Project Summary

Overview

The proposed research will quantify ecosystem services provided by stormwater wet ponds (SWPs), a common anthropized ecosystem in urban landscapes. Research will address the overarching question: How do variations in social norms, values, and decisions across multiple societal levels interact with biological and biogeochemical processes to determine the ecosystem services provided by stormwater ponds? An interdisciplinary team of natural scientists, economists, anthropologists, and engineers will drive this convergent research focused on socio-environmental dynamics of SWPs at local and regional levels to (1) reveal differences in perceptions and values of SWPs across different levels of society and governance, (2) quantify the primary and secondary ecosystem services provided by SWPs, and (3) establish societal preferences for these ecosystem services. The main social science hypotheses are that individual and community levels of society value secondary ecosystem services of SWPs such as aesthetics or property value improvements, whereas regulatory levels place greater value on the primary services provided by SWPs (flood control and pollutant removal). From the natural science domain, the proposed research will quantify spatial and temporal aspects of SWP biogeochemistry and microbial community dynamics, how societal actions affect these dynamics, and how these natural processes influence other ecosystem services provided by SWPs. The primary natural science hypothesis is that nutrient dynamics of SWPs are driven by assimilatory processes, leading to algae driving temporary nutrient removal. As algal blooms develop, however, they ultimately have a negative effect on water quality within SWPs, particularly when harmful algal blooms occur. The social and natural science areas will be linked through synthetic analyses using geospatial approaches to identify relationships between societal demographics and SWP services, and to optimize the value society received from SWPs.

Intellectual Merit

Anthropized ecosystems, such as reservoirs, agricultural fields, or commercial forests, are designed to provide specific services to society. SWPs have become a ubiquitous component of urban landscapes that provide multiple primary (flood control and pollutant removal) and secondary (i.e., aesthetics, biodiversity, carbon sequestration) ecosystem services. Unfortunately, practices that optimize services provided by SWPs and other anthropized ecosystems are hindered by a lack of knowledge related to these integrated socio-environmental systems. Decisions made by society strongly influence the balance of primary and secondary services provided by anthropized ecosystems. The proposed research has the potential to transform our understanding of anthropized ecosystems by providing fundamental insights into how social and environmental factors interact to influence the value of SWPs to society. In particular, this research will develop theory related to maximizing ecosystem services of anthropized ecosystems, and how decisions made at multiple scales of governance affect these ecosystems. The proposed research will advance our understanding of how human actions and environmental dynamics interact to drive the services society derives from SWPs and other anthropized ecosystems.

Broader Impacts

The proposed research is coupled with multiple education and outreach efforts. Results of the proposed research will lead to the development of recommendations for SWP management, which will be provided to managers and technical staff from regulatory agencies. A close working relationship with Cooperative Extension will integrate results of this research into the curriculum of the Healthy Ponds program, providing evidence-based tools for holistic pond management to multiple stakeholders. Results of this study will be further disseminated via webinars and trainings for county extension agents, and Extension publications will summarize results and recommendations for a non-technical audience. In addition, results of the social and environmental components of the research will be disseminated to local stakeholders through UF|IFAS Water School programs within focal communities. Multiple approaches will be taken to broaden participation in convergent research focused on integrated socio-environmental systems, and modules will be developed related to SWPs and anthropized ecosystems for multiple undergraduate courses. Graduate students and postdoctoral researchers will regularly meet across disciplines, providing a convergent training atmosphere for early career STEM researchers. Finally, high school educators will participate in data collection and monitoring of SWPs within focal communities, increasing public participation in the research and providing a sense of ownership for residents.

The Socio-Environmental System

Anthropized ecosystems, such as reservoirs or agricultural fields, are ecosystems built and managed by humans, designed for specific functions (e.g., flood control, food production), which we refer to as primary ecosystem services. In addition to these primary services, anthropized ecosystems provide multiple unintended (hereafter, secondary) services (e.g., recreation on a reservoir, carbon sequestration by agricultural fields; Barot et al. 2017). The design of anthropized ecosystems is often guided by the ecosystem services concept (Lovell and Johnston 2009, McPhearson et al. 2014, Woodruff and BenDor 2016) which quantifies the benefits humans derive from ecosystems (Costanza et al. 1997, MEA 2005). Although anthropized ecosystems were discounted in early ecosystem service assessments due to their human-dominated nature (Costanza et al. 1997, de Groot et al. 2012), their value is increasingly recognized (Gómez-Baggethun and Barton 2013, Haase et al. 2014, Keeler et al. 2019), and ecosystem services are now regularly used to value natural and anthropized urban ecosystems (e.g., Gómez-Baggethun and Barton 2013, Keeler et al. 2019) and to guide local and regional management decisions. **Society has the opportunity to optimize the management of anthropized ecosystems using an adaptive approach** (Green et al. 2016) **across spatial, temporal, and social scales** (Andersson et al. 2014) **based on societal values and perceptions** of the ecosystem services they provide.

Stormwater wet ponds (SWPs) are an anthropized ecosystem designed and managed by individual, community, and regulatory levels of society. These SWPs are designed to provide primary services (flood control, pollutant removal) but can also provide numerous secondary services such as aesthetic appeal, wildlife viewing, and carbon sequestration (Moore and Hunt 2012). SWPs are a nexus within a community where social norms, management, policy, and ecological functioning combine to redefine how these integrated socio-environmental systems perform and function (Figure 1). Each SWP links neighbors together while fulfilling regulatory requirements, but management of these ponds may limit their potential to provide multiple ecosystem services. Our proposed research will quantify interactions among ecological, economic, and social dynamics of SWPs and surrounding residential communities as integrated socio-environmental systems. Insights from our work are applicable to other anthropized ecosystems and hierarchical regulatory frameworks. These results can be applied to other integrated socio-environmental systems to optimize production of ecosystem services for societal benefit.

There are fundamental tradeoffs in management of anthropized ecosystems due to different values placed on ecosystem services by different levels of society (Nassauer 1995, Monaghan et al. 2016). This proposed research will investigate (1) how societal perceptions and values of SWPs and their ecosystem services vary across scales ranging from individual homeowners and communities to regulatory institutions; (2) how SWP design and management affects the ecosystem services they provide; (3) the effect of aquatic ecosystem management on microbial community structure and feedbacks on nutrient dynamics; and (4) how water quality affects the perceived and actual values society derives from SWPs, and how this varies across societal levels. **Quantifying the value society derives from SWPs and identifying approaches to optimize the services they provide requires an understanding of the natural and social dynamics of these integrated socio-environmental systems, and integrated analyses of cross-scale feedbacks between the natural and social domains.**

We will identify how societal perceptions and values affect SWP management, how management affects ecosystem services provided, and how these services feedback on perceptions and management (Figure 1). We will apply social marketing concepts (Ajzen 1991, Andreasen 2006, Schultz et al. 2007) using educational and behavioral interventions to improve stakeholder knowledge regarding ecosystem services provided by SWPs. Choice experiments will quantify the value society derives from SWPs. We will combine this socioeconomic approach with a study of biogeochemical and microbial dynamics of SWPs within focal communities to identify how social decisions related to SWP management affect nutrient removal and microbial community composition. We will establish how environmental dynamics of SWPs affect society using a hedonic housing price model coupled with a statewide SWP water quality survey using remote sensing and geospatial analyses. This approach will allow us to combine revealed and stated preferences to estimate the value of SWP ecosystem services (Whitehead et al. 2008). These results will provide critical information on how to optimize societal benefits while still achieving the primary services these anthropized ecosystems are designed to perform. Resulting information will **enhance our understanding of how social hierarchies influence the tradeoffs between social and environmental factors when considering anthropized ecosystems more broadly**.

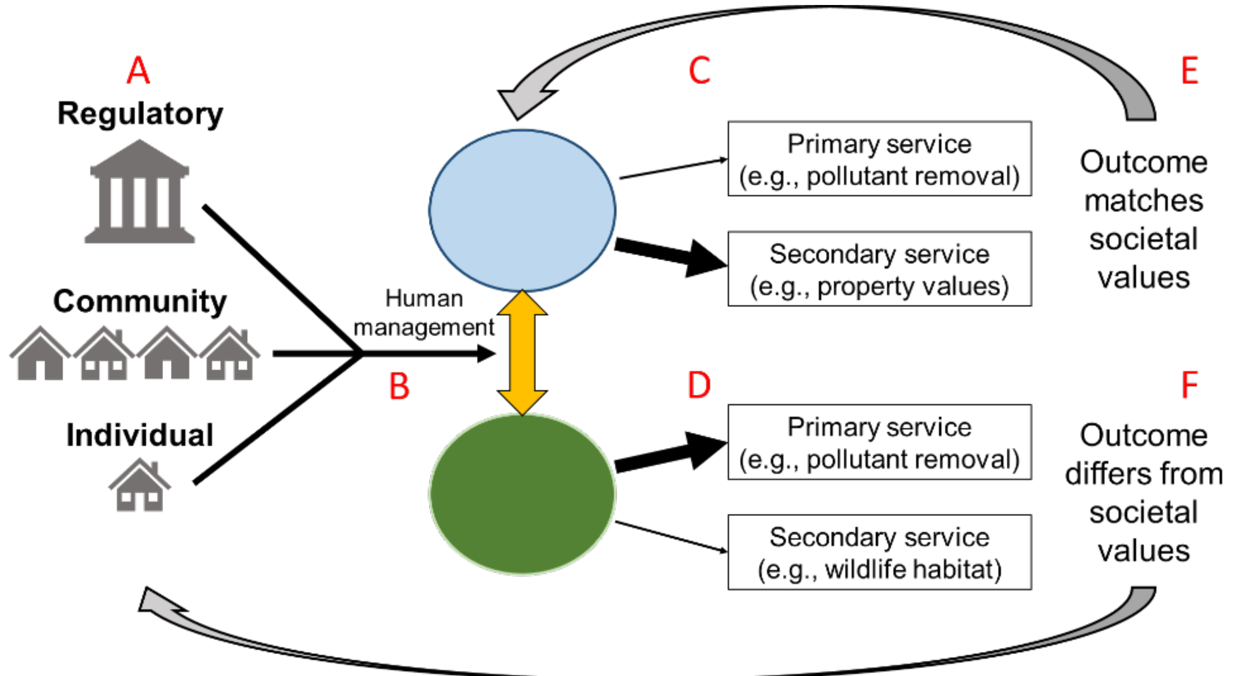

Figure 1. Feedbacks among societal values, natural dynamics, and management of anthropized ecosystems. The (A) perceptions, values, and decisions of different societal levels inform the (B) management of anthropized ecosystems such as stormwater ponds. Management actions interact with natural dynamics to produce primary and secondary ecosystem services (C, a clear pond that meets individual and community goals; D, a pond with algal overgrowth that removes nutrients but does not meet individual or community goals). These services can agree (C) or disagree (D) with societal values. Management decisions (B) are evaluated by decision makers, who decide if the outcome matches societal goals (E), in which case management continues in the same manner (i.e., E→B→C→E...) until the services no longer achieve societal goals (F), either due to changing societal or environmental conditions. Societal values are constantly changing, necessitating an iterative approach to managing ponds. Changes in A directly alter B, subsequently changing C→D, or changes in A can indirectly change E→F, necessitating a subsequent change in B. Understanding how social values, governance decisions, and natural dynamics interact to affect ecosystem services will allow for optimal management of anthropized ecosystems.

Rationale

Changes in technology, design, regulations, and human knowledge/values make residential communities dynamic ecosystems influenced by a wide range of stakeholders and decision makers (Pickett et al. 2011, 2016). Urban and suburban ecosystems are an increasingly prominent feature of the landscape across the U.S. (Alig et al. 2004) and the world (Seto et al. 2011), driving cultural eutrophication and subsequent changes in microbial community structure as well as the formation of harmful algal blooms (HABs) associated with anthropogenic nutrient enrichment (Smith and Schindler 2009) in urban ecosystems (Kaye et al. 2006, Shields et al. 2008). Urban watersheds are major contributors to non-point source nutrient export (Carpenter et al. 1998, Shields et al. 2008, Lapointe et al. 2015). Despite receiving substantial nutrient loading from the surrounding landscape, urban ecosystems such as SWPs are still capable of high rates of nutrient processing (Reisinger et al. 2016a). Yet uncertainty remains regarding mechanisms driving ecosystem services in urban environments as well as how these dynamics are related to human activities throughout the landscape (Kaye et al. 2006, Keeler et al. 2019).

