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Identifying the Sources, Transport Mechanisms, and Management Strategies for Excess Nitrogen and Phosphorus in Marco Island's Inland and Coastal Waters

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Background

The overarching goal of this work is to provide scientifically sound actionable data on the sources, fate, and transport of nitrogen (N) and phosphorus (P) in the surface waters of Marco Island, FL. Excess levels of both N and P have led to anthropogenic eutrophication and algal proliferation in inland and coastal waters of the island. Elevated N concentrations have also led to failure to meet mandated total maximum daily load (TMDL) values for N in segments of the island's surface waters. Because elevated nutrient levels and the consequent eutrophication of aquatic ecosystems can lead to problems such as decline of seagrass beds and harm to commercial fisheries, it is imperative that we identify local N and P sources, the mechanisms by which they are mobilized in the environment, and how management practices may be employed to reduce N and P loading to Marco Island's waterbodies.

A comprehensive review of potential N and P sources, their typical concentrations in stormwater, and the mechanisms of their mobilization and transport to runoff is provided by Yang and Lusk (2018). Potential sources of N and P to nonpoint source water pollution include atmospheric deposition, soils and sediments, fertilizers, pet waste, and organic debris such as leaf litter and grass clippings (Hobbie et al. 2014; Hobbie et al. 2017; Kaushal et al. 2011; Toor et al. 2017; Yang and Toor 2016). In Tampa Bay area studies, Yang and Toor (2017) identified atmospheric deposition, urban turf fertilizers, and soils as the 3 leading sources of nitrate-N to area runoff. In the same study, soil particles eroded from urban lawns and/or deposited on local streets were the leading source of P to runoff.

Urban turfgrass fertilizers are commonly targeted for management practices aimed at reducing nutrient transport from urban landscapes to waterbodies. In the aforementioned Yang and Toor (2016) study of various neighborhoods in the Tampa Bay area, N fertilizers were one of 3 main contributors to nitrate in urban stormwater—with 1 to 39% of nitrate in that study coming from urban fertilizers and the remaining 61 to 99% of nitrate-N attributable to other non-fertilizer sources—highlighting 2 important points: that turf fertilizers were indeed one source of nitrate-N to nonpoint source pollution but that the non-fertilizer sources were also important contributors that need management consideration. Fertilizer ordinances—including seasonal bans on N and P application—are common along Florida's Gulf Coast, but the efficacy of these bans has not been definitively shown. A study funded by the Tampa Bay Estuary Program (TBEP) reported in 2015 that at least 7 years of monitoring would be necessary to observe any statistically significant effects of fertilizer bans on local water quality (Listopad and Souta, 2015). Since that report, we are aware of no long-term monitoring efforts that have been initiated to compare water quality in residential areas with fertilizer bans versus those without the bans.

The same TBEP study observed evidence of nitrate from fertilizer sources in lawn soils of residential neighborhoods both with and without bans. It is possible that residents were unaware of the bans, ignored them, or that even if fertilizers were not applied, pre-ban fertilizer-derived nutrients were still residing in lawn soils. If the latter is the case, and pre-ban fertilizers are remaining in soils, this fertilizer N could potentially become mobilized and transported to water bodies for some time after the last fertilizer application. In this case, "legacy" fertilizer N in soils may hamper our ability to see immediate effects of fertilizer bans on the soil available N pool (Lusk et al., 2018).

Reclaimed water (RW) is former wastewater that has undergone at least secondary treatment and disinfection at a wastewater treatment plant, after which it may be piped back to communities for reuse in numerous activities, including landscape irrigation. The benefits of reusing RW to offset potable water usage in irrigation cannot be overstated, especially in Florida, where population growth is expected to place continued and increased limitations on groundwater supply. However, RW does contain numerous constituents of concern not completely removed by wastewater treatment, such as salts, nutrients, and trace organic chemicals. These constituents may be detrimental to landscape plants or may become part of landscape runoff, potentially harming water quality in downstream water bodies. Therefore, sustainable use of RW requires science-based best management practices that account for these constituents. One possible best management practice (BMP) for using RW on landscapes is to be aware of its nutrient content and adjust fertilizer applications accordingly. While the ability of RW to meet the fertility needs of plants depends on factors such as nutrient content of the water, crop type, water use efficiency, and growing season, there is potential for developing fertilizer offset recommendations when RW is used for irrigation.

