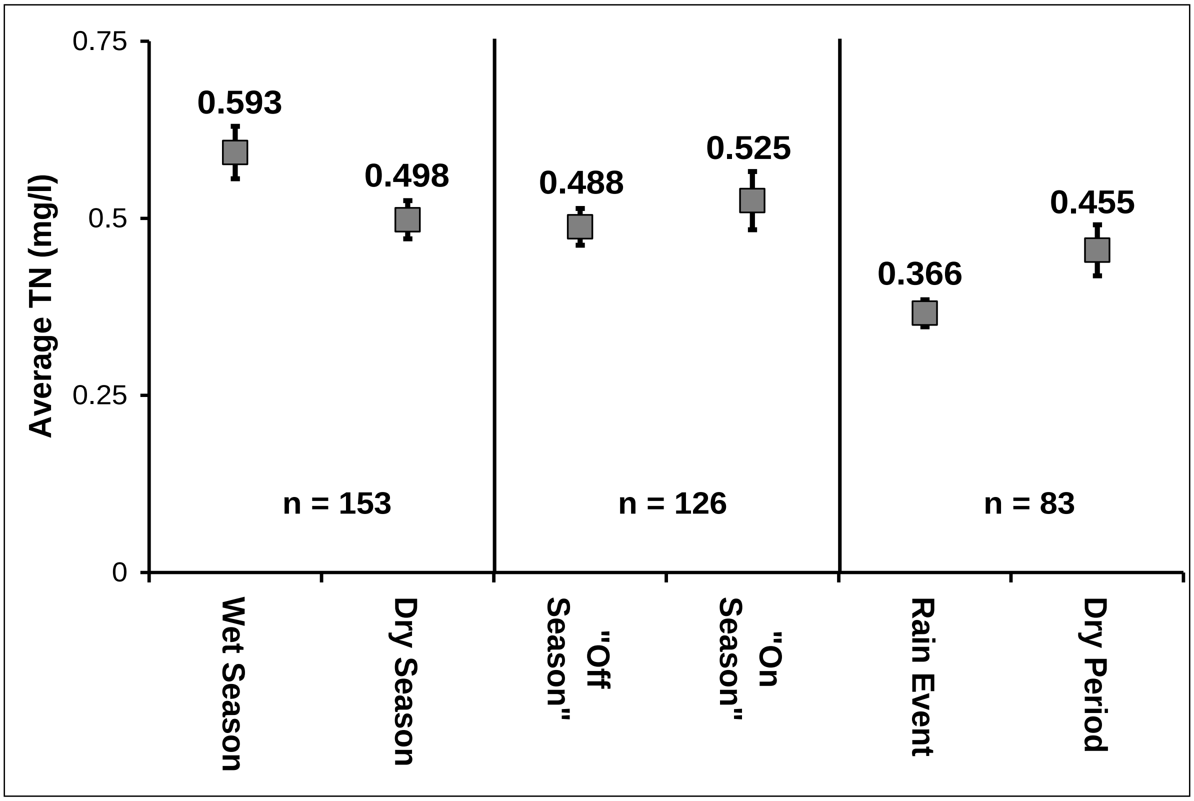

Figure 22. Comparison of mean total nitrogen (TN) concentrations at estuary (Pine Island Sound) stations: “wet” season versus “dry” season; “low” (“off”) season versus “high” (“on”) season; rain event versus no rain (dry) event.

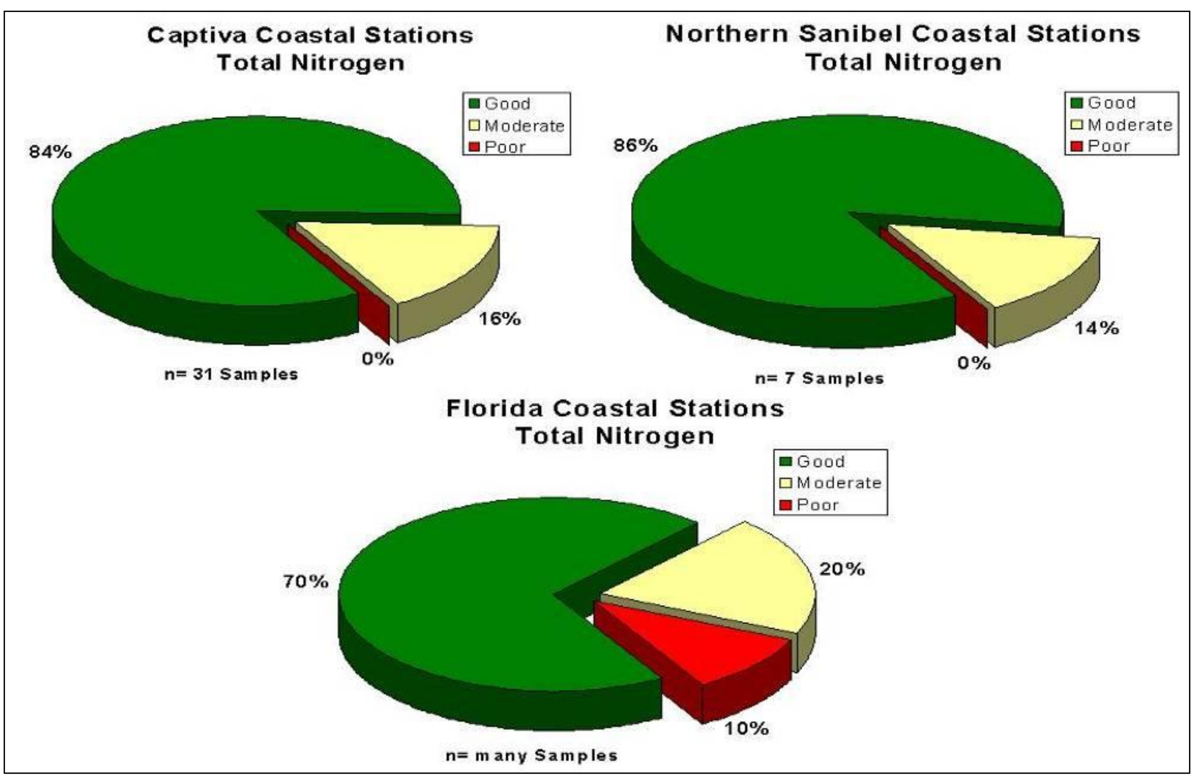

Figure 23. Results of TN monitoring taken during the baseline assessment (2008-2010) for coastal (Gulf of Mexico) stations compared to northern Sanibel Island and all Florida data (FDEP 2008b).

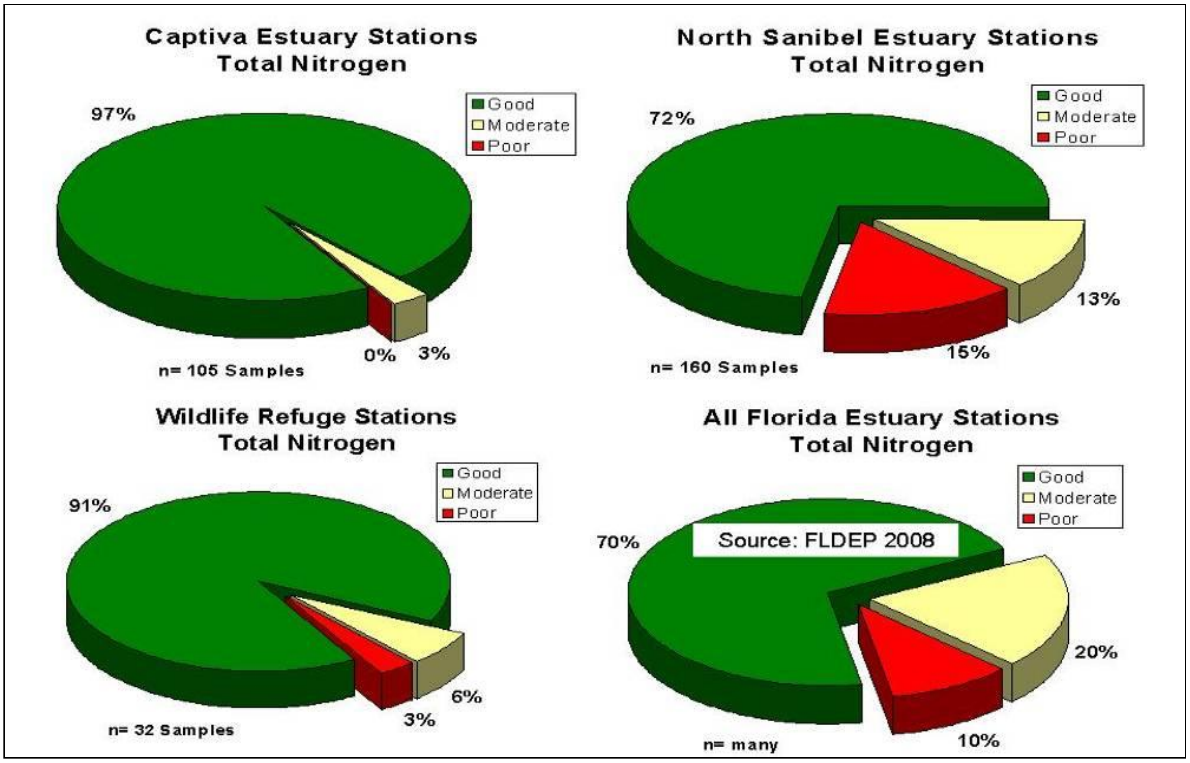

Figure 24. Results of TN monitoring for Captiva estuary stations compared to estuary stations on northern Sanibel, the wildlife refuge and to all Florida estuary stations (FDEP 2008).

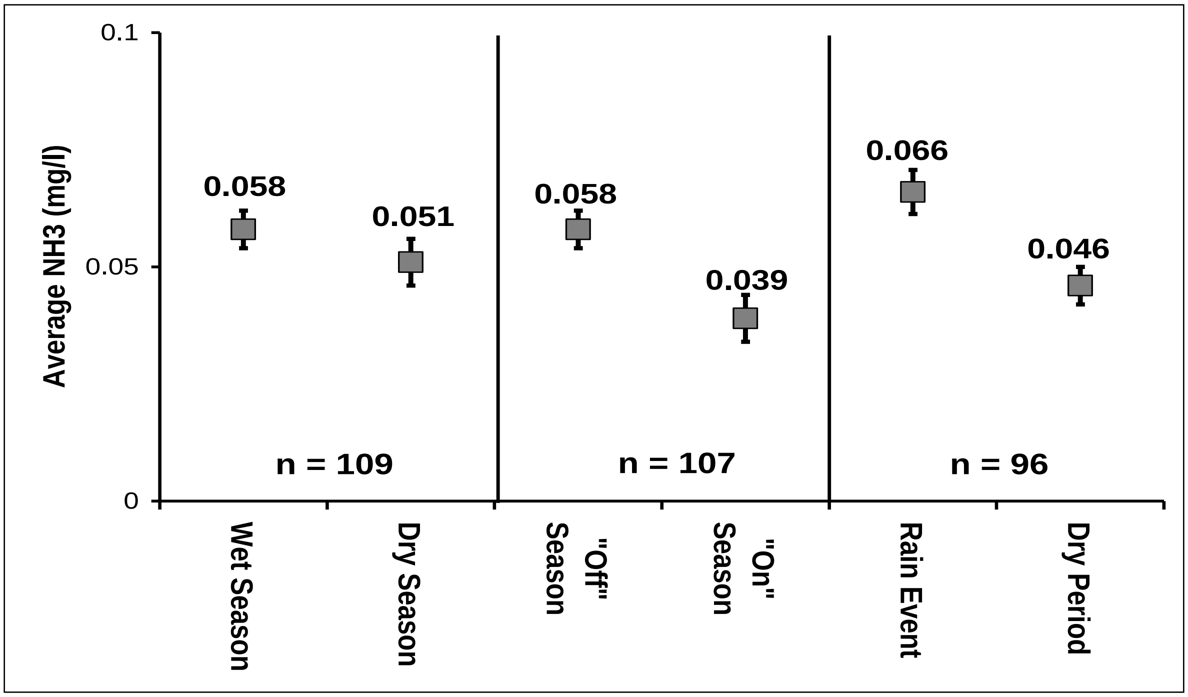

Figure 25. Comparison of ammonia/ammonium concentrations at estuary (Pine Island Sound) stations: wet season versus dry season; "low" ("off") season versus "high" ("on") season; and rain event versus dry periods.

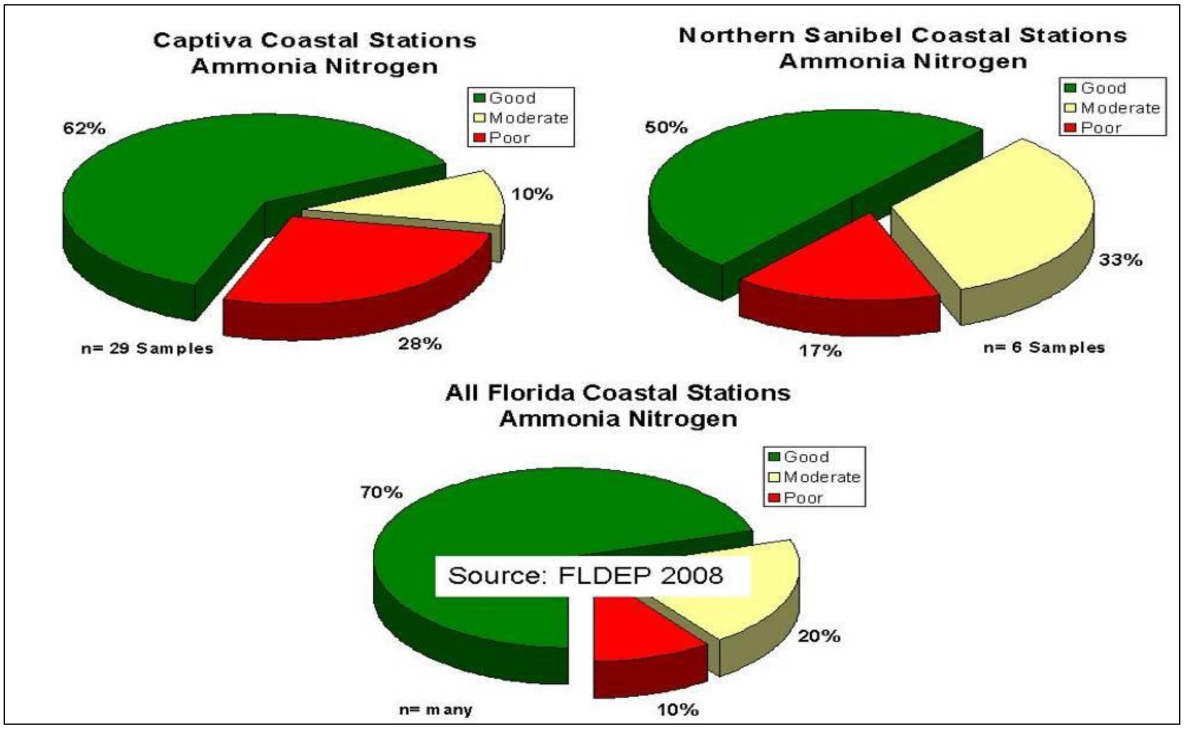

Figure 26. Results of ammonia/ammonium monitoring taken during the baseline assessment (2008-2010) for coastal (Gulf of Mexico) stations compared to northern Sanibel Island and all Florida data (FDEP 2008b).

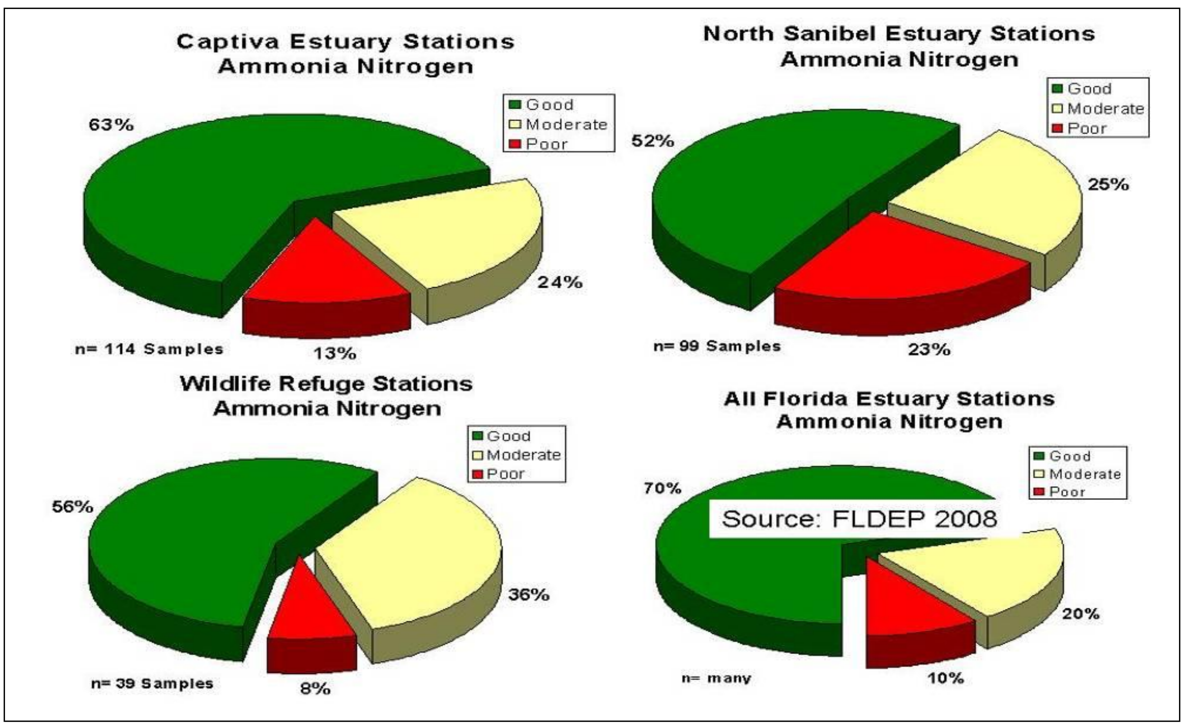

Figure 27. Results of ammonia/ammonium monitoring taken during the baseline assessment (2008-2010) for Captiva estuarine (Pine Island Sound) stations compared to northern Sanibel, the wildlife refuge and all Florida data (FDEP 2008b).