The homogenization of urban landscapes and surface water distributions throughout the United States (Groffman et al. 2014, Steele et al. 2014) make understanding the relationship between urbanization and downstream nutrient export critical in light of the ever-expanding urbanization evident at regional, national, and global scales (Grimm et al. 2008, Pickett et al. 2011). The integrated socio-environmental dynamics of residential landscapes are particularly evident in the management of stormwater runoff (Jefferson et al. 2017). Similar to other anthropized ecosystems (i.e., reservoirs, agricultural fields), there are fundamental tradeoffs in how to properly manage environmental issues like residential stormwater runoff due to conflicting perceptions and values of ecosystem services across different levels of society (Nassauer 1995, Monaghan et al. 2016). SWPs are one of the most common approaches for managing stormwater runoff throughout the United States (Collins et al. 2010) and they are designed to provide flood control while also allowing for biotic and abiotic retention of nutrients, suspended solids, and other pollutants. **Despite these fundamental ecosystem services that SWPs are designed to perform, individuals and communities often place a higher value on secondary ecosystem services** such as aesthetics, effects on property values, or providing habitat for wildlife, particularly as residents may pay a premium for 'lake-front property' to live adjacent to a SWP (Monaghan et al. 2016). SWPs and other anthropized ecosystems also have the potential to cause ecosystem disservices. For example, SWPs in Baltimore, MD, reduce property values of nearby homes (Irwin et al. 2017), suggesting that SWPs function as a disamenity in the Chesapeake Bay region. Differences in how SWPs are managed likely influence both their ecological functioning and their potential to act as a societal amenity or disamenity.

Although SWPs are primarily designed to reduce peak storm flows by temporarily storing stormwater runoff prior to export into natural aquatic ecosystems, they are also assumed to reduce nitrogen (N) and phosphorus (P) concentrations in outflows relative to inflows (Collins et al. 2010). Empirical studies of the effectiveness of SWPs at improving water quality have provided mixed results, however, with some studies finding reductions in N (Mallin et al. 2002) and P (Gold et al. 2017a) concentrations, whereas other studies have found that SWPs can increase nutrient concentrations through indirect biogeochemical pathways (Gold et al. 2017b). A review of nutrient removal efficiencies from 21 SWPs throughout Florida found that total P (TP) retention efficiency only reached 80% removal (a state regulatory threshold) in ponds with exceptionally long water residence times (>200 days), and total N (TN) removal efficiency never reached 80%, regardless of residence time (Harper and Baker 2007). The majority of research on SWP nutrient dynamics has used mass balance approaches to estimate nutrient removal, with a limited number of studies quantifying biogeochemical mechanisms driving removal efficiencies (Gold et al. 2018). Variation in nutrient retention evident from previous studies (Harper and Baker 2007, Koch et al. 2014, Gold et al. 2018) suggests that **retention efficiencies are a product of either SWP design and management driven by human decisions, or inherent variability of biogeochemical processes** (McClain et al. 2003) **driven by extrinsic environmental factors**.

Biogeochemical processes within stormwater ponds are not well described by *in situ* sediment or water chemistry (Blaszczak et al. 2018). Shifts in both microbial community composition and microbial activity likely drive SWP nutrient removal capacity, similar to other aquatic ecosystems (Rees et al. 2006, Ren et al. 2017). In addition, SWPs can be hotspots for the development of HABs (Lewitus et al. 2008), which represents a societal disamenity potentially occurring within SWPs. HABs, specifically cyanobacterial HABs (cyanoHABs), are of increasing global concern due to their detrimental effects on human and environmental health (Graham et al. 2009). CyanoHABs are increasing in frequency, duration, and intensity worldwide (Pitois et al. 2000, Chorus 2005, Lehman et al. 2010, Gkelis and Zaoutsos 2014, Ogashawara et al. 2014), and are linked with high nutrient input (i.e., N and P) due to cultural eutrophication (Smith and Schindler 2009, Paerl and Otten 2013, Watson et al. 2015, Carmichael and Boyer 2016). CyanoHABs are particularly concerning due to the production of toxins, which can directly affect public health and indirectly affect humans through impacts on aquatic animals, livestock, agriculture, fisheries, recreation, and tourism (Pitois et al. 2000, Sharma and Rai 2008, Sharma et al. 2008, Cox et al. 2016, Monaghan et al. 2016). Stormwater ponds in residential communities are often managed to limit the growth of algae due to community concerns related to public health, well-being, and aesthetic values. This management often takes the form of chemical treatment, which may have unintended consequences on the broader microbial community driving biogeochemical processes within SWPs, potentially affecting the ability of SWPs to provide the primary service of nutrient removal.

Regulations implemented by the Federal National Pollution Discharge Elimination System (NPDES) Stormwater Program and the Municipal Separate Storm Sewer System (MS4) Program (United States Environmental Protection Agency 2005) have led to the implementation of stormwater control measures (SCMs) within urban landscapes. State officials typically set requirements for the design and management of SCMs by local jurisdictions (Collins et al. 2010). In Florida, developers are responsible for the design and construction of SWPs, but as the community expands, homeowner's associations (HOAs) are responsible for ensuring that SWPs function as originally designed (St. Johns River Water Management District 2021). Although specific management responsibilities may vary across jurisdictions, communities are typically responsible for management of SWPs and other SCMs. Reducing nutrient loading from terrestrial landscapes is the ideal method for maintaining/improving water quality in SWPs and downstream, but this approach requires a long-term commitment with coordination among multiple stakeholders. Short-term management of HABs (and other nuisance vegetation) often relies on chemical treatment, which can negatively affect non-target species. Ultimately, source control in the watershed is the long-term solution but the apparent disconnect between community values and SWP ecosystem services inhibits the broad implementation of effective watershed-scale source control strategies.

Anthropized landscapes in residential communities set the stage for human interactions with nature. However, these interactions are mediated by social groups of families, friends, neighbors, and HOAs. **While engineers and architects design, approve, and build the stormwater system for residential developments, this system is maintained through a complex relationship among homeowners, landscape contractors, HOAs, and regulators**. Furthermore, the stormwater system is not static; maintenance practices, regulatory requirements, or responses to changing environmental conditions lead to a dynamic system (Jefferson et al. 2017). Despite the ubiquity of SWPs on the landscape (Collins et al. 2010, Sinclair et al. 2020) and the direct connections between SWP dynamics and human management, residents living adjacent to SWPs often do not realize that these 'lakes' are used for retaining stormwater and are intended to reduce downstream pollution (Baxter et al. 1985). Even if residents are aware of the primary ecosystem services of SWPs, they are typically more concerned with secondary services like aesthetics or effects on property values than pollutant load reduction (Monaghan et al. 2016).

The perceptions of and values attributed to SWPs by residents, HOAs, and regulatory agencies clearly influence SWP management (i.e., treatment of HABs). We argue that advancing our understanding of primary and secondary ecosystem services provided by SWPs will require mechanistic studies of water quality within SWPs linked with studies of the perceptions, values, and decision-making processes related to human management of these systems (Figure 1). Developing an empirical basis for feedbacks between SWP management, ecosystem services, and societal values will allow us to provide guidance for managing SWPs to optimize social and ecological functioning in these integrated socio-environmental systems. Furthermore, SWPs represent a specific example of a broader class of anthropized ecosystems. **Understanding how primary and secondary services are valued by different levels of society, and how these values feedback to affect management decisions and subsequent ecological responses, will provide an improved understanding of how to optimize services provided by anthropized ecosystems across a range of integrated socio-environmental systems.**

Questions and Hypotheses

The proposed research is based on the premise that **ecosystem services from anthropized ecosystems are prioritized differently across societal levels** (Figure 2), and that this prioritization alters services provided by anthropized ecosystems. Our overarching question is: **"How do variations in social norms, values, and decisions across multiple societal levels interact with biological and biogeochemical processes to determine the ecosystem services provided by stormwater ponds?"** To answer this overarching question, we will address the following specific questions and hypotheses:

1. *How are SWP ecosystem services valued by individual, community, and regulatory levels of society and how do these varying values affect the management and outcomes of SWPs?*
    - Individual, community, and regulatory levels of society differ in how they value primary (flood control, nutrient removal) and secondary (i.e., wildlife habitat, aesthetics) services (Figure 2).
    - Educational interventions cause a convergence in how individual, community, and regulatory levels of society value primary and secondary ecosystem services of SWPs (Figure 2).
    - Educational interventions based on local information and incorporating social norms have a larger impact on societal perceptions of SWPs than interventions based on generic information.
2. *What are the biological and biogeochemical drivers of nutrient removal, a primary ecosystem service, in SWPs?*
    - Nutrient removal in SWPs is dominated by assimilatory uptake driven by high rates of gross primary production and ecosystem respiration within ponds.
    - Denitrification represents a small proportion of nitrogen uptake relative to assimilatory uptake.
    - Microbial communities differ spatially and temporally within and among ponds, particularly following storm events. Changes in microbial communities in turn affect nutrient removal and potential human health risks (i.e., cyanotoxin formation).

3. *How do management decisions affect microbial/algal community composition and subsequent ecosystem services/disservices and how are these decisions affected by societal perceptions?*
   - Biogeochemical and microbial community dynamics of SWPs differ along a SWP age gradient, but pond and landscape design and management mitigate these differences.
   - Homeowner concerns drive the use of chemical algal controls in SWPs, and chemical use is correlated with individual and community level perceptions of SWP ecosystem services.
   - Different chemical treatment methods implemented by community decisions exhibit differing effectiveness at controlling algal communities, but also have unintended consequences by shifting microbial communities, subsequently altering ecosystem services provided by SWPs.
4. *How do the primary and secondary ecosystem services provided by SWPs feedback on societal perceptions and values?*
   - Algal biomass and microbial diversity within SWPs are inversely related to socioeconomic status of the surrounding community due to increased resources devoted to pond aesthetics in wealthier communities.
   - Homeowners living in close proximity to SWPs place a greater value on secondary SWP ecosystem services (e.g., real estate values, aesthetics, biodiversity), whereas homeowners further away place greater value on primary services (e.g., flood control, pollutant removal).
   - SWPs are an amenity to the surrounding community, with property values increasing with proximity to SWPs, but this relationship is moderated by perceptions of SWP water quality.
5. *(Synthesis) How do the values society derives from SWPs change with differences in management strategies due to varying societal levels and environmental conditions?*
   - Different societal levels derive different values from SWPs (Question 1), and environmental dynamics (Question 2) are affected by management decisions (Question 3). Across geospatial and socioeconomic gradients (Question 4), the optimal combination of services provided by SWPs depends on variation in socioeconomic demographics and environmental conditions.

We will test these hypotheses at local and regional scales by **combining a detailed study of two focal communities with a regional survey of SWPs and their surrounding communities**. At the local scale, we will complete field monitoring, focus groups, and discrete choice experiments to test these hypotheses in Lakewood Ranch (LWR), FL, and St. Lucie County, FL (Figure 3). Both communities are representative of master-planned communities, increasingly common throughout the USA and globally (Webster et al. 2002), and have each recently experienced the effects of HABs (Kirkpatrick et al. 2008, Lapointe et al. 2015, Kramer et al. 2018). Furthermore, both communities contain a large number of SWPs, a fairly ubiquitous component of urban landscapes throughout FL (Sinclair et al. 2020; Figure 3) and nationally (Collins et al. 2010). Both provide a development age gradient spanning >20 years, offering numerous SWPs to include in our study and allowing us to quantify how ecosystem services provided by SWPs change over time. Our research team has working relationships with property managers, county extension agents, homeowners, and HOAs within both communities, simplifying access to SWPs and strengthening community participation in the proposed research (see *Broader Impacts*).

To address question 1, we will conduct surveys and discrete choice experiments of focal community residents, HOA board members, and regulatory officials via email surveys and in-person focus groups. These surveys and focus groups will occur before and after educational interventions implemented within focal communities focused on ecosystem services provided by SWPs. Educational interventions will use either generic information or local field data, allowing us to compare the effectiveness of generic or local information to change perceptions and behaviors. We will compare the efficacy of these interventions with control neighborhoods that do not receive any interventions. This study of focal communities will be coupled with **statewide assessments of SWP water quality and analyses of stated and revealed preferences of individual homeowners**. We will work with high school educators and county extension agents to perform water quality monitoring, while also quantifying a range of ecosystem functions within these SWPs to address questions 2 and 3. We will address question 4 using statewide discrete choice experiments, and a hedonic housing price model to quantify individual homeowner stated and revealed preferences for SWPs. We will further relate these socioeconomic analyses to SWP water quality throughout FL from remote sensing and geospatial approaches previously developed by the PI's (Brophy et al. 2019) using chlorophyll-a (from NASA Earth Observations) as a proxy for water quality. The social, economic, and environmental components will be synthesized to address question 5 by developing scenarios for pond management based on societal values and applying scenarios to all ponds in the geospatial survey. By investigating integrated socio-environmental systems at local and regional scales, **we will gain a detailed understanding of the decisions driving SWP management while enhancing our understanding of feedbacks between societal values and environmental functioning**.

