Jacobs

Memorandum

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Subject	**Task 1 – Limited Technical Review of September 2021 Marco Island Nutrient Source Project Report**
Project Name	Evaluation of Potential Reuse Nutrient Impacts and Nutrient Removal Strategies
Attention	Jeff Poteet, General Manager, Marco Island Utilities
From	Jacobs
Date	July 12, 2022

Executive Summary

The City of Marco Island (City) retained Jacobs to perform a limited review and evaluation of the *Marco Island Nutrient Source Evaluation Project*, submitted by Environmental Research and Design (ERD) to the City in September 2021 (ERD Report). Jacobs review was limited to the findings and recommendations related to reuse water contained in the ERD Report.

Jacobs review of the ERD Report focused on the following topics:

1. Reported water quality data – the ERD Report provided recent study period water quality data for Total Nitrogen (TN) obtained from within both the Marco Island canal waterways and offshore locations. Jacobs found that during the period of the study, reported TN values for the canal waterways and offshore sample locations were similar enough that median values for each sample set were not statistically different.

2. The ERD Report claims that reuse water contributes up to 8,312 kg/yr of TN to canal water in the form of groundwater seepage whereas all island sources of TN contribute 85,298 kg/yr of TN from the combined sources of precipitation, runoff, groundwater seepage, and from sediment release. Jacobs found these reported values to be potentially significant compared to the mass of TN transferred in and out of the canals by tidal exchange. Even so, no statistical difference was observed in concentrations TN present within the canals as compared to offshore locations. Combined with the no observation of extremely high values of TN at stagnant canal waterways suggest the reported TN transfer from the island to the canal waterways is likely overestimated in the ERD Report. If the total of all sources of TN transport provides little observable change in TN concentrations, it is unlikely that the smaller reported value associated with reuse water from groundwater seepage could result in a measurable change in water quality.

3. The ERD Report claimed "Even if a 50% reduction in concentration is achieved during movement through groundwater, the additional nitrogen loading from excess reuse is 8,312 kg/yr which is 40% of the total annual nitrogen loading from groundwater in all sub-basins combined." Jacobs found no supporting information within the ERD Report to provide a basis of limiting the reduction in TN in

reuse water after application by natural processes to 50%. Jacobs also recommended the authors of the ERD Report amend their evaluation of rainfall data, nutrient uptake, and include a review of available groundwater data that would result in potential significant reduction in the estimated TN transferred from the island to the canal waterways as a result of current reuse water irrigation practices.

4. The ERD Report did not present actual groundwater quality data demonstrate that applying reuse water for irrigation purposes results in nitrogen transfer to groundwater. Rather, data on the amount and water quality of groundwater seepage data was presented. The reported conductivity of groundwater seepage was similar to sea water and not to reuse water. This suggests the samples identified as groundwater seepage were heavily influenced by sea water. The ERD Report also demonstrated the potential for sediments to release nutrients. Based on the groundwater seepage sampling method presented in the report, the heavy influence of sea water in collected samples, and the potential for sediments to have contributed to the observed nutrients, interpreting the groundwater seepage water quality data as significantly originating from reuse water seems unlikely. Further, the stable isotope data presented in the ERD Report strongly suggests other sources of nitrogen than reuse water are the likely cause of nitrogen present in groundwater seepage.

5. The observed low dissolved oxygen (DO) levels in the canal waterways of areas M-11, M-10, M12, M-13, and M-17 are consistent with stagnant waters and water column stratification caused by a lack of tidal flushing combined with the occurrence of nutrient cycling associated with sediments. While outside the scope of Jacob's limited review of the ERD Report, Jacobs points to these areas as an opportunity for the City to consider methods of improving canal waterway water quality. Efforts should be made to improve tidal flushing to the extent possible and to evaluate aerating the canal waterways by installing aeration diffusers, air lines, and air compressors to introduce air at the bottom of the canals to cause water column destratification and to improve DO levels.

Jacob's review of the ERD Report shows there is little direct evidence to claim that applying reuse water for irrigation purposes results in a significant impact in waterway water quality degradation. From a high-level perspective, the amount of nitrogen present in reuse water is a fraction of the amount needed for landscape maintenance. The amount of nutrient uptake by landscape and denitrification that occurs within the roots zone of grassy areas likely reduces the nitrogen present in reuse water to insignificant levels.

Jacobs provided recommendations for the City to consider in addressing the findings in the ERD Report related to reuse water irrigation practices. However, Jacobs' review of the report did not find a rationale supporting implementation of Advanced Wastewater Treatment (AWT) at the Marco Island Reclaimed Water Production Facility (RWPF) because reuse water applied for irrigation purposes does not likely affect the water quality of canals and waterways on Marco Island. Jacobs provides the following recommendations for the City to consider in addressing the findings of the reuse irrigation assessment:

1. Conduct additional soil sampling of representative public access areas and golf courses to assess current available and total P levels and P Capacity Indexes.

2. Consider installing additional shallow groundwater monitoring wells in representative areas to assess actual potential impacts to groundwater quality and nutrient levels.

3. Continue with the updating of irrigated area for all reuse customers to provide more accurate tracking of irrigation and nutrient loading rates.

4. For reuse customers with automatic irrigation controllers, promote the use of the IFAS Urban Irrigation Scheduler App (http://fawn.ifas.uf.edu/tools/urban_irrigation/), or other similar irrigation scheduling tools, to help adjust irrigation controller run times based on historical weather data.

5. Consider/promote the use of soil moisture monitoring sensors on existing and new irrigation systems with smart automatic controllers to provide more precise control over irrigation operations. The soil moisture sensor will allow irrigation only if water is required.
6. To control/minimize overspray and water loss in median areas, consider converting spray heads/rotors to subsurface drip or microspray systems. For medians that are irrigated with water trucks, consider installing drip or microspray systems to minimize application of reuse water to road surfaces and other impervious areas.

1 Background

The City operates and maintains the RWPF, which has a 3-month average daily design capacity of 4.9 million gallons per day (mgd). The RWPF currently produces approximately 2.3 mgd of treated effluent, including high-level disinfection, that meets requirements for unrestricted public access reuse. The RWPF is co-located with the City's North Water Treatment Plant. The reuse water currently irrigates approximately 734 acres of landscape on golf courses, roadways, and commercial and residential properties, primarily on the west side of Marco Island (refer to Table 4 for basis for applied area of reuse water).

The City has more than 100 miles of canals and waterways. The Florida Department of Environmental Protection (FDEP) has listed Marco Island canals and waterways as being impaired for nitrogen (N) based on annual geometric mean TN concentrations exceeding 0.300 micrograms per liter (µg/L). Offshore areas southeast of Marco Island also are listed as impaired for TN, total phosphorus (TP), and fecal coliform bacteria.

To address increasing citizen concerns about declining water quality in the canal and waterway system, the City retained the services of ERD in April 2020 to conduct a nutrient source evaluation and assessment and provide recommendations for water quality improvement. The ERD Report was submitted to the City in September 2021.

The report presented a number of findings, conclusions, and recommendations, some of which identified on-island reuse irrigation as a contributing source of nitrogen and phosphorus to the canal waterways and recommended reducing Marco Island reuse irrigation and evaluating alternate methods of reuse water disposal.

The City retained Jacobs to conduct a limited, independent review of the ERD Report conclusions and recommendations related to the potential impacts of reuse water on the canal waterways. Additionally, the City requested Jacobs to evaluate potential reuse nutrient removal strategies that could be implemented at the RWPF. The results of this analysis will be presented in a separate technical memorandum.

2 Limited Review Scope of Services

In May 2022, Jacobs conducted a limited, independent technical review of the September 2021 Final Report of the *Marco Island Nutrient Source Evaluation Project* prepared by ERD. The primary focus of the technical review was to evaluate sections of the report that covered methodologies, assumptions, and data analyses supporting the report conclusions that:

- Public access reuse irrigation was a significant contributor to nutrient enrichment of canal waterways.
- Alternate reuse water disposal methods should be evaluated to reduce the quantity of reuse water applied on the island for irrigation purposes.

Jacobs did not conduct an in-depth review of the entire report, especially sections related to offsite water quality, stormwater management and treatment options, seepage management options, non-structural nutrient management techniques, or regulatory issues.

3 Water Quality Overview

3.1 Introduction

Water quality in canal waterways exceeds numeric nutrient criteria (NNC) for TN. The NNC is presented in Table 2-1 of the ERD Report. The reporting period of 2015 to 2019 is provided in Table 2-3 of the ERD Report. Near offshore waters in the 2020 reporting period all exceeded the NNC for N. Specific canals in the waterway system also are impacted by dissolved oxygen (DO). These impairments also are well documented in the ERD Report. FDEP sets the reference NNC for canal waterways as 300 µg/L for TN and 46 µg/L for TP. Values over the reference criteria are considered impaired. As noted earlier, offshore waters are impaired for TN, TP, and fecal coliform bacteria.

Jacobs' high-level review of the water quality data presented in the ERD Report is an assessment of the study's ability to accurately quantify nutrient loads and relative contributions or sources from Marco Island to the waters of the canals. The assumption is that if nutrients are transported from the island to canal waterways, then mitigation measures could be implemented resulting in reduced nutrient transport. With the reduced nutrient transport, an associated decrease in observed nutrient concentrations in the canal waterways would occur. Secondly, Jacobs' focus was to identify changes in reuse water quality and disposal that, if implemented, would make a positive contribution to canal water quality.

3.2 Nitrogen

Are canal waterways enriched with TN compared to offshore waters? Comparative statistics provide definitive answer to this question.

Table 2-12 in the ERD Report provides flood and ebb tide TN data for sampling sites M-5 through M-17 from April to September 2021. These are interior and canal waters of Marco Island. Table 2-13 provides TN data for sampling offshore sites M-1 through M-4 for the same period.

If there is enrichment of canal TN, ebb tide (outflow) TN would be enriched compared to flood tide (inflow) values. For such a small sample size, comparison of median values (non-parametric test) is used instead of comparison of mean values (parametric test) because the non-parametric test does not assume normal distribution. The test is known as the Wilcoxon-Mann-Whitney (WMW) rank sum test[1]. Many software packages are available for this test, with Jacobs using KaleidaGraph™ by Synergy Software.

Median flood tide TN is 559 µg/L, and median ebb tide TN is 611 µg/L. Sample size of combined means is 13 for both flood and ebb tide samples. The p value is 0.47 (unitless statistical test). For the difference to be considered significant, the convention is for p to be less than 0.05. Therefore, there is no statistically significant difference between flood and ebb tide canal samples. The value of p in this example is the probability that the opposite of what is assumed is true (the null hypothesis). In this case, p equals 0.47,

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[1] Helsel DR, Hirsch RM. 2002. Chapter A3, "Statistical Methods in Water Resources." In: *Techniques of Water-Resources Investigations of the United States Geological Survey, Book 4, Hydrologic Analysis and Interpretation*. Reston, Virginia: United States Geological Survey. http://water.usgs.gov/pubs/twri/twri4a3/

suggesting that a 47% probability that the reported median values for flood and ebb tide for TN are too close to say they are different. When the probability that the reported medians cannot be differentiated has a value of 5% or less, then the difference in median values are considered statistically significantly different.

There is the potential for TN to mix in ebb and flow, which would confound this view of the potential for enrichment. This makes it important to compare canal waters with offshore waters.

Table 2-11 from the ERD Report provides data (ebb and flood tides) for offshore sites M-1 through M-4. Lumping offshore ebb and flood TN values into one data set (n = 8) and all canal TN values into another data set (n = 26) provides a means of comparing median values. For this WMW test, $p = 0.38$. There is no significant difference between median canal TN (595 µg/L) and median offshore TN (569 µg/L) during the April to September 2021 period of record.

Historic data from 2015 to 2020 in Table 2-7 of the ERD Report summarize annual geometric means for several parameters, including TN for offshore sites. These values can be compared to Table 2-4 of the ERD Report, which presents overall mean values from 2015 to 2020 for historical Marco Island monitoring sites. Although Table 2-4 presents mean values for the entire period of record and Table 2-7 presents annual geometric means, it is fair to compare median values provisionally without accessing the original databases. This comparison reveals that the median TN of Marco Island waters (514 µg/L) is significantly higher (p = 0.0002) than the median offshore water TN (424 µg/L).

These comparisons suggest a somewhat complex picture of TN values that exceed the NNC. On one hand, data support the assertion that Marco Island water can be enriched with TN compared to offshore water. On the other hand, during the 2020 reporting period, canal water was not found to be significantly enriched with TN compared to offshore water. On yet another hand, the longer term of the 2015 to 2019 data show a significant difference. In an important sense, however, these mixed results are a moot point because offshore waters violate the canal TN NNC.

Stagnation in canals is most likely responsible for canal TN enrichment. Nitrogen-rich organic material coming into the canals with the flood tide will tend to settle and remain in the canals, thereby enriching canals with nitrogen. The mixed results between the 2020 and 2015 to 2019 reporting period probably reflect the difference between long-term trends and yearly variability of this dynamic process.

Data do not support an assertion of the source of nitrogen enrichment. There are two competing hypotheses. The first hypothesis is that the reuse water and fertilizer use is responsible for canal TN enrichment. The second hypothesis is that stagnation and deposition of nitrogen-rich organic matter is responsible for canal TN enrichment. The data do not support testing of either hypothesis. These hypotheses are testable with an extension of the stable isotope analyses, as will be discussed in the following sections. Both could be true. If so, the question of which one has the greater impact on water quality becomes the more important question.

Despite the ambiguity of the source of TN in canals, data strongly suggest that no amount of nutrient transport reduction from the island to the canal waterways could achieve a reduction in TN concentration equal to or less than the NNC because the TN concentration of at least 90% of offshore waters violates the NNC (Figure 1, Figure 2). There is no plausible assertion that canal waterways can have a lower TN than offshore waters.

Is it possible that offshore waters are nutrient enriched by canal waters? The simple answer is that it is highly unlikely. The canals are stagnant, exporting very little water to offshore. What little is exported flushes away. As discussed in the following sections, the mass load of TN coming from reuse water in the canal waterways is likely very small compared to the TN present in tidal-related water exchange with the offshore environment.

There are also tests of how the summary data normally distribute across sample sites. A simple test of normal distribution for the summary data sets is provided in the ERD Report. A linear fit of data in a probability plot indicates normal distribution (Figure 1, Figure 2). For small summary data sets in the reporting periods, the linear fit of 90% to 98% makes a normal distribution highly probable. If data points were to plot as a “hockey stick” or “dog leg,” that would mean that there are different statistical populations in the data set. That is, some data would have been collected from an area subjected to a fundamentally different environmental influence. But the linear plots mean that data come from sampling sites with an overall similar central tendency. The comparison is “apples to apples”, so to speak, not “apples to oranges.” This simple test builds high confidence in the quality of the data.

In the plot of summary data from the 2015 to 2020 reporting period, these data follow the same normal distribution as in the 2021 reporting period[2] (Figure 2). This allows a high degree of confidence in statistical comparisons.

If the 2015 to 2020 reporting period data accurately demonstrate significant differences in TN between canal waterways and offshore waters what are the scientifically plausible reasons for these differences? One plausible reason is enrichment from the fertilizer and reuse water on Marco Island. Another plausible reason is that poor water circulation in the canals is at fault. The evidence for both will be weighed after the discussion of phosphorus, DO, and the stable isotope data in the following sections.