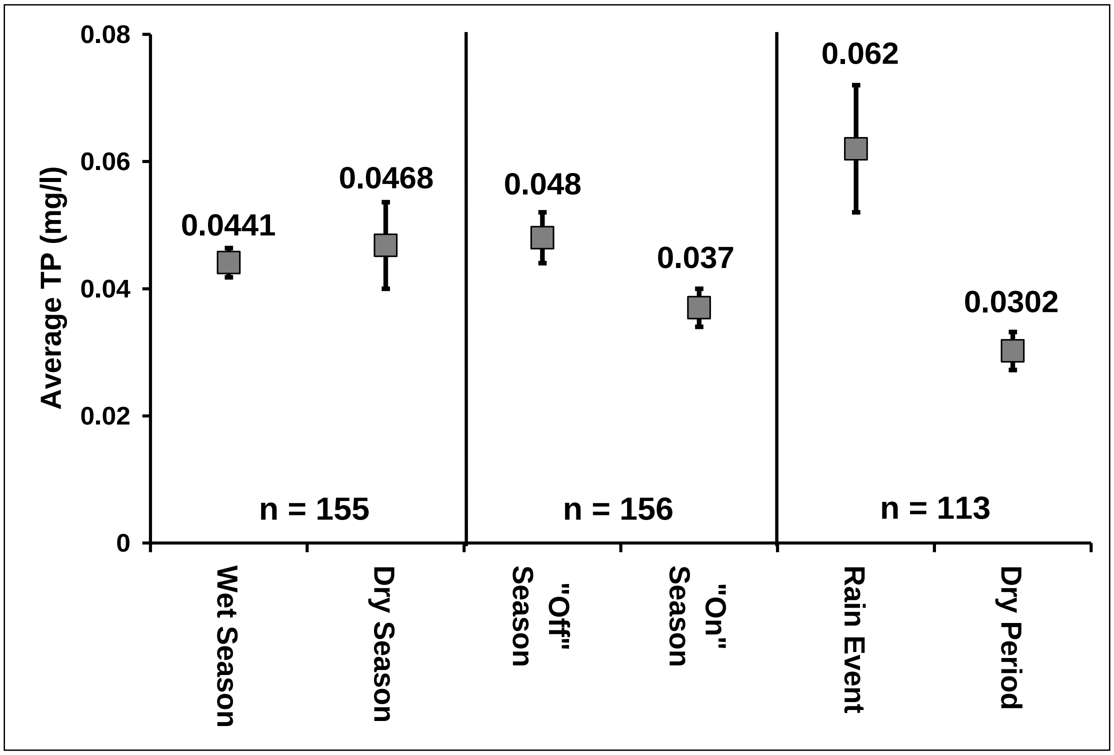

Figure 28. Comparison of mean total phosphorus (TP) concentrations at estuarine (Pine Island Sound) stations: wet versus dry season; "low" ("off") versus "high" ("on") season, and rain versus dry events.

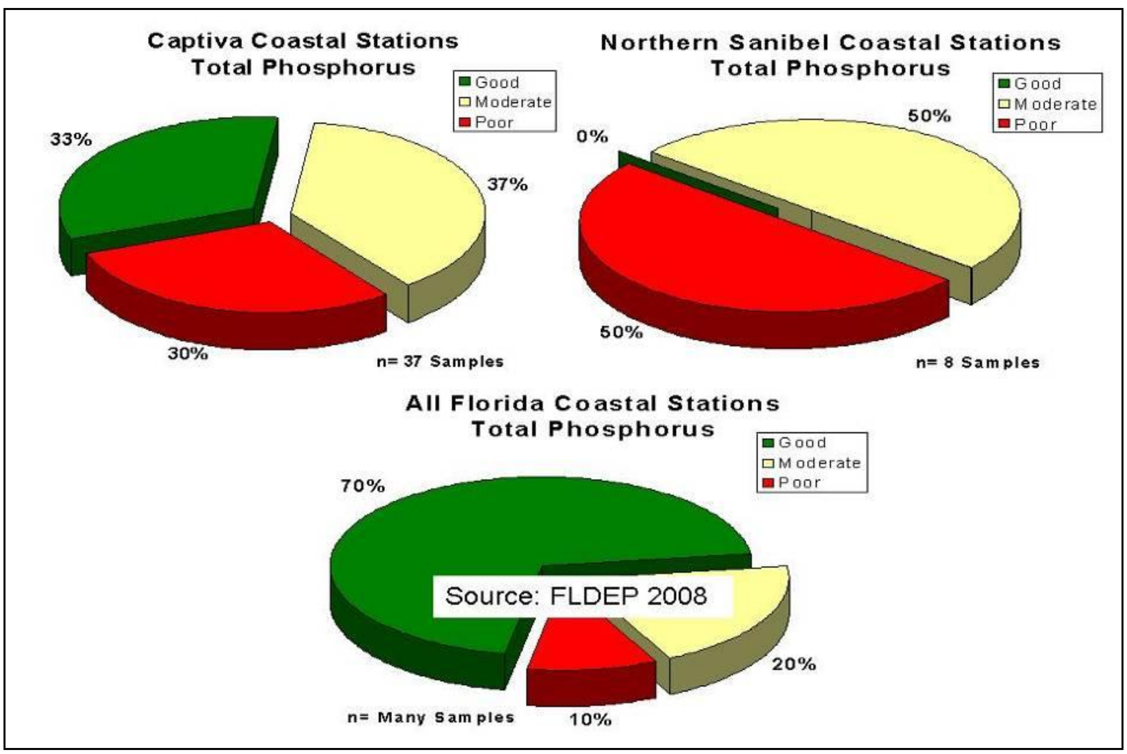

Figure 29. Results of TP monitoring during the study period for Captiva Island coastal (Gulf of Mexico) beach stations compared to northern Sanibel Island and Florida overall beach data (FDEP 2008b).

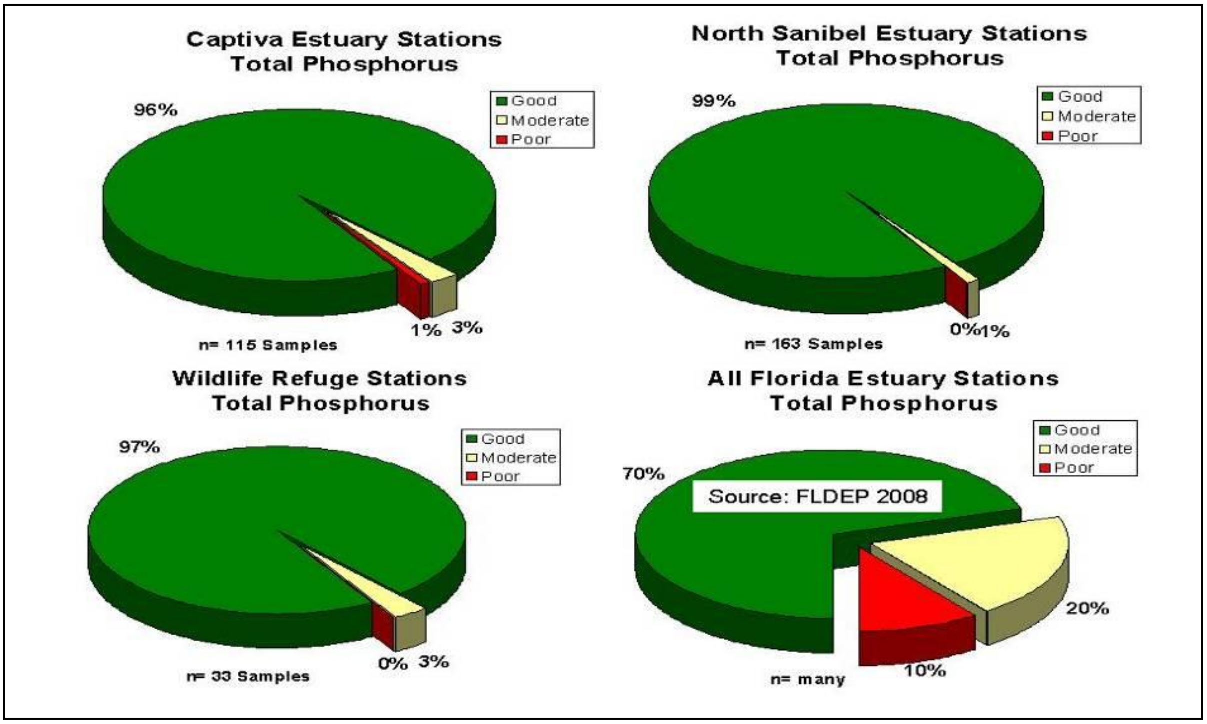

Figure 30. Results of TP monitoring during the study period for Captiva Island estuarine (Pine Island Sound) stations compared to northern Sanibel Island, the NWR and Florida overall data (FDEP 2008 b).

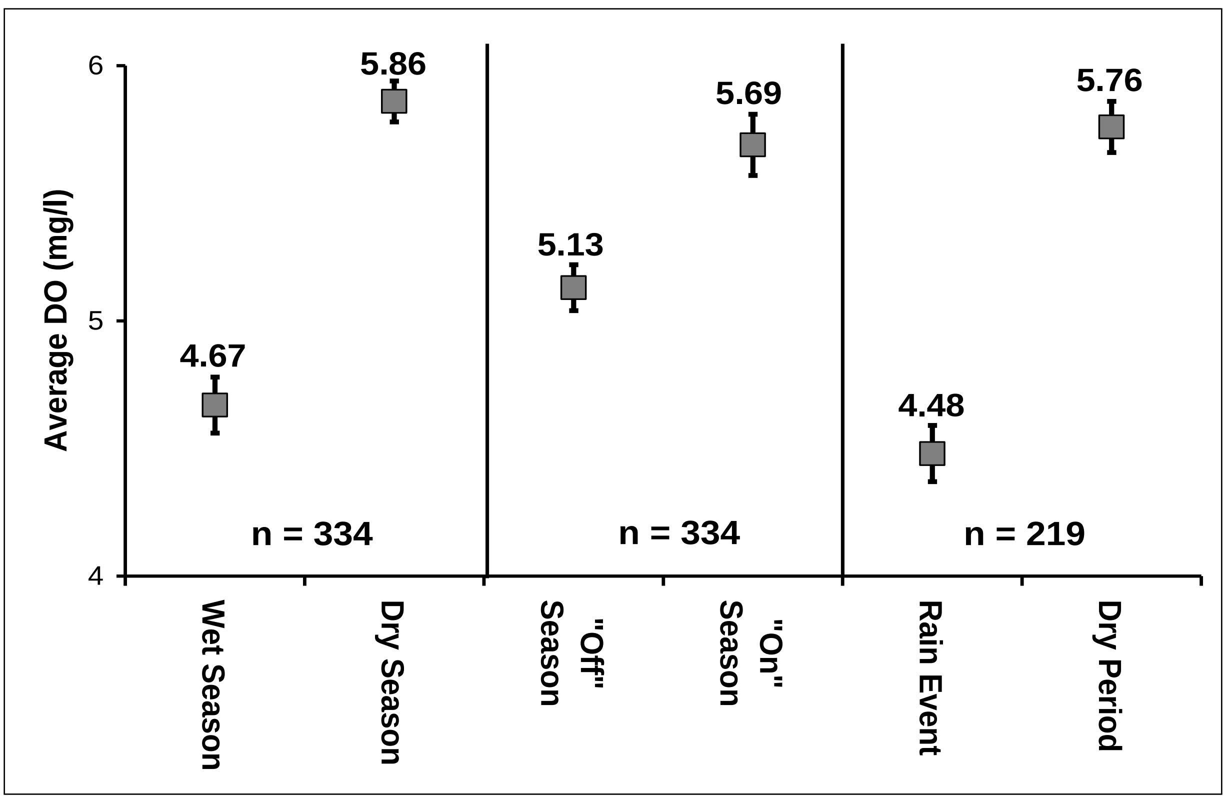

Figure 31. Comparison of mean dissolved oxygen (DO) concentrations at estuary stations (Pine Island Sound): “wet” versus “dry” season; “low” (“off”) versus “high” (“on”) season; rain versus dry events.

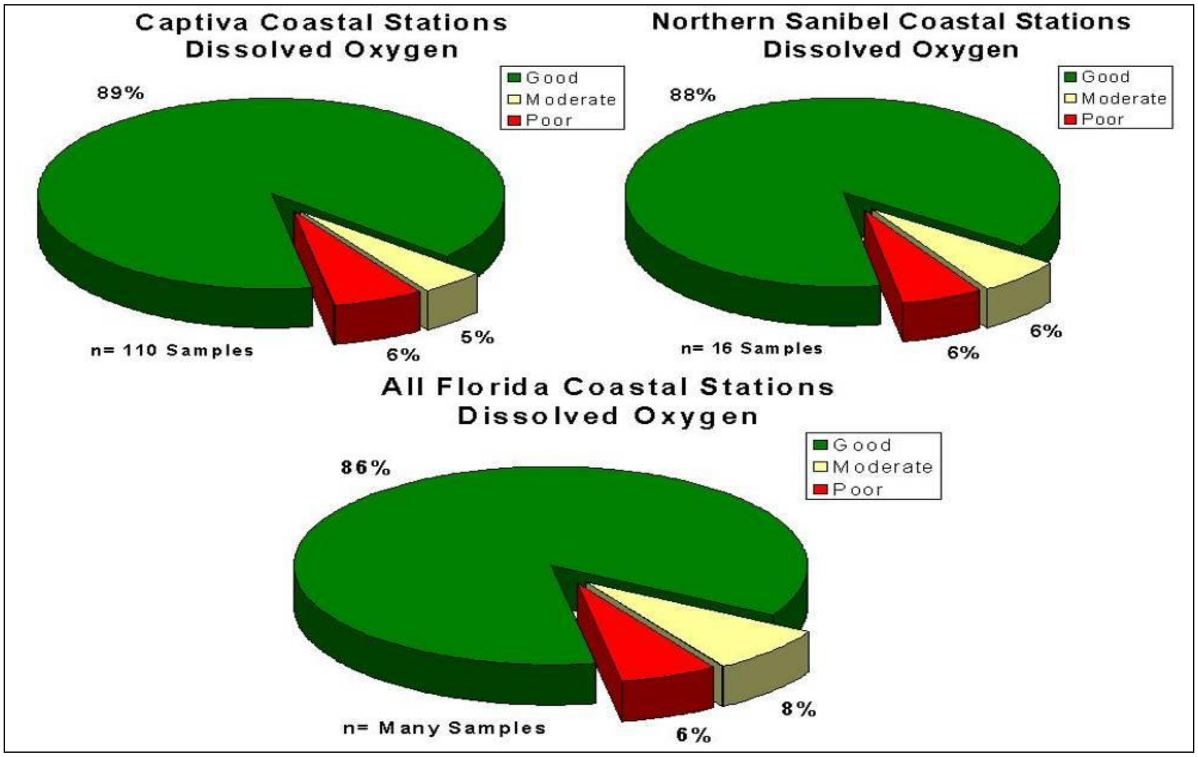

Figure 32. Results of Dissolved Oxygen (DO) monitoring during the study period for Captiva coastal (Gulf of Mexico) beach stations compared to northern Sanibel and Florida overall beach data (FDEP 2008b).

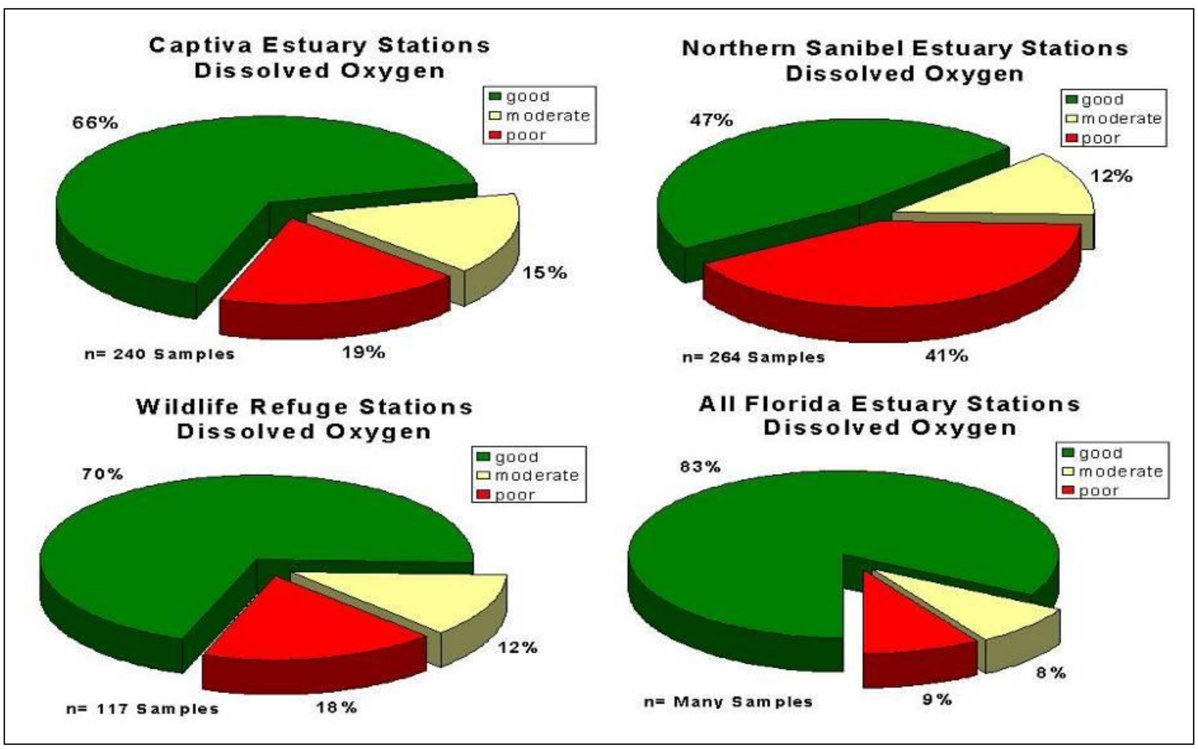

Figure 33. Results of dissolved oxygen (DO) monitoring during the study period for Captiva Island estuarine (Pine Island Sound) stations compared to northern Sanibel Island, the NWR and Florida overall data (FDEP 2008b).

