FLOATING TREATMENT WETLANDS: A PILOT-STUDY OF THE EFFECTS ON URBAN CATCHMENTS IN A SUBTROPICAL ENVIRONMENT

by

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Dedication

I dedicate this work to my mother and father; may they rest in peace. Both taken from this world too soon, but who had a lasting impact during the time that they were here. Their strength and determination were and still are a guiding light for me in the darkest of times. I could not have gotten to where I am today without their love and support.

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I would also like to thank my husband, Gerzan, for his unending love and support throughout my academic endeavors. From feeding me when I was too stressed to cook to attempting to stay up with me during all-night study/writing sessions – you have helped me stay sane when academia demands insanity – I love you.

ABSTRACT

FLOATING TREATMENT WETLANDS: A PILOT-STUDY OF THE EFFECTS ON URBAN CATCHMENTS IN A SUBTROPICAL ENVIRONMENT

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University of Houston-Clear Lake, 2024

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Stormwater runoff from developed land is one of the leading causes of water pollution. Heavy metals, nutrients, oil and grease, suspended sediments, and bacteria represent some of the more common pollutants that end up in urban waterways from stormwater runoff. Current technologies to reduce pollutants like traditional water treatment facilities are expensive and require land development. Floating treatment wetlands (FTWs) are a novel technology that have been shown to reduce stormwater pollutants and enhance water quality of surface waters. FTWs are artificially created islands with (preferably native) wetland plants, grown hydroponically, where the roots are suspended in the water column. These roots act as a physical filter of suspended sediments and as the mechanism for pollutant uptake by the plants. The benefit of FTWs is that they can be retrofitted to existing urban catchment sites such as stormwater detention ponds or other impaired perennial lentic waterbodies. In 2020, the Environmental Institute of Houston in partnership with the Harris County Flood Control District, initiated a pilot-study which examined the potential for FTWs to reduce pollutants of concern in two ponds which received stormwater runoff from the University of Houston – Clear Lake campus, located in the Armand Bayou watershed in Harris County, Texas. Three types of modular FTWs were constructed and evaluated based on selected water quality criteria, as well as durability, ease of construction, and required maintenance. This study also compared the treatment efficiency of DIY FTWs and of two understudied species of wetland vegetation. Overall results showed that the FTWs reduced bacteria and suspended sediments, improving the treatment potential of the stormwater catchments, but nutrients were not removed at the expected levels as there was not a significant difference in removal with and without the FTWs. This pilot-scale study provided many lessons on design, construction, and needed maintenance.

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INTRODUCTION

Stormwater Runoff and the Cause for Concern

Stormwater runoff from developed areas is one of the leading causes of water pollution (Council 2009, Headley and Tanner 2006). Runoff that flows over land and impervious surfaces can pick up and transport harmful pollutants into surface and ground water. Heavy metals from construction or industrial sites, excess nutrients from agricultural fields, oil and other chemicals from road runoff, and waterborne pathogens from leaking or overflowing septic systems are all possible sources of pollutants that end up being carried into waterways by stormwater runoff.

Sedimentation from soil erosion is a natural process that is important for accretion, particurlarly in river deltas, but excess sediment from other sources such as poorly maintained gravel or dirt roads, uncovered soil on lawns, gardens, farmlands, and construction sites, can cause issues in surface waters by smothering stream habitat. Eroded sediments also provide adsorption surfaces for toxic metals and organics. Additionally, excess sediment in surface waters can cause alterations to stream flow and nutrient levels (U.S. EPA 2006a).

Nutrients such as nitrogen and phosphorus, which occur naturally, are essential for healthy aquatic systems, but when levels are unnaturally high, they can cause harmful algal blooms and lower oxygen levels to the detriment of aquatic life (Dubrovsky et al., 2010). Primary sources of excess nutrients originate from anthropogenic activities and sources such as fertilizers, from both home and agricultural uses, wastewater, automobile exhaust and animal waste (USGS, 2019).

High bacteria loads, as measured using *Escherichia coli*, a pathogen indicator bacteria, present another difficult problem with stormwater runoff, especially when discharged into surface waters where recreational users may incidentally ingest the water and/or expose open wounds. It is used as a pathogen indicator because when there are high amounts of *E. coli* present, there also tends to be high levels of pathogens. Livestock manure and improperly disposed pet waste can be carried from pastures and lawns by stormwater runoff and end up contaminating surface and ground waters. Failing human sewage conveyance infrastructure or improperly installed on-site sewage facilities, as well as illicit discharges of human waste are also some of the biggest concerns as possible sources of pathogens. Current technologies to reduce pollutants such as extensive created wetland complexes or traditional water treatment facilities are expensive and/or require extensive land development.

Utilizing Wetlands for Water Treatment

One of nature's methods of filtering pollutants from surface waters is wetlands. Known as the kidneys of the landscape, wetlands can treat surface waters by using natural processes such as sedimentation, photo-oxidation, microbial degradation, and nutrient uptake, among providing many other ecological benefits. Unfortunately, since the late 1700s, the United States (U.S.) has lost over half of its natural wetlands (Fluet-Chouinard et al. 2023), mostly due to drainage and development. Wetlands have been constructed to treat wastewater or stormwater to achieve the National Pollutant Discharge Elimination System (NPDES) and state discharge permit limitations (Kadlec and Wallace 2009; Matthews and Minello 1994; Mitsch 2006).

Land intensive created wetland systems have been used alone or as tertiary treatment after wastewater has undergone primary (mechanical) and secondary (biological) treatment (Kadlec et al. 2000). Generally, these systems have not focused on restoring all the functions of a natural wetland and have often utilized simple designs to treat water (Kadlec et al. 2000). Since the late 1960's, raceway ponds planted with submerged and emergent wetland vegetation have been used as one of the primary approaches to improve wastewater effluent and stormwater runoff quality from detention basins (Headley and Tanner 2006; Vymazal 2011). Popularity has primarily been due to the operational simplicity of these systems which provide a relatively passive, low-maintenance treatment solution while in some cases enhancing aesthetic values and habitat. However, a number of issues have emerged with the application of these traditional wetland/pond systems for stormwater treatment.

Ponds are generally effective at removing coarse suspended sediments, but are less effective at removing dissolved contaminants and finer particulates as they do not have a way to filter the suspended particulates and rely on sedimentation (Headley and Tanner 2006). Most stormwater basins are built for flood management and control during heavy rains, so these systems are designed to maximize the volume of water they can hold during those high flow events. Beneficial wetland plants may be utilized in these basins to help reduce pollutants loads, but sediment-rooted emergent wetland vegetation can only tolerate and persist in relatively shallow water depths and are susceptible to recurring die-back if inundated by high water for too long. Most conventional wetland treatment systems are poorly designed to deal with extreme fluctuations in water level caused by stormwater events. Furthermore, only a small portion of the flowing water effectively receives treatment during large rainfall events because only the perimeter of a detention pond can typically support emergent vegetation during high water levels. As an alternative to traditional wetland systems, municipalities and industry have begun evaluating and using floating treatment wetland systems (FTWs) for stormwater treatment (Headley and Tanner 2006; Kadlec and Wallace 2009).

Floating Treatment Wetlands

Floating treatment wetlands (FTW) are a novel technology that have been shown to reduce stormwater pollutants and enhance water quality of surface waters (Headley and Tanner 2006, Headley and Tanner 2012, Zhou et al. 2019). FTWs are artificially created islands with preferably native wetland plants grown hydroponically, where the roots are suspended in the water. They are low-cost and eco-friendly, as they can be made from reclaimed or recycled materials and can either be purchased from a commercial retailer or constructed on your own.

FTWs tend to utilize wetland plants that have great nutrient uptake capabilities (DeLaune and Reddy 2008). Some wetland plant species are preferred for these systems over others due to having large, fibrous root systems that can act as filters of suspended sediment in the water column (Olguín, Sánchez-Galván et al., 2017). Native plants are preferentially selected to limit the spread of invasive species and due to their adaptation to local conditions. The mats are connected to anchoring systems that allow the islands to rise and fall with the fluctuating water level. FTWs can be retrofitted to existing sites such as stormwater detention ponds, acid-mine drainage, wastewater reservoirs, industrial effluent canals or lagoons, or natural lakes, ponds, or rivers that may be impaired. Theoretically, FTWs can provide stormwater treatment at any water level within a detention basin except for very shallow depths, which can result in the suspended plant roots attaching to bottom substrates.

The undersides of the mats and the suspended roots provide valuable surface area for beneficial microbes to proliferate and remove nutrients from the water while also providing shade, which decreases pond temperatures, and provide cover for fish and other aquatic life (Urakawa, Dettmar, & Thomas, 2017). The substrate provided for microbial growth contributes to the roots releasing oxygen and exudates (Shahid et al., 2020).

Microbes can attach to the roots and form biofilms while attaining nutrients from the plants. This bacterial community then aids in removal of nutrients like nitrogen and phosphorus along with other pollutants such as organic compunds, heavy metals, and hydrocarbons (Shahid et al., 2020). The native wetland plants also attract beneficial insects, pollinators, and other native wildlife, and depending on their design, can provide habitat to aquatic and semiaquatic fish and wildlife, and add aesthetic value to the waterbody.

Numerous lab and mesocosm studies have proven FTWs to be successful at removing bacteria, and excessive nutrient concentrations (Chang et al., 2012; Keizer-Vlek et al., 2014; Lynch et al., 2015), but limited field-scale studies have been conducted to date (but see: Borne et al., 2013; Borne et al., 2015; Olguín et al., 2017). In FTWs, pollutants are removed by three main processes: (1) adsorption, (2) sedimentation, and (3) biodegradation (Pavlineri et al., 2017). Limited literature on FTWs suggest that removal of some dissolved pollutants and nutrients is enhanced by incorporation of these systems (Bing et al., 2017; Masters 2012; Yeh et al., 2015). However, less research has been conducted on optimal stormwater treatment design (Khan et al., 2013). Floating wetlands have been used to treat various types of wastewater but there has been little evaluation of pollutant removal efficiency, cost effectiveness, functionality, and long-term resilience.

There are inherent complications when conducting field-scale trials, luckily some researchers have compiled installation and maintenance recommendations to help future field trials be more efficient in terms of treatment design, longevity, and/or execution (Khan, Melville et al., 2013, Borne, Fassman-Beck et al., 2015, Rehman, Ijaz et al., 2019). This pilot-scale study will abide by the recommendations that best suit our study purpose.

Study Purpose

The Harris County Flood Control District (HCFCD) is a Phase 1 Municipal Separate Storm Sewer System (MS4) co-permittee together with the City of Houston, Texas and Harris County, Texas. Under the Texas Pollutant Discharge and Elimination (TPDES) permit they are responsible for reducing pollutants of concern from facilities operated by the MS4 co-permittees. HCFCD's mission is to "provide flood damage reduction projects that work with appropriate regard for community and natural values". HCFCD was interested in building and deploying FTWs as an additional cutting-edge approach to reduce stormwater pollutant loads in flood control facilities.

This study was designed at the request of HCFCD to test and evaluate multiple floating wetland treatment system designs. Ultimately four candidate systems including one do-it-yourself (DIY) and three premanufactured systems were tested. Criteria provided by HCFCD that were considered when selecting suitable treatment systems included 1) how functional the system was during large water level fluctuations, 2) how well the system enhanced baseline water quality treatment, 3) which system achieved high levels of pollutant removal, 4) the durability of the system, 5) whether the system provided obvious benefits to wildlife (e.g. was it utilized by wildlife), 6) whether the system was aesthetically pleasing and 7) the cost-effectiveness of the system (cost of construction, operations and maintenance).

METHODS

Study Site Description

The University of Houston – Clear Lake (UHCL) FTW project took place in the Armand Bayou Watershed (59 square miles), located in southeast Harris County in Texas. Armand Bayou is a tributary system of the 197-square-mile Clear Creek Watershed. Current consumptive and non-consumptive uses in the Armand Bayou Watershed include residential, commercial and industrial land development; oil and gas production; and recreational uses such as fishing, nature viewing, canoeing, and kayaking. The Armand Bayou Watershed is heavily urbanized and multi-jurisdictional, including portions of the cities of Houston, Pasadena, Deer Park, La Porte, and Taylor Lake Village. One of the primary tributaries within the Armand Bayou Watershed is Horsepen Bayou.

The UHCL campus is located adjacent to Horsepen Bayou in the flat Coastal Plain, about 28.5 miles from the Gulf of Mexico and about 5 miles from Galveston Bay. The climate is predominantly humid subtropical. The terrain includes numerous small streams and bayous that, together with the nearness to Galveston Bay, favor the development of both ground and advective fogs. Prevailing winds are from the southeast and south, except in winter months when occasional passages of high-pressure areas bring polar air and prevailing northerly winds (U.S. Department of Agriculture, 1976). Temperatures are moderated by the influence of onshore winds from the Gulf, which results in mild winters. Another effect of the nearness of the Gulf is abundant rainfall, except for rare extended dry periods. Precipitation data prior to and during sampling were obtained from the League City National Weather Service (NWS) Station. Rainfall records (1971-2000 data from NWS, 2011) from the atmospheric station located at Houston's George Bush Intercontinental Airport, report an average annual total rainfall amount of approximately 48 inches. Monthly rainfall amounts are relatively consistent and can be found in Figure 1.

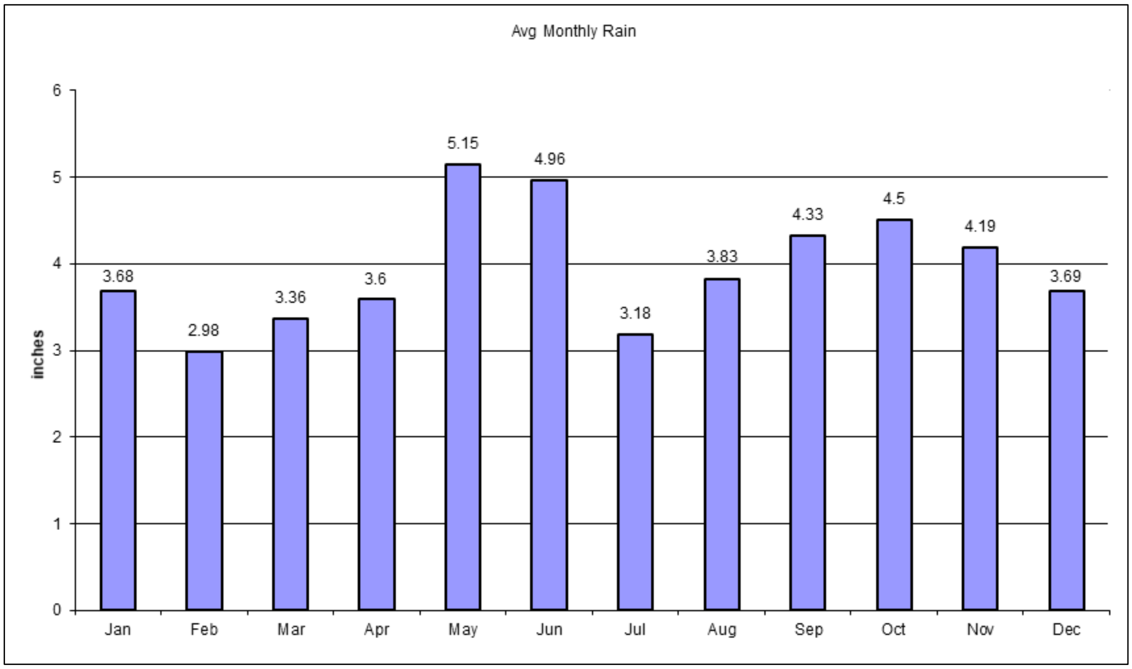

Figure 1. Houston, Texas monthly distribution of rainfall patterns (NWS, 2011).

The UHCL campus is located near the downstream extent of Horsepen Bayou and the two study sites (Potter Pond and Alligator Pond) both flow directly into Horsepen Bayou during high rainfall events. Types of impervious surfaces that produce runoff flowing into the two sites include roads, roofs, and parking lots.

Alligator Pond receives runoff from approximately 21.5 acres of university property including parking lots, roads, university buildings, and a small percentage of lawns and forests that are routed through a constructed wetland built within an existing 0.62-acre detention pond (Figure 2). The created wetland was constructed by widening the pond and creating more shallow areas for the establishment of freshwater wetland plants. Approximately 0.18 acres of wetland were created in 2011 (Guillen et al. 2014).

Potter Pond receives runoff from approximately 40 acres of university property including parking lots, roads and university buildings that are routed through eight in-ground drains and vegetated road-side ditches into Potter Pond, encompassing approximately 25 acres of impervious surface (Figure 2). Soil types in the surrounding area are comprised of Dylan and Lake Charles clay (NRCS, 2023). Both ponds are owned and operated by UHCL and can be accessed by three entryways: two entrances off of the 2700 block of Bay Area Boulevard and one off of Middlebrook Road in Houston, Texas.

Stormwater that falls within the contributing watersheds is conveyed overland to road-side ditches or underground culverts (within the parking lots) to various outfalls which flow into the road-side ditches (Guillen et al. 2014). A basic representation of the flow paths within each watershed are illustrated in Figure 3.

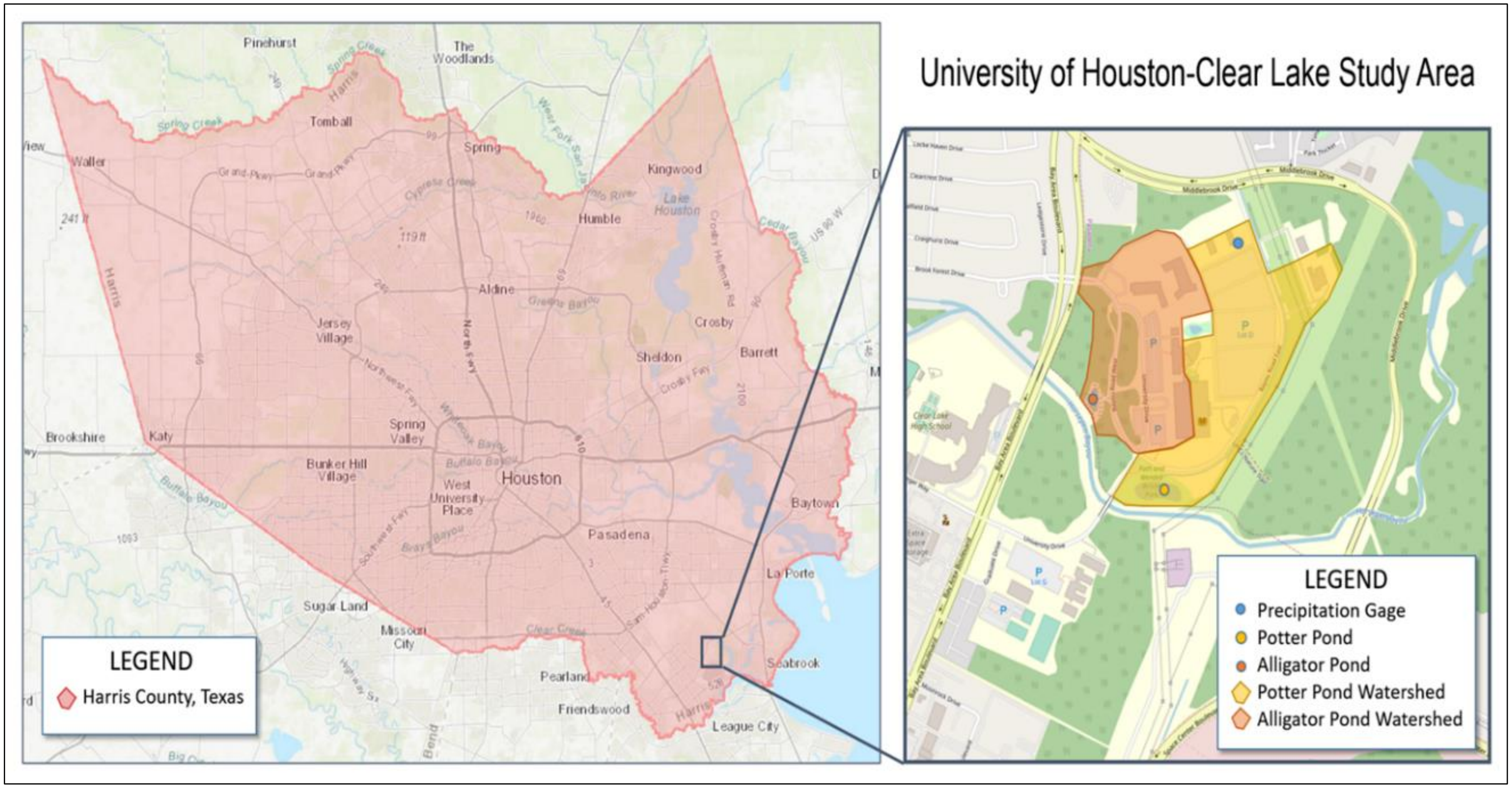

Figure 2. Study area on the University of Houston-Clear Lake campus. Locations of precipitation gage (blue point), Potter Pond (yellow point), approximate Potter Pond watershed (yellow polygon), Alligator Pond (red point), and approximate Alligator Pond watershed.

