CAPTIVA ISLAND SEPTIC TANK IMPACT STUDY

Prepared for:

Captiva Community Panel Wastewater Committee

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EXECUTIVE SUMMARY

At the request of the Captiva Community Panel, ESA conducted a study to determine the impacts to water quality, if any, of the approximately 300 septic tanks systems on Captiva Island. This effort focused on pathogens and nitrogen.

The principal findings of this study can be summarized as below:

- Septic tanks on Captiva Island do not appear to be a substantial source of nitrogen loads to nearshore waters
- Septic tanks on Captiva Island do not appear to be a substantial source of pathogens to nearshore waters
- Septic tanks on Captiva Island are generally set back from coastal waters in accordance with regulatory criteria and non-regulatory guidance
- Many of the septic tanks on Captiva Island do not have adequate separation between the bottom of the drainfield and the wet season water table, compared to regulatory criteria and non-regulatory guidance. This problem is particularly severe in the area of The Village
- Increased sea level over the next 30 years is expected to further exacerbate the issue of inadequate separation between drainfields and the water table
- Decreased separation between drainfields and the water table is likely to reduce the efficiency of soil-based wastewater treatment processes over the next 30 years, perhaps resulting in impacts to water quality that are not yet occurring on Captiva Island
- In areas such as The Village, small lot sizes are could limit the ability of homeowners to build any but performance-based septic tank systems, in response to increases in the water table that are likely to occur with sea level rise
- Currently, it appears that the main source of nitrogen loads to nearshore waters is stormwater runoff
- Areas of above-average stormwater nitrogen loads include South Seas Island Resort, Tween Waters and The Village
- Focused efforts to reduce nitrogen loads from stormwater runoff might be the most cost-effective short-term approach to improve local water quality for Captiva Island

Should Captiva Island decide to replace its septic tank systems with a central sewer system, it would be most beneficial if the destination for those flows is a wastewater treatment plant with Advanced Wastewater Treatment (AWT) capabilities. The widespread movement to AWT processes for sewage treatment in that region of Florida's west coast between Tarpon Springs and Boca Grande is considered to be the most important action behind the widespread recovery of water quality in that region, which has resulted in an increase in seagrass coverage of more than 40 square miles over the past 30 years (i.e., Tomasko et al. 2018 and references within).

Background and Study Design

Prior Studies

Recently, the Sanibel-Captiva Conservation Foundation (SCCF) completed a study on the impacts of septic tank systems on groundwater on Captiva Island (Thompson et al. 2011). The report's main goals were to 1) establish a water quality baseline for surface waters and groundwater, 2) identify potential pollution sources in nearshore waters, 3) to identify any spatial and/or temporal "hot spots" for degraded water quality, 4) coordinate their efforts with other ongoing efforts by local stakeholders, and 5) recommend any potential management actions that might arise, pending the results from their efforts.

The SCCF report sampled both groundwater and surface waters at numerous locations on Captiva Island. With specific reference to Captiva Island, Thompson et al. (2011) concluded the following:

- Levels of the indicator bacteria genus *Enterococcus* were elevated after rainfall events, especially on the east (non-Gulf) side of Captiva Island

- Levels of dissolved oxygen were often classified as "poor" in nearshore areas around Captiva Island

- When using the Florida Department of Environmental Protection's (FDEP) Impaired Waters Rule (IWR) much of the water on the east side of Captiva Island would be classified as "impaired" although the source(s) of the impairment (local vs. regional influences) were not determined in their report

While these findings indicate an overall condition of degraded water quality, the SCCF researchers pointed out that sub-tropical environments with large organic matter inputs from features such as mangrove forests can have naturally occurring reduced water clarity and low levels of dissolved oxygen (Thompson et al. 2011).

In addition to the basic characterization of findings on water quality, the SCCF researchers paid particular attention to the influence of septic tank systems on groundwater and nearshore surface waters in Captiva Island. It was determined that levels of *Enterococcus* bacteria were "low" in the groundwater in all portions of Captiva Island, whether sewered or not, and were actually higher in stormwater runoff than in groundwater. The analysis of results led SCCF researchers to conclude that "…Captiva septic tank systems are not contributing significant numbers of *Enterococcus* bacteria to groundwater." (Page 35 in Thompson et al. 2011).

However, septic tanks were determined to be a potentially important source of nitrogen loads. Nitrogen concentrations in groundwater beneath non-sewered portions of Captiva Island were higher than both reference sites (without any development) and sewered portions of Captiva Island. Based on a nutrient loading model constructed by SCCF (Thompson et al. 2011) the nitrogen load to the nearshore waters of Captiva Island was determined to be 1,550 kilogram (kg) of Total Nitrogen (TN) per year. This amount comes to 36% of the total load of 4,344 kg TN / yr to local waters (mostly from stormwater runoff) indicating that septic tank systems are an important part of local nitrogen loads to nearshore waters.

Nutrient Loading Models

The substantial dataset collected and compiled by SCCF in their study (Thompson et al. 2011) is highly valuable, and the quality of that data collection effort is not in question. However, some of the results suggest that septic tanks might not be as substantial a source of nitrogen loads to nearshore waters as the model indicates. The nutrient loading model for septic tanks constructed by SCCF is, like all loading models, based on a series of assumptions and algorithms that may or may not be locally appropriate. Some preliminary concerns about the accuracy of the septic tank nitrogen loading model estimate are based on the following:

- While the groundwater nitrate concentrations were higher in portions of Captiva on septic tank systems, compared to areas on sewers, the mean value for areas with septic tank systems was only 1.1 mg nitrate (as N) / L

- While nitrate is only one component of TN, it represents that portion of nitrogen that is most likely to travel through groundwater

- If septic tank systems were a substantial source of nitrogen loads to nearshore waters, why is the average groundwater nitrate concentration in areas with septic tanks only 1.1 mg nitrate (as N) / L when nitrogen concentrations in septic tank effluent likely range between 40 to 60 mg TN/L?

- Even if the average groundwater TN value is used, which includes both nitrate and other forms of nitrogen, the average nitrogen concentration is only 1.91 mg TN/L, which is still well below TN concentrations expected in septic tanks themselves

The nitrogen loading model for septic tank systems is based on a number of assumptions that may not be entirely accurate for describing the movement of nitrogen from septic tanks to the drainfield, then to the water table, and then out to surface waters. Those assumptions include many that appear to be entirely reasonable, and the authors (Thompson et al. 2011) obviously took great care to develop a locally-relevant nutrient load. However, there are a number of important assumptions in the model that while they are consistent with prior studies, are nonetheless potentially problematic, such as:

- The failure rate of septic tank systems equals 10%, with the nitrogen load from those systems being delivered with no attenuation to nearby surface waters

- The amount of nitrogen reduction below the drainfield is likely 25%, but no additional attenuation in groundwater appears to have been included in the modeled loads

If either of these two assumptions underestimates the attenuation of nitrogen loads through the linked processes of nitrification and denitrification, then the nitrogen load from septic systems would be overestimated to a degree commensurate with the difference between actual and assumed rates of nitrogen attenuation.

Scope of Services for This Effort

To provide an outside, third party review of the prior studies on the impacts of septic tank systems on water quality in Captiva, ESA completed a number of tasks, starting with a review of the reports produced by TKW (2018) as well as the previously described report from SCCF (Thompson et al. 2011). In addition, ESA collected additional information related to the potential impact of septic tanks on pathogens in nearshore waters. Specifically, ESA completed the following tasks:

- Task 1 – Compilation of existing conditions for septic tanks systems.