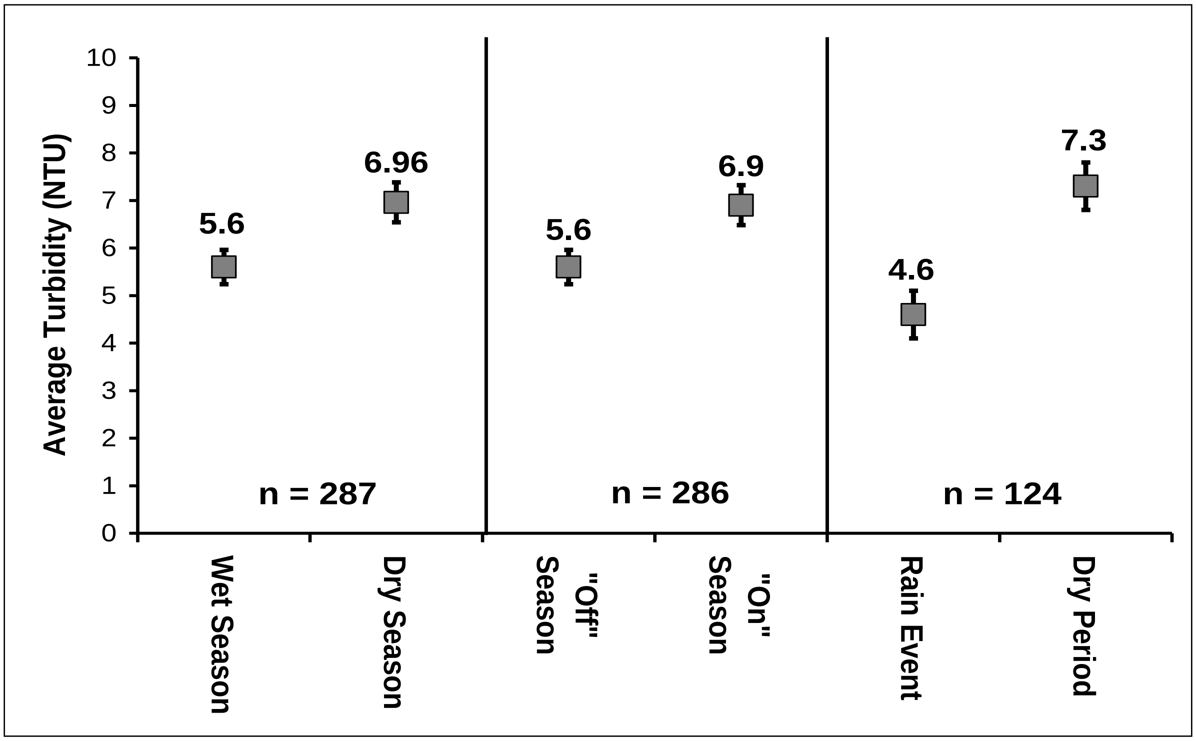

Figure 34. Comparison of mean turbidity concentrations at estuarine (Pine Island Sound) stations: "wet" versus "dry" season; "low" ("off") versus "high" ("on") season; and "rain" versus dry events.

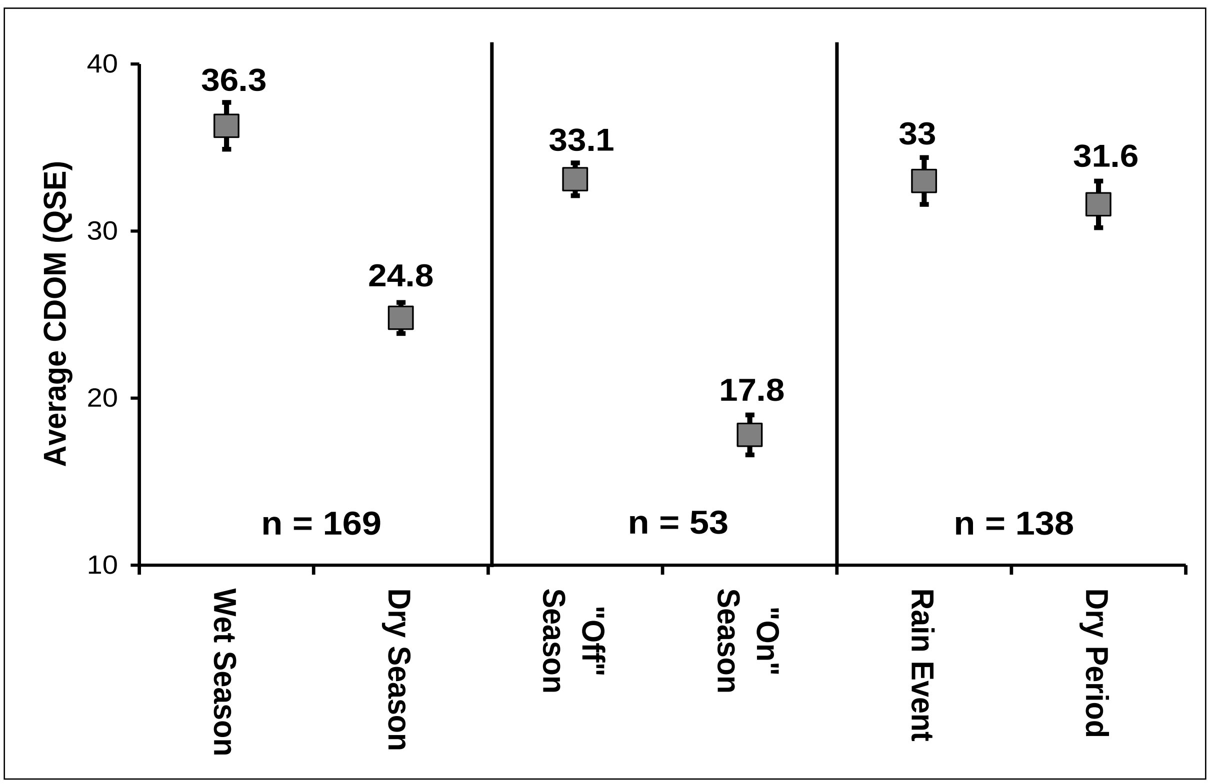

Figure 35. Comparison of mean CDOM concentrations at the study area's estuarine (Pine Island Sound) stations: "wet" season versus "dry" season; "low" ("off") season versus "high" ("on") season; and "rain" versus "dry" events.

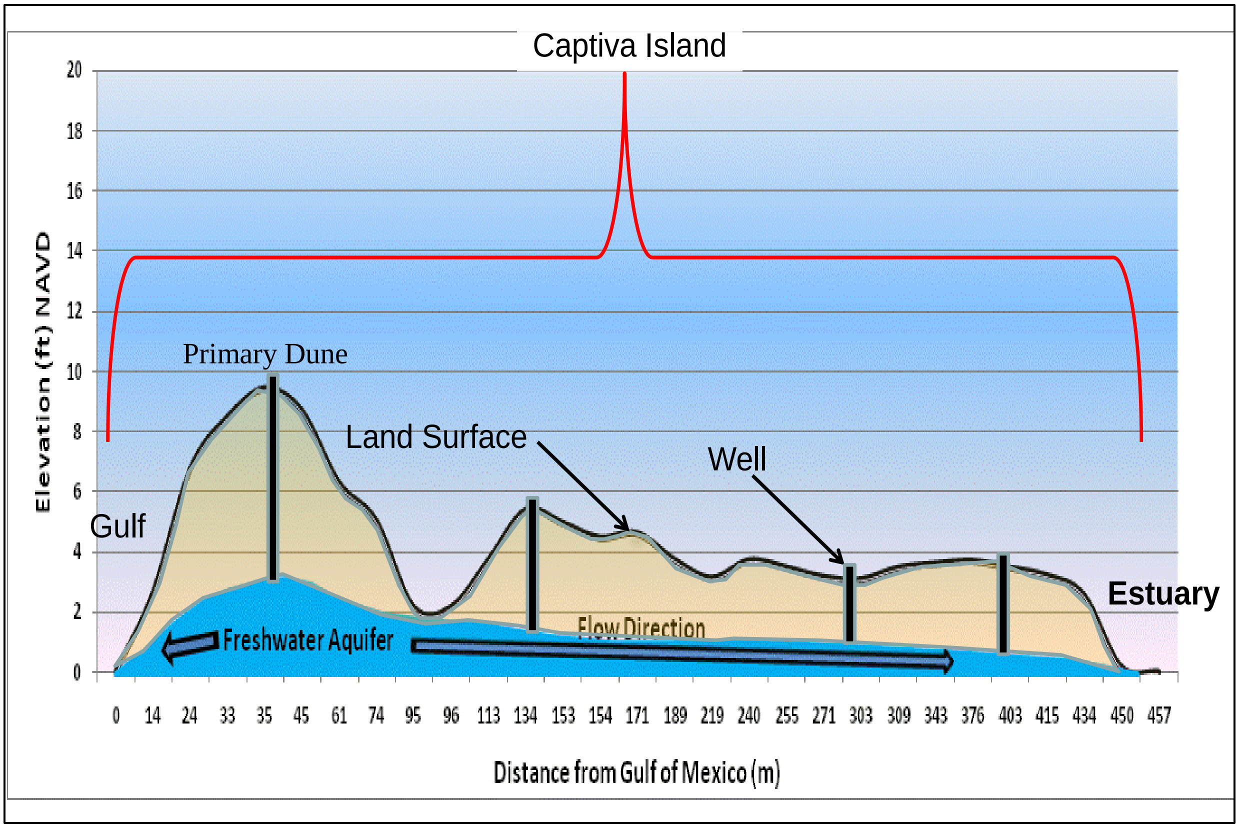

Figure 36. Representation of the flow direction of the upper aquifer beneath Captiva Island taken from data recorded during sampling of a cross island transect of monitoring wells.

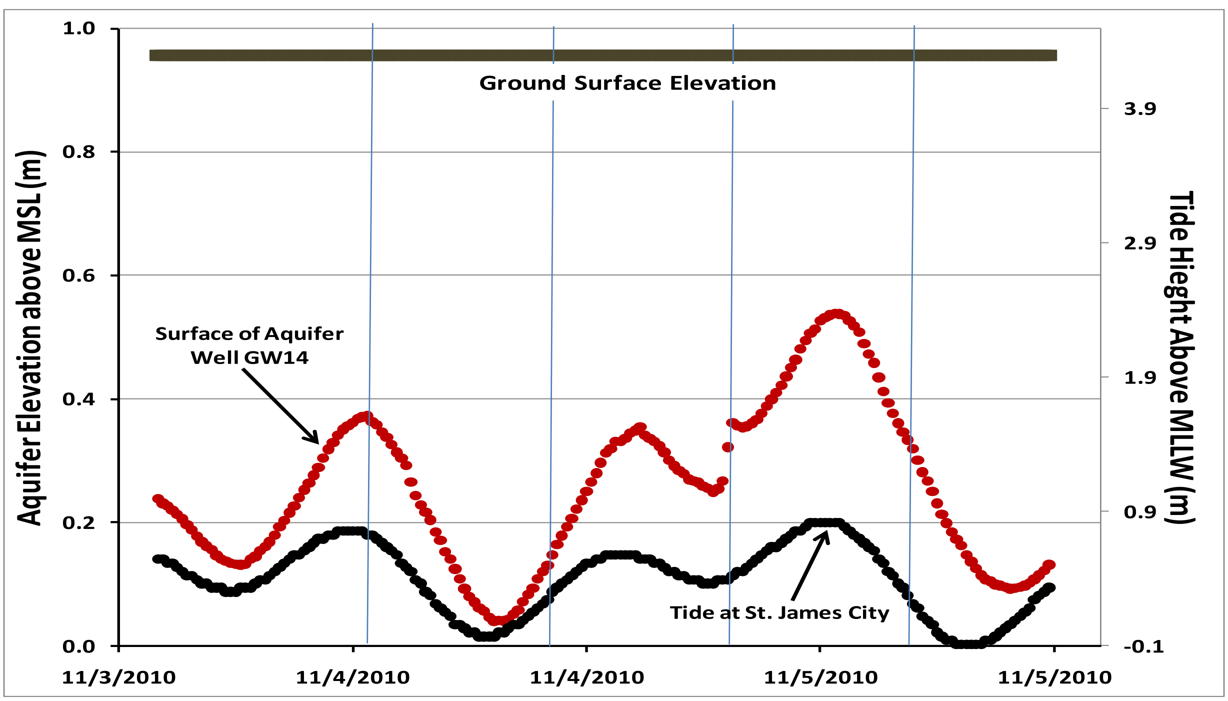

Figure 37. Elevation of groundwater at monitoring well GW14 over a two day period compared to tide chart for St. James City showing a clear tidal signal for the groundwater.

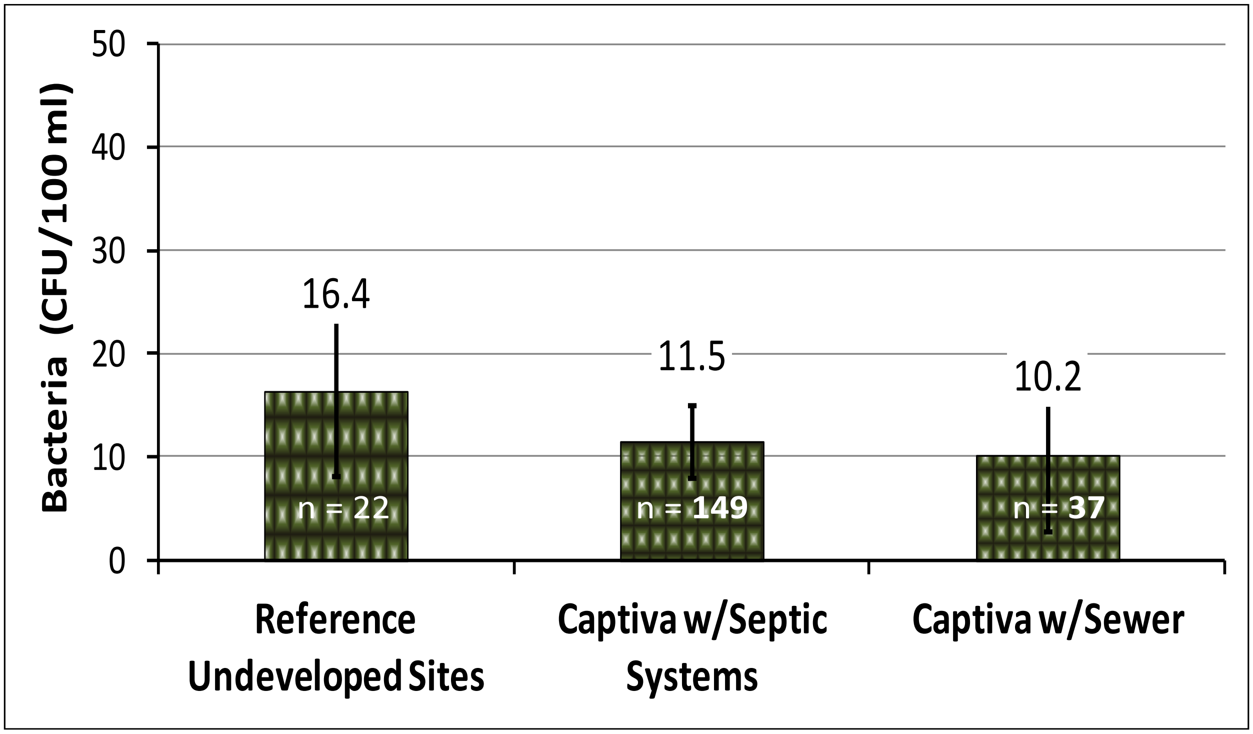

Figure 38. No significant difference could be seen in mean groundwater *Enterococci* bacteria concentrations in the non-sewered portion of Captiva compared to the sewered section and reference wells.

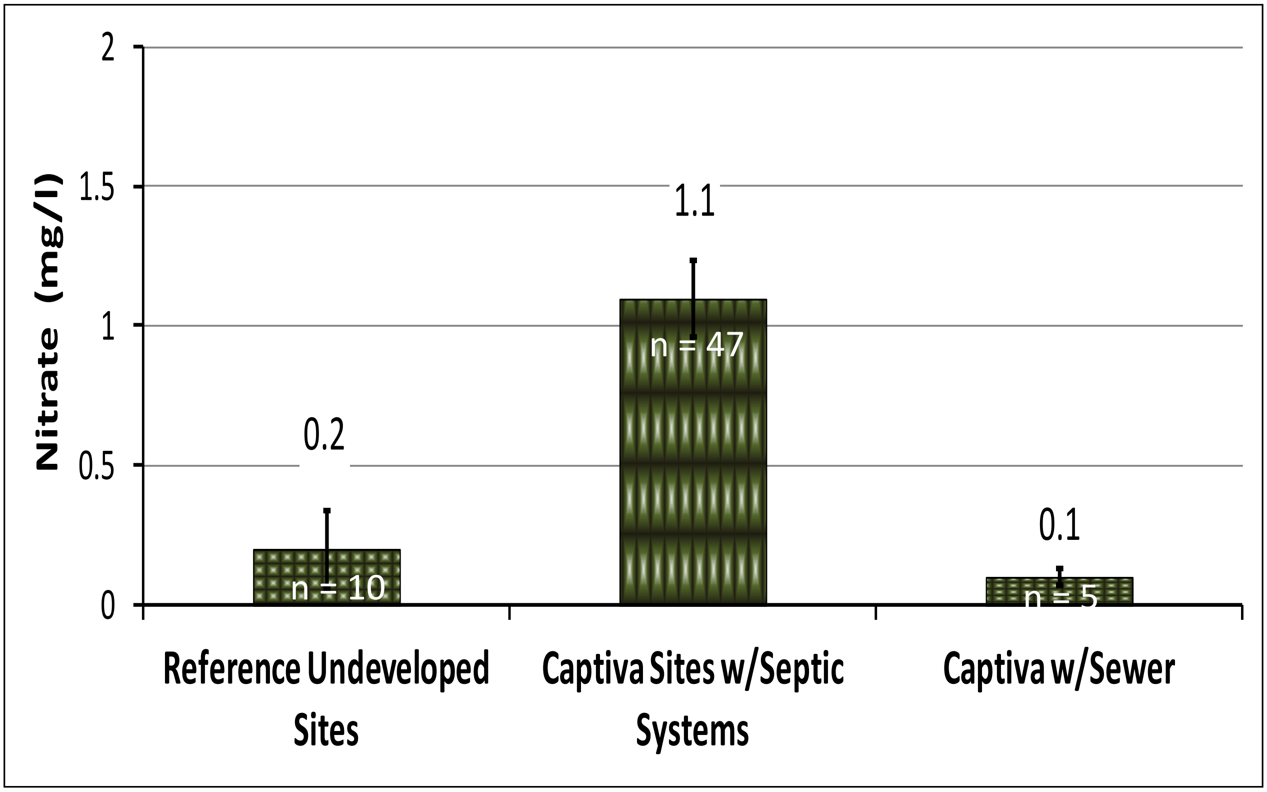

Figure 39. Significantly greater groundwater nitrate concentrations were found in the non-sewered portion of Captiva compared to the sewered section and reference wells.

