Sanibel Nutrient Management Plan Phase 2:

Development of Stormwater Runoff Coefficients, Nutrient Concentrations and Loading Estimates for Sanibel Island, Florida

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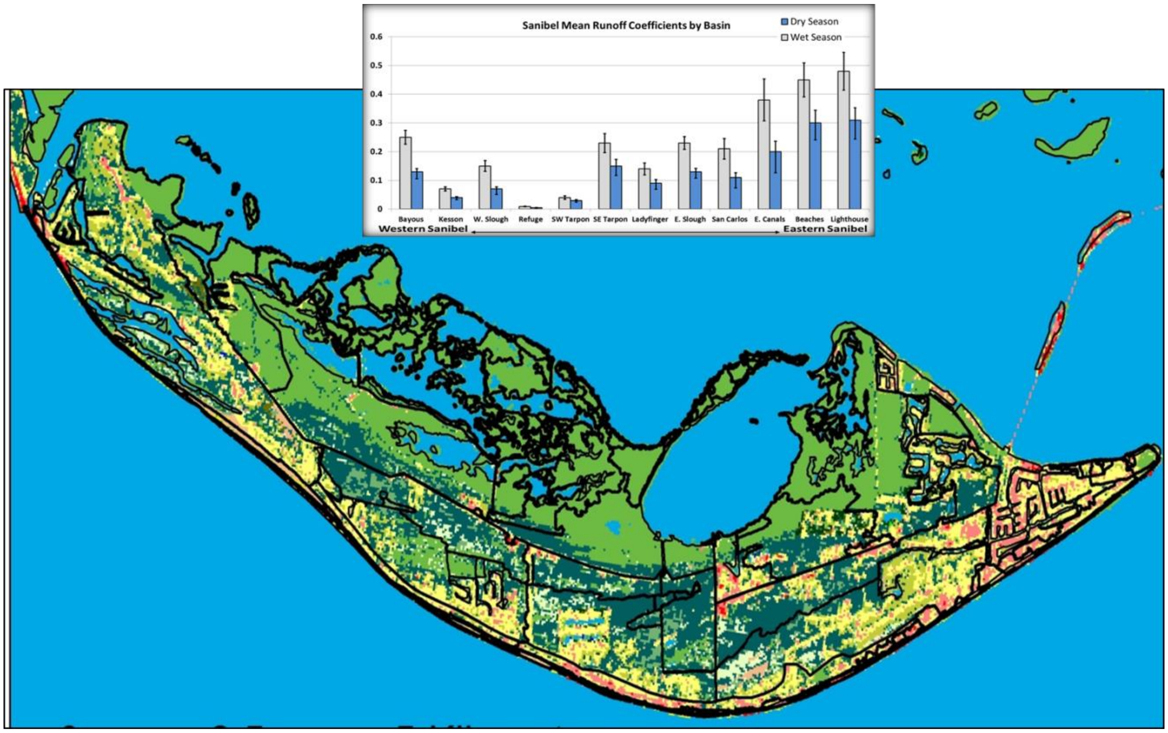

Executive Summary

The City of Sanibel's Department of Natural Resources is developing a Comprehensive Nutrient Management Plan in four phases. Phase 1 was completed in November 2013. That initial work summarized and evaluated existing water quality data, identified watershed basins and land uses, and provided nutrient loading estimates to land surfaces and waterbodies by basin. These initial loading estimates were based upon best literature-based runoff coefficients and nutrient concentrations for Florida.

Phase 1 of the Comprehensive Nutrient Management Plan identified a number of data insufficiencies. One of the most important needs was the accurate determination of stormwater runoff volumes and concentrations for the land use types contributing nutrient loads to Sanibel's waters.

This report summarizes Phase 2 work, including the GIS-based development of stormwater runoff coefficients and collection of rain event nutrient samples in order to define Sanibel-specific runoff concentrations. New coefficients and concentrations are now available for the major land classes to address data deficiencies identified in Phase 1. With these Sanibel-specific coefficients and concentrations, accurate nutrient load estimates can be made. Nutrient loading rates were calculated and presented by land class and drainage basin.

Impervious surface area of each anthropogenic land class on Sanibel was determined using ARC GIS 10 tools. The Florida DEP-modified SCS curve number method was used with the impervious surface information to derive land class and basin specific stormwater runoff coefficients which are the amount of rainfall which actually runs off Sanibel's surface (and into adjacent waterbodies) divided by the total amount of rainfall.

The Sanibel-specific runoff coefficients developed in this effort changed the estimated annual stormwater runoff from Sanibel by 24% over Phase 1 from 7,464,000 m^3/yr. to 5, 609,000 m^3/yr. The more accurate runoff volumes obtained from these new coefficients reduced the total nutrient loading estimates from Sanibel considerably.

Local stormwater nutrient concentration values were also needed to more accurately represent loads from Sanibel. Stormwater runoff was sampled from different land classes during dry and wet seasons. Mean nutrient concentrations were found for each land class for total nitrogen (TN), total phosphorus (TP), inorganic nitrogen (IN) and inorganic phosphorus (OP). The Sanibel-specific stormwater nutrient concentrations for TN, IN and TP were generally lower than best literature values used in Phase 1. New estimated TN loads using concentration data developed here were 55% lower than phase 1 estimates (12, 659 kg/yr. to 5655 kg/yr.) and TP loads 33% lower than previous estimates (2, 431 kg/yr. to 1,631 kg/yr.). In contrast, stormwater

OP concentrations were significantly greater than Phase 1 estimates and corresponding estimated loads were 28% greater than Phase 1 best estimates (778 kg/yr. to 997 kg/yr.).

The TN loading rate for Sanibel (3.1 kg/ha.-yr.) was much lower compared to rates in the Caloosahatchee (8.1 kg/ha.-yr.) and Saint Lucie Estuary (SLE; 6.4 kg/ha.-yr.) watersheds. However Sanibel's TP loading rate (0.9 kg/ha.-yr.) was similar to the Caloosahatchee (0.9 kg/ha.-yr.) and SLE (1.3 kg/ha.-yr.). The Caloosahatchee and SLE watersheds have large areas of intense agriculture and urban development and their nutrient loading rates might be expected to be significantly greater than Sanibel where about 65% of the island area is nature preserve with no agriculture and only moderate urbanization. The comparably high TP loading rate on Sanibel indicates that Sanibel has significant sources of phosphorus runoff. The direct runoff of reclaimed wastewater used for irrigation is the most probable source of this phosphorus. Efforts should be made to eliminate any direct discharges or leaks of reclaimed water into waterbodies (such as sprinkler heads flowing into stormwater ponds or estuary waters).

The highest nutrient concentrations in stormwater runoff were at the island's three golf courses. The golf courses had similar nutrient loading characteristics and were found to be the single largest source of OP loads (35%) from the island even though they make up less than 9 percent of the island's area. Golf courses are the largest reclaim water users on the island based on metered water use. Reclaimed water used for irrigation is relatively high in inorganic phosphorus compared to nitrogen. Inorganic phosphorus and nitrogen are responsible for algae blooms. Runoff sampling sites which used reclaim water for irrigation had significantly greater OP concentrations than sites without reclaimed water use.

The medium density residential land class had the greatest loads of TN, TP and IN. This is due to large land area covered by medium density residential and relatively greater runoff coefficients than low density residential. Our recommendation is to implement BMPs at golf courses and medium density residential lands to further reduce nutrient loadings.

The Sanibel Slough east basin had the highest overall nutrient loads, contributing from 18-22% of the total load leaving Sanibel. Phosphorus loads from the east basin were 2 to 3 times greater than loading rates in the west basin. This corresponds to significantly greater TP and OP concentrations found in the east basin surface water during Phase 1 evaluation. Nitrogen loading rates were also greater in the east basin compared to the west. The east basin has a greater area of medium density residential land class and has one golf course while the west basin has no golf course.

Total nitrogen concentrations in stormwater runoff were found to be significantly greater in the dry season when fertilizer application is allowed on Sanibel. However no greater concentration of inorganic nitrogen, total phosphorus or inorganic phosphorus was found in the dry season as might be expected due to fertilizer application. This finding may reflect success of existing City of Sanibel BMPs (i.e. fertilizer ordinance) at reducing the runoff of fertilizer even when use is allowed.

The Sanibel Slough and the many stormwater retention systems (lakes and ponds) on Sanibel are intimately connected to the upper water table aquifer. Groundwater flows to lakes, ponds, the slough, the gulf and the estuary. Nutrient loads are carried with this groundwater flow and loading rates to surface waters may be significant compared to stormwater loads. Phase 3 of developing the Comprehensive Nutrient Management Plan for the City will evaluate groundwater nutrient concentrations and flow rates.

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Introduction

The City of Sanibel has been successful in implementing strategies to improve the environment and to sustain natural resources that support the nature and tourism-based economy of the island. Examples include implementation of the Sanibel Plan, the installation of island-wide sanitary sewer, the acquisition of conservation lands, adoption of a fertilizer ordinance, the enforcement of vegetation standards, and 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 throughout the island since 2002. And, as part of its diligence in continuing to reduce nutrient loads from the island, the City has a prioritized a long list of possible new BMPs including installation of a nitrogen bioreactor in the Sanibel Slough, the design of a filtering marsh for the slough, and flow monitoring for major stormwater discharge locations.

Barrier islands are surrounded by salt water and often have a freshwater lens or surficial aquifer which contains lower salinity water. Sanibel Island is a barrier island that contains an inland body of freshwater, commonly called the Sanibel River or Sanibel Slough. This waterbody was originally a series of swampy lakes and wetlands which were connected by channelization to control the mosquito population. Historically, the slough discharged to the Gulf of Mexico at two locations where breaches in the dune system occurred during the times of high water levels in the wet season. Today the Sanibel Slough is managed as two basins (east and west) separated by a control structure at Tarpon Bay Road (N26.42752, W82.08021). The western basin has a control structure located north of Sanibel Captiva Rd. (N26.43879, W82.088) which discharges to Tarpon Bay and into waters managed by the J.N. “Ding” Darling National Wildlife Refuge. The eastern basin has a control structure located on Beach Rd. (N26.44311, W82.03989) which allows discharges into the eastern residential canal system. Discharges from the western basin control structure are rare, while the eastern basin control structure can discharge continuously during the wet season. Decreasing trends in certain nutrient concentrations within the Sanibel Slough indicate that the City of Sanibel’s actions taken to date have had positive impacts, however the slough remains classified as impaired by Florida DEP due to elevated nitrogen, phosphorus and chlorophyll *a* levels (FDEP 2014).

To address the Sanibel Slough impairment, a Comprehensive Nutrient Management Plan is being developed by the City’s Natural Resources Department and includes a list of short and long-term projects and best management practices (BMPs) to systematically reduce stormwater runoff and nutrient pollution to the Sanibel Slough and nearshore waters. The City has laid out development of a Comprehensive Nutrient Management Plan in four phases. Phase 1 was completed in November 2013, which summarized and evaluated existing water quality data, identified watershed basins and land uses, and provided nutrient loading estimates to land surfaces and waterbodies by basin (Thompson and Milbrandt 2013).

