Assessing Water Availability and Resources for Improved Agricultural Nutrient Management in Southwest Florida

By Devon Rutledge

Table of Contents

Page

List of Figures

List of Tables

List of Acronyms

BMP	Best Management Practices
CNR	Crop Nutritional Requirement
FDEP	Florida Department of Environmental Protection
HAB	Harmful Algal Blooms
LBF	Linear Bed Feet
MFL	Minimum Flow Levels
N	Nitrogen
NOAA	National Oceanic and Atmospheric Administration
P	Phosphorus
SWFWMD	Southwest Florida Water Management District
TBEP	Tampa Bay Estuary Program
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
VFTF	Vegetable Fertilizer Task Force

Section 1
Overview of Agricultural Practices and Environmental Conditions

This study focused on the following counties: Hillsborough, Manatee, Pasco, Pinellas, and Sarasota (Figure 1) that fall in the Southwest Florida Water Management District (SWFWMD). The purpose of this study is to outline the issues involving water availability and resources of southwest Florida, along with remediation techniques to improve current water quality conditions, and potential solutions to address water scarcity. Florida soils mostly consist of gravelly and sandy soils, which have high permeability and porosity. These soil types, along with high precipitation rates, are the main contributing factors affecting irrigation and fertilizer management in relation to crop productivity (NOAA, 1987). A study by Cantliffe et al. (2006) emphasized three aspects when it comes to recommendations regarding management of vegetable crops, which are meeting demands for crop nutritional requirement (CNR), linear bed feet (LBF) calculations, and monitoring soil conditions through sampling (NOAA, 1987). The CNR is the necessary amount of an analyte for an adequate crop yield in

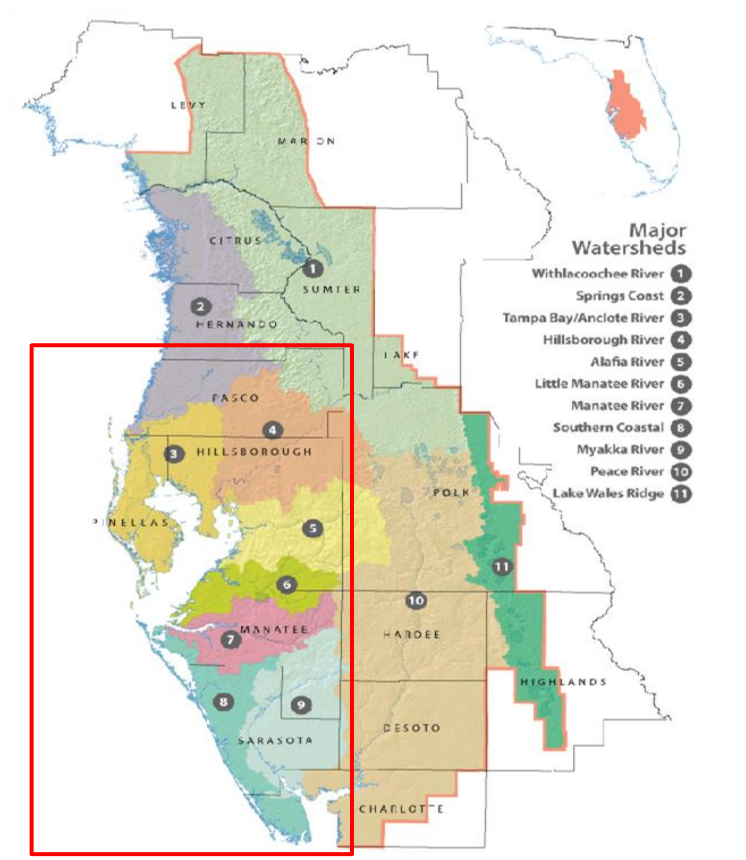

Figure 1. Southwest Florida District Map with Area of Interest (AOI) Outlined (Source: SWFWMD, 2022)