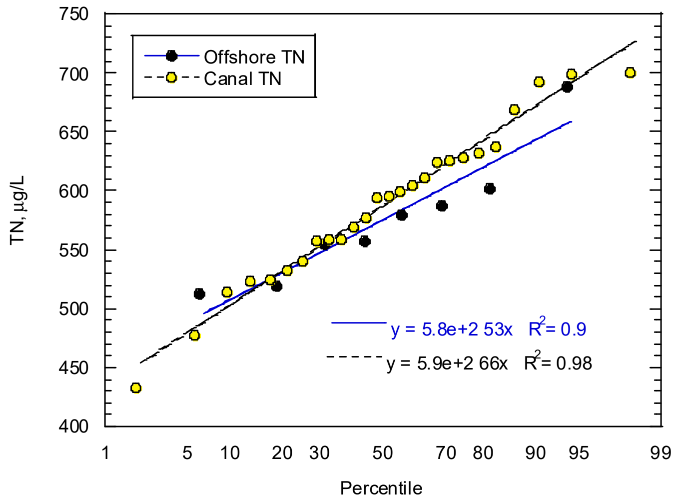

Figure 1. Probability Plot for Offshore and Canal Water TN in the 2021 Reporting Period

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[2] An outlier of 1,900 µg/L has been removed from 2015 data from FDEP site G1SD0006

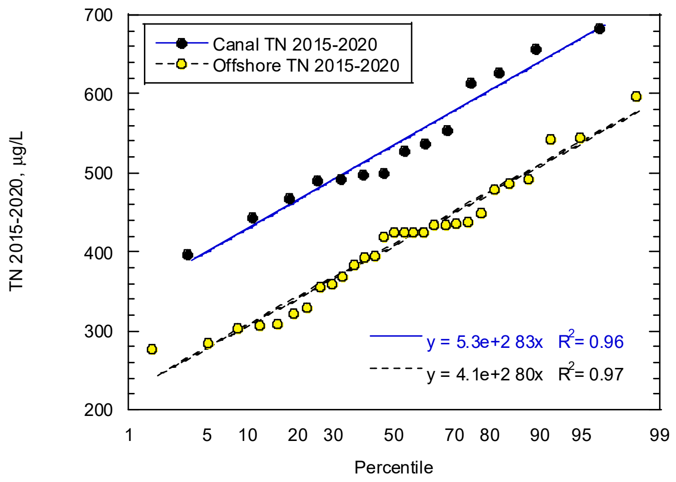

Figure 2. Probability Plot for Offshore and Canal Water TN in the 2015 to 2020 Reporting Period

3.2.1 Assessment of Canal and Offshore Nitrogen Water Quality Relative to Reuse Water

During the period of the study (2020), TN observed in the canal waterways and at offshore locations was not found to be statistically different. The ERD Report claims that 8,312 kilograms per year (kg/yr) of TN from reuse water is transported from the island to the canals by groundwater seepage (page ES-8 in the ERD Report) and that 85,298 kg/yr of TN from the combined sources of precipitation, runoff, groundwater seepage, and from sediment release is occurring from the island to the canals (Table 5-16 of the ERD Report). The expectation is these quantities are significant and have an impact on canal water quality. However, this is not statistically demonstrated by the comparison of canal and offshore water quality data obtained during the time period of the study. The possibility exists from a high-level perspective that the transport of TN from the island to the canals is overestimated or is less than significant when compared to nutrient exchange occurring from tidal influence in the canals.

3.2.2 Potential Groundwater Seepage Contribution to Canal Waterway Nitrogen

As described in Chapter 6 of the ERD Report, stable isotope studies are used to “fingerprint” nitrogen sources transported into canal waterways.

A nitrogen mass balance of canals is essential to apportion the contributions of nitrogen from various sources:

- Atmospheric deposition
- Fertilizer
- Reuse water
- Marine sources (tides and cyanobacteria fixation)

A nutrient mass balance is, by definition, a quantitative exercise. Its goal is to close the mass balance by accounting for, in mass flux terms (for example, a kilogram of a nutrient per day, week, month, or year), all contributing sources of a nutrient to the total nutrient mass in question.

In an environmental mass balance for nitrogen, stable isotope studies are useful to differentiate the various sources of N contributing to TN. Environmental mass balances are hard to close because system boundaries are not neat, as in wastewater treatment systems, and because there is inherently more variability in system elements intrinsic to physical transport of nutrients (precipitation, wind, currents). Consequently, the capacity of stable isotope analyses to approximately apportion sources of N helps a preliminary mass balance. Whereas it may not be possible to close the mass balance quantitatively, insight into sources of N significantly informs the mass balance.

Results from the ERD Report establish unique stable isotope fingerprints for N from atmospheric deposition (ERD Report Figure 6-2), manure and sewage (ERD Report Figure 6-3), and stormwater and baseflow (ERD Report Figure 6-4). The results presented on Figures 6-2 and 6-3 of the ERD Report are for simple samples and the isotope data is highly suggestive of sources of nitrogen. The stormwater and baseflow results presented on Figure 6-4 of the ERD Report demonstrate a large cluster of overlap samples between N sources attributable to manure and sewage, ammonium (NH_4) fertilizer, and soil NH_4. Many samples in this overlapping region are stormwater samples that can pick up N from various sources (e.g. fertilizer, bird droppings, pet excrement, and so on). Thus, the overlapping region of sources in inherently ambiguous.

3.2.3 Assessment of the Utility of Stable Isotope Data Relative to Reuse Water in Groundwater Seepage

A key question is whether stable isotope data from a mixed system of sources such as groundwater seepage can definitively fingerprint the source of nitrogen. Table 6-1 of the ERD Report provides expected ranges of σ^{15} N expected for pure solutions of each source. In Table 6-1, the central tendency for observations originating in samples from sewage and manure is approximately 10. Ninety percent of the reported values from these tests would be expected to be above 4.3. However, Figure 6-5 from the ERD Report for groundwater seepage samples shows the range for sources of sewage and manure to extend down to a value of zero for σ^{15} N. One explanation is the ERD Report considers the impact of a mixture of sources. However, the mixtures make the analysis of sources indeterminate. Only 1 sample out of 74 can unequivocally be associated with sewage and/or manure. The remaining observed values could be from several sources, and possibly not at all from reuse water. Section 6.5 claims that 40% of the groundwater seepage samples had an isotope signature indicating fertilizer and reuse water. The isotope data by itself also could be used to claim that 98% of the groundwater seepage samples may have originated from sources other than sewage and manure. The stable isotope data are indeterminate for a complex collection of mixed sources such as in groundwater seepage samples. The stable isotope data by themselves cannot definitively identify all contributing sources of nitrogen in groundwater seepage samples. On Figure 6-5, only data outside of the ambiguous overlapping zone can be discussed as being meaningful to a specific source. For the 1 out 74 samples definitively identified from either sewage or manure, it is still possible either of these sources is the actual cause of the reported result.

3.3 Mass Balance Approach Used in ERD Report

The ERD Report advances a mass balance approach on Figure 4-1 that ignores tidal exchanges to model nutrient transport from the island to the canal waterways to establish a hydrologic budget. Figure 5-1 adds to the mass balance approach consideration of sediments. This results in identifying relevant methods of nutrient transport from the island to the canal. The methods of nutrient transport are summarized in Table 5-16 of the ERD Report with respective annual mass loading of nitrogen for each island stormwater basin.

In Table 5-16, the annual contribution of groundwater seepage of TN is estimated at 20,506 kg/yr and is approximately 24% of the total annual estimated value of 85,298 kg/yr of TN transported to the canal waterways. Absent the ability to definitely identify source contributions in groundwater seepage data using isotope data, the ERD Report offers only one other method to assess the contribution of TN from reuse water present in groundwater seepage samples. This is found in the following statement:

> "Even if a 50% reduction in concentration is achieved during movement through groundwater, the additional nitrogen loading from excess reuse is 8,312 kg/yr which is 40% of the total annual nitrogen loading from groundwater in all sub-basins combined." (page ES-8).

There is no basis provided in the ERD Report for limiting the reduction of nitrogen from reuse water to 50%. In a discussion provided in the following sections, nutrient uptake by vegetation can easily exceed a 50% reduction in TN present in reuse water. This also is supported by groundwater data obtained from groundwater wells located at the golf course and the City's water treatment plant on the island. Lastly, the previous statement claims that excess reuse water is applied during irrigation; this is discussed in a later section. The reuse water is not applied on average in excess of irrigation needs.

There are two fundamental flaws in the seepage analyses. The first flaw is the overall approach to the hydrological balance (ERD Report Figure 4-1). How does an area with substantial tidal flow ignore tides in a hydrological balance? As outlined in the following discussion, the TN mass flux to the canals can be very large compared to reuse inputs. Without tides in the hydrological balance, there is no mass balance for N in the canals. It is reasonable to suppose there is a seepage influx of N to canals from fertilizer and reuse water. However, a mass balance cannot be done without also considering marine N flux.

Even a mass balance is not closed; there are useful qualitative comparisons that could have been made with isotope data. First, there were no groundwater samples taken in the area near the seepage stations. How does seepage water compare to the groundwater feeding it? This information cannot be determined from the data provided. Second, there were no samples of marine water or sediment porewater. The seepage collection method discarded a volume exchange as potentially contaminated by seawater. This is a reasonable protocol, but since there were not stable isotope N ratios provided for this discarded sample, there is no way to know if it is different from the subsequent seepage sample. How does seepage water compare to seawater? This is not determinable from the data.

This point is especially important considering the salinity of the seepage samples. The average conductivity of Marco Island canal waterways in the 2015 to 2019 reporting period is 50,374 micromhos per centimeter (μmho/cm) (refer to Table 2-4 in the ERD Report). The average conductivity for the seepage test was 45,424 μmho/cm. This difference in conductivity suggests a small freshwater input through seepage. Depending on the conductivity of groundwater, between approximately 5% and 10% of the seepage samples were groundwater.

It appears certain, therefore, that there is seepage of groundwater to canals. Moreover, it also appears certain that there is a nitrogen content of groundwater. However, without a comparison to actual groundwater or seawater stable N isotopes, there is no way to statistically evaluate the contribution of groundwater seepage to the seepage samples.

In Section 5.1.4, the ERD Report presents a detailed assessment of the potential contribution of nutrients from sediments. As with the groundwater seepage analysis, the effort results in estimated annual mass loadings of TN from sediments in Table 5-16. The overall contribution of TN from sediments is 57,959 kg/yr or 68% of the TN transported from the island to the canals (Table 5-16). This raises a question regarding the method of collecting groundwater seepage samples. Figure 4-5 of the ERD Report provides a schematic of the groundwater seepage sample collection chambers installed at the bottom of a canal waterway. The schematic shows that the underlying soil consists of organic sediments of varying depth.

The ERD Report does not explain or demonstrate with data how the organic sediments under the sample chambers are not a contributing source of TN in groundwater seepage samples. Further, the conductivity difference between groundwater seepage data and reuse water suggests the groundwater seepage sample is more than 90% ocean water. Under these circumstances, attempting to differentiate sources of TN present in groundwater seepage samples is speculative. The true groundwater contribution to the water quality present in groundwater seepage samples may be far less than the combined potential alternative contributions of sediment release and ocean water. One approach to avoid the concerns with groundwater seepage water quality data would be to use water quality data obtained from groundwater wells on the island. Groundwater samples collected at locations on the island adjacent to where the groundwater seepage samples were collected would be helpful. Demonstrating impairment of groundwater wells could support the ERD Report methodology, analysis, conclusions, and recommendations. Unfortunately, only a limited amount of groundwater data are available (discussed later) and it does not support the groundwater seepage data analysis and conclusion presented in the ERD Report. While the available groundwater water quality data are not definitive, the data raise questions that deserve further investigation.

3.3.1 Assessment of the Mass Balance Approach Relative to Reuse Water

The ERD Report mass balance approach identifies four methods of nutrient transport from the island to the canal waterways. The methods of nutrient transport are reasonable. However, the mass balance approach falls short in attempting to estimate the contribution of TN from reuse water. The ERD Report claims the dominant method TN transport by reuse water from the island to the canals is from groundwater seepage. The ERD Report also claims that 40% of TN in groundwater seepage originates from reuse water. The isotope data cannot definitively support the claim of 40%. The TN measured in groundwater seepage samples could originate from sediment release and ocean water influence. The mass loading of TN from groundwater seepage data and the relative contribution from reuse water are both in question. To recommend reducing the use of reuse water or improving the quality of reuse water, more convincing data must be presented.

It is important to understand that the isotope data left out dissolved organic nitrogen (DON). The stable isotope method employed can only evaluate dissolved inorganic nitrogen (DIN). But 70% to 80% of canal TN is DON. Because microbial growth in canals is nitrogen limited, cells take up DIN very quickly. Methods to determine stable isotope ratios in DON are difficult. The dynamics of DON in coastal waters are complex and an active area of scientific investigation[3]. To understand the origin of most canal waterway TN, the stable isotope studies would need to be redone with a method that tests DON as well. Doing so would be a daunting task. The method chosen for the study is straightforward and probably the right first attempt to determine the origins of TN in the canal waterways. However, as is often the case in science, the results raise new questions. A larger study employing more difficult methods would be needed to get better information.

3.4 Phosphorus

Phosphorus (P) data come from the same sources as described in the nitrogen section. Median canal TP (44.5 μg/L) is significantly higher ($p = 0.004$) than offshore median TP (39.5 μg/L) for the April to

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[3] Osborne, DM, DC Podgorski, DA Bronk, Q Roberts, RE Sipler, D Austin, JS Bays, WT Cooper. 2013. "Molecular-level characterization of reactive and refractory dissolved natural organic nitrogen compounds by atmospheric pressure photoionization coupled to Fourier transform ion cyclotron resonance mass spectrometry." *Rapid Communications in Mass Spectrometry*. 27(8):851-858.

September 2021 reporting period. However, for the 2015 to 2020 reporting period, median canal TP (43 μg/L) is not significantly different ($p = 0.27$) than the median offshore TP (40 μg/L).

The TP data are well-behaved for the 2021 reporting period (Figure 3), but there are plausible outliers that cannot reasonably be trimmed from the data for the 2015 to 2020 reporting period (Figure 4). There may be turbidity drivers with particulate P that create these outliers.

The reversal of statistically significant differences between TP and TN median values is curious. If an external nutrient load to the canals were an important driver of water quality, a consistent pattern would be expected. However, differences in nutrient central tendencies are as inconsistent as is possible. This inconsistency suggests that other drivers of nutrient water quality dominate data dynamics.

Scientifically, the relevance of phosphorus enrichment to canal water quality merits close attention. In most freshwater environments, P is the limiting nutrient. When freshwater is clear, most of the time that water clarity can be explained by the lack of P to grow algae. When freshwater is "green," it is usually because algae growth is not limited by P.

Seawater is already enriched with P. In freshwater, that P would fertilize sustained, widespread algae blooms most of the time. The reason these blooms do not occur in the canals and offshore is that nitrogen is generally lacking in marine waters[4]. Thus, phosphorus enrichment of seawater generally is not a concern. In coastal systems where freshwater and seawater mix in estuaries, phosphorus can be a water quality issue, but Marco Island canal water is not estuarine water. It is Gulf of Mexico water, which is purely marine.

The concept of nutrient limitation for phytoplankton (algae) growth often is discussed in terms of the Redfield ratio[5]. As the molar ratio of N and P in cells, it is 16:1. Expressed as a mass ratio N to P, it is 7.2:1. If the N to P ratio is less than 7.2:1, N limits algae growth. If N to P is greater than 7.2:1, P limits algae growth. There is some variability in algae growth to the Redfield ratio, especially in freshwater, but it is a consistent value in oceans. The FDEP NNC for TN of 300 μg/L, and TP of 46 μg/L have a mass N to P ratio of 6.5:1, which means that N is limiting if these values are met.

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[4] Iron is often a limiting nutrient in seawater. Adding iron to seawater fertilizes algae growth. However, iron enrichment is a nonissue with Marco Island water quality and thus is only mentioned in this footnote.

[5] Lenton, TM, and AJ Watson. 2000. "Redfield revisited: 1. Regulation of nitrate, phosphate, and oxygen in the ocean." *Global Biogeochemical Cycles*. 14(1):225-248.