Phase 1 of the Comprehensive Nutrient Management Plan identified several key data gaps. One of the most important information needs was the accurate determination of stormwater runoff volumes and concentrations for the land use types contributing nutrient loads to Sanibel's waters. Development of Sanibel-specific stormwater runoff coefficients and nutrient concentrations permits calculation of actual loading rates and are not dependent on best information available in scientific literature. The City of Sanibel contracted the SCCF Marine Laboratory to develop runoff coefficients and concentrations as Phase 2 of its Comprehensive Nutrient Management Plan implementation. In this Phase 2 report, the Sanibel-specific coefficients are presented and explained and are combined with results of stormwater runoff sampling (nutrient concentrations) to provide refined nutrient loading estimates. Activities in subsequent phases will include flow monitoring of the Sanibel Slough, groundwater nutrient loading estimates, and development of a list of projects which accomplish nutrient load reduction.

Phase 2 of the Sanibel Comprehensive Nutrient Management Plan is composed of three parts. The first component is development of Sanibel-specific stormwater runoff coefficients to allow more accurate estimates of stormwater runoff volumes for the basins and land classes found on Sanibel. The second component consists of storm event sampling and sample analyses to determine mean nutrient concentrations for each major land class and basin. The third component consists of combining runoff data with concentration data and producing revised nutrient loading estimates for Sanibel.

Methods

Sanibel-Specific Stormwater Runoff Coefficients

Twelve watershed basins were previously delineated for Sanibel Island (Thompson and Milbrandt 2013). Within these basins, land use classes were identified using South Florida Water Management District (SFWMD) FLUCCS Level 2 classifications and areal coverage for each class calculated using ARCGIS 10® capabilities (Thompson and Milbrandt 2013). A majority of the land use was low, medium and high density residential with commercial and institutional uses representing the balance of the anthropogenic classes. For this analysis, wetlands, forested wetlands, lakes, streams and other waterbodies were considered to be down-gradient receiving waterbodies of anthropogenically-affected stormwater runoff. A stormwater runoff coefficient of zero was used for these classes and pollutant concentrations were not associated with them (nutrient load assumed to zero since these are receiving waterbodies). Anthropogenically affected land classes analyzed for nutrient loadings included, low, medium and high density residential, commercial, institutional, golf courses, beaches, parks, utilities, brush land, and disturbed lands. These land classes were assigned runoff coefficients and nutrient concentrations. To estimate the percent of impervious surface area for each land class, ARCGIS 10® was used on subsamples of each land use class within each watershed basin. At least 20% of the total impervious area of each class was directly digitized and the area determined (Tables 1-6). Impervious surfaces were classified as buildings or pavement. Buildings included swimming pools and tennis courts. Pavement included roads, driveways and sidewalks. These surfaces were considered to be 100% impervious regardless of construction (shell and gravel surfaces considered 100% impervious). Impervious area was reported in table form by land use class and basin (Tables 1-6).

For comparison purposes the proportion of impervious surface on Sanibel was also estimated using the US Forest Service iTree® Canopy analysis tool (USDA 2014). Using this method, random points are analyzed for land class type within a boundary area on Google Earth maps. A shapefile of Sanibel containing 10,062 acres was analyzed using 400 randomly generated points which were categorized in one of 15 classes. A standard error of less than ±2% was achieved for all 15 land types. The roadways and buildings land classes were added together to derive the total percent impervious surface on Sanibel.

The Soil Conservation Service (SCS) curve number (CN) method was used to develop runoff coefficients from impervious cover data following guidelines used by Florida DEP in estimating runoff volumes for nutrient loading (Harper and Baker 2007). In this method impervious surface coverage, soil characteristics, vegetation and rainfall data are combined to provide runoff volume estimates. Estimating the total volume of storm runoff from a watershed using the SCS CN method requires calculation of three components of runoff: 1.) runoff from directly connected impervious areas (DCIA); 2.) runoff from non-directly connected impervious areas (nDCIA) and; 3.) runoff from pervious surface area.

The SCS curve number methodology utilizes separate calculations for runoff volume generated from DCIA and nDCIA areas. An impervious area is considered to be directly connected if runoff from the area flows directly into a drainage system or water body. Areas are also considered to be directly connected if runoff from the area occurs as a concentrated shallow flow that is conveyed through a pervious area, such as a roadside swale, and then into a drainage system. The method assumes that after allotting for some initial retention, all rainfall which occurs on directly connected impervious areas becomes stormwater runoff.

Non-directly connected impervious areas (nDCIA) include all impervious areas which are not considered to be directly connected. The SCS model assumes that runoff generated in these areas has the opportunity to infiltrate into the soil, depending upon the soil types and land cover characteristics, before significant runoff begins. The runoff-generating characteristics of nDCIA areas are quantified through the use of a curve number. A curve number is a hydrologic factor which is used to reflect the runoff potential of a particular land use and soil type. Theoretical values for curve numbers range from 0-100, with low values reflecting low runoff potential and higher values reflecting high runoff potential. Using the SCS method modified by Florida DEP, curve numbers were developed specifically for Sanibel land use classes and watershed basins.

The following equation from Natural Resources Conservation Service Technical Release TR 55 was used to calculate Sanibel-specific curve numbers (USDA 1986):

$$CN = [(CN_{OS}) \times (1 - ISC_i)] + [(98) \times (ISC_i)]$$

Where*:*

CN_{OS}= the runoff potential of the soil assuming the area is open space (OS), in good hydrologic condition, and that the soil is not frozen; the CN_{OS} for HSGs A, B, C, and D are 39, 61, 74, and 80, respectively (National Engineering Handbook, 2004),

ISC = the percent of land use category (*i)* that is impervious,

1-ISC = the percent of land use category (*i)* that is pervious,

98 = maximum potential runoff.

Per NRCS soil maps, Sanibel soil types were assumed to be hydrologic soil group (HSG) B/D, meaning that in dry season the HSG is B with good drainage characteristics (> 0.3”/hour) while in wet season, the HSG is D and drainage is compromised by a high water table and is less than 0.05 inches/hr. For the purpose of HSG classification, soils were grouped as B from October 15th through July 1st and classified as D from July 1st through October 15th.

Maximum potential stormwater retention (S) by the soil is calculated using the equation: $\mathbf{S = (1000/CN) - 10}$. Runoff volume is then estimated with the equation: $\mathbf{Q= (P - 0.2S)^2/ (P + 0.8S)}$**,** where Q is depth of runoff in inches and P is precipitation in inches. To produce runoff, P must be greater than 0.2S. If P is less than or equal to 0.2S, then the runoff amount is essentially zero. When P is greater than 0.2S, multiplying the Q value by the area of the site gives the volume of runoff produced.

The DCIA portion is calculated using $\mathbf{Q = P - 0.1}$**,** When precipitation is less than 0.1 inches, Q DCIA is zero. This factor represents the initial retention of the rainwater within irregularities in the impervious surface. For determination of percent DCIA and percent nDCIAs, the Florida DEP estimates of percent DCIA (Table 7a) was modified to take in account Sanibel’s 1989 ordinance requiring stormwater retention on all building sites (Sanibel Code Sec. 118). For each watershed basin, all development after 1989 was designated to have 0percent DCIA. For all land developed before 1989, the DEP values for estimated percent DCIA were used. The percent impervious area determined through GIS delineation for each basin and land use is then divided into percent DCIA and percent nDCIA using the modified DEP estimates of percent DCIA based on percentage of land developed before 1989 (Table 7b).

To calculate runoff from pervious areas in each basin, the percent pervious surface area for each land use in each basin was obtained by subtracting the delineated percent impervious area determined through GIS analyses from the total area for that land use. A pervious area curve number was then determined for each land use class using the FDEP guidelines (Table 8a). Runoff volume was estimated using the curve number formulas with local precipitation data.

Soil moisture condition (antecedent moisture condition) at the time of a rain event can have significant impact on the runoff generated (FDEP 2007). Following Florida DEP methodology, adjustments were made to the curve numbers when the antecedent 5-day rainfall was greater than 1.1 inches in the dry season or 2.1 inches in the wet season. Modified curve numbers (Table 8b) were calculated for these conditions (antecedent moisture condition III) using this equation:

$$CN(III) = 23CN/(10+0.13CN)$$

The equation produces greater runoff estimates for moist conditions than periods with less antecedent soil moisture.

Using the methods summarized above, runoff coefficients were calculated (per land class and basin) for rainfall data from 2011, 2012 and 2013.These three years had rainfall totals similar to the annual average for Sanibel (42 inches), however the distribution and abundance of rain events differed between years. All 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. Mean runoff coefficients for Sanibel were calculated from values obtained from utilizing these three years of data.

Sanibel-Specific Stormwater Runoff Nutrient Concentrations

Water samples were collected from the following land use types; 1.) low density residential; 2.) medium density residential; 3.) high density residential; 4.) commercial and: 5.) golf courses. A total of 102 water samples were collected over the course of the study period (12 months). Sampling events were divided among land use types in similar proportion as relative area of that land use on Sanibel (Table 9). A total of 31percent of the stormwater runoff samples (n=32) were taken from medium density residential, 24% (24 samples) from low density residential, 21% (n=21) from high density residential, and 9% (n=10) from commercial land types. An additional 15% (n=15) were obtained from the three golf courses on Sanibel. For each land use type, 3 permanent sites and an additional number of randomly selected sites were sampled to allow analyses of inter- and intra-site variance (Table 9). A total of 57 unique sites were sampled during Phase 2 (Figure 1, Table 10).

Table 9. Sampling event information for development of runoff concentration values.

Sampling Event	Date	Season	Precipitaion (In)	Total Number Samples	Number Permanent Sites	Number Random Sites	Number LowDen	Number MedDen	Number HighDen	Number Comrcl	Number Golf Course
1	1/30/2014	Dry	1.5	20	12	8	6	6	5	3	0
2	3/6/2014	Dry	0.65	20	15	5	5	6	3	3	3
3	7/7/2014	Dry	0.4	12	7	5	3	3	3	0	3
4	7/15/2014	Wet	1.1	20	13	7	4	8	4	1	3
5	9/2/2014	Wet	0.59	9	3	6	2	3	1	0	3
6	9/17/2014	Wet	0.5	21	12	9	4	6	5	3	3
Total				**102**	**62**	**40**	**24**	**32**	**21**	**10**	**15**