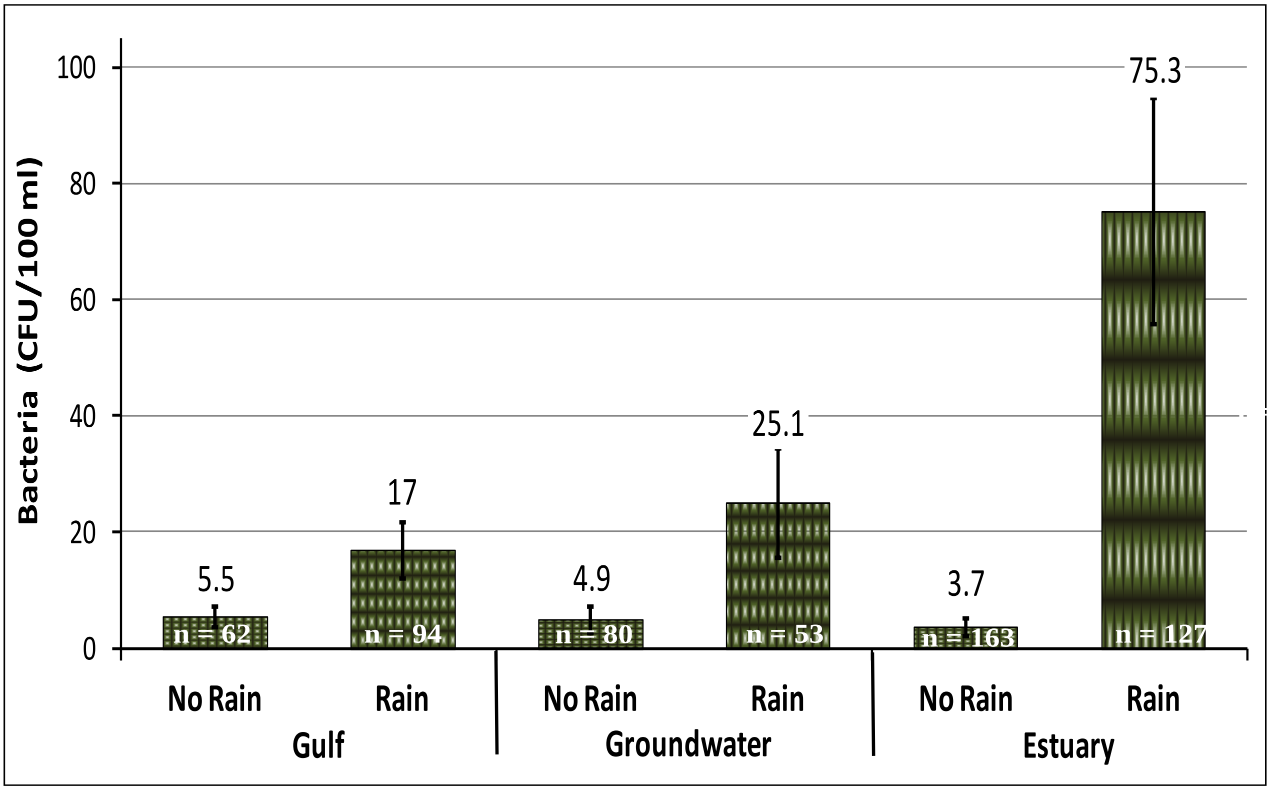

Figure 40. Mean *Enterococci* concentrations were significantly greater for estuary samples after rain events than for groundwater or Gulf side samples. No difference was seen between mean concentrations during dry periods.

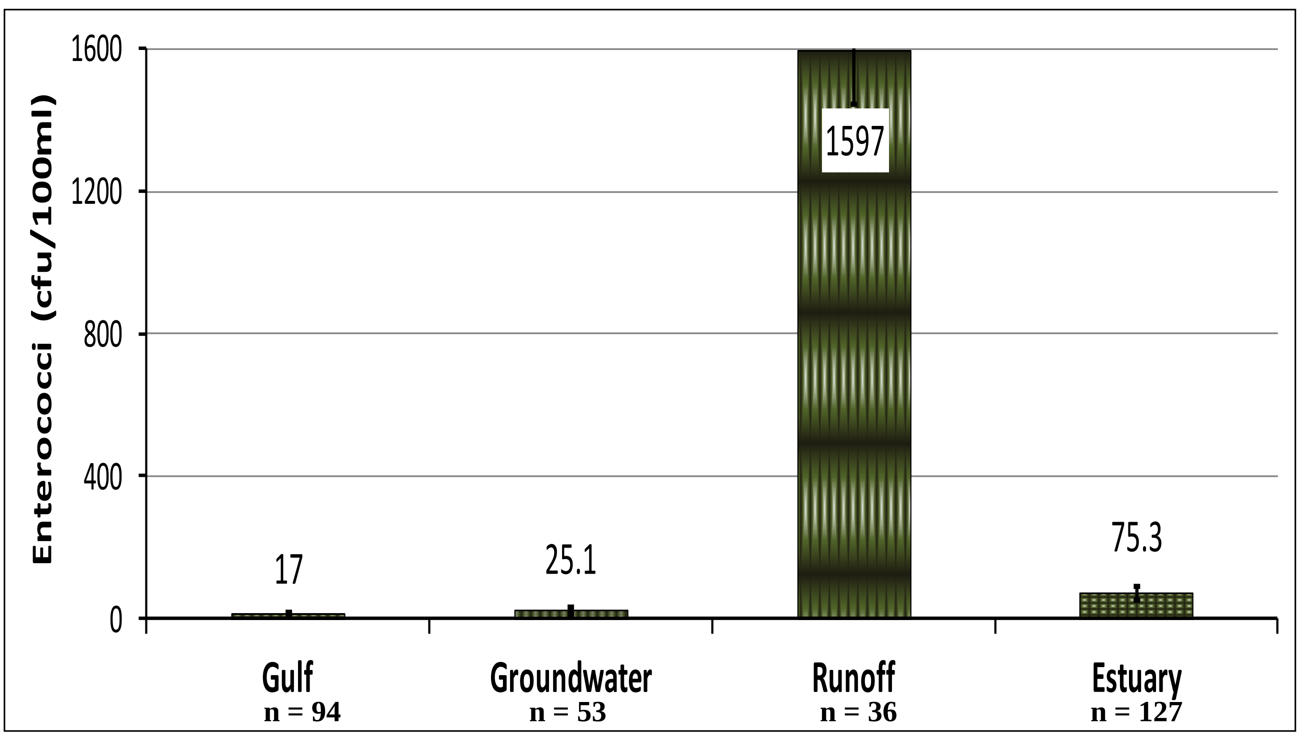

Figure 41. Mean *Enterococci* concentrations were significantly great in stormwater runoff compared to Estuary, Gulf or groundwater.

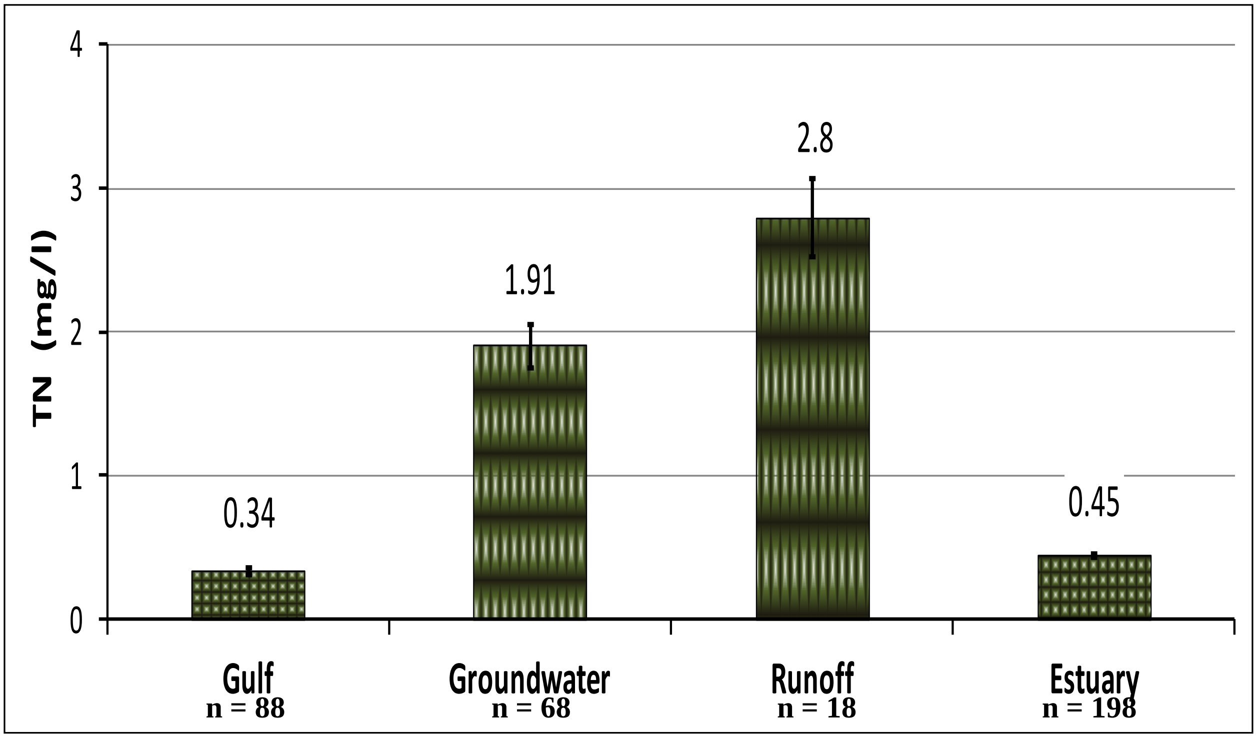

Figure 42. Mean total nitrogen concentrations were significantly greater in runoff and groundwater compared to estuary or gulf.

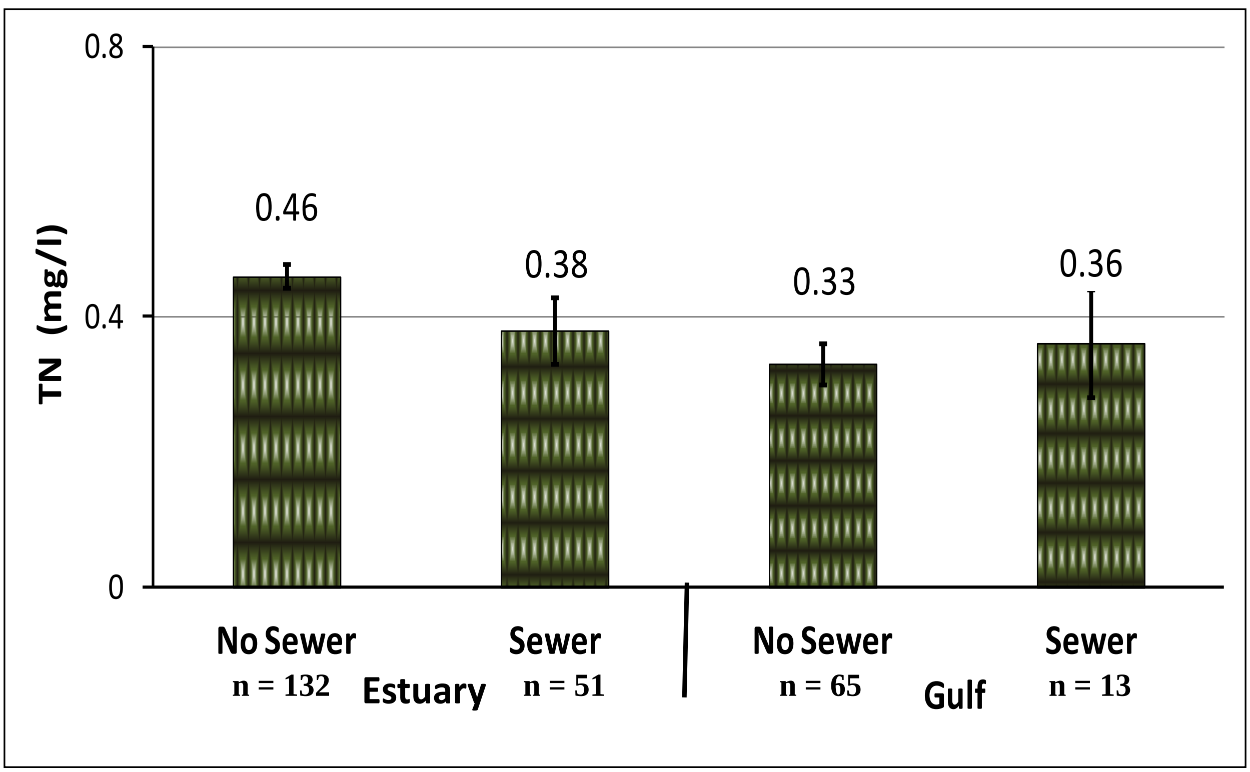

Figure 43. Mean TN was significantly greater for estuary sites within the non-sewered portion of Captiva compared to the sewered portion. No difference could be found between sewered and non-sewered sites on the Gulf side.

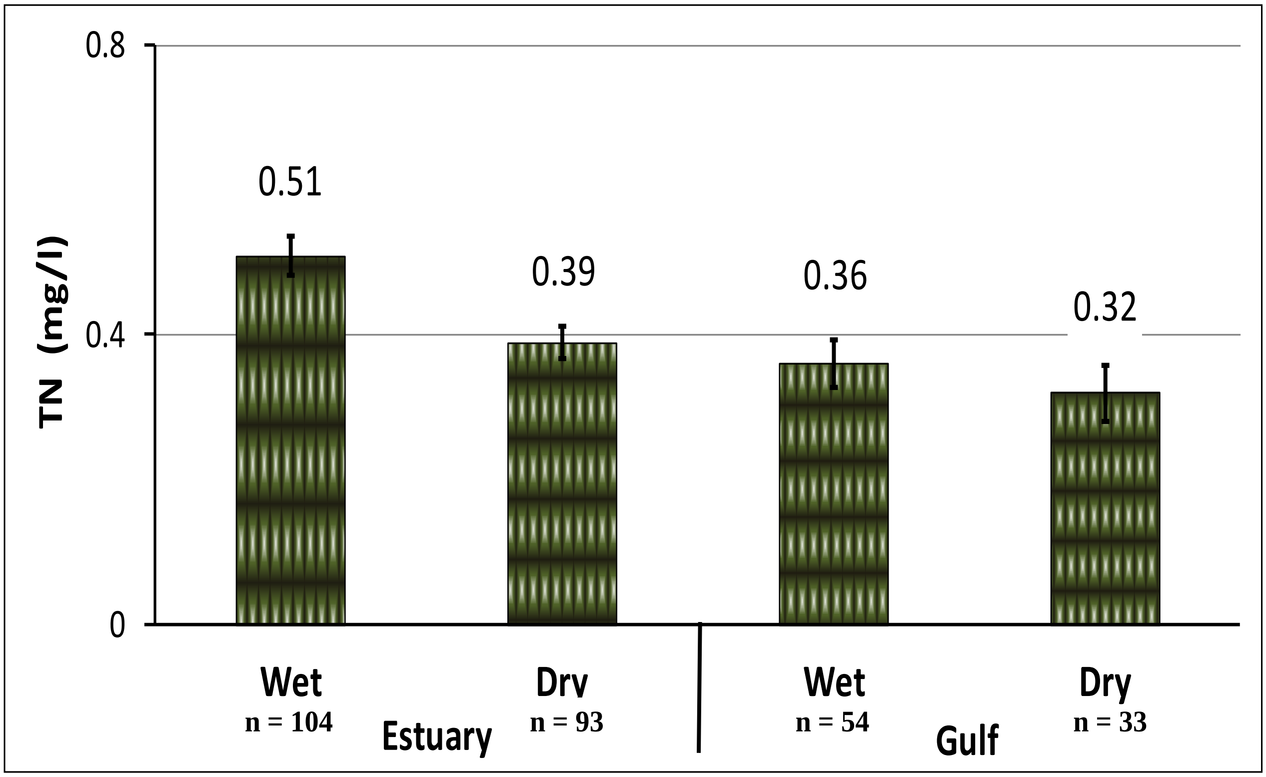

Figure 44. Mean TN was significantly greater during wet season than dry season for estuary samples but no difference could be found for Gulf-side samples.