the units of pounds per acre (Phillips and Goldy, 2016). By calculating this rate, contaminants derived from fertilizer application may be reduced, such as phosphorus (P) or nitrogen (N), contributing to the overall improvement of water quality. Applying fertilizer within the suggested limits lowers the probability of contaminants successfully migrating to water resources. Weather alternates seasonally and influences weather conditions, which is why it is crucial to monitor the rate of fertilizer applied because of the negative aftermath of stormwater runoff acting as a waterway for these chemicals due to overflow. Furthermore, when melting snow infiltrates the surface, these contaminants travel until they ultimately mix with groundwater, and when temperature rises, and farming practices are in full swing – air becomes polluted with oxidized greenhouse gasses (USEPA, 2021). Being mindful when it comes to fertilizer application can make a substantial difference.

According to Hushon (2006), the most detrimental agricultural practice pertaining to water quality within Southwest Florida is row crop production, followed by mosquito management, citrus production, golf course maintenance and lawn maintenance (Denizman, 2017). Row crop production is the most detrimental because of the ditches installed for irrigation, which provide a passageway due to erosion, delivering N and P to nearby water bodies (Forrest, 2011). The Vegetable Fertilizer Task Force (VFTF), a UF/IFAS extension program from 2006, reviewed management techniques for nutrients to prevent fertilization practices from interfering with ecosystems, polluting further environments and waterbodies, and wreaking havoc in other ways. The VFTF suggests a "supplemental rate" to account for heavy rainfall events that would lead to leaching and focuses on CNR and LBF when it comes to crop production so that these seasonal changes have minimal impact (Cantliffe et al. 2006). The recommendations provided by the VFTF for fertilizer application have become semi-regulatory. This task force has already made a difference, and it could influence future water quality if a similar task force is created in other regions as well to remediate contaminated areas. By evaluating the crops and irrigation practices within a study area and considering CNR and LBF calculations before applying fertilizer, it would give us the opportunity to make a change before a threshold is crossed in which remediation would take far longer to achieve (NOAA, 1987).

The southwest region of Florida is dominated by sandy soils, which primarily use seepage and drip irrigation systems with production seasons of winter, spring, and fall (Table 1). Table 1 provides information for the main vegetable crops of southwest Florida (NOAA, 1987). This table shows that bell peppers account for the highest amount of N fertilization at a maximum of 470 lbs/ac. The lowest N fertilization requirement is for cucumbers at a minimum of 175 lbs/ac (SWFWMD, 2022). It is important to understand which type of irrigation is used for each crop as well as the required amount of fertilization because both of these have an impact not only on water quality, but also on water availability. Drip irrigation has a "higher application efficiency" and does not require as much groundwater extraction as seepage, which makes it a more environmentally friendly irrigation type (Dukes et al., 2010). In this chosen study area of southwest Florida, the dominant irrigation type is seepage, and the crops generally have a high amount of required N fertilization. Application of N fertilizer results in roughly a 50% loss on average, whether it is through a gaseous loss or runoff transport (Martinez-Dalmau et al., 2021). Therefore, a lot of what is being applied is actually going elsewhere, which is why it should be a focus to reduce over-application of fertilizer as much as possible. Additionally, the fate and transport of chemicals include erosion through wind and water migration, transference through organisms (bioaccumulation), and other natural processes (Duraes et al., 2018).

Table 1. Main Vegetable Crops of Southwest Florida (Source: Cantliffe et al. 2006)

Crop	**Growing Season**	**Production System**		**N Fertilization (lbs/acre)**	
		PM/BG	**Irrigation**	**UF/IFAS**	**Industry**
Round/Roma Tomato	All Seasons	PM	Drip	200	280 - 420
Round/Roma Tomato	All Seasons	PM	Seepage	200	260 - 350
Grape Tomato	All Seasons	PM	Drip	200	360 - 390
Grape Tomato	All Seasons	PM	Seepage	200	300 - 380
Bell Pepper	Winter and Fall	PM	Seepage	200	300 - 450
Bell Pepper	Winter and Fall	PM	Drip	200	350 - 470
Summer Squash	All Seasons	PM	Seepage/Drip	150	180 - 225
Cucumber	All Seasons	PM	Seepage/Drip	150	175 - 225
Watermelon	All Seasons	PM	Seepage/Drip	150	200 - 220
Eggplant	All Seasons	PM	Seepage/Drip	200	280 - 350
Potato	All Seasons	BG	Seepage	200	200 - 230

1) PM/BG = Polyethylene mulch or bare ground production.