In addition to the various point and nonpoint sources from the landscape mentioned above, aquatic ecosystems have the potential for 'internal eutrophication' (Smolders et al. 2006). As nutrients are continually loaded into a water body, these nutrients can accumulate in the sediment at the bottom of the waters. Due to a combination of physical and chemical processes, nutrients that accumulate in sediments may be unavailable for organisms to use and therefore this nutrient accumulation can represent a temporary removal from the water column. However, as physical and chemical conditions shift, either due to seasonal changes in temperature and dissolved oxygen, or due to human-caused changes such as dredging the sediments, these nutrients can be released from the sediment into the overlying water column, representing an internal nutrient source that could pollute water bodies even if there was no external nutrient source from the landscape.

Sediments are key components of shallow-water coastal ecosystems, both responding to changing environmental conditions and modifying the chemistry of the overlying water column. Sediments play an important role in nutrient transformations and can be sinks or sources of nutrients. Sediments remove nutrients vial burial, or denitrification, the conversion of bioavailable nitrogen to harmless N_2 gas, and assimilation into benthic algae and rooted macrophytes such as seagrass. Sediments also recycle fixed nitrogen (N) and phosphorus (P) to the water column which can support water column primary production. The ability for sediments to remove or recycle nutrients depends on organic matter supply, nutrient loading, and flow. Thus, slight modification to the benthic environment can have consequences for nutrient balance and impact downstream ecosystems. Before management intervention, a baseline understanding of the physical and chemical conditions in the sediments and knowledge of how sediments interact with the water column is needed.

From the handful of studies mentioned above, especially those carried out in Florida's Gulf Coast region (Yang and Toor, 2017 and Lusk et al., 2019, for example), it is clear that there are likely multiple N and P sources from the landscape and from aquatic sediments to Marco Island's urban waterbodies and coasts. To appropriately match management practices and educational efforts to the sources, we must first identify the sources specific to particular places and conditions on the island. This work will use science-based strategies to identify the sources of nutrients on Marco Island, their relative contributions in different locations, and the nutrient concentration trends at intensive spatial and temporal scales. Once this foundation has been laid, we can make science-based recommendations for appropriate BMPs. Potential BMPs that may be recommended include management of fertilizers and RW irrigation, removal of street particulates and other debris, installation of green infrastructure, improvements to drainage infrastructure, dredging of canal sediments, and educational outreach programs.

Research Objectives

We have identified the following research objectives and expected outcomes for the project:

1. **Objective 1**: Provide data analysis support of nutrient concentration data obtained by Marco Island's internal water monitoring efforts.

   Expected Outcomes 1:

   a. Summarize nutrient concentration trends based on the island's own monthly sampling at locations over the entire island.
   b. Identify hotspots of nutrient pollution—that is, areas where N and P levels are consistently high relative to other areas.
   c. Predict locations and seasons where N and P trends are most problematic and where strategic management solutions would be most beneficial.

2. **Objective 2**: Develop high spatial resolution monitoring data of Marco Island canals.

   Expected Outcomes 2:

   a. Identify hotspots of nutrient pollution based on seasonal (wet and dry season) sampling of water bodies at a high spatial resolution (>=100 sampling locations).
   b. Characterize water quality temporal dynamics using high frequency sensor measurements at critical locations.
   c. Quantify sediment nutrient concentrations throughout the island to identify the potential for canal dredging and/or internal eutrophication issues.
   d. With outcome 1c, identify priority locations where N and P concentrations appear most problematic and develop strategic, science-based management solutions.

3. **Objective 3**: Employ stable isotope tools to identify and track sources of nitrate-N to local waterways, including fertilizers, wastewater, atmospheric deposition, soil and organic debris such as grass clippings.