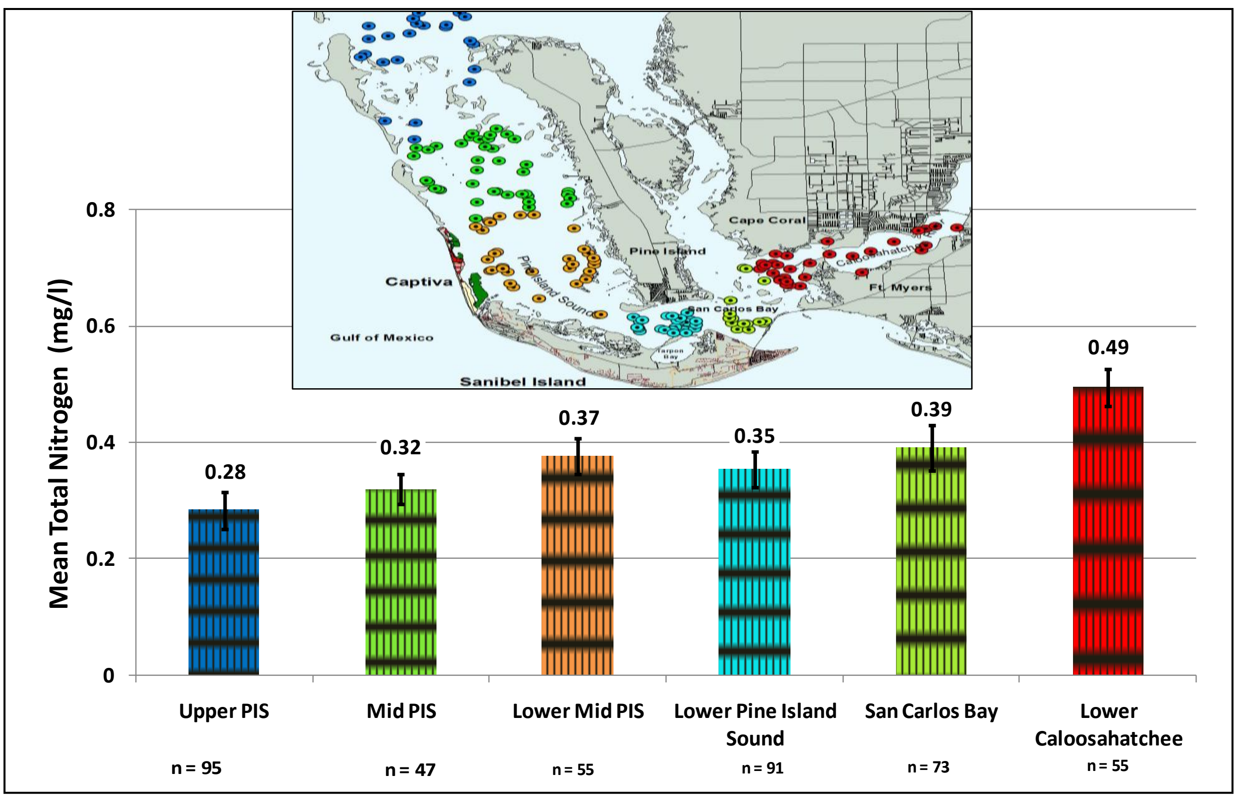

Figure 45. Total nitrogen (TN) along a transect from the lower Caloosahatchee River to upper Pine Island Sound.

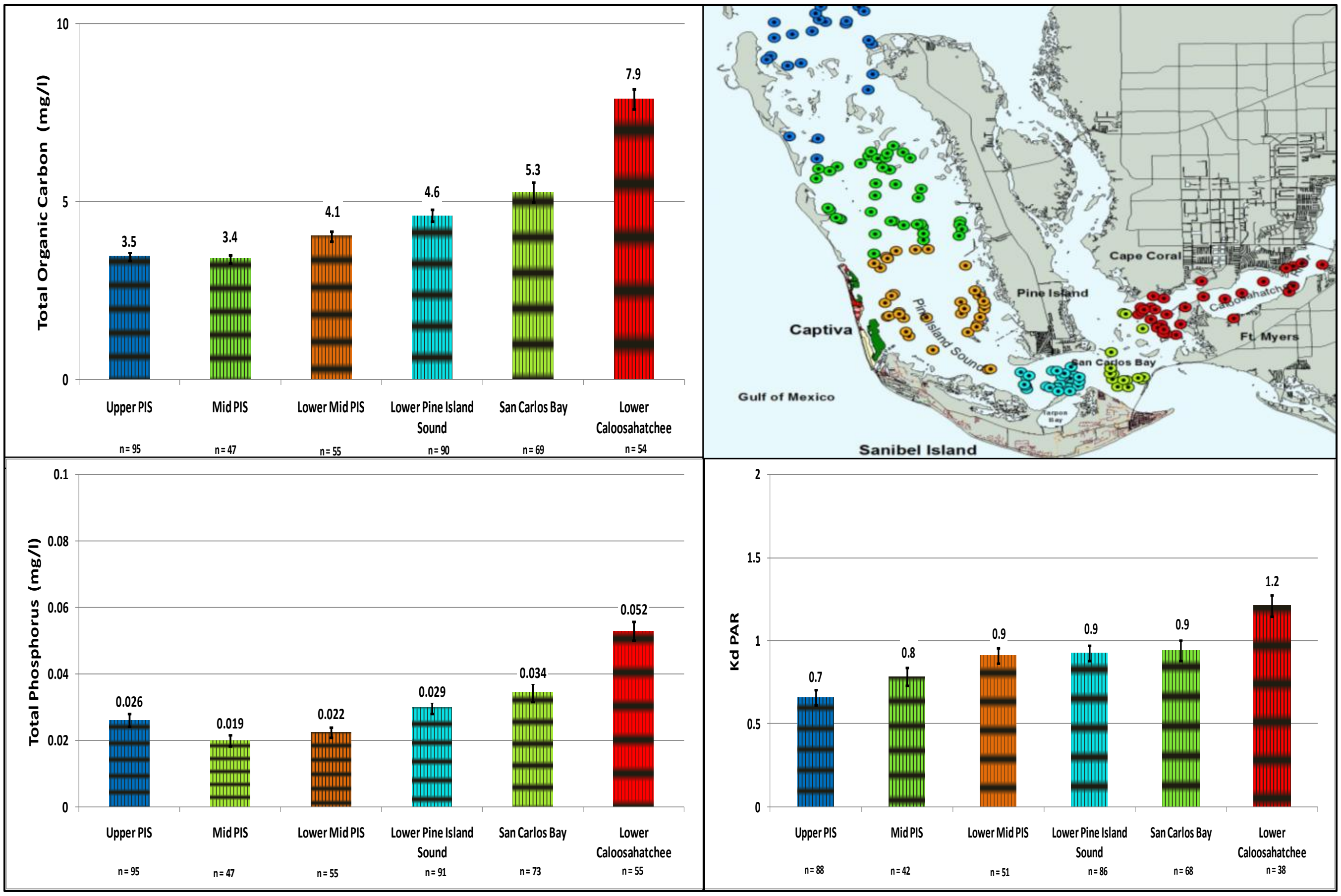

Figure 46. Mean TOC, TP, and KdPAR along a transect from the lower Caloosahatchee River to upper PIS. All show similar decreasing trend in concentration.

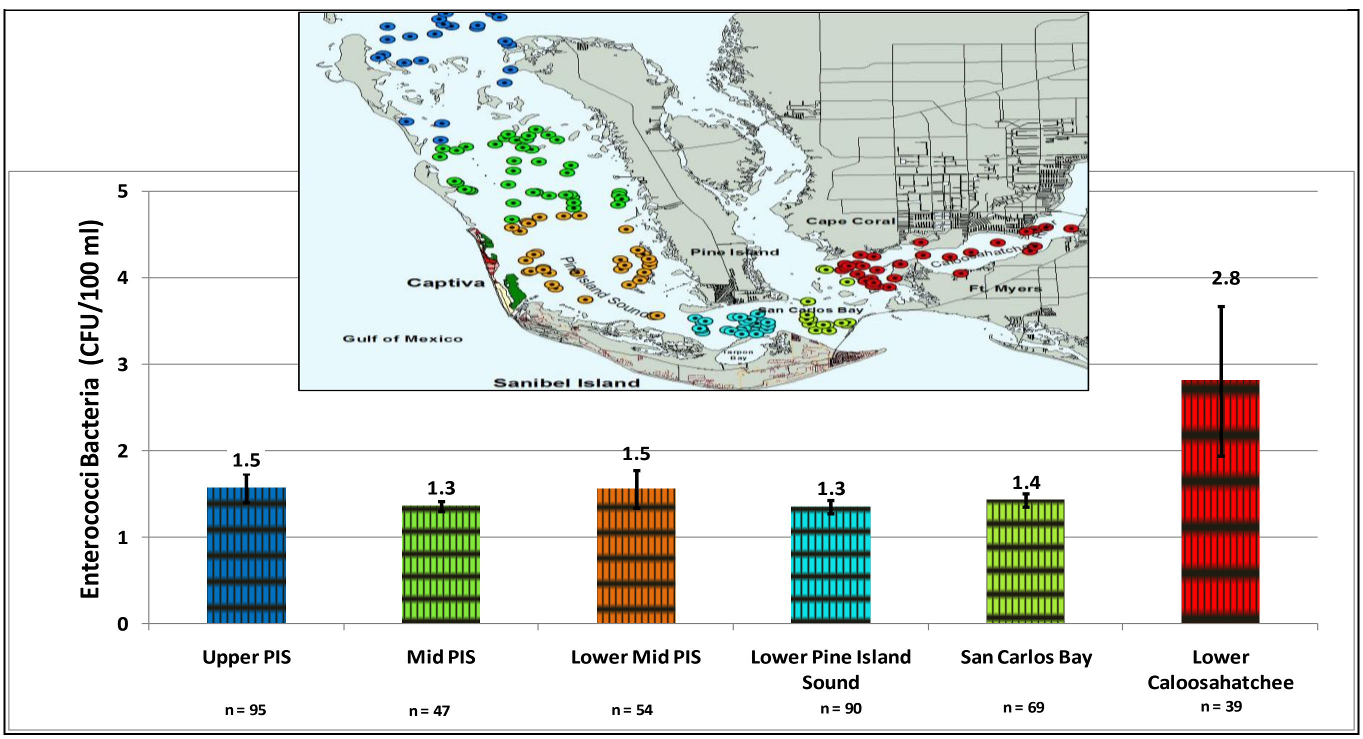

Figure 47. Mean Enterococci along a transect from lower Caloosahatchee River to upper PIS. Mean values are near detection limits for the method.

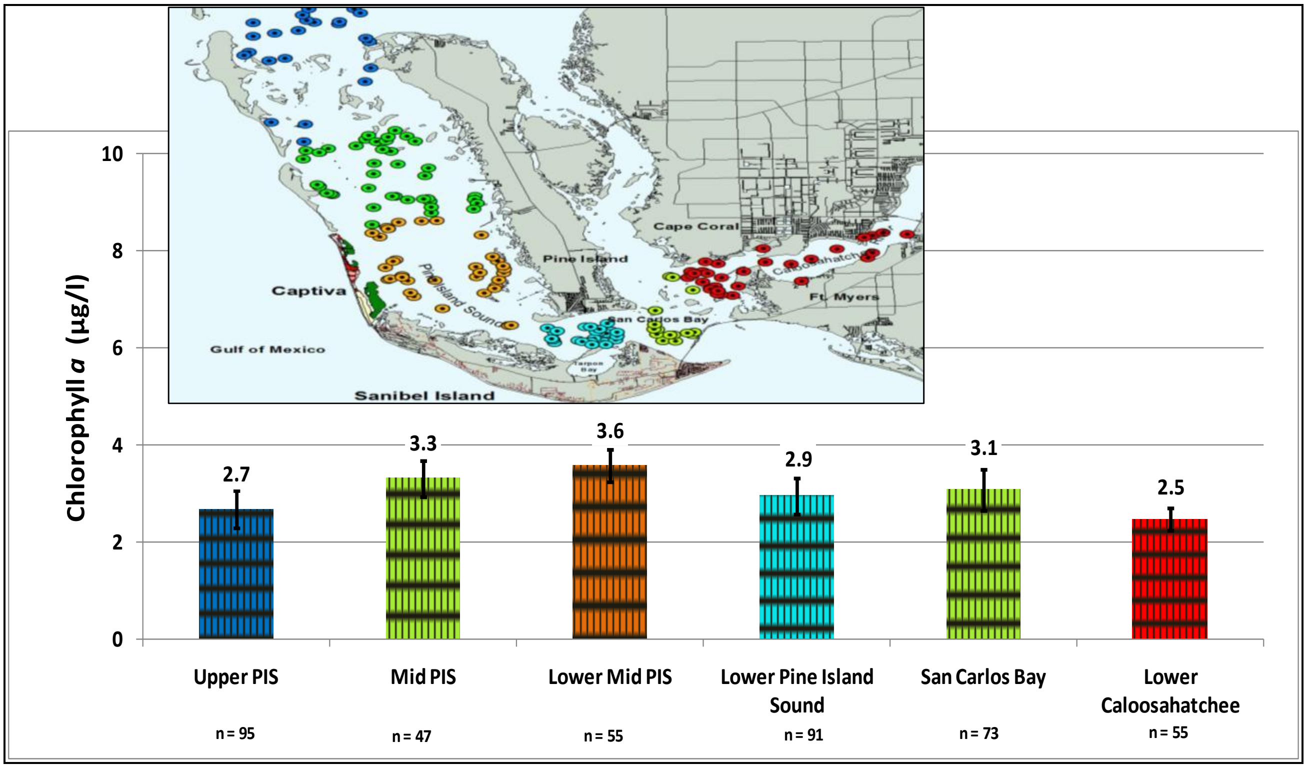

Figure 48. Mean chlorophyll *a* along a transect from the lower Caloosahatchee River to upper Pine Island Sound. Greatest chlorophyll *a* concentration found near mid-Pine Island Sound.

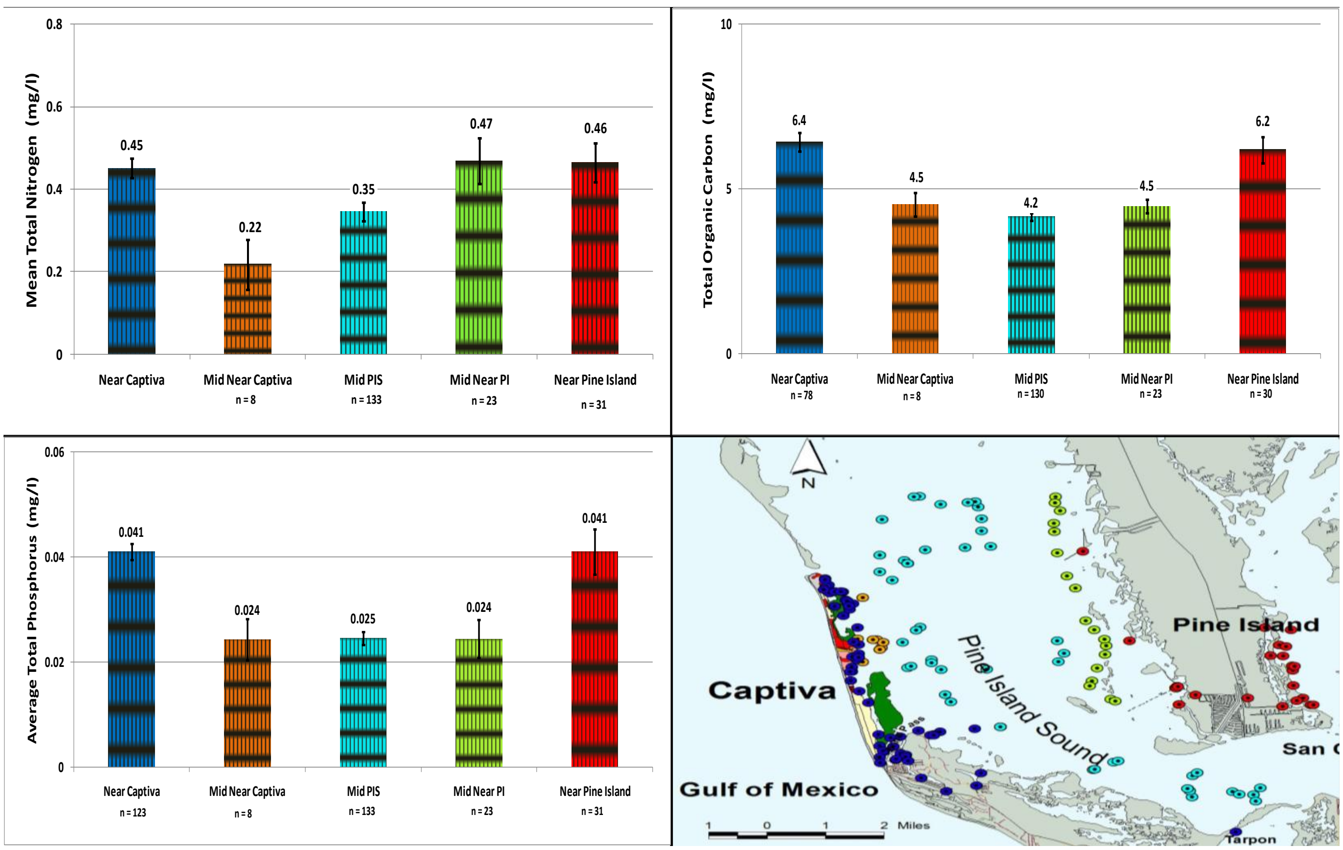

Figure 49. Mean TN, TP and TOC along a transect from Pine Island to Captiva Island.