2) "All Seasons" includes double crops.

Section 2
Description of Hydrologic Conditions of Southwest Florida

Geologic substrates within Florida are dominated by limestone and sandstone. As previously mentioned, the soils in Florida are highly permeable and porous. Therefore, the soil and the regional karst topography promotes a consistent flow of nutrients, incapable of retaining them. The Hawthorn Formation supplies P by means of runoff, which is further contaminated through industrial development (Borisova et al., 2020). According to USEPA, 30% of water contaminants are derived from stormwater runoff (SIG, 2015). The Tampa Bay water sources are comprised of Manatee, Alafia, Little Manatee, and Hillsborough, which are freshwater streams that are 70% responsible for the input of freshwater in Tampa Bay, and contaminants found within the water bodies have been transported by currents guiding these water sources (Cantliffe et al., 2006). The unconfined aquifer overlies the intermediate aquifer with phosphatic clays and limestone, followed by the confined aquifer, also known as the Floridan aquifer, consisting of dolomite and limestone yielding over three million gallons of water per day (Wang et al., 2009). Karst topography is more susceptible to issues associated with drainage and flow because of high porosity, residence time, and the ability for contaminants to be transferred faster than typical aquifers (Romero and Dukes, 2010). The highest concentrations of groundwater contaminants are found shortly after large rainfall events during the end of the summer when irrigation fields contain stagnant water, resulting in a high runoff volume as the surface waters migrate (Denizman, 2017).

A phosphate mining facility, Piney Point, has a total of three retention ponds, which have reduced capacity due to high precipitation rates and dredging occurring in Manatee County (Beck et al., 2022). This fertilizer plant functioned from 1966 – 2001 and is the source of wastewater retained within phosphogypsum stacks (Marella, 2019). Regionally, the industry equates to 20% of P production in Florida, as well as 80% of the phosphate exported from the United States (Yeung, 2009). Over time, the integrity of the phosphogypsum stacks was impacted by mining, and further degradation was caused by escalated rainfall as well as an altered climate (Beck et al., 2022). The southernmost pond consisted of a tear, resulting in a leakage of Diammonium Phosphate leading to elevated concentrations of total P and N (TP and TN respectively) in Tampa Bay. These amounts were determined to be triple the concentrations normally found within Tampa Bay (Figures 2 and 3) (USF, 2021). Following Piney Point's contamination, a diatom bloom of roughly 32 km^2 average was discovered in April near Port Manatee, *Karenia brevis* was rampant throughout the lower portion of Tampa Bay, cyanobacteria was bountiful in the surroundings of

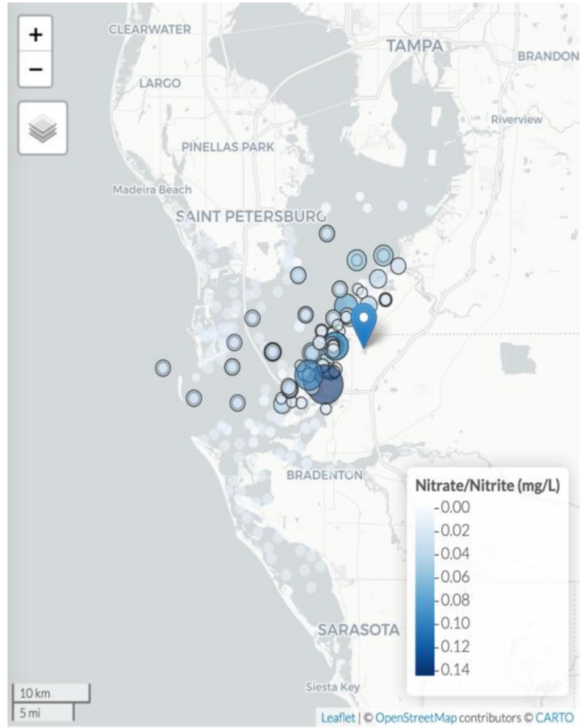

Figure 2. Map of Nitrate/Nitrogen Concentrations (Source: Piney Point Monitoring, 2021)