   Expected Outcomes 3:

   a. Identify the relative contributions of various nitrate sources in island-wide reuse water, surface waters, and stormwater runoff.

4. **Objective 4**: Quantify the N and P loading to stormwater from particulate matter on the island's impervious surfaces.

   Expected Outcomes 4:

   a. Calculate reductions that can be achieved through street vacuuming and/or other comparable practices that remove particulate matter from streets and impervious surfaces (i.e., leaf litter, grass clippings, eroded soil, etc.).

5. **Objective 5**: Describe how Marco Island's canals impact and are impacted by excess N and P.

   Expected Outcomes 5:

   a. Classify if canal sediments are source or sinks of N and P to the overlying water.
   b. Quantify nutrient limitation for microbial communities.
   c. Measure nutrient fluxes from canal sediments.

Research Approaches

The following methods will be employed to meet project objectives.

Objective 1: Currently, water quality sampling occurs on a quarterly basis. We recommend that Marco Island increase that frequency to at least monthly at all current water monitoring locations. We will provide data analysis support to identify trends in the data and hotspots of nutrient pollution, or areas where N and P levels are consistently high relative to other areas. We will also assist in predicting locations and seasons where N and P trends are most problematic and where strategic management solutions would be most beneficial.

Objective 2: Although monitoring at current locations at monthly intervals will allow for capturing the long-term trends in water quality, it may not allow for identifying hotspots of nutrient pollution, which is needed to begin to develop recommendations on how to reduce pollutant levels (Figure 1). Therefore, we will also perform at least two intensive monitoring events, one during the wet season and one during the dry season. During each of these intensive events, we will sample at least 100 locations spread strategically throughout the surface waters of Marco Island. At each site, we will collect water samples to analyze for nitrate (NO3), ammonium (NH4), and total kjeldahl nitrogen (TKN), as well as phosphate (PO4) and total phosphorus (TP). We will also measure water quality parameters at each sampling location, including temperature, pH, conductivity, water clarity, and dissolved oxygen concentrations. We will record these water quality parameters (temperature, pH, conductivity, dissolved oxygen) along a depth profile (i.e., at several incremental depths) at each sampling location, allowing us to assess conditions throughout the entire depth of

Figure 1. Hypothetical data from the proposed monitoring plan. In this example, red points are identified as "hotspots" of nutrient pollution when intensive monitoring shows consistent high N and/or P levels in water. Blue points represent areas at the opposite end of the trend, or those for which N and P levels are relatively lower. Note that this is a hypothetical example for illustrative purposes and not based on real data. Identifying where the actual hotspots are through intensive monitoring will allow prioritization of management actions to hotspot locations.

water. In addition, we will collect sediment samples from a subset of these sampling locations (~25) and analyze the sediments for N and P concentrations, which will allow us to identify the potential for dredging to alleviate water quality impairments based on the nitrogen and phosphorus concentrations in the sediments. By identifying nutrient hotspots in water and sediment (see example in Figure 1), we can prioritize areas of the island where nutrient loading is shown to be highest. We will also install high frequency water quality monitoring stations at critical locations and conduct water quality surveys using the GatorByte platform to better understand the temporal and spatial dynamics of the canal systems.

Objective 3: Potential sources of nutrients to local waterways include fertilizers, reclaimed water used for irrigation, septic systems, atmospheric deposition, and soil and organic debris such as grass clippings. Common tools for tracking sources of nutrients to waterways include isotopic tools, which can be used to infer sources of nitrate-N, and analysis of sucralose, which is used to infer a human wastewater source. We will select at least 6 sites among 3 land uses (highway, commercial, residential and/or golf) and conduct 9 months (to capture dry and wet seasons) of monitoring stormwater runoff for N and P concentrations, N and O isotopic characterization of NO_3, and sucralose. This work will involve instrumenting the stormwater conveyance systems at each study site with an autosampler and flow meter, so nutrient concentrations in runoff can be converted to mass of N and P loading. Storm event runoff samples will be analyzed for NO_3, NH_4, TKN, TP, and PO_4 during the 9 month interval. Samples will be collected in plastic bottles and returned to the University of Florida Gulf Coast Research and Education Center (GCREC) in Hillsborough County. Once at GCREC samples will be stored at 4°C and analyzed according to standard EPA methods. For stable isotope analysis, samples will be shipped frozen to the stable isotope geochemistry lab at the University of California-Riverside and analyzed for the 15N and 18O isotopic signatures of NO_3 by the microbial denitrifier method. The isotope data can be used to infer specific sources of nitrate to stormwater runoff. See Figure 2 for an illustrative example of how 15N and 18O isotopic values can be plotted and assigned to various environmental sources such as atmospheric deposition, fertilizers, etc.