Response to Previous Review

A previous version of this proposal submitted to NSF-DISES in November 2020 received a panel recommendation of "**Highly Competitive- proposal is outstanding in all respects and is the highest priority for funding**". The panel summary stated that the "*SES study system is an increasingly prevalent landscape in urban and suburban environments worldwide. The proposal featured strong hypotheses and testing; a clear SES description that outlines the essential social and environmental components, interactions, and feedbacks; and outstanding broader impacts."* Despite the positive panel review, panelists identified a need for more detail of how focal SWPs would be selected and better justification for the focus on algal nutrient assimilation. Additionally, the panel felt that the geospatial components were not well integrated with the rest of the project. In this revised proposal, we have detailed our plan for selecting focal SWPs that will allow us to better understand focal communities while also providing the ability to generalize at broader geospatial scales. We have further described the importance of understanding assimilatory, dissimilatory, and abiotic processes driving nutrient removal to justify our focus on algal dynamics from a biogeochemical perspective. Finally, we have incorporated geospatial analytical approaches throughout the experimental plan, particularly emphasizing geospatial approaches in both the statewide water quality survey and the synthesis component of the work plan.

Background and Justification

Stormwater wet ponds within developed landscapes: The migration of the human population into metropolitan areas, and the associated increase in urban land use is one of the most dramatic sources of global change over the past century (Foley et al. 2005, Grimm et al. 2008). A major component of this change is the homogenization of urban areas (Groffman et al. 2014), and the associated convergence of surface water distributions (Steele et al. 2014) within metropolitan areas. Regulations implemented by the NPDES Stormwater Program and the MS4 Program (United States Environmental Protection Agency 2005) have led to the implementation of stormwater control measures (SCMs) within urban landscapes. There are a wide range of SCMs, but SWPs are the most commonly used SCM throughout the US (Collins et al. 2010), with ~75,000 in Florida alone (Sinclair et al. 2020; Figure 3).

Stormwater wet ponds are designed to provide flood control and pollutant load reduction. These primary services are achieved by temporarily storing stormwater runoff, reducing peak discharge and enhancing the deposition of suspended solids and associated nutrients. Increased residence time of urban runoff within SWPs should enhance biological nutrient removal (Hancock et al. 2010, Bettez and Groffman 2012). Despite the intended nutrient reduction services, **there are relatively few empirical studies of the effectiveness of SWPs on reducing nutrients, and even fewer mechanistic studies of the biogeochemical processes driving these nutrient reductions** (Gold et al. 2018). Of the studies that have been performed, there is a high degree of variability in the N and P load reduction both within and among SWPs (Harper and Baker 2007, Rosenzweig et al. 2011, Koch et al. 2014, Hohman et al. 2021). Under specific environmental conditions, SWPs are hotspots for nutrient removal (Dietz 2007, Bettez and Groffman 2012, Reisinger et al. 2016a), but the biogeochemical drivers of these water quality improvements are unclear (Bettez and Groffman 2012, Gold et al. 2018). At times, however, SWPs can be net sources of nutrients to downstream ecosystems (i.e., outflow concentrations > inflow concentrations) despite high nutrient loadings from surrounding areas (Rosenzweig et al. 2011, Gold et al. 2017b). Improving our understanding of environmental conditions and biogeochemical mechanisms controlling this variability of SWP nutrient dynamics, and the management decisions driving these mechanisms, is vital given that society expects SWPs to improve downstream water quality.

In addition to their primary services, SWPs provide a multitude of secondary ecosystem services, such as recreation and increased habitat for urban biodiversity (Moore and Hunt 2012, Rooney et al. 2015, Miró et al. 2018). The type and amount of secondary services provided by SWPs depends on the design and management of ponds, driven by decisions of individual, community, and regulatory levels of society (Monaghan et al. 2016, Persaud et al. 2016, Miró et al. 2018). As SWPs and other infrastructure are

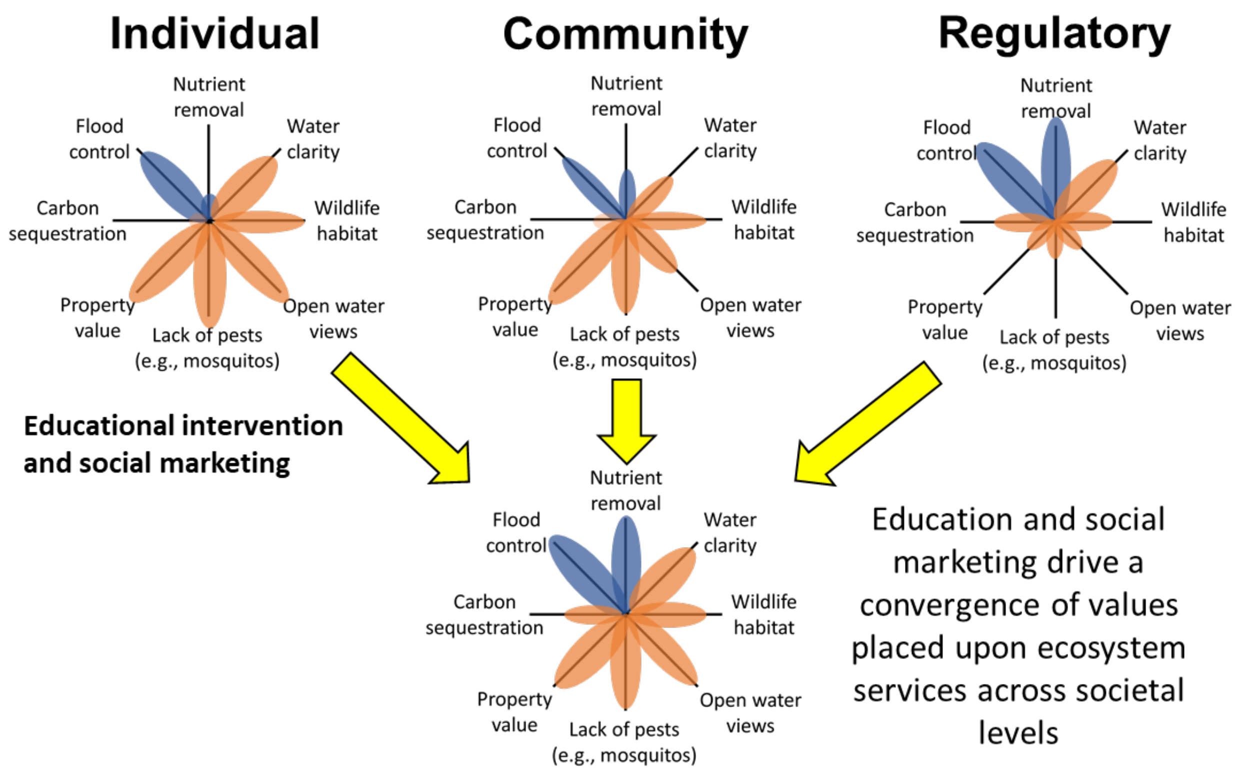

Figure 2. Anthropized ecosystem services are prioritized differently across societal levels. Individual, community, and regulatory levels of society value primary (blue petals) and secondary (orange petals) services differently, as represented by the petal location along each conceptual axis of these flower diagrams. We expect that educational interventions using social marketing concepts (yellow arrows) lead to a convergence of how different societal levels value ecosystem services, allowing for management approaches that optimize the production of primary and secondary ecosystem services.

replacing natural headwater stream and wetland ecosystems in urban areas (Bettez and Groffman 2012, Kaushal and Belt 2012), an improved understanding of how societal perceptions drive the primary and secondary services provided by SWPs will allow for the optimization of SWP ecosystem services. We expect that local decisions related to SWP management, coupled with the intrinsic variability of biogeochemical processes (McClain et al. 2003, Reisinger et al. 2016a) interact to control primary (i.e., flood control, nutrient removal) and secondary (i.e., aesthetics, property values; (Rooney et al. 2015, Monaghan et al. 2016, Persaud et al. 2016) ecosystem services provided by SWPs. There are potential conflicts between the production of primary and secondary services due to differing preferences across different levels of society. Understanding how to balance primary and secondary services will provide a general understanding of how multiple levels of society interact when managing anthropized ecosystems as a common resource. We expect that SWPs will fall along a gradient of primary and secondary ecosystem services: **ponds with high perceived water quality value (i.e., low algal biomass) will have lower rates of nutrient retention, as algal biomass (and subsequently biological nutrient assimilation) is driven by pond management rather than natural environmental factors**. We expect a disconnect in how SWPs are valued by individual homeowners and regulatory officials.

Social drivers of stormwater management: SWPs require regular maintenance and are subject to constant change from environmental fluctuations, landscape maturation, sedimentation, and shoreline erosion (Figure 4). Maintenance decisions are often made in response to aesthetic demands and other secondary ecosystem services (Milcu et al. 2013) or disservices (e.g., mosquitos, odor concerns). Homeowners living near SWPs may be more concerned with open water views and wildlife habitat than nutrient removal by ponds (Monaghan et al. 2016), but different communities likely value ecosystem services differently (Ureta et al. 2021), emphasizing tradeoffs between primary and secondary services. Examples of maintenance activities include sediment dredging, planting of aquatic plants, and the use of chemicals or dyes to inhibit algal growth. Similar decisions must be made when maintaining other anthropized ecosystems such as constructed wetlands (Perni and Martínez-Paz 2017), cultivated fields (Barot et al. 2017), or restored streams (Palmer et al. 2014). How society values primary and secondary services of anthropized ecosystems is reflected in innovative decisions made by individuals, communities, and regulatory authorities (Rogers 2003).

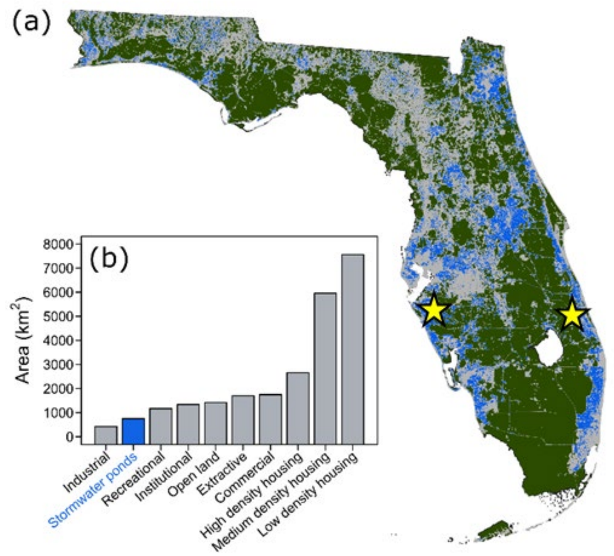

Figure 3. Stormwater ponds are ubiquitous on the landscape. (a) There are >75,000 stormwater wet ponds distributed across the state of Florida (shown in blue). Focal community locations are highlighted by yellow stars. (b) Stormwater ponds (blue bar) represent a small but non-trivial portion of total land area in Florida. Map modified from Sinclair et al. (2020).

Individual innovation decisions are practices and decisions made by households independently of neighbors, reflecting individual homeowner attitudes and knowledge about the landscape, as well as values about maintenance, costs, and satisfaction with outcomes. Education and outreach activities focused on disseminating new ideas, technologies, and management approaches often target the individual. Further, the Theory of Planned Behavior focuses on changes to perceptions and behaviors at the individual level (Ajzen 1991, Harland et al. 1999). Individual behaviors, such as irrigation practices or fertilizer application rates, are made at the individual parcel scale but have a cumulative impact on the environment within a residential community from a watershed perspective. An individual behavior change approach is necessary if innovative practices are to be adopted by the broader community.

Community innovation decisions are the practices that take place at the neighborhood/community level and are influenced by the norms of friends and neighbors. Decisions made at this level include the hiring of pond managers and HOA-wide contractors. It is at this collective level that social pressure to maintain the uniformity of landscapes creates the biggest barrier to the adoption of innovations. We will use the Theory of Prescriptive and Descriptive Norms (Schultz et al. 2007) to address how collective innovation decisions affect and are affected by SWP ecosystem services via electronic surveys and focus groups.

Regulatory innovation decisions reflect norms, values, and practices of communities, but are also rooted in permitting requirements or mandates focused on environmental protection by local, state, or federal agencies. These decisions include HOA codes enforced by boards and management companies as well as permitting requirements (e.g., design specifications for SWPs). At this level, behaviors and practices are rooted in the status-quo, but changes in the regulatory climate are often required to implement alternative practices at individual or community levels. Limitations of decisions and adaptive responses by stakeholders reveal the dynamic interaction of residents with the environment, even at this distant level.