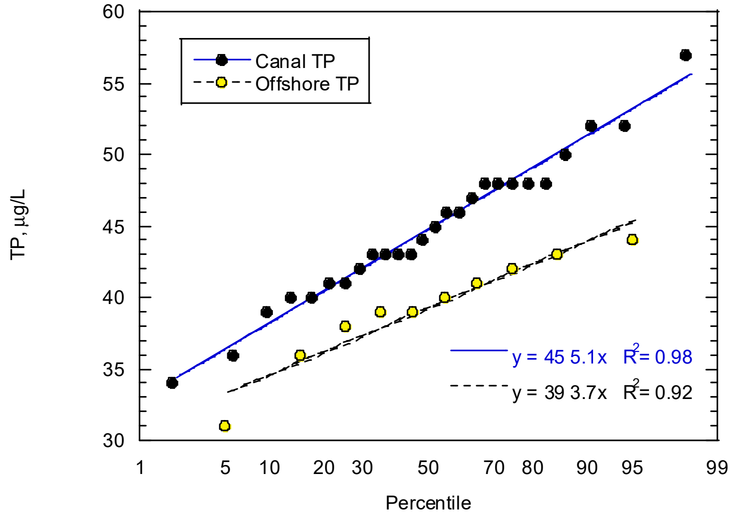

Figure 3. Probability Plot for Offshore and Canal Water TP in the 2021 Reporting Period

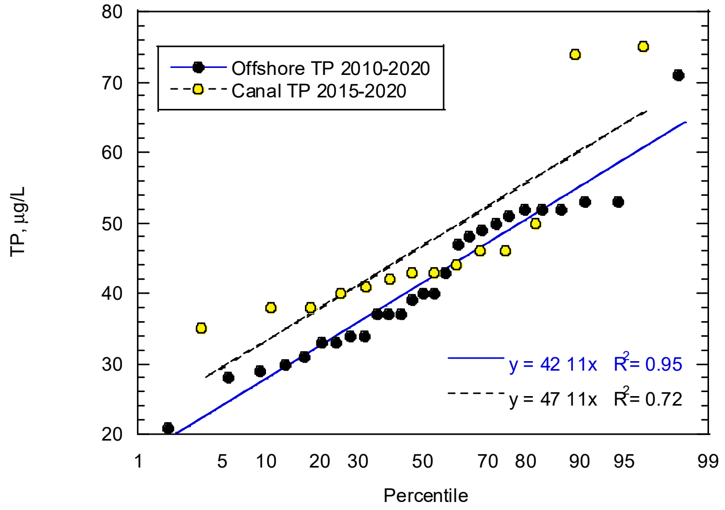

Figure 4. Probability Plot for Offshore and Canal Water TP in the 2015 to 2020 Reporting Period

3.4.1 Nitrogen versus Phosphorus in Canal Water

Using data from the 2021 reporting period, the TN to TP mass ratio in the canal water is 15:1, and in offshore water, it is 13:1. At first glance, it may appear that P is limiting, not N, but the form of N is important. Upon closer scrutiny, it turns out that N is limiting.

In the 2021 reporting period, 79% of canal TN is DON. The highly bioavailable DIN is less than 5% of TN. The rest is in particulate form that is not immediately bioavailable. The Redfield ratio N has bioavailable N incorporated into cell mass. The bioavailability of dissolved nitrogen in water, therefore, is the N that must be considered when determining if N or P limits nutrients.

At the low concentrations of DON observed in the canals and offshore waters, most DON is not bioavailable[6]. Testing for DON bioavailability is sophisticated, expensive, and does not have a standard method. However, marine microorganisms are highly adapted to scavenge bioavailable DON. It is almost certain that less than half of the DON is bioavailable. For the sake of argument, if half of canal DON were bioavailable, the N:P ratios fall to less than 7:1. Therefore, nitrogen is limiting in the canals (and offshore waters), not phosphorus. The report arrives at this same general conclusion that phosphorus does not limit algal productivity (page 2-60, ERD 2nd paragraph).

3.4.2 Sea-based Nutrients versus Other N Inputs

Tides make the sea an important source of nutrients. How does this compare to human inputs?

A simple, conceptual model can provide an order of magnitude estimate for nitrogen (Table 1). The report lists an annual TN load from reuse of 8,312 kg/yr. About 34% of Marco Island is open water. The approximate tidal range is more than 0.2 meter but is rounded down for simplicity. Every flood tide brings TN from the sea. If a 30% tidal exchange rate is assumed, the total TN load to the canals from the sea is approximately 156,000 kg/yr. At the assumed tidal exchange rate, the contribution of reuse water TN is only 5% of the sea-based TN load to the canals. However, the contribution from all sources (not including tides) identified in ERD Report Table 5-16 is 85,298 kg/yr or 55% sea-based TN loads to the canals. These are sizable contributions. It is surprising that TN samples taken in the canal waterways when compared to offshore samples do not result in a significant difference as mentioned previously. This again raises the question of the estimated magnitude of TN loading from the island to the canal waterways presented in the ERD Report. If the total TN loading is 55% of tidal exchange water contribution of TN, then a significant increase in TN concentrations in the canal waterways should be observable and consistent.

Tidal exchange may be substantially less than 30% and will vary along a gradient from canal ends to the sea. It is nonetheless clear that the sea is the large source of TN in the canal waterways. Given that offshore TN exceeds the NNC, it is difficult to convincingly demonstrate how a reduction in TN inputs to the canals from reuse water irrigation can improve canal water quality.

Table 1. Conceptual Calculation of Reuse Contribution to Canal TN

Marco Island Area	17,900,000	m^2
Island percent open water	34%	
Water area	6,171,409	m^2
Average tide range	0.20	m
Tide volume	1,234,282	m^3
Percent tidal exchange	30%	
Tidal exchange volume	370,285	m^3
Tides per day	2	
Total tidal exchange	740,569	m^3/d
Offshore TN	576	mg/m^3 (µg/L)
Offshore TN load	427	kg/d
	155,697	kg/yr

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[6] Osborne DM, DC Podgorski, DA Bronk, Q Roberts, RE Sipler, D Austin, JS Bays, and WT Cooper. 2013. "Molecular-level characterization of reactive and refractory dissolved natural organic nitrogen compounds by atmospheric pressure photoionization coupled to Fourier transform ion cyclotron resonance mass spectrometry." *Rapid Communications in Mass Spectrometry*. 27(8):851-858.

Reuse TN load	8,312	kg/yr
Percent of TN from reuse	**5.3%**	

Notes:

kg/d = kilogram(s) per day

kg/yr = kilogram(s) per year

m^2 = square meter(s)

m^3 = cubic meter(s)

m^3/d = cubic meter(s) per day

mg/m^3 = milligram(s) per cubic meter

The City has received comments that Table 7-2 of the ERD Report proves that reuse water quality is a significant, if not the major, contributor to canal waterway water quality. The data presented in Table 7-2 are TN concentration from sources including precipitation, runoff, reuse water, and groundwater seepage for each basin. The statement that the concentration data prove impacts to water quality in the canal waterways are mostly from reuse water is not claimed in the ERD Report. The data in Table 7-2 does suggest that reuse water should be closely evaluated and that was a focus area of the ERD Report. The discussion of water quality analysis presented previously also applies here. Comparing the differences in concentration from the various sources by itself is not a method to assess relative nutrient loading contributions to the canal waterways. The ERD Report and the effort to develop a mass balance approach supports this assertion.

3.4.3 Poor Tidal Flushing

Stagnant water is the primary problem of canal water, not nutrients. The argument supporting this assertion is reinforced by the report and can be supplemented by other sources.

Canals are very poorly flushed by tides. Residence times in canals are 5 to 11 months (ERD Report, Table 4-16). Canal water is stagnant because the canals were either not built with tidal flushing or because internal culverts which originally allowed sufficient tidal exchange are now blocked. Section 7.6 in the report merits close attention because it directly addresses the issue of stagnant canal water:

> "*There appears to be little argument that enhanced recirculation and flushing would benefit water quality in the canals, particularly in upstream isolated and dead-end areas*."

As pointed out in the report, a hydrodynamic model is needed to assess how tidal circulation can be improved.

This report observation is amply supported in the scientific and engineering literature. Poor tidal flushing is long-established as a driver of poor water quality in Florida[7]. Low DO concentrations near the bottom and high TN concentrations are commonly noted effects of stagnant water. Poor DO concentrations near canal bottoms are well documented in the 2021 reporting period (refer to Section 2.3.2.2 of the ERD Report).

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[7] Goodwin C. 1991. *Simulation of the Effects of Proposed Tidal Gates on Circulation, Flushing, and Water Quality in Residential Canals, Cape Coral, Florida*. Survey UG, Tallahassee, Florida. Open-File Report 91-237.
This reference contains multiple citations dating back to 1968 that describe the effects of stagnant water quality in Florida coastal residential canal systems.

Stagnant water causes sediments in canals to accumulate organic material (refer to Section 2.4 of the ERD Report). Offshore sediments have little organic content because they are well-flushed and well-oxygenated by tidal exchange and currents. The lack of tidal exchange in canals allows algae and organic debris to settle to the bottom undisturbed by currents. This organic matter decays and consumes oxygen. Sediments exert an oxygen demand (SOD) that is expressed as grams per square meter per day ($gm/m^2/d$) of oxygen. Although the SOD has not been measured in the canals, in many places it evidently is greater than the transfer of oxygen to the bottom by natural, vertical mixing of water.

The technical expression of water stagnancy is water age or residence time. A hydrodynamic model of the canals would use this term and actually provide graphic output of water age in the canals under various circulation scenarios. Water age is not just an average from the surface to the bottom, it has layers. Bottom water in poorly flushed canals will typically have a longer water age than surface water for reasons of variation in bottom depth, bottom roughness, and stratification caused by the bottom being a lower temperature or more saline than surface water.

The SOD and water age combine to cause oxygen deficits in bottom water. If the bottom layer of water were to lose DO at a rate of 0.05 milligrams per liter per day (mg/L/d), it would be hypoxic (DO < 2.0 mg/L) in 3 months and anoxic (DO < 0.5 mg/L) in about 4 months if starting from saturation at 6.6 mg/L. Because average water age in the canals varies from 5 to 11 months, this hypothetical DO loss rate in bottom water is likely reasonably close to actual rates.

The water age in the canals may be too long for any nutrient reduction measure to solve. Sediment oxygen demand is now set for many years, if not decades, to come. The SOD responds very slowly to nutrient reduction. If lowering nutrient transport to the canal waterways lowers the DO load rate by half to 0.025 mg/L/d in bottom water, the DO near the bottom will be hypoxic in 6 months. There is no evidence provided in the report to quantify how nutrient reductions will reduce oxygen demand in bottom waters. Consequently, the assertion made in the report of the benefits to water quality of improved tidal flushing should be at the center of any water quality discussion.

3.5 Ecological Consequences of DO Deficits

It is helpful to view the DO deficits documented in the report in terms of ecology (Figure 5). Hypoxia is a redline for all ecologically important higher organisms. Blue crabs must have 60% oxygen (4 mg/L) at the bottom to have suitable habitat. With widespread low DO in canals, the food base for dolphins is low because it is not suitable for prey fish species. That means dolphins will avoid canals because there is little to eat.

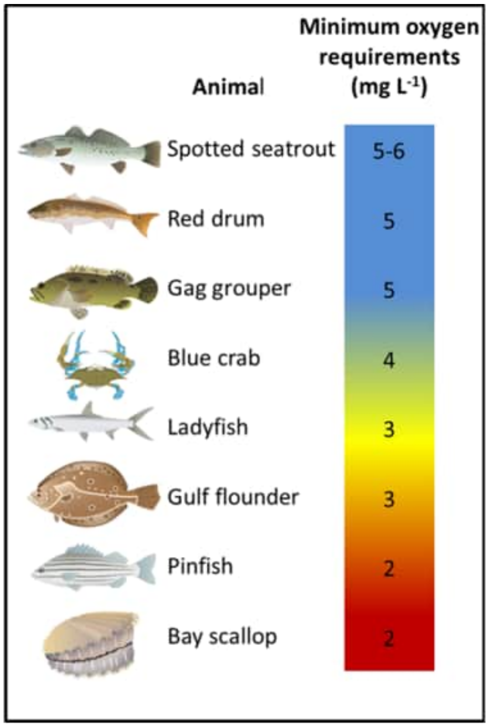

Figure 5. Ecological Impacts of DO

Source: https://recon.sccf.org/events

The problem of hypoxia and anoxia is not just in the water column. Die-off of sea grass can be initiated by hydrogen sulfide in sediments[8]. Sea grass roots in sediments. Hypoxia and anoxia cause sediments to sour with hydrogen sulfide. When sea grass dies off, manatees lose grazing grounds and vital habitat for crabs and fish are lost.

The primacy of DO in the canals as the central problem in canal water quality cannot be overemphasized. In the context of Marco Island, the entire point of considering nutrient reductions in the first place has as its fundamental rationale improvement of DO concentrations in sediments. Excessive algae growth may be considered as a primary concern, but that is a partial misconception of ecological function. Excessive algae grown in the form of red tides or toxic cyanobacteria share center stage as a fundamental ecological concern with DO. Toxic algae are not a problem in the canals, however. The impact of excessive algae growth is loss of DO from decay of settled algae. As there have been no canal waterway systemwide problems reported with algae blooms, poor DO and its ecological impacts are necessarily the central water quality concern.

Ecological recovery of the canals requires addressing the DO directly through engineering means. Section 7.6.2 of the ERD Report correctly addresses the importance of these improvements. A hydrodynamic study would be required to determine what improvements to circulation could reduce canal water age (hydraulic residence time). The efficacy of various improvements would need to be modeled in detail. It is an open question to what degree proposed improvements to circulation would improve water quality.

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[8] Carlson Jr., PR, LA Yarbro, and TR Barber. 1994. "Relationship of sediment sulfide to mortality of *Thalassia testudinum* in Florida Bay." *Bulletin of Marine Science*. 54(3):733-746.

Oxygen deficits can be eliminated through destratification aeration in tidal creeks with poor circulation[9] (Figure 6). Stratification can be thermal (cooler water on the bottom, warmer water on top) or saline (saltier water on the bottom, less salty water on top). Destratification aeration, if done properly, creates the same temperature or salinity from the surface to the bottom. This vertical uniformity in water density makes the water prone to mix from the surface to the bottom under the influence of wind or the ebb and flood of tides. When vertical mixing occurs, oxygen-rich surface water ends up on the bottom and oxygen-depleted water ends up on the surface where oxygen from the atmosphere raises the DO.

The ERD Report identifies the canal section of the M-11 site as having strong stratification that is responsible for oxygen deficits. This location is a good candidate for a destratification aeration system. Other sites with oxygen deficits may be so because they are adjacent to areas with thermal or saline stratification at canal dead ends. If more-detailed monitoring reveals stratification near canal dead ends, these areas also would be good candidates for destratification aeration systems.

Figure 6. Destratification Aeration System after Installation in Rock Creek, Anne Arundel County, Maryland

Photo Source: Mobley Engineering

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[9] Harris LA, Hodgkins CLS, Day MC, Austin D, Testa JM, Boynton W, Van Der Tak L, Chen NW. 2015. Optimizing recovery of eutrophic estuaries: Impact of destratification and re-aeration on nutrient and dissolved oxygen dynamics. Ecological Engineering. 75(0):470-483.