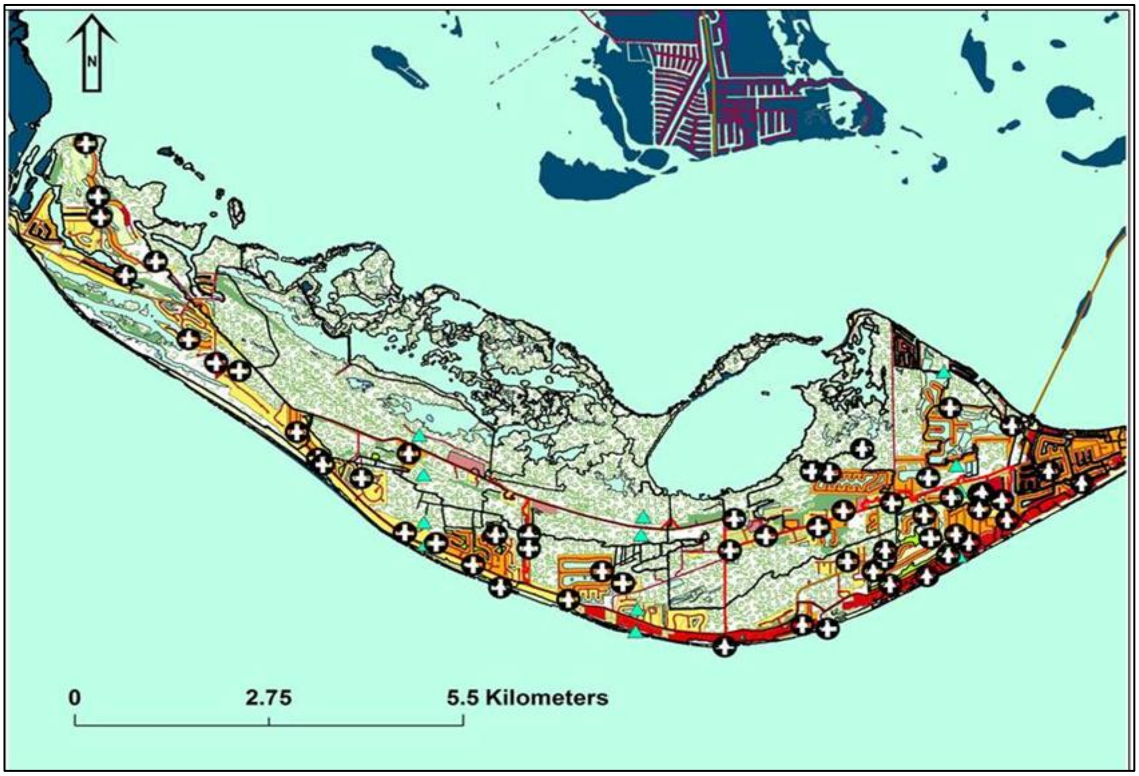

Figure 1. Stormwater sampling sites used to estimate nutrient concentrations for Sanibel land classes.

Additional factors included in the sampling design were seasonality (wet versus dry), fertilizer application season, and size of rain event. Since fertilizer application season corresponds with dry season, these two factors were considered as one. Fifty two (51%) samples were taken during the fertilizer application (dry) season and 50 during the no fertilizer application (wet) season (Table 9). For each season (wet/dry), 3 sampling events were captured. Sampling events were scheduled based upon two precipitation classes; 1.) 0.4-1 inches (2 events each season) or 2.) greater than 1 inch (1 event each season). The effect of reclaimed water use or non-use within a basin was analyzed post-hoc.

In addition to the water sampling described above, three fixed beach sampling stations were established in the Gulf of Mexico adjacent to Sanibel Island at Beach Access One, Tarpon Bay Rd., and Algiers Beach. These stations were also sampled during 6 monitoring trips for the same water quality parameters listed previously. Data from gulf-side sampling is lacking but needed to evaluate nutrient gradients.

Samples were collected directly from pooled or flowing stormwater areas following Florida DEP SOP FS2100 guidelines and using analysis-specific dedicated bottles. Samples for nutrient analysis were preserved to a pH less than 2 with sulfuric acid and placed on ice for transport to Lee County Environmental Laboratory. Orthophosphate samples were filtered through a 0.7 micron filter immediately upon collection and preserved in ice water. All nutrient analyses were completed within the required sample holding period by Lee County Lab which is NELAP certified.

Sanibel-Specific Nutrient Loading Estimates

Nutrient loadings to waterbodies by land use type were revised for each basin. As described, annual Sanibel-specific runoff volumes were calculated for wet and dry season using the custom-derived runoff coefficients. Runoff volume was then multiplied by the mean Sanibel-specific nutrient concentration for the season and results added to obtain annual loading. Loading estimates were then compared to previous estimates made in Phase 1 which were based upon best available runoff and concentration data from literature (Thompson and Milbrandt 2013). Non-parametric statistical analyses (Wilcoxon and Mann-Whitney) were used to test for significant differences between new loading estimates and previous loading estimates at alpha = 0.05.

Results and Discussion

Sanibel-Specific Stormwater Runoff Coefficients

In the Phase 2 analysis, runoff coefficients (C) and volume estimates using the SCS curve number method for three recent years in which total annual precipitation on Sanibel was near the annual mean of 42 inches were computed. As described in the methods, the curve number method for estimating stormwater runoff is based upon the proportion of impervious surface cover, soil hydrologic groups, daily precipitation, antecedent moisture condition and to some extent vegetative cover. Each of these variables was addressed during this analysis. In general, annual variability in stormwater runoff (runoff coefficient) for a given area such as Sanibel is a characteristic of the variability in precipitation events. Runoff for any two years with similar total rain volume will vary significantly due to seasonal distribution, intensity and duration.

Based on direct digitization of land areas, Sanibel land types were primarily wetland forests and residential as classified by SFWMD FLUCCS 2 level. There were 10,062 acres analyzed for this project and 56% was either forested or other type of wetland and not considered to produce runoff in the analysis (Table 11). Low, medium and high density residential, commercial, institutional, golf course, park, beach, utility, brush land and disturbed land classes (anthropogenic land classes) were defined to be those producing nutrient loads. The anthropogenically influenced land classes made up 36% of Sanibel. About 13.2% or 1,334 acres of Sanibel was estimated to be impervious land cover while over 8,700 acres was estimated to be pervious. Buildings made up slightly more than half of the impervious area at 6.7% and roadways were about 6.5% of the impervious area analyzed (Table 11). For comparison, the USDA Forest Service iTree® Canopy software produced an estimate of 12.8% total impervious surface area (Table 12), with roadway at 6.8% compared to buildings at 6.0%. This estimate is based on a smaller sample size but is consistent with impervious area estimates based on direct digitization.

Table 11. Sanibel overall % impervious surface area by land class. No data collected is indicated by ND.

Land Class	Area (Acres)	% Pavement	% Building	% Impervious	% Pervious	Acres Impervious	Acres Pervious
Low Density Residential	825	14.1	13.6	27.7	72.3	228.4	596.3
Medium Density Residential	1,281	15.6	19.8	35.4	64.6	453.6	827.7
High Density Residential	452	18.6	23.8	42.3	57.7	191.4	261.0
Commercial and Services	259	32.8	13.9	65.8	34.2	170.4	88.6
Institutional (School)	62	31.2	14.8	46.0	54.0	28.5	33.4
Recreational (Golf Course)	303	7.1	2.0	9.1	90.9	27.6	275.5
Recreational (Beach)	285	ND	ND	5.0	95.0	14.3	270.8
Recreational (Parks)	11	ND	ND	20.0	80.0	2.2	9.0
Utilities	25	ND	ND	78.0	22.0	19.3	5.4
Shrub and Brushland	587	ND	ND	14.0	86.0	82.2	504.9
Disturbed Land	72	ND	ND	55.0	45.0	39.8	32.5
Upland Hardwood Forests	270	ND	ND	16.0	84.0	43.2	226.7
Lakes/Reservoirs	134	0.0	0.0	0.0	100.0	0.0	134.1
Wetlands (Other)	15	0.0	0.0	0.0	100.0	0.0	15.1
Wetland Forests	5,500	0.0	0.0	0.0	100.0	0.0	5500.5
Total	10,062	6.5	6.7	13.2	86.8	1300.8	8781.4

Further evaluation revealed larger variation in the proportion of impervious surface area between classes than between the same land class in different basins. In general, the proportion of impervious surface area increased from golf courses to low density to medium density to high density residential areas (Table 11). Commercial land types had the highest proportion of impervious surface area. Low density residential had a higher proportion of its impervious surface as road and sidewalk compared to buildings. However, commercial land types had an even greater proportion of impervious surface as pavement, due to parking lots. Medium and high density residential had a higher proportion of its impervious surface as buildings compared to paved surfaces.

The proportion of directly connected impervious area (DCIA) ranged between 5% and 63% dependent upon land class type and the percentage of development occurring after the 1989 stormwater design ordinance (Table 7b). Commercial land classes had the highest proportion DCIA while drainage basins on the east end of the island had the highest proportion of development which occurred before 1990 (Table 7b).

Annual rainfall for 2011, 2012 and 2013 was 42, 33.9 and 44.6 inches respectively compared to the annual mean of 42 inches for Sanibel. The SCS curve number method assumes all land surfaces including impervious have some initial rain storage potential. Lands with a greater proportion of pervious soils produce less runoff, and more rain falls before any runoff is produced. The antecedent moisture condition also effects runoff potential. The initial storage potential of soils is reduced when soil moisture remains from previous rain events. There were 21, 16, and 19 days in 2011, 2012 and 2013 respectively when the antecedent moisture condition was classified as III, meaning enough soil moisture was present from the preceding rain event to increase the proportion of runoff in the current rain event (Table 13).

The annual average number of days with rain events from 2011-2013 was 100. About 40% of the rain days produced no surface water runoff. The difference in rain event distribution and intensity is observed in evaluation of annual precipitation (Table 13). The highest percentage of rain days producing runoff from impervious surface occurred in 2013, while a greater proportion of events in 2011 produced runoff from pervious surfaces and a lower proportion of produced impervious surface runoff. In general 54-63% of rain events recorded during 2011-2013 (or 52 - 69 days each year) were greater than 0.1 inches, producing runoff from impervious surfaces. Only 15-24% of rain events (or 14 – 26 days each year) produced runoff from pervious surfaces.

Due to the change in soil hydric group designation between seasons, the rain storage potential of pervious surfaces increases drastically in dry season compared to wet season. The change in hydric group by season on Sanibel is caused by the elevation of water table levels during the wet season. When the water table is at or near the soil surface, less precipitation can be stored within the soil before runoff occurs. In 2011 only 32% of the rain volume fell in dry season compared to greater than 42% in 2012 and 2013. Because a higher proportion of rain fell when the water table affected runoff characteristics (wet season) in 2011, a higher overall proportion of rain which fell on pervious surfaces that year produced runoff (Table 13).

Curve numbers used in the Florida DEP/SCS methodology for estimating runoff volume were greater for land classes that had a higher proportion of impervious surfaces (Table 14). They were also greater for wet season compared to dry. Larger curve numbers result in greater volume estimates for stormwater runoff. Estimated total stormwater runoff volume from anthropogenic land classes ranged between 9,640,000 m^3 in 2012 and 12,695,000 m^3 in 2013 (Table 15-17). Medium density residential was the largest contributor to the anthropogenic runoff volume while institutional land class was by far the smallest contributor (Appendix 1). The eastern and western basins of Sanibel Slough were areas contributing the greatest discharge volume while the SW Tarpon Bay and refuge basins contributed least (Table 15-17).

Runoff coefficients are simply total estimated stormwater volume discharged from a land area divided by total rain volume which fell in that area (Table 18, Appendix 1). Sanibel-specific runoff coefficients were derived by taking the mean stormwater runoff values for 2011-2013 and dividing that by the mean total volume of rainfall (Table 18, Appendix 1). Coefficient estimates made in this study were highest for commercial land types and lowest for golf courses (Table 18 and Figure 2). They were also greater for the wet season compared to the dry season (Table 18 and Figure 2). In general, coefficients were greater for the eastern basins than the western basins (Table 19 and Figure 3). Compared to the coefficients used for the Phase 1 estimates of nutrient loadings, the Sanibel-specific values are generally lower (Table 18 and Figure 4). As noted previously, Sanibel-specific coefficients were generated for anthropogenic land classes only.