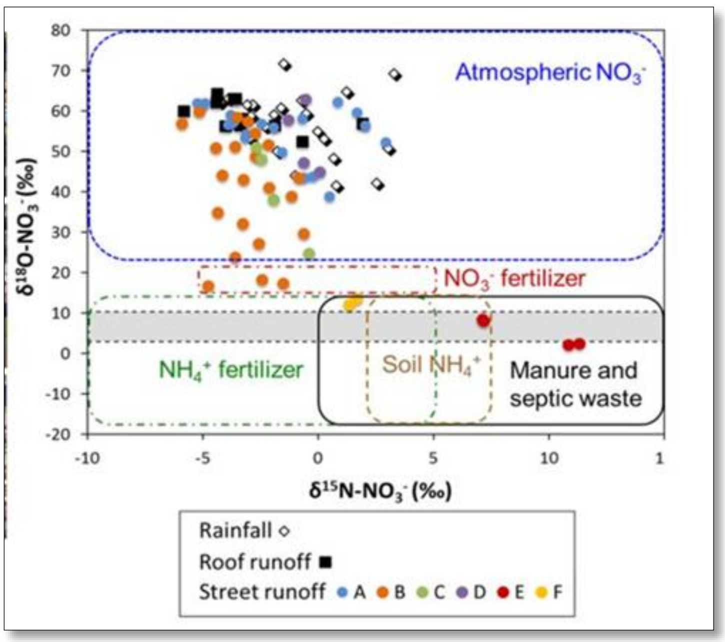

Figure 2. An example of how the 15N and 18O values of nitrate can be plotted to assign samples to various source regions.

We will also conduct an island-wide study of reuse water N and P concentrations at the point of use (e.g., lawn sprinkler) on a seasonal basis for one year. We will identify at least 30 reclaimed water users on the island and collect 4 end-use water samples in a dry season month (Nov.-Jan.) and 4 samples in a wet season month (Jun.-Aug.) (30 users X 4 replicate samples X 2 seasons = 240 samples). Samples will be collected after allowing sprinklers to run for 5 minutes to remove any residual water in the lines and then placing sample bottles in the flow of the sprinkler. Samples will then be processed (filtered, acid preserved) within 24 hours and analyzed for forms of N and P within 28 days, according to standard EPA methods. We will analyze each sample for NH_4-N, NO_3-N, organic N, total N, PO_4-P and total P.

Objective 4: Particulates such as leaf litter, grass clippings, and eroded soil can be mobilized by stormwater runoff and contribute N and P to local waterways. We will conduct a comprehensive, one-year study of the N and P load reductions associated with street vacuuming. We will select 6 to 9 local areas that vary in expected particulate inputs (e.g., areas having varying tree canopy coverage, thus leading to variable annual leaf litter loads) and land use (highway, commercial, or residential). For each study area, quarterly street vacuuming will be carried out by a contracted company and the weight or volume of collected material will be recorded. This weight or volume of material will then be converted to an N or P load (e.g., mg N collected per mile swept) by applying the measured N and P concentrations to the mass of collected material. The N and P concentrations of collected material will be determined by oven drying materials at 80^{o}C for 24 hours, grinding to a fine powder (at least 10 mesh size) and analyzing for total P and total N at the University of Florida Analytical Research Laboratory in Gainesville.