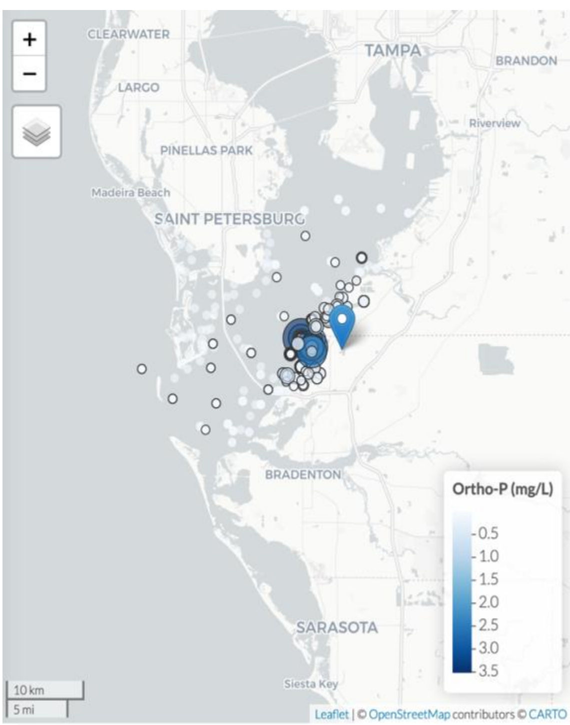

Figure 3. Map of Phosphate Concentrations (Source: Piney Point Monitoring, 2021)

Port Manatee, and fish kill reached a record high exceeding 1600 metric tons (Beck et al., 2022).

The initial response was the Florida Department of Environmental Protection (FDEP) transfer program, which relocated the wastewater, post-treatment, into the Gulf of Mexico as a remediation method. This inevitably would impact the environment whether it be seagrass loss, algal blooms, or harming nearby ecosystems. An emergency protocol, according to the United States Environmental Protection Agency (USEPA), involved the transportation of this wastewater to regions away from important species and habitats. The FDEP's transfer program resulted in a 570-million-gallon decrease of wastewater (Morrison and Greening, 2011). Wastewater contamination is not solely affecting the water quality in southwest Florida, but is equally a global pandemic, especially when it comes to future resources (Beck et al., 2022). Algal blooms are one of the major threats to water bodies in Florida, and these phosphogypsum stacks contribute to this growing issue (Marella, 2019). Viable solutions for Piney Point include an in-situ containment system, the pump-and-treat method, phytoremediation, or a permeable reactive barrier. The permeable reactive barrier is a cost-effective and time efficient solution, but phytoremediation would target P and N, which would decrease the likelihood of eutrophication typically caused by a rise in nutrients (Heil and Muni-Morgan, 2021).

Southwest Florida has a median temperature of 72^{o}F annually, with precipitation rates typically falling between 50 and 55 inches (1270 – 1397 mm) depending on the regional watershed (Wang et al., 2009). Annual rainfall summaries for all five focus counties from 1915 to 2021 are found in Table 2 (TBEP, 2021a). Excessive evapotranspiration is a challenge in this area as a result of the climate variability and precipitation rates. Florida is exposed when it comes to global warming because the environment is so easily altered by precipitation and escalated sea levels, and with an easily altered environment it becomes even more urgent to come up with urban and agricultural Best Management Practices (BMPs) for the purpose of preventing water scarcity and enhancing water quality (SWFWMD, 2022). According to Morrison and Greening (2011), Florida's current stormwater management techniques are focused on BMPs tailored specifically for treatment of water for reuse and reduction of water consumption, but there is currently an abundance of BMPs that are intended to redirect runoff and decrease inputs into nearby water bodies as well. For instance, there was a 95% regulatory decrease of total suspended solids (TSS) in relation to discharge from stormwater outfalls and sources that are already compromised. The current goals of stormwater management are targeting regulations for water quality treatment, protecting the water bodies that are already threatened by pollution, reducing current contamination rates, and making stormwater regulations more consistent throughout all counties in Florida in hopes of improving the overall water quality within southwest Florida (Wang et al., 2009).