Table 18. Mean Sanibel-specific runoff coefficients and standard deviations derived from Phase 2 GIS-based analyses. Coefficients from literature which were used in Phase 1 of this project are also given for comparison.

Sanibel Specific Runoff Coefficients	Mean C				Phase 1 Coefficients	
Land Use	**Dry Season**	**StDev**	**Wet Season**	**StDev**	**Dry Season**	**Wet Season**
LowDenRes	0.12	0.01	0.33	0.042	0.21	0.31
MedDenRes	0.18	0.008	0.38	0.037	0.35	0.45
HighDenRes	0.27	0.006	0.45	0.038	0.5	0.65
Commercial	0.44	0.014	0.59	0.046	0.78	0.97
Institutional	0.18	0.03	0.42	0.048	0.5	0.6
Golf Course	0.04	0.02	0.25	0.04	0.18	0.26

Using the runoff coefficients developed in this study, the estimated mean annual runoff from Sanibel is 24.9% less than that estimated in Phase 1, falling from 7,464,010 to 5,608,500 m^3/yr. (Table 20). The dry season coefficients were 41.1% less while the wet season values were 20.5% less than that estimated in Phase 1 (Table 20).

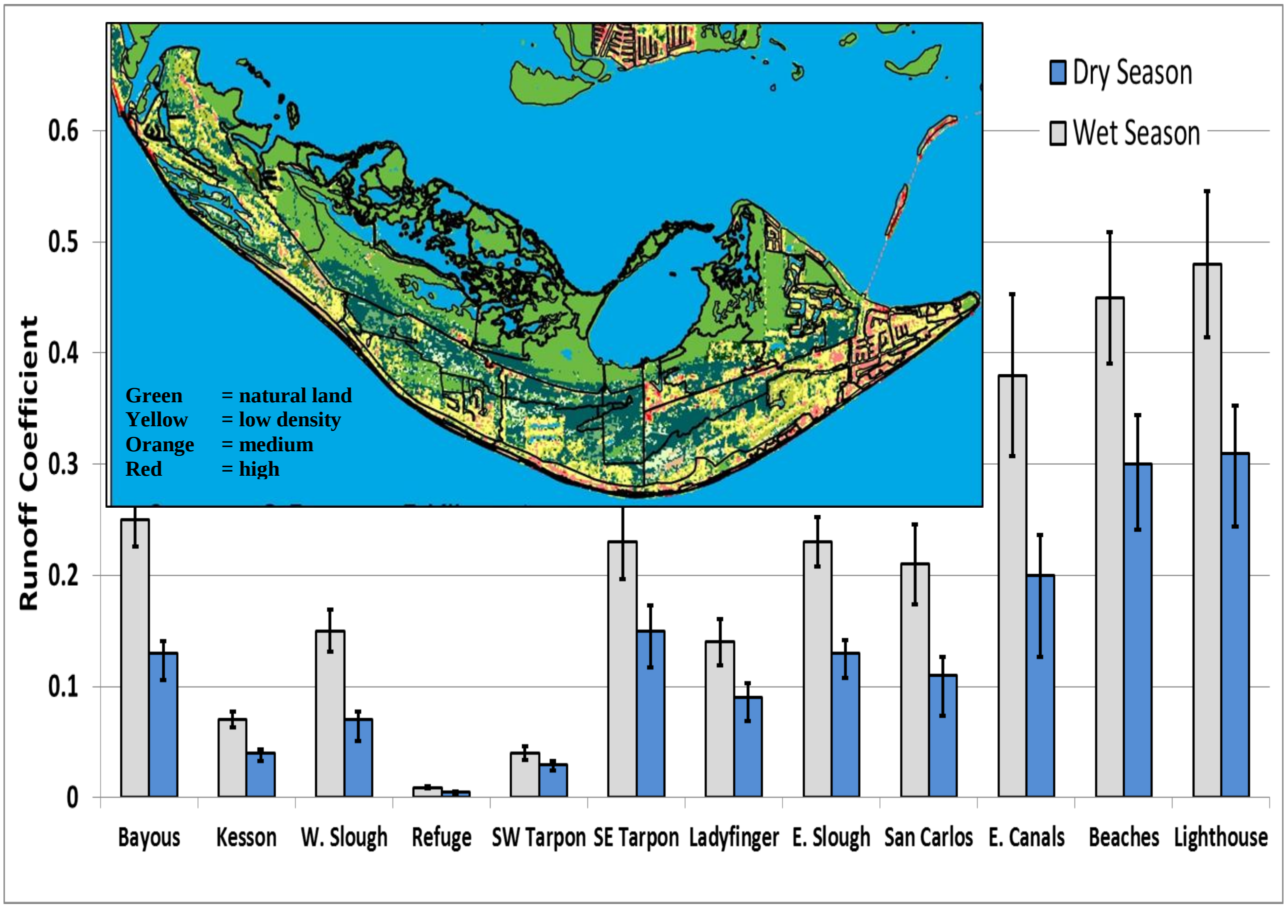

Figure 3. Overall mean runoff coefficients for individual Sanibel drainage basins with inset of Sanibel Island showing decreased runoff in center area of island which contains higher percentage of land in natural state (green).

Table 20. Comparison of stormwater runoff nutrient loading estimates from Sanibel from the Phase 1 study to the revised estimates from this study (Phase 2).

	Phase 1 (m^3/yr.)			Phase 2 (m^3/yr.)			% Change		
	DrySeason	WetSeason	Total	DrySeason	WetSeason	Total	DrySeason	WetSeason	Total
Runoff (m^3/yr.)	1,587,493	5,876,517	**7,464,010**	935,446	4,673,054	**5,608,500**	-41.1	-20.5	**-24.9**
TN Load (Kg/yr.)	2,692	9,967	**12,659**	950	4705	**5655**	-64.7	-52.8	**-55.3**
IN Load (Kg/yr.)	881	3,261	**4,142**	191	1358	**1549**	-78.3	-58.4	**-62.6**
TP Load (Kg/yr.)	517	1,914	**2,431**	171	1460	**1631**	-66.9	-23.7	**-32.9**
OP Load (Kg/yr.)	165	613	**778**	96	901	**997**	-42.0	47.1	**28.1**

Sanibel-Specific Stormwater Runoff Nutrient Concentrations

Mean Sanibel-specific stormwater runoff nutrient concentrations varied between land class, and season. Most notably, nitrogen and phosphorus concentrations were greatest for golf course runoff compared to the other land classes analyzed (Table 21 and Figures 5-8). For pooled land class data, TN was significantly greater during dry (fertilizer) season compared to wet (no-fertilizer) season (paired t-test, n=37, T= 3.1, p= 0.004). In dry season TN concentrations were greater in the low density residential and decreased through the more developed medium and high density residential, and commercial classes (Figure 5). A higher proportion of organic matter in less developed land classes may explain this unexpected gradient. This trend wasn't evident in the wet season likely due to less decomposition time for organics between rain events and larger/more frequent freshwater flushing. Inorganic nitrogen ranged from 12.4% to 53.0% of the TN during dry season compared to 25% to 40% during wet season. The greater IN variability during the dry season may be a reflection of fertilizer application at some of the sample sites. Inorganic nitrogen concentrations did not vary significantly between land classes or between seasons except for the golf course land type (Figure 6). Golf course runoff had greater IN than other land classes but concentrations measured during the dry season were not significantly greater than the wet season (Kruskal Wallis, n = 15, p = 0.141). The restrictions on fertilizer use during wet season are not applicable to golf courses and would explain this result. TP and OP appeared to be greater during the wet season for all land classes (Figures 7 and 8), but no significant differences could be found (Kruskal Wallis, n = 31, p >0.1). Golf course runoff again had the highest concentrations of TP and OP compared to other land classes.

Table 21. Sanibel specific mean nutrient concentrations for stormwater runoff by land use class.

Sanibel Specific Runoff Concentrations	Mean TN Conc (mg/l)		Mean IN Conc (mg/l)		Mean TP Conc (mg/l)		Mean OP Conc (mg/l)	
Land Use Class	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**
LowDenRes	1.61	0.71	0.199	0.244	0.24	0.32	0.085	0.077
MedDenRes	1.22	1.13	0.160	0.413	0.27	0.36	0.200	0.219
HighDenRes	1.04	1.33	0.258	0.267	0.22	0.31	0.107	0.250
Commercial	0.66	0.51	0.110	0.159	0.15	0.15	0.049	0.062
Golf Course	4.32	2.28	2.290	0.517	1.21	1.69	1.087	1.526

Nutrient concentrations in golf course stormwater runoff were generally greater than concentrations found in their stormwater retention ponds (Table 22). As expected, a higher proportion of the nutrient concentration in the runoff is inorganic compared to nutrients in stormwater ponds. Concentrations of inorganic nutrients are generally reduced in these stormwater pond systems (Table 22) as a result of dilution with groundwater, sediment adsorption, assimilation into plants and algae and microbial denitrification.

Of 102 total stormwater runoff samples taken, 29 (29%) had concentrations above the Florida DEP numeric nutrient criteria of 1.54 mg/l for TN. The numeric nutrient criterion for phosphorus (0.12 mg/l) was exceeded in 75% of the samples. All golf course samples were in the highest 25th percentile of all samples for nutrient levels. A few noteworthy sample sites with high levels of phosphorus and nitrogen were medium density residential sites in The Dunes, Wulfert Rd., and Pine Tree Dr. and a high density site at the end of Bowman's Beach Rd (Table 23).

Mean runoff concentrations computed in this Phase 2 effort were generally lower than concentrations borrowed from other studies and used in Phase 1 estimates (Figures 5 through 8). Concentrations of organic and inorganic nitrogen and phosphorus found in Sanibel's golf course runoff were the exception. For golf courses, the mean TN concentration was up to 2.5 times greater than literature estimates (Figure 5), while TP concentrations were 5 to 10 times greater than the estimates used in Phase 1 (Figure 7). The contrast with literature values was even greater for OP with levels from golf courses over 10 times greater than the literature estimates (Figure 8). This finding resulted in greater nutrient loading estimates for the three golf courses while other land classes generally had reduced estimates compared to the Phase 1 work. The proportion of the total nutrient load leaving Sanibel which is attributable to golf courses is significantly greater than first estimated.