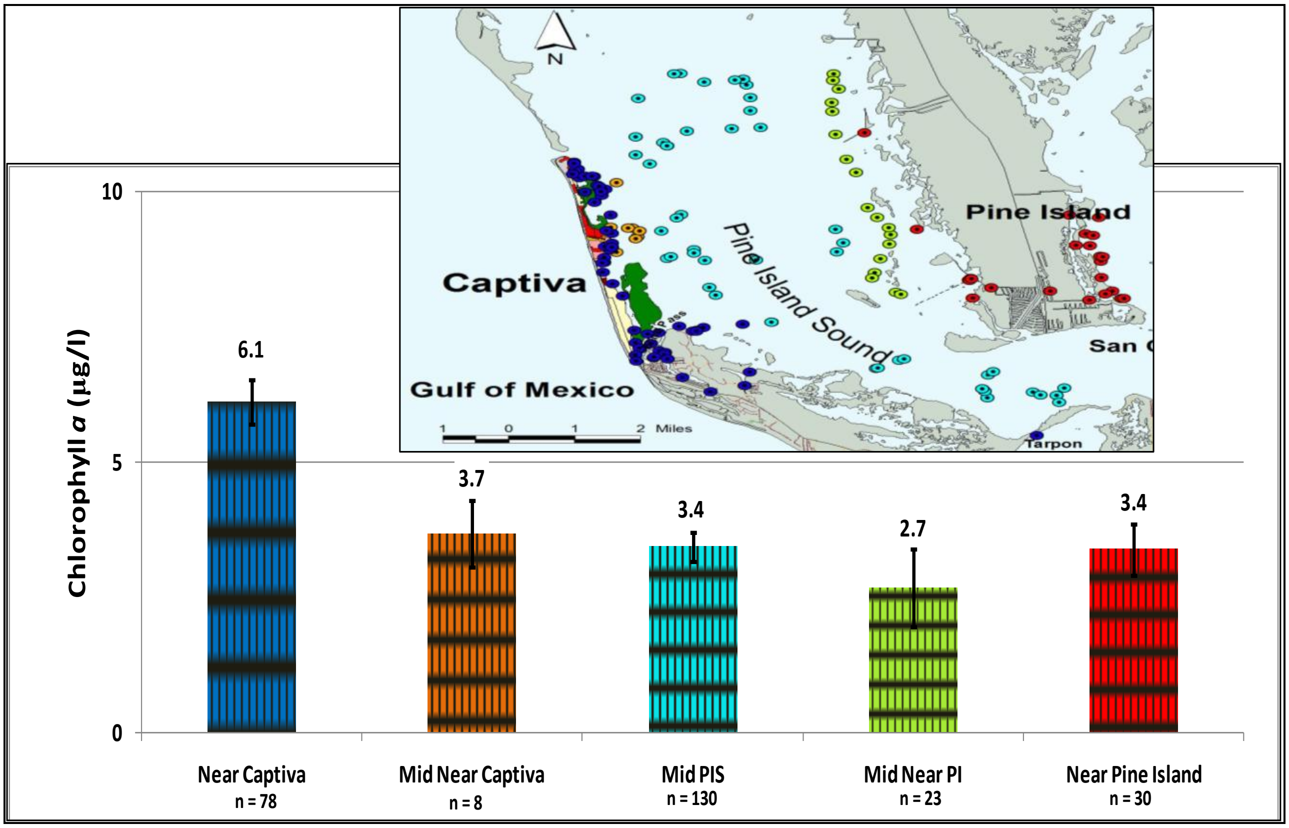

Figure 50. Mean chlorophyll *a* along a transect from Pine Island to Captiva Island. Greatest concentrations of chlorophyll were seen nearest the islands.

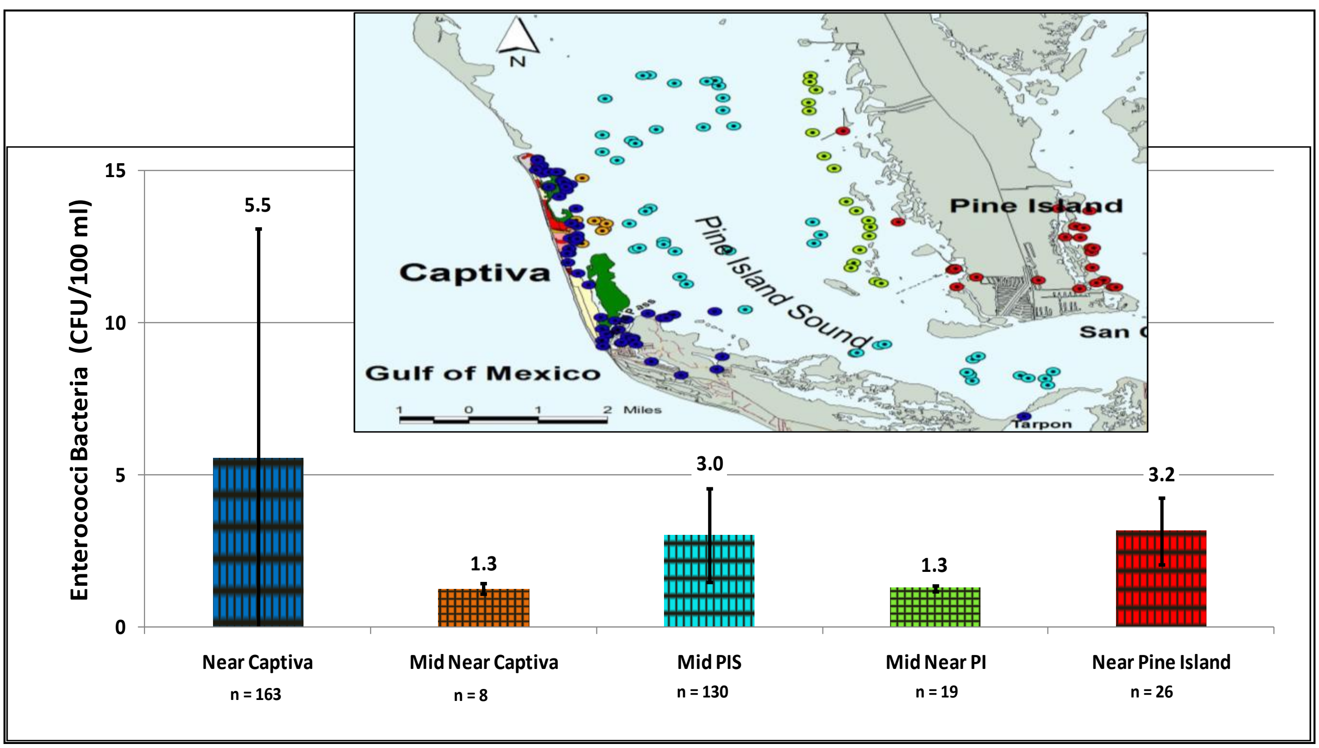

Figure 51. Mean *Enterococci* along a transect from Pine Island to Captiva Island. Mean levels were near the detection limit for the method.

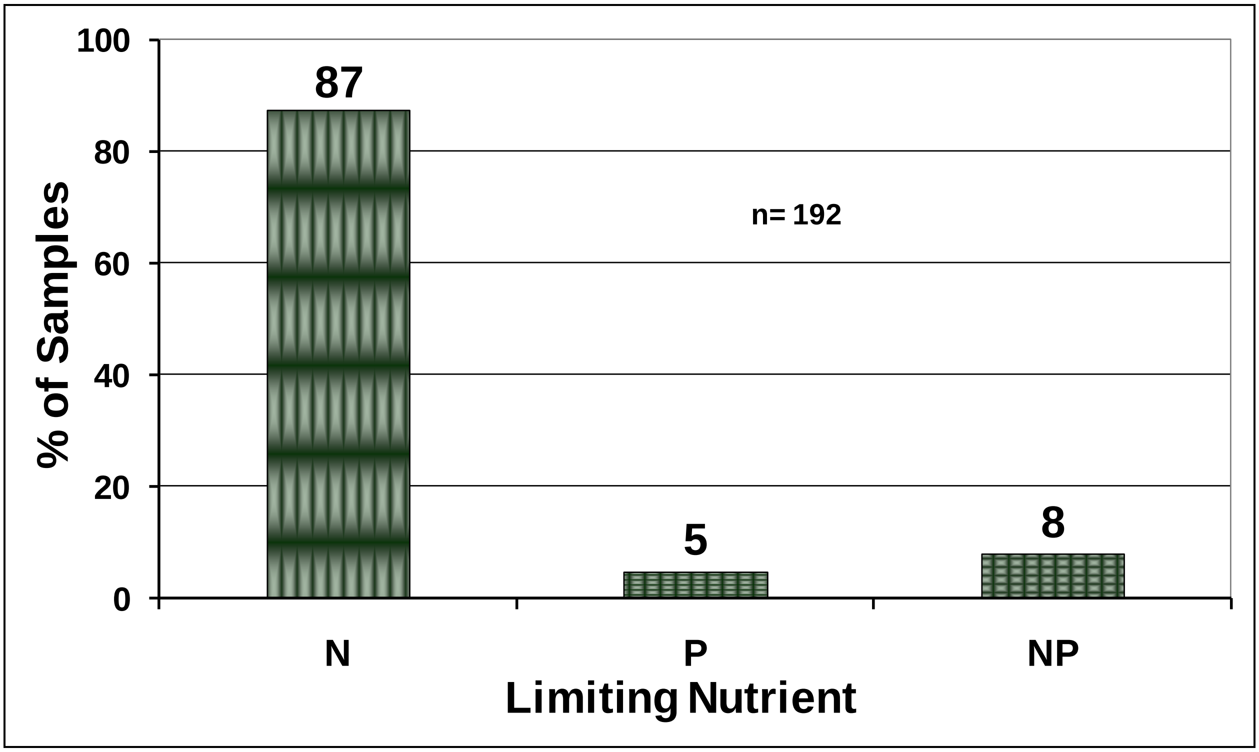

Figure 52. Percentage of Samples taken from Estuary Side of Captiva Island which were growth-limited by nitrogen compared to phosphorus or co-limited.

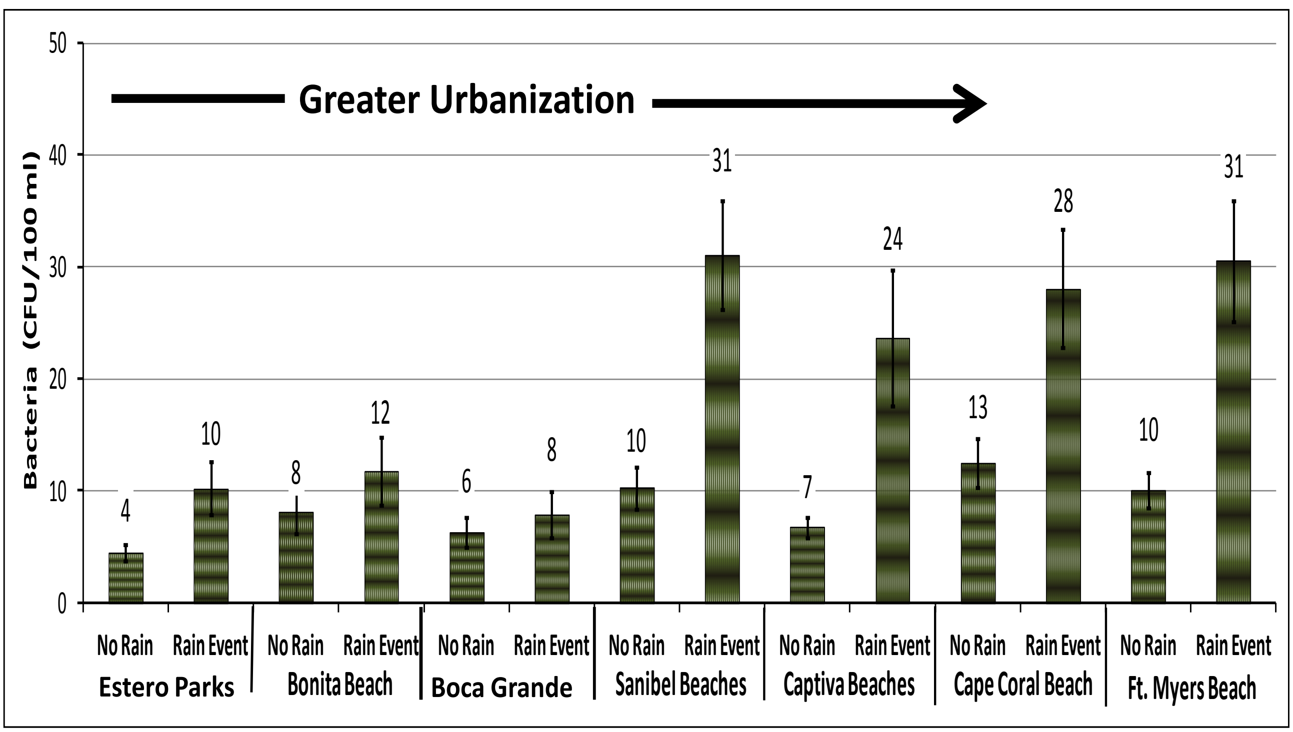

Figure 53. Comparison of mean Enterococci concentrations in near shore waters of Lee County Beaches during a period without rain and after a rainfall event of 0.5 inches or greater.

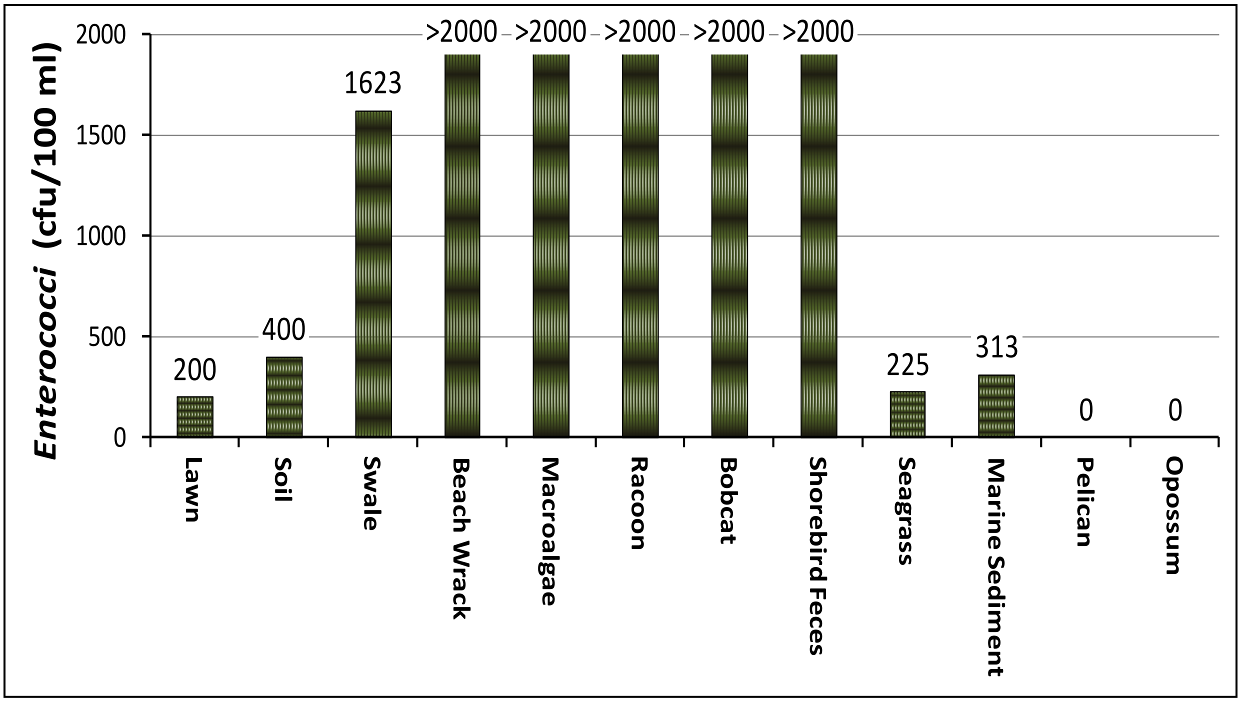

Figure 54. Levels of Enterococci indicator bacteria found in various natural sources sampled during this study.

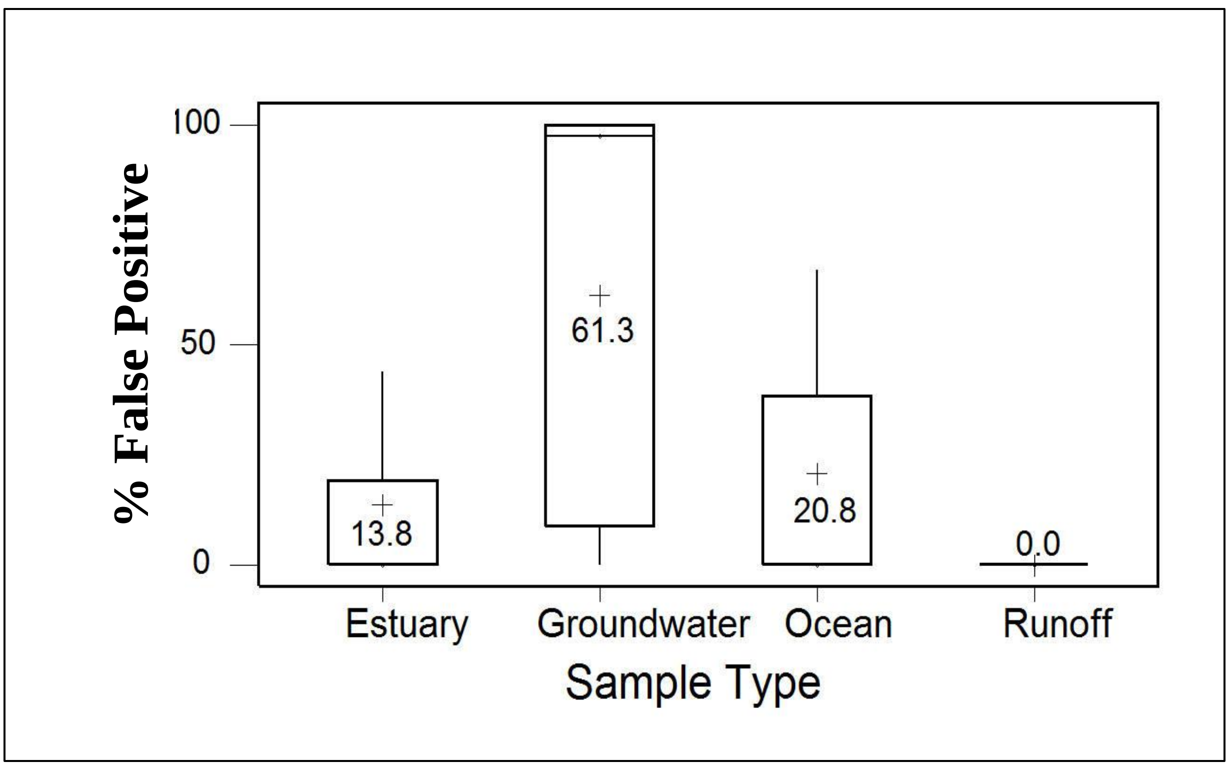

Figure 55. Percentage of results by sample type which were falsely identified as containing *Enterococci* indicator bacteria by Enterolert system in samples reported to have over 20 cfu/100ml. The mean value is signified by a cross, the median is a vertical line within the box, the 25th and 75th percentiles are the upper and lower boundaries of each box and the vertical line is the greatest adjacent value to higher and lower limits ((limits = 75th or 25th percentile value +/- (1.5*75th - 25th percentile)).