Table 2. Annual Rainfall Summary by County from 1915 – 2021 (Source: TBEP, 2021a)

	Hillsboro	**Manatee**	**Pasco**	**Pinellas**	**Sarasota**
Minimum Rainfall (in)	34.10	34.39	31.31	33.76	35.11
Maximum Rainfall (in)	80.69	84.75	75.71	85.19	80.78
Average Rainfall (in)	52.66	53.43	54.04	51.75	52.62

For a variety of reasons, Florida is a conducive environment when it comes to harmful algal blooms (HABs). First are several environments capable of sustaining these blooms with saltwater, brackish water, and freshwater to inhabit. The number of lakes to choose from alone exceeds 7,800 providing more breeding grounds than most areas (Borisova et al., 2020). Influential factors increasing production of dinoflagellate *K. brevis* include a change in ocean current direction, a rise in inhabitants with little regulation, coupled with a decline in several water quality parameters such as temperature, pH, dissolved oxygen, and more. This species favors conditions in the south, thriving off plankton within the water while the process of advection, or horizontal flow of groundwater, stimulates growth (Thyng et al., 2013). Southern environments have waters with particularly beneficial conditions because as summer concludes, there is a “source of cells” available. Followed by winds that are redirected with the seasonal change in the first initial months of fall. As *K. brevis* is transported by currents manipulated by the wind downcoast, a convergent flow is formed by the Ekman transport that is advantageous for bloom initiation (Thyng et al., 2013). There are several ways humans are contributing to HABs such as industrial influences, consumption of food and energy, and a growing population. The combination of these factors, and more, leads to eutrophication from nutrient overload, which heightens the probability of HAB occurrences (Zhang et al., 2022).

Consuming shellfish found in the same waters as *K. brevis* may result in contamination from the toxic chemicals associated with HABs. However, the risks correlated with HAB toxins are not limited to consumption, but also respiratory issues from the aerosolized toxins. The human population is not the only concern by any means, as turtles, fish, benthic and pelagic biota, are all influenced by these water quality parameters as well (Borisova et al., 2020). Around the 1990’s, there was a rise in the study of HABs that revealed similar findings to recent research, spreading far and wide in coverage, closely tied to high input zones of nutrients, which usually were eutrophic environments corresponding to climate change and extensive shellfish communities. The most abundant toxins consist of saxitoxin, demoic acid, and brevetoxin, all of which instigated regulations like closing shellfish beds on behalf of water quality improvement. Starting the month of August until the end of November in southwest Florida, the largest population of *K. brevis* was blooming following the Piney Point contamination in 2021 (Borisova et al., 2020).

Nutrient management techniques in the 1970s showed substantial success following a decrease in nutrient pollution by 90%, which resulted in a 50% less TN after three years of implementing the same strategies leading to the initial enhancement of water quality (Bloetscher, 2012). During this time, Tampa Bay nutrient management and ecosystem recovery strategies consisted of public efforts to achieve remediation targets in which there was a general consensus on what nutrient loading restrictions should be as well as continuous monitoring of seagrass and water quality. Regulations were put in place to restrict water usage, educational awareness of ways to reuse water and prevent contamination was heightened and pairing these efforts with ongoing monitoring of water quality and surrounding ecosystems yielded apparent results. This is what led to the improvement of water quality in the 1980s. The phytoplankton, as well as the macro-algae caused by the eutrophication within Tampa Bay, has been destructive to seagrass and marine life food chains (Bloetscher, 2012). Phytoplankton requires a well-balanced environment to thrive and is responsible for an average of roughly 67% of atmospheric oxygen, carbon sequestration reducing the effects of climate change, and half of photosynthesis globally (Borisova et al., 2020). Four parameters were involved in the Wang et al. (1999) study including phytoplankton, P, dissolved oxygen, and N. This research suggested that changes in N concentrations would influence phytoplankton concentrations and mass to a far greater extent than reduction in P (Cantliffe et al., 2006). Reducing P and N are one of the main goals when it comes to water quality improvement because of P's association with phytoplankton and how closely production and nutrient dispersal are correlated (Harris, 1986). Nutrient limitations then enter the picture, which Thomas and Cebrian refer to as "a fundamental concept in ecological research" that requires a nutrient's presence to be the bare minimum for organisms and plant productivity (2008).