Stormwater runoff from sites using reclaimed water for irrigation was compared to similar sites which did not use reclaim water. In this analysis, samples were paired by similar land class, basin and event number to control for the variability in these factors. Significantly greater concentrations of OP were found in areas using reclaimed water (0.202 mg/l) compared to those not using reclaimed water (0.091 mg/l) (Paired t-test, n= 21, p= 0.07). However statistically significant lower concentrations of TN (0.87 vs 1.51 mg/l) were found for areas using reclaimed water (Paired t-test, n= 21, p> 0.01). No differences were found in TP or IN between sites using reclaimed water and those which were not. Analysis of historical data during Phase 1 of this project found significantly higher surface water concentrations of OP in basins where large volumes of reclaimed water were used (Thompson and Milbrandt. 2013). The greater concentration of OP in runoff samples at sites using reclaimed irrigation water reveals reclaimed water as a principal source of OP (and TP) in surface waters of Sanibel. The significantly lower levels of TN at sites using reclaimed water may be a characteristic of the type of lawn where reclaimed water is used. In general, sites using reclaimed water may have lower vegetative cover and a more "manicured" and maintained lawn. These sites would have less dissolved organic matter (containing TN) in the runoff. The greater concentration of OP found at reclaimed water sites was only marginally significant. Annual reclaimed water usage was 8-11% of the total rainfall volume in basins where it is used. This suggests that reclaimed water can be a significant source of groundwater recharge in addition to rain, possibly affecting groundwater quality. However, if reclaimed water is a main source for OP in surface waters, the direct leakage or application of reclaimed water to the surface waters (from miss-aimed irrigation nozzles) is the most probable route (rather than stormwater runoff) since most phosphorus can be immobilized in soils. Due to the route of the reclaimed water supply piping, most sites using reclaimed water are located near the beach south of Gulf Drive. These sites likely have the greatest percentage of sand and lesser organic material than sites from other parts of the island. Sandy soils have the weakest capacity to immobilize OP (University of Hawaii 2014), allowing OP from irrigation to runoff. The higher OP concentrations found in basins using reclaimed water may be partially due to continuous percolation of reclaimed irrigation water through sandy, pervious surfaces and into the groundwater. The groundwater would then be the source of nutrient loading to adjacent water bodies.

Golf courses had the highest concentrations of inorganic and total nitrogen and phosphorus in their stormwater runoff (Figure 5-8). Although the estimated runoff coefficients for golf courses are relatively low (c = 0.04-0.25), the high concentrations of nutrients in the runoff make golf courses a significant source of nutrient pollution. The constant irrigation of golf course lands with reclaimed water increases the potential of groundwater transfer of anthropogenic nutrients to the adjacent estuary, lakes and the Gulf of Mexico. Phase 1 of this project estimated over 7,000 kilograms of nitrogen and 3,000 kg of phosphorus are applied annually to golf course grounds through reclaimed water usage alone (from actual reclaimed water flow and concentration data). Fertilizer is then applied in addition to this loading, resulting in high concentrations in stormwater runoff and potentially in groundwater.

A paired t-test on pooled data was unable to find a seasonal difference (dry versus wet) between overall mean concentrations of TP, OP and IN in stormwater runoff ($n = 37$, $p > 0.6$). However a significantly greater mean concentration of TN was found in the dry (fertilizer) season compared to the no-fertilizer (wet) season. When data was analyzed by land class the only significant difference was an apparent higher TN in dry season for low density residential land classes (Kruskal Wallis, $n= 22$, $p = 0.027$). Runoff from medium and high density residential, commercial and golf course land classes showed no significant differences in nutrient concentrations (TN, TP, IN, OP) between the dry (fertilizer) and wet (no-fertilizer season). These findings are somewhat contrary to expected findings. Analysis of time series surface water data in Phase 1 revealed that nutrient concentrations were lower in Sanibel Slough after the fertilizer ordinance was enacted in 2007. The ordinance bans residential application of fertilizer from July through September each year and specifies maximum fertilizer loading rates and fertilizer types for the remainder of the year. The failure to find significant lower nutrient concentrations (for pooled data) during the dry, no-fertilizer season is either due to insufficient sample size or it reflects truly insignificant differences in stormwater runoff nutrient concentrations. The similarity of mean stormwater runoff nutrient concentrations between no-fertilizer and fertilizer periods suggest that either fertilizer BMPs have minimized fertilizer runoff year-round, or BMP's have had little effect, or fertilizer-based nutrient runoff has not been reduced significantly during the no-fertilizer season.

Nutrient loading analyses performed in Phase 1 of this study used literature-based runoff concentrations taken from studies done in Florida. We found mean Sanibel-specific runoff concentrations to be significantly lower (Mann-Whitney, $n = 8$, $p < 0.01$) than literature values for TN, TP and IN using pooled land class data excluding golf courses (Figures 5-8). Phase 1 of this study found significantly lower concentrations of IN and TP in the Sanibel Slough after implementation of the fertilizer ordinance. Taken together these findings strengthen the argument that already implemented BMPs are having a positive effect on reducing nutrient runoff and indeed fertilizer-based runoff may be relatively low all year. However an increasing trend in OP and significantly greater concentration of OP in the Sanibel Slough after the fertilizer ordinance implementation provide a warning that all forms of nutrients are not on the decrease. As discussed in the Phase 1 report, high concentrations of OP in Sanibel's surface waters may be associated with reclaim water usage. The annual volume of reclaim water used for irrigation has varied between 22.5 and 38.5 million gallons per year since 2010 (Figure 9) based upon irrigation needs. Concentrations of OP are relatively high in the reclaimed water. If runoff of fertilizer based nutrients has been reduced through BMPs, we would expect IN concentrations and loadings to be reduced as we have found. However if BMP efforts have effectively kept phosphorus loadings from fertilizers low, then the OP in reclaimed water becomes the main phosphorus source. Sampling now detects OP more often and at higher concentrations than previously due to an excess of OP (relative to IN) in the Sanibel Slough.

Sanibel-Specific Nutrient Loading Estimates

Estimates of nutrient loads to waterbodies using Sanibel-specific coefficients and concentrations developed in this effort include: 5,655 kg TN/yr; 1,549 kg IN/yr; 1,631 kg TP/yr; and 997 kg OP/yr (Tables 24-27). These annual loads were released from 1,837 hectares (4,540 acres) of watershed (wetlands excluded). The estimated annual loading rates are found to be: 3.1 kg TN/ha/yr and 0.9 kg TP/ha/yr. Nutrient loading rate estimates including only the same land classes as those evaluated for Sanibel (wetlands and wetland forests excluded) were 8.05 kg TN/ha/yr and 0.90 kg TP/ha/yr for the Caloosahatchee River watershed and 6.43 kg TN/ha/yr plus 1.31 kg TP/ha/yr. for the Saint Lucie Estuary (SLE) watershed (Soil and Water Engineering 2008). The Sanibel TN loading rate is much lower than either the Caloosahatchee or SLE watersheds, while the TP loading is comparable to those watersheds. The two larger watersheds used for comparisons have large areas of intensive agriculture and urban areas and a lower percentage of preserved natural lands than Sanibel. Sanibel has also implemented numerous island-wide BMPs to date aimed at lowering nutrient loads. Lower loading rates are to be expected on Sanibel. However, the phosphorus loading rate on Sanibel is not lower than the two comparison estuaries. Total nitrogen loading rates on Sanibel may be reduced compared to other watersheds because of local efforts to preserve natural land, BMPs which reduce nitrogen preferentially over phosphorus and its lack of agriculture or other intensive land development. Total phosphorus loading rates remain relatively higher due to soil characteristics (more sand = less soil adsorption of P), and the use of reclaimed water (which contains relatively higher P levels than other nutrient sources) over a greater percentage of its land area.

Sanibel stormwater runoff nutrient load estimates for TN, IN and TP were significantly lower than Phase 1 values using Sanibel-specific runoff coefficients and concentrations (Table 20). The revised estimate of stormwater TN load was 55% less (from 12,659 to 5,655 kg/yr.) and IN was 63% less (4,142 to 1,549 kg/yr.) than the previous estimates. Phase 2 estimates for TP load decreased by 33% (2431 to 1631 kg/yr.). In contrast, estimated OP loading increased by 28% (778 to 997 kg/yr.) over Phase 1 predicted values (Table 20). The estimated decrease in TN loading was driven in almost equal parts by reductions in stormwater volume (24% reduction) and concentration estimates (31% reduction). A greater proportion of the estimated IN load reduction was attributable to reduced concentration estimates (39%) compared to runoff volume estimate reduction (24%). Change in the estimated TP load was mostly due to reduction in runoff volume as opposed to reduction in concentration (24% versus 8%) suggesting concentration estimates taken from the literature for TP were fairly accurate. The 28% increase in the OP loading estimate despite the runoff volume reduction, reflects an underestimate of concentrations in Phase 1 as a result of using literature values.

Table 24. Annual Sanibel stormwater TN loading to waterbodies calculated with Sanibel-specific runoff coefficients and concentration data.

Estimated Annual TN Loading	Area (acres)	Annual Dry Season Rain (m)	Annual Wet Season Rain (m)	Sanibel Specific Runoff Coefficient		Sanibel Specific Mean TN Conc (mg/l)		Sanibel TN Loading (kg/yr)		Total TN Loading (kg/yr)
Land Use				**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	
Low Density Residential	825	0.257	0.709	0.12	0.33	1.61	0.71	165	557	722
Medium Density Residential	1281	0.257	0.709	0.18	0.38	1.22	1.13	292	1579	1870
High Density Residential	452	0.257	0.709	0.27	0.45	1.04	1.33	132	778	910
Commercial and Services	259	0.257	0.709	0.44	0.59	0.66	0.51	78	223	301
Institutional (School)	62	0.257	0.709	0.18	0.42	1.18	1.18	14	88	102
Recreational (Golf Courses)	303	0.257	0.709	0.04	0.25	4.32	2.28	54	495	549
Recreational (Beach)	285	0.257	0.709	0.5	0.6	0	0	0	0	0
Recreational (Parks)	11	0.257	0.709	0.21	0.31	1.93	1.93	5	19	24
Utilities (Island Water)	25	0.257	0.709	0.78	0.97	1.82	1.82	37	125	162
Shrub and Brushland	587	0.257	0.709	0.14	0.3	1.2	1.2	103	606	709
Disturbed Land	72	0.257	0.709	0.55	0.65	1.5	1.5	62	202	264
Upland Hardwood Forests	270	0.257	0.709	0.16	0.21	0.2	0.2	9	33	42
Lakes/Reservoirs	134	0.257	0.709	0	0	0	0	0	0	0
Wetlands (Other)	15	0.257	0.709	0	0	0	0	0	0	0
Wetland Forests	5500	0.257	0.709	0	0	0	0	0	0	0
Total	10062	0.257	0.709					950	4705	**5655**

Table 25. Annual Sanibel stormwater IN loading to waterbodies calculated with Sanibel-specific runoff coefficients and concentration data.