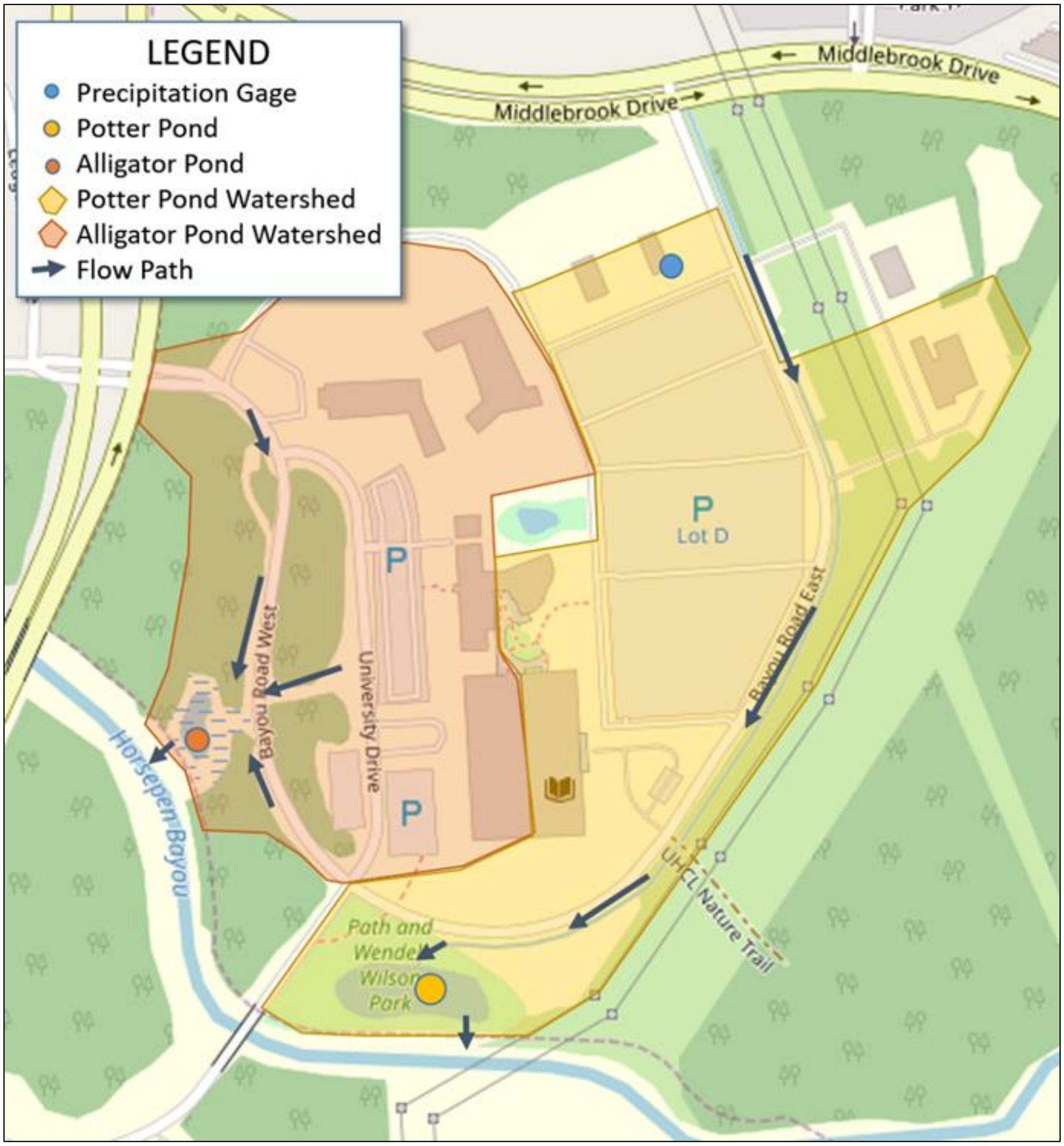

Figure 3. Visualization of stormwater flow path for Potter Pond and Alligator Pond watersheds.

There were two monitoring stations (MS) located on the UHCL campus. Monitoring Station 1 (MS1) also referred to as "Potter Pond" had five sampling stations (SSs). Monitoring Station 2 (MS2), also referred to as "Alligator Pond" had two SSs.

Monitoring Station 1

Potter Pond is a perennial pond approximately 1.61 acres in size with an average depth of 1.72 meters and a maximum depth of 2.34 meters. The outfall for the pond is a standing pipe that empties through a flap gate into the adjacent Horsepen Bayou when the water level in the pond reaches a certain depth. Water quality in Potter Pond is enhanced by an aerating fountain in the center of the pond along with periodic chemical treatments all added by Lake Management Services L.P. – contracted out by UHCL. UHCL has record of these treatments, along with water quality analyses performed by Lake Management Services for the year of 2019. We coordinated with them to cease all chemical treatments and discontinue use of the fountain during the course of this study.

Pre-installation Monitoring

Velocity profile data was collected with a SonTek M9 River Surveyor during numerous storm events to determine the predominant flow path within the pond. In order to properly evaluate the effects of the FTWs on resulting water quality, it was necessary to first estimate hydraulic time of travel. This provided us with background data that was needed to establish appropriate sampling times at sites within the treatment system. This insured that we were sampling, on average, the same parcel of water as it flows downstream through the system. Time of travel studies were conducted at Potter Pond during the baseline sampling portion of the study and post installation of FTWs using tracer dyes. The dye (Rhodamine WT) was utilized as it has been widely used and is federally approved for use in potable and ambient water by the Environmental Protection Agency (EPA). The dye was released at the inlet and a fluorometer was deployed near the center of the pond and at the outfall to monitor the transit time while visual observations of the flow path were made with the assistance of drone aerial footage.

After collecting the baseline flow data, but before the deployment of the FTWs, there were three pre-installation sampling events, 2 wet weather events and 1 dry weather event, in order to evaluate the pre-existing treatment capacity that each pond provided. Two sampling methods were utilized: grab sampling and “first flush” sampling. Grab sampling consisted of manually collecting bacteria, total suspended solids (TSS), oil and grease, 5-day biological oxygen demand (BOD_5) and nutrient samples, while first flush samplers were deployed 1-2 inches above the normal ambient water level in order to collect the first flush of the storm event (See Table 1 for a full list of target constituents). Single grab first flush stormwater samplers (manufactured by Nalgene®), were deployed at the inlet of MS1 before and after every significant rainfall event to evaluate changes in stormwater quality from runoff. The unit is designed to remain sealed until a critical depth (1-2”) of runoff is present at the site and will not collect water until this critical depth occurs. Upon filling, the sample bottle is also designed to self-seal to prevent cross-contamination with additional surface water that may be present after initial first flush runoff conditions occur. Samples collected by the stormwater sampler were tested for standard water quality measures including nutrient samples and TSS (See Table 1 for a full list of target constituents).

Continuous water level data was measured using a YSI Amazon 15 PSI self-contained flow bubbler with an integrated pressure sensor and display. Velocity of inflow was measured using an M9 Hydroboard equipped with RiverSurveyor or a SonTek FlowTracker, depending on minimum water depth at measurement area. A flow curve was developed for the inflow allowing us to estimate the event mean concentration ("EMC") from each qualified storm event. The EMC result was obtained at both sampling locations and is defined as the total constituent mass divided by the total runoff volume (or pumped volume). The EMC is a statistical parameter used to represent the flow-proportional average concentration of a given variable during a storm event or pumping cycle and is calculated as follows:

$$EMC = \frac{total\ pollutant\ loading\ per\ event}{total\ runoff\ volume\ per\ event} = \frac{\sum_{i=1}^{n} V_i C_i}{V}$$

Where EMC = event mean concentration, mg/L; V = total runoff volume per event, L; V_i = runoff volume proportional to the flow rate at time i, L; C_i = pollutant concentration at time i, mg/L; and n = total number of samples during a storm event.

The definition of a qualified storm is defined as one that satisfies the following requirements:

1. Rainfall Volume: 0.10 inch minimum
2. Antecedent Dry Period: 24 hours minimum.

Wet weather sampling required significant coordination between our field crew, laboratory, and weather forecasting services. Weather events were tracked regularly by daily checks of NOAA weather forecasts and local weather station radars and sampling teams were given notice when wet weather appeared promising. When a qualifying weather event occurred, a field crew was deployed, however, mobilization times varied depending on the timing and intensity of the storm. Because of safety considerations, sampling only took place during daylight hours and safe conditions, that is, no lightning or flooding risks. Dry weather sampling efforts followed a dry period of at least three days with only trace rainfall amounts within the watershed.

Surface water was monitored for several target constituents (Table 1) at two sampling stations (SS) for pre-installation events for MS1: the inflow (SS-A) and at the outfall (SS-D). Continuously operating and logging datasondes that monitor the water temperature (°C), specfic conductivity (µS/cm), salinity (psu), dissolved oxygen (DO) (mg/L), pH, and turbidity (nephelometric turbidity unit – NTU) were deployed at all previously mentioned sampling stations (see Table 2 for a full list of variables). Collecting water quality samples and data at both the inflow and outflow allowed us to calculate the removal efficiency of the pond by comparing the incoming water quality with the outgoing. Example datasheets for sampling events can be found in Appendix A.

Table 1. Constituents monitored during this study were analyzed at the Test America Lab. AWRL = Ambient Reporting Limits for Texas Surface Water Quality Monitoring per the Texas Commission on Environmental Quality (APHA et al. 2004).

Parameter	**Units**	**Sampling Stations (SS)**	**Method**	**AWRL**	**Preservative**	**Sample Container**	**Minimum Volume (mL)**
E. coli, IDEXX Colilert	MPN/100 mL	A, B, C, D, E, F, G	SM 9223-B	1	Ice + $NA_2S_2O_3$	Sterile Cup	120
TSS	mg/L	A, A-FF, B, C, D, E, F, G	SM 2540 D	5	Ice	1L Plastic	1000
TKN	mg/L	A, A-FF, B, C, D, E, F, G	SM 351.2 NP	0.2	Ice + H_2SO_4	1L Plastic*	300
NO_2+NO_3 -N	mg/L	A, A-FF, B, C, D, E, F, G	SM 353.3	0.05	Ice + H_2SO_4	1L Plastic*	300
Total Phosphorus-P	mg/L	A, A-FF, B, C, D, E, F, G	SM 4500- PE P E-1999	0.06	Ice	1L Plastic**	500
Ortho-phosphate -P	mg/L	A, A-FF, B, C, D, E, F, G	SM 4500-PE	0.04	Ice	1L Plastic**	500
Ammonia-N, total	mg/L	A, A-FF, B, C, D, E, F, G	SM 350.1	0.1	Ice + H_2SO_4	1L Plastic*	300
BOD_5	mg/L	A, B, C, D, E, F, G	SM 5210B	2	Ice	1L Plastic	1000
Oil and grease	mg/L	A, B, C, D, E, F, G	SM 1664	5	Ice + HCl	(2) 1L Amber Glass	2000
Conventional and bacteriological community parameters collected by EIH and analyzed by HCFCD laboratories. *Combined in single 1L plastic, **Combined in single 1L plastic; volume for first flush sampler: 2900mL.							

Table 2. Measurement performance specifications for field measurements of water quality. Field parameters measured and collected by EIH. TCEQ reporting parameter codes.

Parameter	Units	Method	Parameter Code
pH	pH/units	EPA 150.1 and TCEQ SOP V1	00400
DO	mg/L	SM 4500-O G and TCEQ SOP V1	00300
Specific Conductance	µS/cm	EPA 120.1 and TCEQ SOP V1	00094
Turbidity	NTU	TCEQ SOP V1	N/A
Temperature	°C	SM 2550 B and TCEQ SOP V1	00010
Total water depth	Meters	TCEQ SOP V2	82903
Secchi Depth	Meters	TCEQ SOP V1	00078
Days since last significant rainfall	Days	TCEQ SOP V1	72053
Present Weather	1-clear, 2-partly cloudy, 3-cloudy, 4-rain, 5-other	TCEQ SOP V1	89966
Flow, Instantaneous**	cfs	TCEQ SOP V1	00061
Flow measurement method	1-gage, 2-electric, 3-mechanical, 4-weir/flume, 5-doppler	TCEQ SOP V1	89835
Water Color	1-brownish, 2-reddish, 3-greenish, 4-musky, 5-clear, 6-other	TCEQ SOP V1	89969
Water Odor	1-sewage, 2-chemical, 3-rotten egg, 4-musky, 5-fishy, 6-none, 7-other	TCEQ SOP V1	89971
Wind Intensity	1-calm, 2-slight, 3-moderate, 4-strong	TCEQ SOP V1	89965
Water Surface	1-calm, 2-ripples, 3-waves, 4-whitecap	TCEQ SOP V1	89968
Dye Trace – Time of Travel	hh:mm	USGS, (Jobson 1997)	A9 & A12

Installation of the MS1 FTWs

Three different commercially available mat types were assessed in MS1. They were chosen after a thorough literature review had been completed. Native Texas wetland species also underwent a thorough literature review before being selected.

Features and results from previous studies were compiled into a scoring matrix and were compared using the following criteria. Primary performance standards were given the highest weight in scoring and included (1) cost, (2) water quality enhancement, and (3) ease of constructability. Secondary performance standards were given medium weight during scoring and included (4) anchoring requirements, (5) maintenance requirements, and (6) longevity/warranty. Tertiary performance standards were given the lowest weight during scoring and included (7) aesthetic value.

Scoring was completed during the monitoring period of pre-installation wet weather and dry sampling events, and the following FTW mat types were selected for further assessment: (1) Beemats® Floating Wetlands (hereto referred to as “Beemats”), (2) BioHaven® Floating Islands (hereto referred to as “BioHaven, and (3) PhytoLinks™ Modular Floating Treatment Wetland System (hereto referred to as “PhytoLinks”). Table 3 below provides a detailed description of the three FTW mat types chosen and includes example photos, manufacturer location, mat material, dimensions, accessories, the total number ordered, the price per square foot, and the amount of effort required to assemble the mats. While the number of mats ordered per type may have differed, the square footage they took up was relatively the same, approximately 220 ft^2 per row.

Construction of the mats took place before harvesting and planting of the selected wetland plant species. The Beemats were delivered with no instructions for assembly, but it was somewhat intuitive. The puzzle-piece mats fit together and were secured using the provided nylon ropes in the reinforced pre-cut holes. There were also smaller pre-cut holes (not reinforced with grommets) along the edges that we utilized to better secure the mat edges with zip-ties that we provided ourselves. It took 30 minutes with four people to fully assemble the Beemats. The BioHaven mats did come with instructions for assembly, but they were not adjusted to the design of the mats that were sent to us. No connection materials were provided so we utilized the leftover nylon rope that came with the Beemats as well as some vinyl-coated cable that we purchased ourselves. The manufacturer-intended anchoring points were two eyelet screws mounted to the underside of each mat. This meant that attaching and detaching the mats from the anchoring points in order to rotate them between events would be difficult, thus we drilled two holes on each end of the two edge mats and the two middle mats to attach a bridle we constructed with vinyl-coated cable through the holes for anchoring connections. The total amount of time spent on construction of the BioHaven mats was 75 minutes with three people. The PhytoLinks were delivered with no instructions, but the manufacturer had previously reached out and sent instructions via email. The design was intuitive, the connection points were already attached to each mat, and no additional materials were needed. The construction took a total of 30 minutes with four people.

Table 3. The three FTW mat types, example photos, manufacturer and location, mat material, dimensions, accessories, the total number ordered, the price per square foot, and the construction effort involved.

FTW Mat Type	Example Photo	Manufact-urer	Mat Material	Mat Dimensions	# of Mats Used	Accessories	Price ($/sq. ft)	Construct-ion Effort
Beemats® Floating Wetlands		Steven Beeman - New Smyrna, Florida	EVA foam	8’x4’ rectangles	7	Nylon rope for connections and perforated pots	4.75	120 minutes/ person
BioHaven® Floating Islands		Martin Ecosystems division of Floating Islands International - Baton Rouge, Louisiana	Recycled PET plastic with a polyurea coating for UV protection and marine foam injected	7’x4’ rectangles	8	No additional accessories	27.17	225 minutes/ person
PhytoLinks ™ Modular Floating Treatment Wetland System		Terrapin Water - Owen Sound, Ontario	HDPE with a mesh layer, marine foam filled bottles attached to underside	hexagonal shaped with each side of the hexagon being 18¼”	30	Coconut coir and stakes for optional fencing	14.71	120 minutes/ person

Native Texas wetland plant species were selected after a thorough literature review was completed and the data from the review was compiled into a scoring matrix. The scores were based on the following criteria. Primary performance standards included (1) suspended sediment and bacteria removal efficiency and (2) nutrient removal. Secondary performance standards included (3) wetland indicator status, (4) soil requirements, (5) resiliency to wildlife disturbance, and (6) space requirements. Tertiary performance standards included (7) aesthetic value, (8) carbon sequestration, and (9) wildlife use. Only native Texas vegetation were used and any plants with a mature height greater than 1.5 meters were disqualified as they can cause issues with mat stability during heavy winds. The plant species evaluation was completed during the pre-installation sampling period and the following plant species (Table 4) were selected for further assessment: (1) Common rush (*Juncus effusus*), (2) Pickerelweed (*Pontederia cordata*), (3) Swamp smartweed (*Polygonum hydropiperoides*), (4) Blue Water Hyssop/Lemon Bacopa (*Bacopa caroliniana*), (5) Swamp Lily (*Crinum americanum*), and (6) Virginia Iris (*Iris virginica*).

Table 4. Features and benefits of the six native Texas wetland plant species that were selected for MS1.

Plant Species	**Key Physical Features**	**Water Quality Enhancement**	**Empirical Evidence**
Common Rush (*Juncus effuses*)	Large, fibrous root systems	Nutrient removal and success with FTWs	Borne et al. 2015, Chang et al. 2013, and Wang and Sample 2014
Pickerelweed (*Pontederia cordata*)	Large, fibrous root systems and attractive flowers for pollinators	Nutrient removal and success with FTWs	Borne et al. 2015, Chang et al. 2013, and Wang and Sample 2014
Swamp Smartweed (*Polygonum hydropiperoides*)	Fast growth, nutria resistant, and attractive flowers for pollinators	Nutrient and heavy metal removal	Martins et al. 2010 and Núñez et al. 2011
Blue Water Hyssop (*Bacopa caroliniana*)	High resiliency to wildlife disturbance (nutria and waterfowl in particular) and has a lemony scent, which gives it insecticidal properties	Nutrient removal	Liu et al. 2019 and Ariyakot and Pholchan 2019
Swamp Lily (*Crinum americanum*)	Attractive flower for pollinators	Nutrient removal	Carvalho and Martin 2001
Virginia Iris (*Iris virginica*)	High resiliency to wildlife, attractive flower for pollinators	Nutrient removal	Turk et al. 2017 and White and Lott 2017

The selected plant species were harvested from the HCFCD wetland mitigation bank located in Houston, Texas. A group of EIH staff and students as well as HCFCD staff spent one day, on September 29, 2020, carefully uprooting a total of 1,870 individual plants to be used in both MS1 and MS2 (Figure 4). For MS1, 250 individual specimens of *Juncus effuses*, 270 *Pontederia cordata*, 175 *Polygonum hydropiperoides,* 75 *Bacopa caroliniana*, 250 *Iris virginica*, and 180 *Crinum americanum* were collected. They were transported back to the UHCL campus via sleds and buckets (Figure 5).

Figure 4. Kaylei Chau and HCFCD staff holding up uprooted specimens of Pickerelweed during plant collection at the HCFCD wetland mitigation nursery.

Figure 5. Harvested Common Rush ready for transport back to the UHCL campus.

Planting on the FTWs took place the following day, on September 30, 2020, and was accomplished with the help of EIH staff and students, HCFCD staff, and a large volunteer effort from the local community (Figure 6). The BioHaven and PhytoLinks both utilized soil for initial planting. A mixture of Miracle-Gro All Purpose Garden Soil, Timberline Peat Humus, and Miracle-Gro Perlite was used. Some of the soil mixture was used on the Beemats to help provide stability within the pots for plants with smaller root systems at the time of planting. This soil mixture added to all three FTW types might have added extra nutrients to the pond initially, but due to the long establishment period for the FTWs before post-installation sampling began (~7 months), the added nutrient content would have been negligible at the time of water sampling. Plant species percentages between the three FTW mat types (Table 5) were kept as similar as possible, but due to the extreme size difference of the PhytoLinks modules and wanting to keep the diversity high within each mat, these percentages were not as consistent as with the Beemat and BioHaven mats. Planting schematics (Figure 7) were used during the volunteer planting effort so that these composition percentages could be followed. For the Biohaven mats, plants were planted into holes that were cut only partially through these mats, necessitating some time for the plants to grow through the mat to reach the water column. As a result, the plants on these mats required watering post-planting.

Table 5 Native Texas wetland plant species composition on each FTW mat type. This includes the total counts of each species and the percentage of plants that each species comprises on that mat type.

Plant Species	**PhytoLinks Total Count and %**	**BioHaven Total Count and %**	**Beemat Total Count and %**
Common Rush (*Juncus effuses*)	60 (17%)	44 (22%)	128 (22%)
Pickerelweed (*Pontederia cordata*)	90 (25%)	44 (22%)	126 (22%)
Swamp Smartweed (*Polygonum hydropiperoides*)	60 (17%)	24 (12%)	80 (14%)
Blue Water Hyssop (*Bacopa caroliniana*)	30 (8%)	10 (5%)	34 (6%)
Swamp Lily (*Crinum americanum*)	60 (17%)	36 (18%)	80 (14%)
Virginia Iris (*Iris virginica*)	60 (17%)	48 (24%)	132 (24%)

Figure 6. Photo taken during the massive planting effort that took place on September 30, 2020.

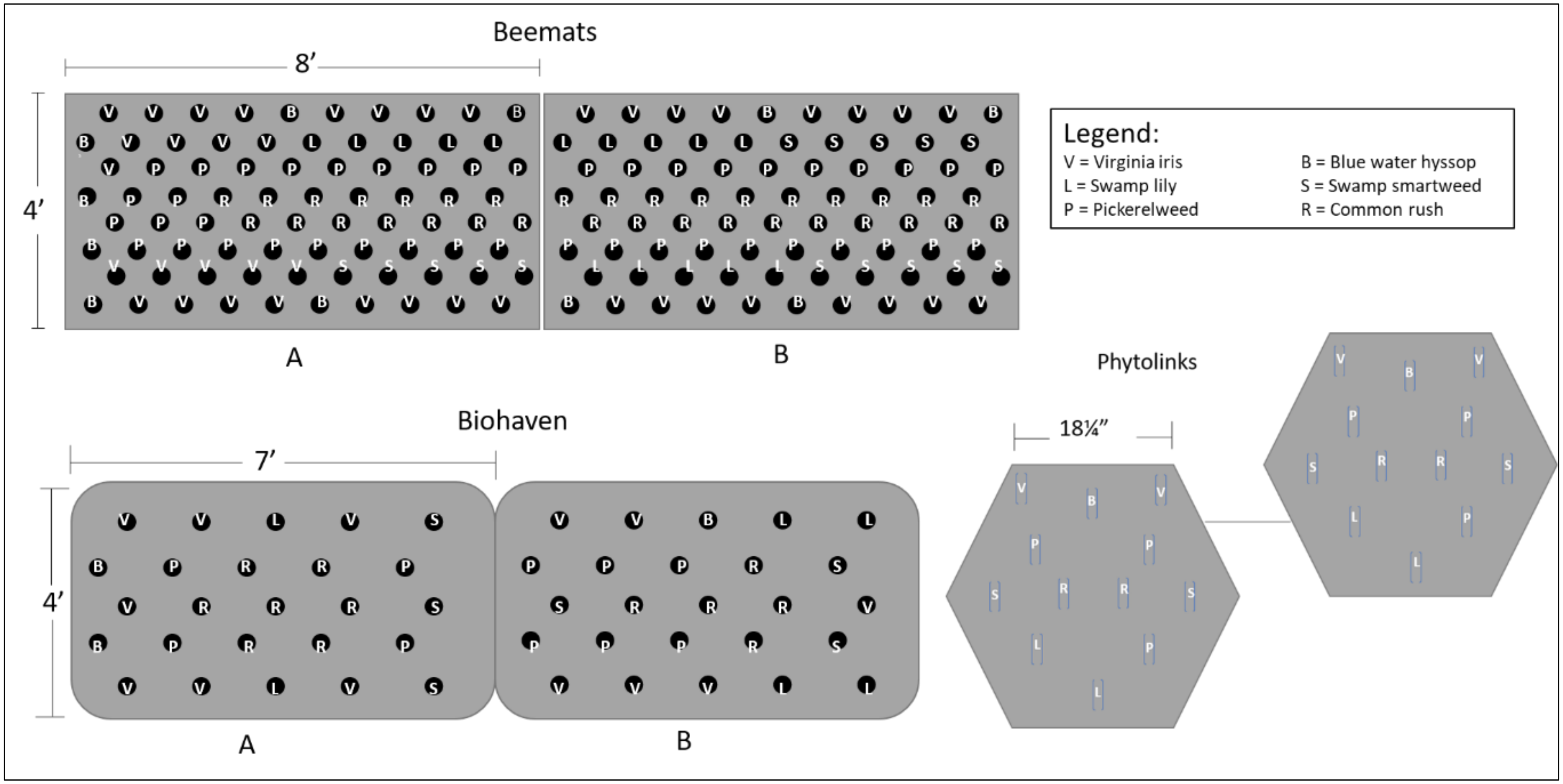

Figure 7. Planting schematic for the Beemats, BioHaven, and PhytoLinks. Mats labelled with an "A" represent an edge mat while mats labelled with a "B" represent an interior mat.