This task involved a review of lot sizes for areas on septic tank systems, utilizing on-line data sources. The project was designed to examine lot sizes from 60 sites, 30 in the Village area, and 30 elsewhere on the island, not inclusive of those portions of Captiva in the South Seas Island neighborhood. In addition, those same 60 lots (all on septic tanks) were further assessed to determine the distance to open water, while a different number of sites (which required homeowner approval) were the focus of an effort to determine the distance between the bottom of the septic tank drainfield and the seasonal high water table. Results were compared to guidance from the scientific literature, as well as regulatory guidance from both the US EPA and the State of Florida's Department of Public Health.

In addition to summarizing existing conditions, an estimate was made to determine the impact of two Sea Level Rise (SLR) scenarios, over 20 and 30-year time frames, to determine if the expected performance of septic tank systems would be compromised in coming decades by accelerated rates of SLR.

- Task 2 – Collection of additional pathogen data

At three locations, and on two occasions, ESA collected samples for determination of pathogen abundance using two different techniques: traditional regulatory pathogen indicators, and indicators that were specific to humans as a source.

- Task 3 – Nutrient loading model

Using a combination of data from the SCCF report (Thompson et al. 2011) and existing literature, a nutrient loading model was developed for both surface water runoff and septic tank loads. The approach for stormwater loads outlined in Thompson et al. (2011) was replicated to determine if similar quantities of freshwater runoff and nutrient loads would be calculated, using the same algorithms in the SCCF model (Thompson et al. 2011). The septic tank nutrient loading model was also examined, to determine if a similar estimate would be calculated, using the algorithms in the SCCF report. Finally, an additional estimate was made of the nitrogen loads from septic tanks, to compare to the estimates from the SCCF model (Thompson et al. 2011).

Results and Discussion

Lot Characterization

A randomization technique was developed to choose 60 sites in Captiva Island to determine their lot size, as well as the estimated distance between the septic tank drainfield and the nearest waterbody, whether the Gulf of Mexico or Pine Island Sound. The randomly chosen sites are not displayed in this report, to protect the anonymity of homeowners. The 60 sites were then stratified *a priori* into the areas of The Village, Tween Waters, Gold Coast and Roosevelt Channel. The Village is that area between South Seas Island Resort and the Green Flash restaurant. Tween Waters refers to the area between the Green Flash and the southern end of the S-curve on Captiva Drive. Below the S-curve on Captiva Drive, properties along the Gulf side are referred to as the Gulf Coast, while those that face Pine Island Sound are termed Roosevelt Channel. For the lot size and set back distance assessments, lots were assessed in the following approach: 30 sites in The Village, 15 in Tween Waters, 9 in Gold Coast, and 6 in Roosevelt Channel.

Findings on lot sizes, setback distances and the distance between the bottom of the drainfield to the seasonal high water table are compared to existing guidance criteria for each characteristic, as listed in Table 1.

Table 1 – Summary of literature-based and regulatory guidance criteria for lot sizes, setback distances and separation distances between the bottom of drainfields and seasonal high water tables.

Paramater	Criterion	Justification	Source
Lot size	> 6 acres	Shellfish closures due to bacteria	Duda and Cromartie (1982)
	> 6 acres	Nutrient impacts to surface waters	Malin (2013)
	> 6 acres	Potentially problematic	USEPA (2002)
	1/2 acre	Standards for onsite sewage treatment and disposal	FAC 64-E 6.005(7)(a)
Setback distance	150 feet	Nutrient loading	Corbett et al. (2002)
	75 feet	Standards for onsite sewage treatment and disposal	FAC 64-E 6.005(3)
Bottom of drainfield to seasonal high water table	3 feet	Nutrient impacts to surface waters	Corbett et al. (2002)
	2 feet	Suggested guidance for minimum	USEPA (2002)
	5 feet	Suggested guidance	USEPA (2002)
	2 feet	Standards for onsite sewage treatment and disposal	FAC 64-E 6.0006(2)
	3 1/2 feet	Standard for locations with coarse sand	FAC 64-E 6.008

Results from the lot size assessment are shown in Figures 1, 2, 3 and 4 for The Village, Tween Waters, Gold Coast, and Roosevelt Channel, respectively.

Figure 1 – Distribution of lot sizes (acres) in The Village.

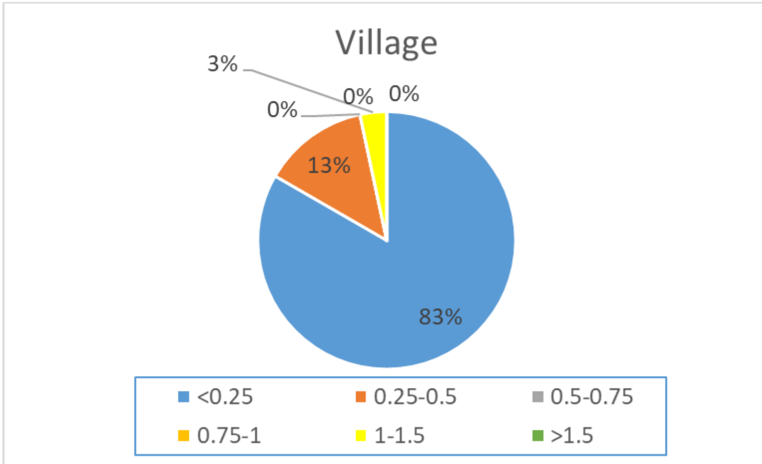


Figure 2 – Distribution of lot sizes (acres) in Tween Waters.

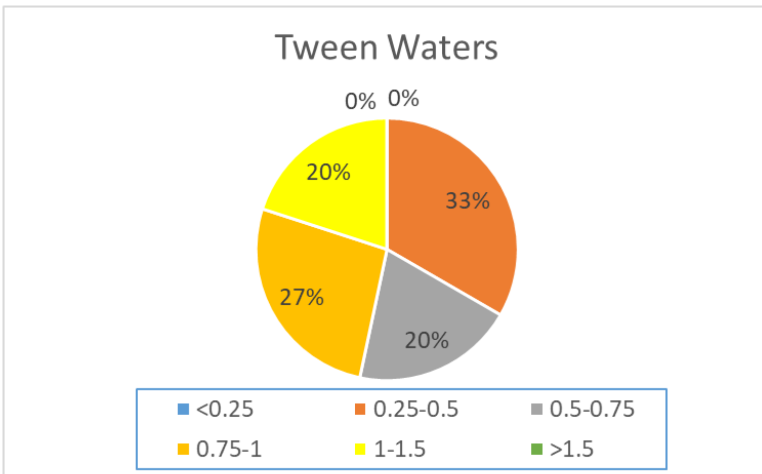


Figure 3 – Distribution of lot sizes (acres) in Gold Coast.