Estimated Annual IN Loading	Area (acres)	Annual Dry Season Rain (m)	Annual Wet Season Rain (m)	Sanibel Specific Runoff Coefficient		Sanibel Specific Mean IN Conc (mg/l)		Sanibel IN Loading (kg/yr)		Total IN Loading (kg/yr)
Land Use				Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
Low Density Residential	825	0.257	0.709	0.12	0.33	0.20	0.24	20	190	211
Medium Density Residential	1281	0.257	0.709	0.18	0.38	0.16	0.41	38	577	615
High Density Residential	452	0.257	0.709	0.27	0.45	0.26	0.27	33	156	189
Commercial and Services	259	0.257	0.709	0.44	0.59	0.11	0.16	13	70	83
Institutional (School)	62	0.257	0.709	0.18	0.42	0.50	0.50	6	37	43
Recreational (Golf Courses)	303	0.257	0.709	0.04	0.25	2.29	0.52	29	112	141
Recreational (Beach)	285	0.257	0.709	0.5	0.6	0	0	0	0	0
Recreational (Parks)	11	0.257	0.709	0.21	0.31	0.73	0.73	2	7	9
Utilities (Island Water)	25	0.257	0.709	0.78	0.97	0.5	0.5	10	34	44
Shrub and Brushland	587	0.257	0.709	0.14	0.3	0.2	0.2	17	101	118
Disturbed Land	72	0.257	0.709	0.55	0.65	0.543	0.543	22	73	96
Upland Hardwood Forests	270	0.257	0.709	0.16	0.21	0	0	0	0	0
Lakes/Reservoirs	134	0.257	0.709	0	0	0	0	0	0	0
Wetlands (Other)	15	0.257	0.709	0	0	0	0	0	0	0
Wetland Forests	5500	0.257	0.709	0	0	0	0	0	0	0
Total	10062	0.257	0.709					191	1358	**1549**

Table 26. Annual Sanibel stormwater TP loading to waterbodies calculated with Sanibel-specific runoff coefficients and concentration data.

Estimated Annual TP Loading	Area (acres)	Annual Dry Season Rain (m)	Annual Wet Season Rain (m)	Sanibel Specific Runoff Coefficient		Sanibel Specific Mean TP Conc (mg/l)		Sanibel TP Loading (kg/yr)		Total TP Loading (kg/yr)
Land Use				Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
Low Density Residential	825	0.257	0.709	0.12	0.33	0.24	0.32	25	251	276
Medium Density Residential	1281	0.257	0.709	0.18	0.38	0.27	0.36	65	506	570
High Density Residential	452	0.257	0.709	0.27	0.45	0.22	0.31	28	182	209
Commercial and Services	259	0.257	0.709	0.44	0.59	0.15	0.15	18	64	82
Institutional (School)	62	0.257	0.709	0.18	0.42	0.15	0.15	2	11	13
Recreational (Golf Courses)	303	0.257	0.709	0.04	0.25	1.21	1.69	15	367	382
Recreational (Beach)	285	0.257	0.709	0.5	0.6	0	0	0	0	0
Recreational (Parks)	11	0.257	0.709	0.21	0.31	0.4	0.4	1	4	5
Utilities (Island Water)	25	0.257	0.709	0.78	0.97	0.27	0.27	5	19	24
Shrub and Brushland	587	0.257	0.709	0.14	0.3	0.07	0.07	6	35	41
Disturbed Land	72	0.257	0.709	0.55	0.65	0.15	0.15	6	20	26
Upland Hardwood Forests	270	0.257	0.709	0.16	0.21	0.01	0.01	0	2	2
Lakes/Reservoirs	134	0.257	0.709	0	0	0	0	0	0	0
Wetlands (Other)	15	0.257	0.709	0	0	0	0	0	0	0
Wetland Forests	5500	0.257	0.709	0	0	0	0	0	0	0
Total	10062	0.257	0.709					171	1460	**1631**

Table 27. Annual stormwater OP loading to waterbodies adjacent to Sanibel calculated with Sanibel-specific runoff coefficients and concentration data.

Estimated Annual OP Loading Land Use	Area (acres)	Annual Dry Season Rain (m)	Annual Wet Season Rain (m)	Sanibel Specific Runoff Coefficient		Sanibel Specific Mean OP Conc (mg/l)		Sanibel OP Loading (kg/yr)		Total OP Loading (kg/yr)
				Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
Low Density Residential	825	0.257	0.709	0.12	0.33	0.09	0.08	9	60	69
Medium Density Residential	1281	0.257	0.709	0.18	0.38	0.20	0.22	48	305	353
High Density Residential	452	0.257	0.709	0.27	0.45	0.11	0.25	14	146	160
Commercial and Services	259	0.257	0.709	0.44	0.59	0.05	0.06	6	27	33
Institutional (School)	62	0.257	0.709	0.18	0.42	0.06	0.06	1	4	5
Recreational (Golf Courses)	303	0.257	0.709	0.04	0.25	1.09	1.53	14	332	345
Recreational (Beach)	285	0.257	0.709	0.5	0.6	0	0	0	0	0
Recreational (Parks)	11	0.257	0.709	0.21	0.31	0.143	0.143	0	1	2
Utilities (Island Water)	25	0.257	0.709	0.78	0.97	0.08	0.08	2	6	7
Shrub and Brushland	587	0.257	0.709	0.14	0.3	0.03	0.03	3	15	18
Disturbed Land	72	0.257	0.709	0.55	0.65	0.03	0.03	1	4	5
Upland Hardwood Forests	270	0.257	0.709	0.16	0.21	0	0	0	0	0
Lakes/Reservoirs	134	0.257	0.709	0	0	0	0	0	0	0
Wetlands (Other)	15	0.257	0.709	0	0	0	0	0	0	0
Wetland Forests	5500	0.257	0.709	0	0	0	0	0	0	0
Total	10062	0.257	0.709					96	901	**997**

Though stormwater nutrient loading rates on Sanibel are low compared to other watersheds, Phase 1 of this project found that TN and TP increased significantly in the Sanibel Slough after rainfall events. Loads are significant enough to raise concentrations in the Sanibel Slough after rain events, encouraging consideration of additional BMPs to decrease loads. In addition, IN was found to be significantly greater in nearshore estuarine surface water samples after rain events (Thompson and Milbrandt 2013).

The medium density residential land class is the greatest source of loadings for TN, IN and TP (Figures 10 through 12). This is primarily due to its larger total area than other classes. Though comprising a small part of the land area, golf courses were the leading source of inorganic phosphorus loads (Figure 13). Golf courses make up about 9% of the anthropogenic land area on Sanibel and produce 35% of the inorganic phosphorus (OP) load. The inorganic forms of nitrogen and phosphorus are preferred by algae and thus most likely to cause blooms. Compared to Phase 1 estimates, the golf course land class substantially increased in its relative importance as a phosphorus source. The higher measured concentrations of nutrients in golf course stormwater samples compared to the Phase 1 estimates accounted for the entire increase in golf course loading values. The Sanibel-specific golf course runoff coefficients developed during this work were slightly lower than the estimates used in Phase 1 (Table 18). A recommended priority is to target load reduction efforts at medium density residential and golf course land classes.

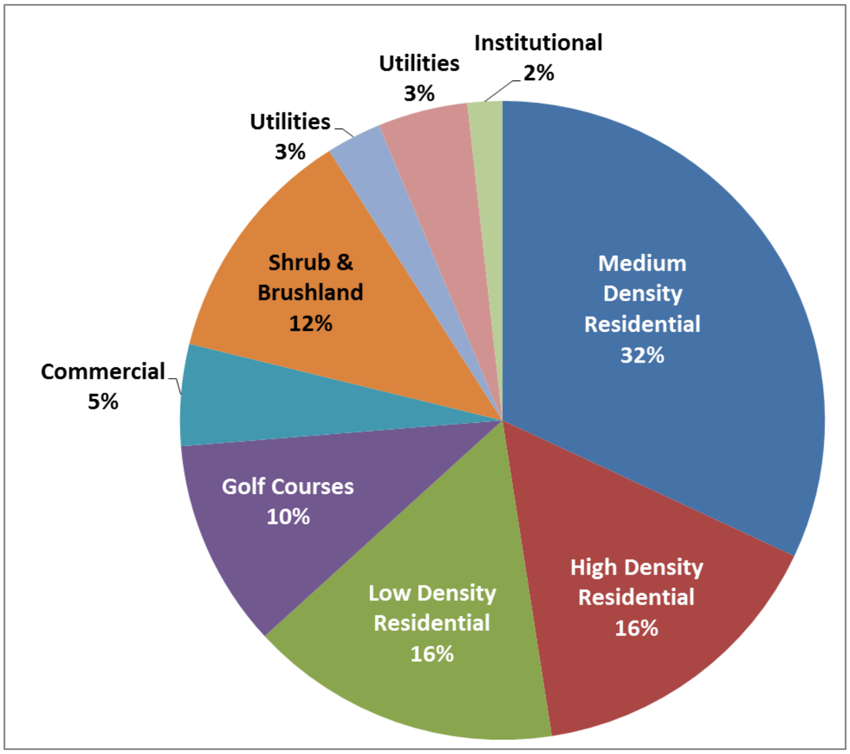

Figure 10. Proportion of estimated TN loading by each anthropogenic land class on Sanibel.

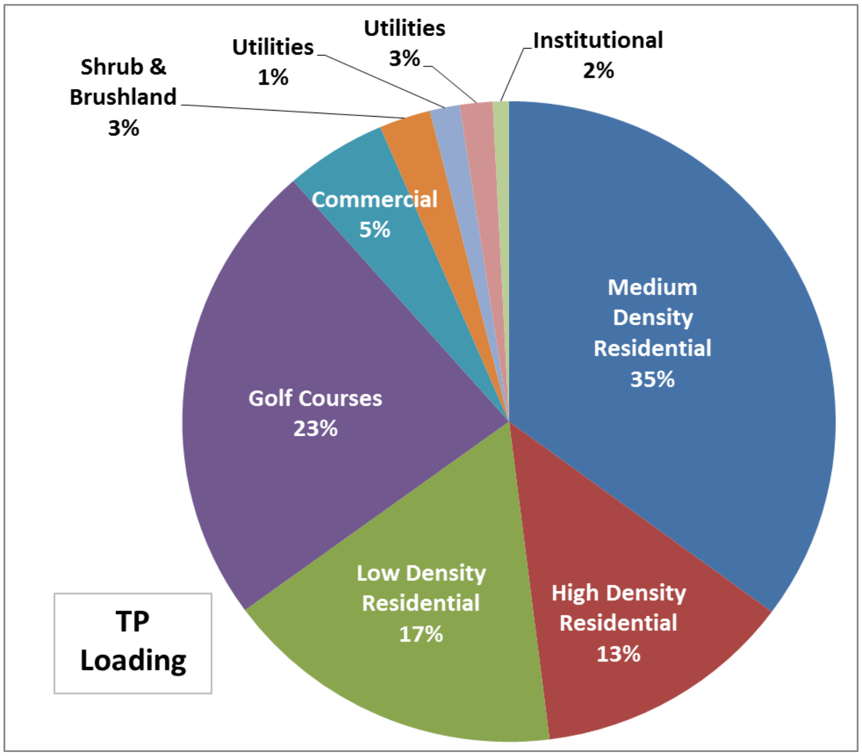

Figure 11. Proportion of estimated TP loading by each anthropogenic land class on Sanibel.