Once the FTWs were fully planted (Figure 8 and Figure 9), bridles made of plastic-coated cables were attached to each end of all three rows. Anchoring systems were made by attaching nylon rope ~3 meters long to two cinder blocks at the bottom and a carabiner and buoy at the top of the rope. Four anchors were used for each row, one on each end and two in the middle of the row. The anchors stayed in place during the post-installation phase of the study and the FTWs were attached to the anchors with carabiners so that they could be unclipped and moved to a different row between events. The initial locations the FTWs were placed in (Figure 10) were Beemats in row 1, PhytoLinks in row 2, and BioHaven in row 3. The resident alligator was attracted to the BioHaven mats as a basking spot, as these mats can support the weight of a full-grown man and apparently a full-grown alligator, thus fencing had to subsequently be added to the perimeter of these mats in order to protect the plants during the establishment period.

Figure 8. The BioHaven mats immediately after planting.


Figure 9. The Beemats and PhytoLinks immediately after planting.


Figure 10. All three of the FTWs set in their initial rows in MS1.

Post-Installation Events in MS1

The three different commercially available FTW mat designs were installed, each as its own row, placed directly perpendicular to the main flow path (Figure 11). These three rows were rotated after each sampling event to evaluate the efficiency individually and when combined. Just as in the pre-installation events, two sampling methods were utilized at both ponds: grab sampling and “first flush” sampling (see Table 1 for a full list of sample target constituents). Continuous monitoring gear was deployed at Sampling Stations A-E (please refer to Table 2 for a full list of field parameters).

SS-A was located at the inflow to measure water quality as the stormwater enters the pond, SS-B was located behind the first row of FTWs, to measure any potential changes in water quality after the water has passed through one row of FTWs, SS-C was located behind the second row to measure any changes in water quality after water has passed through two rows of FTWs, SS-D to measure water quality at the outflow, and SS-E as the Control station, located in the flow path prior to the flow coming into contact with the FTWs. First-flush samples were collected at SS-A (sample ID referred to as “SS-A-FF”) and grab samples were collected at SS A-E.

A total of six wet weather events and three dry weather events were sampled during the post-installation phase. Wet weather and dry weather requirements remained the same as in the pre-installation phase. First-flush and grab samples were analyzed for the same constituents as in the pre-installation phase, (please refer to Table 1 for a full list of constituents). Game cameras were also deployed on PVC poles in the water adjacent to the three rows of FTWs to monitor wildlife use. The main objective at this MS was to evaluate the different commercially available designs on their constructability/durability, pollutant removal abilities and biological benefits.

Figure 11. Monitoring Station 1 (Potter Pond) with approximate locations of SS-A through SS-E.

Monthly surveys of plant communities including species identification, density, and average height were conducted. Other plant species that were not originally planted that may have colonized the mats were identified down to species, if possible, and were not removed throughout the study period so that we could determine the trajectory of plant community development and how much maintenance would be needed for future installations of FTWs. This was done to help characterize the health and longevity of the vegetation community among the three FTW designs. Plant species that were found to have colonized the FTWs were grouped as “volunteer species.” Limited surveys of other wildlife were conducted as well using game cameras and occasional point-count surveys. Example datasheets for vegetation monitoring can be found in Appendix A.

Monitoring Station 2

Alligator Pond is a 0.62-acre detention pond that was altered to improve water quality before water is released into Horsepen Bayou. The site was designed to increase the detention time of stormwater. An additional 0.56 acres of wetland was created and 0.25 acres of the original borrow pond (Alligator Pond) and drainage ditches were modified. The design incorporated a flow pattern where stormwater enters the wetland treatment system at point (A) (Figure 12). It travels through the primary wetland and under Bayou Blvd. There it mixes with water from Horsepen Bayou, which is pumped into the system using solar energy (B). The water flows through the secondary wetland and eventually discharges over a weir (C) into Alligator Pond (D). The treated water flows from Alligator Pond into Horsepen Bayou through a submerged outfall pipe (E). There is also some inflow of untreated water from the nearby roadside ditch. Stormwater runoff from precipitation is the primary source of water to the created wetland complex, which can be augmented manually by the lawn irrigation system at the UHCL campus. At MS2 we tested the nutrient removal efficiency of certain species of wetland plants for which little to no peer-reviewed studies existed. Four mats were installed and rotated periodically, each with a different plant community: (1) a monoculture of Swamp smartweed, (2) a monoculture of Swamp lily, (3) a monoculture of Virginia iris, and (4) a control mat with no vegetation (Figure 13). Grab sampling was the only method used for water collection at MS2 and was done at SS-F (inflow) and SS-G (outflow). Target sample constituents are listed in Table 1. Continuous monitoring sondes were also deployed at these sampling stations (see Table 2 for a full list of field variables).

The DIY floating mats were constructed using my own designs and materials informed by past literature and existing products (Figure 14). This was done to evaluate the constructability, durability, cost-effectiveness, and overall function of constructing these FTWs on your own compared to purchasing commercially available designs. The mats were originally made for recreational use on lakes and ponds. They are buoyant enough to hold the weight of a grown adult, laying horizontally, but do slightly submerge with this added weight. Hydroponic pots that were 3 inches in diameter at the lip were purchased and holes 2.75 inches were drilled into the mats to be planted.

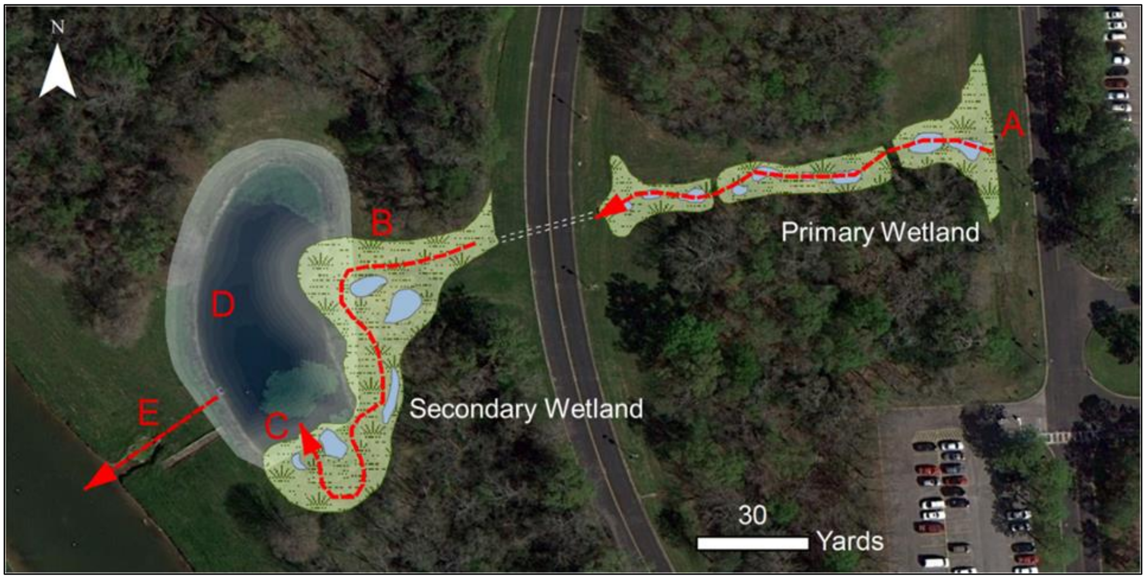

Figure 12. Alligator Pond and the surrounding constructed wetlands. Stormwater enters the system at point A and flows through the primary wetland and under the road where it then mixes with water from Horsepen Bayou using a solar-powered pump (B). The water flows through the secondary wetland and eventually discharges over a weir (C) into Alligator Pond (D) The treated water flows from the pond into Horsepen Bayou through a submerged outfall pipe (E).

Figure 13. Monitoring Station 2 (Alligator Pond) with corresponding Sampling Stations F and G. The green circles numbered 1-4 represent the four mat types. The mat being tested for treatment potential would be placed directly in between the inflow and outflow while the mats that were not being tested during an event would be out of the main flow path in a holding area.


Figure 14. Kaylei Chau deploying the DIY FTWs into the holding area after planting. One mat contains a monoculture of Swamp Lily, one with Virginia Iris, and one with Swamp Smartweed. Not pictured is the control mat located at SS-F.

Environmental sampling was conducted with and without the FTWs installed with a minimum of two wet weather events and one dry weather event during the pre-installation period and six non-routine events and three routine events after the FTWs were installed. In MS2, the FTWs were rotated immediately following a sampling event. The mat was placed directly in the flow path between SS-F and SS-G, while the other 3 mats that were not being tested at the time were anchored in the portion of the pond that received little to no flow during events and was referred to as “the holding area” (Figure 13). Each mat was maintained regularly to ensure that any plant species other than the intended species (i.e. Virginia iris, Swamp lily, or Swamp smartweed) were removed from the mats. Vegetation growth and cover was not tracked for MS2 FTWs. Example datasheets for MS2 sampling events can be found in Appendix A.

Structural damage occurred to the inflow area of MS2 during a heavy rain event prior to the pre-installation sampling period. Repairs were not finished until December of 2020. Sampling in MS2 without the FTWs installed thus had to occur after the post-installation sampling period ended. Sample events in MS2 without the FTWs installed are still referred to as “pre-installation events” for consistency with MS1 event results. Due to a freeze event in February of 2021, the establishment period for the plants had to be extended. The DIY mat with a monoculture of Swamp smartweed (*Polygonum hydropiperoides*) did not recover after the freeze. This mat was left out of the remainder of the study due to this.

Data Analysis

The event mean concentration (EMC) efficiency method was used to determine the average reduction in pollutant concentration by dividing the total mass of pollutant by the total volume of stormwater (Gulliver, 2010). In order to standardize the data among events, pollutant removal efficiency was calculated as follows:

$$Removal\ Efficiency = \frac{(Influent\ concentration - Effluent\ Concentration)}{Influent\ Concentration}$$

The removal efficiency was then be multiplied by 100 to obtain the percent removal efficiency.

Data were statistically analyzed to test for significant differences in target constituents among sampling locations, wet/dry periods, and sampling periods/dates. Concentrations of TKN, NO_2+NO_3 -N, and Ammonia-N were minimal and consequently added together to represent Total Nitrogen (TN). The hypothesis was that the water quality would improve (i.e. concentrations of indicator bacteria, TSS, and nutrients would be reduced) at the outfall versus inflows when compared to pre-wetland conditions.

RESULTS

A total of 8 wet weather events and 4 dry weather events were sampled in both MS1 and MS2. These sampling events took place over the course of two years, with the first event taking place on July 17, 2020 and the last event taking place on December 6, 2021 (Table 6).

Table 6. Dates of sampling events in both MS1 and MS2.

Pre/Post-Installation	Event Type and Number	MS1	MS2
Pre-installation (without FTWs)	Wet Weather Event 1	07/17/2020	11/11/2021
	Wet Weather Event 2	09/04/2020	12/06/2021
	Dry Weather Event 1	08/13/2020	11/16/2021
Post-Installation (with FTWs)	Wet Weather Event 3	06/03/2021	06/03/2021
	Wet Weather Event 4	07/14/2021	07/14/2021
	Wet Weather Event 5	08/03/2021	08/03/2021
	Wet Weather Event 6	09/01/2021	09/01/2021
	Wet Weather Event 7	09/28/2021	09/28/2021
	Wet Weather Event 8	10/11/2021	10/11/2021
	Dry Weather Event 2	07/27/2021	07/27/2021
	Dry Weather Event 3	08/13/2021	08/13/2021
	Dry Weather Event 4	10/20/2021	10/20/2021

Monitoring Station 1

A range of rainfall conditions were sampled throughout the study with precipitation totals between 0.12 and 1.64 inches of rain with an average of 0.53 inches (Table 7). During dry weather conditions, the discharge into Potter Pond was <0.01 cfs and during wet weather events, the discharge ranged from 0.5 to 4.1 cfs. Water level and discharge were measured at the time of sampling, which was dependent on when within the wet weather event the sampling window occurred (Figure 15). The sampling window for events 1, 3, and 4 occurred on the falling limb of the hydrograph following the precipitation events. Events 2, 5, 6, 7, and 8 occurred on the rising limb and peak of the hydrograph following the precipitation event. These differences in sampling windows were influenced by the time of day of the rain event and safety considerations (sufficient light, presence of lightning, and unsafe flow conditions). Raw data, such as field observations and notes, can be found in Appendix B.

Table 7. Rainfall amounts, days since last significant rain (DSLSR), rate of discharge, water level at the inflow, sampling window and FTW orientations for all wet weather events in MS1. BM=Beemats, BH=BioHaven, and PL=PhytoLinks.

MS1	Event	Rainfall (in.)	Start of Rainfall	DSLSR	Rate of Discharge (cfs)	Time of Flow Reading	Water Level (ft.) at SS-A at Time of Flow Reading	Sampling Window	Row 1	Row 2	Row 3
Pre-Install	1	1.00	08:45	21	1.1690	13:10	2.44	12:20-13:45	N/A	N/A	N/A
	2	0.12	05:00	4	0.7180	10:00	2.25	09:10-10:40	N/A	N/A	N/A
Post-Install	3	1.64	11:15	5	3.8480	14:00	2.53	13:45-15:25	BH	BM	PL
	4	0.68	09:00	4	1.0710	13:30	2.38	13:30-15:30	PL	BH	BM
	5	0.16	08:30	11	4.0710	11:40	2.26	11:30-13:00	BM	PL	BH
	6	0.32	11:15	2	1.2930	13:45	2.28	13:20-14:30	BM	PL	BH
	7	0.20	06:00	9	1.1660	09:50	2.29	08:55-10:15	PL	BM	BH
	8	0.12	05:00	8	0.5134	08:27	2.23	08:25-09:55	BH	PL	BM

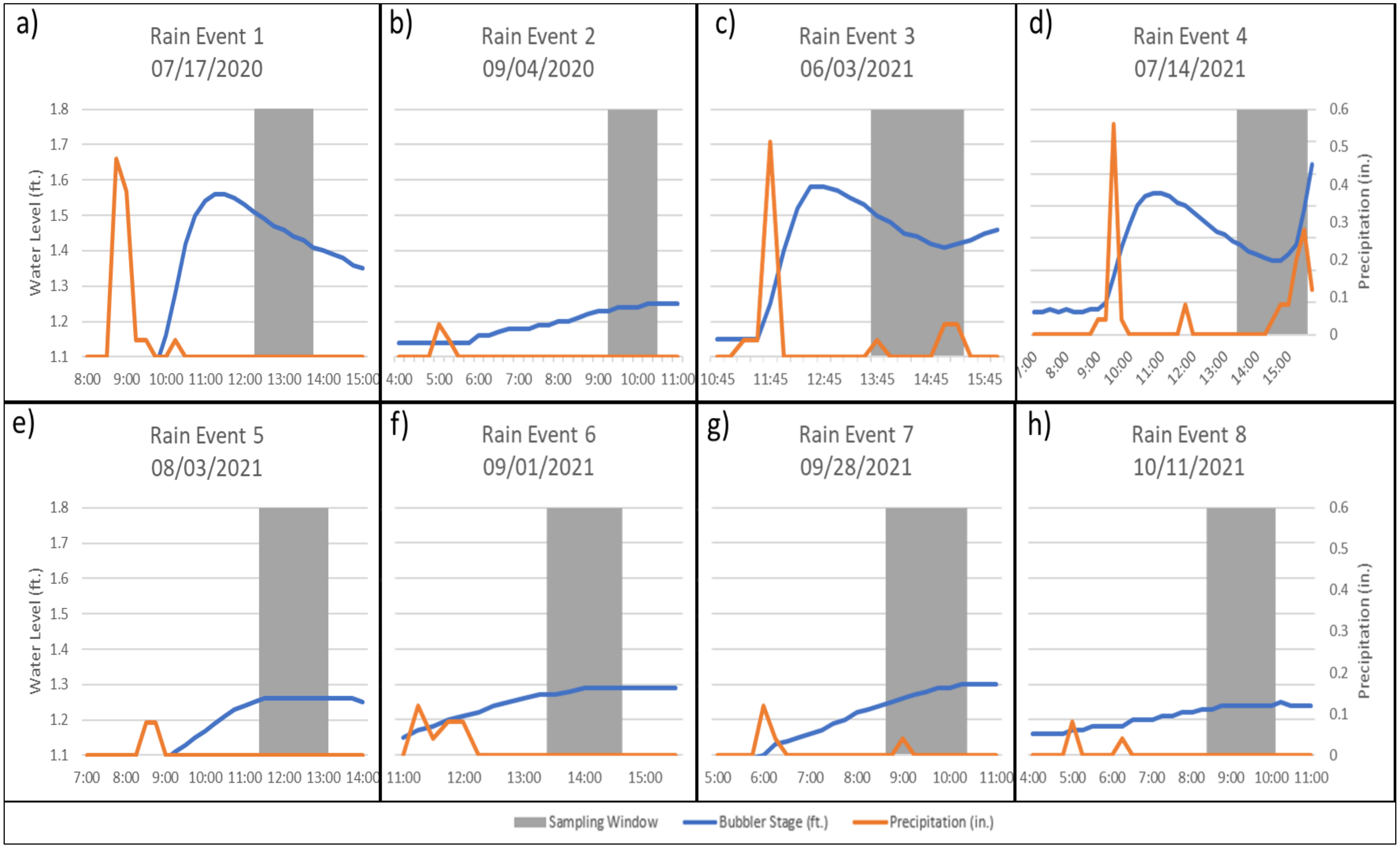

Figure 15. MS1 rain event hydrographs and sampling windows (gray bar). The left axis is water level (ft.) and the right axis is precipitation (in.). Water level increase shown by bubbler stage (ft.) in blue and precipitation (in.) shown in orange.

Water Quality Enhancement

Results from sampling events varied depending on rainfall amounts and days since the last significant rainfall before an event. Results from the BOD_5 and oil and grease samples were found to be at extremely low and similar amounts and so will be left out of further detailed discussion within this section. Raw values for all samples collected during all sampling events as well as all paired sonde readings are provided in Appendix B. Concentrations of BOD_5 ranged from 3 to 26 mg/L with an average removal efficiency of 18.55%. Concentrations of oil and grease samples ranged from 1.4 to 6.3 mg/L with an average removal efficiency of -0.33%. Overall changes in concentrations of other target constituents within the entire system (from inflow "SS-A" to outfall "SS-D") and removal efficiencies for all 8 sampling events exhibited a general reduction (Table 8).

Concentrations of all target constituents steeply declined downstream of the initial inflow (SS-A) station, with the exception of Total Phosphorus (TP) levels during rain event 3. The levels of *E. coli* were reduced at the control (SS-E) station, which sampled the water parcel before it reached the FTWs. This pattern in *E. coli* levels was observed for all post-install rain events except event 4. The levels of TSS were reduced downstream of the control station for all post-install rain events except event 8. Reductions of TSS were not consistent between dry weather events. During dry event 2 with the FTWs installed we documented an overall reduction in TSS downstream, but during dry events 3 and 4 we observed an increase between inflow and outflow stations (Table 8).

The changes in concentrations for TN and TP between stations were not as consistent between events as *E. coli* and TSS. We observed reductions in TN for all events when comparing inflow (SS-A) to outfall (SS-D) concentrations, but during some events, levels fluctuated as the flow passed through the rows of FTWs, like in rain events

3, 4 and 6, where there was a reduction in TN after the control station and Row 1, but then an increase in concentration after Row 2. During rain event 8, there was an increase after Row 1, but then TN decreased after passing through rows 2 and 3. During all of these events just mentioned, the FTW mats associated with the rows were not the same. During all rain events, TP did not decline between SS-A to SS-D. During rain event 3, which was the first post-install sampling event, a steady increase in TP was observed between SS-A to SS-D as samples were collected throughout the system. There were some events where overall reductions occurred, but were accompanied by fluctuations in concentration gradients, sometime increasing or decreasing from station to station. An example of this pattern is illustrated by rain event 5, where reductions of TP were seen after the control and then were further reduced after Row 1, then increased after Row 2 of the FTWs.

Table 8. Water sample analysis results for all sampling events in MS1. Listed here are the changes in concentrations (conc.) from inflow (SS-A) to outflow (SS-D) and the removal efficiencies for E. coli, TSS, Total Nitrogen, and Total Phosphorus.