Objective 5: Monitoring nutrient concentrations and identifying the sources of those nutrients is crucial to develop strategies to address these elevated nutrient concentrations. However, in order to understand some of the underlying ecological processes related to how the canals are responding to elevated nutrients, we propose an advanced ecological monitoring program where we assess various ecosystem processes within the canals. We will assess nutrient limitation of algae in the water column and bottoms of the canals using a combination of different experimental methods including nutrient diffusing substrates (which quantify nutrient limitation status and magnitude; Tank et al. 2017), water column nutrient uptake chamber incubations (which quantify the rates of nutrient removal by the microbial community in the water column; Reisinger et al. 2015) and flow-through sediment core incubations (which quantify microbial processes that transform nitrogen and phosphorus, either temporarily or permanently remove them from the system; Smyth et al. 2013). Through these approaches, we can develop a more mechanistic understanding of the ecological processes occurring within the canals and identify strategies to maximize this internal nutrient removal. In particular, this study will enable us to determine if canal sediments are removing nutrients or if they are instead actually contributing nutrients to the overlying water column.

Educational Strategies

Participation through citizen science, education, and outreach programs are important non-structural BMPs for nutrient management. Through services offered by the University of Florida/IFAS Extension, we will work with Marco Island residents to deliver science-based education on nutrient reduction strategies for homes and businesses.

Overall, this UF/IFAS Extension initiative will lead to increased knowledge and behavior change in the professional landscape industry including residential outreach with regard to nutrient and irrigation management practices as well as landscape design and installation. Increased knowledge and behavior change will reduce potential risks to nonpoint sources of pollution resulting from adopted landscape best management practices.

Educational Objective 1: Collaborate with city staff along with established advisory committees to strengthen and address recommendations according to monitoring data and overall BMPs:

- Assisting in writing a strategic plan (including communication/ marketing, educational outreach, assessment, and partnerships).
- Identifying additional partnerships and funding to enhance strategic objectives.

Educational Objective 2: Provide multidisciplinary perspectives and research to citizens, industry and city staff by:

- Developing and implementing water resource programs that target specific areas of risk identified by monitoring analysis.
- Creating evaluation and performance indicators to measure educational program success.
- Suggesting additional research and publications for use by partners, including local municipalities, County Extension Programs, Estuary Programs, Water Management Districts, and Regional Planning Councils.
- Indicating sources of external funding that will expand and broaden the program (with partners).

Proposed Activities:

- Irrigation Audit and Education: utilize workshops, financial incentives and a Mobile Irrigation Lab (MIL) to identify irrigation over-use and inappropriate system operation.
- Stormwater Education: use of onsite demonstrations; use of signage to identify major outfalls to associate connection to water. Installation of Low Impact Design/Green Infrastructure demonstrations.
- Calculate Reclaimed Nutrient Values: assist landowners and landscape personnel in formulating a fertilizer budget based on the N and P loading from reclaimed water and typical irrigation usage. Additionally, we will develop workshops and printed materials to educate residents about BMPs for reclaimed water use.
- Florida-Friendly Landscape Yard Workshops and Checklist –UF/IFAS Extension Professional will onsite inspection and recommendations to address stormwater conditions and possible nutrient contribution.
- HOA Landscape Management Model Contract –we will work with city managers and other stakeholders to develop an editable document template designed to help HOA representatives determine, prescribe and monitor landscape maintenance BMPs such as fertilizer and pesticide application scheduling.
- Training according to Green Industries Best Management Practices for professional landscape professionals.

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Timeline

Task	Summer 2019	Fall 2019	Spring 2020	Summer 2020	Fall 2020	Spring 2021
Obj. 1- data analysis support	X	X	X	X	X	
Obj. 2- high resolution spatial monitoring of canals	X	X	X			
Obj 3- runoff study and source identification			X	X	X	
Obj. 4- street particulate study			X	X	X	
Obj. 5- sediment nutrient flux study	X	X	X	X		
Education and outreach support	X	X	X	X	X	X
Delivery of final report and recommendations						X