Tradeoffs among ecosystem services: Stormwater wet ponds are often viewed as aesthetic amenities, evident via increased property values (Luttik 2000, Sander and Polasky 2009). Indeed, homeowners may purchase their lots explicitly due to the proximity to a SWP (Monaghan et al. 2016). Maintaining this aesthetic appeal can come at an environmental cost, however, as residents prefer well maintained landscapes which may not provide as many ecological benefits as ‘natural’ looking landscapes (Nassauer 1995, Hu et al. 2017). Previous research within the LWR focal community suggests that homeowners prioritize open views of water, flood control, and effects on property values, with less importance given to water quality (Monaghan et al. 2016, Persaud et al. 2016). However, amenities provided by SWPs are not universal. For example, property values of homes in Baltimore, MD, decreased with proximity to SWPs, and this effect was enhanced by SWP age (Irwin et al. 2017). **Although SWPs can provide amenities or disamenities at individual, community, and regulatory levels of society, the ultimate value of these ecosystems must recognize both primary and secondary ecosystem services at regional scales.** A pond may be an aesthetic amenity for an individual homeowner, but if it is not protecting downstream water quality it may be a disamenity for the broader community. Understanding how different levels of society influence these tradeoffs and identifying strategies to maximize primary and second services will improve the management of SWPs and other anthropized ecosystems.

While homeowners have a variety of expectations for SWPs, algal (over)growth is a major concern, and is commonly viewed as a negative feature (Hu et al. 2017). Despite a negative social connotation, algae provide essential services within aquatic ecosystems. For example, assimilatory nutrient uptake by primary producers within SWPs is a major (albeit temporary) nutrient removal mechanism (Harper and Baker 2007, Hancock et al. 2010) and algae can provide a carbon source to fuel denitrification (Reisinger et al. 2013). Therefore, concerns about algal overgrowth potentially conflict with the primary SWP ecosystem service of nutrient removal. Despite potential environmental benefits provided by primary producers, eutrophic conditions within ponds driven by external nutrient loading can lead to algal bloom formation which can cause nuisance conditions due to odor and reduced aesthetics (Dodds et al. 2009, Persaud et al. 2016). If these blooms proliferate, they can contaminate drinking water, damage aquatic ecosystems, and negatively impact recreational, agricultural, and economic interests (Lehman et al. 2010, Paerl and Otten 2013, Watson et al. 2015, Carmichael and Boyer 2016).

Management strategies that balance the primary and secondary services of SWPs are needed to achieve water quality improvements mandated by regulations while also maintaining the desired secondary benefits of SWPs such as aesthetic appeal, increased property values, and habitat for wildlife. As HABs are driven by cultural eutrophication (Smith and Schindler 2009), nutrient source reduction strategies are the best way to mitigate bloom formation. Unfortunately, nutrient loading in residential areas derives from nonpoint sources (Carpenter et al. 1998, Shields et al. 2008) such as lawn fertilizer, atmospheric deposition, and pet waste (Hobbie et al. 2017, Yang and Toor 2017), making nutrient load reduction difficult to achieve. Communities are often relegated to treating the symptoms of eutrophication (i.e., algal blooms) using algaecides. Although algaecide treatment is highly effective at controlling algal communities, negative secondary effects such as toxicity to non-target species (Le Jeune et al. 2007, Closson and Paul 2014), copper accumulation within sediments (Liu et al. 2006), or the lysing of algal cell walls and subsequent release of cellular-bound nutrients or toxins such as microcystin (Jones and Orr 1994), necessitate the consideration of alternative treatment options. Effects on non-target organisms or processes may alter SWP primary and secondary services, suggesting that ineffective pond management may be a disamenity for the broader community. Alternative treatment options include holistic strategies such as nutrient source control through altered landscape management (i.e., reduced fertilizer use), enhanced plant diversity/biomass (i.e., installation of ornamental plants along the littoral shelf), alternative chemical methods (i.e., blue pond dye, hydrogen peroxide), or modifying community expectations. We hypothesize that these management decisions are driven by aesthetic and logistic concerns of homeowners, HOAs and landscape contractors, leading to low-cost, low-maintenance vegetation such as turfgrass along the shoreline of ponds (Figure 4) and subsequent chemical treatment of algae.

Plan of Work

The proposed research will take place within focal communities and throughout the state of Florida. At both levels, we will integrate environmental, social, and economic data to understand tradeoffs between primary and secondary services and how they are valued by different levels of society. Focusing on a single state provides a consistent regulatory environment that improves our ability to compare hierarchical social dynamics affecting this integrated socio-environmental system across multiple levels of society.

Community focus: The focal community component of the proposed research will take place in Lakewood Ranch (LWR) and St. Lucie County, FL. Lakewood Ranch is an ~2.8 km^2 master-planned residential community in Manatee County, located on the Southwest coast of FL. St. Lucie County contains multiple cities and master-planned communities similar to LWR, such as Tradition, FL, located within Port St. Lucie (Figure 5). These master-planned communities contain hundreds of SWPs that are viewed as aesthetic amenities by residents who pay more for homes adjacent to SWPs to secure 'lake-front' property (Monaghan et al. 2016). **These communities are ideal for studying the integrated socio-environmental dynamics of SWPs in developed landscapes because SWPs are ubiquitous, often managed by singular management companies, and residents are willing to participate in socio-ecological research** (Monaghan et al. 2016, Persaud et al. 2016, Hu et al. 2017). Within these communities, pond vegetation is highly managed (Figure 4), limiting the influence of variation in terrestrial

Figure 4. Pond management affects natural dynamics and social perceptions of stormwater wet ponds (SWPs). Examples of SWPs (A) with vegetation planted along the shoreline and (B) with turfgrass up to the pond edge. Despite potentially increasing ecosystem services, residents tend to dislike vegetation surrounding SWPs that obscure open-water views of the pond.

plant communities on within-pond ecological dynamics. At 10 SWPs within each community, we will quantify physical, chemical, and biological properties of SWPs. We will select representative SWPs within each community based on communication with local stakeholders (Extension agents, pond managers, residents) and initial community visits. To understand biogeochemical and algal dynamics of these focal SWPs while also being able to generalize results to the state level, we will identify SWPs that are representative for the community (e.g., typical algal growth, vegetation management, surrounding landuse). After identifying potential ponds, we will select 10 focal ponds within each community based on a socioeconomic gradient that maximizes socioeconomic variation across SWPs. We will estimate socioeconomic status of each pond based on adjacent property values. Further, we will use social surveys, HOA management plans, and SWP engineering plans to provide data on variation in SWP management, hydrological connections among SWPs and residential parcels, and preliminary perceptions and values of the primary and secondary ecosystem services of SWPs within the focal communities. Selecting representative ponds along a socioeconomic gradient will increase our ability to generalize results from focal communities to the statewide level using geospatial approaches.

We will assess the internal ecological dynamics of SWPs by monitoring hydrological, biological, chemical, and biogeochemical dynamics over two years, quantifying how these natural and engineered dynamics vary across socioeconomic gradients. Through County Extension connections (see *Broader Impacts*), we will coordinate with local pond managers to document specific maintenance practices performed in each pond (e.g., aquatic weed removal, algaecide applications). After the first year of monitoring, we will install experimental limnocorrals and stormwater autosamplers within three ponds in each community to quantify the effects of different algal control techniques and hydrochemical dynamics on microbial, algal, and biogeochemical dynamics. Throughout the two years of fieldwork within focal communities, we will conduct annual workshops for residents, landscape managers, and HOA board members to provide science-based evidence on the effectiveness of different management approaches. We will use empirical field results to inform surveys, focus groups (Monaghan et al. 2016), and choice experiments (Khachatryan et al. 2017) to assess resident preferences and decision-making processes, allowing us to identify the optimal management approach to balance primary and secondary ecosystem services.

Statewide focus: We will perform a statewide analysis linking SWP water quality with revealed and stated preference modeling approaches to assess feedbacks between environmental and social dynamics. We will use data from *Florida LAKEWATCH*, a >30 year old participatory science monitoring program coordinated by the University of Florida Institute of Food and Agricultural Sciences (UF|IFAS) with 600+ sampling sites, including multiple SWPs (Hoyer et al. 2014), to develop time-series of water quality within the SWPs sampled by *LAKEWATCH* (see *Statewide geospatial SWP water survey*, below). These time-series will then be correlated with remotely-sensed data to establish the relationship between water quality collected in the field and remotely sampled water quality. We will use these correlations to combine the statewide SWP water quality inventory with real estate transaction and demographic data to develop a hedonic housing price model (Gibbs et al. 2002, Paterson and Boyle 2002, Messer et al. 2006, Sander and Polasky 2009, Walsh et al. 2017). This hedonic modeling approach will quantify the revealed preferences of society for SWPs and how water quality affects these preferences. We will also complete a statewide discrete choice experiment to quantify the stated preferences of individual homeowners for different SWP ecosystem services, providing broader demographic coverage than the focal-community analyses. **Revealed and stated preferences will allow us to assess the observed and intended values given to SWPs, and to modify outreach and education approaches to optimize SWP ecosystem services valued by society.**

The proposed research falls under six foci: social perceptions, biogeochemical functions, management practices, geospatial assessment of SWP water quality, economic values of SWPs, and synthesis.

1. **Exploring ecosystem services valuation at individual, community, and regulatory levels**

We will test our hypotheses about societal values of SWP ecosystem services using a mixed-methods approach of surveys, focus groups, and discrete choice experiments to assess the attitudes and perceptions of primary and secondary services provided by SWPs expressed by homeowners, green-industry professionals, HOAs, and regulatory officials. These approaches will provide qualitative and quantitative results on how likely a respondent is to accept a SWP management practice, such as a reduction in algaecide use leading to a reduction in water clarity, relative to alternative options. We will then use Extension outreach activities as an educational intervention in targeted neighborhoods within focal communities to assess opportunities to change societal values, perceptions and behaviors. The individually named and managed HOAs within LWR and St. Lucie County provide an opportunity to randomly select units to receive an educational intervention that uses social marketing principles (Andreasen 2006), including a customer orientation, focus on the benefits to change and lowering the barriers to acceptance. **We will incorporate either local, site-specific information about SWP functions or generic, literature-based information into the interventions, allowing us to quantify the effectiveness of local knowledge leading to changes in societal perceptions and values of anthropized ecosystems across multiple scales of governance**. Selected neighborhoods will receive the messages and assistance through different media along with workshops and events that focus on best management practices for SWPs recommended by the UF|IFAS *Healthy Ponds* program (co-led by senior personnel Atkinson and Bean). The social marketing campaign will last for 12 months and will be followed by an electronic survey sent to homeowners in each neighborhood associated with the focal communities (including neighborhoods that did not receive an intervention to act as a control). We will extend this electronic survey to HOA board members and local regulatory officials to assess different values and perceptions across each societal level. A final stage will consist of focus groups with residents, HOA board members, and regulatory officials from both control and intervention neighborhoods to probe the findings of the survey, including questions intended to address uncertainties associated with social surveys by controlling for cross-contamination of communities (i.e., how aware of the research and educational interventions were individuals from control and intervention communities).

At the *individual* level, we expect that environmental attitudes and knowledge correspond with reported perceptions and values. This relationship will depend on exposure to educational materials, engagement in participatory science efforts, knowledge about the ecosystem services of SWPs, and perceptions of regional environmental issues. These efforts are ongoing in LWR and will be expanded in year 1 into additional neighborhoods. In year 1 we will also identify target neighborhoods in St. Lucie County for the study and complete the intervention, with follow up surveys and focus groups in year 2.

At the *community* level, we will use an electronic survey to compare households sharing SWPs and drainage areas and collect data on their discussions about best practices, willingness to accept tradeoffs among primary services (flood prevention, water quality improvement), secondary services (e.g., aesthetics, biodiversity, carbon sequestration, property values), or potential disservices (e.g., mosquitos and other pests) and the influence of neighborhood norms. As SWPs can be disamenities under certain circumstances (Irwin et al. 2017), considering the actual and perceived production of disservices within SWPs is necessary. However, SWPs are typically viewed as amenities within our study region (Monaghan et al. 2016). Our **surveys will establish whether this apparent lack of disamenities is a driver of or response to maintenance decisions** at individual, community, or regulatory levels. Educational interventions will include general information about the contribution of urban ecosystems to water quality impairments and/or results from the first year of the biogeochemical monitoring study (see

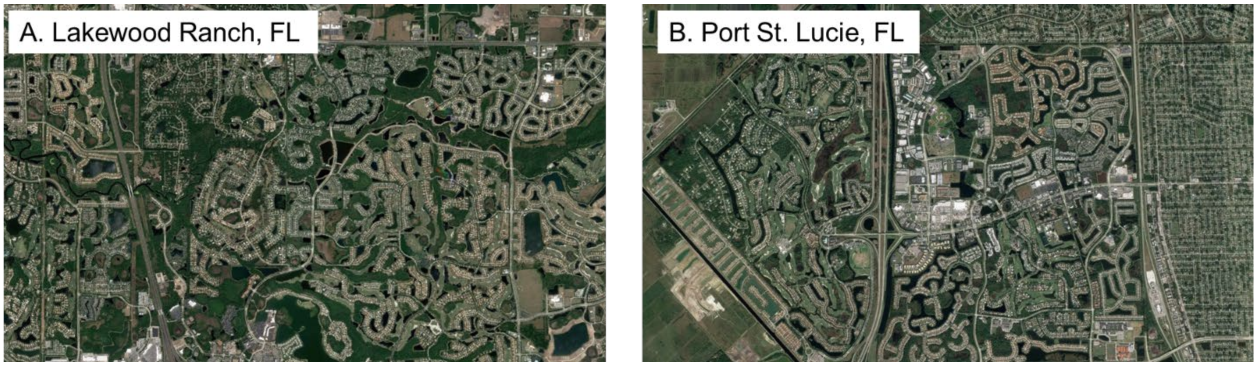

Figure 5. Stormwater wet ponds are common features of residential developments. Overhead view of (A) Lakewood Ranch and (B) Port St. Lucie, the two focal communities included in the proposed research. As is evident from the maps, stormwater ponds are ubiquitous in both landscapes.

below) to assess whether local or generic information is more likely to change behaviors and preferences. The targeted nature of these education and outreach efforts will allow a comparison between neighborhoods that receive different interventions or neighborhoods that do not receive interventions.