MS1		***E. coli* (MPN)**		**TSS (mg/L)**		**Total Nitrogen (mg/L)**		**Total Phosphorus (mg/L)**	
		Δ in Conc.	**Removal Efficiency (%)**	**Δ in Conc.**	**Removal Efficiency (%)**	**Δ in Conc.**	**Removal Efficiency (%)**	**Δ in Conc.**	**Removal Efficiency (%)**
Pre-Install	**Rain Event 1**	2,315.0	95.68%	8.8	26.50%	0.4049	81.63%	0.169	41.83%
	Rain Event 2	1,067.9	95.36%	2.6	14.78%	0.6140	79.95%	0.375	56.22%
	Dry Event 1	9.4	56.97%	13.9	52.85%	0.3536	79.64%	0.260	16.67%
Post-Install	**Rain Event 3**	24,176.0	99.92%	112.1	85.57%	0.4005	84.10%	-0.139	-87.42%
	Rain Event 4	9,248.0	94.33%	19.8	46.48%	0.1354	64.02%	0.008	4.37%
	Rain Event 5	2,383.2	98.50%	30.9	63.98%	0.4959	88.76%	0.165	39.66%
	Rain Event 6	9,289.0	99.89%	34.7	67.91%	0.6189	75.90%	0.096	34.16%
	Rain Event 7	3,428.0	99.42%	14.4	53.93%	0.2860	64.05%	0.091	41.00%
	Rain Event 8	1,419.0	98.61%	10.8	51.92%	1.5361	90.65%	0.343	65.46%
	Dry Event 2	15.7	67.97%	9.0	46.62%	0.0927	59.61%	0.001	0.57%
	Dry Event 3	45.0	60.00%	-14.7	-88.50%	0.1605	48.78%	0.093	31.63%
	Dry Event 4	86.0	89.58%	-15.9	-56.99%	4.5548	95.68%	0.734	84.86%

E. coli

The change in concentration of *E. coli* between inflow (SS-A) and the outfall (SS-D) in the pre-installation dry weather event was 9.4 MPN, while the average change in concentration for the post-installation dry weather events was 48.9 MPN (Table 8). For the wet weather events, the average change in concentration pre-installation was 1,691 MPN, while the post-installation change in concentration was 8,324 MPN (Table 8). *E. coli* were reduced after the control (SS-E) location, which was sampled before the flow reached the FTWs, for all post-installation wet weather events except for event 4 (Figure 16).

The average removal efficiency for *E. coli* between inflow (SS-A) and outflow (SS-D) for the pre-installation dry weather event was 56.97 % and the average removal efficiency for post-installation dry weather events was 72.52% (Table 8). The average removal efficiency for E. coli between SS-A and SS-D in MS1 for pre-installation wet weather events was 95.52 % and the average removal efficiency for post-installation wet weather events was 98.44% (Table 8, Figure 17) which represented a statistically significant increase in removal efficiency (T statistic = -3.34, p = 0.0204, t-test).

Wet weather event 4, which consisted of 0.68 inches of rain for the event (just above the average size of rain event monitored – Table 7), was sampled at the low end of the falling limb of the hydrograph (Figure 15) and had the lowest removal efficiencies for *E. coli* during post-installation wet weather events. The removal efficiency for that event was observed to be 94.3% which was lower than the average removal efficiencies for the pre-installation events (Figure 17).

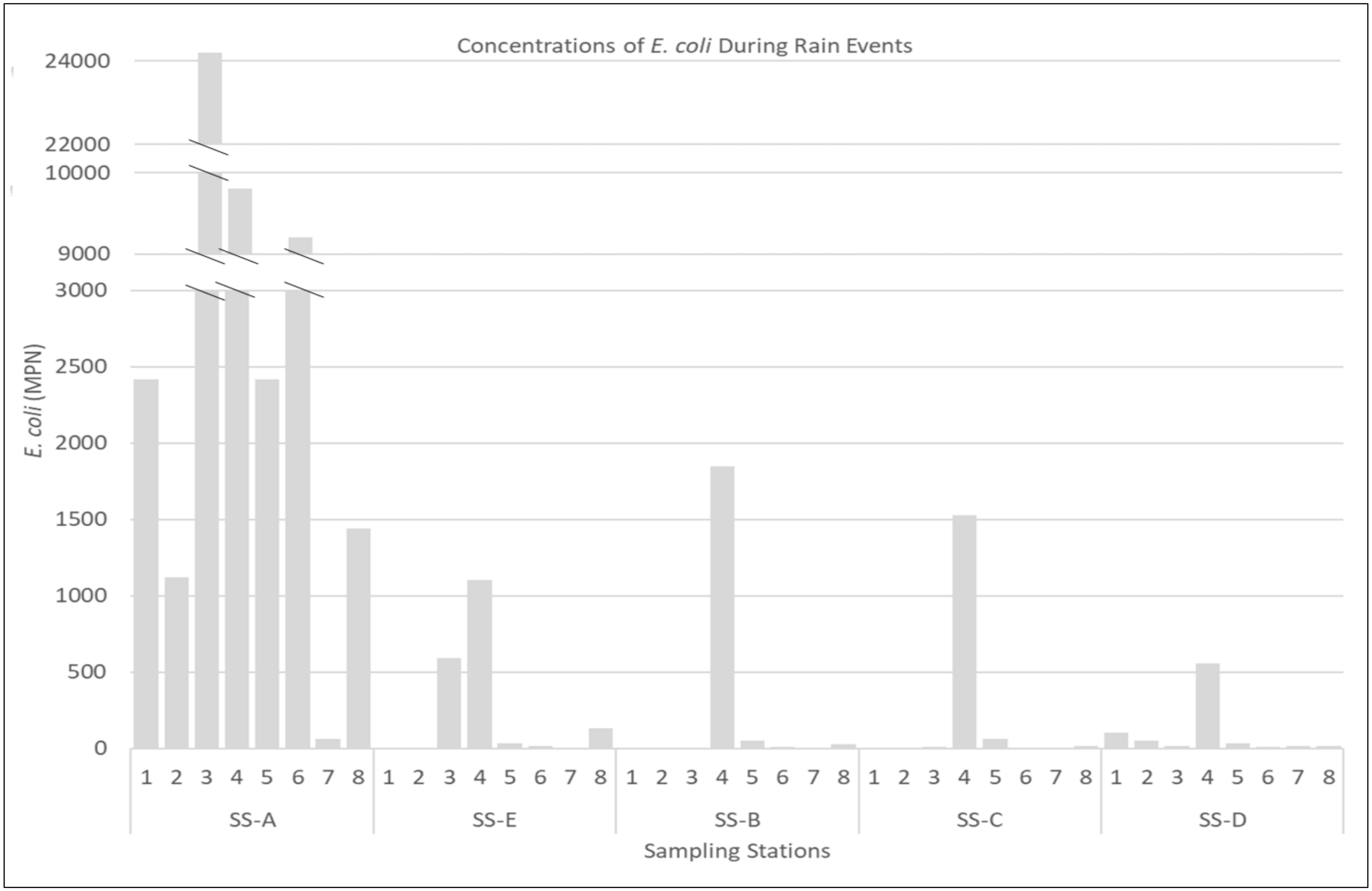

Figure 16. Concentrations of E. coli throughout the system during rain events in MS1. Events 1 and 2 were sampled without the FTWs installed and samples were only collected at SS-A and SS-D. Events 3-8 were sampled with the FTWs installed and samples were collected at every sampling station (A-E).

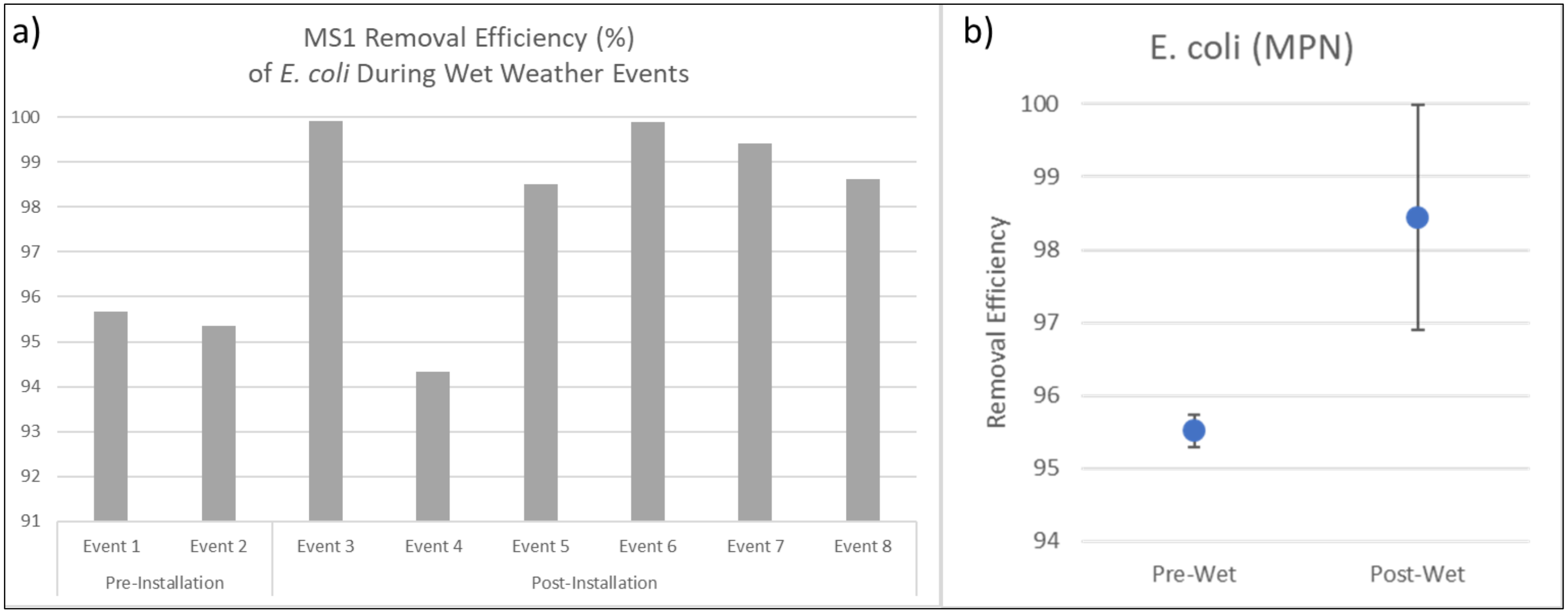

Figure 17. Removal efficiencies for E. coli in MS1. a) is the removal efficiency of E. coli for each wet weather event and b) illustrates the average removal efficiency (blue dots) with standard error (bars) of E. coli for pre-installation wet weather events and post-installation wet weather events for better comparison.

Total Suspended Solids

The change in concentration of TSS between inflow (SS-A) and the outfall (SS-D) in the pre-installation dry weather event was 13.9 mg/L, while the average change in concentration for the post-installation dry weather events was -7.2 mg/L (Table 8). For the wet weather events, the average change in concentration pre-installation was 5.7 mg/L, while the post-installation change in concentration was 37.12 mg/L (Table 8). TSS levels were reduced after the control (SS-E) station, which was sampled before the flow reached the FTWs, for post-installation wet weather events 3, 4, and 5 (Figure 18).

The removal efficiency for TSS between inflow (SS-A) and outflow (SS-D) for the pre-installation dry weather event was 52.85% and the average removal efficiency for post-installation dry weather events was -32.96% (Table 8). The average removal efficiency for TSS between SS-A and SS-D in MS1 for pre-installation wet weather events was 20.64% and the average removal efficiency for post-installation wet weather events was 61.63% (Table 8, Figure 19) which was a statistically significant increase in removal efficiency (T statistic = -4.98, p=0.0155, t-test).

Wet weather event 4, which saw 0.68 inches of rain (just above the average size of rain event monitored – Table 7), was sampled at the low end of the falling limb of the hydrograph (Figure 15), and had the lowest removal efficiencies for TSS during post-installation wet weather events at 46.48% which was still higher than the average removal efficiencies for the pre-installation events (Figure 19).

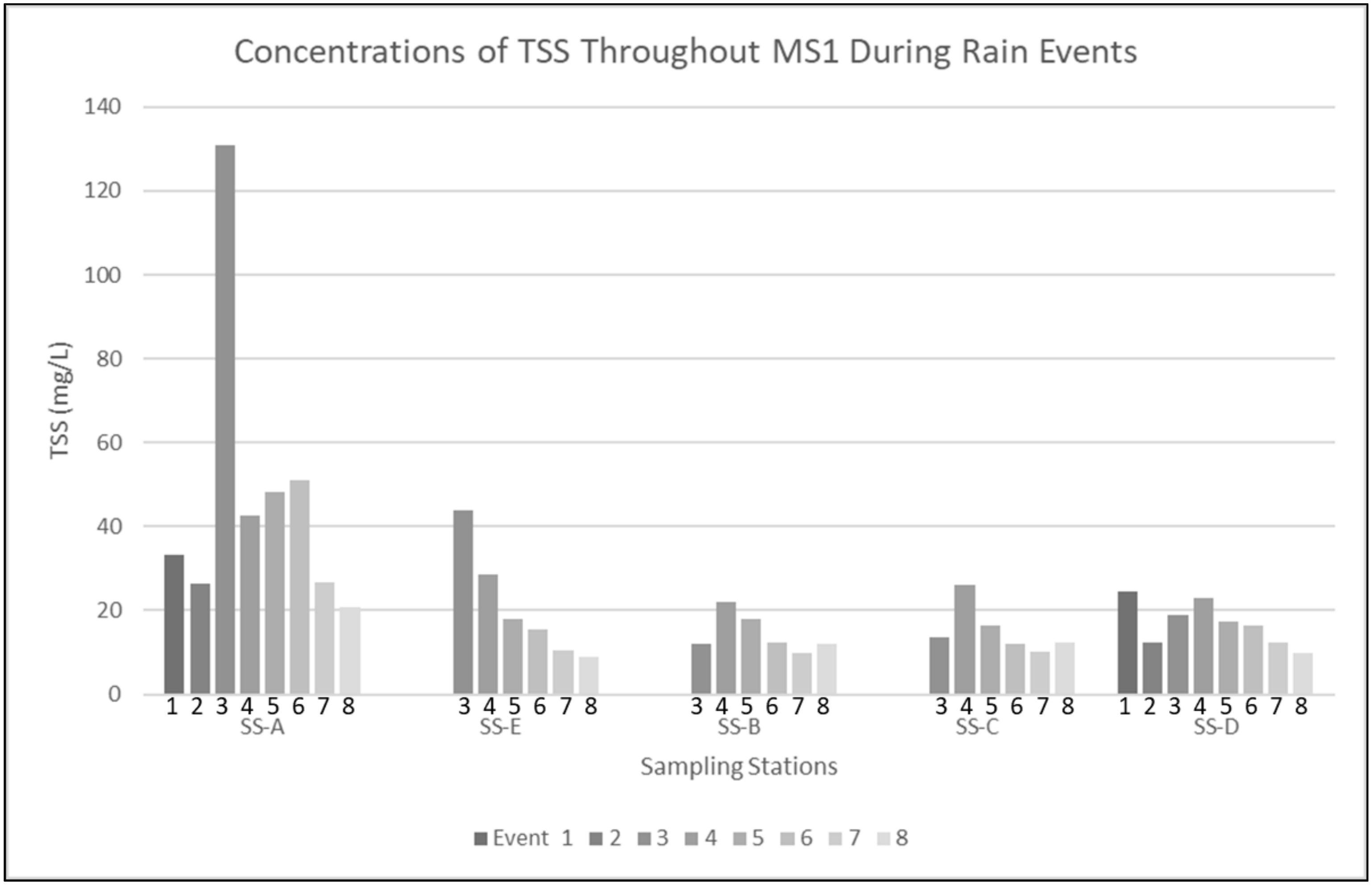

Figure 18. Concentrations of TSS throughout the system during the rain events in MS1. Events 1 and 2 were sampled without the FTWs installed and samples were only collected at SS-A and SS-D. Events 3-8 were sampled with the FTWs installed and samples were collected at every sampling station (A-E).

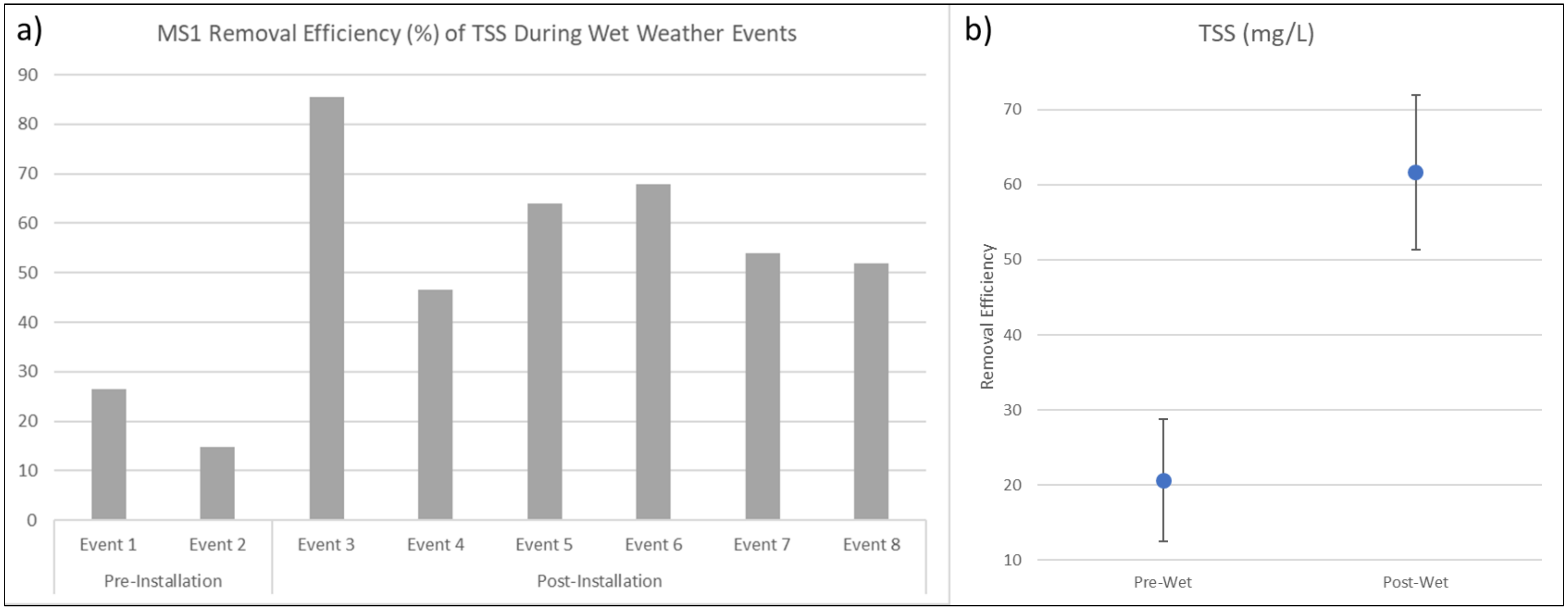

Figure 19. Removal efficiencies for TSS in MS1. a) is the removal efficiency of TSS for each wet weather event and b) illustrates the average removal efficiency (blue dots) with standard error (bars) of TSS for pre-installation wet weather events and post-installation wet weather events for better comparison.

Total Nitrogen

The change in concentration of TN between inflow (SS-A) and the outfall (SS-D) in the pre-installation dry weather event was 0.3536 mg/L, while the average change in concentration for the post-installation dry weather events was 2.3577 mg/L (Table 8). For the wet weather events, the average change in concentration pre-installation was 0.5095 mg/L, while the post-installation change in concentration was 0.5788 mg/L (Table 8). TN was reduced after the control (SS-E) location, which was sampled before the flow reached the FTWs, for all post-installation wet weather events except 3 and 8 (Figure 20). During event 3, TN decreased after SS-B, the first row of FTWs, but then rose to more than double what was measured at SS-E, before decreasing to an amount lower than what was measured at the inflow and control once the flow reached the outfall (Figure 20).

The removal efficiency for TN between inflow (SS-A) and outflow (SS-D) for the pre-installation dry weather event was 79.64% and the average removal efficiency for post-installation dry weather events was 68.02% (Table 8). The average removal efficiency for TN between SS-A and SS-D at MS1 for pre-installation wet weather events was 80.79% and the average removal efficiency for post-installation wet weather events was 77.91% (Table 8, Figure 21), which was not a statistically significant decrease in removal efficiency (T statistic = 0.4964, p = 0.3203, t-test).

Wet weather events 4, 6, and 7 had the lowest removal efficiencies (64.02%, 78.53%, and 64.05% respectively) for TN during post-installation even when compared to the removal efficiencies of the two pre-installation wet weather events (81.63% and 79.95%) (Figure 21). Wet weather event 4, had the lowest amount of TN observed at SS-A (0.2115 mg/L) during all wet weather events that were sampled at MS1. Wet weather events 5 and 8 saw the highest removal of TN (88.76% and 90.65%, respectively) out of all wet weather events.

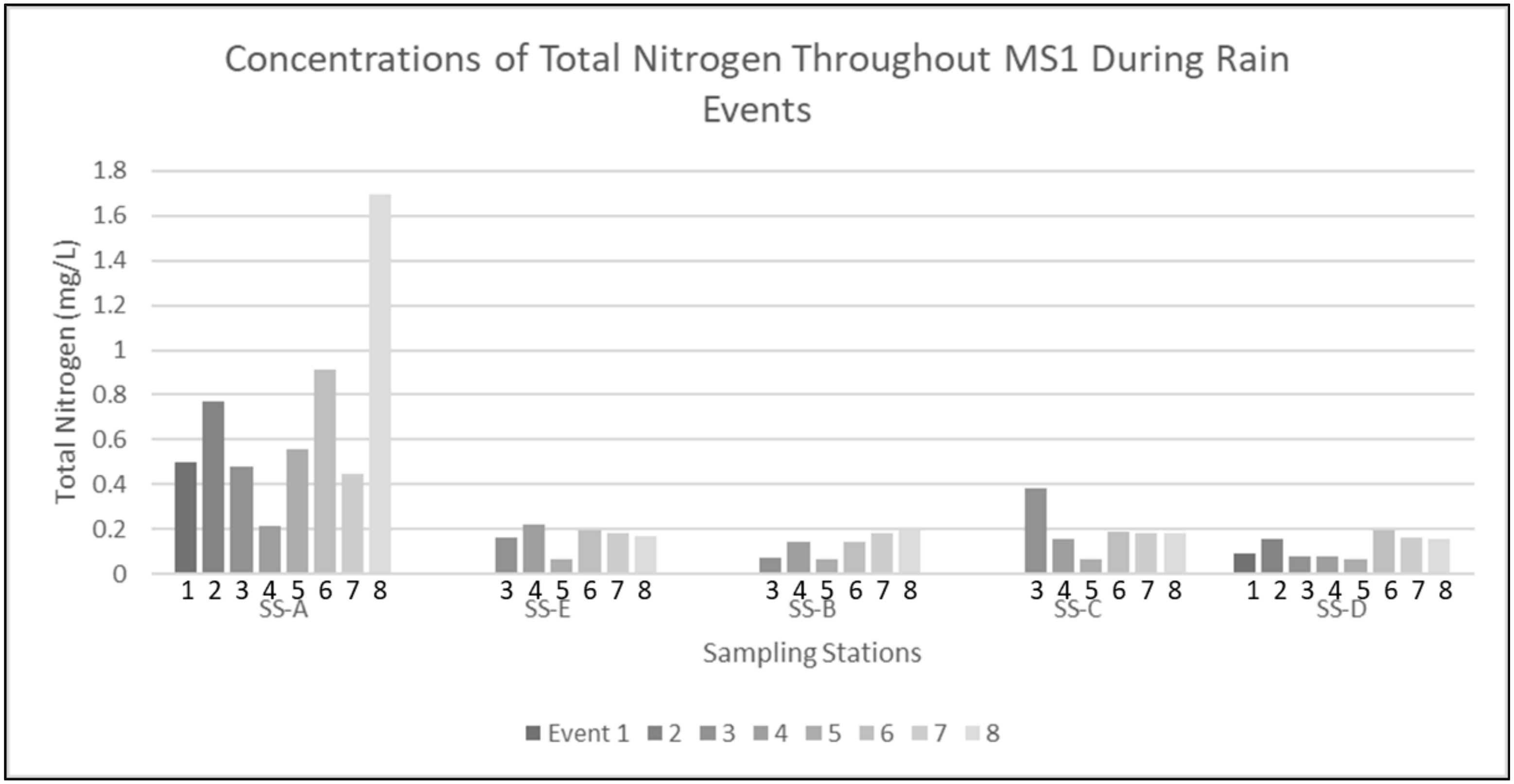

Figure 20. Concentrations of Total Nitrogen throughout the system during the rain events in MS1. Events 1 and 2 were sampled without the FTWs installed and samples were only collected at SS-A and SS-D. Events 3-8 were sampled with the FTWs installed and samples were collected at every sampling station (A-E).