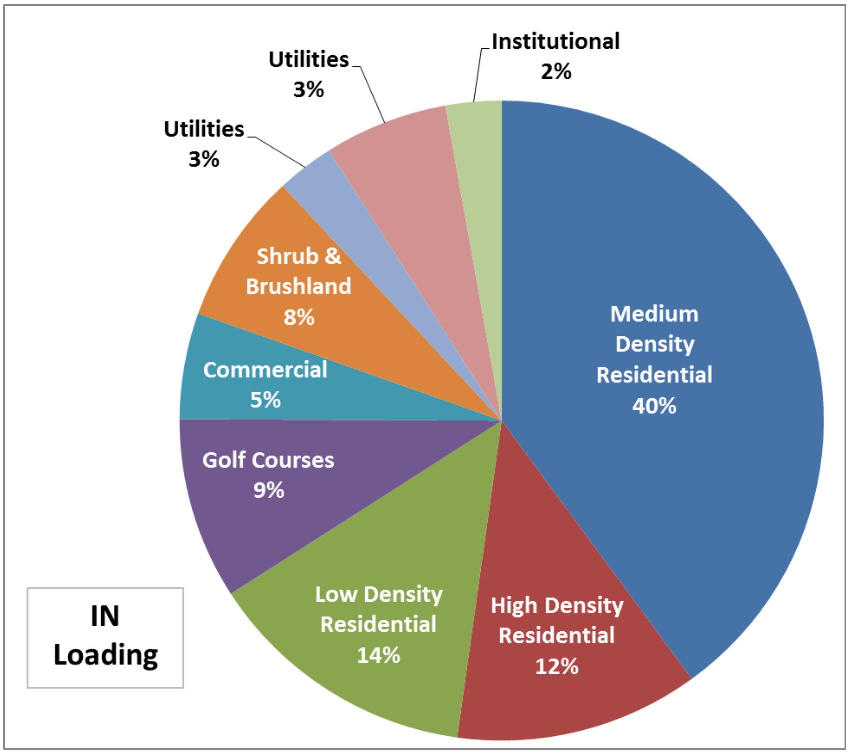

Figure 12. Proportion of estimated IN loading by each anthropogenic land class on Sanibel.

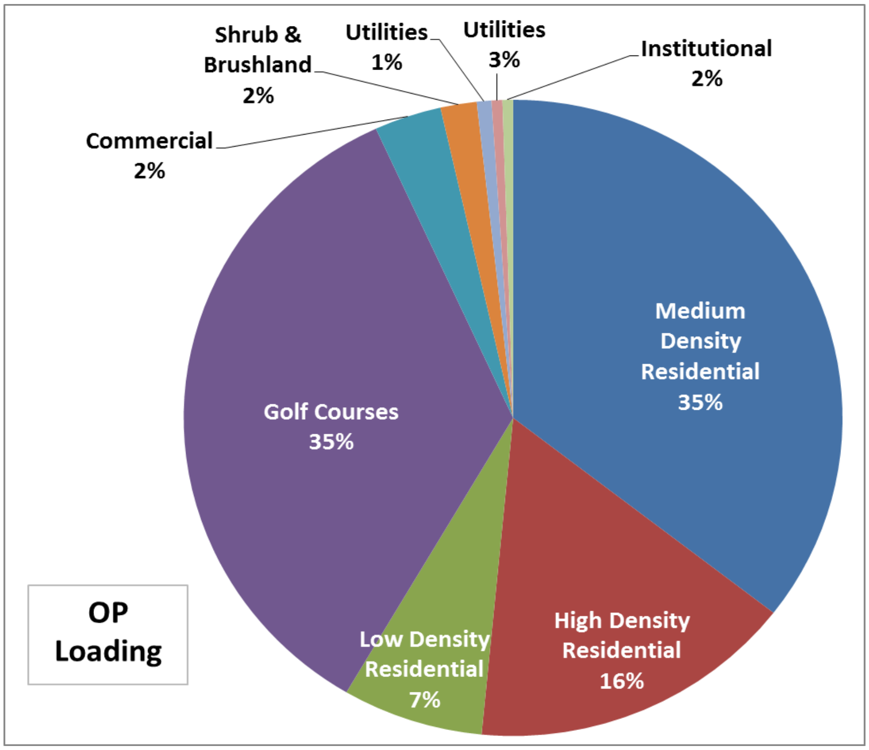

Figure 13. Proportion of estimated OP loading by each anthropogenic land class on Sanibel.

The east slough basin had the largest proportion of Sanibel's nutrient load (Figures 14 through 16; Table 28) accounting for between 18-22% of the total mass of nutrients leaving Sanibel. This basin has a relatively large area, the highest proportion of medium density residential land plus a golf course. In Phase 1, significantly greater TP and OP concentrations were found in the east basin of Sanibel Slough compared to the west basin. The annual stormwater TP and OP loads from the east basin were 341.3 kg and 227.6 kg respectively which were added to approximately 21.8 hectares of Sanibel Slough water surface area in that basin. The annual loading rate to the waterbody was approximately 15.6 kg.TP/ha-yr. and 10.4 kg OP/ha/yr. The TP and OP loading in the west basin was 236.1 and 97.8 kg respectively discharged into 28.9 hectares of west slough water surface area. This results in a loading rate of 8.2 kg TP/ha/yr and 3.4 kg OP/ha/yr in the west slough. Assuming the cross sectional area of the Sanibel Slough is similar in each basin, the loading rate for TP in the east basin is twice as high as the west basin and OP loads are 3 times as great. No significant differences in surface water nitrogen concentrations were found between the Sanibel Slough basins in Phase 1. However, loading rates in the east slough were also greater for TN (45.3 vs. 30.8 kg./ha-yr.) and IN (12.7 vs. 8.5 kg./ha-yr.) than the west slough. This loading data supports the surface water concentration findings in Phase 1, and leads to a recommendation that the east basin may be a priority for BMPs compared to the west basin.

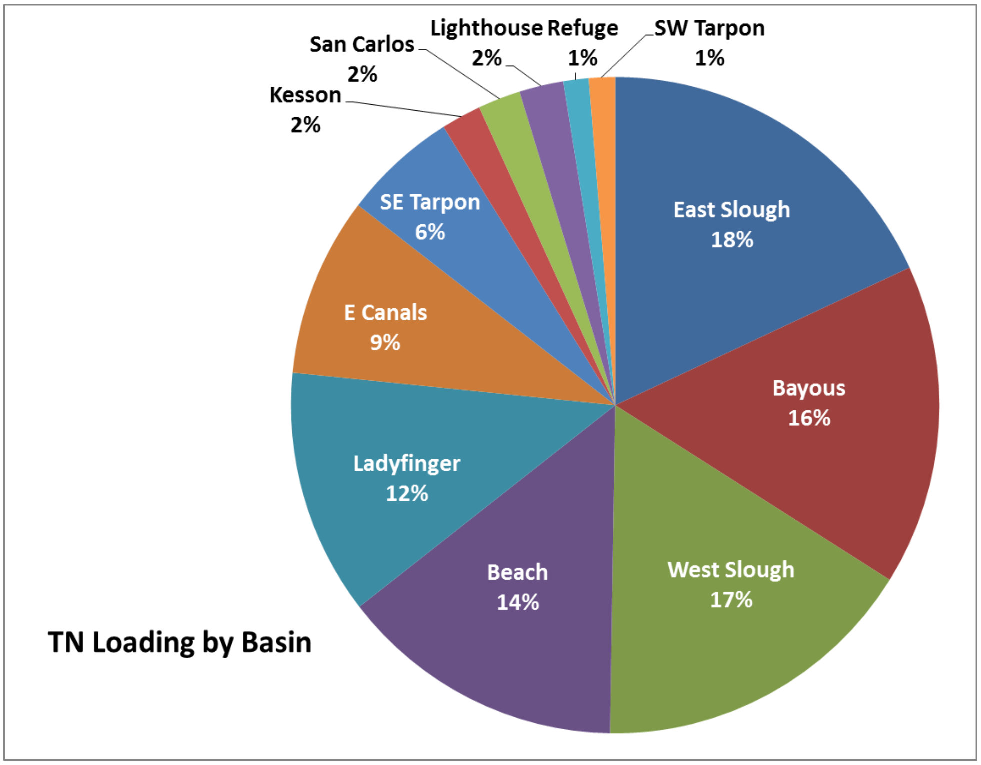

Figure 14. Proportion of estimated TN loading from each discharge basin on Sanibel.

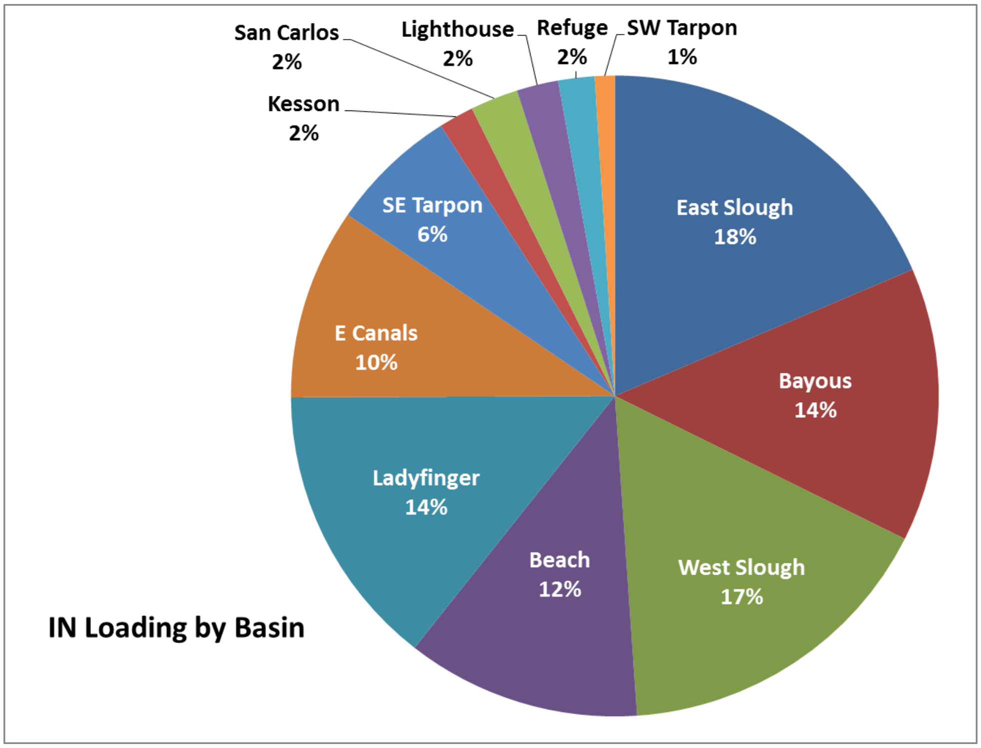

Figure 15. Proportion of estimated IN loading from each discharge basin on Sanibel.