Waterlogging is a prominent water scarcity issue within Florida since irrigation involves flooding of fields, thus resulting in seepage. In fact, according to Wallace (2000), there is a 60% loss of water from starting point to final destination of irrigation water. Romero and Dukes (2010) found that elevated irrigation trends were far greater in Tampa than any other county from 2001 to 2007 by nearly double on average (Greening et al., 2014). A study by Borisova et al. (2020) focused on financial investments to ensure water management reforms are proven effective. This study suggests utilizing previously neglected water sources such as runoff, retention ponds, and groundwater mixed with both saline and fresh water. Taking this study into consideration, the total funds needed to sustain the current infrastructure in Florida is nearly $22 billion by 2040 (Pimental et al., 2004). However, this number is likely not accounting for other remediation methods that would need to be implemented such as monitoring and management of the nutrients and resources that are mandatory for a stable water supply (Pimental et al., 2004). Water scarcity, ecosystems, and water management strategies are a few of the most eminent subjects when developing a successful infrastructure. Once a healthy infrastructure is established, then a prosperous economy is foreseeable.

Groundwater recharge rates are not capable of replenishing what is being extracted from the water system, and groundwater is a distinguished source of water in Florida. Florida is ranked third when it comes to the highest population in the United States, and over four billion gallons are withdrawn from groundwater supply daily, which is why it is no surprise there is a water scarcity (Pimental et al., 2004; TBEP, 2021b). Pimentel et al. states that water scarcity is, "when its availability drops below 1 million liters per capita per year (Hushon, 2006)." To put it into perspective, there are minimum flow levels (MFLs), meaning the threshold in which continuing withdrawal from the source would have a negative impact, and there were over 426 water bodies with problematic MFLs by March 2019. These MFLs involve magnitude, duration, and return intervals when assessing groundwater and surface water extraction over extended periods of time so that eco-hydrologic necessities are met and all hydrologic possibilities are addressed (Neubauer et al., 2008). The flow of surface water is expected to stay above a certain standard that correlates with an appropriate amount of water being retained within the water table. It is important to utilize other water sources, boost the number of projects addressing water supply needs, and be mindful with water consumption, conserving as much as possible to avoid depletion of groundwater supply. Opting to use brackish groundwater, water that has been reclaimed, and stormwater are all beneficial choices for groundwater conservation (Pimental et al., 2004). There is a severe lack of financial resources available for updating infrastructures to ensure a consistent water supply and adequate regulations to improve the environment. With the population expected to grow in Florida by roughly 4 million people by 2040, the supply will undoubtedly be insufficient given current conditions and water sources (Pimental et al., 2004).

Section 3
Concluding Summary

In conclusion, there are a variety of ways to improve water quality conditions in southwest Florida while simultaneously attempting to resolve the growing water scarcity. A few solutions not previously mentioned include increased sampling and monitoring stations, educational awareness in the farming community, and focusing on nutrient loads with the goal of achieving water clarity to enrich ecosystems (Hushon, 2006). Continuing to remediate Piney Point will provide an opportunity for improvement of water quality in Tampa Bay. Decreasing the amount of groundwater withdrawal and utilizing other water sources that we already have access to, putting restrictions in place, and focusing on BMPs for a more efficient and resourceful future are important when it comes to solving the water scarcity crisis in southwest Florida.

Section 4
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