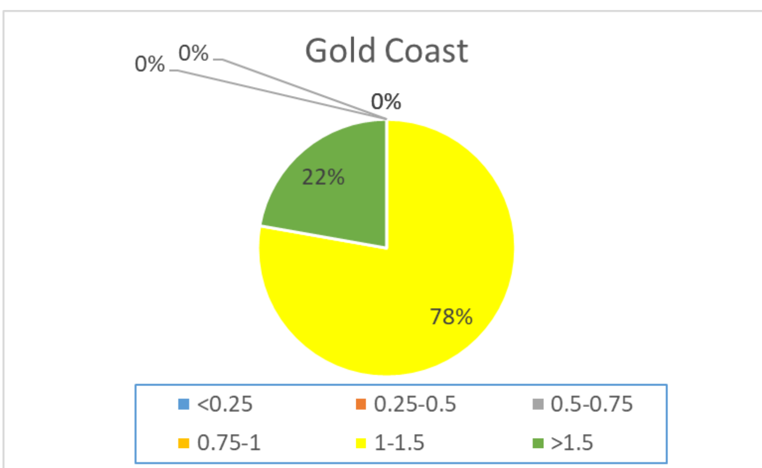
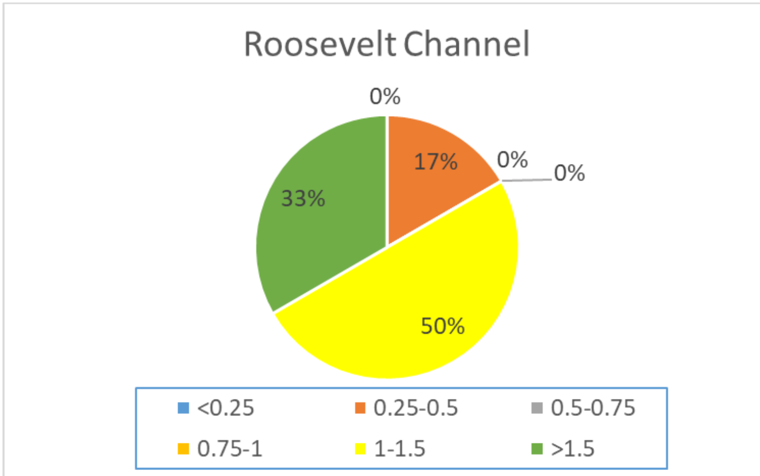


Figure 4 – Distribution of lot sizes (acres) in Roosevelt Channel.



Lot sizes differ quite substantially between The Village and the other areas examined. In The Village, more than 80% of lots were a quarter acre or smaller in size, while none of the remaining 30 lots (chosen at random) examined in the other three regions had lots of a quarter acre or smaller. The largest lots were found in Gold Coast, where each of the 9 lots (chosen at random) were on lots of at least 1 acre in size.

Based on results displayed in Table 1, very few lots on the island meet suggested criteria of 6 acres for septic tank systems. However, Florida Administrative Code (FAC) 64-E 6.005(7)(a) lists a much smaller lots size for new septic tank systems – a value of ½ acre. Results displayed in Figures 1 and 2 show that the vast majority of lots in The Village, and about a third of lots in Tween Waters as well, are smaller than the most lenient guidance criteria of lot sizes for septic tank systems.

Setback distances were estimated for the same houses as were used for lot size characterization. However, the actual distance between the drainfields and surface waters was estimated using available aerial photography, rather than measured with more formal survey techniques (which was outside the scope and budget of this effort). Drainfields can be placed in front yards or back yards or along the side of houses (Tomasko, personal observation) and so their exact location cannot be determined for the houses used for the lot size estimates using aerial photography alone. Therefore, the setback distance estimates displayed here should be considered values that approximate the actual distances. Distances were calculated using ArcGIS, by measuring the shortest distance between those portions of the 60 houses examined here and the nearest open waterbody, whether the Gulf of Mexico or Pine Island Sound.

Estimates of setback distances are shown in Figures 5, 6, 7 and 8 for The Village, Tween Waters, Gold Coast and Roosevelt Channel, respectively.

Figure 5 – Setback distances (feet) for septic tanks and nearby waters in The Village.

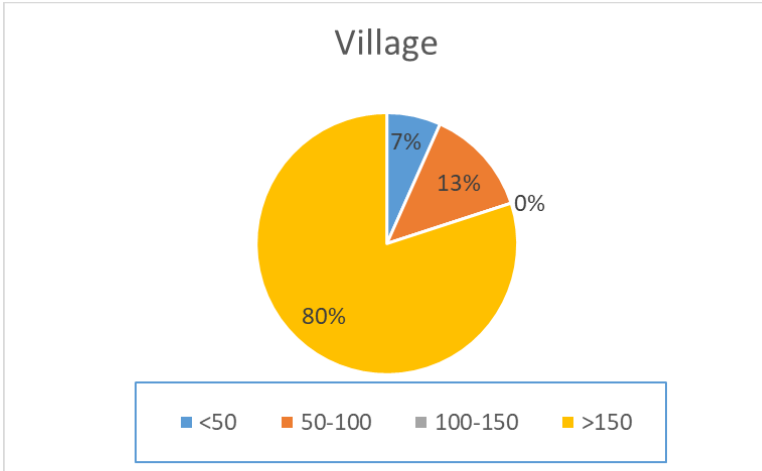


Figure 6 – Setback distances (feet) for septic tanks and nearby waters in Tween Waters.

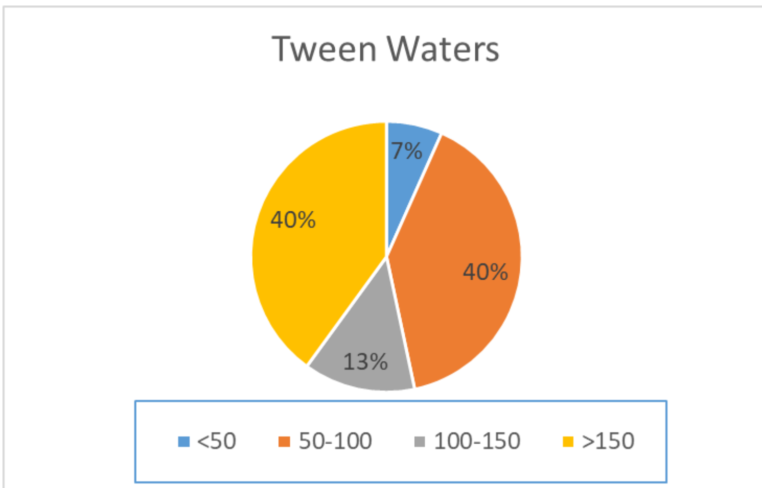


Figure 7 – Setback distances (feet) for septic tanks and nearby waters in Gold Coast.

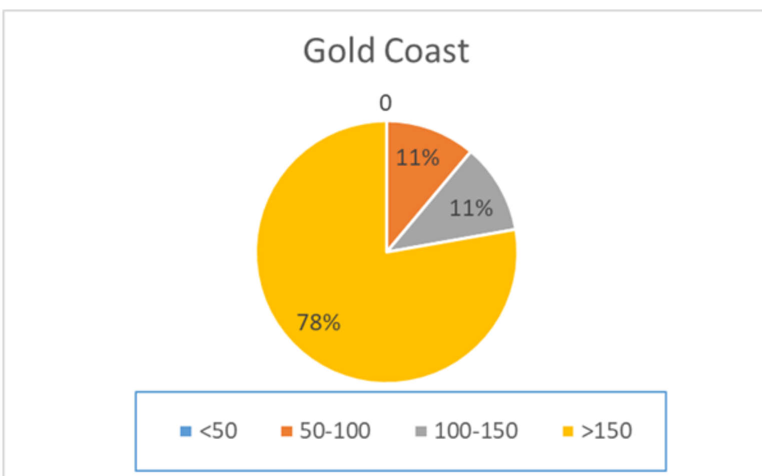
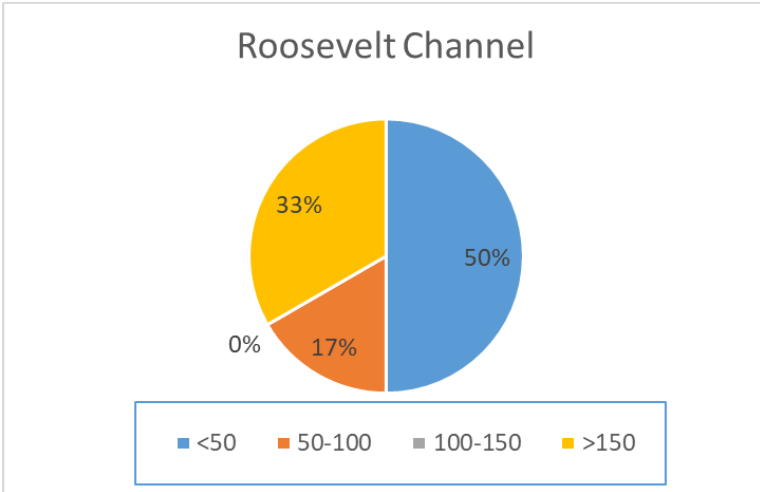


Figure 8 – Setback distances (feet) for septic tank systems and nearby waters in Roosevelt Channel.