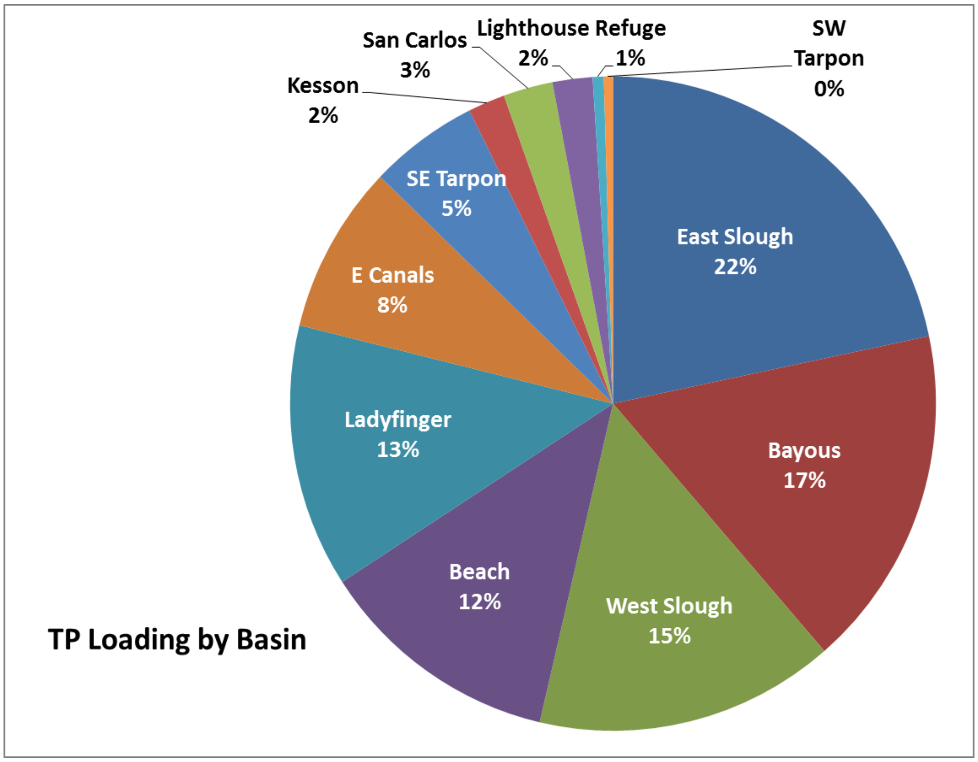

Figure 16. Proportion of estimated TP loading from each discharge basin on Sanibel.

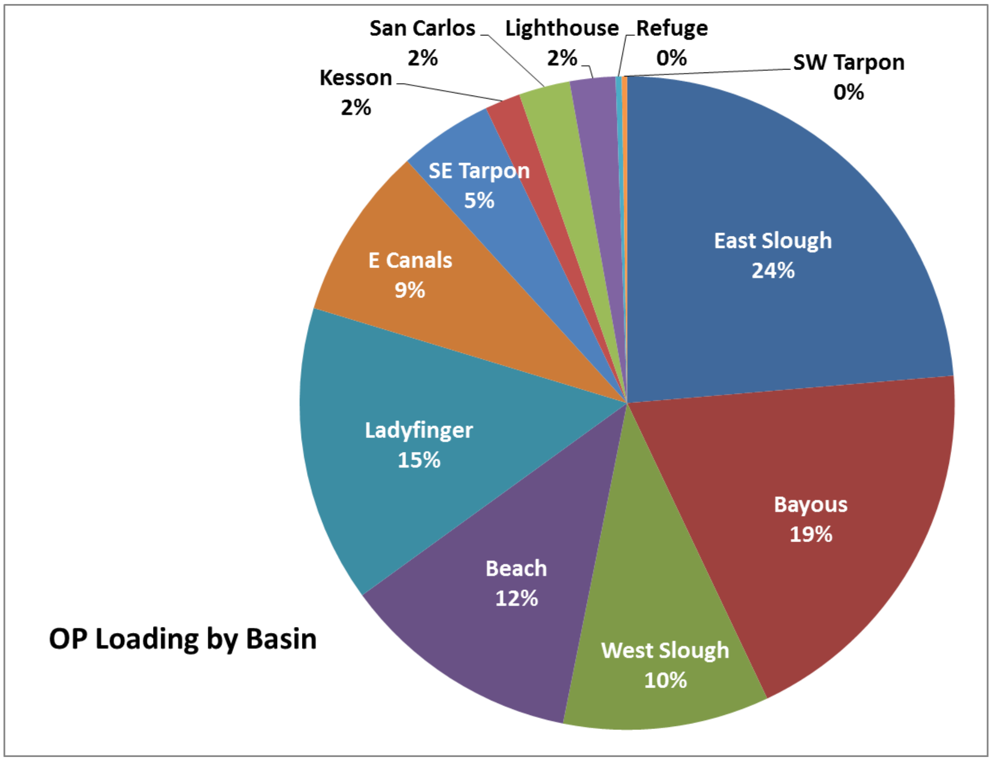

Figure 17. Proportion of estimated OP loading from each discharge basin on Sanibel.

The three basins with golf courses (east slough, bayous and ladyfinger) are the basins with greatest inorganic phosphorus loadings (Figures 15 and 17; Table 28). The nitrogen and phosphorus in reclaimed water (which is used for golf course irrigation) are primarily in inorganic form. The considerable proportion of nutrient load contributed by the west slough basin is primarily due to its large land area (19% of total). In contrast, the refuge basin has a large relative land area (28% of total) but a very small proportion of nutrient load due to its lack of development and significant wetland classes assigned no runoff in this evaluation.

Sanibel bayous basin estuarine surface water samples had the highest concentration of TP and TN among estuarine sites in near shore waters in Phase 1. Surface water concentrations of TN and TP were also significantly greater than those found in the refuge basin estuarine samples. The loading estimates in this work support those findings with the bayous basin contributing high total nutrient loads while the refuge basin had the lowest (Table 28).

Stormwater systems (community ponds and lakes) on Sanibel collect and retain much of the stormwater runoff in several of the drainage basins. Nutrient concentrations are typically high compared to all Florida lakes and approach levels found in stormwater runoff. The stormwater systems have been designed to contain a design storm runoff volume without discharge. However some of the systems do discharge regularly and interact with estuarine waters and the Sanibel Slough system (Thompson 2013). In addition, these systems are directly connected to the water table aquifer and groundwater moves through the porous sands of the island to the Sanibel Slough, the estuary, and the ocean. In Phase 3, we will evaluate groundwater nutrient loadings to and from Sanibel waterbodies and compare those loads to surface water runoff.

Conclusions

Development of Sanibel-specific runoff coefficients and concentrations significantly lowered estimates of nutrient loading rates originally developed in Phase 1 (Thompson and Milbrandt 2013). Stormwater runoff coefficients are now available for the major anthropogenic land classes and unique values are available for each of the 12 Sanibel drainage basins defined in Phase 1. Sanibel-specific coefficients were derived using revised runoff models and resulted in an estimate of total stormwater runoff from Sanibel that was 24% less than values calculated in Phase 1. In general lower nutrient loading rates were found after analyzing nutrients in water samples collected during storm events. The lower runoff volume compared to estimates derived from Florida-specific literature values is likely a result of conditions unique to Sanibel such as soil type and connectivity of stormwater areas. The City of Sanibel has also implemented stormwater retention requirements, impervious surface limitations, and vegetation and fertilizer ordinances. This combined with an acutely aware community and City Council makes Sanibel unique and well positioned to address nutrient management effectively.

Mean nutrient concentrations obtained from water samples collected in Phase 2 during precipitation events further refined loading estimates. The new data reduced TN loading estimates by 55% and IN loading by 62% compared to Phase 1 loading estimates. However, we found inorganic phosphorus concentrations in Sanibel runoff to be greater than those found in Phase 1. The new loading estimates for inorganic phosphorus (OP) increased 28% over Phase 1 estimates even though runoff rates decreased 24%. The increase in inorganic phosphorus loading was due to the finding of higher phosphorus concentrations in stormwater runoff. Estimated total phosphorus (TP) loads decreased by 33% suggesting that the total phosphorus concentration estimates used in Phase 1 were close or slightly higher than actual levels found.

As expected, Sanibel's stormwater TN loading rates were found to be lower than rates for the Caloosahatchee and Saint Lucie watersheds which have large areas of intensive agricultural and urban land uses. However Sanibel's TP loading rate was as high as those agricultural and urbanized watersheds. The main source of phosphorus on Sanibel is reclaimed water used for irrigation. The mean OP concentrations in runoff from sites using reclaimed water was significantly greater than sites not using reclaimed water. Phase 1 found significantly greater OP concentrations in basins which used reclaimed water. Modeling done in that initial work found that a 30% reduction in phosphorus would be necessary before any reduction in algae biomass could occur in Sanibel Slough (Thompson and Milbrandt 2013). The reduction in runoff of phosphorus from reclaimed water should be one of the highest priorities of any additional BMP programs undertaken on Sanibel.

Golf courses and medium density residential land classes proved to be the largest contributors to nutrient loads. Golf courses made up 9% of the anthropogenic land area while they are the source of over 35% of the inorganic phosphorus load from Sanibel. Inorganic nutrients are known to cause algae blooms and fish kills. Medium density residential nutrient concentrations were highly variable with many sample sites having concentrations well above nutrient criteria for nitrogen and phosphorus while others had very low levels. The variability is likely due to differences in fertilizer use between landowners and time since last application. When considering BMPs for the reduction of nutrient loads to the Sanibel Slough and Pine Island Sound, resources may be wisely focused on golf courses and medium density residential land classes. Specifically the fact that there are only 3 golf courses but they contribute so significantly to loading, making them a logical choice for nutrient loading reduction activities.

The eastern basin of Sanibel Slough was found to contain significantly greater concentrations of TP and OP than the western basin during Phase 1 evaluation (Thompson and Milbrandt 2013). In this effort, we found TP and OP stormwater loading rates to the eastern slough basin were 2-3 times greater than those in the western slough. In addition, TN and IN loading rates were greater in the eastern slough. The east slough basin accounted for 18-22% of the total mass of stormwater runoff-associated nutrients leaving Sanibel.

Nutrient loads from Sanibel bayous basin were highest amongst watersheds discharging to the estuary. This finding corresponds to significantly greater concentrations in that basin's estuary surface water samples compared to the wildlife refuge basin (Thompson and Milbrandt 2013). The very low stormwater nutrient loads originating in the Wildlife Refuge basin corresponded to the lowest nutrient concentrations in estuarine surface waters found in Phase 1. This basin may serve as a 'control' for implementation of BMPs in other basins.

Comparisons of nutrient concentrations between dry (fertilizer allowed) and wet (no-fertilizer) season found only TN to be greater during fertilizer season. The expected greater concentration of IN in dry season runoff was not realized and this may be a credit to city-wide BMPs including the fertilizer ordinance.

Findings in this work and in Phase 1 suggest groundwater may have significant interaction with surface waters. Its known connectivity with the Gulf of Mexico and Pine Island Sound provides another route for nutrients to move from Sanibel. Stormwater pond systems which are intended to hold runoff, redirect it to aquifers providing an indirect route for discharge to surface waters. To get a complete picture of nutrient loading from Sanibel to adjacent waterbodies, estimates of groundwater flows and concentrations are needed. Phase 3 of this project involves estimating groundwater nutrient concentrations and discharge rates. Water table aquifer monitoring wells will be installed at representative locations throughout Sanibel. Groundwater flow rates will be estimated using slug in and slug out methods (ASTM 2014) at the well sites. Historical groundwater flow monitoring data will be combined with this new data to estimate flow rates for the differing hydrologic areas of the island. The estimated flow rates will be combined with groundwater sampling results to get estimates of nutrient loadings through Sanibel groundwater.

The Sanibel Slough is listed by Florida DEP as impaired due to enriched nutrient concentrations. With this classification comes the requirement of developing a basin action management plan (BMAP) which will initiate an efficient, information-based implementation of activities designed to improve water quality in the slough. The information provided in the Sanibel Nutrient Management Plan will guide the activity of resource managers by highlighting the major sources and areas requiring attention.

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