Summary and Evaluation of the Surface Water Quality of Sanibel to Guide Development of a Comprehensive Nutrient Management Plan

SCCF

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Executive Summary

Florida Department of Environmental Protection (FDEP) has listed the interior freshwater body on Sanibel Island known as the Sanibel River as impaired due to nutrient enrichment. As a result, a management plan for reducing nutrient loading to the waterbody must be developed. Although known as the Sanibel River, the waterbody is actually more like a slough which was developed by dredging channels between wetlands on the island. In this document we will refer to the waterbody as the Sanibel Slough to more properly describe it.

To provide a framework for the development of a nutrient management plan for the City of Sanibel, existing water quality data was gathered, analyzed and presented with an emphasis on revealing possible regional and local influences on Sanibel's water quality. A general linear model ANOVA was used to investigate possible changes in nutrient levels associated with factors such as implementation of a fertilizer ordinance, sanitary sewer installation, change of analytical laboratory, rain events, season, site and basin. Geospatial analyses options in ArcGis10® were used to delineate watershed basins on Sanibel Island. Using the South Florida Water Management District (2008) Florida land use coverage, land use was determined for 12 basins delineated in the project area. Runoff coefficients and estimated nutrient concentrations were developed from land use profiles for each basin. Rainfall data was coupled with this information for estimation of nutrient loads to freshwater and estuarine waterbodies. Conclusions were formed and recommendations were developed.

Twelve watershed basins were delineated from GIS analysis of LIDAR elevation data for Sanibel Island. Two Basins drain exclusively to the freshwater slough in the center of Sanibel. Nine basins discharge to estuary waters of Pine Island Sound and portions of two basins drain directly to the Gulf of Mexico. Geostatistical analysis of regional nutrient water quality data showed the waters surrounding Sanibel are influenced by discharges from the Caloosahatchee River. However, local influences on nearshore nutrient concentrations were also evident especially the north-eastern Sanibel shoreline. Data from the interior freshwater body, the Sanibel Slough indicated both the east and west basin would be classified as eutrophic (and impaired according to FDEP water quality standards) due to high nitrogen and phosphorus levels and elevated chlorophyll *a* values. The east basin had significantly greater levels of phosphorus while the highest concentration of inorganic nitrogen was identified near Rabbit Rd. in the west basin. Data from a 1976 water quality study on Sanibel showed the slough was already eutrophic at that point in time and levels of nitrogen (N) and phosphorus (P) were generally greater in 1976 than today especially in the east basin near the former Jamestown-Beachview wastewater treatment plant. In 1976 wastewater on Sanibel flowed to both septic systems and private wastewater treatment plants. Data from freshwater lakes (stormwater systems) on Sanibel's golf courses showed those lakes to be similarly eutrophic with levels of N and P slightly-to-moderately greater than Sanibel Slough. Reclaimed water from the City's Donax wastewater treatment facility is used for irrigation in several of the watershed basins with greatest volumes applied on the three golf courses. Using water quality data provided by the City of Sanibel it was determined that 0.044 lb. N and 0.018 lb. P are applied to a land surface for every 1000 gallons of reclaimed water used. Currently this application of readily available nutrients is not taken into account by golf course managers and others who use this water for irrigation. The proportion of P relative to N is much higher in reclaimed water compared to fertilizer formulations specified by Sanibel ordinance. Basins which had large reclaimed water use also had higher concentrations of phosphorus relative to other basins and lower N:P ratios.

Statistical analysis (GLM ANOVA) found concentrations of inorganic (IN) and total phosphorus (TP) in Sanibel Slough were less after implementation of the fertilizer ordinance, while orthophosphorous (OP) was greater. Trend analyses found a decreasing trend in IN in the eastern slough and an increasing trend in OP. We attribute implementation of the fertilizer ordinance partly responsible for the overall decrease in IN in the east basin. Decreased input of IN from fertilizer runoff coupled with a constant application of OP-laden reclaimed water accounts for an increase in OP in that basin with a corresponding decrease in N:P. The decrease in total phosphorus (after ordinance implementation) further supports the theory that fertilizer runoff has been reduced.

The greatest estimated nutrient loading to waterbodies occurred where a combination of large basin size and high urban land use was found. The Sanibel Slough basins, Sanibel Bayous Basin and the Beach Basin had the greatest estimated loads to waterbodies on Sanibel. However, on a load per acre basis, the developed eastern basins stood out as high load sources. Loadings from the National Wildlife Refuge Basin were lowest per acre and nutrient concentrations in the estuary were also lowest in that basin. This provides a “control” or target condition by which to gage other basins on Sanibel.

Loads to land surfaces were also estimated in an effort to begin development of a nutrient mass balance around Sanibel. In all basins, application of fertilizer to residential and commercial property was the greatest potential for loadings. However these estimated loading rates were based upon the maximum allowed fertilization allowed by City code and are likely over-estimations. In basins where reclaimed water was used extensively for irrigation, total phosphorus loads were significantly increased or dominated by this source.

It is estimated that Sanibel discharges over 7000 kg of nitrogen and 1655 kg of phosphorus each year directly to the estuary and Gulf. In addition, over 4200 kg of nitrogen and nearly 800 kg phosphorus flow into the Sanibel Slough which periodically discharges to the estuary. The City cannot currently estimate the volume of water periodically discharged from the two control structures which separate Sanibel Slough from the adjacent estuary. Record of gate openings and overflows do not provide any basis for even a rough estimate. We calculated that for every inch of water released from the East Slough Basin, 1.5 million gallons are discharged along with 18.9 pounds of nitrogen and 1.6 pounds of phosphorus.

Sanibel Slough remains eutrophic and classified as impaired by Florida DEP. The nearshore waters of Sanibel have also experienced water quality related problems which may have local influence. Development and implementation of best management practices which reduce stormwater runoff and nutrient loading should continue. The target condition could be seen as the natural landscapes of the wildlife refuge which has the best water quality and least nutrient loading. The more successfully we emulate natural landscapes, the less chance we will degrade water quality.

Reducing runoff volume is a key element in reducing nutrient loads. The City's vegetation standards and stormwater retention requirements are good examples of the City's efforts to reduce stormwater runoff volume. These activities filter nutrients from stormwater by directing runoff through the soil/vegetation filter to recharge the shallow groundwater aquifer. Additionally, we recommend the following activities for reducing runoff volume:

- Maximize native plant cover and vegetative canopy offered by trees.
- Discourage turf and encourage native vegetation in its place. Where turfgrass is used encourage taller grass height which decreases runoff.
- Reduce the area of impervious surfaces such as concrete, rooftops and pavement. New City projects (such as paving, resurfacing) should prevent further spread of impervious surfaces. Use of natural vegetated surfaces for parking or pervious pavement systems should be encouraged. Shell roadways and drives instead of pavement.
- Discourage artificial stormwater conveyances such as ground level catch basins with drainage piping which remove stormwater quickly from an area and transfer it downstream. Encourage storing stormwater onsite to allow percolation. Wetlands can remove inorganic nitrogen – emulate wetlands.
- Survey and maintain irrigation systems to prevent runoff. **Prevent any direct runoff of reclaimed water – this is a critical issue.**
- In areas where development of a vegetated canopy is not easily accomplished, small stormwater detention areas (water gardens) and cisterns from roof tops can be designed to capture runoff. The captured water can then be used for irrigation.
- Investigate expanding use of existing lands as a filter marsh for stormwater retention and nutrient removal with periodic vegetation harvest.

Reducing nutrient concentrations is the second element in load reduction. The fertilizer ordinance, vegetation requirements, installation of centralized sanitary sewers, and the golf course management guidelines are all good examples of the City's efforts to reduce the concentration of nutrients in stormwater runoff. We recommend additional actions including:

- Setting a target of 30% reduction in TP concentrations within Sanibel Slough to yield a reduction in algal biomass.

- Further reduce or eliminate use of fertilizers through additional educational efforts. Collect fertilizer use information from commercial applicators. Inform all reclaim water users of the phosphorus and nitrogen content loadings associated with its use and adjust fertilizer application accordingly.
- Encouraging natural littoral zone vegetation development in lakes (such as planting *Vallisneria*) and eliminating use of herbicides to control aquatic vegetation. Use periodic manual harvesting methods to remove nutrient-containing vegetation from waterbodies (Sanibel Slough) and eliminate the recycling of nutrients within eutrophic waterbodies.
- In areas where a vegetated littoral zone cannot be developed, floating island technology can allow similar nutrient removal opportunities.
- Conduct pilot tests of reclaim water only fertigation (no fertilizer application) for lawns and landscapes to show fertilization value.
- Encourage use of stormwater pond system water (or Sanibel Slough) for irrigation to allow nutrient removal in landscapes.
- Investigate development of filter marshes to remove nutrients from Sanibel Slough waters. Plan for periodic harvest and removal of vegetation.

We also recommend the following general activities to improve our knowledge and control of nutrient loads to nearshore waters:.

- Implement water quality monitoring on the Gulf side of Sanibel to provide information concerning possible local impacts.
- Keep precise records of discharges from Sanibel Slough weirs. Calibrate weirs to allow estimates of daily discharge volume over the weirs as well as through the gates. Consider installation of real-time flow monitoring equipment at Tarpon Bay and Beach Road weirs.
- Inform all reclaimed water users of its fertilizer value (0.044 lbs.N/1000 gallons, 0.018 lbs.P/1000 gallons) and have them reduce fertilizer application appropriately.
- Develop loading estimates for discharges of the underground freshwater lens to nearshore waters.
- Investigate the source of relatively high IN concentrations near the Rabbit Rd. monitoring station.
- Investigate the source of relatively high concentrations of TP in the Sanctuary golf course lakes.
- Collect records of commercial fertilizer application and develop application rate estimates for different land use types on Sanibel.
- Develop Sanibel-specific runoff coefficients.
- Develop Sanibel-specific runoff nutrient concentrations.

- Identify and characterize discharges to Sanibel Slough from stormwater and lakes systems on Sanibel.
- Record stormwater system discharges from the three golf courses on Sanibel.

Florida DEP will develop a total maximum daily load (TMDL) for the Sanibel Slough, requiring the City to reduce nutrient loads to meet the TMDL target. A Basin Management Action Plan (BMAP) will be developed by the Florida DEP, working with the City, to help guide nutrient reduction to achieve compliance within a specified timeframe. This project provides information on Sanibel's higher nutrient loading areas and some possible sources. It also identified measurable water quality improvements which may be associated with proactive measures already taken by the City. Developing additional methods of controlling nutrient loads based on focused and efficient monitoring should further improve conditions in the local waterbodies.

Introduction

Tourism is one of the largest drivers of commerce 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 located along the coast, 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. In 2012, the Tourist Tax collection generated $23.1 million dollars. 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 ecological "services" provided by healthy ecosystems (Costanza et al. 1997). In a recent valuation of ecosystem services of Sanibel Island, (Beever and Walker 2012), the total economic value (TEV) of these services exceeded $5 billion, including swimming beaches ($81 million), seafood production, storm protection, water quality improvement, eco-tourism, and more.

The City of Sanibel has been successful in implementing strategies to improve the environment and to sustain natural resources that support the tourism-based economy of the island. Examples include implementation of the Sanibel Plan, installation of island-wide sanitary sewer, conservation land purchases, a fertilizer ordinance, Vegetation Standards, and the Golf Course BMP Report Cards. In 2007, the City implemented a fertilizer ordinance to reduce nutrient loading to Sanibel waterbodies from harmful fertilization practices. The City has also been monitoring water quality at 12 sites since 2002 (Figure 1).