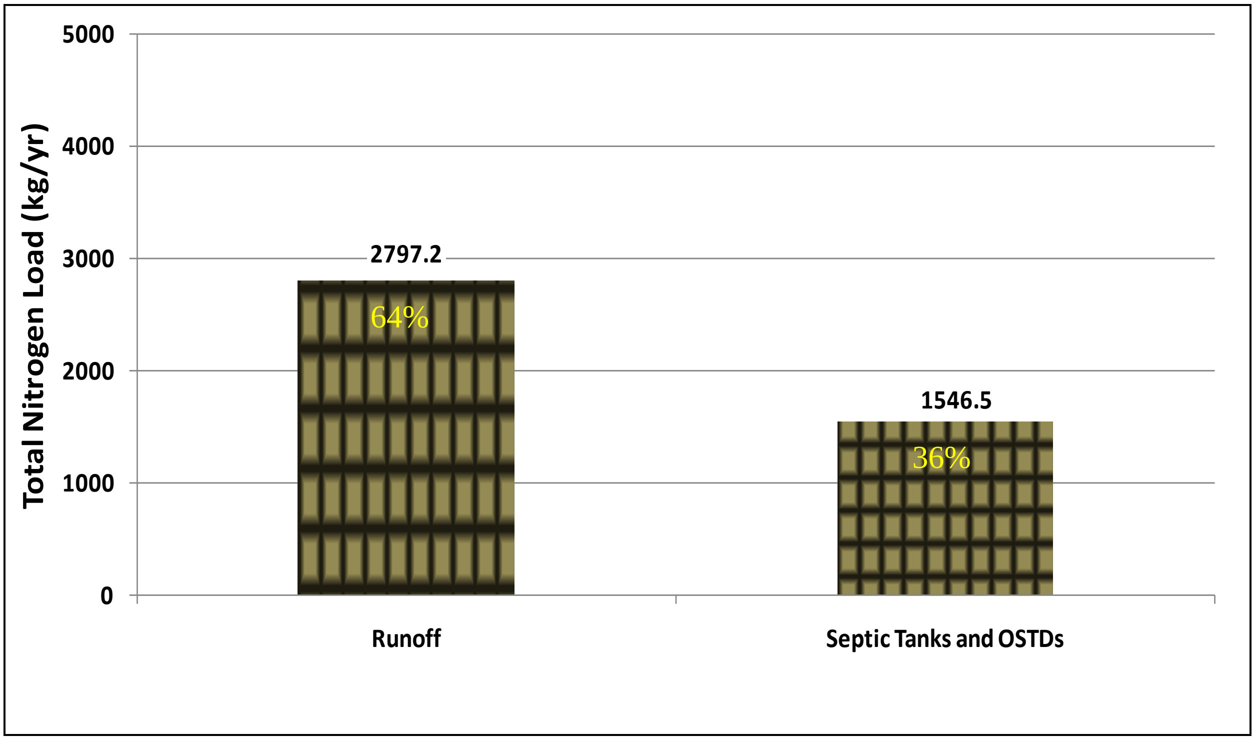

Figure 56. Estimated Annual TN Loading from Captiva Runoff and OSTDs (Septic Systems).

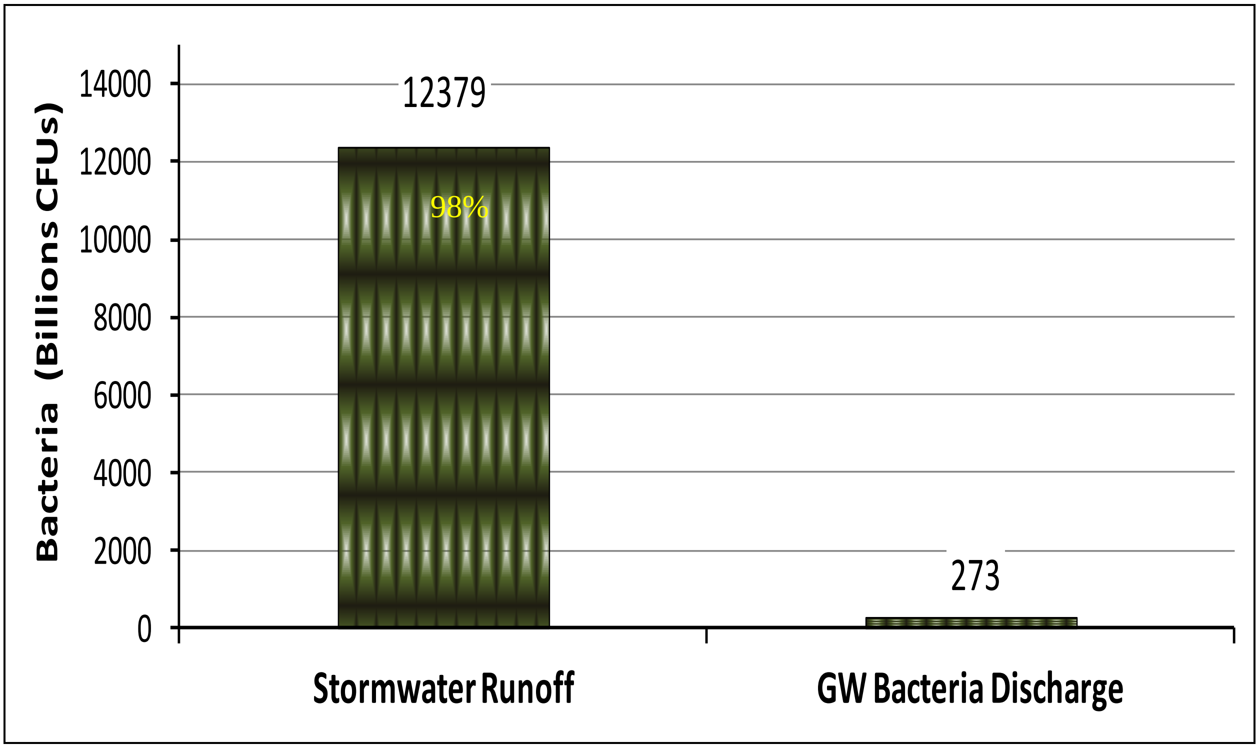

Figure 57. Estimated Annual *Enterococci* bacteria loading from Captiva stormwater runoff and groundwater discharges.

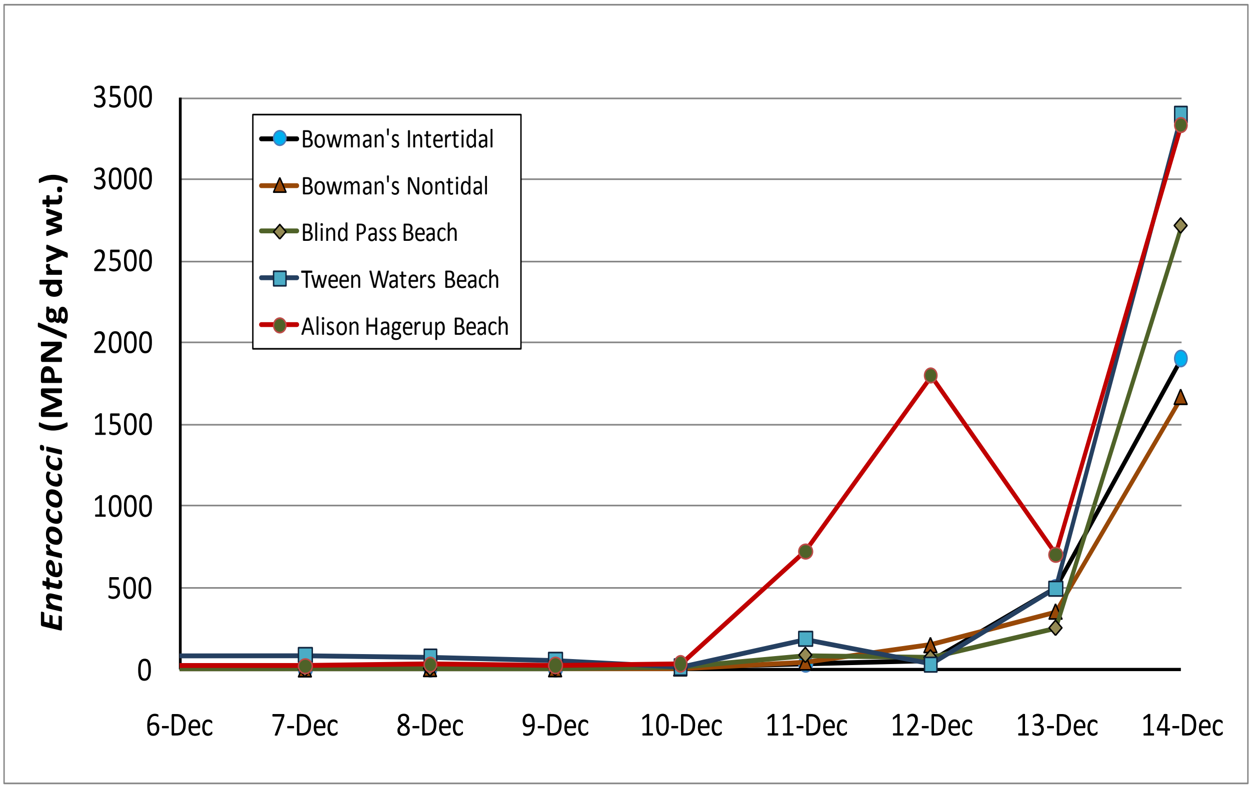

Figure 58. *Enterococci* concentrations on sterilized macroalgae deployed in mesh bags on area beaches over an eight day experimental period.

Appendix

List of all water quality sites (with locations) established for this project.

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
BPAClam	Bayous Preservation Association Site in Clam Bayou 5703 San-Cap Road	Estuary	6/16/2006	26.471783	-82.166430
BPADink	Bayous Preservation Association Site in Dinkins Bayou 5800 Pine Tree Drive	Estuary	6/16/2006	26.475633	-82.168470
BPARoos	Bayous Preservation Association Site in Roosevelt Channel 16825 Captiva Drive	Estuary	6/16/2006	26.490217	-82.183367
BPASun	Bayous Preservation Association Site in Sunset Bay 2617 Coconut Drive	Estuary	6/16/2006	26.483400	-82.178183
TDC03	5415 Osprey Ct. (Dock) Clam Bayou	Estuary	10/15/2008	26.469575	-82.161116
TDC04	End of Pine Tree Dr. Dinkens/Clam Bayou	Estuary	10/15/2008	26.478342	-82.173937
TDC07	Mouth of Halloway/Kasson Bayou	Estuary	10/15/2008	26.479848	-82.153505
TDC09	End of Coconut Drive (2727 Coconut Drive) (Dock) Dinkins Bayou	Estuary	10/15/2008	26.486091	-82.175718
TDC10	Wulfert Blind Pass West Mid Channel off Sanctuary Golf Course	Estuary	10/15/2008	26.494332	-82.171351
TDC12	Tween Waters small boat dock Roosevelt Channel	Estuary	10/15/2008	26.509405	-82.188061
TDC13	Roosevelt Channel Off Tween Waters Big Dock mid channel	Estuary	10/15/2008	26.510646	-82.188412
TDC14	McCarthy's Dock at end of Andy Rosse Rd Captiva (Sound)	Estuary	10/15/2008	26.521787	-82.187756
TDC17	Mouth Rossevelt Channel near Chadwick Bayou (Sound)	Estuary	10/15/2008	26.529709	-82.186696
TDC18	Near Southseas Plantation WWTP - end of WWTP Rd.	Estuary	10/15/2008	26.541668	-82.190550
TDC19	SSP Large Marina Boat Basin - end of short dock	Estuary	10/15/2008	26.547339	-82.197001
TDC20	Creek mouth - entrance to bay at SSP - midpoint seawall	Estuary	10/15/2008	26.548826	-82.195671
TDC21	Redfish pass nearshore SSP Stormwater Outfall/Golf course	Estuary	10/15/2008	26.551451	-82.196508
NWR01	Mouth Tarpon Bay	Estuary	5/15/2009	26.464566	-82.066212
NWR02	Mid Tarpon Bay	Estuary	5/15/2009	26.453042	-82.069636
NWR03	Tarpon Bay Mouth Sanibel River	Estuary	5/16/2009	26.445525	-82.088411
NWR04	NWR Inside mouth of Macintyre Creek	Estuary	5/17/2009	26.462844	-82.103850
NWR05	NWR Inside mouth of Duffy Creek	Estuary	5/18/2009	26.470036	-82.117928

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
NWR06	Wildlife Drive Darling NWR East impoundment second culvert (NWR Site 6)	Estuary	5/19/2009	26.454356	-82.115777
NWR07	Wildlife Drive Darling NWR West impoundment second culvert (NWR site 11)	Estuary	5/20/2009	26.464894	-82.133603
NWR08	NWR at alligator curve - estuary side	Estuary	5/21/2009	26.470802	-82.151479
NWR09	Wulfert Flats South near Halloway Creek	Estuary	5/22/2009	26.481620	-82.153567
NWR10	North Wulfert Flats	Estuary	5/23/2009	26.491747	-82.167707
RF_3	Redfish Pass Just inside (sound side) the pass	Estuary	8/15/2009	26.553253	-82.198285
RC1	Roosevelt Channel at mouth near blind pass	Estuary	10/5/2009	26.488370	-82.181240
RC15	Seagrass station north of Buck key Roosevelt Channel	Estuary	10/5/2009	26.521566	-82.186055
RC16	TDC Seagrass Station north of Roosevelt Channel and Buck Key	Estuary	10/5/2009	26.525663	-82.181479
RC17	TDC Seagrass Station north of Buck Key and Roosevelt Channel	Estuary	10/5/2009	26.529433	-82.183500
RC18	TDC Seagrass Station north of Roosevelt Channel and Buck Key	Estuary	10/5/2009	26.531454	-82.182571
RC20	TDC Seagrass Assessment Station	Estuary	10/5/2009	26.540032	-82.185412
RC21	TDC Seagrass Assessment Station	Estuary	10/5/2009	26.544078	-82.189388
RC24	TDC Seagrass Assessment Station	Estuary	10/5/2009	26.537258	-82.191611
RC3	Creek within Roosevelt Channel, 1000 m north of the mouth of RC at blind pass	Estuary	10/5/2009	26.492530	-82.182700
RC5	Roosevelt Channel north of the first small island as you travel north; about 2000 m north of mouth	Estuary	10/5/2009	26.491650	-82.182870
RC7	Between red marker 24 and coconut tree at white house in Roosevelt Channel	Estuary	10/5/2009	26.499510	-82.183530
BB01	Bunche Beach for algae experiment water sample	Estuary	11/15/2009	26.472338	-81.963963
BB02	Bunche Beach for algae experiment Water sample	Estuary	11/15/2009	26.472338	-81.963963
BB03	Bunche Beach for algae experiment water sample	Estuary	11/15/2009	26.472338	-81.963963
BB04	Bunche Beach for algae experiment - Sand under wrack	Estuary	11/15/2009	26.472338	-81.963963
BB05	Bunche Beach for algae experiment Sand above wrack line	Estuary	11/15/2009	26.472338	-81.963963
BB06	Bunche Beach for algae experiment Sand under bird poo	Estuary	11/15/2009	26.472338	-81.963963

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
BB07	Bunche Beach for algae experiment - Wrack sample	Estuary	11/15/2009	26.472338	-81.963963
BB08	Bunche Beach for algae experiment - Sand under wrack	Estuary	11/15/2009	26.472338	-81.963963
BB10	Water, right at shoreline (low tide) Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB11	Algae, near water line (low tide)Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB12	Algae, mid-beach Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB13	Algae, top of beach Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB14	Sand, directly under algae Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB15	Sand, mid-beach Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB16	Sand, above wrack line Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB17	Sand/sticks wrack, top of beach Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB18	Algae, in water Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
BB19	Mulch, near water Bunche Beach	Estuary	11/15/2009	26.476915	-81.971892
BB20	Mulch (dead-looking leaves and twigs, small pieces), mid beach Bunche Beach	Estuary	11/15/2009	26.476915	-81.971892
BB21	Algae, top of wrack line (pretty dried out) Bunche Beach	Estuary	11/15/2009	26.476915	-81.971892
BB23	Sand, mid-beach (in between two mulch wrack lines) Bunche Beach	Estuary	11/15/2009	26.476915	-81.971892
BB24	Mulch, near water Bunche Beach	Estuary	11/15/2009	26.476915	-81.971892
BB25	Algae, near water Bunche Beach	Estuary	11/15/2009	26.472338	-81.963963
ST59	Lots of algae and seagrass, 100 meters north of TDC 18	Estuary	11/15/2009	26.542718	-82.190558
ST60	Very dense algae, 100 meters south of TDC 18	Estuary	11/15/2009	26.540939	-82.190092
ST61	100 meters east of TDC14 at out fall	Estuary	11/15/2009	26.521744	-82.187734
ST64	Mouth of Wulfert Flats (northwest)	Estuary	11/15/2009	26.492818	-82.167470
ST65	Almost slack 10 meters of SW outfall	Estuary	11/15/2009	26.550711	-82.196531
ST66	End of Caloosa Dr	Estuary	11/15/2009	26.473703	-82.155926
ST67	Pine Tree Court	Estuary	11/15/2009	26.476699	-82.171152

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
ST68	Clam Bayou Culvert	Estuary	11/15/2009	26.471666	-82.164229
ST69	End of Starling Drive	Estuary	11/15/2009	26.483151	-82.174592
ST70	Osprey nest near golf course Storm Water discharge	Estuary	11/15/2009	26.492600	-82.168370
ST71	50 meters east Golf course storm water outfall	Estuary	11/15/2009	26.492600	-82.167420
ST73	Mouth Halloway Bayou	Estuary	11/15/2009	26.478350	-82.154530
ST75	Captiva Shores Dock	Estuary	11/15/2009	26.516460	-82.190150
ST76	End of McCarthy's Dock, 100meters east of TDC14	Estuary	11/15/2009	26.521744	-82.187734
ST78	100m north of SSP Outfall at pool.. In Pine Island Sound near shore	Estuary	11/15/2009	26.551686	-82.196978
TDCOB1	Station at Captiva Cruises dock	Estuary	11/15/2009	26.521787	-82.187781
TDCOB2	Roosevelt Channel 100 meters east of Captiva Cruises Dock	Estuary	11/15/2009	26.521890	-82.187626
ST01	Source tracking Captiva station 1	Estuary	12/1/2009	26.494870	-82.156020
ST02	Source tracking station 2	Estuary	12/1/2009	26.493840	-82.165630
ST03	Source Track 3 Blind Pass	Estuary	12/1/2009	26.494330	-82.171590
ST04	Source Track 4	Estuary	12/1/2009	26.492150	-82.176700
ST05	Source Tracking 5	Estuary	12/1/2009	26.488460	-82.178660
ST06	Source Track Station 6	Estuary	12/1/2009	26.485950	-82.176710
ST07	Source Track Station 7	Estuary	12/1/2009	26.483500	-82.178110
ST08	Source Track Station 8	Estuary	12/1/2009	26.485410	-82.175160
ST09	Source Track Station 9	Estuary	12/1/2009	26.491750	-82.179370
ST10	Source Track Station 10	Estuary	12/1/2009	26.486560	-82.181410
ST11	Source Track Station 11	Estuary	12/1/2009	26.488790	-82.182450
ST12	Source Track Station 12	Estuary	12/1/2009	26.493080	-82.182720
ST13	Source Track Station 13	Estuary	12/1/2009	26.504930	-82.185300
ST14	Source Track Station 14	Estuary	12/1/2009	26.509250	-82.187790