At the *regulatory* level, we will distribute the electronic survey to HOA board members and regulatory officials at local or regional (state) scales to contrast values and perceptions with individual and community levels (Figure 2). We will conduct UF|IFAS Extension Water School events for local decision-makers and integrate the Water School with targeted neighborhood efforts. Water schools are one or two-day events that educate citizens and decision-makers about complex local water issues and the role of policy in water conservation. We will integrate neighborhood members with regulatory officials for Water Schools tailored specifically to residential stormwater management. Following the neighborhood intervention, regulators will be presented with results from the field monitoring campaign and will participate in focus groups to understand the effectiveness of different approaches to environmental change and the barriers to acceptance of innovative management decisions.

2. Quantifying biogeochemical functioning of stormwater wet ponds

To test our hypotheses related to SWP nutrient removal, we will monitor water quantity, quality, and biogeochemical functions within 10 SWPs in each focal community (Figure 5). We will quantify dissolved inorganic N (as NH_4^+-N and NO_2^-+NO_3^--N) and P (as PO_4^{3-}) concentrations as well as TN and TP at inflow and outflow locations within each SWP during monthly monitoring trips for two years. We will also characterize dissolved organic matter (DOM) composition across stormwater ponds as a potential driver of nutrient dynamics and to quantify how DOM quality changes between baseflow and stormflow events in urban ecosystems (Williams et al. 2013, Hosen et al. 2014, Khamis et al. 2017). In year 2, we will install automated water sampling devices at inflow and outflow locations of three ponds in each community (using year 1 monitoring data to identify ponds representative of the hydro-biogeochemical gradient in each community). Autosamplers will be connected to a low-cost sensor management system (developed by senior-personnel Bean) and will be programmed to collect flow-weighted samples integrating individual precipitation events. We will deploy samplers for at least one year to capture storm events of various magnitudes and antecedent conditions. The sensor management system includes cellular communication that will allow us to activate autosampler programs remotely based on weather forecasts. We will capture integrated inflow and outflow samples from representative storm events spanning hydrologic conditions (magnitude, intensity, antecedent conditions). We will coordinate with local Extension agents and high school educators (see *Broader Impacts*, below) to regularly collect and maintain samples from autosamplers, collecting samples during monthly monitoring visits or as needed. Due to limited preservation capabilities, we will analyze integrated samples for total N and P rather than specific inorganic or organic forms. We will complete detailed bathymetric assessments of ponds on a subset of sampling dates to quantify SWP storage volume and relate storage volume to pond water level that will be continuously monitored using water level loggers at all sites. Combining inflow and outflow nutrient concentrations with SWP water volume will allow us to calculate N and P mass-balances for each pond on each monitoring date (all ponds) and storm event (autosampler ponds). We will relate water levels with pond-adjacent topography and storage capacity to assess the flood control provided by these ponds and compare these values to pond design permits to confirm that SWPs are providing this primary service.

Assimilatory, dissimilatory, and abiotic processes combine to remove nutrients from the water column. However, the fate of those nutrients depends on the removal pathway. Assimilatory uptake represents a temporary storage of nutrients in organic form, but eventually nutrients assimilated will either be remineralized or discharged downstream. Although not a permanent removal from the ecosystem, assimilatory uptake buffers downstream ecosystems from pulses of highly bioavailable inorganic nutrients. This buffering can reduce the likelihood of downstream algal bloom formation. We will use multiple approaches to better understand the relative contributions of assimilatory, dissimilatory, and abiotic processes driving nutrient removal within SWPs. We will estimate nutrient assimilation by quantifying ecosystem metabolism within individual SWPs. Ecosystem metabolism is an empirical measure of the amount of carbon fixed (gross primary production; GPP) and respired (ecosystem respiration; ER) within a given ecosystem, and drives nutrient removal in aquatic ecosystems (Hall and Tank 2003, Hoellein et al. 2013). Each pond will be outfitted with dissolved oxygen and temperature sensors set to log every five minutes over two years. We will access publicly available data for photosynthetically-active radiation, wind speed and barometric pressure, necessary components for modeling metabolic activity and gas exchange. We will estimate daily GPP and ER from each pond over the two-year monitoring period by coupling these data with Bayesian inverse-modeling approaches implemented in the *LakeMetabolizer* package (Winslow et al. 2016) in the statistical program R (R Core Team 2021), providing daily estimates (and uncertainty) for GPP and ER across all ponds. We will use ecosystem metabolism estimates to approximate assimilatory nutrient removal, but these data will also provide valuable information on carbon and energy cycling of small, sub-tropical lentic ecosystems, which are severely understudied relative to larger or more temperate ecosystems (Holgerson et al. 2021).

In addition to whole-pond metabolism, we will estimate denitrification, nutrient burial, and carbon sequestration in SWPs seasonally during the second year of the study. We will collect sediment cores from each pond and quantify N, P, and C concentrations within each core to estimate total N, P, and C burial rates from each pond (Moore and Hunt 2012),. We will estimate whole pond denitrification by quantifying diel patterns in dissolved N_2:Ar ratios in SWP surface waters using Membrane Inlet Mass Spectrometry (MIMS) in a subset of ponds (specific sites will be selected based upon ponds that show evidence of being hotspots of N removal during the first year of monitoring). Dissolved N_2 saturation has shown that lakes in the upper Midwestern US exhibit net denitrification (Loeks-Johnson and Cotner 2020). Diel patterns in dissolved N_2:Ar will be coupled with Bayesian modeling approaches similar to those employed for ecosystem metabolism to estimate whole-ecosystem denitrification. This approach has been used previously to estimate whole-ecosystem denitrification in rivers (Reisinger et al. 2016b). The proposed research will expand on this work by quantifying diel patterns in N_2 to quantify the rate of denitrification within a given pond. Translating this whole-ecosystem denitrification approach established in rivers to SWPs will provide a novel technique for quantifying denitrification in SWPs and other lentic ecosystems, and coupling denitrification and metabolism approaches will allow us to assess the relative assimilatory and dissimilatory contributions to N removal in SWPs.

We will use relationships between continuous (metabolism), seasonal (denitrification), monthly (nutrient mass balances), and sporadic (autosamplers) measures of SWP nutrient dynamics to **estimate annual nutrient removal within SWPs**. Using statistical approaches based on stoichiometric theory and ecosystem metabolism (Hall and Beaulieu 2013, Roley et al. 2014), we will estimate assimilatory nutrient uptake within SWPs which will be coupled with estimates of dissimilatory nutrient removal via denitrification to establish the relative contribution of assimilatory, dissimilatory (denitrification), burial, and abiotic (i.e., sorption) processes to total nutrient removal. We will complete this modeling approach using established stoichiometric conversions for various processes and will conduct formal sensitivity analyses to control for uncertainty in conversion factors throughout. This approach has been successfully implemented in streams (Roley et al. 2014), and our extension to produce mechanism-specific estimates of nutrient removal in lentic ecosystems represents an innovative product of the proposed research.

3. Documenting environmental controls on microbial communities within SWPs

We focus on microbial (bacterial and eukaryotic) and algal dynamics within SWPs as the microbial community contributes to primary (nutrient removal) and secondary (e.g., carbon sequestration) ecosystem services while also causing ecosystem disservices due to aesthetic, odor, or health concerns. Our proposed research will test hypotheses related to management impacts on microbial communities using current molecular approaches to assess microbial community dynamics within a subset of the focal SWPs. We will link microbial communities with environmental monitoring data collected during the biogeochemical functioning component of the study to identify environmental drivers of microbial communities, and further link these dynamics with pond management and resident perceptions of SWP ecosystem services to identify socioecological feedbacks (see *Synthetic Integration*, below).

We will characterize microbial (i.e., bacterial, protistan, and algal) community dynamics within three ponds from each focal community spanning the socioeconomic gradient of SWPs included in the monitoring program using metagenomic (amplicon-sequencing) approaches. These **microbial taxonomic data will be linked with environmental and social factors to improve our understanding of what drives the shift of microbial processes from ecosystem services (nutrient removal) to disservices (e.g., HABs)**. In year 1, we will sample water from six ponds (three from each focal community) quarterly and after a storm event for algal counts, chlorophyll *a*, phycocyanin, and microcystin (toxin) abundance (via ELISA). We will use inverted microscopy (Uthermohl) and/or flow cytometry approaches to quantify the total phytoplankton community. Genetic analyses will be completed via 16S and 18S rRNA sequencing for bacteria (including cyanobacteria) and eukaryotes (including protistan algae), respectively (Bower et al. 2004, Caporaso et al. 2011, Pessi et al. 2016, David et al. 2020).

In Year 2, we will use limnocorrals to test different algal treatment methods. We will deploy five limnocorrals in each SWP used for algal analyses in the previous year (n=3 in LWR and St. Lucie County, each). Within each limnocorral, we will apply one of four commonly used algal treatments (copper sulfate pentahydrate, hydrogen peroxide/peroxyacetic acid, Phoslock [lanthanum-modified bentonite clay], and blue pond dye) according to mean label rate or no chemical treatment as a control (Laughinghouse IV et al. 2020, Kinley-Baird et al. 2021). We will sample each limnocorral quarterly using morphological and molecular approaches to quantify microbial and algal communities. If algal blooms are occurring during either the whole-pond monitoring (Year 1) or the limnocorral study (Year 2), we will collect additional samples to be analyzed using liquid chromatography tandem mass spectrometry (LC-MS/MS) to describe toxins present, as HAB toxins are likely of concern across all levels of society. We will quantify the effects of algal control treatments on nutrient dynamics in stormwater ponds using chamber incubation experiments designed to assess nutrient removal and metabolic activity in the water column of each limnocorral (Reisinger et al. 2015). We will combine chamber results with annual monitoring to estimate the effects of different algal control approaches on annual SWP nutrient and energy dynamics.

4. **Statewide geospatial SWP water quality survey**

A statewide survey of SWP water quality will allow us to extrapolate results from focal communities to the state level and to establish how socioeconomic and biogeochemical interactions vary across the state. We will apply a geospatial characterization technique to identify the location, size, and perimeter of SWPs throughout FL. We will use our previous analysis of SWP locations (Figure 3; Sinclair et al. 2020) to estimate various SWP physical factors (e.g., area, perimeter) and we will estimate SWP algal biomass (as chlorophyll *a*) from high-resolution satellite imagery (Landsat-8 and Sentinel-1B, both publicly available) (Rokni et al. 2014, Urbanski et al. 2016, Boucher et al. 2018). These algal biomass estimates will be ground-truthed using a combination of geo-referenced data streams: a summer field survey of SWPs throughout FL (100 SWPs sampled once, see below), water quality monitoring from focal communities (20 ponds sampled regularly during years 1 and 2 of the project, see above), and community-scientist collected data through the *Florida LAKEWATCH* program (600+ water bodies sampled at varying intervals). The *LAKEWATCH* program works with community scientists throughout Florida to regularly monitor water quality parameters from a range of Florida water bodies, including streams, springs, ponds, lakes, and SWPs (Hoyer et al. 2014). The statewide survey will quantify water quality metrics (e.g., nutrients, chlorophyll *a*, conductivity, turbidity) from 100 quasi-randomly selected SWPs dispersed according to the statewide distribution, and spanning multiple surrounding land uses (e.g., low and high density development). We will complete the field survey throughout the summer of Year 2, sampling all ponds within a region within a short period of time, minimizing the potential for stochastic weather conditions to impact water quality. We will investigate additional algorithms to estimate other water quality metrics using satellite imagery, but will focus primarily on algal biomass given the importance of algae from biogeochemical and social perspectives. The spatial resolution of the statewide survey coupled with the temporal resolution (including autosamplers) within focal communities will allow us to assess dynamics of SWPs in response to drivers that vary across space (e.g., soils, geology) and/or time.