Sanibel contains an inland body of freshwater commonly called the Sanibel River but more aptly described as the Sanibel Slough. This waterbody was originally a series of swampy lakes and wetlands which were connected by channelization for better control of mosquito abundance. Historically, the slough discharged to the Gulf of Mexico at two breaches in the dune system during wet season high water levels. Today the slough is managed as two basins (east and west) separated by a control structure at Tarpon Bay Road. The Western Basin has a control structure located north of Sanibel Captiva Rd. which discharges into Southern Tarpon Bay. The Eastern Basin has a control structure located on Beach Rd. which allows discharges into the eastern canal system on Sanibel. Discharges from the Western Basin control structure are rare while the Eastern Basin control structure can discharge continuously during dry season. Decreasing trends in some nutrient levels within the Sanibel Slough provide encouragement that actions taken to date have had positive impacts, however the slough is still classified as impaired by Florida DEP standards with elevated nitrogen, phosphorus and chlorophyll *a*.

Nutrients in Sanibel's waters are present in several forms. Inorganic nitrogen (IN) and the inorganic form of phosphate called orthophosphate (OP) are the most readily available to promote algae blooms and thus have the potential for most immediate problems. Total nitrogen and phosphorus (TN and TP) values show the total amount of nutrient in the water column which has the potential to become available if converted to more useable forms. Reduction of both inorganic and total nitrogen and phosphorus is required to successfully improve water quality conditions.

In order to address the Sanibel Slough impairment, a plan is desired by the City and required by the State of Florida which includes a list of prioritized projects and management measures (e.g. best management practices) to systematically reduce stormwater runoff and nutrient pollution to the Sanibel Slough and nearshore waters. Phase I is described in the workflow diagram (Figure 2) and includes a list of activities to be completed as a first step in development of a nutrient management plan.

This Phase I report summarizes and evaluates existing water quality data, identifies watershed basins and land uses, and provides nutrient loading estimates to land surfaces and waterbodies by basin. This fulfills the following objectives for development of a Comprehensive Nutrient Reduction Plan for Sanibel:

1. Identify potential nutrient sources that can contribute to water quality impairment;

2. Estimate annual loadings for the Sanibel Slough and Sanibel's nearshore waters.

The results of this analysis (Phase I) will be used to develop management strategies for each basin on Sanibel with assistance from the City of Sanibel Natural Resources staff (Phase II-III). This strategy mirrors that used by Florida Department of Environmental Protection (FDEP) to identify and prioritize projects and evaluate the effectiveness of BMPs. Management practices and projects that have been implemented, such as the Fertilizer Ordinance (07-003), the conversion of septic to sewer, and the overall development of Sanibel were evaluated in respect to possible influences on water quality.

Methods

Analyses of Water Quality Monitoring Results

An aggregated dataset consisting of all available water quality monitoring data for the local area was developed. The latest water quality monitoring data was obtained from Lee County Environmental Laboratory which includes data from various agencies and organizations that conduct monitoring in Lee County and is the main source of EPA and Florida Department of Environmental Protection (DEP) STORET data for this area. Data from the City of Sanibel's NPDES monitoring program and SCCF Marine Lab monitoring within the J.N. Ding Darling National Wildlife Refuge, Blind Pass area, and lower Caloosahatchee River was added to the Lee County database.

Interpolated maps of nutrient concentrations for Sanibel nearshore waters and the region were made using ARC GIS 10 geostatistical analyst on the aggregated dataset. Data used was limited to the last three years (2010-2012) in order to focus on current conditions. Parameters in our analyses included TN, IN, TP and OP, chlorophyll *a*, salinity, and total organic carbon (TOC). In the aggregated dataset, outliers were investigated and data with obvious errors was omitted and noted in the dataset. There were very few data omissions due to QA/QC efforts of Lee County, SCCF, and the City of Sanibel.

For purposes of identifying areas of higher nutrient concentrations, plots of relative mean nutrient and chlorophyll *a* concentrations were developed for the Sanibel Slough using ARCGIS 10. The data for these maps was also limited to the last three years to represent current conditions.

A timeline of events which may have influenced Sanibel's water quality (or WQ data) during recent history was developed with information from Lee County Property Appraiser, City of Sanibel Natural Resources Department and Public Works Department, and a number of historical documents related to water quality on Sanibel (Figure 8). Relevant "factors" were identified which may have influenced on the water quality monitoring datasets. These factors were then considered as inputs in the general linear model (GLM) ANOVA analysis of differences in mean water quality.

Land development data from the Lee County Property Appraiser was collected, entered into a database and graphed to show the approximate periods of greatest land use change on the island. This evaluation was needed to appraise the concurrent effect of land development on water quality monitoring programs.

For this study, dry season was defined as July 15th through October 15th. Actual wet season and dry season start dates were estimated for each year from 2008 through 2013. In analyses where wet season-dry season comparisons were made, these estimated start dates were used when possible. Analyses in this report used rainfall data collected at MesoWest station

TS755 (University of Utah), located at the J.N. Ding Darling National Wildlife Refuge. If greater than 0.5 inches of rain fell in the previous 48 hours, samples were defined as being taken after a significant rain event for comparisons to periods with no-rain in the previous 7 days.

Trends in water quality monitoring data were analyzed with the Seasonal Kendal Test in Water Quality Stats® V1.5. Data was manipulated to provide analyses of trends before and after factors which may have influenced water quality results including: change of analytical lab; installation of sewers; and implementation of the fertilizer ordinance.

Differences in mean nutrient concentrations were tested using a general linear model ANOVA (Minitab 13®). Factors included basin, site, season (wet/dry), fertilizer ordinance implementation (before/after), sewer installation (before/after), rain event (no rain/rain), and blind pass opening (before/after). These analyses were performed separately on data from Sanibel Slough, estuary and gulf locations. All data was transformed before analyses using square root or natural log functions depending on normality test results. Residuals were plotted to check for normality and homogeneous variance after GLM ANOVA tests. Results were summarized in tables with significant differences noted in bold font.

The following dates were associated with NPDES monitoring sites (Figure 1) to divide data into bins representing before and after sanitary sewer installation: WQ1/WQ2 = 12-31-2007; WQ3 = 2-28-2006; WQ4/WQ5 = 12-31-2003; WQ6/WQ7/WQ8 = 12-31-2001; DB1/BP1/BP2 = 12-31-2007. Division for the change in analytical lab was set at 3-1-2006, while the divisional date for implementation of the fertilizer ordinance was 10-1-2007.

Ratios of N:P in water quality samples were calculated using the concentration of inorganic nitrogen divided by the concentration of inorganic phosphorus. Using Florida DEP Impaired Waters Rule guidelines (FDEP 2013a), values of N:P greater than 13.5 (by weight) were considered P-limited while values less than 4.52 were considered N-limited. Values between 4.52 and 13.5 are considered to be co-limited by N and P.

Trophic State Indices (TSI) were calculated for each basin of the Sanibel Slough using methods employed by Florida DEP (FDEP 2013b). The mean phosphorus, nitrogen and chlorophyll *a* trophic scores were averaged into a mean overall trophic score called the TSI. A TSI value over 60 is an impaired state due to nutrient enrichment (FDEP 2013c).

NPDES monitoring data from the two Sanibel Slough basins was used to examine mean nutrient concentrations before and after the implementation of the Sanibel fertilizer ordinance (October 2007) and before and after the installation of sanitary sewer. The City of Sanibel Public Works Department provided a map showing dates when sewer service was provided to each area of Sanibel (Figure 3). Using the map provided by Public Works, a sewer system installation date was derived for each of the City's NPDES monitoring sites.

In March 2006, the City of Sanibel changed analytical labs and sampling personnel for their NPDES monitoring program. A plot of parameter values before and after lab change showed an apparent difference in several parameters after the lab change. To determine if the change in lab and sampling personnel influenced results, “lab” was added as a factor in the GLM ANOVA performed on Sanibel Slough and Sanibel Bayous estuary data.

Historical data evaluated in this study originated from previous studies and monitoring programs including: a groundwater study by Missimer (1976); a USGS surface water study (1976); the Sanibel Study (1979); SCCF’s volunteer monitoring program (1982 – 1991); and the Beachview Golf Course Expansion Study (1989). Results from historical data were only used in comparisons to recent data if analysis methods had similar detection limits. This requirement eliminated most of the available historical data except for results from the 1976 USGS study (McPherson and ODonnell 1979). Its 63 sampling points provided a snapshot of conditions in the Sanibel Slough basins in 1976, before most of the residential development occurred. This dataset was analyzed using GLM ANOVA for differences between season, rain event, basin and site. The USGS study data was collected before installation of the centralized sanitary sewer, fertilizer ordinance implementation or the NPDES program monitoring began.

The 1976 USGS study data was also compared to the current City of Sanibel NPDES monitoring data. Nutrient data from 2010 through 2012 was compared to the 1976 data by basin (east and west) using ANOVA on natural log transformed data (Minitab 13®). Using ARCGIS 10, mean values were also plotted together on a map for comparison purposes.

Analysis of nearshore estuary and ocean data showed significant differences between data sets (SCCF vs. City of Sanibel NPDES) for similar monitoring periods and locations. However, all SCCF monitoring data was collected after the fertilizer ordinance was in effect and after the majority of Sanibel was connected to sanitary sewer. Therefore it would have been inappropriate to include the SCCF data in the analysis of possible differences before and after sewer installation and fertilizer ordinance implementation. A comparison of data before and after the fertilizer ordinance and sewer installation was limited to data from Sanibel NPDES estuary/ocean sites (Figure 1). These sites were all located within the Sanibel Bayous Basin except for a single gulf site just outside the mouth of Blind Pass.

For purposes of identifying areas exhibiting higher nutrient concentrations, GIS was used to produce maps of nutrient concentrations based upon the mean nutrient monitoring data obtained from local monitoring programs. These maps show relative differences in mean concentrations by season in the Sanibel Slough, estuary and region.

Estimation of Nutrient Loadings

ArcHydro in ESRI’s ArcGIS 10® was used to delineate watershed basins on Sanibel Island using LIDAR – based elevation data obtained from Lee County. It is difficult to accurately delineate basins on Florida barrier islands where maximum total relief is only a few meters. Each basin predicted by ArcHydro was further refined using local knowledge of artificial drainage systems and roadways which change predicted flow patterns. Basins were named using local landmarks or relevant information to provide a useful grouping of areas for water quality comparisons. Basin-specific data including area, % impervious surface area, runoff coefficients and estimated nutrient concentrations were summarized in tables.

FLUCCS level 2 plus “Other Description” on the South Florida Water Management District’s (SFWMD) 2008 land use coverage was used to classify land use types in this analysis. Due to imperfect ground-truthing, there are likely some inaccurate land classifications in the SFWMD data. Runoff coefficients for each land type were obtained from the EPA Nationwide Urban Runoff Program (1983), and other land use runoff studies from Florida (Janicki Environmental, 2010; Graves et al 2005). Both wet and dry season coefficients were used to more closely approximate runoff conditions (Janicki 2010). Soil type for each land use parcel was obtained by overlaying the NRCS soils coverage for Lee County on the land use coverage. Soil type was needed to determine runoff coefficient to be used in the analysis (Janicki 2010). Average precipitation on Sanibel for 2009-2012 was 38 inches per year with 10.1 inches occurring during dry season and 27.9 inches in wet season.

In an effort to obtain a mass balance of nutrient loads applied to and discharged from Sanibel, total loadings to each basin were estimated including the following nutrient sources: irrigation with IWA water; irrigation with reclaimed water; fertilizer applied to golf courses; fertilizer applied to residential and commercial lands; and atmospheric deposition.

Nutrient loadings to waterbodies by land use type were obtained for each basin by calculating annual runoff volume using local rainfall data, surface area of each land use type from ArcGIS10®, and land use specific runoff coefficients, then multiplying calculated runoff volume by estimated nutrient concentrations. Estimated runoff concentrations for specific land use types were taken from a Charlotte Harbor National Estuarine Program (CHNEP) nutrient loading study by Janicki (2010) and modified with values from a Florida DEP study on runoff concentrations for south Florida land use types (Graves et al. 2005).