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
ST15	Source Track Station 15	Estuary	12/1/2009	26.516580	-82.189610
ST16	Source Track Station 16	Estuary	12/1/2009	26.521480	-82.187990
ST17	Source Track Station 17	Estuary	12/1/2009	26.526480	-82.187590
ST18	Source Track Station 18	Estuary	12/1/2009	26.532900	-82.187800
ST19	Source Track Station 19	Estuary	12/1/2009	26.541730	-82.188880
ST20	Source Track Station 20	Estuary	12/1/2009	26.546140	-82.191630
ST21	Source Track Station 21	Estuary	12/1/2009	26.551090	-82.196430
ST22	Source Track Station 22	Estuary	12/1/2009	26.548780	-82.195590
ST23	Source Track Station 23	Estuary	12/1/2009	26.545730	-82.195370
ST24	Source Track Station 24	Estuary	12/1/2009	26.548380	-82.196370
ST25	Source Track Station 25	Estuary	12/1/2009	26.547060	-82.196810
ST26	Source Track Station 26	Estuary	12/1/2009	26.546300	-82.193833
ST30	Source track 30	Estuary	12/1/2009	26.484691	-82.175394
ST31	Source track 31	Estuary	12/1/2009	26.483861	-82.177996
ST33	Source Track 33	Estuary	12/1/2009	26.487015	-82.181421
ST36	Source Track 36	Estuary	12/1/2009	26.546360	-82.192200
ST37	Source track station 37	Estuary	12/1/2009	26.541739	-82.190375
ST38	Source Track 38	Estuary	12/1/2009	26.539646	-82.189969
ST39	Source Track Station 39	Estuary	12/1/2009	26.537258	-82.191611
ST40	Source Track Station 40	Estuary	12/1/2009	26.540784	-82.193981
ST41	Source Track Station 41	Estuary	12/1/2009	26.455537	-82.084634
st50	300m north of TDC18	Estuary	1/15/2010	26.543170	-82.190998
ST51	Front of SSP Boat Basin Condos near entrance South Seas Plantation	Estuary	1/15/2010	26.527584	-82.188934
ST52	Jensen's Dock	Estuary	1/15/2010	26.520959	-82.188098
ST53	End of old lodge rd Captiva from dock	Estuary	1/15/2010	26.523080	-82.187642
ST54	Dock front of the green flash in Captiva	Estuary	1/15/2010	26.518240	-82.189584
ST55	lot north of Captiva yacht club 500 m from dock	Estuary	1/15/2010	26.513224	-82.190084
st56	blind pass near 1st green mark inside pass	Estuary	1/15/2010	26.484627	-82.182457

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
R_Gibson	Well just behind R . Gibson House at blah Captiva Drive	Estuary	6/18/2010	26.506110	-82.186600
RoosHolz	Dock behind Holzhiemers house at 16455 Captiva Dr.	Estuary	6/18/2010	26.499205	-81.184737
WWTP3_Eff	Effluent from South Seas Plantation WWTP	Facility	6/1/2009	26.541573	-82.192160
TDCOB3	Sample of Reclaim Water from Wulfert road reclaim water tank after mixing with well water	Facility	11/15/2009	26.474993	-82.159133
SunsetWWTP	Effluent from sunset Captiva WWTP	Facility	6/18/2010	26.520527	-82.192127
OSTD_1	Septic tank at SCCF Intern housing - effluent manhole	Facility	10/18/2010	26.439746	-82.009435
OSTD_2	On site treatment system (septic tank) at Jensen's on the Sound	Facility	10/18/2010	26.520769	-82.189211
WWTP1_Eff	Effluent from WWTP at Sunset Captiva.. Try to get unchlorinated	Facility	10/18/2010	26.520529	-82.192211
WWTP2_Eff	Effluent from City of Sanibel WWTP at Secondary clarifier trough - before chlorination	Facility	10/18/2010	26.442623	-82.044424
WWTP2_IN	Influent at Donax WWTP City of Sanibel	Facility	10/18/2010	26.442728	-82.044886
LK1_Sanct	Lake 1 discharge area sanctuary golf course Sanibel	Lake	11/15/2009	26.475187	-82.161746
LK2_Sanct	Lake 2 discharge area sanctuary golf course Sanibel	Lake	11/15/2009	26.476808	-82.166688
LK3_Sanct	Lake 3 discharge area sanctuary golf course Sanibel	Lake	11/15/2009	26.477890	-82.167748
LK4_Sanct	Lake 4 discharge area sanctuary golf course Sanibel	Lake	11/15/2009	26.480346	-82.166601
LK5_Sanct	Lake 5 discharge area sanctuary golf course Sanibel	Lake	11/15/2009	26.482507	-82.167290
LK6_Sanct	Lake 6 discharge area sanctuary golf course Sanibel	Lake	11/15/2009	26.487184	-82.171177
LK7_Sanct	Lake 7 discharge area sanctuary golf course Sanibel	Lake	11/15/2009	26.491338	-82.171050
SSPGCMidNLK	South Seas Plantation Golf Course Lake - Middle Northern Lake	Lake	11/15/2009	26.550162	-82.199153
SSPGCNLK	Northern Lake at South Seas Plantation Golf Course	Lake	11/15/2009	26.551596	-82.197601
AROUT	Outfall at east end of Andy Rosse Rd Captiva Town.	Land runoff	6/1/2009	26.521927	-82.188445
SSPGCCB1	Stormwater Catch pipe on SSP Golf Course near TDC 23B	Land runoff	11/15/2009	26.546827	-82.197851
SSPGCCB2	Stormwater Catch pipe on SSP Golf Course near maintenance building	Land runoff	11/15/2009	26.547196	-82.198006
SSPGCCB3	Stormwater Catch pipe on SSP Golf Course north of proshop	Land runoff	11/15/2009	26.548799	-82.198417
SSPOutFall1	Outfall at South Seas Plantation near pool.	Land runoff	11/15/2009	26.550685	-82.196649
ST62	Storm Sewer on Andy Rosse to side of Bubble room	Land runoff	11/15/2009	26.521974	-82.189346
Swale01	Baileys grocery Parking lot standing water	Land runoff	8/23/2010	26.434343	-82.080035

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
Swale02	Hungry Heron Parking lot north entrance. Standing Water	Land runoff	8/23/2010	26.438150	-82.077059
Swale03	Big Arts Parking lot standing water	Land runoff	8/23/2010	26.439933	-82.075847
Swale04	St. Michael's Catholic Church Swale beside San Cap Rd	Land runoff	8/23/2010	26.441920	-82.106002
Swale05	SCCF West San River Preserve Standing Water after rainfall	Land runoff	8/23/2010	26.453276	-82.136987
Swale06	Sanctuary residential swale 5663 Baltusrol Ct. standing water	Land runoff	8/23/2010	26.481904	-82.164860
Swale07	Sanctuary GC Practice Green drain	Land runoff	8/23/2010	26.485943	-82.167963
Swale08	Sand trap at sanctuary hole #___. Standing water. Runoff	Land runoff	8/23/2010	26.491430	-82.172200
Swale09	Sanctuary GC Hole___ . Catch Basin	Land runoff	8/23/2010	26.982060	-82.168950
Swale10	16285 Captiva Drive vacant lot. Standing water.	Land runoff	8/23/2010	26.502820	-82.187310
Swale11	Murmond and Wiles Rd. Captiva town. Empty lot. Swale standing water.	Land runoff	8/23/2010	26.518469	-82.191275
Swale12	Residential area South Seas Plantation sod yard. Runoff	Land runoff	8/23/2010	26.528880	-82.193250
Swale13	standing water at SCCF Marine Lab near boats during storm event	Land runoff	11/4/2010	26.441996	-82.083101
Swale14	Swale on Tarpon Bay road opposite Post Office	Land runoff	11/4/2010	26.436740	-82.080060
Swale15	Sanibel Gardens preserve standing water during rain event	Land runoff	11/4/2010	26.431850	-82.087240
Swale16	Swale behind Sanibel City Hall during storm event	Land runoff	11/4/2010	26.441140	-82.073990
Swale17	Retention pond behind Sanibel recreation center during storm event	Land runoff	11/4/2010	26.448270	-82.117430
Swale18	Walker Preserve SCCF Land. Wulfert Rd.	Land runoff	11/4/2010	26.472710	-82.157540
Swale19	Taylor Beach Parking Lot Standing Water	Land runoff	11/4/2010	26.483320	-82.183490
Swale20	Tween Waters parking lot standing water	Land runoff	11/4/2010	26.509250	-82.189620
Swale21	Captiva Civic Center Standing water in road	Land runoff	11/4/2010	26.519940	-82.191700
Swale22	Andy Rosse Rd Captiva in front of Bubble Room	Land runoff	11/4/2010	26.522020	-82.189550
Swale23	South Seas Plantation Standing water on road	Land runoff	11/4/2010	26.550870	-82.197340
Swale24	SSP Golf Course Turf Grass	Land runoff	11/4/2010	26.546590	-82.197940
Swale25	South Seas Plantation Home yard turf grass	Land runoff	11/4/2010	26.544750	-82.197110
Swale26	Captiva Town home site yard.. Turfgrass sample	Land runoff	11/4/2010	26.518230	-82.191420
TDC01	Offshore Bowman's beach 0.25 mile - Gulf	Ocean	10/15/2008	26.457157	-82.161342
TDC02b	Bowman's beach at Park (Gulf)	Ocean	10/15/2008	26.458896	-82.158200

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
TDC05	Offshore Blind Pass Beach 0.50 mile - Gulf	Ocean	10/15/2008	26.477112	-82.188840
TDC06	Offshore Blind Pass Beach 0.25 mile - Gulf	Ocean	10/15/2008	26.479724	-82.186263
TDC08b	Blind Pass Beach Mouth of blind pass (Gulf)	Ocean	10/15/2008	26.482975	-82.184341
TDC11b	Tween Waters Beach Gulf	Ocean	10/15/2008	26.509144	-82.190901
TDC15b	Beach at west end of Andy Rosse Rd. Captiva (Gulf)	Ocean	10/15/2008	26.522108	-82.193513
TDC16b	Public Beach at end of Captiva Drive Near SouthSeasPlantation Entrance	Ocean	10/15/2008	26.526508	-82.194480
TDC22b	Beach at SSP GC south of Redfish Pass Jetty	Ocean	10/15/2008	26.550757	-82.201013
TDCTB1	Tarpon Bay Road Beach Located at south end of Tarpon Bay Road Sanibel Island	Ocean	10/15/2008	26.421946	-82.080106
Cswy_1	Sanibel Causeway southern island east side facing gulf	Ocean	8/15/2009	26.467389	-82.029321
Cswy_2	Causeway Sanibel, Southern Island facing eastward toward ocean	Ocean	8/15/2009	26.469074	-82.028499
Cswy_3	Sanibel Causeway northern island facing gulf	Ocean	8/15/2009	26.479656	-82.022073
Cswy_4	Sanibel Causeway northern island facing gulf	Ocean	8/15/2009	26.480471	-82.021282
RF_1	Redfish Pass Sampling Area 1	Ocean	11/15/2009	26.552602	-82.200595
RF_2	Redfish Pass Sampling Area 2	Ocean	11/15/2009	26.553203	-82.199292
ST63	Beach on Sanibel side of Blind Pass	Ocean	11/15/2009	26.482440	-82.182337
ST77	Captiva Beach Across street from 16737 Captiva Dr.	Ocean	11/15/2009	26.491824	-82.186897
TDC23b	BEACH ACESS ACROSS FROM SSP MARINA RD	Ocean	11/15/2009	26.541480	-82.198918
TDC24b	PLANTATION BEACH CLUB HOUSES 1001-1008 SSP NEAR CURVE	Ocean	11/15/2009	26.541480	-82.197258
TDC25b	HOMES 6,7,8,9 SSP	Ocean	11/15/2009	26.533961	-82.195358
TDC26b	2000-2014 CONDOS 100 M NORTH OF TDC 16	Ocean	11/15/2009	26.529537	-82.194881
TDC27b	END OF GORE DRIVE CAPTIVA	Ocean	11/15/2009	26.519027	-82.192866
TDC28b	100M SOUTH OF CURVE FROM Captiva town (Jensen's Oceanside)	Ocean	11/15/2009	26.517142	-82.192535
TDC29b	front of gray's painting service	Ocean	11/15/2009	26.512839	-82.191716
TDC30b	front of Captiva yacht club	Ocean	11/15/2009	26.510729	-82.191288

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
TDC31b	curve south of Tween waters	Ocean	11/15/2009	26.504273	-82.189767
TDC32b	construction site at 16406 Captiva rd	Ocean	11/15/2009	26.500354	-82.188905
TDC33b	across street from 16979 Captiva rd	Ocean	11/15/2009	26.488144	-82.185769
TDC34b	mouth of blind pass at Gulf of Mexico - Sanibel beach access site	Ocean	11/15/2009	26.479880	-82.181182
TDC35b	Sanibel Beach Access #1 West Gulf Drive	Ocean	11/15/2009	26.430068	-82.112053
ST43	Source Track Algae Experiment	Ocean	12/1/2009	26.441991	-82.082856
ST44	Source Track Algae Experiment	Ocean	12/1/2009	26.441991	-82.082856
ST46	Site 12 SCCF Drift Algae Project	Ocean	1/15/2010	26.554320	-82.285760
ST46A	Drift algae site 12 - algae sample after boiling water	Ocean	1/15/2010	26.554320	-82.285760
ST46B	Drift algae site 12 sterile water extract after boiling water on algae sample	Ocean	1/15/2010	26.554320	-82.285760
ST47	Drift Algae Site 12	Ocean	1/15/2010	26.554320	-82.285760
ST47A	Drift Algae Site 12 Algae sample after boiling water - bottryocladia algae	Ocean	1/15/2010	26.554320	-82.285760
ST48	Drift Algae Site 12	Ocean	1/15/2010	26.554320	-82.285760
DNX_WWTP_IN	Influent at Donax WWTP Sanibel Island	Waste sewer	10/1/2010	26.442755	-82.045032
DNX_WWTP_EF	Effluent from Sanibel Island Donax Wastewater treatment plant	Waste sewer	10/2/2010	26.442755	-82.045032
WWTP1_IN	Influent at Sunset Captiva WWTP	Waste sewer	10/18/2010	26.520711	-82.192124
GW03	Low spot on north side of sunset cap boardwalk midway from beach to pool. 4-27-10	Well	4/27/2010	26.521000	-82.192500
GW04	Southeast corner of Sunset Cap community building beside pool.	Well	4/27/2010	26.520810	-82.191780
GW05	Southeast corner lot 38 sunset Captiva	Well	4/27/2010	26.520500	-82.190780
GW06	Southeast corner Lot 57 15124 address.	Well	4/27/2010	26.520420	-82.190300
GW07	West of Sunset Captiva Bayside Condos in landscaping section beside bamboo palms.	Well	4/27/2010	26.520610	-82.189300

List of all water quality sites (with locations) established for this project (continued).

Station	Station_Description	Primary Type	Station_Estb_Date	Latitude	Longitude
GW10	Near North property line east of front shrubs Cap Yacht Club	Well	4/28/2010	26.511080	-82.190520
GW11	Near northern property line and picnic table east of Cap Yacht Building 4-28-10	Well	4/28/2010	26.511310	-82.189630
GW02	Dunes near sitting bench off boardwalk Sunset Captiva. 4-30-10	Well	4/30/2010	26.520850	-82.192990
GW08	26.5 paces toward ocean from GW9. Sight GW9 with telephone pole 5-7-10	Well	5/7/2010	26.511020	-82.191210
GW09	Near ocean edge of dune west of Cap Yacht Club	Well	5/7/2010	26.511090	-82.190990
GW12	near Eastern Fence Ron Gibson's house 10 meters from Roosevelt Channel	Well	6/15/2010	26.506085	-82.186723
GW13	Front of Brunie's property along Ron Gibson's driveway just north of green CB house	Well	6/15/2010	26.506218	-82.188598
GW14	Front of M. Mullins house north side of property near road. 17171 Captiva Dr.	Well	6/18/2010	26.484483	-82.183319
GW15	Middle of Holzhiemer's property 16455 Captiva Rd. on south side of driveway midway to house	Well	6/18/2010	26.498916	-82.186064
GW16	Groundwater monitoring: located on SCCF Gulf Ridge Preserve behind sanitary sewer lift station	Well	6/30/2010	26.456100	-82.143090
GW17	Groundwater monitoring: SCCF Gulf Ridge Preserve just east Island Water Well S-8.	Well	6/30/2010	26.459803	-82.146441
GW18	Monitoring well: SCCF West Sanibel River Preserve access entrance. 100 ft south of San Cap Road.	Well	6/30/2010	26.453332	-82.136955
GW19	Captiva WQ Study monitoring well:16970 Captiva Dr.beside Road just north of driveway	Well	8/6/2010	26.487450	-82.184116
GW20	Captiva WQ Study Monitoring well:NW Corner, 50 ft from Road Holzhiemer property 16455 Captiva Dr	Well	8/6/2010	26.499300	-82.186650
GW21	Captiva WQ Study Monitoring Well;16455 Captiva Dr. Holzhiemer N property line mid lot	Well	8/6/2010	26.499210	-82.185830
SSP_3	Groundwater monitoring well near WWTP	Well	10/26/2010	26.541627	-82.190948
SSP_5	Groundwater station South Seas Plantation GW monitoring well # SSP_5 in hole #7 sand trap	Well	10/26/2010	26.550386	-82.199236