4 Assessment of Reuse Water Impacts and Recommendations

4.1 Specific Areas of Focus

The ERD Report presented several primary findings and recommendations related to the application of reuse water for irrigation use on Marco Island. From page ES-8, the following report findings and recommendations were assessed by Jacobs to evaluate the premise that reuse water is being excessively used on Marco Island:

1. “Reuse irrigation is currently being applied at rates which exceed the ability of turfgrasses to provide uptake of the water and nutrients, and results in a large amount of the reuse leaching past the root zone into groundwater.“
2. “Even if a 50% reduction in concentration is achieved during movement through groundwater, the additional nitrogen loading from excess reuse is 8,312 kg/yr which is 40% of the total annual nitrogen loading from groundwater in all sub-basins combined.”
3. “Alternative methods of reuse disposal should be evaluated, and reuse should be applied only as needed to meet evapotranspiration requirements. If reuse were applied only as needed, the groundwater nitrogen impacts would be substantially reduced, resulting in a visible improvement in waterway water quality.
4. “Reuse irrigation is also used on the golf course, but the water is stored in a surface pond prior to application. Nutrient reduction occurs within the pond which reduces the nutrient loading to concentrations similar to urban runoff in other parts of Florida which reduced potential groundwater impacts. However, at the irrigation rates indicated by annual reuse summary forms provided to FDEP, the irrigation rates also exceed evapotranspiration requirements, although not to the extent observed by reuse application in other public areas, and irrigation reduction should be considered to match evapotranspiration requirements”.

4.2 Marco Island Reuse Water Irrigation Data and Nutrient Concentrations

To assess hydraulic and nutrient loading rate data presented in the ERD Report, Jacobs used FDEP annual reuse report data for the period of 2019 to 2021 for reuse water loading rates and monthly Discharge Monitoring Rate (DMR) reports from January 1, 2019, to April 28, 2022, to estimate current nitrate, TN, and TP reuse water concentrations. This information then was compared to the rates presented in the ERD Report. In 2018, the wastewater treatment processes at the RWPF were modified to increase nitrogen removal via denitrification. These changes resulted in significant reductions in nitrate and TN concentrations beginning in 2019. As shown in Table 2, the annual average daily flow geometric mean for all golf courses and other public access areas (OPAA) were 0.589 mgd and 1.372 mgd, respectively.

Table 2. 2019 to 2021 Reuse Water Data

Year	All Golf Courses	OPAA
2019	0.550	1.34
2020	0.519	1.45
2021	0.716	1.33
Geometric Mean	**0.589**	**1.372**

Source: City of Marco Island 2019, 2020 and 2021 FDEP Annual Reuse Reports.

Table 3 summarizes the nitrate, TN, and TP geometric mean concentrations from 2019 to 2022 and the concentrations presented in the ERD Report. As shown in Table 4-2***, nitrate and TN concentrations were reduced by approximately 30% after process modifications were implemented at the Marco Island RWPF***. Current phosphorus concentrations are similar to the 2012-2021 geometric mean concentration.

Table 3. Comparison of Current Nitrate, TN, and TP Geometric Mean Concentrations to ERD Reported Values

Constituent	(2012-2021) ERD Report[a]	(2019-2022) Current[b]
Nitrate, mg/L	7.49	5.23
TN, mg/L	8.63	6.03
TP, mg/L	3.33	2.91

[a] Source: Table 3-13, 2021 ERD Report

[b] Source: Marco Island RWPF 2019-2022 DMR Reports

4.3 Estimated Reuse Water Irrigated Areas

Figure 7 shows the approximate route of reuse mains and locations of reuse water customers on Marco Island. The majority of the reuse water application areas are located on the western and southwestern side of Marco Island, adjacent to South Collier Boulevard. Other major application areas are associated with irrigation of the Marco Island Golf Course (Island Country Club) and OPAAs and medians adjacent to West Elkcam Circle, Elkhorn Drive, and Bald Eagle Drive.

Table 4 summarizes estimated reuse water irrigated areas from three sources that were used in this assessment to compare irrigation rates. The FDEP operating permit for the Marco Island RWPF shows a total of 864 acres. The ERD Report indicated that the acreage in the operating permit included some impervious areas and developed new estimates for irrigated areas. The City of Marco Island is currently in the process of updating irrigation areas for all reuse customers and has completed updating the golf course irrigated areas. The City's golf course area estimates are 54 acres higher than ERD's estimate. It is anticipated that the final total irrigated area of all OPAA users will be greater than the quantity developed by ERD based on known areas on the island that were not included in the ERD totals. Therefore, for comparison purposes, an additional 50 acres were added to the ERD OPAA area to estimate irrigation and nutrient loading rates.

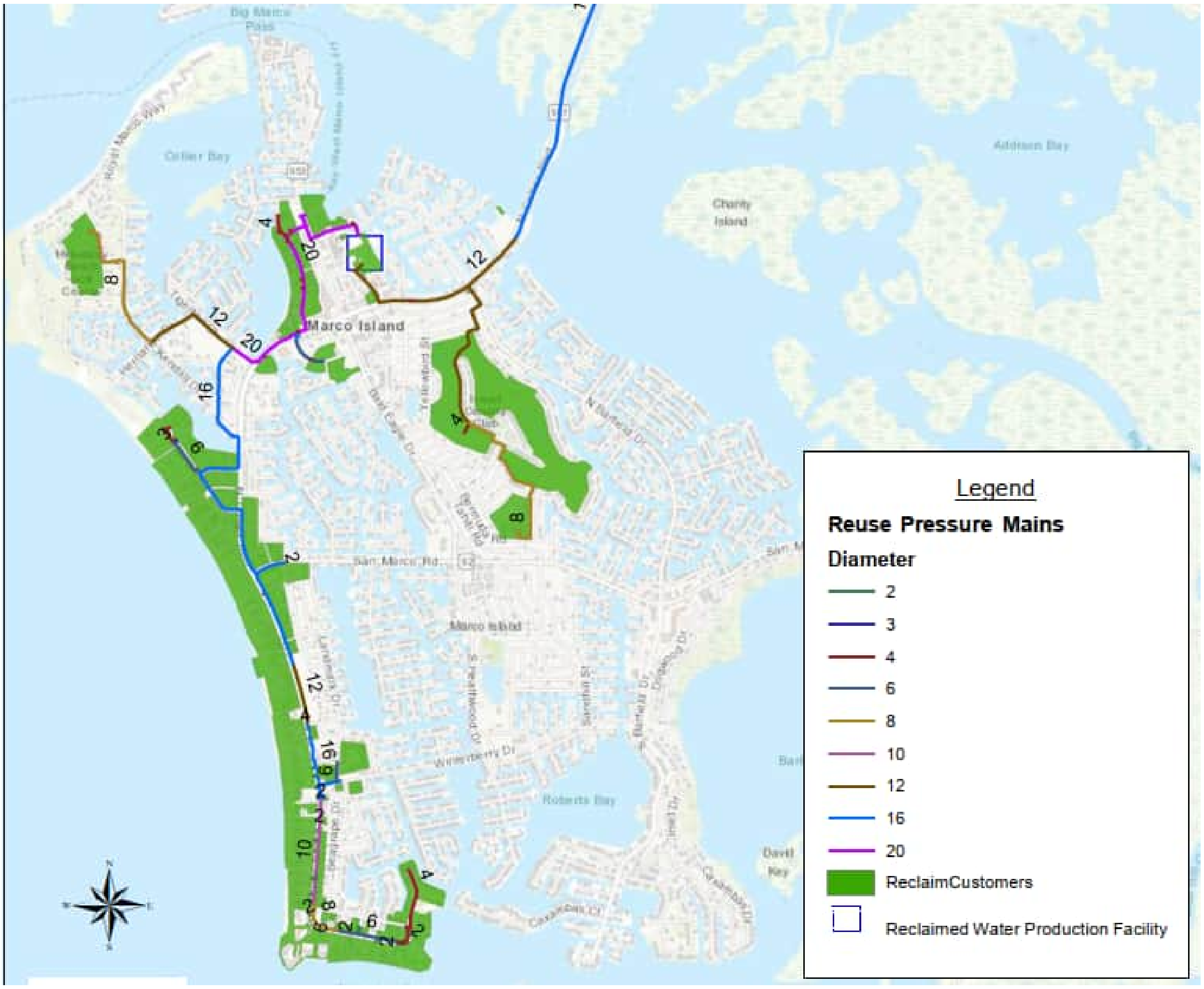


Figure 7. Reuse Mains & User Locations

Table 4. Estimated Reuse Water Irrigated Areas (acres)

User Type	Marco Island RWPF Permit[a]	ERD Report[b]	City GIS Update[c]
All Golf Courses	314	230	284[c]
OPAA	550	400	450[d]
Totals	864	630	734

[a] Source: Current Marco Island RWPF Operating Permit

[b] Source: Table 3-12, 2021 ERD Report

[c] Source: City of Marco Island reuse customer GIS update. All golf course areas have been updated and total 284 acres.

[d] Source: City of Marco Island reuse customer GIS update. OPAA updates are currently ongoing. It is anticipated that the final total irrigated area of all other OPAA users will be greater than the quantity developed by ERD due to known areas on the island that were not included in the ERD totals. For comparison purposes, an additional 50 acres were added to the ERD OPAA area.

4.4 Comparison of ERD Reuse Water Loading Rates to IFAS Irrigation Rates

4.4.1 Irrigation Rate Comparison

The irrigation water balance methodology used in the ERD Report was based on a simplified model that did not account for the available water holding capacity (AWC) of the soil. Only water that is in contact with the roots can be absorbed by the plant. The volume of soil where water can be stored is as deep as the roots are. Root depth is affected by mowing, fertilizing, and irrigation practices. A well-managed turf system will develop most of its roots in the first 12 inches of the soil. Another important property of the soil reservoir is that most Florida soils have a limited ability to store water. The larger the pores in the soil, the less water the soil will hold. The AWC for the majority of Marco Island soils is approximately 0.08 inch per inch of soil or approximately one inch for a 12-inch root zone.

For comparison purposes, Jacobs elected to use a water balance model developed by the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) (Dukes et al 2011) that uses a daily soil water balance to calculate net irrigation requirements for Florida turfgrass lawns based on 30 years (1980 to 2009) of historical weather data. The soil water balance method is an accepted standard practice and is similar to methodologies used by all of the Florida water management districts to estimate irrigation requirements for consumptive use permitting.

The soil water balance model was run for 10 sites in Florida and one site in Alabama. Jacobs used the model output for Fort Myers, Florida, since that was the closest site to Marco Island and the rainfall, evapotranspiration, crop coefficients, and soil characteristics were similar to those of Marco Island. Daily gain and loss of water was computed by the equation when the maximum allowed depletion (MAD) was reached. In the model, a 50% MAD was used.

Refer to Attachment 1 for a tabular summary of monthly net irrigation requirements (NIR) from the UF/IFAS model. Gross irrigation requirements (GIR) also are shown in the table and were calculated assuming an average irrigation efficiency of 80%. The estimated turfgrass total annual NIR and GIR for the Marco Island area are 34.2 inches per year (in/yr) and 43 in/yr, respectively. The annual average weekly GIR is 0.83 inch/week (in/wk). Figure 8 shows the monthly GIR distribution in both inches per month and inches per week. The peak monthly irrigation requirement typically occurs in May and the minimum irrigation requirement in January and December. The average monthly gross irrigation requirement during the rainy season (June 1 to September 30) is 3.05 inches.

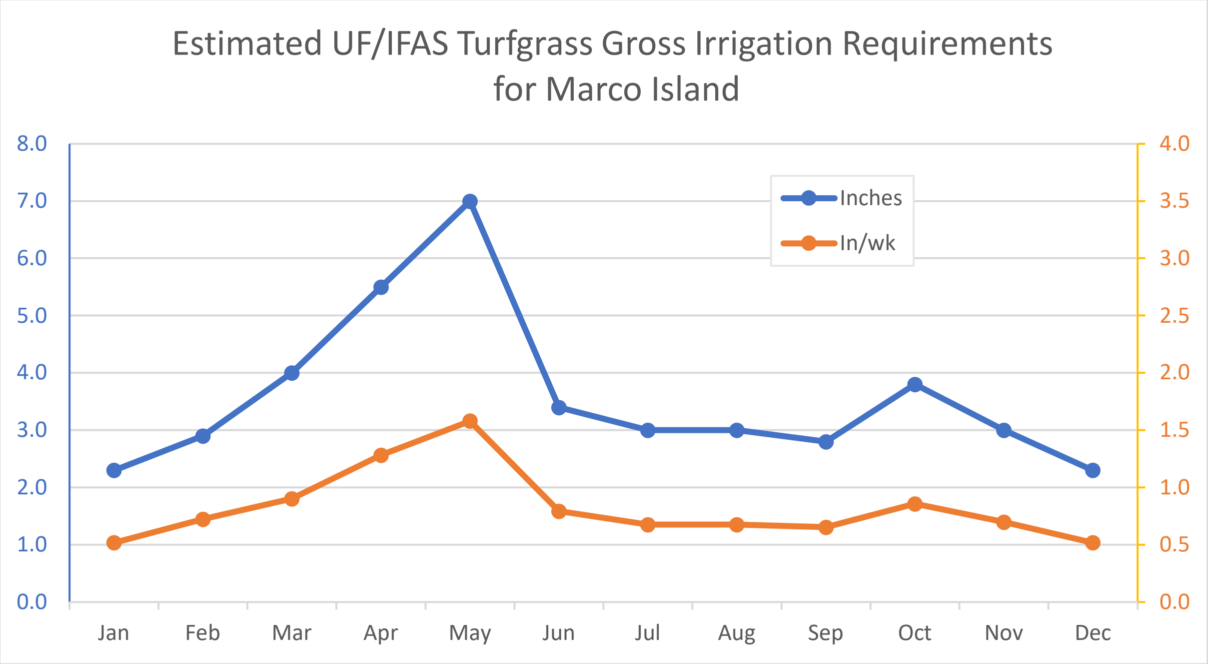


Figure 8. UF/IFAS Estimated Gross Turfgrass Irrigation Requirements for Marco Island

ERD estimated the annual average weekly reuse irrigation rates for OPAA and golf courses to be 0.88 in/wk and 0.56 in/wk, respectively. The UF/IFAS irrigation requirement is similar to ERD's OPAA rate and is about 1.5 times higher than ERD's golf course irrigation rate. **Based on this comparison, the observed irrigation rates presented in the ERD Report do not appear to be excessive and are in line with irrigation requirements from the UF/IFAS model.** Additional evaluation and comparison of current irrigation rates and nutrient loading rates to those based on UF/IFAS irrigation requirement are presented in Section 4.4.2.

4.4.2 Nutrient Loading Rate Comparison

Jacobs used the data presented in Tables 2, 3, and 4 to compare current irrigation and nutrient loading rates for the UF/IFAS model, MIWRF Permit acreages, ERD Report acreages, and the City's updated GIS acreages for golf courses and OPAAs. Table 5 summarizes this information for all golf courses and OPAAs. Based on the reported flows to the golf courses and OPAAs during this period, golf course application rates were less than UF/IFAS irrigation requirements. For OPAAs, the ERD rate was 0.06 inch/wk higher than the UF/IFAS rate and other estimated OPAA irrigation rates were below the UF/IFAS irrigation requirements.

Annual TN loading rates for all cases were well below the maximum allowable annual TN application rate of 4 lbs/1,000 ft^2, the loading rate based on ERD Report irrigated areas being the highest for OPAA areas. However, this loading rate is still only 36.3% of the maximum allowable rate. In all cases, supplemental fertilizer would be required to achieve optimum TN loading rates.

Annual TP loading rates for all cases exceed the recommended maximum annual application rate of 0.5 lbs/1,000 ft^2, with the loading rate based on the ERD Report OPAA irrigated area being the highest at 1.6 lbs/1,000 ft^2. The average TP application rate for the ERD and City's updated GIS OPAA area is 1.5 lbs/1,000 ft^2 or about 3 times the maximum rate. Based on these estimates, reduction in reuse water TP may warrant investigation. If the reuse water TP concentration was reduced to 1 mg/L, the annual TP application rate would be lowered to approximately 0.5 lb/1,000 ft^2. Additional discussion of potential impacts of phosphorus on Marco Island waterways are included in Section 1.4.