To estimate the maximum annual load of fertilizer N and P to land surfaces, the maximum potential fertilized land area for each basin was determined. Sanibel ordinance describes the allowed percentage cleared and re-vegetated (turfgrass) land per lot size (Sanibel Municipal Code 126-454 g-h). Estimated maximum fertilization rate was then based upon the Sanibel fertilizer ordinance maximum allowed application of 4lbs.N/1000 ft^2-year applied over the total maximum potential fertilized area. The fertilizer ordinance limits P in fertilizer to 2%, which is $1/10^{th}$ of the maximum nitrogen concentration. An assumption was made that the maximum P application rate would be $1/10^{th}$ that of nitrogen or 0.4lbs.P/1000 ft^2-year.

Rates of fertilizer application to the three Sanibel golf courses were estimated using actual usage data from The Sanctuary golf course. Application data from 2011 was obtained and the amount of N and P applied per acre for that year was calculated. Due to the lack of data from the other two golf courses, the same application rate per acre for The Sanctuary golf course was applied to Sanibel Island (formerly Beachview) and the Dunes course. Since The Sanctuary Golf Course uses a different primary turfgrass, thought to need less irrigation and fertilization, the nutrient application estimates for The Dunes and Sanibel Island may be less than actual values.

Analysis concentrated on calculating loads to existing natural and man-made waterbodies and wetlands. Sanibel Slough, lakes and wetlands were considered the ultimate receiving bodies and were not included as sources of loadings for this analysis. We assumed that there was no nutrient loading from the recreational beach land use type. This was due to a lack of data and the prohibition of development on beaches.

The total volume of distributed "IWA" water was obtained from Island Water Association for estimating irrigation loads. To obtain nutrient concentrations, three samples of water from separate locations in the Island Water system were tested for orthophosphate while inorganic nitrogen concentrations were obtained from monthly testing results by Island Water. Estimates of the volume of IWA water used for irrigation were based upon an assumption of 50% of the total distributed water being used outdoors (SFWMD 2012) with 80% of metered distributed flow going to Sanibel and 20% to Captiva (per Island Water Association). From land use data, the proportion of urban land use in each basin was used to estimate the distribution of TP and TN loadings from irrigation with Island Water product (IWA water).

Volume of reclaimed water from the Sanibel Donax wastewater treatment plant (WWTP effluent) used for irrigation was obtained from customer meter readings provided by the City of Sanibel. Mean monthly usage was calculated from meter data collected between October 2011 and July 2013. Usage data was overlaid on watershed basins in ARCGIS 10 to match reclaimed water usage to basin. The City's monthly water quality reports from the past three years were used to calculate the mean nutrient concentrations in reclaimed water. Loadings by basin were then calculated from mean monthly flow and concentration. Mean flow and nutrient concentrations were tested for differences between wet and dry season using nonparametric methods (Kruskal Wallis; Minitab 13®).

Results

General

Interpolated maps show a gradient of IN, OP, and TP highest in the Caloosahatchee River and decreasing towards Sanibel during the dry season (Figures 4a, 5a, 5b). During the dry season a plume of nitrogen can be seen emanating from Sanibel with highest concentrations near Tarpon Bay/Ladyfinger Lakes and the northeastern shoreline of Sanibel (Figures 4a, 4b). It is interesting to note a plume of relatively greater inorganic nitrogen exists around the southern half of Captiva Island and extends to the Refuge's Wulfert Keys (Figure 4a). The southern half of Captiva utilizes on-site treatment and disposal systems (OSTDs) for their domestic wastes. A study by

SCCF Marine Lab (Thompson et al. 2012) found that elevated nitrogen levels in nearshore waters were associated with areas of Captiva still using OSTDs.

The same gradient can be seen during the wet season with the highest phosphorus (Figure 7) and nitrogen (Figure 6) upstream in the Caloosahatchee and decreasing downstream toward Sanibel. In addition to the Caloosahatchee gradient a local influence can be seen in the nearshore waters of northeastern Sanibel for phosphorus and nitrogen (Figures 6 and 7). The higher concentrations of inorganic and total nitrogen seem to be associated with Tarpon Bay and the northeastern shore of Sanibel.

The timeline of events developed to identify possible influences on water quality monitoring results included: land development and sanitary sewer installation dates for each watershed; Hurricane Charley; date of change in lab analysis and sampling services; the implementation of the Sanibel Fertilizer Ordinance; the opening of Blind Pass; and the Clam Bayou culvert installation (Figure 8). These factors were used in the GLM ANOVA analyses to determine those that had measurable impacts on water quality data.

Land development data (Table 1, Figure 9) revealed that nearly 80% (by tract) of residential land development on Sanibel occurred between 1970 and 1995. Since nearly all of the data used in this analysis were collected since 2002, the initial impacts of land conversion (increased runoff, increased fertilization, increased sediment loading, abrupt changes in water quality, etc.) preceded the current water quality monitoring programs and associated results.

Sanibel Slough Monitoring

Concentrations of TP and TN in the Sanibel Slough were significantly greater after a rain event but differences in inorganic nutrient concentrations were not significant after rain (Tables 2-5; GLM ANOVA with Tukey's Pairwise Comparisons). Seasonal differences in total and inorganic nutrients were not significant (Tables 2-5; GLM ANOVA with Tukey's Pairwise Comparisons).

No significant difference in total or inorganic nitrogen was observed between sites or between basins (East vs. West) (Tables 2-3; GLM ANOVA with Tukey's Pairwise Comparisons), however differences were seen for both TP and OP (Figures 12-13; Tables 4-5; GLM ANOVA with Tukey's Pairwise Comparisons). The east basin had significantly greater OP and TP concentrations than the west basin and eastern-most sites (WQ8, WQ7) also had higher concentrations than other sites (Tables 4-5). The N:P ratio in samples from the east basin were significantly less than samples from the west (Table 6). In the west basin, the site at Rabbit Rd. (WQ4) had the highest mean TN/IN (Figures 10-11) and TP/OP concentrations (Figures 12-13) as well as the greatest mean chlorophyll *a* (Figure 14). In the east basin, less contrast was seen between sites, however the eastern-most sites (WQ7 and WQ8) had the highest mean concentrations of total and inorganic nitrogen and phosphorus as well as chlorophyll *a* (Figures 10-14).

Analyses of data after the change in laboratories showed no measurable trend in TN for Sanibel Slough while IN exhibited a significant decreasing trend in the east basin (Table 7). Total phosphorus exhibited a general decreasing trend after the lab change and OP showed a significant increase throughout the slough but especially in the east basin.

Mean IN and TP concentrations were significantly lower in the slough after implementation of the Sanibel fertilizer ordinance (Tables 2, 5). Mean IP concentrations were higher. Mean TN was not measurably different after fertilizer ordinance implementation. The N:P ratio was significantly reduced after implementation of the fertilizer ordinance (Table 6). Analyses found a significant increasing trend in TN before the fertilizer ordinance implementation in both basins, while the analysis could find no significant trend after the ordinance (Table 7). For IN no significant trend was present before the ordinance for either basin while a significant decreasing trend was present in the east basin after the fertilizer ordinance (Table 7). One third of the Sanibel Slough monitoring sites exhibited a significant decreasing trend in TP after the fertilizer ordinance while OP changed from a decreasing trend to an increasing trend after the ordinance in both basins (Table 8).

No significant difference was found for mean IN, OP, or TP after the installation of the sanitary sewer on Sanibel compared to before. The GLM ANOVA showed that mean TN did increase after sewer installation; however, significantly greater mean TN values were also found after the change in laboratories (Table 3). The same was true of the N:P ratio, with significantly greater N:P after sewer installation along with greater N:P after lab change (Table 6). Trend analysis indicated a general increasing trend in TN after the sewer installation and a general decreasing trend in IN (Table 7). Phosphorus trends were inverse of nitrogen with a general decrease in TP before sewer and general increase in OP after sewer (Table 8). Due to the few results available before sewer installation, it would be erroneous to attribute these changes in trends to sewer installation without further supporting evidence.

Chlorophyll *a* was significantly greater in the east basin compared to the west basin (Table 9), but differences in chlorophyll *a* between sites were not significant. The change of laboratories in 2006 had a significant effect on the chlorophyll *a* results (Table 9) and likely influenced the finding of significantly lower chlorophyll a before sewer installation compared to after (Table 9). There was no detectable difference in mean chlorophyll *a* before compared to after the fertilizer ordinance was enacted. Though mean chlorophyll *a* values in wet season (37.3 mg/l) were greater than dry season values (25.7 mg/l), the difference was not significant (Table 9).

Analyses of TOC data showed a distinct difference between trajectories in the east basin (decreasing trend) and the west basin (increasing trend) (Table 10). Salinity showed a slight increasing trend at 2 of 3 sites in each basin using all data collected since lab change (Table 10).

Analysis of the 1976 USGS study data for Sanibel Slough (Table 11) showed IN and TP (0.192 mg/l, 0.782 mg/l) in the east basin was significantly greater than the west basin (0.061 mg/l, 0.073 mg/l) (GLM ANOVA, $p \leq 0.05$). No significant between-basin differences were found for inorganic phosphorus or total nitrogen in the 1976 USGS data. In addition, no significant differences were detected between wet and dry season values for TN, TP, IN and OP. However, significant differences were found between monitoring locations.

Significant differences were found in mean nutrient concentrations between the 1976 USGS dataset and the 2010-2012 City of Sanibel dataset for Sanibel Slough (Tables 11-12). In the east basin, the 1976 dataset exhibited significantly greater mean TN (3.54 mg/l vs. 1.84 mg/l), TP (0.782 mg/l vs. 0.132 mg/l) and OP (0.641 vs. 0.048 mg/l) than the current NPDES monitoring data (Figures 15-16; ANOVA, n= 397, F = 51 - 63, $p < 0.001$). No significant difference in mean inorganic nitrogen was detectable comparing the 1976 data and NPDES data (ANOVA, n = 397, F = 0.43, p = 0.514).

Mean TN in the west basin was significantly greater in 1976 data than the modern data (2.68 mg/l vs. 1.72 mg/l) (Figure 15-16; ANOVA, n = 381, F = 12.2, $p < 0.01$), while IN was greater for the modern samples (0.190 mg/l) than the historical data (0.061 mg/l) (ANOVA, n = 381, F = 4.1, p = 0.012). No significant differences were found between TP and OP comparing the historical dataset to the modern dataset.

A comparison of mean nutrient values between Sanibel Slough and stormwater lakes at The Dunes and The Sanctuary showed locations to be similarly eutrophic with high TSI values (Table 13). The lakes had generally higher levels of nutrients than the slough but had similar N:P values. Of particular note is the exceptionally high TP level in The Sanctuary lake system (Table 13).

Estuarine Monitoring

IN was significantly greater for pooled Sanibel estuarine data after rain events (0.074 vs. 0.067mg/l) (GLM ANOVA, n = 1107, F = 9.2, $p < 0.01$), but no seasonal IN differences were found. Mean estuarine site TN was significantly greater during the wet season (0.74 mg/l) than the dry season (0.62 mg/l) (GLM ANOVA, n = 1061, F = 18.5, $p < 0.01$), but no significant differences were observed after rain events.

No seasonal or rain event differences were found for OP data but mean TP was significantly greater during the wet season (0.057 mg/l) compared to the dry season (0.053 mg/l) (GLM ANOVA, n = 907, F=5.42, p = 0.02), with no significant difference after rain events.