Data from focal community monitoring and *LAKEWATCH* will allow us to construct a water quality time series for the sampled SWPs, which can be coupled with natural water bodies sampled by *LAKEWATCH*. We will link *LAKEWATCH* sampling events with satellite imagery data to compare trends in SWP water quality with natural lake water quality trends. We will further assess how water quality parameters are influenced by antecedent rainfall. **Ultimately, these multiple data sources with empirical estimates of SWP water quality will be used to extrapolate our water quality estimation approach across the >75,000 SWPs in Florida**. This approach coupled with statewide socioeconomic surveys (see below) will allow us to visualize spatial variation in water quality and socioeconomic perceptions of SWPs across the state, to further understand linkages between primary and secondary services, and to test for how these services are related to additional socioeconomic and environmental factors such as median household income, population density, or annual precipitation. We will assess the contribution of uncertainty from each step of this process (SWP identification, empirical water quality estimates, remotely-sensed water quality) to model outputs using sensitivity analyses based on the Sobol index approach (Sobol 2001) to quantify confidence in the approach and to establish the applicability of this approach to other regions.

5. **Homeowners choices regarding tradeoffs between primary and secondary ecosystem services provided by SWPs**

In conjunction with surveys described above, we will employ a discrete choice experiment (Khachatryan et al. 2017) to **identify the drivers of homeowner's willingness to accept alternative SWP management strategies** (i.e., accept a higher level of algal biomass, alternative algal control methods). Although this discrete choice experiment will be developed for the focal communities, a subsequent statewide choice experiment will assess the perceptions of homeowners throughout Florida. The survey questions will first document individual knowledge and perceptions about SWPs. In the second part of the survey, homeowners will be presented with a series of discrete choice scenarios where they select their preferred SWP management approach from different options presented side-by-side. The SWP management options will be a randomized combination of multiple attributes which we expect to influence homeowner decisions. These different parameters will include nutrient removal (% N or P reduction), algal biomass, maintenance costs, algal management approach, presence of shoreline plants, level of open-water views, presence/absence of mosquitos or other pests, and individual homeowner management restrictions (i.e., fertilizer application ordinances; Souto et al. 2019). Each of these attributes, and their levels, will be explained in the survey prior to the presentation of the discrete choice scenarios. The last section of the survey will focus on respondents' demographic characteristics, allowing us to extrapolate results statewide and combine with other geospatial data (e.g., proximity to SWPs, precipitation, population density) to identify potential spatial patterns that emerge (see *Synthetic Integration*, below).

We will complete the focal community choice experiment before and after environmental monitoring and educational and social marketing behavior change interventions. Initially, environmental parameters (water chemistry, algal dynamics, management effects) of the choice experiment will be described using general information based upon best available literature data. For the second survey, we will use empirical data obtained from environmental monitoring components of this proposal whenever possible to describe the environmental parameters, **allowing us to quantify the effects of local, science-based information on individual perceptions and values**. The focal community choice experiment will be distributed to the same mailing list as the individual perception and values survey, whereas the statewide choice experiment will be conducted through Qualtrics, Inc., a professional survey software company. These discrete choice experiments will establish the importance of different SWP management practices. We will further assess how these preferences are influenced by socio-demographics, environmental attitudes and perceptions, and educational interventions at community and statewide levels.

In addition to the choice experiment, we will complete a hedonic property value model to estimate the implicit price of SWPs and their water quality throughout Florida. We will combine geo-referenced SWP locations and water quality time series data produced via the geospatial water quality survey (see above) with home sales data for nearby properties using current and historic property transaction data accessible via the Zillow *ZTRAX* database. We will combine property transactions with pond locations and demographic characteristics from U.S. census tracts to develop the hedonic property value model (Gibbs et al. 2002, Paterson and Boyle 2002, Messer et al. 2006, Sander and Polasky 2009, Walsh et al. 2017). The hedonic model will predict property values based on distance to a SWP, water quality (algal biomass) of the nearest SWP, additional property details (e.g., square footage, number of bedrooms), and additional amenities (e.g., distance to green space). We will apply spatial regression techniques to address spatial correlation and heterogeneity. **This hedonic model will directly assess the impact of SWPs on property values** by comparing homes within the same community but differing in distance to a SWP. Further, incorporating SWP water quality into the hedonic model will allow us to directly **quantify the effect of water quality** on property values. Results of the choice experiments and hedonic model will provide us with stated and revealed preferences of communities across a range of demographics, allowing us to **identify the combination of social and environmental parameters needed to balance the tradeoffs between primary and secondary ecosystem services provided by SWPs**. Identifying specific drivers of individual perceptions is necessary to develop education and outreach materials targeted at influencing the decision-making behaviors at individual, community, and regulatory levels.

6. Synthetic Integration of SWPs as a Dynamic and Integrated Socio-Environmental System

We will integrate social and biogeochemical results from focal community and statewide project components into a synthetic framework that combines demographic, biogeochemical, and regulatory data to estimate how the values society derives from SWPs change with varying societal levels and environmental conditions. Using statewide water quality and socioeconomic data, we will investigate the degree of equitability in SWP primary and secondary services at multiple spatial scales using hot/cold spot analyses (e.g., kernel-density or Getis-Ord G_i*). In years 3-4, we will use results from focus groups and discrete choice experiments to develop SWP management scenarios and subsequent ecosystem services provided. We will combine these scenarios with the geospatial water quality survey to make predictions about how shifts in societal preferences will alter SWP water quality. Finally, we will combine these simulated outcomes with the hedonic housing price model and other ecosystem services values (e.g., the value of N removal) to identify the optimal combination of societal values and management preferences to maximize the value of SWP ecosystem services. For example, if regulatory officials' value nutrient removal above all else due to regional water quality benefits, we would use biogeochemical results to identify the optimal level of pond management to enhance nutrient removal. Next, we would scale water quality within every pond from the statewide survey based on the empirical results of biogeochemical and algal management studies and extract the values of SWPs from the hedonic model. We would contrast that scenario with a scenario focused on preventing algae in ponds, and estimate subsequent changes in ecosystem services (e.g., property values, aesthetics, nutrient removal) across SWPs statewide. We will use results of the statewide discrete choice experiments to modify management approaches and preferences based on socioeconomic demographics and identify the relative importance of societal level, demographics, and environmental components for controlling SWP ecosystem services. Multiple scenarios, combining various outcomes from surveys and focus groups, will be developed and compared. Although this synthetic approach focuses on SWPs in Florida, **the framework and results are applicable to any anthropized ecosystem managed by stakeholders with competing goals and values**. Ultimately, results of this synthetic analysis will inform how different levels of society perceive, influence, and respond to changes in environmental conditions of **any human-managed ecosystem**.

Despite their ubiquity and the multitude of ecosystem services they provide (Gómez-Baggethun and Barton 2013, Haase et al. 2014, Keeler et al. 2019), interactions between human and ecological drivers of SWP ecosystem services are poorly understood. The proposed research will lead **to optimizing services provided by anthropized ecosystems based on an improved understanding of how primary and secondary services are related to each other and to societal perceptions and goals.** In addition, the proposed research will increase our understanding of biogeochemical and microbial community dynamics within these anthropized ecosystems by coupling novel biogeochemical methods with traditional and big data approaches to microbial systematics. **Incorporating geospatial analyses into statewide socioeconomic and water quality surveys will allow for expansion of this research beyond the study region**, expanding the generalizability beyond SWPs and beyond Florida.

Results of this project will advance our theoretical understanding of the dynamics of integrated socio-environmental systems. Identifying strategies to optimally balance the primary ecosystem services required by regulatory agencies with secondary services often valued more broadly by different levels of society will improve management of a wide range of anthropized ecosystems, such as reservoirs, agricultural fields, green roofs, or city parks. Further, **any ecosystem that is managed by humans and has multiple competing stakeholders (seemingly every dynamic integrated socio-environmental system) would benefit from the improved understanding of how hierarchical interactions within society combine with and respond to shifting environmental conditions, and how these interactions and feedbacks affect values provided to society.** An improved understanding of how local, science-based information can alter societal perceptions of ecosystem management will allow for improved community decision making using place-based information for management of local environmental issues. This proposal represents a convergent research approach using a combination of traditional and 'big-data' methods and by combining the expertise of ecologists, anthropologists, economists, and engineers. Although not a primary goal, the proposed research addresses the NSF Big Idea of "Harnessing the Data Revolution" through social- (real-estate transaction data, hedonic pricing model) and natural-science (microbial molecular taxonomy, remote sensing) approaches.

Broader Impacts

The proposed research will provide education and training opportunities related to socio-environmental convergent research, use DISES research for societal benefit, broaden the diversity of scholars engaged in socio-environmental research, and disseminate results beyond the academy. Both focal communities have experienced harmful algal blooms in recent years (Kirkpatrick et al. 2008, Kramer et al. 2018), raising water quality issues into the general social consciousness. We will capitalize on this social awareness by interacting with homeowners through in-person focus groups, town hall-style workshops, and educational materials provided via electronic mailing lists. The dissemination of educational materials and training will be guided by the empirical research and will include communication strategies focused on the function of local SWPs, their primary (flood control, water quality protection) and secondary ecosystem services and disservices (Milcu et al. 2013), and the effectiveness of SWP management techniques for enhancing ecosystem services. Results will be incorporated into a unique dissemination program known as UF|IFAS *Water Schools* within each focal community. These *Water Schools* will bring multiple stakeholders, representing different levels of society, together to discuss strategies for managing SWPs to meet multiple societal objectives. The effectiveness of *Water School* events will be assessed using pre- post-surveys targeting knowledge-gained and behavior changes related to SWP management.

Enhancing education and training related to socio-environmental convergent research: To enhance the convergent approach of this research, individual trainees will incorporate interdisciplinary products into their specific research and the graduate student trainees will have at least one committee member from a separate field. We will further this convergent training with a weekly journal club for all team members (and open to others in our academic community interested in DISES research) in which we read articles and discuss concepts from multiple disciplines. We will ask trainees to identify and present articles from outside of their field to immerse them in interdisciplinary training. We will expand undergraduate awareness of convergent research by developing modules focused on convergent research and the interdisciplinary approach of this project into undergraduate and graduate courses. These modules will be co-developed by postdoctoral associates and senior personnel Smidt for courses focused on urban water quality, water resource policy making, and sustainable land management.

Broadening the diversity of scholars engaged in socio-environmental research: We will recruit trainees (graduate students, postdoctoral associates) through traditional outlets while also actively recruiting students from underrepresented communities by sending targeted opportunity announcements to minority-serving institutions with strong ecology, economics, and/or sociology programs. We will recruit students at annual society meetings, coordinating with specific societal programs (e.g., the Seeds program of the Ecological Society of America). We will provide funds to visit UF for top candidates and will work with the UF Office of Graduate Minority Programs to facilitate visits. UF's large minority student enrollment provides a diverse environment and an important source of peer support. For example, the UF population is 29% underrepresented minority students, and UF ranks #1 and #3 nationally among public AAU in professional degrees and research doctorates awarded to African American students.

Additionally, we will recruit high school educators and students to participate in water quality monitoring within focal communities through our connections made via Extension outreach. During initial sampling trips, we will fine-tune sampling protocols. Once protocols are established, we will invite local K-12 STEM classrooms to join our field sampling campaigns. This local participant involvement will be led by graduate and postdoctoral trainees, providing a participatory science component into the focal community monitoring program. **This participatory science program will provide a sense of ownership for the community and ensure lasting changes to how SWPs are perceived and managed in these communities**. In addition, the Reisinger lab will host at least one high school student through the UF Student Science Training Program (SSTP) each summer, exposing them to socio-environmental research. The Reisinger Lab has previously hosted students through SSTP, which recruits students from across the US to complete a summer research and academic program.