The setback distance guidance of 75 feet listed in FAC 64-E 6.005(3) is half that derived by Corbett et al (2002) for septic tank systems on a barrier island in North Carolina. In contrast to the lot size criteria, where The Village had the lowest percentage of systems meeting guidance criteria, the setback distances in The Village were greater, on average than the other three regions examined. In The Village, 80% of setback distances were greater than 150 feet, a slightly greater rate than the 78% value found for Gold Coast lots. In contrast, fewer than half of the lots in Tween Waters and Roosevelt Channel had setback distances greater than the more restrictive 150-foot criterion.

The distance between the bottom of the drainfield and the seasonal high water table was determined by a licensed professional geologist, using soil profiles to document the average depth below the surface of the wet season water table and combining that information with measurements of the depth below the surface of the bottom of the drainfield. Since this estimate was an intrusive exercise that required the permission of the homeowners, the locations and number of locations examined differed from the prior two analyses, which were based on randomly picking lots using GIS-based statistical approaches. In The Village, measurements of the water table elevation were made at 21 houses. In Tween Waters, 7 houses were visited, while 6 houses were visited in Gold Coast, and 9 in Roosevelt Channel.

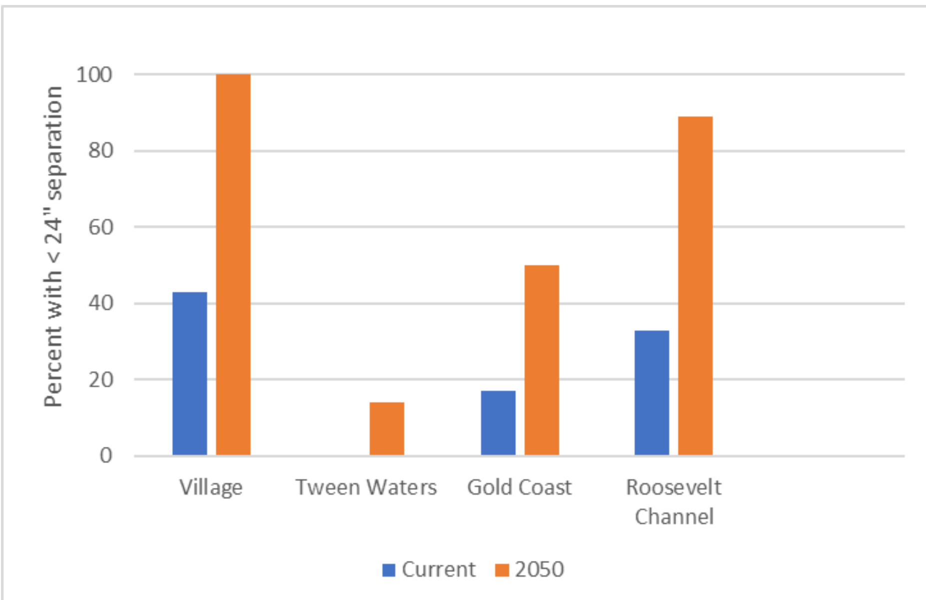
In addition to measuring the distance between the bottom of the drainfield and the wet season water table, estimates were made of the effect of Sea Level Rise (SLR) on water table elevations over a 30-year horizon. Estimates of SLR were based on the Sea-Level Change Curve Calculator (Version 2019.21) – http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html.

The SLR estimate used in this study was the Intermediate High scenario, as was also used in the report "Captiva Sea-Level Rise Resiliency Committee: Working Document." To calculate the effect of SLR over a 30-year horizon, the difference in expected sea levels between 2020 and 2050 was calculated – an increase of 1.3 feet over the next 30 years.

Prior studies have concluded that the water table on barrier islands with unconfined surficial aquifers (as is the case on Captiva Island) will likely track SLR on a one-to-one basis (i.e., Roshani et al. 2013) and the response of septic tank systems to SLR has been studied using a similar approach in Southeast Florida (Miami-Dade County 2018). The increase of 1.3 feet of sea level between 2020 and 2050 was then subtracted from the measured distances between the bottom of the drainfield and the top of the wet season water table, and results compared to existing conditions.

The differences in water table determinations, with the two timeframes and two scenarios are summarized in Figure 9, in terms of the percentage of houses with less than a 24-inch separation between the bottom of the drainfield and the top of the wet season water table.

Figure 9 – Percent of houses in The Village, Tween Waters, Gold Coast and Roosevelt Channel with less than a 24-inch separation between the drainfield and the wet season water table for existing conditions (2019) and estimates for 2050 using the Intermediate High SLR scenario.



The least restrictive criteria, related to the separation of drainfields and wet season water tables is 2 feet, as listed by both the USEPA (2002) and FAC 64-E 6.0006(2). In the coarse sand environments such as are found in many locations in Captiva Island (Travis Richardson, personal communication) guidance criteria are for a 3 ½ foot separation (FAC 64-E 6.008). However, homeowners can overcome the 3 ½ foot separation criteria by importing fine sand onto their lot and replacing the coarse sand under their drainfield (T. Richardson, personal communication). Consequently, the guidance criteria that cannot be overcome by modifying the soils themselves is the less restrictive 2-foot guidance criteria, which is what is used in this analysis.

Using the least restrictive criteria, our results indicate that 43% of lots in The Village do not currently have an adequate separation between the drainfield and the water table, at least in the wet season. By the year 2050, none of the lots in The Village are expected to have adequate separation from the water table. None of the 7 lots visited in Tween Waters currently had less than a two-foot separation, and only one of those 7 lots is expected to have an inadequate separation from the water table in the year 2050.

In both Gold Coast and Roosevelt Channel, 17 and 33 percent of lots visited currently have inadequate separation between the drainfield and the water table. By 2050, the percent of lots with inadequate separation is expected to increase to 50 and 89 percent, respectively, for Gold Coast and Roosevelt Channel.

The need for additional separation distance can be brought about through the construction of a "mounded" drainfield, such as those shown in Figures 10 and 11.

Figure 10 – Example of a mounded septic tank system to increase the separation between the drainfield and the wet season water table. Note how the mounded drainfield occupies the entire side yard.

Figure 11 – Example of a mounded septic tank system to increase the separation between the drainfield and the wet season water table. Note how the mounded drainfield occupies almost the entire front yard.

The ability of lots to accommodate mounded systems for their drainfields is likely to be influenced by the size of the lot available for such systems to be installed. By the year 2050, it is anticipated that every septic tank system in The Village would need be a mounded system. Otherwise, such systems might be difficult or impossible to get permits when their septic tanks fail, which is more likely to occur with higher water tables. The reduced depth between the drainfield and the water table represents an unsaturated zone that is required for septic tank systems to discharge effluent from their tanks into the groundwater. Without adequate separation, the likelihood of encountering compromised drainage from sinks, washing machines and toilets will increase, as the soils below the drainfield become increasingly saturated with water from elevated sea level.