Mean IN concentrations (Table 14) in the Sanibel Bayous Basin estuary samples (0.089 mg/l) were highest among basins with estuarine data available, and significantly greater than levels in the refuge basin (0.035 mg/l) (GLM ANOVA, n = 791, T = 5.1, p = < 0.01). Mean TP values in the Sanibel Bayous estuary (Table 14) (0.064 mg/l) were also highest amongst the basins and significantly greater than those in the refuge (0.022 mg/l).

Mean TN, TP and OP in the Sanibel Bayous estuary were significantly less after the opening of Blind Pass (Tables 15-16). In contrast, mean TN of the gulf site just outside Blind Pass (BP2_Out) was significantly greater after the opening of Blind Pass, while IN, TP and OP at the site after Blind Pass opened was not significantly different (Tables 17-18).

Estuarine TP, OP and IN were significantly reduced after installation of sanitary sewers in the Bayous Basin (Table 15-16). OP was also significantly reduced after implementation of the fertilizer ordinance in October 2007 (Table 16).

Analysis of all Sanibel Bayous estuary data collected since the change of analytical laboratories found a general decreasing trend for IN and an increasing trend for TN (Table 7). In addition, site BP1 showed a decreasing trend in TP and BP1 and BP2 showed decreasing trends in OP (Table 8).

At the Blind Pass gulf site (BP2_out), IN was significantly lower after sewer installation and OP was significantly lower after the fertilizer ordinance was implemented (Table 17-18).

The estuary samples from Kesson Bayou Basin had relatively low values of TN but IN was elevated relative to the Refuge Basin.

The National Wildlife Refuge Basin had the lowest mean IN and TN concentrations for estuarine samples. Mean IN was significantly lower in the refuge (0.35 mg/l) than in Sanibel Bayous (0.89 mg/l) (Tukey's, $n = 791$, $T = 5.1$, $p = < 0.01$) and TN (0.62 mg/l) was significantly lower than the Ladyfingers Lakes Basin (0.70 mg/l) (Tukey's, $n = 791$, $T = 5.1$, $p = < 0.01$). The Refuge also had the lowest mean OP (0.007 mg/l) and TP (0.021 mg/l) values of the estuarine basins evaluated.

The Ladyfinger Lakes Basin had the highest mean TN concentrations for estuarine samples. Total nitrogen was significantly greater in the Ladyfingers Lakes (0.71 mg/l) estuary than the Refuge (0.62 mg/l), Kesson Bayou (0.68 mg/l) or Sanibel Bayous Basins (0.69 mg/l) (Tukey's, $n= 150\text{-}815$, $T = 3.4\text{-}4.6$, $p < 0.01$). This basin's estuary samples also had relatively high TP (0.043 mg/l) values that were significantly greater than TP in the Refuge Basin (0.021 mg/l) (Tukey's, $n = 791$, $T = 5.1$, $p = < 0.01$).

Nutrient Loading Estimates

The LIDAR-based, ArcGIS® analyses produced 12 major watershed basins on Sanibel (Figure 17; Appendix 1). Several small watersheds were artificially created from residual land areas not falling within major basins (San Carlos Bay Basin, Lighthouse). The largest watershed basins on Sanibel were the Refuge (2073 acres), the Sanibel Slough West (1838 acres) and East (1177 acres) basins, and the Sanibel Bayous Basin (1169 acres).

The proportion of urban land use types varied between basins with the highest proportion in the Sanibel Slough basins and lowest in the Wildlife Refuge Basin (Figure 18; Table 19; Appendix 1). Overall, medium density residential occupied the largest area of urbanized lands on the island. Sanibel Slough's west basin had the highest percentage of total urbanized land area (19.3%), however it was primarily low density residential lands which have less impact than the more impervious higher density residential and commercial land use types. The basins with greatest areal percentage of commercial and higher density residential development were Sanibel Slough's east basin (13%), Sanibel Bayous Basin (11%) and East Canals Basin (9.3%). These are the most impervious basins on Sanibel.

The primary hydrologic soil groups on Sanibel are C, B/D and D (Figure 19). Group C soils are found beneath urban land use types and are a result of artificially placed fill. These soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. Group C soils have a low rate of water transmission (0.05-0.15 in/hr). Soils in Group D are found throughout Sanibel and are classified in this group due to a high water table that creates a drainage problem. Group B/D soils are typically influenced by the water table during part of the year and are well-drained for part of the year. They have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr.) (NRCS 2013).

Waterbody Nutrient Loadings

Runoff coefficients used in this study reflected the estimated percent impervious surface area for each land use type (Table 20) with higher percent storm runoff with higher percent impervious surface. From 2009-2012 the annual average dry season rainfall was 0.257 meters (10.1 inches) while the annual wet season rainfall was 0.709 meters (27.9 inches). The estimated runoff concentrations of nitrogen and phosphorus were highest for medium and high density residential land use types and lowest for upland hardwood forests (Table 20).

Stormwater runoff estimates by basin show Sanibel Slough east and west basins plus Sanibel Bayous and Sanibel Beach Basins all had over 1 million cubic meters of runoff discharge into their receiving waterbodies (Appendix 2). These basins all had relatively large drainage areas and significant percentages of urban land use types.

Total estimated nitrogen load to Sanibel Slough was 4206 kg/yr. while total N load to the estuary and Gulf was 7036 kg/yr. (Table 21). Total estimated load of phosphorus to Sanibel Slough was 778 kg/yr. and 1655 kg/yr. of P was discharged to the estuary and Gulf (Table 21).

Estimated N and P loadings to waterbodies from stormwater were highest for the Sanibel slough east (2271/431 N/P kg/yr.) and west basins (1821/345 N/P kg/yr.), Sanibel Bayous (2449/464 N/P kg/yr.), and the Beach Basin (1945/415 N/P kg/yr.) (Table 22, Appendix 2). For contrast estimated loadings for the refuge and Tarpon Bay SW Basins were 115 and 89 kgN/yr. respectively (Table 22; Appendix 2). On a kgN/acre-yr. basis, the more developed basins have highest values (East Canals = 39.8 kgN/acre-yr.; Lighthouse, Sanibel Slough east and Sanibel Bayous ~ 29 kgN/acre-yr.) (Table 22, Appendix 2).

Terrestrial Nutrient Loadings

Total estimated nitrogen load to land surfaces of Sanibel was 129,144 kg/yr (Table 21). Total estimated phosphorus load to lands was 15,724 kg/yr (Table 21).

Atmospheric deposition of nitrogen to terrestrial (non-wetland or waterbody) portions of Sanibel's basins ranged from nearly 1000 kg/yr. in the Sanibel Bayous Basin to 42 kg/yr in the Refuge Basin (Table 23). The estimated terrestrial loading rate of N from atmospheric deposition was not negligible compared to other sources of load, however it is only 1-3 % of total estimated nitrogen load. Atmospheric phosphorus deposition was minor compared to all other components of terrestrial P loading (Table 23).

Mean distributed water flow to Sanibel from Island Water Association's potable water supply (IWA water) was significantly greater (Kruskal Wallis, H == 204, $p < 0.01$, n = 2010) during the dry season (3.48 MGD) than the wet season (3.04 MGD). Mean inorganic phosphorus concentrations were 0.12 mg/l (Lee County Environmental Laboratory 2013) while mean inorganic nitrogen concentration was 0.02 mg/l (Island Water 2013). Estimated annual terrestrial loadings from irrigation with IWA water were highest in the Sanibel Slough Basins and lowest in the Refuge Basins (Table 24). Loadings of P were about 3 times greater than N using IWA water. The relative terrestrial load of N and P from irrigation with IWA water is low compared to estimated loadings from fertilizer, reclaimed water irrigation and atmospheric deposition (Table 22).

For August 2010 through July 2013 (3 Years) TP and OP in reclaimed water (Table 25) were significantly greater (Kruskal Wallis, H = 5.8, $p < 0.01$, n = 2010) in the dry season (IP = 2.19 mg/l, TP = 2.92 mg/l) than the wet season (IP = 1.61 mg/l, TP = 2.15 mg/l; Table 25). No significant differences were found between wet and dry season for mean reclaimed water nitrogen or flow values. At these mean concentrations, inorganic nitrogen and phosphorus application rates are 0.044 lb. IN/1000 gallons applied and 0.018 lb. OP/1000 gallons applied, respectively.

Most of the total terrestrial loading attributable to reclaimed water occurs within the 3 basins with golf courses (Ladyfinger Lakes, Sanibel Bayous and Sanibel Slough East) plus the Beach Basin which has reclaimed water available to a large proportion of its condominium and resort facilities (Table 26; Figures 20-21). The three golf courses on Sanibel each use about the same annual volume of reclaimed water for irrigation resulting in about 2000 kilograms of nitrogen and 1000 kilograms of phosphorus being applied to these land areas from irrigation alone. Loadings from commercial and residential reclaimed water irrigation within the Beach

Basin are about 1500 kilograms of nitrogen and 750 kg of phosphorus annually (Table 26). Relative to the total estimated nutrient load to waterbodies, the load associated with reclaimed water (in basins which have reclaimed water available) are significant, especially for phosphorus (Table 22). The load directly to urban land attributable to reclaimed water is considerably less than the load estimated from maximum fertilizer.

Estimation of maximum urban fertilization application suggested the Sanibel Slough basins together had the greatest fertilized land area and greatest potential maximum total N and P application of the 12 basins (Tables 27). The estimated maximum terrestrial load due to fertilizer application ranged from 22,222 kgN/yr. (2,222 kgP/yr.) in the Western Slough Basin to 660 kgN/yr. in the SW Tarpon Bay Basin (Table 27). In most basins, the estimated maximum load due to residential fertilizer application was the largest component of the total terrestrial nutrient load. However in the Ladyfinger Lakes Basin, terrestrial loadings from reclaimed water was greatest and golf course fertilization was equal that of other urban fertilizer application (Table 22b). The P load from golf course and/or reclaimed water is also comparable to residential fertilization in the Sanibel Bayous, East Sanibel Slough and Beach Basins (Table 22a).

Discussion

GIS analysis of mean nitrogen and phosphorus concentrations along a transect from the lower Caloosahatchee estuary through San Carlos Bay and Pines Island sound reveal that river is the main source of loadings to the local estuary (Figures 4-7). Significant relationships between the discharge rates at S79 (Franklin Locks) on the Caloosahatchee and the conservative parameters salinity and CDOM in Tarpon Bay and MacIntyre Creek have been demonstrated (Thompson et al 2012a). Despite the reaching influence of Caloosahatchee River discharges on the Pine Island Sound estuary, geospatial analyses suggest Sanibel may also be adding significant loadings to its nearshore waters. Plumes of higher concentrations of inorganic nutrients were noted adjacent to Sanibel during the wet season near Tarpon Bay and San Carlos Bay. In the dry season these plumes fade and the nearshore estuarine waters around Sanibel remain under the influence of the Caloosahatchee River (Figures 4-7). Due to a lack of data, geostatistical analyses could not be performed for the gulf side of Sanibel. The probable interaction between the underground freshwater lens (surficial aquifer) and the gulf at Sanibel's shoreline advocates a need for monitoring of nutrients in the nearshore gulf waters and the surficial aquifer. Previous work has shown elevated levels of nitrogen and phosphorus can exist in Sanibel's freshwater lens (Thompson et al 2011; Missimer 1976). In addition, with the opening of Blind Pass, nutrient loadings from Sanibel watersheds can more easily influence gulf waters especially in the absence of large discharges from the Caloosahatchee.

Land development is known to be the major factor in degrading adjacent surface water quality (Caccia and Boyer 2005; Bergquist et al. 2008; Holland et al 2004). Therefore in determining factors to be used in analyzing impacts on nutrient concentrations in Sanibel surface waters, the history of land development was needed. The analyses of Lee County Tax Appraiser land parcel data showed 80% of development on Sanibel occurred before 2000 (Figure 9). However, reliable surface water quality monitoring did not begin until 2002 with the City's NPDES monitoring program. This allowed us to exempt ongoing land development as a major contributor to water quality changes in the dataset. Instead, major factors used in the GLM ANOVA model included more recent possible influences including the enactment of the fertilizer ordinance in 2007, the installation of sanitary sewer between 1992 and 2011 and the 2006 change in the contracted analytical laboratory for the City's NPDES water quality monitoring.