Table 5. Comparison of Theoretical and Estimated Current Annual Average Reuse Water Irrigation and Nutrient Loading Rates for Marco Island

Source	UF/IFAS	ERD Report	WRF Permit	ERD+50 acres OPAA
All Golf Courses				
Annual Gross Irrigation (inches)	43.0	34.4	25.2	27.9
Avg Gross Weekly Rate (in/wk)	0.83	0.66	0.48	0.54
Annual TN Loading (lb/1,000 ft^2)	1.33	1.08	0.79	0.88
Annual TP as P2O5 Loading (lb/1,000 ft^2)	1.48	1.20	0.88	0.97
Other Public Access Areas				
Annual Gross Irrigation (inches)	43.0	46.1	33.5	41.0
Avg Gross Weekly Rate (in/wk)	0.83	0.89	0.64	0.79
Annual TN Loading (lb/1,000 ft^2)	1.33	1.45	1.05	1.29
Annual TP as P_2O_5 Loading (lb/1,000 ft^2)	1.48	1.6	1.16	1.42

Jacobs used golf course and OPAA flows reported in the 2021 FDEP Reuse Report and the 2021 TN geometric mean concentration to estimate and compare monthly TN application rates for ERD acreages and the City's updated GIS OPAAs. Figure 9 shows the estimated monthly TN application rates for both OPAA areas and the UF/IFAS recommended monthly nitrogen requirements for St. Augustinegrass in the Naples area (Unruh, J.B. 2015). It should be noted that the monthly nitrogen requirement curve is based on an annual total of 4.8 lbs/1,000 ft^2 which is higher than the maximum allowed by the Marco Island fertilizer ordnance but is still within the recommended range of 4-6 lbs/1,000 ft^2 for South Florida.

Figure 9 shows the monthly applied TN amounts for the ERD Report OPAA are approximately equal to the monthly turfgrass nitrogen requirements for January and February and below the monthly nitrogen requirements for all other months. For the normal wet season months (June through September), the average monthly TN application from reuse water is only 12.6% of the average monthly nitrogen requirement of 0.65 lbs/1,000 ft^2. For the 4-month period, only 8% of the total annual maximum allowable loading rate would be applied. This data clearly shows that additional supplemental nitrogen fertilizer would be required in most months to achieve UF/IFAS nitrogen application rates for acceptable turfgrass quality and reuse water TN is not being overapplied. In fact, reuse water TN is being applied in small amounts that matches the turfgrass's nitrogen utilization rate, which is more conducive to maximize plant uptake and minimizing nitrogen leaching.

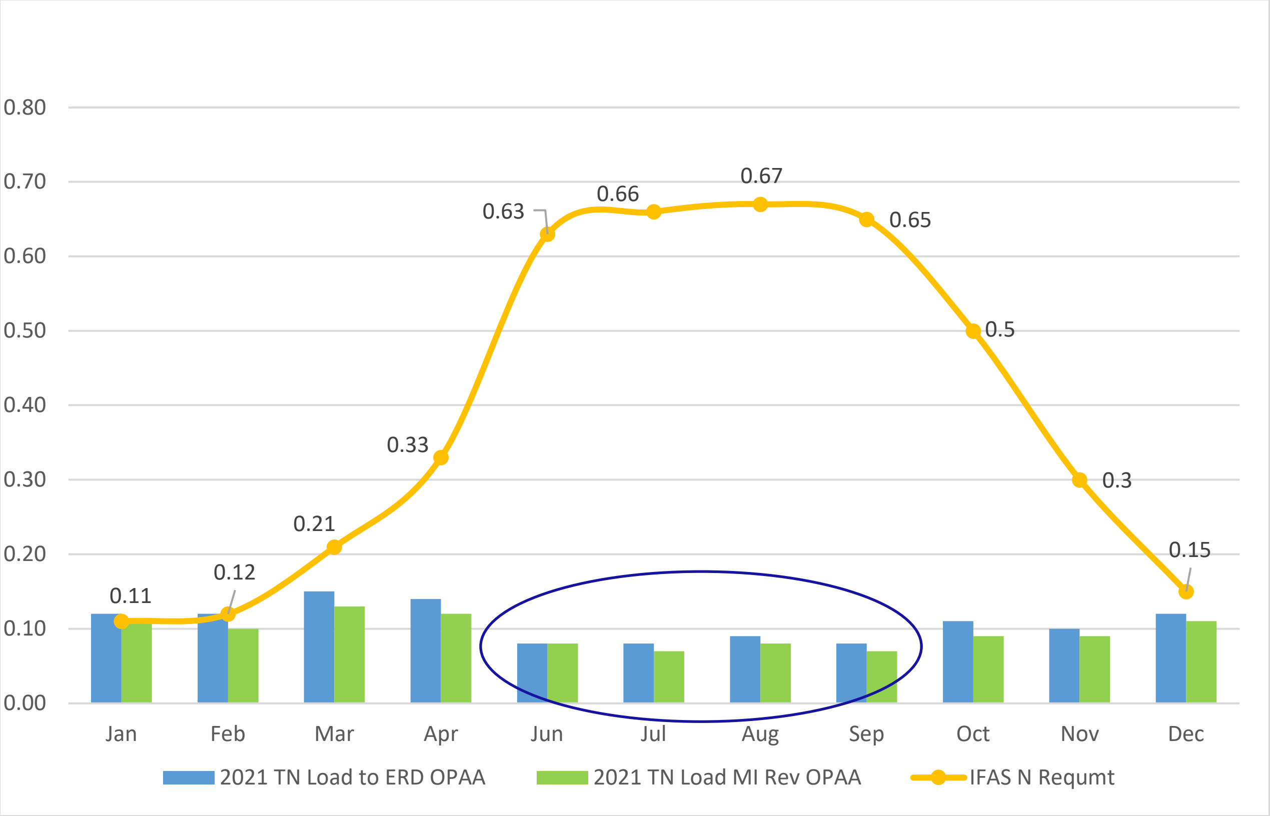


Figure 9. Estimated Monthly TN Application Rates for Both OPAA Areas and the Monthly Turfgrass Nitrogen Requirement

4.4.3 Nitrogen Losses Via Leaching in Urban Landscapes

ERD Report Finding 1 stated that the excessive irrigation and TN application amounts in the reuse water *"results in a large amount of the reuse leaching past the root zone into groundwater. ". Finding 3 also implied that the additional nitrogen loading from excess reuse contributes 40% of the total annual nitrogen loading from groundwater seepage into the waterways.* The analyses and data presented in Sections 4.4.1 and 4.4.2 show that this is not the case. However, additional discussion is presented in this section related to nitrogen losses via leaching in urban landscapes that provide additional support for Jacob's position that contributions TN from reuse water are not a significant contributing factor to the water quality degradation of Marco Islands waterways.

Extensive research on leaching of nitrogen under turfgrass systems has been conducted by multiple researchers. When applied to actively growing, healthy turf, nitrate leaching was minimized even when treatments were applied as soluble urea at rates exceeding the current UF/IFAS recommendations (McGroary et al. 2017; Shaddox et al. 2016a; Shaddox et al. 2016b; Shaddox et al. 2017; Telenko et al. 2015; Trenholm et al. 2012). In a Fort Lauderdale study, N applied according to UF/IFAS loading rates for South Florida (4 lbs/1,000 ft^2/year) produced acceptable-quality turf and nitrogen applications to healthy St. Augustinegrass do not pose increased risk to nitrate leaching. The same study found that only 2.25 kilograms/hectare (kg/ha) or 0.05 lb/1,000 ft^2 of nitrate leached from test plots receiving 196 kg/ha (4 lbs/1,000 ft^2) of urea fertilizer over a 1-year period (Shaddox et al. 2016b). Current University of Florida recommendations do not pose an increased risk to NO_3–N leaching. However, N applications within the current recommended ranges may increase NO_3–N leaching if applied to stressed or unacceptable turf.

The results from these studies indicate that nitrate leaching does not increase significantly during the months of fertilizer bans in many county/municipality fertilizer ordinances (June to September 30). This is primarily because of the increased root mass and shoot growth during this time (Telenko et al. 2015; Trenholm et al. 2012). Research from North Central Florida and South Florida indicates that the most nitrate leaching is likely to occur in late winter or early spring, and that nitrate leaching can increase significantly during winter months when N is applied at rates of 1 lb/1,000 ft^2 or greater on a monthly schedule (Shaddox et al. 2016a). This increase in leaching is attributed to the reduced nutrient assimilation by the semidormant or dormant turfgrass. Finally, there were few differences in nitrate leaching based on N source, whether treatments were soluble, biosolid, or controlled-release sources, if turf was actively growing and healthy (Saha et al. 2007).

4.4.4 Reuse Water Loading Impacts versus Fertilizer TN Loading

ERD concluded that additional nitrogen loading from excess reuse was 8,312 kg/yr, which represented 40% of the total annual nitrogen loading from groundwater in all Marco Island sub-basins combined. The basis for this statement was not clearly presented in the ERD Report. Additional discussion and evaluation of this statement is provided in Section 3. However, based on the fact that reuse water is applied to less than 25% of the total pervious area on Marco Island and most of the remaining pervious area is irrigated with potable water and receives fertilizers, Jacobs believes that the nitrogen loading from fertilizers is significantly higher than nitrogen loading from applied reuse water. Also, even though fertilizer use is undoubtedly one of the largest nitrogen sources on Marco Island, ERD did not attempt to quantify the amount and types of fertilizers applied on Marco Island for use in preparing nutrient budgets for the ERD Report.

To assess potential reuse water loading impacts versus fertilizer TN loading, Jacobs used pervious and impervious areas with and without reuse irrigation from Table 4-7 of the ERD Report and the following assumptions to estimate nitrogen contributions from applied reuse water and fertilizer:

- Average annual hydraulic loading rates based on 2019-2021 FDEP Reuse Report data.
- TN and TP reuse water concentrations are based on 2019-2021 MIRWPF DMRs geometric means.
- TN maximum annual loading rate is 4 pounds per 1,000 square feet (lbs/1,000 ft^2). TN loading impacts also were analyzed for a second maximum TN loading rate at 3 lbs/1,000 ft^2.
- All areas irrigated with reuse water also receive supplemental fertilizer applications to achieve the TN maximum annual loading. All areas irrigated with other water sources receive the maximum annual TN loading.

Refer to Attachment 2 for calculation sheets showing the estimated net impact of reuse water applied to all on-island OPAAs for two maximum annual TN loading rates (4 lbs and 3 lbs/1,000 ft^2/yr.)

Based on the ERD estimated areas, the total reuse irrigated area is approximately 20% of the total Marco Island pervious area and approximately 25% of the total on-Island irrigated and fertilized pervious area. Table 6 summarizes the percent of TN loading for OPAAs and OPAAs plus on-Island golf courses as a percentage of the estimated TN loading from reuse and fertilizers on Marco Island.

Table 6. Estimated Impact of Reuse Water TN Loading as Percentage Total Nitrogen Loading from All Sources

Source	4 lbs/ksf/yr TN Max Loading	3 lbs/ksf/yr TN Max Loading
OPAA Reuse TN/Total MI TN Load	5.8%	7.7%
OPAA + Golf Course TN/Total MI TN Load	8.3%	11.0%

Source: Current MIRWPF Operating Permit

lbs/ksf/yr = pound(s) per 1,000 square feet per year

These data show that nitrogen loading from applied reuse water is only a fraction of the TN loading from applied reuse and fertilizers on the island and reuse water application to OPAAs, even assuming a lower maximum TN application rate, is less than 10% of the TN applied on the island. The other 90% is likely to be sourced from fertilizer according to ERD's land use and should be considered when reviewing isotope data. ERD failed to estimate the quantity of fertilizer and its associated TN load and focused entirely on nutrient loading from applied reuse water.

4.4.5 Golf Course Irrigation Rates and Groundwater Monitoring Data

ERD concluded that, although irrigation rates and nutrient loading rates for golf courses were lower than those estimated for OPAAs, the irrigation rates also exceeded evapotranspiration requirements and irrigation reduction should be considered to match evapotranspiration requirements (page ES-8, ERD Report). However, as discussed previously, golf course irrigation rates were actually less than the estimated IFAS gross irrigation requirement of 43 inches per year. Calculated annual irrigation volumes based on the ERD and updated City irrigated areas were 34.4 and 27.9 inches per year, respectively. The average weekly GIRs also were less than the IFAS average weekly GIR of 0.83 inch per week (0.66 and 0.54 inch per week, respectively). These data show that golf course irrigation rates are not excessive.

Regarding TN nitrogen loading rates, Table 7 shows that the annual TN loading based on ERD's acreage estimate and the City's updated acreage were below the IFAS estimated loading rate and were only 27% and 22% of the maximum annual TN loading rate of 4.0 lb/1,000 ft^2. Based on these data, TN application rates are not excessive and the golf courses would need to apply additional supplemental nitrogen fertilizers to provide the appropriate amount of nitrogen to maintain acceptable turf and quality.

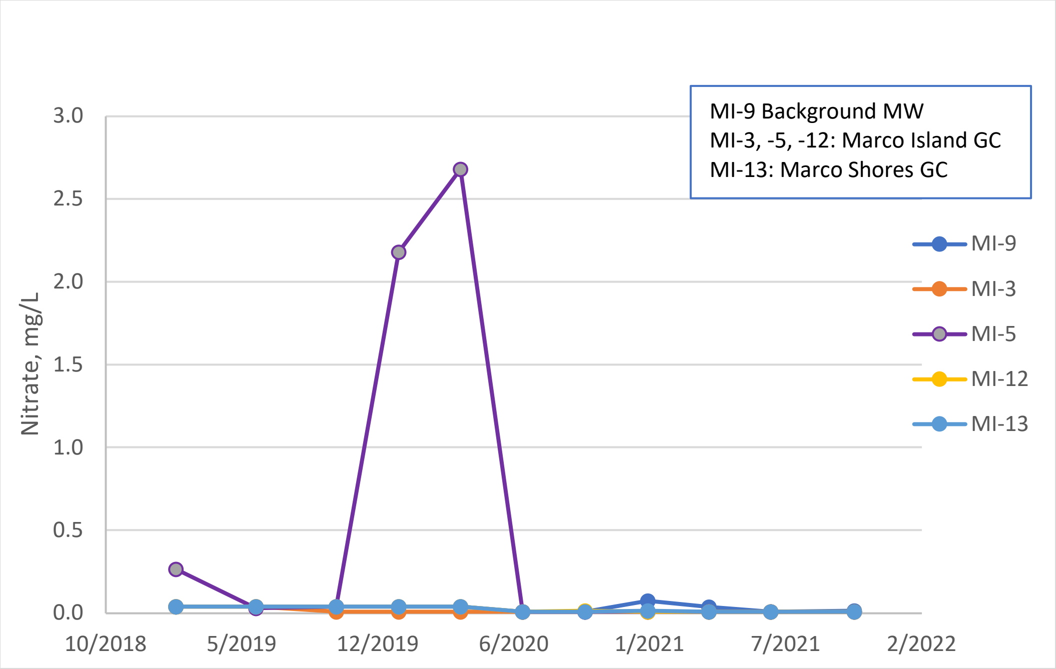
Table 7. Estimated Average Annual TN Loading Rates for 2019-2021

	IFAS GIR	ERD Estimate	City Updated Estimate
Annual TN Loading (lb/1,000 ft^2)	1.33	1.08	0.88
Percent of Max Loading Rate	33.3%	27.0%	22.0%

Loading rates are based on estimated golf course irrigated areas estimated by ERD (230 acres) and City GIS update (284 acres).

The manner in which reuse irrigation delivers nutrients is slow and regular. Irrigation occurs multiple times in a week. Fertilizer application typically is performed on a campaign basis. Slow-release fertilizers can be applied, but reuse water has built in a regular small dose of fertilizer. As provided in Table 6, reuse by itself does not provide sufficient nitrate and should be augmented. Fertilizer use and reuse water application should be considered in combination to avoid excess nutrients. If applied correctly, nutrient uptake from nutrients present in reuse water can be maximized.