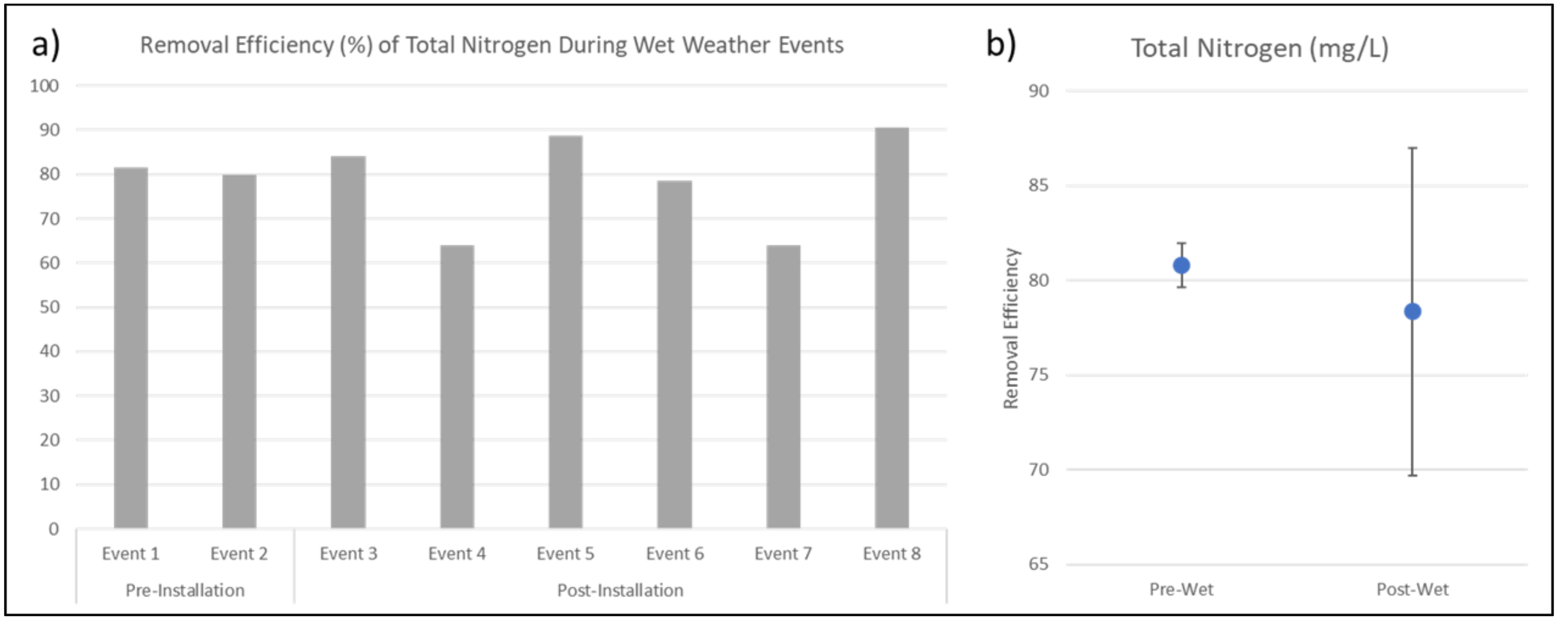

Figure 21. Removal efficiencies for Total Nitrogen in MS1. a) shows the removal efficiency of TN for each wet weather event and b) illustrates the average removal efficiency (blue dots) with standard error (bars) of TN for pre-installation wet weather events and post-installation wet weather events for better comparison.

Total Phosphorus

The change in concentration of TP between inflow (SS-A) and the outfall (SS-D) in the pre-installation dry weather event was 0.26 mg/L, while the average change in concentration for the post-installation dry weather events was 0.276 mg/L (Table 8). For the wet weather events, the average change in concentration pre-installation was 0.272 mg/L, while the post-installation change in concentration was 0.094 mg/L (Table 8). TP was only continuously reduced after the control (SS-E) location, which was sampled before the flow reached the FTWs, for post-installation wet weather event 6 (Figure 22).

The removal efficiency for TP between inflow (SS-A) and outflow (SS-D) for the pre-installation dry weather event was 16.67% and the average removal efficiency for post-installation dry weather events was 39.02% (Table 8). The average removal efficiency for TP between SS-A and SS-D in MS1 for pre-installation wet weather events was 49.03% and the average removal efficiency for post-installation wet weather events was 16.21% (Table 7, Figure 23), which was a statistically significant decrease in removal efficiency (T statistic = 1.4069, p = 0.1045, t-test).

Wet weather events 3 and 4, had the lowest removal efficiencies for TP during all wet weather events at -87% and 4.37%, respectively (Figure 23). Wet weather event 8, which was sampled during the post-installation phase, had the highest removal efficiency for TP out of all wet weather events at 65.46% removal (Figure 23).

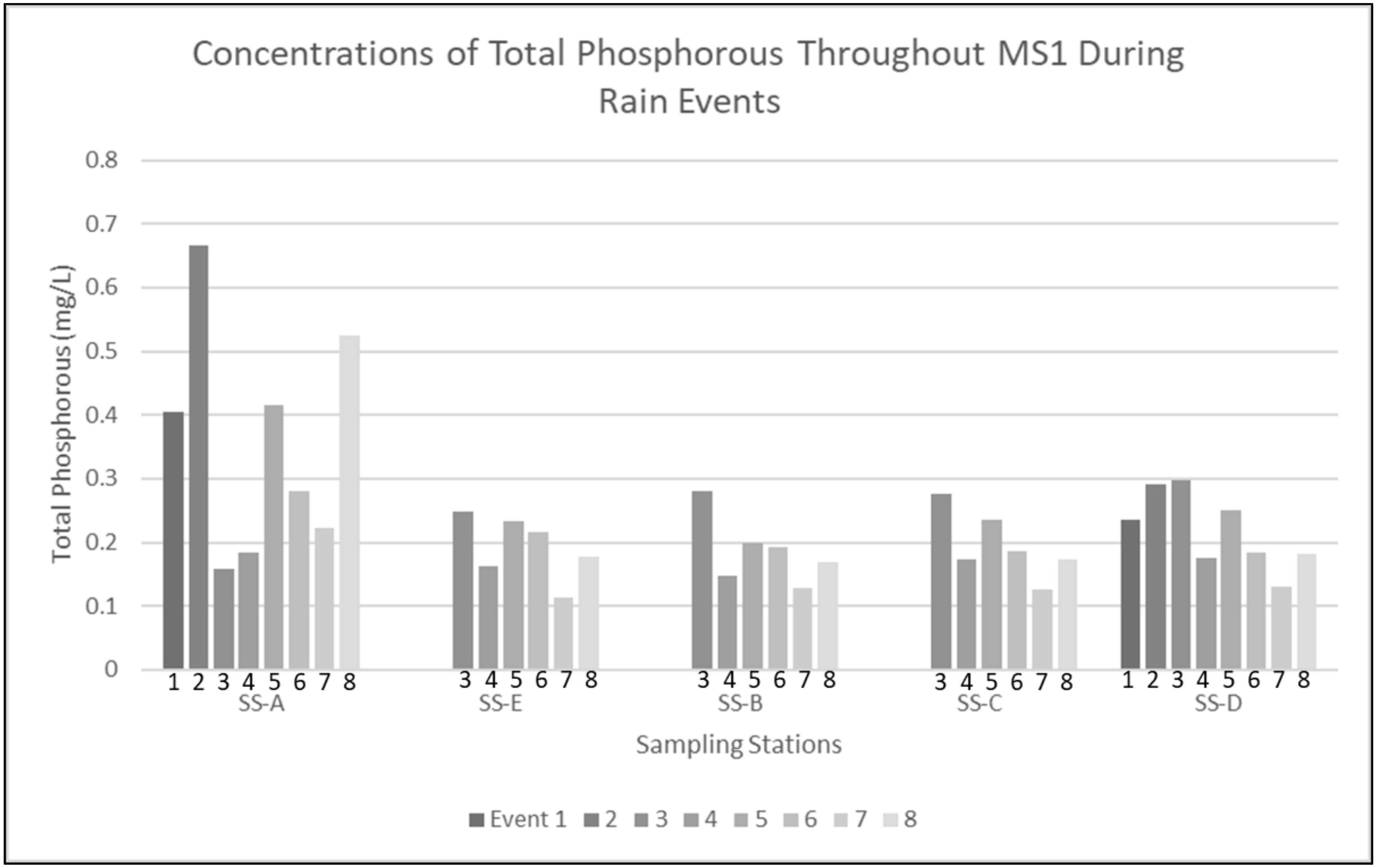

Figure 22. Concentrations of Total Phosphorus throughout the system during the rain events in MS1. Events 1 and 2 were sampled without the FTWs installed and samples were only collected at SS-A and SS-D. Events 3-8 were sampled with the FTWs installed and samples were collected at every sampling station (A-E).

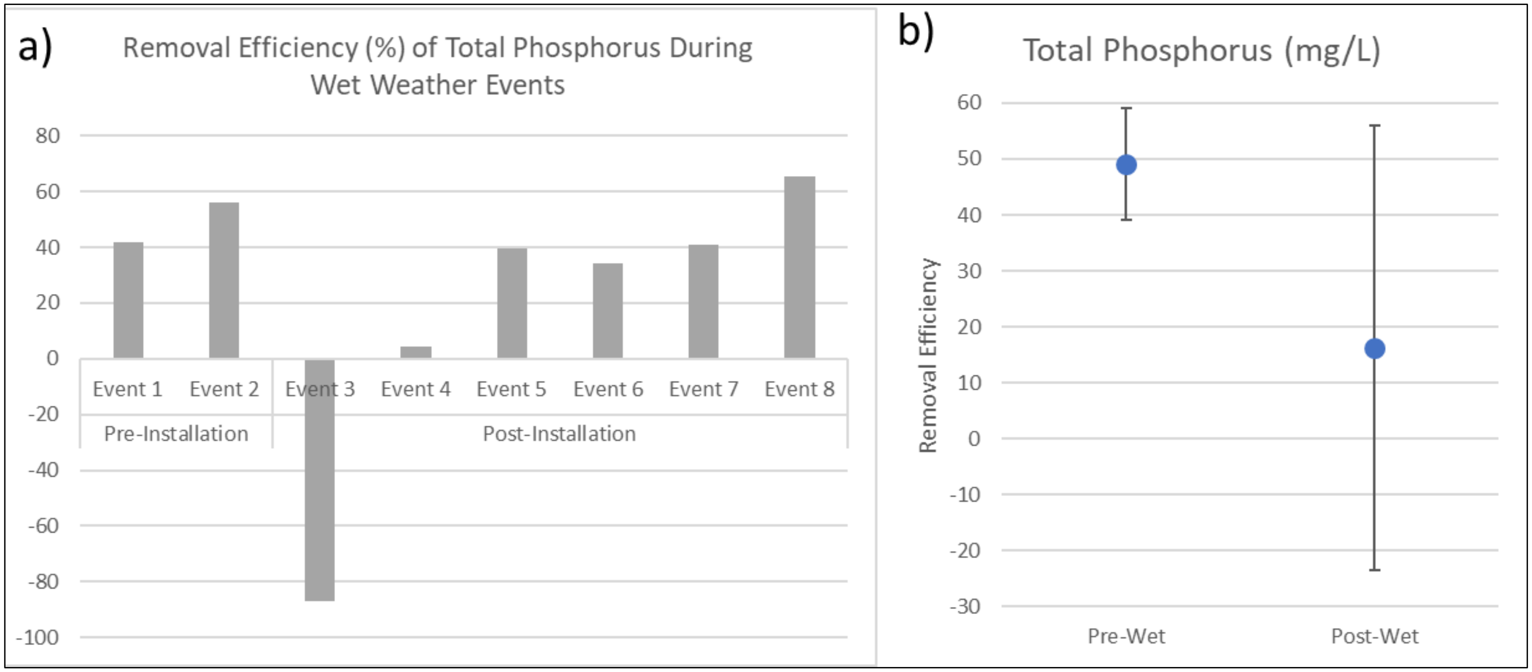

Figure 23. Removal efficiencies for Total Phosphorus in MS1. 23a) is the removal efficiency of TP for each wet weather event and 23b) illustrates the average removal efficiency (blue dots) with standard error (bars) of TP for pre-installation wet weather events and post-installation wet weather events for better comparison.

Enhancement by Mat Type

There was not a significant difference in the average removal efficiencies among the three FTW mat types in MS1. Figure 24 illustrates the treatment efficiency by mat type for *E. coli* (a), TSS (b), Total Nitrogen (c), and Total Phosphorus (d). Beemats performed generally, on average, the best at removing *E. coli*, TSS, and Total Phosphorus, but performed the worst at removing Total Nitrogen. PhytoLinks generally performed, on average, the best at removing Total Nitrogen, and came in second for removing *E. coli*, TSS, and Total Phosphorus. BioHaven, on average, performed generally the worst, but also had the largest outliers of results.

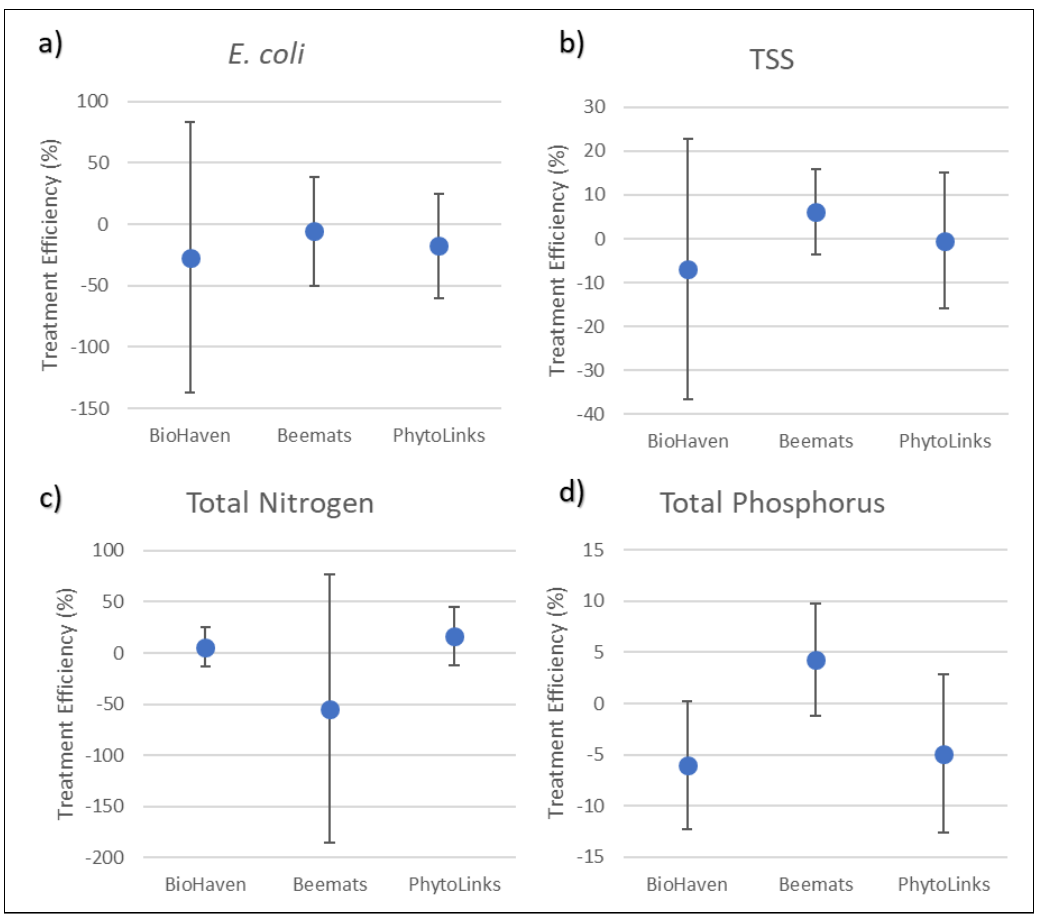

Figure 24. Average removal (treatment) efficiencies by FTW mat type with standard error bars for a) E. coli, b) TSS, c) Total Nitrogen, and d) Total Phosphorus.

Vegetation Monitoring

Monthly surveys of vegetation height and percent coverage of the mat were conducted to track changes in composition on each FTW mat type in MS1. Growth of each of the six planted wetland vegetation species were combined for all of the FTW mat types and by sampling date (Figure 25). Common rush maintained, on average, the highest vertical growth of the six planted species. Lemon bacopa did not see much growth in terms of height, but this was expected as this is a ground cover species. Pickerelweed saw a decrease in vertical growth during the winter months but recovered and continued to grow in height during each of the spring and summer months. Swamp lily showed the same vertical growth pattern as Pickerelweed, as did Virginia Iris. Swamp smartweed exhibited the most fluctuation in height, where it seemed to almost die back completely during the spring to early summer months, then had a huge growth spurt at the end of July 2021. After one-year, post-planting all species had sustained growth in terms of average height compared to when they were initially planted. The February 2021 survey documented a decrease in average height for all planted species.

Vegetation percent cover on each mat was also recorded for the six planted species. Percent cover of the six planted species were combined across all of the FTW mat types by sampling event (Figure 26). All plant species observed growing on all FTWs in MS1 are listed in Appendix C, along with the average coverage percent and height associated with each species throughout the entire study period. The FTW mats were originally planted with a fair amount of bare space to allow for growth of the original six planted species and to avoid over-crowding; BioHaven mats had an average of 87.6% bare space per mat, PhytoLinks had an average of 72.4% bare space per mat, and Beemats had an average of 59.7% bare space per mat.

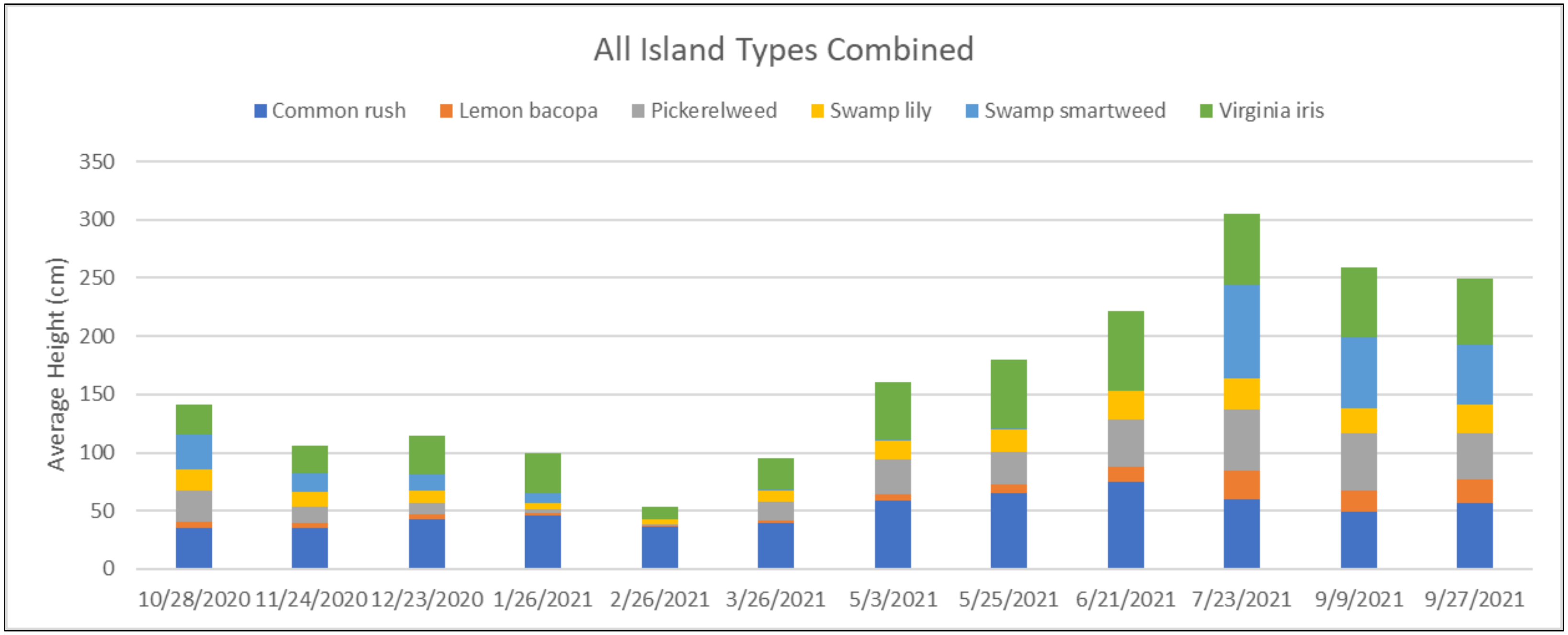

Figure 25. MS1 vegetation growth for the six planted wetland species as average height (cm) with all FTW mat types combined. Tracked monthly over a one-year period.