The mean rainfall (38.1 inches) from the last three years of data obtained from station TS755 corresponds well with locally-obtained data used in historical studies of Sanibel watersheds (McPherson and ODonnell 1979; Missimer 1976). We imply that concentration and runoff data used in this study is not skewed by unusual seasonal precipitation conditions.

Sanibel Slough Monitoring Results

The mean TN concentrations for the east (1.84 mg/l) and west basins (1.72mg/l) were at or above the 90th percentile value of all Florida lakes (Hand 2008). The mean IN values (east = 0.17, west = 0.19) were not as elevated relative to other waterbodies in Florida being in the 75th percentile of all Florida Lakes. The fact that both east and west basins of the slough are potentially subject to high inorganic nutrient loadings from fertilizer and other runoff (see later section) suggests the majority of IN available to the slough is quickly converted to organic nitrogen. The east basin had significantly greater TP and OP than the west basin and its eastern-most sites (WQ7 and WQ8) were highest amongst sites. A significant decreasing trend in IN was noted at all three stations in the east basin while only one station in the west basin showed a decreasing trend for IN. The mean N:P ratio was not seasonal and the western basin was P-limited on the average while the east was co-limited by inorganic phosphorus and nitrogen. These findings suggest that in general the basins should be considered separately when developing nutrient management strategies. Actions that affect one basin may not affect the other.

Both the east and west basin of Sanibel Slough would be classified as eutrophic by the state of Florida with TSI scores of 76.3 and 69.7, well above the state's impaired water score of 60. These scores are comparable to those from the stormwater ponds in the Dunes development which range from 68 to 92. A score of 72 or above is in the 90th percentile for all Florida lakes. Though Sanibel Slough is not technically a lake, it is managed much like a reservoir with discharge control structures and no existing natural outlets. It is also now classified as a lake under FDEP's impaired waters listing for the waterbody (FDEP 2013).

Statistical analysis shows implementation of the Sanibel Fertilizer had a measurable effect on nitrogen in the slough. The significant reduction in mean IN after implementation of the ordinance can be partially explained by a reduction in inorganic nitrogen applications to residential lawns. Concurrently there was a decrease in TP while OP increased after implementation of the ordinance. Associated with these changes the ratio of N:P was significantly reduced. This suggests the typical P-limited environment of freshwater systems was changing to a co-limited situation with inorganic nitrogen now sharing status with phosphorus. The shift in N:P ratio was most noticeable in the east basin where reclaimed water is used for irrigation. The reclaimed water has higher phosphorus levels relative to nitrogen than fertilizer runoff. The combined added P from reclaimed water usage and successful reduction in N loading due to fertilizer runoff reduction can help to explain the shift in N:P.

Sediments in the slough may also release OP back into the water column for an extended period of time after external P loading reductions. Studies have found that levels of TP will follow a reduction in nutrient inputs into a lake system; however the reduction lags behind TN reduction sometimes by years (Jeppesen et al. 2007; Havens 2013; Olila 1994). Inorganic P can be released back into the water column after inflow P reductions and continue to fuel phytoplankton (Havens 2013; Olila 1994).

The inputs of OP from reclaim water usage and from legacy sediments in the slough along with IN reduction associated the fertilizer ordinance will cause the TN:TP ratio to be reduced as found. We would then see more N-limiting periods where OP would still be available in the water column (and measured in more samples) while inorganic nitrogen is absent or low due to its successful control. Because the total amount of phosphorus in the waterbody (TP) decreased suggests the fertilizer ordinance is working to control total P inputs as well as N. These same dynamics were found to be occurring in the Dunes' stormwater pond system where reclaimed water is used as irrigation on the golf course. The lakes in that system are monitored quarterly for nutrients by SCCF Marine Lab. After implementation of a variety of best management practices, the N:P ratio in those lakes has decreased significantly and some are now periodically N-limited (Thompson 2013).

Jeppesen et al. (2007) summarized that the N:P ratio typically increased after nutrient reduction efforts in shallow lakes where nutrient reduction efforts focused on P only. They found that in general the N:P ratio of the lakes followed the N:P ratio of the influent water at a lag. In a lopsided effort to control P the N:P would increase. Noges et al. (2007) found the N:P ratio of shallow lakes in Estonia decreased significantly after inputs of nitrogen were controlled more successfully than phosphorus inputs. The Sanibel Slough case would be similar. The fertilizer ordinance and other efforts by the City have helped control both N and P. However, latent P in bottom sediments, and P from unrestricted use of reclaimed water continues to supply P at levels higher relative to nitrogen than previously.

Trend analysis determined that the east basin of Sanibel slough exhibited a significant decrease in inorganic nitrogen after implementation of the fertilizer ordinance while one of the three stations in the west basin also showed a decreasing trend (Table 7). For the period of record before the fertilizer ordinance, no significant trends were found for IN, suggesting an external factor (such as change in fertilizer loading to waterbodies) influenced the trajectory of data. Both basins saw a decreasing trend in OP before the fertilizer ordinance change to an increasing trend after. In addition, one third of the stations in each basin exhibited a significant decreasing trend in TP after the fertilizer ordinance. Again this suggests less IN and TP making their way into the water column over time in part due to the success of the fertilizer ordinance, allowing OP (from sediments or reclaimed water) to be detectable in a higher percentage of samples due to the decrease in available nitrogen (less immediate OP demand due to growth limitation by lowered IN).

Jeppesen et al.'s review of data from multiple lakes undergoing nutrient reduction efforts shows new TP and TN equilibriums may take from 10-15 years and 5-10 years respectively. The nutrient reduction efforts implemented so far for Sanibel Slough have had 5-22 years to have an effect. We are within the timeframe of new nutrient equilibria to be taking effect. The changes discussed above may be a result of these new conditions brought on by nutrient loading reduction efforts such as stormwater retention, sanitary sewer installation, vegetation ordinance, fertilizer ordinance and educational outreach efforts. As these measures become more effective over time, further reduction in nutrient concentrations can be expected.

Chlorophyll *a* was not shown to be different before implementation of the fertilizer ordinance compared to after. In a eutrophic system, changes in chlorophyll *a* will be less readily noticeable than changes in nutrient concentrations (Carstensen et al. 2006; Boynton et al. 2008). Other studies have shown that reductions in chlorophyll *a* lag behind nitrogen by 5 or more years (Jeppesen et al. 2007). Following nutrient input reductions, shallow lakes have been shown to have greater submerged macrophyte abundance which supports enhanced top-down control by zooplankton (Jeppesen et al. 2007). Associated with this change was an increase in zooplankton:phytoplankton biomass and increase in the contribution of cladocerans. It is likely that chlorophyll *a* will remain relatively high until long-term nutrient reductions have occurred and changes in the ecosystem have followed (Jeppesen et al. 2007; Carstensen et al. 2006; Boynton et al. 2008; al. Artioli 2008; Taylor et al. 2011).

In an attempt to estimate the magnitude of nutrient reduction required to effect change in phytoplankton mass with Sanibel Slough, a nutrient-saturation concept for algae control as outlined in Lewis et al. (2008) was employed. Algal abundance could be suppressed by reducing P below the threshold of nutrient saturation in the water column. Research has shown that under healthy conditions the mass ratio of carbon:phosphorus (C:P) is about 41:1. Phytoplankton growth studies show P starvation begins when the ratio increases to 100 or above (Lewis et al. 2008). Algal growth could be controlled by reducing the concentration of P in Sanibel Slough so that the C:P ratio is at least 100. Using methods outlined in Lewis et al. (2008) C content can be estimated from chlorophyll using a ratio of 27:1 C to chlorophyll. Using TP and OP data, an estimate of particulate P in the water column is obtained. The particulate P is an indication of phytoplankton P and is then used to estimate the C:P mass ratio in the water column. The amount of P in excess of the 100:1 mass ratio is designated as excess P. Comparing the excess P to TP gives an idea of how much the phosphorus concentration would need to be reduced in order to suppress phytoplankton growth (Lewis et al. 2008). Using data from Sanibel Slough, this analyses suggested that the excess P in the East Basin was around 30% while the excess P in the West Basin was around 26%. The total P in the Slough would need to be reduced by 25-30% to expect a reduction in phytoplankton. From this analyses we can set a target of 30% reduction in P concentrations to effect noticeable change in algal biomass.

The sanitary sewer system was installed on Sanibel in phases with some parts of Sanibel connected to sewer nearly 20 years earlier than others. Analysis of nutrient data showed little evidence linking sanitary sewer installation to changes in nutrient concentrations in Sanibel Slough. The multi-phased installation most likely confused any influences and masked them within other factors such as change in laboratory. In addition the dataset examined in this project post-dated much of the sewer system installation and there simply wasn't enough data to find any associated differences.

Change in analytical laboratory was found to be a significant factor explaining variation in chlorophyll *a*, TN, IN and to a lesser extent OP in the NPDES dataset (Tables 2-4, 9). Mean chlorophyll *a* in the slough before the lab change was lower (12.4 µg/l) than after the change (37.5 µg/l) and the F-value was much higher than any other factors used in the GLM ANOVA (Table 9). The values after the change are more in line with those which would be expected in a highly eutrophic slough, and it would be prudent to discount use of chlorophyll data collected before the lab change.

Comparison of nitrogen and phosphorus data between NPDES monitoring sites revealed the greatest TP and OP levels occurred at the eastern-most sites in the eastern basin (Figures 12-13). The eastern sites also had higher TN and IN values along with the site at Rabbit Rd (WQ4.) basin (Figures 10-11). Data from the 1976 study of Sanibel Slough revealed high levels of nutrients (Table 11, Figures 15) in the eastern basin adjacent to and downstream of the Beachview-Jamestown WWTP, (located on the site of the current City of Sanibel Donax WWTP). The significantly greater levels of nutrients currently observed at those sites may be in part due to legacy loading from the WWTP's historical discharges to the slough. However there may still be unintended connections between wastewater effluent and the slough through groundwater seepage from holding ponds or leaks in piping.

Statistical comparison indicated that levels of TN, TP and OP in the east basin were higher in 1976 than presently, and TN was also greater in 1976 in the west basin. It would be difficult to determine precisely why current nutrient levels in the east basin are lower than historical data; however efforts to improve water quality must be given credit. These efforts would include foremost the City's takeover of the former Beachview-Jamestown WWTP which was upgraded to become the Donax WWTP. In addition the island-wide conversion from septic to central sewer system and the implementation of the fertilizer ordinance and BMPs at Sanibel's golf courses highlight efforts. Jeppesen et al.'s (2007) review of data from multiple shallow lakes found impacts of nutrient reduction could be found 5-15 years after efforts began. The efforts on Sanibel fall within this timeframe.

As discussed above, there is statistical evidence that nutrient reduction efforts are significantly improving water quality in both basins. However, we found that current levels of IN were greater in the west basin than those in 1976, and in the east basin IN is the only parameter which was not reduced since 1976. The main anthropogenic source of inorganic nitrogen to Sanibel Slough would be fertilized (and irrigated) lawns. Though the most current data shows IN to be on a decreasing trajectory in Sanibel Slough since implementation of the fertilizer ordinance, it is evident that fertilizer runoff has increased IN levels since 1976 while other nutrients forms have been better controlled. Water quality improvement efforts seem to have had the least impact so far in the middle of the western basin of the slough (Rabbit Rd. area), where no decreasing trend in IN was discovered and IN levels are the highest among sampled sites. This area should be a target for increased nutrient reduction efforts.