Stormwater Nitrogen Loading Model

The stormwater loading model developed by SCCF researchers (Thompson et al. 2011) was reviewed in terms of the assumptions and algorithms, to determine their reasonableness. All nutrient loading models involve a combination of measured data and assumptions. The actual measured data inputs include the different land uses and soil types underlying those land use types, as well as the amount of rainfall that occurs. The SCCF stormwater loading model included GIS-based assessments of the amount of land in the general categories of natural systems (i.e., mangroves, beaches and shrub and brushland) as well as the amount of developed land (i.e., low, medium and high density residential, roadways and golf courses). There is no reason to conclude that the acreage estimates used in the SCCF model are anything but accurate, based on the detailed breakout of land uses in that model.

Stormwater models then have to incorporate various model assumptions, including the amount of stormwater runoff generated, as well as the concentration of nutrients (in this case nitrogen) in the predicted amount of stormwater runoff, often termed the Even Mean Concentration (EMC) value.

The review of the SCCF model found that the runoff coefficients and EMC values used in the model are reasonable, and fit within the range of expected values found in a state-wide guidance document prepared for FDEP (Harper and Baker 2007).

As a next step, ESA used the acreages, rainfall amounts, runoff coefficients and EMC values provided by SCCF (Table 8 in Thompson et al. 2011) to re-run the stormwater loading model. This effort was run to determine if the calculated values could be replicated, as a step to ensure that volumes and loads were properly derived. Results are displayed in Table 2.

Table 2 – Stormwater runoff volumes and nitrogen loads from stormwater runoff on Captiva Island. LDR = Low density residential. HDR = High density residential.

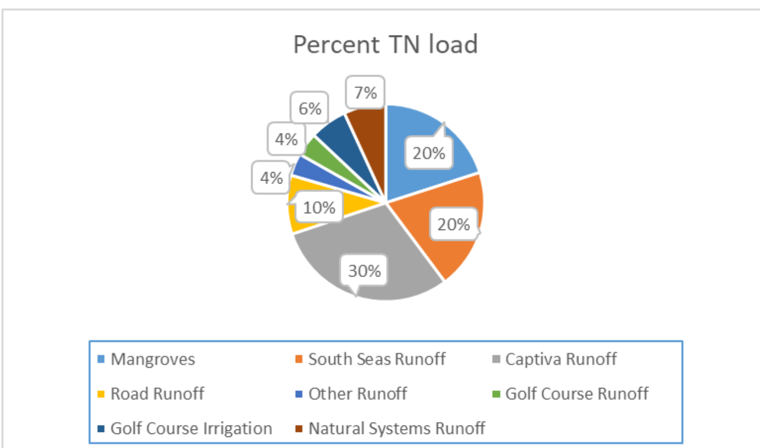
Land use	Percent impervious	Area (acres)	Percent of Captiva	Soils group	Dry season runoff coefficient	Annual dry season rain (m)	Annual dry season runoff (m3)	Wet season runoff coefficient	Annual wet season rain (m)	Annual wet season runoff (m3)	Total runoff (m3/yr)	Total runoff (liter/yr)	Percent total runoff	EMC value for TN (mg/L)	TN load (kg/yr)	Percent TN load	Load to area ratio
Mangroves	6	141.1	18%	D	0.95	0.33	179,012	0.95	0.73	395,996	575,008	575,008,461	26%	1.00	575	20%	1.1
LDR - South End Captiva	17	216.1	28%	C	0.25	0.33	72,148	0.35	0.73	223,441	295,590	295,589,647	13%	1.70	503	18%	0.6
LDR - South Seas Plantation	25	26.5	3%	C	0.35	0.33	12,386	0.45	0.73	35,229	47,615	47,615,308	2%	2.10	100	3%	1.0
LDR - Mid Captiva	15	12.6	2%	C	0.21	0.33	3,534	0.31	0.73	11,539	15,073	15,072,758	1%	2.10	32	1%	0.7
LDR - Captiva Town	25	8.5	1%	C	0.25	0.33	2,838	0.35	0.73	8,789	11,627	11,626,617	1%	2.10	24	1%	0.8
MDR - Captiva Town	30	55.3	7%	C	0.35	0.33	25,848	0.45	0.73	73,515	99,363	99,363,265	4%	2.10	209	7%	1.0
HDR - South Seas Plantation	60	80.8	10%	C	0.50	0.33	53,953	0.65	0.73	155,155	209,108	209,107,524	9%	2.10	439	15%	**1.5**
HDR - Middle Captiva	40	10.5	1%	C	0.45	0.33	6,310	0.55	0.73	17,061	23,371	23,370,593	1%	2.10	49	2%	**1.3**
HDR - Captiva Town	60	8.7	1%	C	0.50	0.33	5,809	0.65	0.73	16,706	22,515	22,515,290	1%	2.10	47	2%	**1.5**
Roadways	90	30.7	4%	C	1.00	0.33	40,999	1.00	0.73	90,694	131,693	131,692,788	6%	2.10	277	10%	**2.5**
Golf Course rainfall	30	42.7	5%	C	0.21	0.33	11,975	0.28	0.73	35,320	47,296	47,295,566	2%	2.32	110	4%	0.7
Golf Course irrigation runoff*	30	42.7	5%	C	0.15	1.08	27,994	0.16	1.72	47,555	75,548	75,548,488	3%	2.32	175	6%	1.1
Recreational - beach	0	120.6	15%	C	0.10	0.33	16,106	0.31	0.73	110,446	126,552	126,551,581	6%	1.40	177	6%	0.4
Commercial - Tween Waters	85	9.6	1%	C	0.78	0.33	10,000	0.97	0.73	27,510	37,509	37,509,499	2%	2.81	105	4%	**3.0**
Commercial - South Seas	85	4.2	1%	C	0.78	0.33	4,375	0.97	0.73	12,035	16,410	16,410,406	1%	1.70	28	1%	**1.8**
Shrub and brushland	10	14.4	2%	C	0.18	0.33	3,462	0.26	0.73	11,061	14,522	14,522,062	1%	1.40	20	1%	0.4
Total		**782.3**	**100%**				**476,748**			**1,272,052**	**1,748,800**	**1,748,799,853**			**2,870**		

The nitrogen load calculated from this exercise came out to 2,870 kg TN/yr, a value less than 3% different from the TN load of 2,797 kg TN/yr calculated by SCCF researchers (Thompson et al. 2011).

By combining runoff of different land uses within the same geographic area, the ratio between the acreage in different parts of Captiva was compared to the percentage of the stormwater nitrogen load from those same areas. Ratios higher than 1 represent parts of the island that appear to be producing more stormwater runoff than would be expected based on area alone. In this way, geographic "hot spots" of stormwater loads can be identified. Based on this approach, hot spots for stormwater loads include the commercial land use in Tween Waters, road runoff across the island, and commercial areas in the South Seas part of the island. Of lesser importance, but still with elevated stormwater loads, are high density residential in South Seas Island Resort and in The Village. In those areas, special attention should be paid to identify and act on any areas of direct stormwater runoff to local waters, so that such areas can be retrofitted to reduce any identified discharges of untreated stormwater runoff. However, it is likely that some of the nitrogen load from roadways, for example, is already attenuated quite effectively in those areas where runoff is routed towards grassy swales; the priority should be those areas where runoff is routed directly to storm drains, or directly to surface waters.

An additional assessment was done with the results shown in Table 2; the stormwater runoff from multiple land use types in a single geographic area were combined, so that broader categories of loads could be developed. The results of this exercise are displayed in Figure 12.

Figure 12 – The percent of island-wide stormwater loads of Total Nitrogen (TN) from various areas and/or land use types.



Results displayed in Figure 12 show that the largest stormwater load comes from the combined land use types in the Village region (grouped as "Captiva Runoff" to be consistent with the SCCF land use categories). The second biggest source of stormwater loads of TN comes from South Seas Island Resort, followed by those from the island's mangrove forests. It should be noted that nitrogen loads from mangrove forests should be considered "natural" loading sources, rather than a load that needs to be attenuated in some manner. The results displayed in Table 2 and Figure 12 suggest that the practice of the South Seas Island Resort to use wastewater effluent for golf course and other irrigation needs is a fairly minor source (ca. 6%) of island-wide nitrogen loads from stormwater runoff.