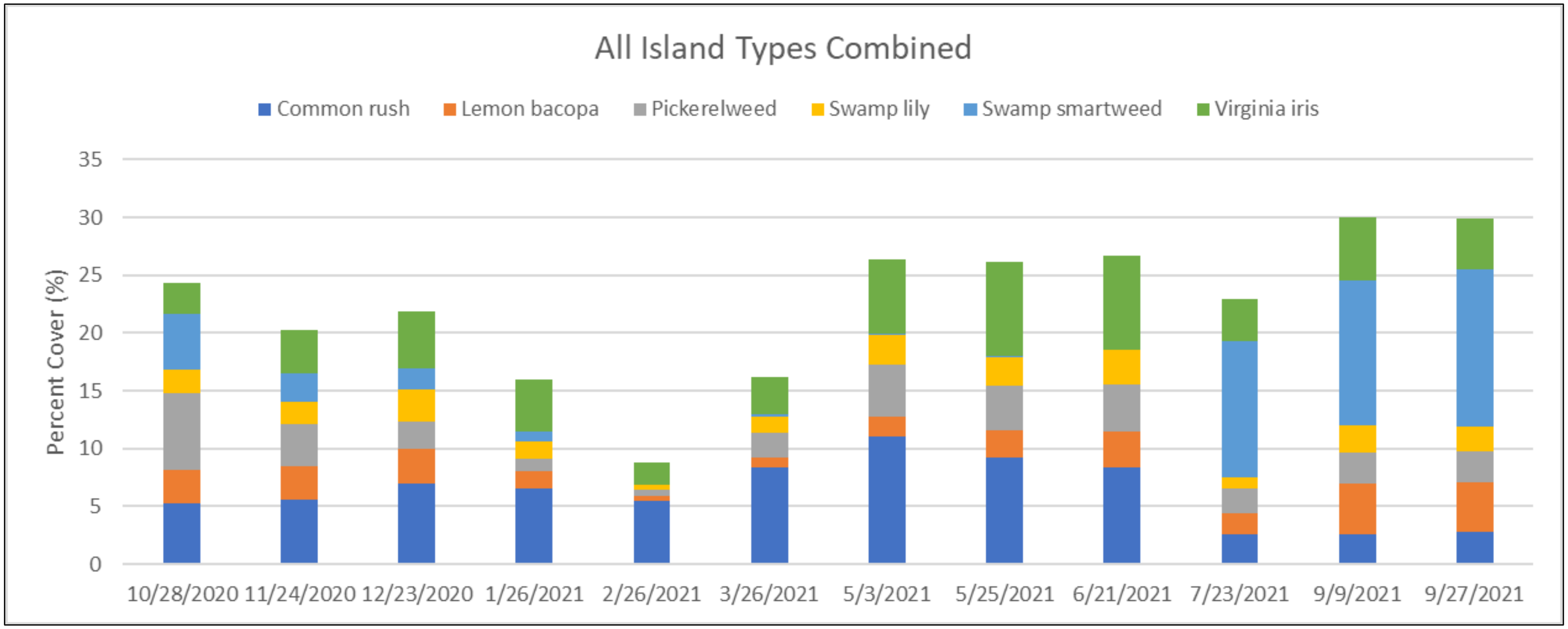

Figure 26. MS1 vegetation percent cover for the six planted wetland species with all FTW mat types combined. Tracked monthly over a one-year period.

There was a large decline in cover of all planted species, except Common rush, documented during the February 2021 survey. Five out the six planted species saw an increase in coverage during late spring/early summer. As mentioned previously, Swamp smartweed did not recover until late July 2021. Common rush and Virginia iris maintained the highest coverage out of the planted species until Swamp smartweed recovered in late July. Once this happened, Swamp smartweed dominated in coverage of the FTWs when compared to the other planted species.

In addition to the planted species, the cover of bare ground and “volunteer” species was also tracked during each sampling event and combined for all mats (Figure 27, Figure 28, and Figure 29). While we did see an overall increase in percent cover of the planted species, they were outcompeted by the volunteer species after ~6 months post-planting.

All plant species observed growing on all FTWs in MS1 have been identified and listed in Appendix C, along with the average coverage percent and height associated with each species throughout the entire study period.

Total FTW plant composition grouped as “planted” (all six of the original planted wetland species), “volunteer” (any other plant that was not originally planted), and “bare” (bare space on the FTW mat) for each mat type can be found below: Beemats in Figure 27, BioHaven in Figure 28, and PhytoLinks in Figure 29.

After one-month post-planting, Beemats coverage exhibited ~60% bare space, ~4% presence of volunteer species, and ~36% coverage of the six planted species. Volunteer species started to out-compete with the planted species the next month but died back during December of 2020. The freeze in February of 2021 caused all plant species, planted and volunteer, to die back and the mats were predominantly bare until late May of 2021. The last four surveys after May 2021 saw a huge increase in volunteer species on the Beemats, whereby the end of the summer 2021, there was no bare space left and the Beemats were ~87% covered by volunteer species.

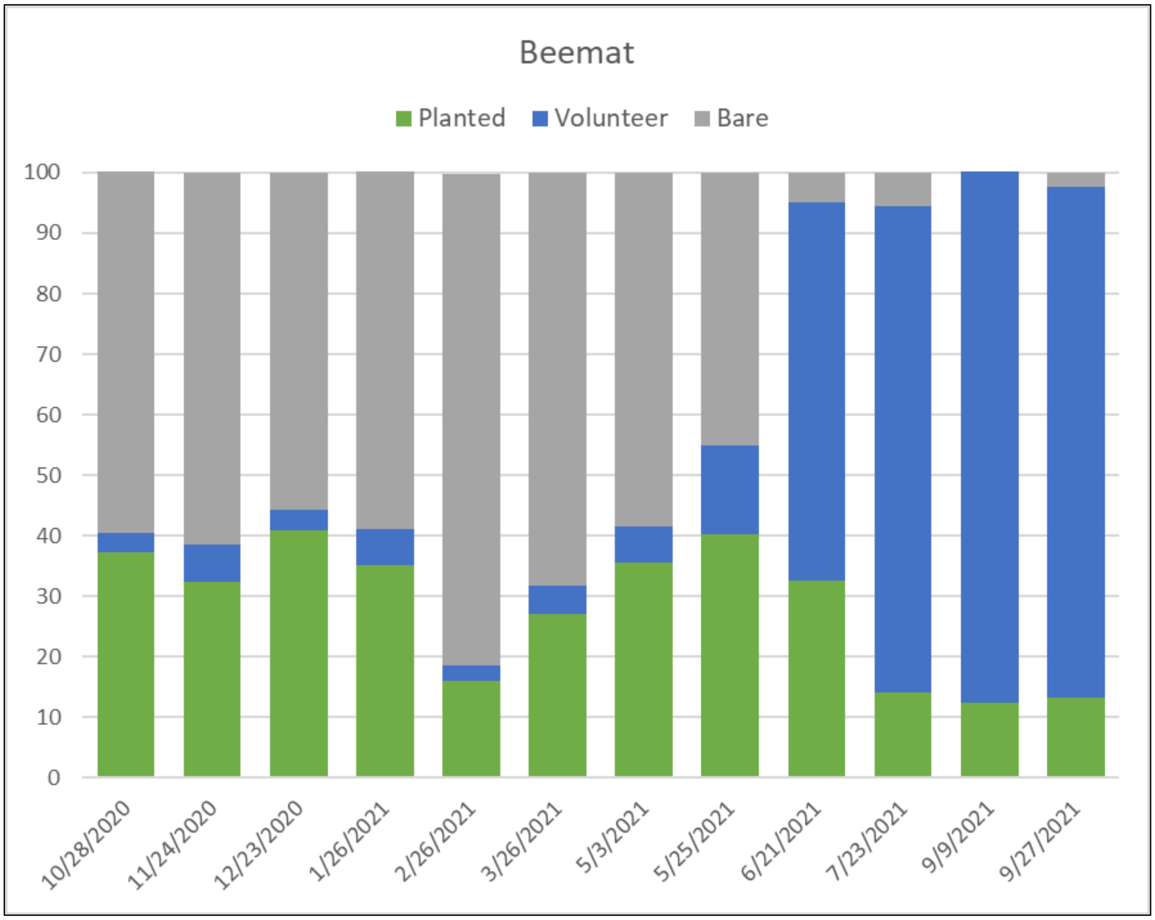

Figure 27. Beemats composition tracked monthly over a one-year period. Planted species percent cover can be seen in green, volunteers in blue, and bare space in grey.

After one-month post-planting, the BioHaven mats had ~87% of the mats as bare, ~1% presence of volunteer species, and ~12% of the mats covered with the six planted species. Both planted and volunteer species started to increase the following month, then the next month the volunteer species died back ~2%. During the colder months of January, February, and March, the BioHaven mats were at or above 90% bare coverage. In the springtime, the planted species finally reached a higher cover percent than what was originally planted and continued to spread out onto the BioHaven mats until the end of July 2021, when volunteer species started to outcompete for space. By the last survey in Figure 28, the volunteer species had covered ~79% of the BioHaven mats while the planted species only accounted for ~13% of the cover and the remaining 8 % was bare.

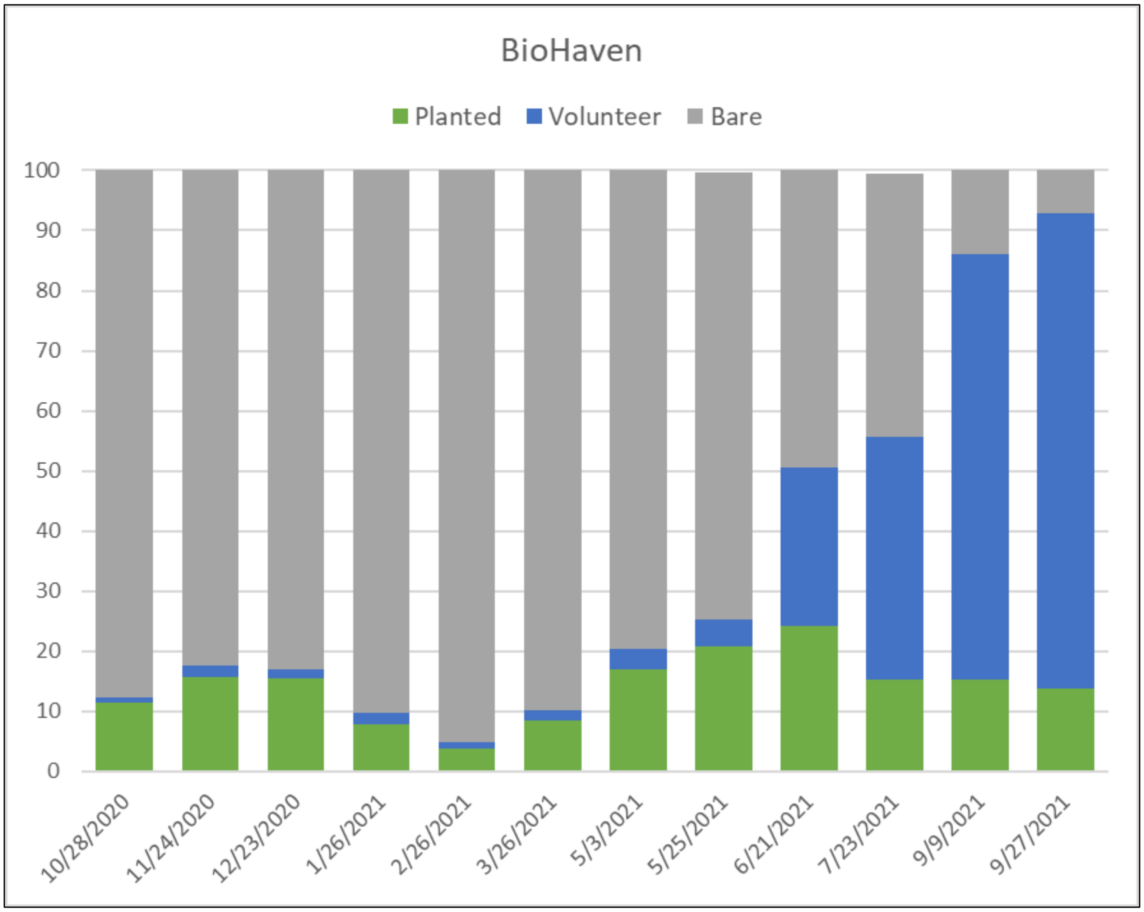

Figure 28. BioHaven composition tracked monthly over a one-year period. Planted species percent cover can be seen in green, volunteers in blue, and bare space in grey.

After one-month post-planting, the PhytoLinks mats had ~72% of the mats as bare, ~2% presence of volunteer species, and ~26% of the mats covered with the six planted species. During the months of November – February there was a steady decrease in the planted species, but they started to recover in the months March – May. In June of 2021, the volunteer species started to outcompete the planted species for space and continued to do so until the last survey in Figure 29. By July of 2021, there was no bare space left on the PhytoLinks and the volunteers attributed for roughly 83-85% of the cover after that.

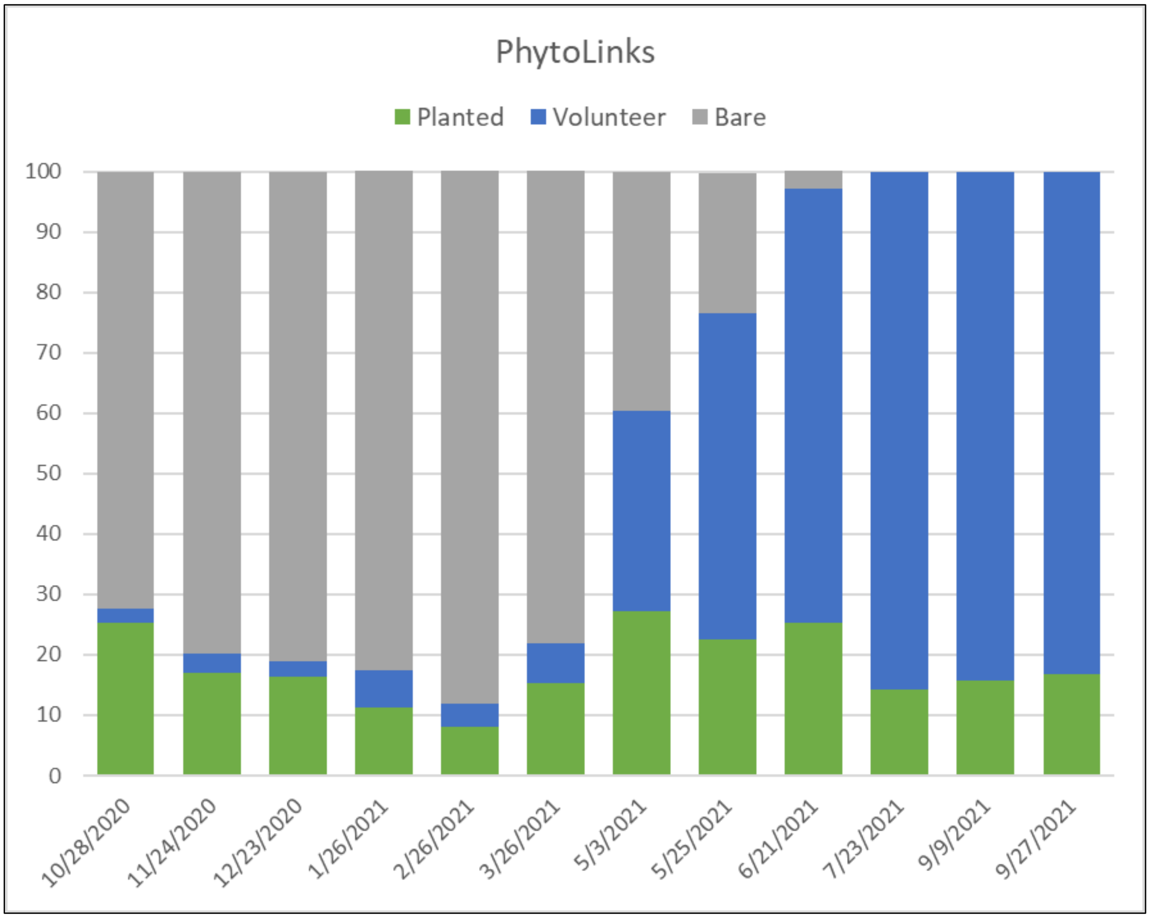

Figure 29. PhytoLinks composition tracked monthly over a one-year period. Planted species percent cover can be seen in green, volunteers in blue, and bare space in grey.

Monitoring Station 2

Water Quality Enhancement

A total of three dry-weather sampling events were conducted, one pre-installation of FTW and two post-installation (Table 6). Eight wet-weather events were sampled, two pre-installation of FTW and six post-installation (Table 6 and Table 9). Conditions describing the wet weather events varied by event such as rainfall (0.12 to 1.64 inches of rain), rate of discharge (0.075 to 1.33 cfs), FTW mat placement and sampling times (Table 9). A complete table of all field data collecting, including field observations and notes, can be found in Appendix B.

Table 9. Rainfall amounts, days since last significant rain (DSLSR), rate of discharge, sampling window and FTW placement for all wet weather events in MS2.

MS2	Event	Rainfall (in.)	Start of Rainfall	DSLSR	Rate of Discharge (cfs)	Time of Flow Reading	Sampling Window	Treatment in Place
Pre-Install	1	1.08	08:20	7	1.3333	09:45	09:35-10:30	N/A
	2	0.40	12:00	2	0.3083	13:10	13:00-13:40	N/A
Post-Install	3	1.64	11:15	5	0.5943	15:15	15:15-16:05	Control
	4	0.68	09:00	4	0.3440	14:15	14:00-15:20	Virginia Iris
	5	0.16	08:30	11	0.0470	11:50	11:35-12:30	Virginia Iris
	6	0.32	11:15	2	0.2050	14:30	14:30-15:00	Swamp Lily
	7	0.20	06:00	9	0.2018	10:40	10:20-10:45	Swamp Lily
	8	0.12	05:00	8	0.0752	10:09	10:05-11:00	Control

Table 10. Water sample analysis results for all sampling events in MS2. Listed here are the changes in concentrations (conc.) from inflow (SS-F) to outflow (SS-G) and the removal efficiencies for E. coli, TSS, Total Nitrogen, and Total Phosphorus.

MS2		***E. coli*** **(MPN)**		**TSS (mg/L)**		**Total Nitrogen (mg/L)**		**Total Phosphorus (mg/L)**	
		Δ in Conc.	**Removal Efficiency (%)**	**Δ in Conc.**	**Removal Efficiency (%)**	**Δ in Conc.**	**Removal Efficiency (%)**	**Δ in Conc.**	**Removal Efficiency (%)**
Pre-Install	**Rain Event 1**	57,367.0	99.01	23.7	82.01	0.1755	49.09	0.023	13.86
	Rain Event 2	3,441.0	94.17	18.1	73.58	0.0000	0.00	0.062	28.31
	Dry Event 1	0.0	0.00	1.2	23.08	-0.0610	-37.77	0.033	17.19
Post-Install	**Rain Event 3**	2,889.0	99.31	3.4	15.38	0.6830	73.44	0.046	9.06
	Rain Event 4	18,721.0	77.37	16.8	44.56	0.1064	24.89	-0.092	-36.51
	Rain Event 5	18.9	50.53	-2.3	-29.65	0.0188	23.04	-0.006	-2.11
	Rain Event 6	130.0	76.02	-25.2	-185.00	0.0200	8.18	0.021	7.42
	Rain Event 7	1,567.0	99.43	3.2	44.44	1.3110	88.31	0.177	46.95
	Rain Event 8	-10.0	-100.00	0.0	0.00	-0.0097	-5.27	0.052	14.29
	Dry Event 2	103.2	82.56	-1.3	-27.08	0.0000	0.00	-0.008	-2.61
	Dry Event 3	-31.0	-310.00	1.2	151.00	0.0138	6.32	-0.024	-7.50
	Dry Event 4	5.0	50.00	1.3	24.53	0.0144	5.35	-0.006	-1.96

E. coli

The change in concentration of *E. coli* between inflow (SS-F) and the outfall (SS-G) in the pre-installation dry weather event was 0 MPN, while the average change in concentration for the post-installation dry weather events was 25.73 MPN (Table 10). For the wet weather events, the average change in concentration pre-installation was 30,404 MPN, while the post-installation average change in concentration was 3,886 MPN (Table 10).

When looking at the removal efficiencies by mat type in MS2 during rain events (Figure 30), the average removal efficiency of *E. coli* with the Virginia iris mat as the treatment in place was 63.95%, with the Swamp lily mat as the treatment in place was 87.73%, and with the control mat with no vegetation was -0.35%. Rain events 5 and 8 had the lowest removal efficiencies out of all of the eight rain events. These two events also had the lowest rainfall amounts and the slowest rates of discharge into the pond Table 9).

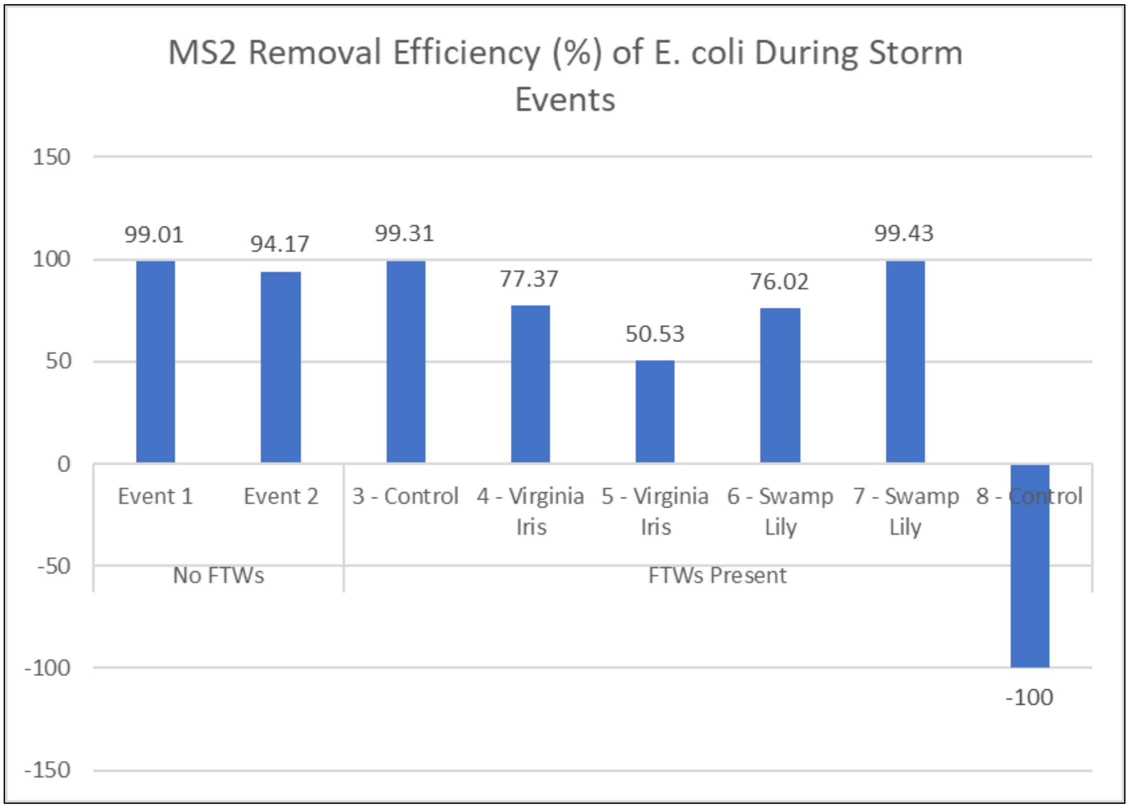

Figure 30. MS2 Removal Efficiency of E. coli with and without the FTWs present during all wet weather events.