Comparisons of Sanibel Slough nutrient and chlorophyll data to results from monitoring at the Dunes and Sanctuary lakes shows similar eutrophic conditions with the lakes having typically greater concentrations of nutrients overall and a slightly higher TSI value (Table 13). Of special note is the exceptionally high value of TP found in The Sanctuary lake system (Table 13). Since both of these lake systems discharge into the nearshore waters of Sanibel, estimated nutrient loadings from these sources should be calculated. Discharge data is needed to estimate nutrient loadings. Manual or automatic methods of measuring discharge can be adapted to these locations. In addition added effort is recommended in reducing loading potential from these systems including in-lake nutrient reduction activities and source control.

Estuarine Monitoring Results

Estuarine inorganic nutrient samples collected in the Refuge Basin were significantly less than all other basins for which data was available. Since the Refuge Basin contains the smallest amount of urbanized land, we would expect to see lower levels of inorganic nutrients which are often associated with development, fertilizer use and irrigation. The Refuge Basin provides a semi-natural "baseline" by which other estuarine water quality results can be compared. However other analyses have shown that discharges from the Caloosahatchee River in the wet season have a strong effect on water quality values even in the refuge (Thompson 2012a).

In the Sanibel Bayous Basin, the gradient of decreasing nutrient and chlorophyll *a* concentrations from the most inland monitoring site seaward would be expected due to the diluting effects of tidal exchange through Blind Pass. Overall the basin's estuary data was average for Florida estuary nutrient samples but was at the 90th percentile of Florida estuaries for chlorophyll *a*. Even with the opening of Blind Pass and the installation of a culvert system to flush Clam Bayou, the Sanibel bayous remains poorly flushed by tidal exchange compared to other estuary areas. The relatively quiescent areas afforded by lesser tidal exchange offer phytoplankton more opportunity to proliferate, resulting in higher chlorophyll concentrations. With the installation of culverts at Clam Bayou, and the opening of blind pass, the reestablishment of healthy seagrass, oyster and mangrove habitats is still underway. As these habitats recover, we would expect more of the nutrient load to the bayous to be tied up in macrophytes and sediments with a reduction in chlorophyll *a*. As seen in lakes, a significant reduction in chlorophyll may lag behind actual reductions in nutrient water column concentrations (Krumholz 2012).

The Sanibel Bayous Basin was one of the last areas of Sanibel to be completely converted to sanitary sewer. Prior to the sanitary sewer installation, a package WWTP served many of the basin's households and on site treatment and disposal systems (OSTDS) served others. The package plant had a history of operating violations and its holding pond was cited several times for illicit discharges to adjacent ditches. This may explain a finding of significantly reduced IN, OP and TP after this basin was completely connected to sanitary sewer. Centralized sewer was installed later in the Bayous Basin compared to other basins. This allowed a sufficient number of water quality samples to be taken before the sewer installation to provide a robust before and after installation comparison. A majority of nitrogen and phosphorous discharged into an OSTD drainfield is in the inorganic form (Bicki et al. 1984) and GLM ANOVA analyses found that the greatest variability in inorganic nutrient data in the Bayous Basin was explained by the sanitary sewer installation factor (Table 15-16).

A study by SCCF Marine Lab comparing water quality parameters before and after the opening of Blind Pass showed significant reductions in TN and TP after the opening in an area within 1.8 km of the pass (Milbrandt et al. 2012). Reductions in nutrient concentrations were also seen by an evaluation of the Sanibel Bayous Basin data for this study (Tables 15-16). An estimated 10 fold increase in flow volume was found at the Clam Bayou culvert after Blind Pass was opened (Milbrandt et al. 2012). The dilution effects of Gulf water tidal exchange account for decreases found after the opening.

The effect of the fertilizer ordinance on nutrient levels was not readily apparent in the Bayous Basin. A small but significant effect was detected in reduced OP after the ordinance but no effect on IN, TN or TP was found. The before/after differentiation dates for implementing the fertilizer ordinance were very similar to the dates in this basin for sanitary sewer installation. These two factors may easily have interacted in the analyses making it difficult to distinguish possible effects leading to differences. The GLM ANOVA could not test for interaction due to co-linearity between these two factors.

The N:P ratio (Figure 22) in the Sanibel Bayous estuary increases along a gradient towards the gulf. Evaluation of mean data suggests the upper portion of the bayous is N-limited while Blind Pass is co-limited. Possible explanations include influence of regional IN loading flowing from the Caloosahatchee River through Blind Pass, discharge of IN-laden groundwater to the nearshore waters of Sanibel and Captiva which is then transported by tidal currents into

Blind Pass, and release of phosphorus from bayous sediments during the increased turbulence caused by the opening of Bland Pass and installation of the Clam Bayou culverts. The successful implementation of the fertilizer ordinance in this basin may also partially account for reduced IN upstream in the Bayous compared to Blind Pass sites which are influenced by runoff from Captiva and inorganic nitrogen from septic systems. An investigation of Captiva nearshore waters identified elevated levels of IN in the nearshore waters of Captiva where septic systems are still in place (Thompson 2012b). The GIS plot of regional IN concentration data (Figure 6) also shows relatively high levels of IN surrounding Captiva in both wet and dry season.

Nutrient data from Kesson Bayou, Tarpon Bay and Ladyfinger Lakes estuaries indicates TN, TP, OP and IN levels are generally all at or below the 50th percentile of Florida estuary samples (from Hand 2008). The relatively small area of developed land associated with Sanibel watersheds compared to other Florida watersheds make this finding expected. However, Sanibel's position immersed in the Gulf of Mexico at the lower edge of the estuary makes any concentration of nutrients over ambient Gulf values to be of concern for possible effects on off-shore habitats. Lack of local coastal data leaves a gap in our knowledge of the effects that Sanibel and Captiva have on coastal water quality. Water quality monitoring is necessary in Sanibel's near shore Gulf waters to help understand any impacts on these habitats.

Nutrient Loadings Estimates

Due to foresight and responsible planning, over half of Sanibel Island is classified as preserve lands (City of Sanibel 2011) and in this way differs from most barrier islands in Florida. However development is still a major issue on Sanibel and its effects on water quality are significant, especially in the Sanibel Slough.

In this analysis, land use types classified as waterbodies (lakes, rivers, streams, etc.) or wetlands were defined to be the sink for loadings and not a source. In reality this may not always be true as with wetland nutrient cycling processes which may at times export loads downstream. However this study focuses on anthropogenic sources which can be managed and therefore become part of a nutrient management plan.

Watershed basins identified in this analysis for the most part are natural delineations based upon topography (Appendix 1). By using LIDAR elevation data (Lee County 2010) with Arc Hydro GIS tools, basins could be parsed into almost infinitely smaller polygons, however we attempted to identify basins which ultimately discharge into waterbody areas which had common characteristics. The 12 basins we used in this study work well in that they have limited discharge areas into single waterbody types. A majority of the basins are easily defined by natural topographic features which have been identified in previous ecological and geological studies of Sanibel (McPherson and ODonnell 1979; Johnson Engineering 1976; Merrill and Byle 1975; Provost 1953). The Beach Basin boundary was largely defined by roadways and additional work may be needed to refine the local drainage patterns in its island-length extent. Culverts and swale systems may connect areas of the beach to interior basins classified as draining toward the Gulf. We anticipate these corrections if needed will be minor. Similarly, drainage patterns for small areas of the basins may be altered due to unrecognized drainage conveyances not accounted for in this study. For more accuracy, further work would be needed ground truthing basin boundaries. However, as defined in this study, each of these basins could be managed separately to address unique issues of that basin and its receiving waterbodies. We expect future work may adjust boundaries of these basins but the general size, shape and characteristics will remain as viable management units.

Total estimated nitrogen load to waterbodies (12,772 kg/yr.) was 10% of that to land surfaces (129,144 kg/yr.) while phosphorus load to waterbodies (2,433 kg/yr.) was 15.4% of the load to land surfaces (15,724 kg/yr.) (Table 21). Since phosphorus is typically less mobile through the soil and over land surfaces, this finding indicates the estimates developed in this analysis should be further refined. Sanibel-specific runoff coefficients and concentrations are needed to produce a more accurate representation of what is actually happening in the watershed. These coefficients can be developed with minimal additional efforts through GIS interpretation and a single wet season/dry season runoff monitoring project.

Estimates of total nutrient loading to waterbodies by basin (Table 22; Appendix 2) reveal east and west Sanibel Slough, Sanibel Bayous and the Beach basins have far greater N and P loading (1,800-2,500 kg/yr./basin) than other basins. These basins also cover much of the urbanized land area on Sanibel. For management purposes annual loadings on a per-acre basis allow us to further focus on sources and potential problem areas. For the two basins discharging into the Sanibel Slough, the predicted loading per acre in the east basin (1.97 kgN/acre-yr.) is much greater than the west basin (1.03 kgN/acre-yr.) (Table 22a). Best management practices aimed at reducing nutrient loadings in Sanibel Slough may have a higher rate of return in the east basin due to its more "concentrated' discharge character. Similarly, for basins discharging into the estuary, the East Canals (3.31 kgN/acre-yr.) and Lighthouse basins (3.14 kgN/acre-yr.) top all basins in potential nutrient loading per acre. The east Sanibel Slough is connected via control structure to the East Canals Basin and even though there are few planned discharges, periodic weir overflows occur during wet season along with unaccounted for loadings through leaking structures, and leaching through soils. A potential plume of inorganic nitrogen identified in the regional GIS analysis of water quality data (Figure 6) looks to be fed from the north eastern coast of Sanibel in the vicinity of these high loading/acre basins.

Estimates reveal the Sanibel Bayous, and Beach basins to be major load contributors to adjacent waterbodies in addition to the two Sanibel Slough basins (Table 22a). On a per acre basis, the Lighthouse, East Canals and Tarpon Bay SE basins join this group as major contributors, and as priorities for BMP activity (Table 22b-c). The estimated load to land surfaces also represents "potential" impact on waterbodies (Table 22). The same basins make the list of potential major loading sources based upon terrestrial loading per acre. Ladyfinger Lakes and Tarpon Bay SE basins also have significant urbanized land use and large watershed areas which combine for a potential large nutrient load to their receiving waterbodies (Table 22b). Management of nutrient loads from all of these basins may be necessary to curtail the total loadings coming from Sanibel.

The nutrient assimilative capacity of a basin's terrestrial component depends upon soil type, soil redox, vegetation, impervious surface area, rainfall, landscape management practices, and natural ecosystem components such as grazers and other factors. Each basin on Sanibel will have different environmental conditions which affect what proportion of the nutrient load applied to terrestrial components actually makes it to a waterbody. As presented in our estimates (Table 22), there is a large variation in predicted loadings per acre to land surfaces and somewhat lesser variation in predicted loadings per acre to waterbodies. The percentage of N or P load which is assimilated by terrestrial surfaces equals the mass of N or P which is estimated to runoff into a waterbody divided by the mass applied to the land (load to waterbody/ load to land surfaces x 100). These values range from about 6 (Ladyfinger Lakes Basin) to 18.3 (Kesson Bayou Basin) for N and from 8 (Ladyfinger Lakes Basin) to 30.3 (Kesson Bayou Basin) for P (Table 22). The fact that the estimated percentage of P out to P in is greater than percentage N out to in may indicate the need for more accurate loading estimates. Normally P has a greater affinity for soil and is not as mobile as N which would result in a lower percentage of P running off land surfaces (Corbett and Iverson 1999; Bicki et al. 1984).