SCCF Septic Tank System Nitrogen Loading Model

Similar to the development of a stormwater loading model, the construction of a model to quantify loads from septic tank systems involves a number of assumptions and algorithms. The main assumptions include the following: 1) the number of septic tanks, 2) how many people in the typical household, 3) how much volume is generated per household, 4) what is the amount of nitrogen loaded into the septic tank itself, 5) how much nitrogen remains in the tank, and how much is loaded into the groundwater via the drainfield, 6) what types of processes occur that can affect nitrogen between the drainfield and the water table, and 7) what types of processes can affect nitrogen as it travels from below the drainfield out to nearby surface waters.

The SCCF researchers did an admirable job quantifying expected nitrogen loads from septic tanks, but as in any model, the accuracy of load estimates is dependent upon the validity of the various model assumptions and algorithms.

Those assumptions that are likely to be the most accurate include estimates of the number of septic tank systems, the number of people per household, and the volume of wastewater entering the groundwater below septic tank drainfields. Those assumptions that are likely to have the greatest uncertainty include those related to the transport of nutrients (in this case, nitrogen) through groundwater. The SCCF loading model uses assumptions and algorithms from prior studies, such as those by Janicki (2010) and Hazen and Sawyer (2009). However, some of the assumptions in both those studies are in turn estimates based on other earlier work that may be assumptions themselves, or which could be process rates that may not be appropriate for Captiva Island.

The main assumptions used in the septic tank nitrogen loading model include the following (pages 30 to 31 in Thompson et al. 2011):

- There are 303 septic tank systems on Captiva Island
    - 121 systems are continuously occupied, while 78 are seasonally occupied
    - It is not clear why the number of continuously and seasonally occupied systems does not equal the estimated 303 systems on the island
- Each system has an estimated 1.95 users
- By comparing the portion of seasonal and continuously occupied systems, the total amount of "people-days" calculates to 100,000
- The mean TN load per person-day is 11.2 grams

- A 10% failure rate was used, with failure defined as those systems that discharge effluent directly to surface waters, with little to no attenuation of nitrogen

- For properly functioning systems, there are three main assumptions -

    - 10% of the TN load to septic tank systems is left behind in the tank itself

    - Nitrogen reduction in the area between the drainfield and the groundwater table is 25%

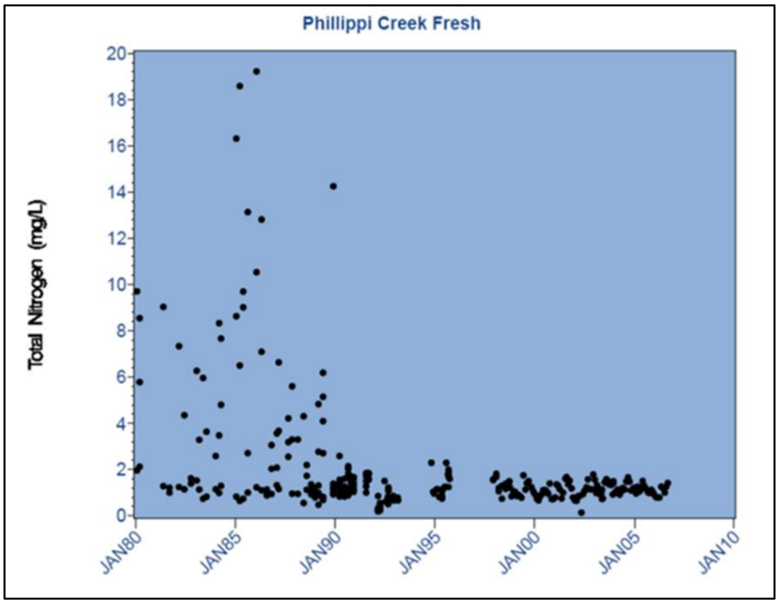
    - No further attenuation of nitrogen in groundwater is anticipated (p. 17)

The assumptions listed above are reasonable and have been used in prior loading models. But many of the assumptions are problematic when looked at in greater detail, or when they are examined in comparison to local water quality data. For example, if there are an estimated 100,000 people-days for septic tank users, and the mean TN load per person day is 11.2 grams, then the total amount of TN from septic tanks would calculate to 1,120 kg TN per year, after converting grams to kg. However, the nitrogen load estimate from septic tank systems is 1,550 kg TN/yr, a value 38% higher than the calculated amount of nitrogen estimated via the combination of people-days per year and nitrogen load per person-day.

In addition, the implications of an assumed 10% failure rate - while fully consistent with prior FDEP guidance – is problematic when viewed as how such impacts would manifest themselves. Using FDEP guidance, the load from "failed" systems is calculated by assuming that there is a direct flow of untreated waste from 10% of septic tank systems in any given neighborhood. This requires one or two scenarios to occur: 1) there is an overland flow of sewage across the landscape out to nearby surface waters, with no attenuation in flow or nutrient content, and/or 2) there is no additional reduction of nitrogen through the processes of denitrification in the groundwater. The first scenario is unlikely, as it would result in an obvious health hazard that would require 30 houses on Captiva Island to create a continuous stream of sewage across yards, into ditches and out to nearby waters. This is unlikely, as it would create odiferous and aesthetically unpleasant condition to be clearly visible in multiple neighborhoods. The second scenario is also unrealistic. On a barrier island community in Northwest Florida, a setback distance of 150 feet was found to be capable of reducing nitrogen concentrations to background levels (ca. 1.1 mg TN/L) provided there was an adequate separation between the drainfield and the wet season water table (Corbett et al. 2002). Nitrogen attenuation in groundwater can be minimal, but it can also range to values as high or higher than 90% loss via the linked processes of nitrification and denitrification (Hazen and Sawyer 2009)

In Philippi Creek, in the Sarasota Bay watershed, elevated levels of nitrogen were originally determined to be due to the <u>thousands</u> of septic tank systems in the watershed (Heyl, 1992). However, a significant reduction in TN concentrations in Philippi Creek occurred in 1990, prior to the initiation of a septic tank replacement program (Figure 13).

Figure 13 – Pattern of TN concentrations in Philippi Creek, in the Sarasota Bay watershed.



The reduction in TN concentrations in Philippi Creek in 1990 was not due to the elimination of thousands of septic tank systems in the watershed, it was due to a change in the disposal practices of a privately run wastewater treatment plant (WWTP). That WWTP only treated effluent to secondary standards, it did not have advanced wastewater treatment (AWT) for biological nitrogen reduction (BNR). The WWTP discharged of its effluent through the use of a percolation pond for its secondarily treated effluent, which was responsible for the very high TN concentrations in the creek prior to it shifting to a deep well injection system for effluent in 1990. Post-1990, the thousands of septic tank systems remained in the Philippi Creek watershed, yet nitrogen concentrations in downstream waters averaged less than 2 mg TN/L.