Total Suspended Solids

The change in concentration of TSS between inflow (SS-F) and the outfall (SS-G) in the pre-installation dry weather event was 1.2 mg/L, while the average change in concentration for the post-installation dry weather events was 0.4 mg/L (Table 10). For the wet weather events, the average change in concentration pre-installation was 20.9 mg/L, while the post-installation change in concentration was -0.0685 mg/L (Table 10).

When looking at the removal efficiencies by mat type in MS2 during rain events (Figure 31), the average removal efficiency of TSS during rain events with the Virginia iris mat as the treatment in place was 7.46%, with the Swamp lily mat as the treatment in place was -70.28%, and with the control mat with no vegetation as the treatment in place was 7.69%. The Virginia iris and control mats had very similar removal efficiencies of

TSS but were still significantly lower than the average removal of the pond without the FTWs installed. The Swamp lily mat had the highest removal of TSS for all four of the dry weather events.

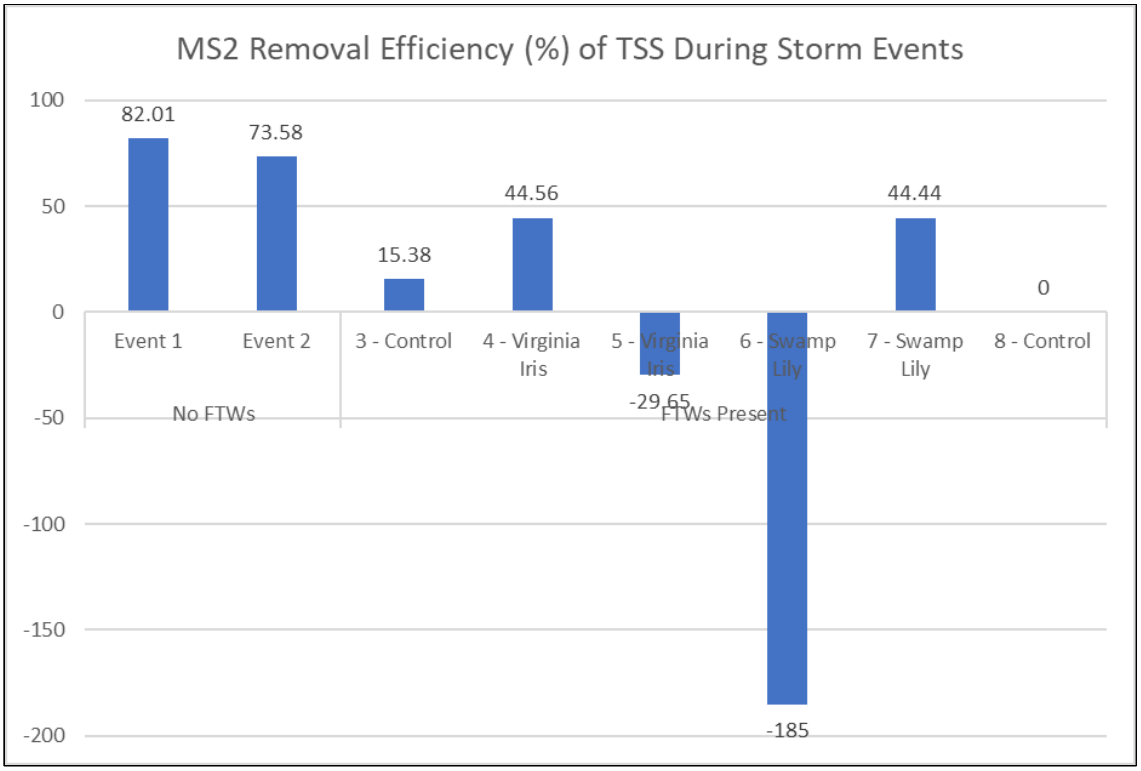

Figure 31. MS2 Removal Efficiency of TSS with and without the FTWs present during all wet weather events.

Total Nitrogen

The change in concentration of TN between inflow (SS-F) and the outfall (SS-G) in the pre-installation dry weather event was -0.061 mg/L, while the average change in concentration for the post-installation dry weather events was 0.0094 mg/L (Table 10). For the wet weather events, the average change in concentration pre-installation was 0.0878 mg/L, while the post-installation change in concentration was 0.3549 mg/L (Table 10).

When looking at the removal efficiencies by mat type in MS2 during rain events (Figure 32), the average removal efficiency of TN with the Virginia iris mat as the treatment in place was 23.97%, with the Swamp lily mat as the treatment in place was 48.25%, and with the control mat with not vegetation as the treatment in place was 34.09%. Overall, more TN was removed from the system with the DIY FTWs installed than without the FTWs installed. Swamp lily generally outperformed all other mats in terms of removing TN from the system and had a higher average removal efficiency than when there were no FTWs installed.

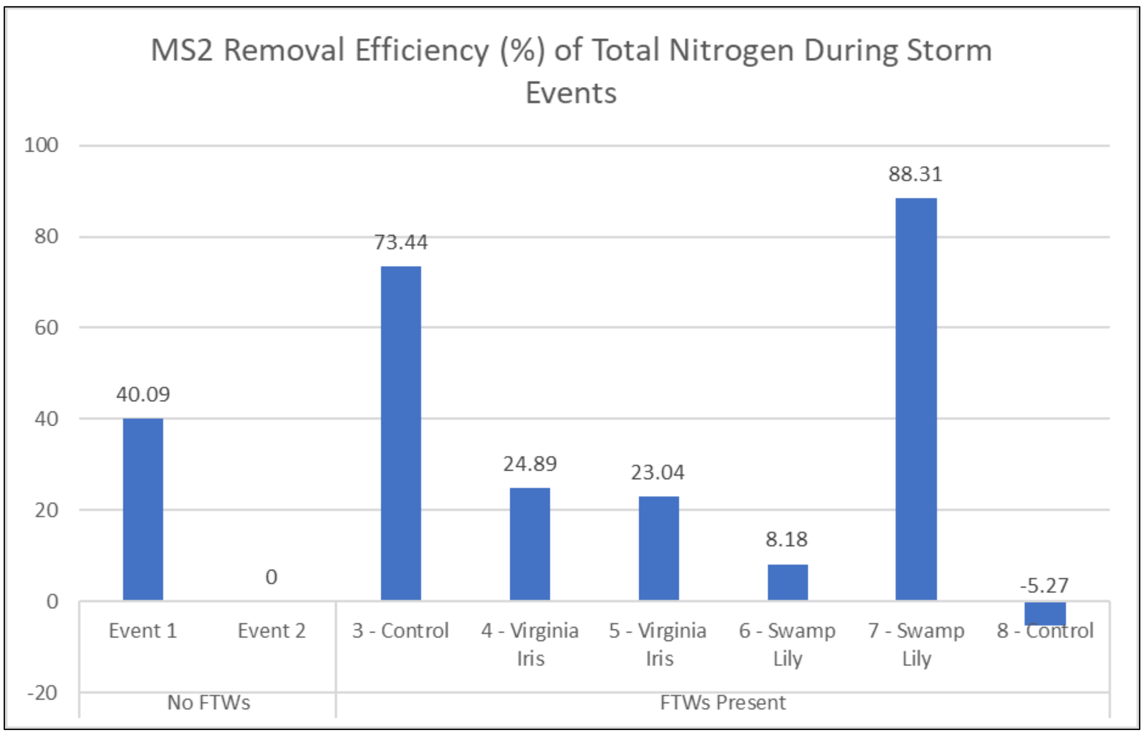

Figure 32. MS2 Removal Efficiency of Total Nitrogen with and without the FTWs present during all wet weather events.

Total Phosphorus

The change in concentration of TP between inflow (SS-F) and the outfall (SS-G) in the pre-installation dry weather event was 0.033 mg/L, while the average change in concentration for the post-installation dry weather events was -0.0127 mg/L (Table 10). For the wet weather events, the average change in concentration pre-installation was 0.0425 mg/L, while the post-installation change in concentration was 0.033 mg/L (Table 10).

When looking at the removal efficiencies by mat type in MS2 during rain events (Figure 33), the average removal efficiency of TP with the Virginia iris mat as the treatment in place was -19.31%, with the Swamp lily mat as the treatment in place was 27.19%, and with the control mat with not vegetation as the treatment in place was 11.98%. The Swamp lily mat outperformed the other DIY FTW mats when comparing removal efficiencies of TP and did better than without the FTWs installed at all. None of the FTW mats had a higher removal efficiency during dry weather events than compared to the pre-installation dry weather event.

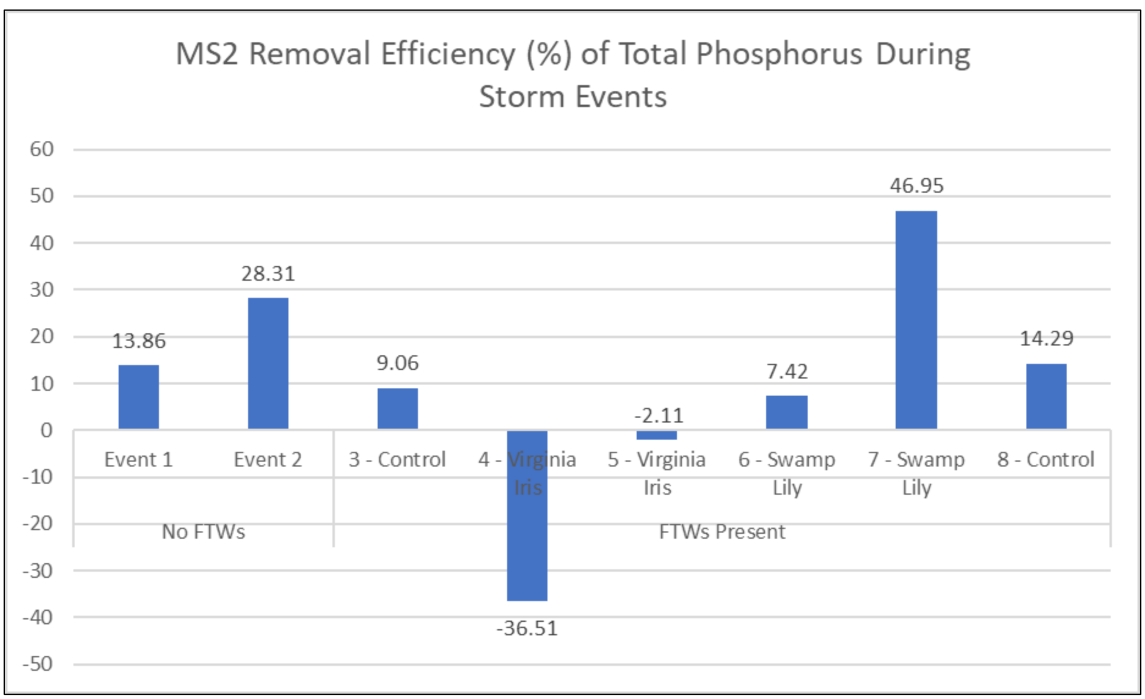

Figure 33. MS2 Removal Efficiency of Total Phosphorus with and without the FTWs present during all wet weather events.

DISCUSSION

Monitoring Station 1

Water Quality Enhancement

The plants chosen for their large, fibrous root systems did well at removing suspended sediments and in turn, bacteria in the form of *E. coli*, because bacteria often adhere to suspended sediments (Liang et al. 2017). Since many water pollutants often bind to the particles of sediments, this increase in treatment with the addition of the FTWs shows great promise. Literature shows that FTWs can be successful at removing pollutants from stormwater detention basins (Borne 2015, Headley and Tanner 2012, Zhou et al. 2019). However, nutrients (Total Nitrogen and Total Phosphorus) were not removed at the expected levels during post-installation events. This may be due to the percent cover of the FTWs relative to the pond surface area not being high enough to reach optimal treatment efficiency. The optimal percent cover found by Borne at al. (2013) was that ~50% of the pond surface area needed to be covered by FTWs for optimal nutrient reduction. In a more recent study done by Hanna et al. (2024), found that increasing that coverage ratio to 72% improved TN removal by an average of 12% when compared to a conventional wastewater lagoon. In our pilot-study, we were assessing the FTWs for much more than just nutrient removal and only ~ 15% of the pond was covered with the FTWs as a greater percentage of open water limits DO depletion. The purpose of installing FTWs should be defined when considering design and coverage. Literature shows that if the main purpose is habitat creation and enhancing biodiversity, then smaller individual modules (~1-3 m^2) are more effective since they limit DO depletion, but if the main goal is targeted at improving nitrate or metal removal, then larger individual FTW modules (~50 m^2) should be used (Borne 2013).

Removal efficiencies of target constituents between events could differ for a myriad of reasons. Rain event 3, for example, saw improvements in most pollutant concentrations in MS1, especially when compared to pre-installation rain events, but TP actually increased from SS-A to SS-D. This could have been influenced by the biochemical cycle of TP regeneration from hypoxic/anoxic sediment that can occur in the beginning of the summer season (when rain event 3 was sampled) where temperatures start to increase and some phosporus is released back into the water from sediments (Pan et al., 2020 and Yang et al., 2021). The outfall (SS-D) at MS1 is located under a large elm tree, which was observed to be the home to a variety of wildlife, and may have contributed waste to the system in that area. Lower inflow concentrations of nutrients also seem to be correlated with lower removal efficiencies of said nutrients (Nichols et al., 2016).

Rain events also varied in terms of the amount of rainfall, rate of discharge into the system, and when sampling was able to occur after first rainfall. Crews attempted to sample as soon as possible after the event criteria was met, but there were safety or time restraints that did not always allow for this to happen. Rain event 4 was such an event where sampling was not able to occur until the hydrograph had since peaked and was at the lower end of the falling limb. This is evident when comparing the total rainfall amount (0.68 in.) to the rate of discharge at the inflow (1.071 cfs). Other events with lower rainfall amounts, such as rain event 5 which saw only 0.16 inches of rain, but was sampled at the peak of the hydrograph where the rate of discharge into the inflow was 4.071 cfs, had much higher removal efficiencies for all of the target constituents than rain event 4. This could conclude that the timeframe in which sampling occurs is vital to capturing an accurate representation of the treatment potential of the FTWs. Borne (2013) found positive correlations between TSS outlet event mean concentrations (EMCs) and flow ratio as well as with inlet peak flows. They concluded that the performance of a FTW system was more affected by the size and intensity of a storm event than when compared to a conventional retention pond. We were limited in our number of sampling events due to the variability of wet weather sampling and wanting to keep the study period within a certain timeframe. This did limit the results observed because of insufficient replication for capturing and testing all of the combinations of variables that affect water quality, essentially not allowing us enough degrees of freedom. Location of the FTWs also plays a factor in removal efficiency and it is recommended that installation of the FTWs occur as close to the inlet of the pond as possible in order to increase distribution of the inflow which would increase the hydraulic efficiency and treatment performance of the FTWs (Persson et al., 1999). When choosing the location for our FTWs to be installed, we had to consider where the best control area was located and since we needed water that had not yet been treated by the FTWs to compare to, we decided to have our control sampling station (SS-E) closer to the inlet and our FTWs closer to the outfall so that they would not interfere with the control samples.

Enhancement by Mat Type

PhytoLinks performed, on average, the best at decreasing the trubidity of the water during rain events. This may be due to the PhytoLinks maintaining the highest coverage of plants once post-installation events started when compared to Beemats and BioHaven. More plant coverage means more root structures to act as a physical filter for the stormwater runoff. The PhytoLinks came in close second to having the best average removal efficiency of TSS; Beemats had the highest in this category.

There were pros and cons to all mat types used. While Beemats were the cheapest and easiest to construct and plant, they are not made for long-term use. The manufacturer suggests removing the Beemats from the system prior to winter when the plants begin to senesce. This is for two main reasons: (1) the plants may re-release nutrients and other pollutants that were taken up back into the water column once they senesce and (2) the mat material is not durable enough to remain intact and fully buoyant over a long period of time. The BioHaven mats are extremely durable, but anecdotally I did notice that they lost some buoyancy over time as they began to become saturated. The BioHaven mats also required a much longer establishment period than the rest of the FTW mat types, as the plant roots were not in immediate contact with the water column once planted due to mat design. This meant that the plants on the BioHaven mats also needed to be watered regularly until the roots were able to grow through the mat matrix and reach the water column below. They did provide larger animals ample basking area as they could withstand a large amount of weight and still remain buoyant. This however, presented the problem of the plants being smashed by the resident adult alligator who discovered the BioHavens were perfect for basking. The fencing that was installed to protect the plants had to have a balance between being sturdy, protective fencing and fencing that would not ensnare any wildlife, and that ended up meaning that the fencing needed regular maintenance. The PhytoLinks mats were very easy to assemble together, but construction of the slits for the plants to be inserted in was difficult to keep consistently the same size or the appropriate size for the intended plant species and as a result some plants were easily pulled through by herbivores or perhaps by gravity alone. The coconut coir also provided ample opportunity for unwanted plant species to take root and potentially out compete our chosen wetland plant species. The PhytoLinks mats did, however, remain buoyant and intact during our entire study period. They performed the best in terms of all the performance standards mentioned in the Methods section.

Vegetation Monitoring

Over the course of one year where vegetation surveys were conducted monthly, composition of species varied across all three mat types, until the summer of 2021 where volunteer species began dominating the cover percentage and continued to do so until the last vegetation survey was conducted in September of 2021. There were several factors at play that affected the success of the planted species on the FTWs. The FTWs were not able to be planted until the end of September of 2020, which is slightly after the optimal wetland planting season for the gulf coast Texas region (USDA Plants 2023). During the first month of the establishment period, fencing had not yet been installed. Once it was observed that the plants were being negatively affected by the larger basking animals, it was decided that fencing was necessary for the successful establishment of the planted species. Multiple cold fronts moved through the region in the month of December in 2020 and an arctic cold front hit the region in February of 2021. Ice and snow cover stretched into South Texas and the amount of consecutive days of freezing temperatures broke records for the longest freezing streak in the state's recorded history (NOAA, 2022). The effects of the extended freeze on the planted species during that month can be seen in the composition changes per month for all three mat types where there was an obvious drop in cover and an increase in bare space on all mats. This caused the establishment period of the plants to be extended even longer, especially for the BioHaven mats, as the roots of those plants had not yet all made it thoroughly through the mats to the water column where they could have had more protection from the freezing temperatures. It was not until May of 2021 that it was confirmed that the roots of the plants for all three mat types had made contact with the water column and were considered firmly established. During that time when the plants were recovering from the freeze, this increase in bare space on the mats allowed for other plants that were able to establish themselves much quicker to utilize that open space. This may help to explain why the planted species were eventually outcompeted by the volunteer species – majority of which came from the banks of MS1 where they had already been established or had washed into the pond during rain events as they were established in the vegetated ditches that contribute to MS1. Borne et al. (2015) found that when a pond that originally had ~20% coverage of creeping water primrose (*Ludwigia hexapetala*), which is listed as a Class B state noxious weed in their study area of North Carolina, the coverage percentage would increase to ~70% after FTW installation as they acted as new footholds for the plants. Due to some undesirable consequences of this increase in growth of the primrose, such as clogging of equipment and expensive removal, they suggest all invasive aquatic weeds be removed from the system prior to FTW installation.

The reasoning behind not weeding the mats during this study period was to better understand the maintenance that the FTWs would require. If the FTWs are installed in systems where there is already an established seed bank on the banks or in the contributing drainage areas, especially if some of the species are invasive or easily outcompete other species for space, removal of these non-planted species would be necessary for the success of the chosen planted species. This removal of the non-planted species could help decrease the variablity in future studies of FTW systems. The increase in volunteer species on all three mat types coinscided with the beginning of our rain event sapling period and may help explain the variablity among pollutant removal efficiencies. Some studies have noted a negative correlation between an increase in invasive or undesirable plant species and success of the chosen wetland plant species (Borne et al., 2015, Shahid et al., 2018, Wang and Sample 2014), but no studies were found to date that specifically analyze the relationship between amount of invasive species and treatment efficiency of the FTWs. It is noted that species with dense, fibrous root systems are the most successful at pollutant removal and it is unclear if an invasive species matching this criteria would be detrimental to the FTW treatment potential.

Monitoring Station 2

As with MS1, the fact that no overall improvement in treatment of nutrients, as well as *E. coli* and TSS in this case, is likely due to a low percent cover of FTWs relative to the pond surface area. When assessing the MS2 wetland species treatment performance, the poor performance is likely due to root system structures of Swamp Lily and Virginia Iris. These root systems are not as large and fibrous as some of those chosen for MS1, like Common Rush or Pickerelweed, which made up a large percent cover of the planted species composition on those FTWs and which are adept at acting as a large physical filter for runoff passing through the root structures. The root structures of Swamp lily are large, stoloniferous bulbs that reach up to about five inches in diameter. They are thick but are not considered to be very fibrous and do not exhibit large vertical growth, which would be necessary for achieving more physical filtering capabilities. The fleshy roots, about 1-2 cm in diameter, of the Virginia iris plant are rhizomes that spread underground but are relatively shallow in terms of length of roots. They do exhibit more of a fibrous structure than the Swamp lily roots, but as stated, they remain fairly shallow and longer lengths of roots are necessary for acting as a large physical filter for runoff flowing through. These plant species were chosen to be studied more closely because of the other characteristics that they exhibited, such as nutrient removal capabilities, resilience to wildlife disturbance, being beneficial to native pollinators, and having aesthetic benefits, but were not species that had publications showing success in the use of FTWs. They were thought to have the potential for use in these systems as they have sister species that have shown to be successful when used in FTWs. For example, *Iris hexagona* (used in White, 2021) has an extremely similar root structure compared to *Iris* *virginica* and was still shown to be successful at removing nitrogen and phosphorus from stormwater runoff from a drainage basin that incorporated FTWs.