The estimated maximum urban fertilizer application was the largest contributing load to the total land mass of Sanibel (Table 22). In most basins it was the greatest estimated load by far. However in some basins the P load from reclaimed water usage or golf course fertilization were greatest. In most cases phosphorous loadings parallel nitrogen loadings due to the estimation of residential phosphorous fertilization at $1/10^{th}$ that of the nitrogen application rate (from Sanibel's fertilizer ordinance). However in basins with reclaimed water available for irrigation, basin phosphorus loads could be dominated by reclaimed water usage (Table 22). The Sanibel fertilizer ordinance limits the amount of phosphorus in fertilizer to 10% that of the nitrogen. On the other hand the proportion of TP to TN in the reclaimed water is much higher at nearly 50% the nitrogen load. Due to this character of the reclaimed water, phosphorus loadings from irrigation are more likely to be significant in the basins which use reclaimed water.

As explained previously, phosphorus concentrations in the east basin were significantly greater than in the west basin, however TN and IN were not significantly different between basins. Irrigation with reclaimed water is great in the east basin compared to the west basin. The terrestrial phosphorus load from reclaimed water was nearly 1000 kg/yr. in the east basin compared to only 33 kg/yr. in the west basin. At maximum fertilizer application rates the phosphorus load from reclaimed water irrigation in the east basin is about 30% of the total load. However, maximum fertilization rates likely overestimate the actual rates of fertilizer application greatly, and contributions from reclaimed water irrigation would be even more significant. The 30X greater application of reclaimed water to the East Slough Basin landscape compared to the west could be a major factor in significantly greater concentrations of P found in that basin. It would also affect the N:P ratio, decreasing it relative to the west basin (as is seen in the data).

Available data from lakes on the Dunes and Sanctuary golf course show mean TP levels in those lakes are comparable or greater than levels in the East Slough Basin (Table 13). Like the east basin, these golf courses (and their basins) have relatively high reclaimed irrigation water usage. This is another indicator that the use of reclaimed water can significantly affect levels of P in areas where it is used.

Monitoring of the Dunes lakes over the course of BMP implementation has indicated the a change in the lakes from a predominantly P- limited environment (N:P above 13.5) to co-limitation or N-limitation (SCCF 2013). The implementation of BMPs has resulted in a decrease in runoff-based IN while the rate of irrigation with OP-laden reclaimed water has remained constant. This would lead to a decrease in the IN:OP ratio and a shift towards co- or N-limitation. The decreasing trend in IN and the increasing trend in OP in the East Slough Basin may be due to a similar set of circumstances.

Additional support for the idea that reclaimed water contributes significant loadings to basin waterbodies comes from the estuarine monitoring data. The two basins which have significant reclaimed water usage and discharge to the estuary (Ladyfinger Lakes and Sanibel Bayous) have the highest mean concentrations of TP and OP in the estuarine basins (Table 14). They also contain golf courses which are sources of fertilizer and the greatest users of reclaimed water. Evaluation of the N:P ratio along a gradient from upper Sanibel Bayous Basin to the Gulf illustrates the level of P verses N is greater (lower N:P) the higher you are into the basin. It can be concluded that the use of reclaimed water for irrigation at present levels has a significant impact on the nutrient dynamics of Sanibel's freshwater and estuarine waterbodies. The inorganic phosphorus loads in reclaimed water are the main source of P to lands and waterbodies in the Ladyfinger Lakes Basin and may also be the most significant source in the beach, Sanibel Bayous and Sanibel Slough eastern basins.

Nutrient load from reclaimed and IWA water used for irrigation can take several routes to contribute loadings to waterbodies. The most direct route is through surface runoff which occurs when irrigation water is sprayed directly on impervious surfaces or waterbodies – usually due to faulty installation and maintenance (overspray). If only 2% of the reclaimed water applied runs off directly to a waterbody, in some Sanibel basins this may represent over 10% of the total estimated P loading. A second route is through leaching into the surficial aquifer and then transport to surface waterbodies or to the gulf or estuary. The proportion of applied nutrient loading which is transported by groundwater to surface water depends on many factors including soil and vegetation types, antecedent moisture condition and head pressure. In general, well vegetated surfaces which are not submerged will take up most of the nutrient loading applied (Wanielista and Hulstien 2006). Overflows or spills from storage tanks, and leaching from storage ponds can also contribute to nutrient loading.

Residents and golf course managers should be aware that for every 1000 gallons of reclaimed water used for irrigation, 0.044 pounds of readily available inorganic N and 0.018 pounds of inorganic P are being applied. In the future golf course managers and commercial fertilizer applicators should take this in to account and adjust their application of fertilizer downward.

BMPS which will reduce loadings attributable to use of reclaimed and IWA water for irrigation include: maintaining complete vegetated surface wherever irrigation is applied, assuring no water is applied to impervious surfaces (nozzle adjustment and maintenance); reduction of irrigation when antecedent moisture conditions are high; reduction of other fertilizer use when using reclaimed water (0.044 lbs.N/1000 gallons; 0.018 lbs.P/1000 gallon); and prevention of spills, leaks or leaching from reclaimed water storage facilities.

To accurately assess the contribution of Sanibel's watershed to nutrient loadings in the freshwater, estuary and gulf coast ecosystems we must determine the nutrient inputs into each basin, the assimilative capacities within each basin and the loadings from each basin to the associated waterbody. The more complete our nutrient mass balance around Sanibel is, the more potential we have for identifying where nutrient management practices will be most effective and how we successfully implement practices.

Runoff coefficients used in this study were derived from other studies undertaken in SW Florida. These are good for initial estimates presented in this work, however there is a need to develop land use specific runoff coefficients specifically for Sanibel. With 38 inches of rainfall each year, small differences in runoff coefficients can result in very large differences in loadings estimates. It is essential that loading estimates are as accurate as possible to be able to efficiently identify and manage problem areas and estimate reductions needed to meet loading goals. Tools in the ArcHydro GIS extension allow basin specific coefficients to be developed relatively easily (1 wk.).

The same situation exists when using nutrient concentration data derived from other areas of Florida and not specific to Sanibel. Sanibel is unique amongst other areas of Florida in that it is largely an affluent community with most landscaping done by professionals who take pride in assuring "green" landscapes with less consideration of cost or consequence. Fortunately, the City has implemented BMP's associated with the fertilizer ordinance and native vegetation requirements which attempt to reduce potential detrimental impacts to surrounding natural systems from over-zealous lawnscapers. There is very little runoff monitoring data available for Sanibel's different land use types. What little data is available suggest nutrient runoff concentrations differ from the SW Florida data used here and also vary greatly between basins and land use types. It is suggested that the City initiate a one-time study of nutrient runoff concentrations from Sanibel's major land use types. Wet and dry season samples from low, medium and high density residential land uses as well as commercial types should be collected from 3 or 4 different basins (east slough, west slough, Ladyfinger Lakes and Sanibel Bayous basins). Approximately 80 samples analyzed for inorganic and total N and P would be required.

Use of the maximum allowable fertilization rate (by ordinance) to estimate nutrient loads almost certainly overestimates the loads presented in this analysis. With no data available to more accurately estimate actual loadings, this analysis gives us a starting point from which to refine our knowledge. The Sanibel fertilizer ordinance (City of Sanibel 2013) states that a city licensed fertilizer applicator must maintain a record of all nitrogen applications (lbs. N/1000 ft^2) for each property treated and allow City staff to obtain a sample of fertilizer to be analyzed for nitrogen/phosphorus content. It is highly recommended that this data be collected from at least 3 different applicators. We also recommend the data be collected from different basins which have different major land use types and discharge to different waterbodies. For example, application rates may be very different in the West Slough Basin than the East Basin due to smaller lot sizes and differences in predominant landscape vegetation. Fertilizer application data collected from the Ladyfinger Lakes and Sanibel Bayous basins would also be recommended.

There are a variety of nutrient loading models used by agencies in assessing and predicting assimilative capacities of waterbodies and terrestrial systems. Florida DEP uses the watershed assessment program (WASP) in conjunction with other loadings prediction models to develop estimates for total maximum daily loads for waterbodies deemed as impaired. Application of the WASP or similar model to Sanibel's basins and waterbodies would be helpful in estimating what reductions are needed to bring the Sanibel Slough into compliance (lower the TSI score below 60 or reduce nutrient concentrations and chlorophyll a to state criteria levels). The WASP model analysis can be run using current Sanibel Slough nutrient and water quality data to estimate needed nutrient loading reductions.

Releases from Sanibel Slough through the Tarpon Bay and Beach Rd. weirs can add significant loads to the estuary. Available records show a decreasing trend in discharges at the Beach Rd. weir with no recorded discharges in 2011 and 2012 (Figure 23). However discharges from 2002 through 2005 were very common, peaking at over 200 days of annual discharge. Records for the Tarpon Bay weir are scarce and no data was available after 2008. The only recorded discharges for Tarpon Bay weir were 20 days in 2004, 48 in 2005 and 3 in 2006 (Figure 23). With no record of discharge depth over the weirs it is impossible to estimate discharge volume during release events. In the future the City should maintain a daily record of discharge depth over each weir whenever discharges are occurring. From this information rough estimates can be made of discharge volume and from that, nutrients loads can be calculated. We provide an easy reference for mangers: for every inch of water released from the Beach Rd. structure (gage), at least 18.9 lbs N and 1.6 lbs P are discharged to the estuary; for every inch released from the Tarpon Bay Rd. weir, a minimum of 24.8 lbs N and 1.1 lbs. P are discharged (Table 28) .

Conclusions and Recommendations

GIS spatial analyses of regional water quality data showed Sanibel as a possible source of inorganic nitrogen and phosphorus plumes to Tarpon Bay and San Carlos Bay in the wet season. Analysis of water quality monitoring data revealed Sanibel Slough to have levels of nitrogen and phosphorus between the 70^{th} and 90^{th} percentile of Florida Lakes, while exceeding state numeric nutrient criteria for both TN and TP. The TSI scores for both east and west basin were well above the impaired waters score of 60. By all Florida state criteria, Sanibel Slough is properly listed as an impaired waterbody due to nutrient enrichment.

Statistical analysis shows strong evidence that the implementation of the fertilizer ordinance has been successful at lowering inorganic nitrogen loads in Sanibel Slough. We did not test for the effects of the City's vegetation requirements or stormwater retention requirements but suspect these efforts have also contributed to reduced levels of nutrients in Sanibel Slough. Though much of the island-wide sanitary sewer installation occurred before the beginning of the NPDES monitoring program, we suspect that the conversion to sanitary sewer improved water quality offering consistently good wastewater treatment and disposal. Current nutrient levels in the east basin are generally lower now than during a water quality study in 1976. The west basin also showed decreased levels of TN since 1976. The city should be commended for its efforts to date and should take note that these efforts have had measurable positive results.

The rabbit road site in the west basin had significantly greater IN than other sites. Overall the west basin does not seem to be having as much success in nitrogen reduction as the east basin. The area near Rabbit Road should be targeted for better nitrogen-based fertilizer runoff prevention and surveyed for unknown inorganic nitrogen sources.

Residential fertilizer application was estimated to be the largest single source of N and P to landscapes on Sanibel, though reclaimed water and golf course fertilizer application had comparable values in some basins. BMP's directed at reducing residential fertilization, reducing nutrient runoff from residential lands and reducing the volume of stormwater runs off will be the most effective tool in reducing loadings from Sanibel. The City's efforts to date have been substantial and have produced positive results. These efforts should be continued and compliance by residents maximized to realize continuing improvements.

The basins with the highest mean P levels (and lowest N:P ratios) were also the basins in which reclaimed water is used for irrigation. The P level in reclaimed water is greater relative to levels in other sources of nutrient loadings. The east basin of Sanibel Slough had higher levels of phosphorus than the west basin. Its eastern-most sites are typically higher in nutrients and are also closer to the Donax WWTP. The basin has large inputs of nitrogen and phosphorus from three major sources; residential landscape fertilization, golf course fertilization and use of reclaimed water. Higher relative levels of P in this basin may be associated with reclaimed water use for irrigation, release of phosphorus from waterbody sediments, or possible legacy nutrients from historical problems with the operation of the Beachview-Jamestown WWTP. This basin should be targeted for BMP's due to its concentration of urban land use types, size discharges to San Carlos Bay and nearshore water quality data indicating this area of Sanibel is a source of inorganic nutrients.