The findings displayed in Figure 13, and the results discussed in Corbett et al. (2002) do not support the model assumption that no attenuation of nitrogen would be expected as wastewater volumes from septic tanks systems migrate to nearby surface waters. If there was no significant attenuation of nitrogen loads via denitrification, it would be expected that nitrogen concentrations in groundwater in areas on septic tank systems would be elevated above areas not on septic tank systems, which is the case, as areas of developed areas of Captiva Island on septic tank systems had 11 times as much nitrate (1.1 mg nitrate (as N)/L) as developed areas on sewer (0.1 mg nitrate (as N)/L) as shown in Table 2 of Thompson et al. (2012). The highest nitrate value listed in Thompson et al. (2011) is 2.48 mg nitrate (as N)/L, still far below the TN concentration of wastewater loaded into septic tanks. The other form of dissolved nitrogen is ammonia/ammonium. The mean value for ammonia/ammonium in areas of Captiva on septic tanks was recorded as 0.096 mg Total Ammonia Nitrogen (TAN)/L (Table 2 in Thompson et al. 2012). Using TN as a more inclusive indicator of nitrogen content (of all forms) the mean groundwater content on Sanibel and Captiva Island was 1.91 mg TN/L (Table 2 in Thompson et al. 2012). Unfortunately, TN concentrations were not recorded for areas exclusively on septic tanks, although nitrate and TAN levels were.

In contrast, the nitrogen content of raw wastewater loaded into septic tanks can be as high as 40 to nearly 60 mg TN/L (Hazen and Sawyer 2009). Assuming TN concentrations contain nitrate, TAN and other forms of nitrogen, the mean groundwater TN concentrations is still substantially lower than the TN concentration in wastewater.

Although this discrepancy could be due to the fact that much of the nitrogen below these drainfields could be in forms other than nitrate (such as ammonium) it could also be that naturally occurring soils on Captiva Island could be attenuating nitrogen loads via linked nitrification and denitrification processes at rates that are higher than the presumed values.

In a review of the rates of natural soil processes for “normal” septic tank systems, it was concluded (Long 1995, as cited in Hazen and Sawyer, 2000) that “...soil treatment removes between 23 to 100 percent of the nitrogen.” Whether high rates of nitrogen attenuation via natural soil processes occur in Captiva Island is unknown, which means that the transport of nitrogen from drainfields to surface waters is also unknown.

Alternative Septic Tank System Nitrogen Loading Model

The relatively low levels of nitrate and TAN in groundwater in areas on septic tanks suggests that there could be more attenuation of nitrogen via soil processes than is assumed in the SCCF septic tank nitrogen loading model (Thompson et al. 2011). An alternative septic tank nitrogen loading model was constructed, using the following assumptions:

- 303 septic tank systems on Captiva Island
- Literature based estimates of the volume of water used per person per day
    - Low-range estimate of 50 gallons / person / day
    - High-range estimate of 78 gallons / person / day
- 1.95 people per household on septic tank systems
- Mean level of dissolved inorganic nitrogen (DIN) of 1.196 mg N/L
    - Mean nitrate of 1.100 mg (as N)/L plus mean TAN of 0.096 mg (as N)/L

Using these assumptions, the nitrogen load to nearby waters was thus calculated as the volume of water added to the groundwater table from septic tank systems multiplied by the concentration of dissolved forms of inorganic nitrogen in areas on septic tank systems, with no attenuation in volume or concentration.

This assessment can be construed as a conservative one, as it assumes that there is no attenuation of nitrogen via natural soil processes between the drainfields and nearby surface waters, and that the ammonia/ammonium (aka TAN) is as mobile through groundwater transport as nitrate. After converting from gallons to liters and from milligrams to kilograms, the nitrogen load estimates calculated with the low-range and high-range scenarios come to 49 and 76 kg TN/yr, respectively.

The nitrogen load estimates calculated here are 97 and 95% lower than SCCF's estimate of 1,550 kg TN/yr for low and high range scenarios, respectively. While the nitrogen loading estimates calculated here also rely on assumptions and algorithms that are untested locally, they do appear to be more consistent with the fairly low concentrations of nitrogen in the groundwater in those neighborhoods in Captiva Island served by septic tank systems. Even if the estimates derived above are off by an order of magnitude, they would still represent nitrogen loads at least 50% lower than the prior estimate of 1,550 kg TN/yr.

Wastewater Treatment Plant Nitrogen Loading Model

In addition to the estimates of nitrogen loads from stormwater runoff and septic tanks, an estimate was made of the potential nitrogen load from three small capacity wastewater treatment plants on Captiva Island. The nitrogen load from the South Seas Island Resort facility is included in the stormwater loading model, under the category of "irrigation runoff" as treated effluent from that facility is typically used for irrigation on the resort's various properties.

In contrast, wastewater effluent from the treatment plants for Tween Waters Inn, Sunset Captiva and Captiva Shores Condominium mostly dispose of effluent through the use of drainfields, rather than an elaborate irrigation system. Staff at the SCCF were queried for any relevant information related to each plant's treatment capacity, and the flow data were then combined with to other estimates to determine the potential nitrogen load from these small treatment plants. It was assumed that the effluent from the plants would be at nitrogen concentrations typical of treatment plants not using linked nitrification/denitrification systems for biological nitrogen removal; or approximately 20 mg TN/L. It was further assumed that approximately 80 percent of the nitrogen load applied to the groundwater below the drainfields would be attenuated by natural soil processes prior to any plumes of water reaching nearby surface waters.

The results of this assessment are displayed in Table 3.

Table 3 – Effluent volumes, model assumptions and estimated nitrogen loads for the Tween Waters Inn, Sunset Captiva, and Captiva Shores Condominium wastewater treatment plants.

Facility	Capacity (mgd)	Capacity (L/yr)	Discharge type	Assumed TN in discharge (mg/L)	Assumed attenuation (%)	Potential load to surface water (kg TN/yr)
Tween Waters Inn	0.040	55,261,000	drainfield	20	80	221
Sunset Captiva	0.025	34,538,125	drainfield	20	80	138
Captiva Shores Condominium	0.010	13,815,250	drainfield	20	80	55
Sum						**414**

It should be noted that a small change in the assumptions shown in Table 3 can make a large difference in the estimated nitrogen load from these three wastewater treatment plants. For example, the groundwater quality data from areas with septic tanks suggest that there might be more nutrient removal on Captiva Island's soils than the estimate of 80 percent used here. If an attenuation rate of 90 percent is used, the estimated load decreases to 207 kg TN/yr. Similarly, if an estimated attenuation rate of 70 percent is used, the estimated load increases to 622 kg TN/yr.

Even if the TN concentration of effluent is as high as 20 mg/L, and if soil attenuation of nitrogen is only 70 percent, that estimate (622 kg TN/yr) is only about 22 percent of the estimate for the amount of nitrogen loaded to nearby waters by stormwater runoff (2,870 kg TN/yr).

Pathogen Survey

The State of Florida uses three main categories of bacteria to serve as indicators of potential human health risks. These indicators are fecal coliform bacteria, enterococci bacteria, and *E. coli* bacteria. Fecal coliform refers to a broad category of bacteria that are rod-shaped, and which grow on media that are created to try and discriminate against bacteria from non-human sources. Enterococci bacteria are bacteria from the genus *Enterococcus*, which includes more than a dozen species. And *E. coli* refers to bacteria of a particular species in the genus *Escherichia*. These indicators are thus increasingly specific, from a group to a genus to a species. However, none of the three indicators are specific to humans as a source, nor are they specific to mammals, or even animals as sources.

Different types of "fecal coliform" bacteria have been associated with non-fecal sources, such as pulp and paper miss wastes (Knittel 1975, Caplenas et al. 1984) fresh vegetables (Duncan and Razzell 1972) and even grass clippings (Tomasko et al. 2017). Enterococci bacteria can persist and grow on decomposing seaweeds (Byappanahalli et al. 2003, Whitman et al. 2003) a finding supported by SCCF researchers (Thompson et al. 2011). And even *E. coli*, considered a precise indicator of human fecal sources by some, can be associated with the decomposition of algae, at least in freshwater systems (Ksoll et al. 2007). Therefore, while levels of fecal coliform bacteria, enterococci bacteria or *E. coli* bacteria are used as indicators of the potential threat to human health in Florida, they are not by themselves evidence of human fecal matter as a source.