Disseminating results beyond the academy: Our education outreach will be developed for focal communities but will also be incorporated into statewide Extension projects through the UF|IFAS *Healthy Ponds* program, co-organized by Bean and Atkinson. The *Healthy Ponds* program provides **evidence-based tools for holistic pond management to commercial pond managers, HOAs, local government officials, and private pond owners, enhancing water quality, wildlife habitat, and pond longevity**. The *Healthy Ponds* program has already developed assessment tools for the broader program; we will coordinate with the program organizers to quantify the benefits of incorporating information from this proposal into the *Healthy Ponds* curriculum. Further, we will develop Extension publications related to SWP functions, ecosystem services, and landscape management to be distributed through the UF|IFAS Electronic Data Information Source platform which houses >6,000 peer-reviewed Extension publications and received >17.5 million pageviews in 2020. Adding multiple publications to the platform will improve the understanding and management of SWPs by residents and managers. Additional dissemination of results will be accomplished via traditional avenues, such as peer-reviewed journal articles, and scientific conference presentations. We will convene special sessions focused on ecosystem services of anthropized ecosystems at conferences spanning multiple disciplines (e.g., Association of Environmental and Resource Economists, Agricultural and Applied Economics Association, Ecological Society of America, North American Lake Management Society). Natural scientists, economists, anthropologists, and engineers will be invited to each of these special sessions, **bringing convergent research to traditionally discipline-specific conferences**.

In addition, **we will disseminate beyond the academy by developing recommendations for statewide SWP best management practices**. Through our surveys and focus groups, we will work directly with stakeholders to help define the problem and develop recommendations for SWP management. These recommendations will be directed at state agencies associated with permitting SWP design and management, as well as HOA's and municipal governments seeking guidance on how to improve SWP management to meet homeowner expectations. We will work directly with regulatory agencies and focal communities to develop these recommendations. **This co-production of knowledge with stakeholders will ensure that recommendations are economically and logistically feasible.**

Results from Prior NSF Support

Reisinger (Co-PI): DEB-1838336, $153K; 2018-2020 with no cost extension to 2021, *RoL: FELS: EAGER: Environmental drivers of intraspecific variation in animal behavior and consequences for ecosystem functions.* **Intellectual Merit**: Research will identify fundamental rules bridging organismal biology and ecosystem ecology, focused on relationships between drivers of individual behavior, and subsequent impacts on ecosystem functions. **Broader Impacts**: Partnering with the UF Fishing for Success program and local educators to link animal behavior with environmental impacts. Supported 2 MS recipients (one under-represented minority), 2 undergraduate students, and a high school science teacher. No publications have come from this project yet, but three manuscripts are currently in prep.

Monaghan (Co-PI): MCB-2129768, $99K; 2021-2022. *MoCelS-DCL: Building a Network for Functional Annotation of Protein Families*. **Intellectual Merit**: Solving the issues surrounding genomic sequences and protein function requires revising the flow of scientific information and integrating data capture strategies. This conference will create a diverse community to brainstorm the best mechanisms and create the roadmap to achieve this next step in bringing genomic sciences to reach their full potential. **Broader Impacts:** Few experimentalists are aware of how functional data are captured in databases. This conference will devise strategies to educate biologists to make them an integral part of the functional data flow. This project was recently awarded and no results are available at this time.

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Facilities, Equipment, and Other Resources for NSF – DISES Proposal – University of Florida

Laboratory

The Reisinger urban ecosystem ecology laboratory has approximately 500 ft^2 of analytical lab and sample processing space equipped with a fume hood, sinks, drying oven, muffle furnace, and specific analytical equipment (see Major Equipment, below) and sufficient bench space for multiple individuals to be working simultaneously. This laboratory space is slated for renovation to occur in winter 2021-spring 2022. The renovation will increase lab storage space and work space for individuals. In addition to this primary laboratory, Reisinger shares a "dirty" lab (~200 ft^2) with one other PI equipped with sample processing equipment, benches, and freezers, for processing field samples. The laboratories include standard and advanced field equipment including extensive electronic monitoring capacity for physical and chemical water parameters as well as laboratory equipment and PPE required for the ecological field work described in the proposal. Specifically relevant to this project, Reisinger has at least 40 PAR/temperature sensors that will be devoted to this project and coupled with PAR/temperature sensors to be purchased specifically for this project (see *Budget Justification*) to quantify light/temperature profiles of focal SWPs. The Reisinger Lab also has additional DO sensors currently assigned to other projects that could be mobilized for this research in the unforeseen event that a DO sensor assigned to a focal SWP needs to be taken offline for maintenance. Furthermore, Reisinger has access to the Wetland Biogeochemistry Laboratory and the Coastal Biogeochemistry Laboratory, both within the Soil and Water Sciences Department at UF, which contains a wide range of analytical instrumentation and technical support.

The Laughinghouse phycology laboratory has approximately 700 ft^2 of laboratory space located at the UF Fort Lauderdale Research and Education Center (FLREC). This space includes 'clean labs' for molecular work, culture facilities for growing algae (both indoor and outdoor greenhouse space), and 'dirty labs' for environmental work. Molecular work required for this project will be undertaken in the Laughinghouse Lab, which has clean lab facilities with the capabilities to extract DNA from samples, amplify genes with thermocyclers, assess the quantity of DNA through gel separation and spectrophotometry, and run real-time qPCR. The Laughinghouse lab has a separate PCR and qPCR workstation with UV sterilization to prevent cross-contamination between PCR products and genomic DNA. Furthermore, spectrophotometers in the Laughinghouse lab allow quantification of algal growth via chlorophyll and phycocyanin analysis.

The Smidt Land and Water Laboratory is a data and computing workspace used for remote imaging and geographic information systems (GIS), hydrological modeling, data analytics, teaching, and education. The workspace hosts up to 8 researcher stations, 4 laptop stations, and has available remote connectivity. Each researcher station has individual personal computers (PCs) with dual monitors. PCs are high-performing Dell Precision models all connected to a shared server with backup system operated by UF|IFAS. Commonly used software packages include MATLAB, ESRI ArcGIS, Python, R, and Adobe Suite. UF provides a shared app system which includes ESRI AcrGIS. Other software programs are purchased annually or freely available. The lab also has an extensive digital library of relevant data products that include land cover, climate, and hydrology, among many others.

The UF Interdisciplinary Center for Biotechnology Research offers multiple core labs available to UF faculty, including the Bioinformatics Core Lab and the NextGen DNA Sequencing Core Lab. The Bioinformatics core offers bioinformatics and biostatistics consulting and data analysis services to help researchers develop an in-depth understanding of large-scale data sets acquired from next generation DNA sequencing. The Core develops multiple comprehensive pipelines enabling large-scale data processing including metagenomics (characterization of environmental microbial communities). Bioinformatics staff members have extensive experience in bioinformatics, genomics, transcriptomics, medical informatics, and translational research. The NextGen DNA Sequencing Core provides researchers with quality, massively parallel, high-throughput sequencing data using the most current instrumentation, including Illumina MiSeq. Consultation services provided by the Sequencing Core includes providing guidance on a range of considerations, including read length, error rate, predominant type of error, data output/run, speed, and cost.

Computer

All PI's and senior personnel have access to university-owned personal computers and to all appropriate software (e.g., ArcGIS, Microsoft products) through UF licenses. Furthermore, PI's and senior personnel have access to the Land and Water lab (described above) and HiPerGator - a high performance supercomputer offering remote storage for large data sets, a large computer cluster for high-performance and high-throughput computing, and comprehensive support through the UF Department of Research Computing.

Office

Administrative support is provided to all faculty by their respective departments and/or research and education centers (RECs). All PI's and senior personnel have individual office space located within their respective departments or RECs, and office space is available for graduate students, research assistants, and the postdoctoral associates.

Other

PI's and senior personnel have access to university vehicles to complete field work. Co-PI Savchenko has an agreement through the University of Florida with Zillow to access the *ZTRAX* database that contains current and historical property transaction data throughout the United States.

Major Equipment

The Reisinger Lab is equipped with an AQ400 discrete water chemistry autoanalyzer to quantify nutrient concentrations of water samples, an Aqualog benchtop spectrofluorometer for dissolved organic matter analyses, and multiple field-deployable sensors capable of measuring temperature, pH, and conductivity in real-time or set up for logging. The Coastal Biogeochemistry Lab at UF contains a membrane-inlet mass spectrometer (MIMS); Reisinger contributed to the initial MIMS purchase and therefore has access to MIMS analyses at reduced rates. The Laughinghouse Lab at the FLREC has access to inverted and compound microscopes with phase contrast, dark field, fluorescence, and Nomarski to analyze and quantify the abundance of bacteria and algae morphologically, with and without staining. Laughinghouse also has a StepOnePlus™ Real-Time PCR System (Applied Biosystems) to run real-time qPCR, a Nanoppore (MinION) for in-house metagenomic sequencing, and access to a Sanger Sequencer at the FLREC.

Postdoctoral Mentoring Plan for NSF - DISES Proposal - University of Florida

Three postdoctoral research associates sponsored by this proposed research will work under the supervision of Khachatryan, Laughinghouse, and Savchenko (one each). Each supervisor will provide office space and computer equipment to successfully start the project. Beyond the specific focus of their research, each postdoctoral associate will contribute to environmental field sampling protocols, educational interventions, and participate in survey instrument development, gaining experience in multiple disciplines. The postdocs will be trained primarily by Khachatryan, Laughinghouse, or Savchenko but will receive input on research progress as well as career development from the entire leadership team. The range of disciplines and career stages represented by our leadership team will provide the postdocs with a clear vision of what early career researchers need to succeed, and how to mentor them to achieve their goals.

Postdoctoral Associate: The main responsibilities of these positions include algal community dynamics and limnocorral experiments (Laughinghouse), choice experiment design and econometric modeling of discrete choice data (Khachatryan) and the hedonic model of real estate transactions (Savchenko). Each postdoc will attend a new employee orientation session before the start of the project. After the orientation week, project deliverables and responsibilities will be clearly communicated, and an attainable timeline will be established for project implementation. In addition to closely working with their supervisor, each postdoc will have opportunities to collaborate with researchers in their home research groups, the Consumer Behavior and Insights lab (CBI; Khachatryan), the Applied Phycology lab (Laughinghouse), and the Agricultural and Economics Policy Group (Savchenko). The postdoc's will be introduced to novel methods in experimental economics such as integration of visual attention data in choice analysis as well as cutting-edge field and lab research methods (e.g., whole-pond metabolism, molecular genomics). The postdocs will have an opportunity to guest-lecture in the Soil and Water Sciences Department as well as their home department, while also collaborating with graduate students interested in their area of expertise.

A **Postdoctoral Professional Development Plan (PPDP)** will be developed by postdoc's and their supervisor (Khachatryan, Laughinghouse, Savchenko) in four stages:

1) The postdoc will conduct a self-assessment and their supervisor will research additional opportunities for postdoctoral professional development.
2) The postdoc and supervisor will discuss opportunities related to the proposed research as well as opportunities outside the scope of the proposed research.
3) The postdoc will write a formal PPDP that establishes specific areas of improvement, deliverables (with anticipated deadlines), and SMART (Specific, Measureable, Achievable, Relevant, and Time-Oriented) objectives for their tenure on the project.
4) The postdoc will implement the PPDP and the supervisor will establish a regular progress assessment schedule, providing opportunities for the postdoctoral associate to give feedback on project- and career-specific development goals.

Networking: The multidisciplinary leadership team will provide the postdocs with a broad cross-section of investigators to meet with during regular project meetings, expanding their professional network. The postdocs will be encouraged to present their research results at disciplinary and interdisciplinary meetings and will be expected to help in convening special sessions related to ecosystem services of anthropogenic ecosystems along with the project leadership team.

Professional Development: The postdocs will be encouraged to attend annual grant-writing workshops at UF and to develop proposals during their tenure at UF. Members of the leadership team will provide advice and constructive criticism on application materials, presentations, interviews, negotiations, etc. as the postdocs progress in their careers. The postdocs will work closely with the research assistant focused on social surveys and focus groups, along with the PI, co-PI's, senior personnel, and graduate trainee on the project, providing a truly collaborative, interdisciplinary research environment. The postdocs will be encouraged to develop leadership skills as the project progresses by leading group meetings, developing synthetic products, and receiving in-depth experience with grant project management through interactions with their mentor, the lead PI (Reisinger), and the rest of the project team.

Data management plan for NSF - DISES Proposal - University of Florida

The University of Florida is committed to ensuring that the results of this project, including original raw data, derived data products (i.e., model outputs), and appropriate documentation are properly archived and made publicly available for the broader research community and for relevant local, state, and national stakeholders. Our data management plan will consider the data life cycle (https://www.dataone.org/data-life-cycle) by 1) planning data management and collection by training all participants in proper data management, curation, and dissemination; 2) collecting data necessary to achieve project objectives; 3) assuring the quality of the data by properly maintaining instruments and following QA/QC protocols; 4) accurately describing data following data and metadata standards; 5) preserving and archiving collected data through various public repositories; 6) discovering additional data for use in the project by actively reading literature and incorporating new datasets into ongoing analyses; 7) integrating various data streams, both from this project and external sources to address project objectives; and 8) analyzing data using appropriate statistical approaches for a given task - analytical approaches will account for, and incorporate, uncertainty into analyses using various approaches including Bayesian modeling, time-series analyses, and sensitivity analyses. Overall data management will be tailored to the needs of individual datasets, but will be overseen by lead PI Reisinger and senior personnel Smidt, who is an expert in geospatial analyses and has experience integrating big data from multiple sources through his role as the director of the UF Land and Water Data Computing Lab.