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Budget

	Year 1 (July 2019 to June 2020)	Year 2 (July 2020 to June 2021)
Graduate Student Salary	21,333	21,973
Fringe benefits for graduate student (11.7%)	2,496	2,571
Graduate student tuition	11,734	12,321
Project technician, average 20 hours per week for 2 years, salary plus fringe	14,756	14,756
High spatial scale canal monitoring and Gator Byte (obj. 2)	19,200	- - - - - - -
Runoff characterization (obj. 3)	40,000	30,000
Street particulates study (obj. 4)	8,000	5,000
Advanced canal sediment study (obj. 5)	10,310	3,437
Educational materials and workshops, etc (Educ. Obj. 1)	8,000	8,000
Educational outreach support (training of local personnel) (Educ. Obj. 2)	18,750	6,250
Total Direct Cost for year	154,579	104,308
Project total direct costs Years 1-2		258,887
Project total IDC for years 1-2 (10%)		25,889
Project total direct plus indirect costs, years 1-2		**284,776**

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Budget Justification

Graduate student salary, fringe, and tuition: A graduate student will work on the advanced canal sediment study and will assist in overall project management. The minimum allowed salary, fringe (11.7%) and tuition waiver allowed by UF for a graduate student research assistant is $35,563 for Year 1 and $36,865 for Year 2 (to allow for expected cost of living raises).

Technician salary plus fringe: A project technician will assist with field sampling and lab analysis. The technician will have variable hours but will average approximately 20 hours per week and will not exceed 2,000 hours for the entire project duration. The technician will be paid $14/hour with a 5.4% fringe rate. $14/hour x 0.054 fringe = $14.756/hour; $14.756 x 2000 hours = $29,512.

High spatial scale canal monitoring and Gator Byte: We request a two-year total of $19,200 for this part of the project. $13,200 will be for Gator Byte supplies, installation and training, including travel to the field sites. The remaining $6,000 will cover supplies and analytical costs for analysis of water and sediment samples, as follows: Materials and Supplies: $3800 - includes sample analytical costs ($12/sample for NH4, NO3, TKN, PO4, TP at ARL lab in Gainesville), sediment sampling ($16/sampling for NH4, NO3, TKN, PO4, TP at ARL lab), filters, syringes, and sample vials. Travel: $1750 - includes 2 trips at 625 miles per trip ($0.445/mile) and 3 nights of lodging per trip at $200/night

Runoff Characterization: We request $50,000 for purchase of stormwater autosamplers that can be placed in the study neighborhoods to collect storm event runoff samples. We request an additional $20,000 for isotopic analysis of stormwater samples, for analytical supplies, and miscellaneous lab equipment such as filter papers and sample bottles.

Street particulates study: We request at total of $13,000 to contract a local street vacuuming company to collect materials and to run analytical tests on the nutrient content of collected material.

Advanced canal sediment study: Flow-through cores (Total cost: $9,000) - includes materials and supplies (filters, sample vials, labels, syringes, tubing), analytical costs (nutrients, MIMS), and travel for Ashley's crew to/from Homestead.

Nutrient diffusing substrates (Total cost = $920) - includes reagent costs for chlorophyll extraction and nutrient analysis, sample vials, and construction materials

Water column nutrient dynamics (Total cost = $2878) - includes water column chamber purchasing, sample filters, and costs for analyzing samples in house for NH4, NO3, and PO4

Travel (Total cost = $950) - travel for AJR crew to/from GNV for NDS and water column samples - two trips, one night per trip

Educational materials and workshops: (Total cost – $2,000) – travel for Don Rainey to/from island to initially setup, train and facilitate program; provide incentives.

Purchasing of Mobile Irrigation Lab (MIL) equipment (Total cost $5,000) to identify irrigation over-use and inappropriate system operation.

Stormwater education workshops and demonstration (Total cost $5,000).

Creation of website interactive kiosk and videos to highlight programs and impact (Total cost $4,000).

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Educational outreach support:

Under the supervision of Don Rainey, a UF/IFAS temporary employee will be positioned on the island to lead and oversee outreach programs. (Total cost $25,000). Don will seek additional matching funding to build personnel capacity to operate.

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