This portion of the study involved the collection of the three above-mentioned indicators of human health, along with the use of indicators that were specific to humans as a source. The human specific indicators that were measured include two techniques that looked for a human gene biomarker termed Human Bacteroidetes Identification: Dorei and Human Bacteroidetes Identification: EPA method. These two techniques looked for a human gene marker using real-time quantitative Polymerase Chain Reaction (QPCR) analytical techniques, where water samples were sampled for a DNA sequence that is restricted to humans, for a bacterial genus, *Bacteroidetes*, that is itself not specific to humans as a source (as is the case for the other three bacterial indicators). In addition, water samples were taken for detection of viruses that would be indicative of human fecal contamination, including one technique for adenoviruses, and two techniques that tested for noroviruses. Adenoviruses are associated with common maladies such as conjunctivitis (aka pink eye) while noroviruses are capable of causing vomiting and/or diarrhea upon exposure. For these assays, virus detection was accomplished using droplet digital PCR (ddPCR) DNA/RNA assays.

The three traditional and four human-specific indicators were all quantified on two occasions at each of three locations. Sampling was conducted on April 15, 2019 and then again on June 25, 2019. Samples were taken at three locations – in the storm drain located at the eastern terminus of Andy Rosse Lane, at the point of discharge of a large storm drain into the nearshore waters of Pine Island Sound along the mangrove shoreline east of the first location, and then along the shoreline just south of the pier at McCarthy's Marina. Figures 14, 15 and 16 show the locations of the sampling locations.

Figure 14 – Storm drain sampling location at the corner of Andy Rosse Lane, SW and Binder Drive. Note vegetation on top of grate.

Figure 15 – Point of discharge of storm drain system into Pine Island Sound, east of the corner of Andy Rosse Lane, SW and Binder Drive

Figure 16 – Shoreline south of the McCarthy's Marina pier. Note substantial amount of decomposing seagrass blades and macroalgae along the shoreline.

Results from the pathogen testing are displayed in Table 4.

Table 4 – Results of testing for each of three standard techniques for quantifying pathogen indicator bacteria, as well as tests for human-specific markers. TNTC = too numerous to count (inadequate dilution). ND = not detected. Values in yellow highlight indicate values in excess of existing criteria, or likely in excess of existing criteria (for TNTC, if upper limit would exceed criteria).

Date	Location	Fecal coliform bacteria (count/100 ml)	Enterococci bacteria (count / 100 ml)	E. coli bacteria (count / 100 ml)	Bacteroidetes dorei	Bacteroidetes – EPA Method	Adenovirus	Norovirus – Group I	Norovirus – Group II
4/15/2019	**Storm drain**	TNTC	24,196	TNTC	ND	ND	ND	ND	ND
4/15/2019	**Storm drain outfall**	TNTC	15,500	TNTC	ND	ND	ND	ND	ND
4/15/2019	**Shoreline**	60	262	TNTC	ND	ND	ND	ND	ND
6/25/2019	**Storm drain**	13	10	10	ND	ND	ND	ND	ND
6/25/2019	**Storm drain outfall**	9	31	585	ND	ND	ND	ND	ND
6/25/2019	**Shoreline**	45	134	431	ND	ND	ND	ND	ND

Results displayed in Table 4 show that bacteria levels exceeded, or likely exceeded (in the case of TNTC values) guidance criteria for fecal indicator bacteria on 11 of 18 possible combinations of date, location and indicators. Where values could be compared, they were higher on April 15, 2019 than samples collected on June 25, 2019. However, none of the human-specific markers were detected for any of the 30 combinations of dates, locations and indicators. This is in contrast to prior work in the Miami River watershed and in the Cocohatchee River, where at least one of these human specific indicators was found in at least one location and date combination, in prior studies using these or similar indicators (Tomasko, personal observation).

The lack of evidence of humans as a source should not be interpreted as if humans are never a source of these bacteria. Rather, the more appropriate interpretation is that very high levels of FDEP's fecal indicator bacteria can arise from mostly natural sources, as has been previously concluded by other researchers (e.g., Duncan and Razzell 1972, Knittel 1975, Caplenas et al. 1984, Byappanahalli et al. 2003, Whitman et al. 2003, Tomasko et al. 2017) and in agreement with conclusions reached by SCCF researchers (Thompson et al. 2011). As seen in Figure 11, a significant amount of plant debris gets washed into the storm drain system. Figures 12 and 13 show that the stormwater runoff which contains decomposing vegetation discharges into water which itself often contains decomposing seagrass blades and macroalgae. These results should not be interpreted as suggesting that high levels of bacteria from "natural" sources are not a health concern, but that human fecal matter does not always explain high levels of fecal indicator bacteria that are relied upon by FDEP and other regulatory agencies.

Conclusions

Recent studies by SCCF researchers (Thompson et al. 2011 and 2012) have documented problematic water quality in both surface waters and groundwater on Captiva Island. These findings should be a concern for local residents, as levels of bacteria that the State of Florida uses to determine impairment status are elevated beyond state criteria in nearshore waters on the east side of the island, and levels of nitrogen, capable of stimulating algal blooms, are higher in the groundwater in developed areas on septic tanks, compared to developed areas on sewers.

Our findings suggest that septic tanks on Captiva Island do not appear to be a substantial source of nitrogen loads to nearshore waters, and that they are also not likely a substantial source of pathogens, even though elevated levels of “fecal indicator” bacteria have been found in the shallow waters of Captiva Island, especially on the east side.

However, many of the septic tanks on Captiva Island do not have adequate separation between the bottom of the drainfield and the wet season water table, compared to regulatory criteria and non-regulatory guidance. This problem is particularly severe in the area of The Village, where nearly half of the lots do not currently have the regulatory minimum distance between the drainfields and the wet season water table. By the year 2050, none of the lots in The Village would likely have adequate elevation to allow for a two-foot separation between the drainfield and the water table. In Gold Coast and Roosevelt Channel, the percentage of lots with inadequate separation between the drainfield and the water table was estimated at 17 and 33 percent, respectively. By the year 2050, the percentage of lots with inadequate separation between the drainfield and the water table is estimated to be 50 and 89 percent, respectively, for Gold Coast and Roosevelt Channel lots. The decrease in the separation distance between drainfields and the water table is likely to reduce the efficiency of soil-based wastewater treatment processes over the next 30 years, perhaps resulting in impacts to water quality that are not yet present on Captiva Island.

Should Captiva Island decide to replace its septic tank systems with a central sewer system, it would benefit local waters if the destination for those flows is a wastewater treatment plant with Advanced Wastewater Treatment (AWT) capabilities. Not all sewage treatment plants are similar in the nutrient content of their effluent, and the widespread movement to AWT processes for sewage treatment is widely considered the most important activity that has allowed for the recovery of water quality in that portion of coastline from Tarpon Springs down to Boca Grande, where a 40 square mile increase in seagrass coverage has occurred during the past 30 years (Tomasko et al. 2018).

A stormwater nutrient loading model constructed by SCCF researchers (Thompson et al. 2011) was replicated in this study, with an outcome within 3% of the original estimate. The closeness of the two estimates indicates that the calculations, assumptions and algorithms are repeatable, and thus capable of being used for forecasting future scenarios of land use impacts on stormwater nitrogen loads. While actual loads from any particular land use in any geographic region may differ from model estimates, the loading model suggests that geographic "hot spots" for nitrogen loading occur in the commercial areas of South Seas Island Resort and Tween Waters, along with the entire area of The Village. Follow up studies should be considered, to validate nitrogen loading model assumptions, and if findings are consistent with model output, such areas might benefit by careful selection of stormwater retrofits and focused public education efforts.

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