Expected data types and formats

- *Environmental data* - The project team and trainees will produce a variety of data types, including quantitative measurements for water quality monitoring, algal community composition derived from morphological and molecular approaches, social surveys, and geospatial model results derived from remote sensing products (Landsat-8 and Sentinel-1B).
  - Environmental data including physical (i.e., hydrology and bathymetry) and chemical (i.e., water chemistry) data, algal morphological inventories, and high resolution data for pond metabolism, including dissolved oxygen, water temperature, barometric pressure, and wind speed data will be collected. These data will be stored as either text (.txt or .docx), comma separated (.csv), or MS Excel (.xlsx) formats and will be managed by Reisinger.
  - Microbial molecular information including taxonomic analyses based on MiSeq Illumina runs. The UF Bioinformatics Core Lab will host data on secure servers and Laughinghouse will coordinate with the Core Lab to manage data storage, processing, and analytical pipelines.
  - Remote sensing data and derivatives will include various geospatial data streams, including remote imagery data accessed from publicly available sources (Landsat-8, Sentinel-1B) coupled with water quality estimates to develop derivative data products including model estimates of algal biomass in water bodies throughout the state and associated uncertainty in these estimates. GIS data will be in raster or shapefile formats, whereas water quality data will be stored as other discrete environmental datasets. These data will be managed by Smidt.
- *Human subjects data* will include responses to surveys, discrete choice experiments, and focus groups within focal communities. Due to the sensitive nature of human subjects data, we will assign alphanumeric codes to each subject as soon as possible and will follow University of Florida guidelines for securely storing data from human subjects.
  - Social surveys and discrete choice experiments will include responses to social survey instruments. These data will be recorded and assigned alphanumeric values as soon as possible. Questions will include demographic data but not restricted or highly sensitive data. Anonymized data will be in spreadsheet format (.csv or .xlsx) managed by Khachatryan, Savchenko, and/or Monaghan.
  - Focus groups will provide long-form data with narrative responses to individual questions. These data will be transcribed from recording of original focus groups, with the transcribed versions being anonymized with alphanumeric codes. The original recordings will be stored in locked locations only available to the senior leadership team. These data will be managed by Monaghan.
- *Documentation* - Project documentation will be prepared to describe the outcomes of all project activities. These documents will include project updates from trainees (e.g., annual reports), peer-reviewed publications, conference presentations, and educational modules for undergraduate courses and Extension programs. These documents will be produced using MS Office products and made publicly available through the PI's website (or peer-reviewed journals, when applicable).

Data and Metadata Standards
Data produced through this project will be formatted and archived with sufficient metadata to ensure compatibility and to facilitate dissemination and sharing. Although standards and guidelines for metadata content and formatting are constantly evolving, we will use the Ecological Metadata Language (EML) schema for all metadata unless specific metadata formats are required by data repositories or journals. EML is generic enough to accommodate most forms of data being produced in this project, including biophysical, social, ecological, and spatial. We plan to archive data through the Environmental Data Initiative (see below), which uses EML as their metadata standard. For geospatial data, we will also comply with the Content Standard for Digital Geospatial Metadata (CSDGM) set forth by the Federal Geographic Data Committee (FGDC).

Policies for Access, Sharing, Protection, Privacy, Re-Use, Re-Distribution, and Data Derivatives

- *Data storage, sharing, and access* (among project personnel) will be coordinated by Reisinger. Data will be stored using a cloud-based data management system (Microsoft OneDrive) which is freely available to the project team through UF licensing agreements. We will couple this data management system with project facilitation through Microsoft Teams, an app that allows users to share files and communicate remotely via multiple platforms. Use of OneDrive and Teams will allow for remote data entry and provide a uniform platform for personnel to easily share data. Furthermore, use of these cloud-based services ensures that project data are password-protected and are backed up daily via a remote server. The project team will receive an initial 'Teams' training (led by Reisinger) and will develop the internal Teams architecture during the first project meeting. Further, we will develop a project GitHub account that will be used to generate scripts, analyze data, develop derivative products, and ultimately make all scripts, data, and analyses publicly available. The use of these cloud-based, collaborative software applications will ensure that all data remain available to all project members in the unforeseen event of a key member of the team leaving the project.
- *Dissemination and distribution of data and derivatives* will facilitate replication of project findings and further generalizability of the proposed research. Data and metadata will be archived and made publicly available upon publication, within two years of collection, or at the end of the project, whichever comes first. Dissemination will be led by personnel most directly involved with data collection and management, but will be overseen by Reisinger. All datasets will be versioned to indicate changes since initial release. Data will be made publicly available via multiple outlets: 1) ecological, biogeochemical, and (anonymized, non-restricted) social data will be deposited into the Environmental Data Initiative (https://environmentaldatainitiative.org) data repository; 2) molecular data will be archived in GenBank (https://www.ncbi.nlm.nih.gov/genbank/) and phylogenetic trees will be deposited in TreeBase (https://treebase.org); 3) original data, scripts, and derived products will be made public via our project GitHub; 4) publishing in journals that support archival data publishing, prioritizing open-access options; and 5) data that do not conform to these dissemination options will be archived through the Institutional Repository at UF (https://ufdc.ufl.edu/ufir), which provides public access to all materials. The leadership team will work to identify additional outlets for data products with the goal of dissemination to a range of audiences.
- *Data privacy and protection* is an important consideration when dealing with human subjects data. All human subjects data will be anonymized and converted to a randomized alphanumeric basis to ensure security and anonymity. We will adhere to University of Florida policies regarding human subjects. We do not anticipate collecting restricted personal health or financial information. All data used for this project will either be in the public domain or collected directly by the project team, which will subsequently be made publicly available. We do not anticipate specific restrictions on any of our published datasets except the requirement that users properly acknowledge and cite the data source as indicated in the metadata and online instructions for data access.

Plans for Archiving and Preserving Data Access
Data generated through this project will be stored indefinitely through the various dissemination platforms mentioned above (public repositories, GitHub, open-access journals), with the aim that these data and derived products will contribute to our long-term understanding of the coupled human and natural system dynamics of stormwater ponds and other integrated socio-environmental systems. All data types described above, as well as any unforeseen data generated by this program, will conform to data and metadata standards and policies as outlined above and will be archived and accessible for perpetuity.

Project Management Plan for NSF - DISES Proposal - University of Florida

1. Project Organization

This project includes 7 major research and outreach elements: 1) Social perceptions of stormwater pond ecosystem services across different societal levels 2) Quantifying biogeochemical functions within focal stormwater ponds; 3) Algal community dynamics and management; 4) Geospatial analyses of SWP water quality and socioeconomic drivers; 5) Discrete choice experiments to assess stated preferences; 6) Hedonic housing price model to assess revealed preferences; and 7) Educational outreach and dissemination to multiple stakeholders. Each element will be led by specific members of the project with requisite expertise (Table 1). Overall project management and coordination will be led by Reisinger.

2. Personnel and Responsibilities

Table 1. Project Personnel, expertise, roles, and responsibilities

Team member	Expertise	Roles/Responsibilities
Alexander J. Reisinger	Urban biogeochemistry	Overall project coordination; lead Element 2 (biogeochemistry), co-lead Element 3 (algae) and 7 (outreach)
Olesya Savchenko	Environmental and resource economics	Lead for Element 6 (Hedonic model)
Hayk Khachatryan	Experimental economics	Lead for Element 5 (Discrete choice experiments)
H. Dail Laughinghouse	Phycology	Lead for Element 3 (algae)
Paul Monaghan	Social marketing and behavior change	Lead for Element 1 (social perceptions), co-lead for Element 7 (outreach)
Michelle Atkinson	Env. horticulture and Extension outreach	Lead for Element 7 (outreach), co-lead Element 1 (social perceptions)
Eban Bean	Urban water resources	Co-lead for Element 2 (biogeochemistry), 4 (geospatial analyses) and 7 (outreach)
Basil Iannone	Geospatial analysis/community ecology	Aid in field operation coordination; co-lead Element 4 (geospatial analyses) and 7 (outreach)
Samuel Smidt	Geospatial analysis/remote sensing	Lead for Element 4 (geospatial analyses) and for developing educational modules

Other project personnel:

Postdoctoral Associates - a postdoctoral associate will be responsible for completing discrete choice experiments within focal communities and at a regional scale (2 years, advised by Khachatryan). A second postdoctoral associate will be responsible for developing and completing the hedonic housing price model (2 years, Savchenko). A third postdoc will be responsible for leading the algal and microbial community composition components of the research (2.5 years, Laughinghouse). Each postdoctoral associate will also aid in synergistic investigations across research elements (supervised by Reisinger).

Research Technician - a research technician will be responsible for coordinating social surveys and focus groups within focal communities, enacting educational interventions, and developing/coordinating community outreach activities (3 years, supervised by Monaghan).

Graduate students - One PhD student (advised by Reisinger) will be fully supported by this project. The student will develop their own research project based on the foci of this proposal. Two additional graduate students will be partially supported and advised by Bean (stormwater sampling, low-cost sensor management), and Smidt (remote sensing, geospatial analyses).

All project personnel will be exposed to the disciplines and foci of other personnel. Students will have opportunities to collaborate on tasks beyond their discipline, but their roles will be clearly defined to protect their careers and ensure all work is additive.

3. Project coordination and integration

Project management will be facilitated through ongoing activities and relationships among the leadership team. The leadership team and all trainees will meet regularly throughout the project (i.e., monthly during the initiation of the project, and at least quarterly throughout the project) via in-person and/or virtual meetings to ensure that project milestones are met. If possible, dependent upon COVID-19 developments, the project team will convene annually at the main UF campus for a project update. Sub-groups focused on specific tasks (e.g., the seven major elements detailed above) will be formed and will meet at least quarterly. PI Reisinger and postdoctoral associates will participate in all sub-groups to insure consistent and transparent communication within and among all sub-groups and to allow the postdoctoral associates to develop convergent, synthetic products.

4. Project milestones and timeline

Success of this project will be assessed by meeting specific milestones detailed below. Further, we will assess our outreach activities using assessment protocols (e.g., pre-, post- surveys and 6-month follow-up surveys) already established for the *Healthy Ponds* and *Water School* programs.

Year 1

- Project initiation: Recruit all trainees and enact a collaborative meeting across the entire team establishing timelines and protocols for field work, social surveys, and educational interventions.
- Design and implement data storage, management, and archiving architecture as described in the Data Management Plan to ensure collaboration across research elements.
- Data collection: focal community social surveys, discrete choice experiments, recruit K-12 educators and begin biogeochemical and algal monitoring.
- Workflow development: Personnel from tasks starting in years 2-4 design workflows and data sources necessary for meeting objectives (i.e., satellite imagery for SWP water quality survey).

Year 2

- Complete biogeochemical and algal monitoring within focal communities.
- Develop educational materials for and conduct focus groups within targeted communities.
- Data collection: limnocorrals, remote sensing, statewide SWP survey, and hedonic housing price model data collection, processing and analysis.
- Conduct statewide discrete choice experiment based on results from focal communities.
- *Manuscript*: Willingness to pay for primary and secondary ecosystem services of stormwater ponds (statewide discrete choice experiment).
- Synergistic Activities: Special session at e.g., the Ecological Society of America on managing anthropized ecosystems; incorporate results from year 1 into UF *Healthy Ponds* curriculum.

Year 3

- Complete post-intervention social surveys and discrete choice experiments.
- Complete data processing and analysis for remote sensing, statewide SWP survey, and hedonic housing price model.
- *Manuscript*: Nutrient and energy dynamics of stormwater ponds spanning an age gradient.
- *Manuscript*: Algal community composition patterns within anthropized stormwater ponds
- *Manuscript*: Efficacy of alternative algal control methods within stormwater ponds (limnocorrals).
- Synthesize social and environmental data from focal communities and statewide assessments.
- Synergistic Activities: Complete Water Schools within focal communities; develop Extension publications targeted at individual, community and regulatory levels of society.

Year 4

- Complete data synthesis and ensure data is publicly available as outlined in data management plan.
- *Manuscript*: Effectiveness of educational interventions for changing social perceptions of stormwater ponds using general or local information.
- *Manuscript*: Revealed preferences of SWP ecosystem services (hedonic housing price model).
- *Manuscript*: Water quality of stormwater ponds assessed using satellite imagery.
- *Synthesis manuscript*: Optimizing ecosystem services provided by stormwater ponds using ecological and social data (synthetic manuscript).
- Synergistic activities: lead workshops focused on optimizing ecosystem services of SWPs targeted at individual, community, and regulatory stakeholders at local and statewide scales.