Other basins (besides the east basin of the Sanibel Slough) to be prioritized for increased implementation of BMPs include the East Canals Basin, Sanibel Bayous Basin, the Beach Basin and the West Sanibel Slough Basin. Due to their size or high proportion of urban land, these basins are the major contributors to nutrient loads from Sanibel.

Reclaimed water use in landscape irrigation has been shown to be a significant contributor to nutrient loads in the basins it is used. A high priority should be given to assure that direct runoff from use of reclaimed water is not occurring due to poor system maintenance, improper nozzle aim and improper use. Some initial inspection of all irrigation systems using reclaimed water should be made by City representatives, to assure initial system setup eliminates the possibility of runoff or direct spraying into waterbodies or conveyances. Those using reclaimed water should be contacted and educated to the importance of reducing potential runoff from their systems. Any reported problems should be investigated by proper personnel.

All users of reclaimed water should be aware of its value as a fertilizer on its own and reduce concurrent fertilization according to the amount of reclaimed water nutrient load applied. For every 1000 gallons of reclaimed water used, 0.044 lbs. N and 0.018 lbs. P are applied to the irrigated surface. Golf courses managers should be educated to this fact and should include this information in their calculated needs for fertilizer. Records submitted to the City Natural Resources Department should reflect these calculations

Nutrient saturation analyses performed on data from Sanibel Sough indicate a 30% reduction of TP in the water column will be necessary to control phytoplankton blooms in the Slough. A 30% reduction in TP concentrations should be set as a target to improve water quality. Obvious targets are elimination of P from fertilizer application and strict control of reclaimed water runoff. In addition, reduction of the P concentration within reclaim water may be considered, although this would certainly involve significant process upgrades at the City's Donax WWTP.

The data collected and analyzed in this study, may be modeled further employing different nutrient loading scenarios of nutrient loading scenarios using the watershed assessment program model (WASP). WASP will provide additional estimates of nutrient reductions needed to provide a specific outcome. For the nutrient-impaired Sanibel Slough, targets used in the model would include water quality criteria values for nitrogen and phosphorus plus reductions in chlorophyll *a* to produce mean TSI scores below 60. For use with this model some additional monitoring may be necessary such as CBOD and SOD analyses.

The NPDES surface water monitoring program of the City of Sanibel provides adequate data to coarsely evaluate the water quality status of Sanibel. However several needs were identified when evaluating the data for this project. First, monitoring is needed to provide a characterization of nutrient conditions in the nearshore Gulf waters. The Gulf side data will allow a more complete analysis of local and regional impacts on the Gulf waters. Second, a small groundwater quality study should be initiated. The shallow freshwater lens of Sanibel may regularly discharge nutrient loads to the Gulf during wet season, and nearshore surface water monitoring coupled with groundwater monitoring will help evaluate this component of Sanibel's impact.

The shallow groundwater aquifer on Sanibel (also known as a freshwater lens) has been previously studied and reported to discharge to the Gulf and Pine Island Sound (Provost 1953; Boggess 1974; Missimer 1976; Missimer 1989 Johnson Engineering 1990). Due to its connection between surface water features such as the Sanibel Slough, localized elevated levels of nutrients can be expected in the aquifer. A shallow aquifer study should be undertaken to determine mean inorganic and total nutrient concentrations during wet and dry season along with estimates of loadings from the groundwater system to nearshore waters. Information from previous studies can be used to develop estimated discharge rates.

Our results suggest that the City's NPDES monitoring results for chlorophyll *a* before the change of laboratories in March 2006 should not be used in comparisons with data after the contracted laboratory change. It is suggested that chlorophyll a data be qualified from 2002 until the lab contractor change in 2006.

Sanibel specific runoff coefficients and nutrient concentration values should be developed to provide a more accurate estimate of loadings to Sanibel Slough and the nearshore waters of Sanibel. With Sanibel's unique combination of highly maintained residential landscapes and progressive environmental protection ordinances, runoff from its urban land scape will likely differ significantly from the best available values used in this analysis.

Realistic estimates of fertilizer application to land use types are needed to better determine nutrient loads being applied in each watershed basin. As discussed, the records required of commercial applicators by the Sanibel fertilizer ordinance should be collected and analyzed to develop an accurate nutrient loading estimate to Sanibel urban land types. This will allow us to be more efficient in directing BMP efforts.

Annual discharge volumes from the Beach Rd. Weir and Tarpon Bay weir must be estimated. We recommend at least weekly monitoring of gage level behind both discharge weirs for Sanibel Slough with accurate recordkeeping and notes of discharge. When overflow discharges occur, depth of discharge over the weir crest should be recorded to allow rough estimates of discharge rates. During discharges, levels should be recorded daily. As an alternative, weir crest depth sensing and recording devices can be purchased and installed. A basin-specific discharge relationship should be developed to allow estimation of discharges when gates are open. We have estimated volume of water released and mass of N and P discharged per inch of drawdown for each basin (Table 28). The proper city personnel should be made aware of this information and use it to better manage discharge decisions. To make discharge monitoring more efficient, real time flow sensing systems can be installed on the two discharge weirs. These systems would allow the discharge to be monitored remotely providing more accurate records.

Data from lakes on the island can provide valuable information on loadings and effects of BMPs in specific residential areas, since most lakes on Sanibel are part of a stormwater retention system. We recommend additional effort be made in collecting existing nutrient data for Sanibel lakes from Florida Lake Watch participants and others. We also recommend that all 3 golf courses maintain a minimal lake nutrient monitoring program sampling at least the most downstream lake in their systems for nutrients in wet and dry season. Samples should be analyzed for inorganic and total N and P. Currently the Dunes meets these nutrient monitoring recommendations. The Sanctuary also has a good record of lake monitoring; however we recommend that they change their monitoring slightly by adding orthophosphate, ammonia and NOx to their analyte list and deleting the separate nitrate and nitrite analyses. Additionally, exceptionally high TP concentrations reported in the Sanctuary lakes should be investigated. They are almost a magnitude higher than other available data for Sanibel lakes and Sanibel Slough. No known monitoring occurs at the Beachview stormwater system.

It would be advisable to maintain records of lake system discharges for all three Sanibel golf courses. The Sanctuary and Dunes golf courses lake systems discharge to the protected estuaries of Wulfert Flats and Tarpon Bay respectively. The Beachview golf course flows into Sanibel Slough, which is listed by the state as impaired due to elevated nutrient levels. A rough estimate of discharge volume can be developed for each discharge point by measuring depth of flow over weir and developing hydrographs for the lakes which show change in lake volume per inch of rain. In this way estimates of discharge volume can be made by knowing rainfall amounts.

Discharge points for all stormwater systems (lakes, ponds, etc.) on Sanibel should be documented by Sanibel natural resources managers and those systems evaluated for possible significant impact to their receiving waters. Discharge and nutrient monitoring may or may not be needed depending in their size, and discharge frequency. Though most of these systems were originally designed and built to retain large storm events, over time the systems can become compromised and unanticipated discharge routes develop or control structures fall into disrepair. As an example, in 2012 and 2013 the stormwater system at the Dunes development has been overtopped by very high tides late in the dry season. These tides fill the stormwater system to capacity and then when the wet season begins, the system discharges continuously over the structure and to the protected Tarpon Bay estuary due to lack of holding capacity.

The basin boundaries developed for this project are a good rough estimate of watershed boundaries. However additional ground truthing is needed to improve the divisions between basins and provide more accurate loading distributions by basin. This would be a low priority recommendation compared to other needs suggested in this work.

Well vegetated, native landscapes which are not fertilized or irrigated should be maximized for every land use type in every basin of Sanibel. The City has taken great effort to realize this goal and should continue with this as a guide for the future. As we maximize well-vegetated native landscapes, we reduce runoff volume and nutrient concentrations. These in turn will decrease nutrient loads which cause impairment such as found in Sanibel Slough. Reduction of impervious surface area through replacement of sidewalks, pavement with vegetation or more pervious surfaces (pavers) is expensive but should be considered whenever opportunity arises. The City should consider minimizing the conversion of unpaved roadways, driveways and walkways to impervious pavements. Roof surface area should be minimized or “green” roves used when possible.

Management of stormwater ponds, lakes and the Sanibel Slough should minimize or eliminate use of herbicides, fertilizers, and algaecides and maximize manual removal of vegetation (nutrient sinks) from the systems. Techniques such as development of a vegetated littoral zone with submerged and emergent vegetation will act as a sink for legacy and incoming nutrients in these systems. Annual or semi-annual trimming and harvesting of the vegetation will also remove nutrients from the system (Boyd 1970). Studies have shown that where significant loading of N or P relative to the annual inputs (±50%) can removed from lakes in plant material, nutrient reductions within the water column are seen (Wile 1975). By allowing healthy vegetated littoral zone to develop, algae-grazing zooplankton will become more numerous and help control nuisance macroalgae and phytoplankton. Plants should be harvested at the end of wet season when their nutrient concentrations will be greatest (Boyd 1970; FAO 1979). Pilot studies performed by SCCF have shown the native freshwater SAV, *Vallisneria* to survive in littoral zones of slightly saline (3-6 PSU) stormwater lakes on Sanibel. Planting and nurturing the development of *Vallisneria* beds in the littoral zones of Sanibel’s inland waterbodies can help transform a phytoplankton based system to a more preferable macrophyte base system (Cronin et al. 2006; Bailey 2011).

The freshwater features of Sanibel contain invasive, exotic cichlid fish. These fish can add to management problems by overeating zooplankton, disturbing phosphorus-rich bottom sediments (Havens 2013; Jeppesen 1997; Vanni et al. 2006) and displacing native fish. Annual massive culling of these fish numbers will reduce nutrients within the system as well as improve zooplankton stocks. Fish can then be donated to the local wildlife hospital to provide needed food for their patients. We recommend periodic exotic fish removal as a BMP for Sanibel’s freshwater system.

Some of the stormwater systems and lakes on Sanibel were designed with steep slopes and little area available to develop a vegetated littoral zone. In absence of the needed littoral shelf, vegetated floating islands are recommended as a BMP alternative. These islands contain plant species which develop large root systems while floating in the waterbody. The roots systems and associated periphyton absorb nutrients from the water which are transformed into plant material which is then harvested annually through trimming. There are several of these installations in the area which are proving to be helpful in reducing macroalgae blooms (City of Naples 2013). These systems have also been used in WWTP effluent to help in nutrient removal and should be considered for use in the City's reclaimed water storage ponds.

There is evidence that the Sanibel Slough is a nutrient source for adjacent estuarine waters. Possible treatment of the nutrient-laden water within the slough may be feasible through the design of a filter marsh system utilizing existing marshes on preserve land or by creating a constructed wetland in existing disturbed land. The east basin is the prime candidate for constructing a filter marsh as it has higher potential for loading adjacent waterbodies. As an alternative to creating filter marsh area, floating vegetated island installations could accomplish much of the same objectives but at a higher long term cost. These installations have successfully reduced macroalgae blooms at installation sizes of 0.5% of waterbody surface area (or about 11,000 sq. ft. for the east basin).

Florida DEP will develop a total maximum daily load (TMDL) for the Sanibel Slough requiring the City to reduce nutrient loads. This project provides information on Sanibel's higher load areas and some possible sources. It also shows progress already made towards improving water quality due to proactive measures implemented to date by the City. Developing additional methods of controlling nutrient loads based on focused and efficient monitoring should further improve conditions in the local waterbodies.

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