To assess potential groundwater impacts of long-term application of reuse water to these sites, Jacobs also reviewed FDEP quarterly groundwater monitoring reports for monitoring wells located on the Marco Island and Marco Shores golf courses and a background monitoring well. Reports covering the period 2019 to 2021 were reviewed. This groundwater monitoring data is summarized on Figure 10. These data show that except for two 2020 monitoring periods for Well MI-5, nitrate concentrations were below method detection limits. Even the small increase observed for MI-5 in early 2020 returned to method detection limits by the end of 2020. These low groundwater nitrate concentrations are observed on these golf courses even after long-term application of reuse water and supplemental fertilizers. These data offer additional proof that nitrogen in the reuse water and applied fertilizers are being managed in an environmentally sound manner and are not excessive.



Source: FDEP Quarterly Groundwater Monitoring Reports for 2019, 2020, 2021.

Figure 10. Background and Golf Course Groundwater Nitrate Concentrations (2019 to 2021)

4.5 Reuse Irrigation Review Findings and Conclusions

Based on the results of Jacobs' review and analyses presented previously, Jacobs' findings and conclusions related to the four ERD Report findings listed earlier in this section are presented in the following sections.

4.5.1 ERD Finding No.1

"Reuse irrigation is currently being applied at rates which exceed the ability of turfgrasses to provide uptake of the water and nutrients, and results in a large amount of the reuse leaching past the root zone into groundwater. "

As demonstrated in Section 4.4, annual average reuse water application rates to golf courses and OPAAs are similar to, or less than, IFAS turfgrass irrigation requirements. Also, based on a review of 2021 monthly irrigation data and TN concentrations for ERD OPAAs and Marco Island GIS OPAAs, actual monthly applied irrigation rates tracked closely to the modeled IFAS GIRs. Tables 5, 6, and 7 and Figure 9 demonstrate that TN loading on an annual basis represents from about 33% to 49% of the annual total nitrogen loading allowed by the Marco Island fertilizer ordinance and TN loading during the summer wet season and fertilizer application ban is estimated to be 8% to 14% of the annual TN requirement.

Irrigation rates and TN application rates are not excessive.

4.5.2 ERD Finding No. 2

"Even if a 50% reduction in concentration is achieved during movement through groundwater, the additional nitrogen loading from excess reuse is 8,312 kg/yr which is 40% of the total annual nitrogen loading from groundwater in all sub-basins combined."

As demonstrated in Section 4.4.3, reuse water is only applied to approximately 20% of the total pervious area of Marco Island and 25% of the estimated irrigated and fertilized pervious area of the island. Reuse irrigation of only OPAAs account for only 13% of the total pervious area and 16% of the total estimated irrigated and fertilized pervious areas. ERD focused entirely on estimating nutrient loads from applied reuse water and did not attempt to estimate or project TN loading of applied fertilizers. **Reuse water TN application may account for less than 10% of all applied nitrogen on Marco Island. The other 90% is likely to be sourced from fertilizers according to ERD's land use and seepage isotope data. ERD's isotope data results discussed in Section 3 support this conclusion and emphasize the importance of promoting fertilizer application best management practices in adherence to the Marco Island fertilizer ordinance.**

4.5.3 ERD Finding No. 3

"Alternative methods of reuse disposal should be evaluated, and reuse should be applied only as needed to meet evapotranspiration requirements. If reuse were applied only as needed, the groundwater nitrogen impacts would be substantially reduced, resulting in a visible improvement in waterway water quality.

No alternative disposal methods need to be evaluated. On average, data indicates that reuse water is manage appropriately regarding hydraulic and TN loading. Also, Marco Island already has an alternate disposal method in place (two aquifer storage recovery/deep injection wells), that are used when irrigation demands are lower because of rainfall or seasonal variation in irrigation rates. Review of 2021 operations records show the aquifer storage recovery wells being used in this manner during the June to September period.

TP loading exceeds the fertilizer ordinance maximum annual rate of 0.5 lb/1,000 ft^2/yr, but the actual impact of this excess TP loading was not established in the ERD Report.

Even if reuse water were to be immediately discontinued, it is highly unlikely that discernable changes in waterway water quality could be detected within a reasonable time period. Refer to Section 3 conclusions for further detail regarding this conclusion.

4.5.4 ERD Finding No. 4

"Reuse irrigation is also used on the golf course, but the water is stored in a surface pond prior to application. Nutrient reduction occurs within the pond which reduces the nutrient loading to concentrations similar to urban runoff in other parts of Florida which reduced potential groundwater impacts. However, at the irrigation rates indicated by annual reuse summary forms provided to FDEP, the irrigation rates also exceed evapotranspiration requirements, although not to the extent observed by reuse application in other public areas, and irrigation reduction should be considered to match evapotranspiration requirements".

As discussed previously in Section 4.5.1, Annual average and monthly irrigation rates and TN application rates to golf courses are not excessive and are actually lower than IFAS mean gross irrigation requirements and TN application rates for landscape turfgrasses such as St. Augustinegrass and hybrid bermudagrass varieties used on the golf courses.

ERD did not present or evaluate any of the long-term groundwater monitoring data nor was any groundwater or soil water sampling performed on representative reuse water sites. Long-term groundwater monitoring data for Marco Island and Marco Shores golf courses presented in Section 4.4.4 demonstrate that nitrate concentrations of monitoring wells on these golf courses are routinely below method detection limits. These data appear to show that nitrogen in the reuse water and applied fertilizers are managed in an environmentally sound manner.

4.6 Recommendations from Reuse Irrigation Assessment

Jacobs provides the following recommendations for the City to consider in addressing the findings of the reuse irrigation assessment:

7. Conduct additional soil sampling of representative public access areas and golf courses to assess current available and total P levels and P Capacity Indexes.
8. Consider installing additional shallow groundwater monitoring wells in representative areas to assess actual potential impacts to groundwater quality and nutrient levels.
9. Continue with the updating of irrigated area for all reuse customers to provide more accurate tracking of irrigation and nutrient loading rates.
10. For reuse customers with automatic irrigation controllers, promote the use of the IFAS Urban Irrigation Scheduler App (http://fawn.ifas.uf.edu/tools/urban_irrigation/), or other similar irrigation scheduling tools, to help adjust irrigation controller run times based on historical weather data. UF/IFAS recommends that when using a time clock for irrigation scheduling, run times based on historical weather data can be found in Operation of Residential Irrigation Controllers (https://edis.ifas.ufl.edu/ae220). If an automatic controller is used, it is recommended that irrigation schedules be changed each month according to recommendations outlined in AE220. The Urban Irrigation Scheduler tool assists with adjusting smart irrigation controllers by adjusting for weather conditions once installed and set up properly.
11. Consider/promote the use of soil moisture monitoring sensors on existing and new irrigation systems with smart automatic controllers to provide more precise control over irrigation operations. The soil moisture sensor will allow irrigation only if water is required. Refer to Attachment 3 for UF/IFAS Bulletin AE437 for more detailed information on the use of soil moisture sensors with smart irrigation controllers and Bulletin 343 for descriptions and evaluations of field devices for monitoring soil water content.
12. To control/minimize overspray and water loss in median areas, consider converting spray heads/rotors to subsurface drip or microspray systems. For medians that are irrigated with water trucks, consider installing drip or microspray systems to minimize application of reuse water to road surfaces and other impervious areas.

4.7 ERD Recommendations Supported

The ERD Report provide several excellent recommendations related to the irrigation system operation and management and fertilizer usage that Jacobs wholeheartedly supports. These recommendations are as follows:

- *Reuse water nutrient content should be considered in fertilization applications*. Reuse water should be considered as a liquid fertilizer source and applied nitrogen, phosphorus, and potassium as well as other micronutrients in the reuse water should be subtracted from the target nutrient application rates to determine additional supplemental fertilization needs.
- *Additional public education related to Fertilizer Ordinance and Fertilizer Use Best Management Practices.* Jacobs supports this recommendation and suggests that UF/IFAS information on best management practices for urban landscapes be made available to all island utility customers and residents. One such publication is Bulletin ENH979, *Homeowner Best Management Practices for the Home Lawn*. A copy of this bulletin is provided in Attachment 4.
- *Routine inspections to prevent overspray and repair of damaged irrigation systems*. This should be a standard best management practice for all on-island irrigation systems to minimize, to the greatest extent possible, the application of reuse water to impervious areas or direct discharge to storm sewer systems and waterbodies.
- *General public education on watershed activities and water pollution in waterways*.

5 References

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Attachment 1

UF/IFAS Net and Gross Irrigation Requirements for Florida Turfgrasses

IFAS Net & Gross Irrigation Requirements for Florida Turfgrass Lawns & Estimated Marco Island Nutrient Loading from Reclaimed Water Irrigation[1]

Current Conditions (TN & TP Concentrations from 1/2019 to 4/2022)

Irrigation Eff. %	**80%**	(assumes surface sprinkler irrigation)
Total N, mg/L	**6.0**	Geom. Mean (1/2019-4/2022)
Total P as P, mg/L	**2.91**	Geom. Mean (1/2019-4/2022)
Total P as P2O5, mg/L	6.7	

Marco Island Fertilizer Ordinance
<= 4 lbs/ksf TN per calendar year
<= 0.5 lbs/ksf P2O5 per calendar year

Estimated Turfgrass Irrigation Requirement

	Fort Myers												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Gross Irrigation (inches/wk)	0.52	0.73	0.90	1.28	1.58	0.79	0.68	0.68	0.65	0.86	0.70	0.52	0.83
Gross Irrigation (inches)[2]	2.3	2.9	4.0	5.5	7.0	3.4	3.0	3.0	2.8	3.8	3.0	2.3	43.0
Net Irrigation (inches/wk)	0.41	0.58	0.72	1.03	1.26	0.63	0.54	0.54	0.51	0.68	0.56	0.41	0.66
Net Irrigation (inches)	1.8	2.3	3.2	4.4	5.6	2.7	2.4	2.4	2.2	3.0	2.4	1.8	34.2
Drainage (inches)	1.8	2.2	2.2	1.5	2.0	7.2	5.8	6.8	6.3	2.6	1.8	1.3	41.5
Effective Rainfall (inches)	0.5	0.6	0.7	0.7	1.1	2.3	2.7	2.6	2.0	0.9	0.6	0.4	15.1

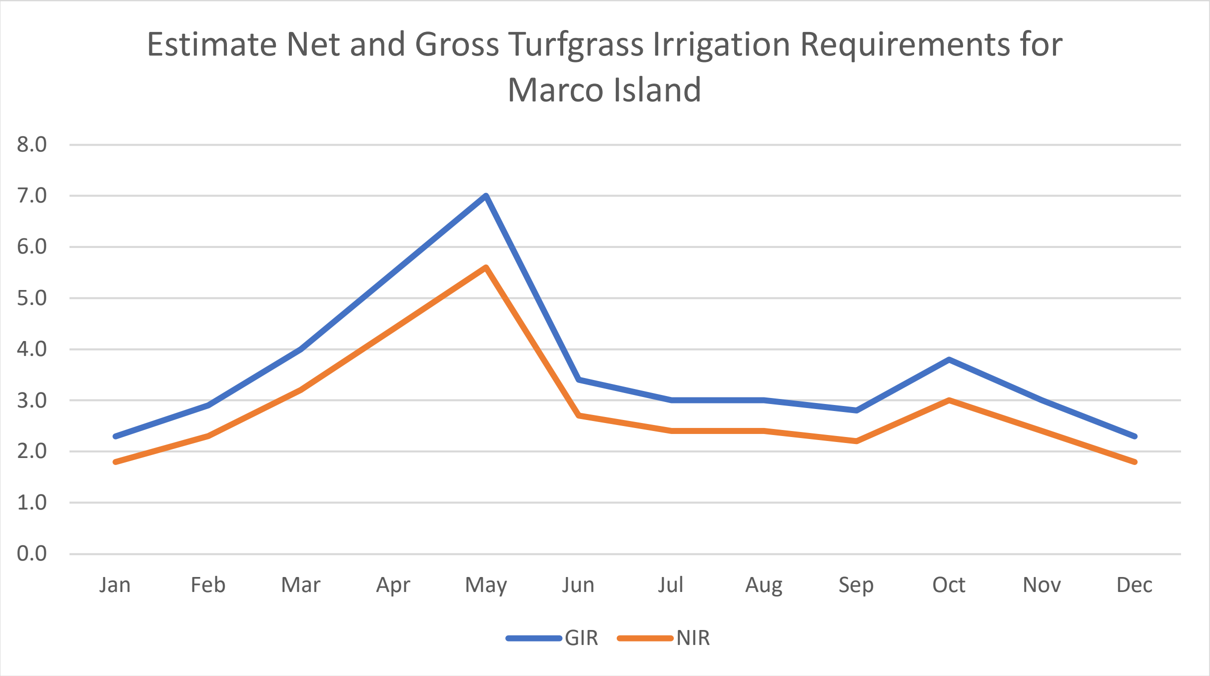
Estimated Nutrient Loading

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Gross Irrigation (inches)	2.3	2.9	4.0	5.5	7.0	3.4	3.0	3.0	2.8	3.8	3.0	2.3	43.0
TN Loading (lbs/acre)	3.13	3.94	5.44	7.48	9.52	4.62	4.08	4.08	3.81	5.17	4.08	3.13	58.5
TN Loading (lbs/ksf)	0.07	0.09	0.12	0.17	0.22	0.11	0.09	0.09	0.09	0.12	0.09	0.07	1.33
IFAS N Requ. (lb/ksf)[3]	0.11	0.12	0.21	0.33	0.50	0.63	0.66	0.67	0.65	0.50	0.30	0.15	4.83
TP Loading as P2O5 (lbs/acre)	3.49	4.40	6.07	8.35	10.63	5.16	4.55	4.55	4.25	5.77	4.55	3.49	65.3
TP Loading as P2O5 (lbs/ksf)	0.08	0.10	0.14	0.19	0.24	0.12	0.10	0.10	0.10	0.13	0.10	0.08	1.48

[1] Source: IFAS Extension Bulletin AE482, Net Irrigation Requirements for Florida Turgrass Lawns: Part 3-Theoretical Irrigation Requirments, Table 4 Mean monthly net irrigation requirement, drainage, and effective rainfall for the 30-year period (1980-2009) of weather station data records (considering the average between 8 and 12 in root zone for Fort Myers, FL)

[2] Gross irrigation requiment (GIR) = Net Irrigation Requirement/Irrigation Efficiency. Typical range for residential surface sprinklers 70% - 80% with 75% average. Conservative estimate of 80% used to calculate GIR.

[3] Source: Trends in Turf Nutrition-Balancing Environmental Protection and Turf Performance.


Estimate Net and Gross Turfgrass Irrigation Requirements for Marco Island
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
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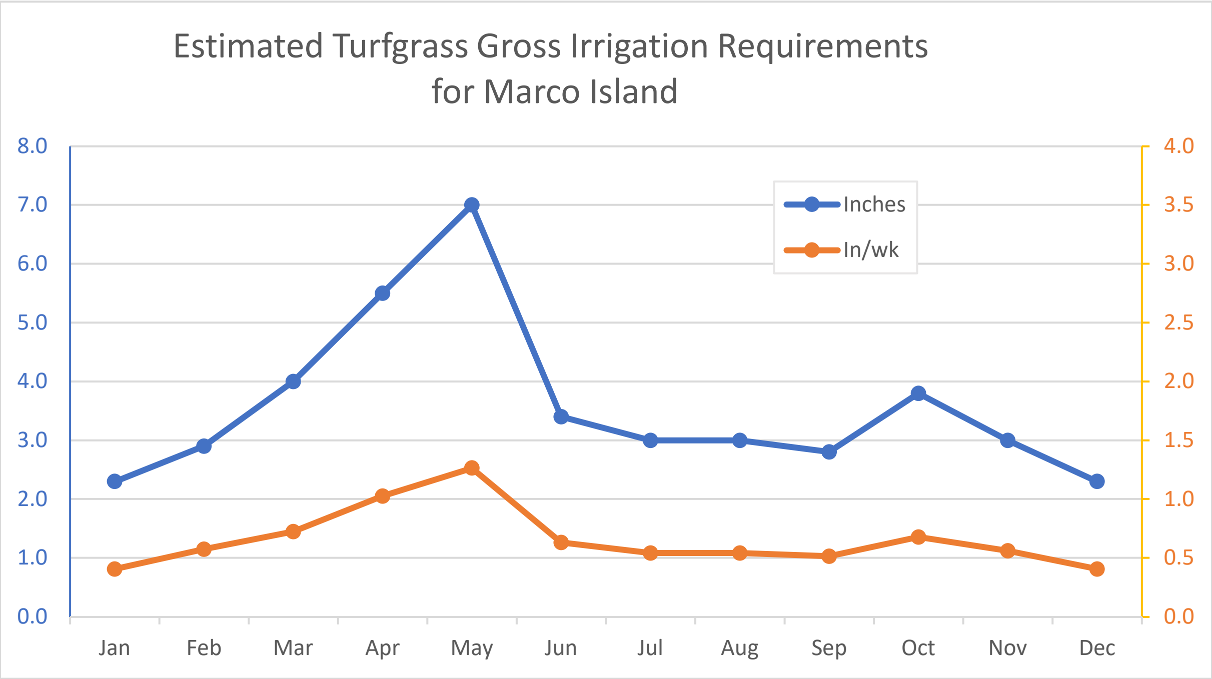
Dec
GIR
NIR


Estimated Turfgrass Gross Irrigation Requirements
for Marco Island
8.0
7.0
6.0
5.0
4.0
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4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Inches
In/wk
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Attachment 2

Calculation Sheets for Estimated Impact of Reuse Water TN Loading to On-Island OPAAs

Estimated Impact of Reuse Water TN Loading to On-Island Other Public Access Areas

Annual Maximum TN Loading Rate 3 lbs/1000 ft2/year

Total Area (ac)	5,257.57
Tota Impervious Area (ac)	2,165.82
Total Pervious Area (ac)	3,091.75
Est. Irrig. & Fert Perv. Area (ac)	2,193.98
ERD Total on-island Irr & Fert Area (ac)	2,503.50
ERD On-island Golf Course Reuse Area (ac)	229.99

TN Max Application Rate (lb/1000 ft²)	3.0
Total ERD On-Island Other PA Users Irrigated Area (ac)	400
ERD OPAA Reuse TN Loading Rate (lb/1000 ft²)	1.45
ERD OPAA Golf Course Reuse TN Loading Rate (lb/1000 ft²)	1.08

Other PA Users Irrigated Area/Total Pervious Area:	13%
Other PA Users Irrigated Area/Est. Fertilized Pervious Area:	16%

Total Reuse Irrigated Area/Total Pervious Area:	20.4%
Total Reuse Irrigated Area/Total Irrig & Fertilized Pervious Area	25.2%

		Comments/Assumptions
Annual Reuse TN Load to Other PA Users (lbs)	25,265	Only considering irrigation of Other Public Access Areas with RW
Remaining TN load to Other PA to achieve max TN (lbs)	27,007	Additional 2.55 lb/1000 ft² applied to Other PA users reach max allowable
Annual Reuse TN Load to On-Island Golf Courses (lbs)	10,820	
Remaining TN Load to On-Island Golf Courses to achieve max TN (lbs)	19,235	Additional 2.92 lb/1000 ft² applied to golf courses to reach max allowable
Annual TN Load to Remaining ERD Estimated Pervious Area (lbs)	244,830	Based on estimated non-reuse pervious areas receiving other irrigation source from Table 4-7 ERD Report assumed to be fertilized to max allowable TN rate
Other PA Users Reuse TN/Total Marco Island TN Load	7.7%	
Other PA Users + Golf Courses Reuse TN/Total Marco Island TN Load	11.0%	

E

Estimated Impact of Reuse Water TN Loading to On-Island Other Public Access Areas

Annual Maximum TN Loading Rate 4 lbs/1000 ft2/year

Total Area (ac)	5,257.57
Tota Impervious Area (ac)	2,165.82
Total Pervious Area (ac)	3,091.75
Est. Irrig. & Fert Perv. Area (ac)	2,193.98
ERD Total on-island Irr & Fert Area (ac)	2,503.50
ERD On-island Golf Course Reuse Area (ac)	229.99

TN Max Application Rate (lb/1000 ft^2)	4.0
Total ERD On-Island Other PA Users Irrigated Area (ac)	400
ERD OPAA Reuse TN Loading Rate (lb/1000 ft^2)	1.45
ERD OPAA Golf Course Reuse TN Loading Rate (lb/1000 ft^2)	1.08

Other PA Users Irrigated Area/Total Pervious Area:	13%
Other PA Users Irrigated Area/Est. Fertilized Pervious Area:	16%

Total Reuse Irrigated Area/Total Pervious Area:	20.4%
Total Reuse Irrigated Area/Total Irrig & Fertilized Pervious Area	25.2%

		Comments/Assumptions
Annual Reuse TN Load to Other PA Users (lbs)	25,265	Only considering irrigation of Other Public Access Areas with RW
Remaining TN load to Other PA to achieve max TN (lbs)	44,431	Additional 2.55 lb/1000 ft^2 applied to Other PA users reach max allowable
Annual Reuse TN Load to On-Island Golf Courses (lbs)	10,820	
Remaining TN Load to On-Island Golf Courses to achieve max TN (lbs)	29,254	Additional 2.92 lb/1000 ft^2 applied to golf courses to reach max allowable
Annual TN Load to Remaining ERD Estimated Pervious Area (lbs)	326,440	Based on estimated non-reuse pervious areas receiving other irrigation source from Table 4-7 ERD Report assumed to be fertilized to max allowable TN rate
Other PA Users Reuse TN/Total Marco Island TN Load	5.8%	
Other PA Users + Golf Courses Reuse TN/Total Marco Island TN Load	8.3%	

E

Attachment 3

UF/IFAS Bulletin AE437

Smart Irrigation Controllers: How Do Soil Moisture Sensor (SMS) Irrigation Controllers Work?[1]

Michael D. Dukes, Mary Shedd, and Bernard Cardenas-Lailhacar[2]

This article is part of a series on smart irrigation controllers. The rest of the series can be found at https://edis.ifas.ufl.edu/TOPIC_SERIES_Smart_Irrigation_Controllers.

Introduction

Water is required for the basic growth and maintenance of turfgrass and other landscape plants. When a sufficient amount of water is not present for plant needs, then stress can occur and ultimately lead to reduced quality or death. Irrigation is common in Florida landscapes because of sporadic rainfall and the low water holding capacity of sandy soil. This inability of many of Florida soils to hold substantial water can lead to plant stress after only a few days without rainfall or irrigation.

Water conservation is a growing issue in Florida due to increased demands from a growing population. One of the areas with the largest potential for reducing water consumption is residential outdoor water use, which accounts for up to half of publicly supplied drinking water. Most new homes built in Florida have automated irrigation systems. These irrigation systems use an irrigation timer to schedule irrigation. These automated irrigation systems have been shown to use 47% more water on average than sprinkler systems that are not automated (i.e. hose and sprinkler), which can be attributed largely to the tendency to set irrigation controllers and not readjust for varying weather conditions. Irrigation control technology that improves water application efficiency is now available. In particular, soil moisture sensor (SMS) irrigation controllers can reduce the number of unnecessary irrigation events.

How Soil Moisture Sensor Systems Work

Most soil moisture sensors are designed to estimate soil volumetric water content based on the dielectric constant (soil bulk permittivity) of the soil. The dielectric constant can be thought of as the soil's ability to transmit electricity. The dielectric constant of soil increases as the water content of the soil increases. This response is due to the fact that the dielectric constant of water is much larger than the other soil components, including air. Thus, measurement of the dielectric constant gives a predictable estimation of water content. For more information on soil moisture sensors see, *Field Devices for Monitoring Soil Water Content* https://edis.ifas.ufl.edu/ae266.

Bypass type soil moisture irrigation controllers use water content information from the sensor to either allow or bypass scheduled irrigation cycles on the irrigation timer (Figures 1 and 2). The SMS controller has an adjustable threshold setting and, if the soil water content exceeds that setting, the event is bypassed. The soil water content threshold is set by the user. Another type of control

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1. This document is AE437, one of a series of the Agricultural and Biological Engineering Department, UF/IFAS Extension. Original publication date October 2008. Revised February 2015 and May 2021. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Michael D. Dukes, professor; Mary Shedd, former graduate research assistant; Bernard Cardenas-Lailhacar, research associate; Department of Agricultural and Biological Engineering, UF/IFAS Extension, Gainesville, FL 32611.

technique with SMS devices is "on-demand" where the controller initiates irrigation at a low threshold and terminates irrigation at a high threshold. The "on-demand" SMS controller concept is discussed in *What Makes an Irrigation Controller Smart?* http://www.edis.ifas.ufl.edu/ae442.

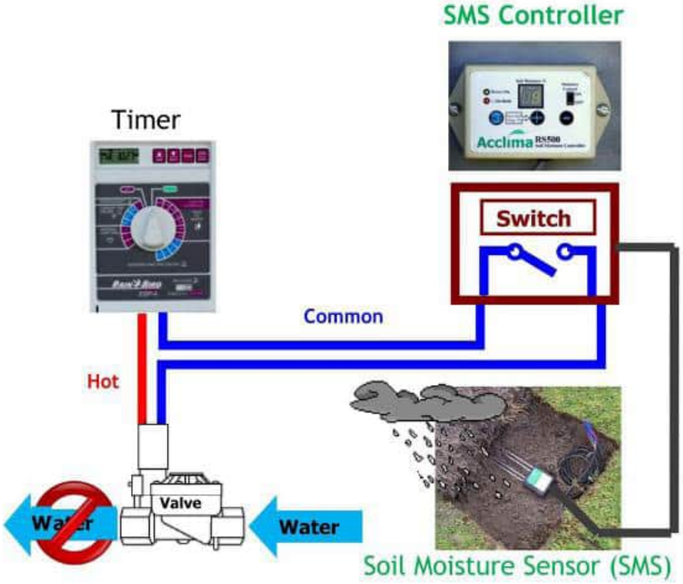

Figure 1. Simplified diagram showing how a soil moisture sensor (SMS) is typically connected to an automated irrigation system. The irrigation timer is connected to a solenoid valve through a hot and a common wire. The common wire is spliced with the SMS system (a controller that acts as a switch, and a sensor buried in the root zone that estimates the soil water content). The SMS takes a reading of the amount of water in the soil and the SMS controller uses that information to open or close the switch. If the soil water content is below the threshold established by the user, the controller will close the switch, allowing power from the timer to reach the irrigation valve and trigger irrigation. In this example the controller opens the switch, bypassing irrigation, because of rainfall wetting the soil around the soil moisture sensor.
Credits: Melissa Haley

Sensor Installation

A single sensor can be used to control the irrigation for many zones (where an irrigation zone is defined by a solenoid valve) or multiple sensors can be used to irrigate individual zones. In the case of one sensor for several zones, the zone that is normally the driest, or most in need of irrigation, is selected for placement of the sensor in order to ensure adequate irrigation in all zones.

Some general rules for the burial of the soil moisture sensor are:

- Soil in the area of burial should be representative of the entire irrigated area.

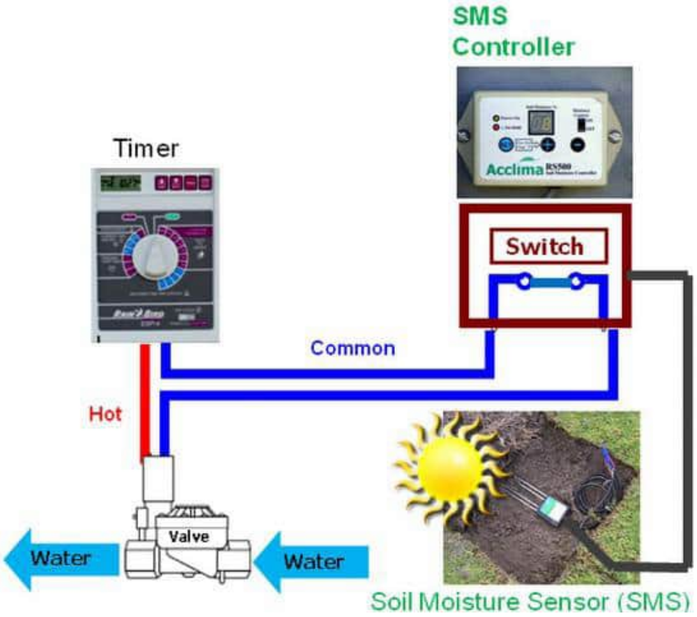

Figure 2. In this example the controller closes the switch allowing irrigation because of dry conditions in the soil around the soil moisture sensor.

- Sensors should be buried in the root zone of the plants to be irrigated, because this is where plants will extract water. Burial in the root zone will help ensure adequate turf or landscape quality. For turfgrass, the sensor should typically be buried at about three inches deep.
- Sensors need to be in good contact with the soil after burial; there should be no air gaps surrounding the sensor. Soil should be packed firmly but not excessively around the sensor.
- If one sensor is used to control the entire irrigation system, it should be buried in the zone that requires water first, to ensure that all zones get adequate irrigation. Typically, this will be an area with full sun or the area with the most sun exposure.
- Sensors should be placed at least 5 feet from the home, property line, or an impervious surface (such as a driveway) and 3 feet from a planted bed area.
- Sensors should also be located at least 5 feet from irrigation heads and toward the center of an irrigation zone.
- Sensors should not be buried in high traffic areas to prevent excess compaction of the soil around the sensor.

Setting the Sensor Threshold

Once the sensor has been buried and the SMS controller has been connected to the irrigation system, the sensor needs to be calibrated and/or the soil water content threshold needs to be selected.

Based on the sandy soils in much of Florida, the following steps should be followed to calibrate or select a threshold for the soil moisture sensor controller:

Step 1. Apply water to the area where the sensor is buried. Either set the irrigation zone to apply at least 1 inch of water or use a 5-gallon bucket to apply directly over the buried sensor.
Step 2. Leave the area alone for 24 hours, and do not apply more water. If it rains during the 24 hours, the process should be started over.
Step 3. The water content after 24 hours is now the sensor threshold used to allow or bypass scheduled irrigation events. This threshold may be decreased slightly (~20%) to allow more storage for rainfall; however, the landscape will still need to be carefully monitored to ensure that adequate irrigation is being supplied.

The last step may vary slightly for each type of SMS controller. Generally, the manufacturer's instructions should be followed for the actual setup of the controller. These steps are provided mainly to direct how to establish the proper soil moisture content for the specific soil.

Programming the Irrigation Timer with a Soil Moisture Sensor System

Soil moisture control devices can reduce water use on the lawn by bypassing scheduled irrigation events, but it is important to make sure the irrigation schedule is programmed into the irrigation timer correctly. Programming the irrigation timer correctly for the area to be irrigated can make the use of irrigation water more efficient. Before setting the irrigation schedule it is important to determine when the water will be applied and how much to apply with each irrigation event. In most areas of Florida the days per week in which irrigation is allowed is already limited by water restrictions. Irrigation run time is the amount of time an irrigation zone has to be turned on to apply the desired amount of water. It is affected by the water application rate of the irrigation sprinklers and the time of the year. For more information on setting the irrigation timer properly see *Operation of Residential Irrigation Controllers* https://edis.ifas.ufl.edu/ae220, which is also provided as a tool in the Florida Automated Weather Network (FAWN) urban irrigation scheduler (http://fawn.ifas.ufl.edu/tools/urban_irrigation/).

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Attachment 4

UF/IFAS Bulletin ENH979, *Homeowner Best Management Practices for the Home Lawn*

ENH979

Homeowner Best Management Practices for the Home Lawn[1]

Laurie E. Trenholm[2]

A healthy lawn is an important component of an urban landscape. Not only do lawns increase the value of a property, they reduce soil erosion, filter stormwater runoff, cool the air, and reduce glare and noise. A healthy lawn effectively filters and traps sediment and pollutants that could otherwise contaminate surface waters and groundwater.

Management of home lawns is often not well understood by residents and can often have adverse effects on turf health. Loss of turf health can render it less able to filter stormwater runoff and reduce soil erosion, which can lead to increased nonpoint source pollution. Misuse of fertilizers can result in direct deposition of granules into water bodies or increased risk of leaching into groundwater. In either case, the result can be unhealthy turf and increased nonpoint source pollution. Therefore, it is very important that homeowners who do their own lawn care use Best Management Practices (BMPs) when maintaining their lawns. Best Management Practices follow Florida Friendly Landscaping™ principles, developed for maintenance of a healthy landscape that does not contribute to nonpoint source pollution. Following BMPs can reduce potential pollution of Florida's surface or groundwater resources as a result of lawn and landscape maintenance. Here are some easy-to-follow tips on Florida-Friendly lawn maintenance:

Fertilization

Fertilize Appropriately

Proper fertilization consists of selecting the right type of fertilizer, applying it at the right time and in the right amount for maximum plant uptake and benefit.

Lawns require nutrients throughout the growing season to stay healthy. The growing season will vary depending upon location in the state. The amount of fertilizer required annually will primarily depend on the grass species and geographical location.

In June of 2007, the Florida Department of Agriculture and Consumer Services (FDACS) passed a rule regulating labeling requirements for urban turf (home lawn) fertilizers (Urban Turf Fertilizer Labeling Rule (RE-1.003(2) FAC). This rule requires fertilizer manufacturers to place specific language on fertilizer bags with the intent of reducing potential nonpoint source pollution that might result from misapplication of fertilizer to lawns. The rule regulates the maximum amount of nitrogen and phosphorus that is in the bag and directs users to follow UF/IFAS recommendations for annual fertilizer application rates. The rule is based on scientific research conducted by UF/IFAS.

Selecting a Fertilizer

The labeling requirements make it easier for homeowners to find appropriate lawn fertilizers in the retail market.

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1. This document is ENH979, one of a series of the Environmental Horticulture Department, UF/IFAS Extension. Original publication date April 2004. Revised January 2018. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Laurie E. Trenholm, professor, Extension turfgrass specialist, Environmental Horticulture Department; UF/IFAS Extension, Gainesville, FL 32611.

Select only a fertilizer that says for use on urban turf. Do not use a fertilizer for flower or vegetable gardens on lawns. For homeowners doing their own fertilizing, these products will contain both slow-release nitrogen and low or no phosphorus. Slow-release nitrogen will provide a longer-lasting response from the grass and reduces the potential for burning from excess application. The low phosphorus will not be harmful for many lawns in Florida because some Florida soils are already high in phosphorus and turf requirements for this nutrient are low relative to nitrogen and potassium. However, there have been increased phosphorus deficiencies in a number of lawns throughout Florida and soil tests may be warranted if deficiency symptoms occur. These symptoms include reduced growth and dark green followed by purple shoot color of lower leaves. A soil test is required to identify a phosphorus deficiency and allows for supplemental phosphorus to be applied when a deficiency exists.

Fertilizer Timing

Our warm-season grasses grow in response to both increasing temperature and day length, making summertime the time of most active growth. This is when grasses have the best ability to take up the nutrients and also have the most need for them. It is important to not fertilize when grasses are not growing, as this can increase the possibility of nutrients leaching through the soil or running off. This occurs largely because the root systems of warm-season grasses "slough off" during the winter months (Figure 1), rendering them less able to assimilate nutrients from fertilizer. This is especially true in north and central Florida and becomes less common as you head further south in the state. University of Florida research on nitrate leaching from various lawngrass species found that the potential for nitrate leaching in north central and northwest Florida is greatest in the months of January through March, when the root system has the least mass and the grass may be in some stage of cold-induced dormancy. It is therefore important to wait until growth begins in the spring to fertilize. For north Florida and the panhandle, this would be around the middle of April. For north-central and central Florida, it would be early April.

The last fertilizer application should be around the middle or end of September in north Florida and early October in central Florida. In south Florida, you can apply fertilizer throughout the year.

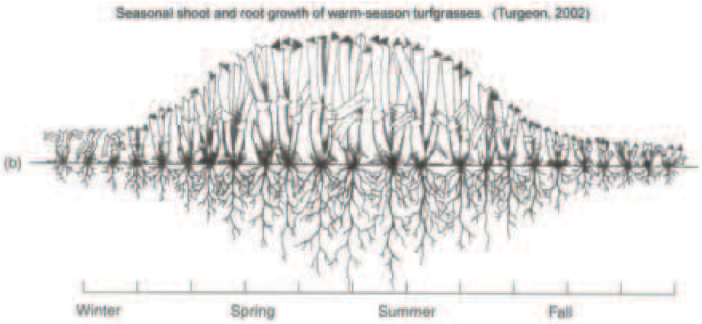

Figure 1. Annual root and shoot growth cycle of warm-season turfgrass species.
Credits: Turgeon (2002)

Fertilizer Application Rate

No matter what species of grass you have or where you live in the state, you should apply only up to 1 lb of nitrogen for every 1000 square feet of lawn each time you apply fertilizer. To see how much fertilizer 1 pound of nitrogen is, refer to Table 1, which lists the amount of fertilizer needed by percentage of nitrogen in the bag. For example, if you have a fertilizer that has 15% nitrogen (first of the 3 numbers on the bag), you would apply 6.5 pounds of that product per 1,000 square feet to apply the correct amount of nitrogen.

Rates for annual fertilization should follow the UF/IFAS recommendations found in Table 2 for your grass species. Applying fertilizer at rates greater than listed can contribute to increased disease or insect problems and may increase the potential for increased nutrient leaching or runoff. This will determine how many applications you will make annually. For example, if you live in central Florida and have St. Augustinegrass, you can apply anywhere from 2–5 pounds of nitrogen on a yearly basis. This means that you might apply fertilizer anywhere from 2 to 5 times a year. Typically, the commercial lawn care companies would fertilize at the higher range (4–5 times yearly), while a homeowner may fertilize fewer times a year.

An important part of figuring out how much fertilizer to apply is to know the size of your lawn. It is easiest to do this by breaking it into the front, back and sides of the house and adding those amounts of fertilizer to the spreader. This will help you apply the right amount.

What if you live in an area where lawn fertilization is prohibited from June 1 through September 30?

A number of cities and counties in Florida have passed fertilizer ordinances that do not allow for application of nitrogen or phosphorus fertilizers during the summer. These ordinances are passed out of concern for nutrient leaching due to potential heavy rainfall, but research has shown that this is the time of least nitrate leaching (Trenholm et al. 2012). If you are in one of these restricted areas, fertilize with a long-term controlled release product at the end of May. The grass will receive low doses of nitrogen over a period of 3 to 4 months, depending on the product used. When the restrictive period is over, fertilize again with a product that has a more soluble nitrogen component, such as sulfur-coated urea. This will reduce the potential for the fertilizer to release nitrogen during the winter months when the ability to take up the nutrients is reduced.

Other Important Fertilization BMPs for Homeowners

SOIL TEST

It is important to test your soil to determine phosphorus and other nutrient levels. Check with your local UF/IFAS Extension office for information on how to submit soil samples for testing or go to http://soilslab.ifas.ufl.edu/ESTL%20Home.asp for online information on soil testing.

FERTILIZING SMALL STRIPS OF GRASS AND AROUND WATER BODIES

If you have a small strip of lawn that adjoins impervious surfaces, such as a sidewalk or pavement, use a spreader equipped with a deflector shield that will spread the fertilizer in a 180º arc to keep it away from the paved area. Use the same shield when you are fertilizing areas next to water bodies. Leave a 10-ft strip of turf around the water body unfertilized to avoid polluting the water.

FERTILIZER SPILLS AND STORAGE

If you spill fertilizer on the driveway or sidewalk, sweep it up and put it back in the bag. Always sweep up spilled fertilizer rather than rinsing it away, even when the spill is on the lawn. Spilled fertilizer easily finds its way down storm drains or into the ground and from there into the water supply.

Store your unused fertilizer where it will stay dry. Do not store it next to pesticides, fuel, or solvents.

WATERING FERTILIZER IN

After applying fertilizer, you will need to irrigate long enough to move the granules off of the leaf blades and into the soil, where they will be taken up for use by the plant. This will avoid leaf burn and reduce potential runoff of nutrients. Only apply enough water to moisten the top ½ inch of soil. This will wash most of the fertilizer into the top few inches of the soil, where it will best be taken up. More water than this may lead to leaching of the nutrients past the root zone, which will result in potential groundwater contamination.

FERTILIZING NEWLY PLANTED TURF

Research has shown that the risk of nutrient leaching is much greater on newly planted sod than on established turfgrass. This is due to the lack of a deep root system on newly planted grass and due to import of some nutrients from the sod farm. Wait at least 30 to 60 days after planting to apply nitrogen fertilizer to turfgrass.

WEATHER AND FERTILIZATION

Do not fertilize if the National Weather Service has issued a flood, tropical storm, hurricane watch or warning, or if heavy rains (greater than 2 inches) are likely within 24 hours.

Mowing

Mowing may seem like a never ending chore during the summer months, but it is one of the most important practices that can influence the health of your lawn. Follow these suggestions for a healthy, happy lawn:

- Mow at the highest recommended height for your grass species. For St. Augustinegrass standard cultivars, this is 3.5–4 inches. If you have St. Augustinegrass “dwarf” cultivars ‘Delmar’, ‘Seville’ or ‘Captiva’, mow at 2–2.5 inches. Zoysiagrass cultivars such as ‘Empire’ should be mowed at 2”. Mow bahiagrass at 3–4 inches and centipedegrass and bermudagrass at 1–2 inches. Mowing at these heights promotes a deep root system, which makes grass more stress tolerant.
- Never remove more than ⅓ of the leaf blade at any one time. Removing too much of the leaf blade can stress your lawn and leave it susceptible to insect or disease invasion. If you miss a scheduled mowing event, raise the mower height and bring the grass back down to the recommended level gradually over the next few mowing events.
- Leave grass clippings on the lawn. They do not contribute to thatch and actually return a small amount of nutrients and organic matter back to the lawn.
- Keep your mower blades sharp. Dull mowers tear the leaf blades. This makes the lawn look bad and leaves it susceptible to insect or disease invasion.
- Do not mow your lawn when it is wet. This may be dangerous for you if you slip and can be tough on the mower.
- Always wear heavy, closed-toed shoes and eye protection when mowing.

Irrigation

Improper irrigation practices damage more lawns than any other single cultural practice. Train your grass to be more drought tolerant using the following methods:

- Irrigate as infrequently as you can without having your grass start to go into excess drought stress. When you water, apply ½–¾ inch to help encourage the roots to grow deep into the soil. Grasses irrigated in this manner will have a better chance of surviving watering restrictions or drought periods.
- Turn your automatic sprinkler system to the "off" position and turn it on when your lawn shows signs of needing irrigation. Adjust your timer seasonally. Irrigation frequency will vary depending on where you are in the state, as well as on the amount of shade in the landscape, soil type, etc. Many areas of the state have mandated watering restrictions, so be sure to be aware of and follow any regulations regarding when you can irrigate your lawn. A lawn is ready for water when the leaf blades show at least one of the three wilt signs: when leaf blades start to fold in half lengthwise, when the grass takes on a bluish cast, or when footprints remain visible in the lawn long after being made. Unless restrictions do not allow, irrigate when about 50 percent of the lawn shows one of these signs, unless rain is forecast in the next 24 hours.
- In most parts of Florida, irrigate to apply ½–¾ inch of water. If you live in an area with a hard pan layer right below the soil surface, you will likely get runoff before that amount of water can be delivered. In that case, irrigate to the point of runoff, let the water drain, and then apply the remainder of the needed amount a short time later. Do not continue to let the irrigation system run past the point of runoff; this only wastes water. Coastal areas that experience sea breeze may require more frequent irrigation.
- To determine how long you need to run your irrigation system to apply ½–¾ inch of water to the whole lawn, place straight-sided cans around the perimeter of each irrigation zone. Turn on the irrigation system and monitor the cans to see how long it takes to fill them to ½–¾ inch. Each zone will likely have different run-times, therefore, time irrigation intervals for the zones accordingly. For additional information refer to AE220, *Operation of Residential Irrigation Controllers* (http://edis.ifas.ufl.edu/ae220).
- If you are in an area with very sandy soil, you may need to apply the higher amount of water. Heavier clay soils may only need the ½-inch rate.
- In north or central Florida, irrigate every two to three weeks during the winter months if rainfall does not occur, even if your grass is dormant. The roots are still viable, and irrigating through the winter will help the grass green up more quickly in the spring.
- Irrigate around sunrise or in the early morning hours. The leaf blades must dry out fully during the day to reduce disease.

Reference

Trenholm, L. E., J. Bryan Unruh, and Jerry B. Sartain. 2012. "Nitrate leaching and turf quality in established 'Floratam' St. Augustinegrass and 'Empire' Zoysiagrass." *J. Envir. Quality* 41: 793–799.

Table 1. Recommended application rates for turfgrass fertilizers to Florida lawns.

	6% N	**10% N**	**12% N**	**15% N**	**16% N**	**23% N**	**27% N**
1,000 ft^2	16.5 lbs	10 lbs	8.5 lbs	6.5 lbs	6 lbs	4.5 lbs	4 lbs
1,100 ft^2	18.5 lbs	11 lbs	9.5 lbs	7 lbs	7 lbs	5 lbs	4 lbs
1,200 ft^2	20 lbs	12 lbs	10.5 lbs	8 lbs	7.5 lbs	5 lbs	4.5 lbs
1,300 ft^2	22 lbs	13 lbs	11.5 lbs	8.5 lbs	8 lbs	5.5 lbs	5 lbs
1,400 ft^2	23.5 lbs	14 lbs	12.5 lbs	9 lbs	9 lbs	6 lbs	5 lbs
1,500 ft^2	25 lbs	15 lbs	13.5 lbs	10 lbs	9.5 lbs	6.5 lbs	5.5 lbs
2,000 ft^2	33.5 lbs	20 lbs	17 lbs	13 lbs	12 lbs	9 lbs	8 lbs
2,500 ft^2	41.5 lbs	25 lbs	21 lbs	16.5 lbs	15.5 lbs	11 lbs	9.5 lbs
3,000 ft^2	50 lbs	30 lbs	25.5 lbs	19.5 lbs	18 lbs	13 lbs	12 lbs
3,500 ft^2	58 lbs	35 lbs	30 lbs	23 lbs	21.5 lbs	15.5 lbs	13.5 lbs
4,000 ft^2	66 lbs	40 lbs	34 lbs	26 lbs	24 lbs	18 lbs	16 lbs
4,500 ft^2	74 lbs	45 lbs	38 lbs	29.5 lbs	27.5 lbs	20 lbs	17.5 lbs
5,000 ft^2	82 lbs	50 lbs	42.5 lbs	33 lbs	31 lbs	22 lbs	19 lbs

*These recommendations assume use of a properly calibrated spreader. See http://hort.ufl.edu/yourfloridalawn for instructions on calibrating your spreader.

Use this table to match the size of your lawn to the percentage of nitrogen in your fertilizer to find the amount of fertilizer you need to apply. It is best to break the lawn into front, back, and sides and determine the square footage of each area.

Table 2. UF/IFAS recommendations for annual nitrogen application rates in pounds of nitrogen per 1,000 square feet of lawn.

	Annual Nitrogen Application Rates			
Region of State	**Bahiagrass**	**Centipedegrass**	**St. Augustinegrass**	**Zoysiagrass**
North	1–3	0.4–2	2–4	2–3
Central	1–3	0.4–3	2–5	2–4
South	1–4	0.4–3	4–6	2.5–4.5