When comparing the MS2 chosen plant species to each other, Swamp Lily had the highest average removal of *E. coli*, TN, and TP, while Virginia iris and the control mat had nearly the same treatment of TSS, 7.46% and 7.69%, respectively. More sampling events would likely have resulted in being able to make more substantial claims about treatment capabilities. When focusing on assessing certain plant species' pollutant removal capabilities, a more controlled laboratory setting could help avoid the high variability in event conditions as seen in this study.

The DIY mats used in MS2 were easy to construct, but as the mats were originally made for recreational use and to be stored when not in use, they did experience some degradation from the constant sun exposure. This was not a problem if the mats were left untouched, but as wildlife often used them for basking habitat, they did occasionally get scratched and small pieces of the foam mat would flake off into the waterway. They also required weeding during the course of the study as persistent volunteer plant species were able to take root in the foam or in the pots along with the planted species.

Recommendations for Future Work

Literature shows that FTWs can be successful at removing pollutants from stormwater detention basins (Borne 2015, Headley and Tanner 2012, Zhou et al. 2019). Future studies on FTWs should follow Borne's (2013) optimal coverage percentage of ~50% if nutrient removal is an intended outcome. More sampling events would also be necessary if a significant difference in treatment efficiency is to be seen. A power analysis of how many samples (replicates) per category are needed to achieve a certain level of power depending on the variability of the measured variables would be helpful when determining number of sampling events. Following the natural seasonality of the chosen wetland species when determining timing of planting and installation would help to ensure a higher success rate of plant growth and survival. Unwanted plant species that happened to colonize the FTW mats in MS1 were not removed in order to determine the maintenance requirements for the FTWs, but periodic removal would also help to ensure a higher success rate of chosen plant growth and survival. Overall, adding the FTWs to existing catchments will improve the treatment potential and will result in cleaner water making its way to the receiving water. FTWs will also create more wildlife habitat – this is especially beneficial in those catchments that are specifically designed to have extreme water level fluctuations that make it difficult to sustain bank habitat. It is very important to have your goals in mind when planning a treatment design utilizing the FTWs as there are a variety of tailored outcomes depending on what the focus is. Each type of FTW mat type has different benefits and drawbacks and having a clear outline of priorities is key to a successful treatment design.

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APPENDIX A:

FLOATING TREATMENT WETLANDS DATASHEETS

Environmental Institute of Houston - University of Houston Clear Lake

Potter Pond (MS-1) Floating Treatment Wetland Field Data/Sampling Sheet

Date:________________ Time: arrive___________ depart___________ Collected by: ________________________________

GENERAL FIELD OBSERVATIONS

	WATER ODOR	1-sewage 2-chemical 3-rotten egg 4-musky 5-fishy 6-none 7-other		WIND INTENSITY	1-calm 2-slight 3-moderate 4-strong
	WATER COLOR	1-brownish 2-reddish 3-greenish 4-blackish 5-clear 6-other		PRESENT WEATHER	1-clear 2-partly cloudy 3-cloudy 4-rain 5-other
	WATER SURFACE	1-calm 2-ripples 3-waves		DAYS SINCE LAST SIG. RAINFALL	
	AIR TEMP (°C)			FLOW (cfs) at inflow	
	BUBBLER DEPTH (ft) (at time of flow reading)			TIME OF FLOW READING	
	EVENT RAINFALL AMOUNT (in)			TIME OF STORMWATER SAMPLER RETRIEVAL	

FIELD MEASUREMENTS
All sonde readings and water samples taken at 0.3m from surface

Site -->	SS-A (Inflow)	SS-E (Control)	SS-B (after 1st FTW)	SS-C (after 2nd FTW)	SS-D (Outfall)
Sample Time					
Total Depth (m)					
Secchi (m)					
Temp (C)					
Sp. Cond. (uS)					
Turbidity (NTU)					
DO (%sat)					
DO mg/L					
pH					

WATER SAMPLES

Container	Preservative	Analysis Requested	Sampling Method
1L - Plastic	Ice	TSS	First-Flush and/or Grab
1L - Plastic	Ice, 2 mL H2SO4	NH3 - N, TKN, NO2 + NO3 - N, TP	First-Flush and/or Grab
1L - Plastic	Ice	Orthophosphorus	First-Flush and/or Grab
1L - Plastic	Ice	BOD	Grab Only
(2) 1L - Amber Glass	Ice, HCl	Oil and Grease	Grab Only
100ml - Sterile Plastic	Ice, Na2S2O3	E. coli	Grab Only

Sample notes:

ADDITIONAL INFORMATION & REMARKS

Remarks:

Appendix Figure 1
MS1 Event Sampling Datasheet.

Environmental Institute of Houston - University of Houston Clear Lake

Alligator Pond (MS-2) Floating Treatment Wetland Field Data/Sampling Sheet

Date:______________ Time: arrive__________ depart__________ Collected by: ______________________________

GENERAL FIELD OBSERVATIONS

	WATER ODOR	1-sewage 2-chemical 3-rotten egg 4-musky 5-fishy 6-none 7-other		WIND INTENSITY	1-calm 2-slight 3-moderate 4-strong
	WATER COLOR	1-brownish 2-reddish 3-greenish 4-blackish 5-clear 6-other		PRESENT WEATHER	1-clear 2-partly cloudy 3-cloudy 4-rain 5-other
	WATER SURFACE	1-calm 2-ripples 3-waves		DAYS SINCE LAST SIG. RAINFALL	
	AIR TEMP (°C)			FLOW (cfs) at inflow	
	LEVEL DEPTH (ft) (at time of flow reading)			TIME OF FLOW READING	
	EVENT RAINFALL AMOUNT (in)			TIME OF STORMWATER SAMPLER RETRIEVAL	

FIELD MEASUREMENTS All sonde readings and water samples taken at 0.3m from surface

Site -->	SS-F (Inflow)	SS-G (Outfall)
Sample Time		
Total Depth (m)		
Secchi (m)		
Temp (C)		
Sp. Cond. (uS)		
Turbidity (NTU)		
DO (%sat)		
DO mg/L		
pH		

Treatment in Place (check ONE)

- ☐ Control (No Vegetation)
- ☐ V1: Smartweed (*Polygonum hydropiperoides*)
- ☐ V2: Swamp Lily (*Crinum americanum*)
- ☐ V3: Virginia Iris (*Irs virginica*)

WATER SAMPLES

Container	Preservative	Analysis Requested	Sampling Method
1L - Plastic	Ice	TSS	First-Flush and/or Grab
1L - Plastic	Ice, 2 mL H2SO4	NH3 - N, TKN, NO2 + NO3 - N, TP	First-Flush and/or Grab
1L - Plastic	Ice	Orthophosphorus	First-Flush and/or Grab
1L - Plastic	Ice	BOD	Grab Only
(2) 1L - Amber Glass	Ice, HCl	Oil and Grease	Grab Only
100ml - Sterile Plastic	Ice, Na2S2O3	E. coli	Grab Only

ADDITIONAL INFORMATION & REMARKS

Remarks:

Appendix Figure 2
MS2 Event Sampling Datasheet.

Environmental Institute of Houston,
University of Houston-Clear Lake
Stream Flow (Discharge) Measurement Form

Environmental Institute of Houston

Stream: Unnamed Trib. To Potter Pond Date:________

Station: SS-A (Inflow)

Description: Confluence of inflow ditch and Potter Pond

Time Begin:________ Time End:________ Meter Type:________

Observers:________ Stream Width*:________ Section Width (W):________

Observations:________

Section Midpoint (ft) (m)	Section Depth (ft) (m) (cm) (D)	Observational Depth** (ft) (m)	Velocity (V)		Flow (Q) (m^3/s) (ft^3/s) Q = (W)(D)(V)
			At Point (ft/s) (m/s)	Average (ft/s) (m/s)	

m3/s x 35.3 =ft3/s

Total Flow (Discharge) (Σ Q)	*
Field Discharge (Σ Q)	

*See Attached Discharge Sheet

Modified from TCEQ-20117 (Rev. 04/22/2004)

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Bubbler depth reading (ft):________ Time:________

Appendix Figure 3
MS1 Event Sampling - Flow Datasheet.

Environmental Institute of Houston,
University of Houston-Clear Lake
Stream Flow (Discharge) Measurement Form

Environmental Institute of Houston

Stream:__Secondary Wetland Inflow To Alligator Pond__________ Date:__________

Station:_SS-F (Inflow)__________

Description:__Confluence of inflow and Alligator Pond__________

Time Begin:________ Time End:________ Meter Type:__________

Observers:__________ Stream Width*:______ Section Width (W):______

Observations:__________

Section Midpoint (ft)(m)	Section Depth (ft) (m) (cm) (D)	Observational Depth** (ft)(m)	Velocity (V) At Point (ft/s)(m/s)	Velocity (V) Average (ft/s)(m/s)	Flow (Q) (m^3/s)(ft^3/s) Q = (W)(D)(V)
			Total Flow (Discharge) (Σ Q)	*
			Field Discharge (Σ Q)	

m3/s x 35.3 =ft3/s

*See Attached Discharge Sheet

Modified from TCEQ-20117 (Rev. 04/22/2004)

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Bubbler depth reading (ft):________ Time:________

Appendix Figure 4
MS2 Event Sampling - Flow Datasheet.

Environmental Institute of Houston - University of Houston Clear Lake

FTW Field Data/Equipment Download Datasheet

Retrieve Date:________________________ Deploy Date: ____________________________

Collected By: __________________________________ Collected By: ____________________________________

SITE:	**FIELD MEASUREMENTS**						
Retrieval	Continuous Monitoring Sonde s/n:______________			**Deployment**	Continuous Monitoring Sonde s/n:______________		
SxS Time		Turbidity (NTU/FNU)		SxS Time		Turbidity (NTU/FNU)	
Retrieve Time		pH		Deploy Time		pH	
Total depth		DO (%sat)		Total depth		DO (%sat)	
Temp (C)		DO (mg/L)		Temp (C)		DO (mg/L)	
Sp. Cond (uS/cm)		Depth (m)		Sp. Cond (uS/cm)		Depth (m)	

SITE:	**FIELD MEASUREMENTS**						
Retrieval	Continuous Monitoring Sonde s/n:______________			**Deployment**	Continuous Monitoring Sonde s/n:______________		
SxS Time		Turbidity (NTU/FNU)		SxS Time		Turbidity (NTU/FNU)	
Retrieve Time		pH		Deploy Time		pH	
Total depth		DO (%sat)		Total depth		DO (%sat)	
Temp (C)		DO (mg/L)		Temp (C)		DO (mg/L)	
Sp. Cond (uS/cm)		Depth (m)		Sp. Cond (uS/cm)		Depth (m)	

SITE:	**FIELD MEASUREMENTS**						
Retrieval	Continuous Monitoring Sonde s/n:______________			**Deployment**	Continuous Monitoring Sonde s/n:______________		
SxS Time		Turbidity (NTU/FNU)		SxS Time		Turbidity (NTU/FNU)	
Retrieve Time		pH		Deploy Time		pH	
Total depth		DO (%sat)		Total depth		DO (%sat)	
Temp (C)		DO (mg/L)		Temp (C)		DO (mg/L)	
Sp. Cond (uS/cm)		Depth (m)		Sp. Cond (uS/cm)		Depth (m)	

ADDITIONAL INFORMATION & REMARKS

Level TROLL s/n:_____________ Retrieve Time:___________ Deploy Time:____________

Baro TROLL s/n:____________ Retrieve Time:____________ Deploy Time:____________ Amazon Bubbler Level:_______

Time:________

Game Cameras retrieved and downloaded: YES/NO If so, redeployed? YES/NO

Remarks:
____
____
____
____

Appendix Figure 5
Equipment Download Datasheet.

BioHaven

Environmental Institute of Houston, University of Houston-Clear Lake
FTW Vegetation and Island Monitoring Datasheet

Date(mm/dd/yyyy):________________________ Time Start(hh:mm): ______________ Time Finished(hh:mm): ____________

Collected By(F. Last):____ Island Row Location (circle one): 1 2 3
Row 1 - closest to fountain, Row 3 -closest to outfall

Note: Mat 1 is marked with flag.

	Mat 1		Mat 2		Mat 3		Mat 4		Mat 5		Mat 6		Mat 7		Mat 8	
Species	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover
Bare/Duff																
Juncus effusus Common Rush																
Pontederia cordata Pickerelweed																
P. hydropiperoides Smartweed																
Bacopa caroliniana Lemon Bacopa																
Crinum americanum Swamp Lily																
Iris virginica Virgina Iris																
Volunteers ↓																
A. philoxeroides Alligatorweed																
Hydrocotyle spp. Pennywort																
Dichondra spp. Ponysfoot																
Ipomoea spp. Morning-glory Vine																
Eleocharis spp. Spikerush																
Water Depth (m)																
Observed Wildlife Use																
Signs of Herbivory																
Notes																

See back for schematic of island design and planting

Appendix Figure 6
MS1 Vegetation Monitoring - BioHaven Datasheet.

Beemat

Environmental Institute of Houston, University of Houston-Clear Lake
FTW Vegetation and Island Monitoring Datasheet

Date(mm/dd/yyyy):______________________________ Time Start(hh:mm): ________________ Time Finished(hh:mm): ______________

Collected By(F. Last):____ Island Row Location (circle one): 1 2 3
Row 1 - closest to fountain, Row 3 -closest to outfal

Note: Mat 1 is marked with flag.

	Mat 1		Mat 2		Mat 3		Mat 4		Mat 5		Mat 6		Mat 7	
Species	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover
Bare/Duff														
Juncus effusus Common Rush														
Pontederia cordata Pickerelweed														
P. hydropiperoides Smartweed														
Bacopa caroliniana Lemon Bacopa														
Crinum americanum Swamp Lily														
Iris virginica Virgina Iris														
Volunteers ↓														
A. philoxeroides Alligatorweed														
Hydrocotyle spp. Pennywort														
Dichondra spp. Ponysfoot														
Ipomoea spp. Morning-glory Vine														
Eleocharis spp. Spikerush														
Water Depth (m)														
Observed Wildlife Use														
Signs of Herbivory														
Notes														

See back for schematic of island design and planting

Appendix Figure 7
MS1 Vegetation Monitoring - BeeMats Datasheet.

PhytoLinks

Environmental Institute of Houston, University of Houston-Clear Lake
FTW Vegetation and Island Monitoring Datasheet

Date(mm/dd/yyyy):______________________ Time Start(hh:mm): ______________ Time Finished(hh:mm): ______________

Collected By(F. Last):__________________________________ Island Row Location (circle one): 1 2 3
Row 1 - closest to fountain, Row 3 -closest to outfall

Note: Mat 1 is marked with flag.

Species	Mats 1 & 2		Mats 3 & 4		Mats 5 & 6		Mats 7 & 8		Mats 9 & 10		Mats 11 & 12		Mats 13 & 14		Mats 15 & 16	
	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover
Bare/Duff																
Juncus effusus Common Rush																
Pontederia cordata Pickerelweed																
P. hydropiperoides Smartweed																
Bacopa caroliniana Lemon Bacopa																
Crinum americanum Swamp Lily																
Iris virginica Virgina Iris																
Volunteers ↓																
A. philoxeroides Alligatorweed																
Hydrocotyle spp. Pennywort																
Dichondra spp. Ponysfoot																
Ipomoea spp. Morning-glory Vine																
Eleocharis spp. Spikerush																
Water Depth (m)																
Observed Wildlife Use																
Signs of Herbivory																
Notes																

See back for schematic of island design and planting

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Appendix Figure 8
MS1 Vegetation Monitoring - PhytoLinks Datasheet Page 1 of 2.

PhytoLinks

Environmental Institute of Houston, University of Houston-Clear Lake
FTW Vegetation and Island Monitoring Datasheet

Date(mm/dd/yyyy):____________________________________

Note: Mat 1 is marked with flag.

Species	Mats 17 & 18		Mats 19 & 20		Mats 21 & 22		Mats 23 & 24		Mats 25 & 26		Mats 27 & 28		Mats 29 & 30	
	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover	Avg. Height (cm)	% Cover
Bare/Duff														
Juncus effusus Common Rush														
Pontederia cordata Pickerelweed														
P. hydropiperoides Smartweed														
Bacopa caroliniana Lemon Bacopa														
Crinum americanum Swamp Lily														
Iris virginica Virgina Iris														
Volunteers ↓														
A. philoxeroides Alligatorweed														
Hydrocotyle spp. Pennywort														
Dichondra spp. Ponysfoot														
Ipomoea spp. Morning-glory Vine														
Eleocharis spp. Spikerush														
Water Depth (m)														
Observed Wildlife Use														
Signs of Herbivory														
Notes														

See back for schematic of island design and planting

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Appendix Figure 8
MS1 Vegetation Monitoring - PhytoLinks Datasheet Page 2 of 2.

APPENDIX B:

EVENT SAMPLING RAW DATA

Appendix Table 1

Field observations and notes from all sampling events.

MS	Date	Time Arrive	Time Depart	Collected By (F. Last)	Water Odor	Water Color	Water Surface	Air Temp . (°C)	Wind Intensity	Present Weather	Days Since Last Sig. Rain	Notes
MS1	07/17/2020	12:23	13:45	K. Chau, N. Zarnstorff	6- none	1- brownish	1- calm	28.7	1- calm	2- partly cloudy	21	Unable to sample before the inflow reached peak but runoff still flowing in during sampling
MS1	08/13/2020	11:25	12:05	J. Oakley, K. Chau	6- none	1- brownish	1- calm	29.6	1- calm	2- partly cloudy	9	Ambient conditions – no First Flush samples retrieved
MS1	09/04/2020	009:13	10:36	K. Chau, J. Doyal	6- none	1- brownish	1- calm	27.3	1- calm	2- partly cloudy	4	FF samplers didn't provide enough for OP sample
MS1	06/03/2021	13:49	15:25	T. McKenzie, K. Chau	6- none	1- brownish	2- ripple	27.1	2- slight	3- cloudy	5	Row 1= BH, 2=BM, 3=PL
MS2	06/03/2021	15:50	16:05	T. McKenzie, K. Chau	6- none	1- brownish	1- calm	22.9	1- calm	4- rain	5	Treatment in place = Control Mat
MS1	07/14/2021	13:30	15:30	T. McKenzie, K. Chau	6- none	1- brownish	1- calm	28.5	1- calm	2- partly cloudy	4	Row 1=PL, 2=BH, 3=BM
MS2	07/14/2021	14:00	15:20	G. Dennis, S. Lesher, N. Zarnstorff	6- none	1- brownish	1- calm	29.2	1- calm	2- partly cloudy	4	Treatment in place = *I. virginica*; water much clearer at outflow than at inflow
MS1	07/27/2021	08:40	10:10	J. Doyal, K. Chau	6- none	5- clear	1- calm	27.3	1- calm	2- partly cloudy	6	Ambient conditions event. Row 1=BH, 2=BM, 3=PL
MS2	07/27/2021	10:20	10:45	J. Doyal, K. Chau	6- none	1- brownish	1- calm	30.6	1- calm	2- partly cloudy	6	Ambient conditions. Treatment in place = Iris; invasive apple snails present and seen on mat
MS1	08/03/2021	11:30	12:58	G. Dennis, K. Chau, J. Doyal	6- none	1- brownish	1- calm	26.2	2- slight	3- cloudy	11	SS-D: surface scum on water. Row 1=BM, 2=PL, 3=BH
MS2	08/03/2021	11:35	12:26	S. Lesher, J. Nagro	6- none	5- clear	2- ripple	27.5	2- slight	2- partly cloudy	11	DO checked in ambient air and good
MS1	08/13/2021	14:03	14:29	S. Lesher, K. Chau	6- none	1- brownish	1- calm	28.9	2- slight	2- partly cloudy	10	Ambient conditions. Row 1=BM, 2=PL, 3=BH

MS	Date	Time Arrive	Time Depart	Collected By (F. Last)	Water Odor	Water Color	Water Surface	Air Temp. (°C)	Wind Intensity	Present Weather	Days Since Last Sig. Rain	Notes
MS2	08/13/2021	14:32	14:51	S. Lesher, K. Chau	6- none	1- brownish	1- calm	31.1	1- calm	2- partly cloudy	10	Ambient conditions. Treatment in place = swamp lily
MS1	09/01/2021	13:24	14:30	K. Chau, R. Gray	6- none	1- brownish	1- calm	30.1	1- calm	2- partly cloudy	2	Row 1=BM, 2=PL, 3=BH; checked DO in ambient -good
MS2	09/01/2021	14:39	14:56	K. Chau. R. Gray	6- none	1- brownish	1- calm	30.1	1- calm	3- cloudy	2	Checked DO in ambient air and good
MS1	09/28/2021	08:58	10:15	K. Chau, C. Thompson	6- none	1- brownish	2- ripple	26.4	1- calm	2- partly cloudy	9	SS-A: ditch flowing swiftly into inflow; started raining again at SS-B, stopped at SS-C; Row 1=PL, 2=BM, 3=BH
MS2	09/28/2021	10:23	10:45	K. Chau, C. Thompson	6- none	5- clear	1- calm	27.9	1- calm	2- partly cloudy	9	Treatment in place = lily; SS-G: lots of loose stands of cut grass at outfall
MS1	10/11/2021	08:27	09:51	J. Doyal, K. Chau	6- none	1- brownish	1- calm	22.8	1- calm	2- partly cloudy	8	FF samplers did not completely fill- couldn't fill all samples completely
MS2	10/11/2021	10:09	10:57	J. Doyal, K. Chau	6- none	1- brownish	1- calm	27.9	1- calm	2- partly cloudy	8	Treatment in place = control
MS1	10/20/2021	08:58	09:41	S. Lesher, K. Chau	6- none	5- clear	1- calm	23.8	2- slight	2- partly cloudy	9	Ambient conditions. SS-D: lots of duckweed on water surface
MS2	10/20/2021	09:46	10:10	S. Lesher, K. Chau	6- none	5- clear	1- calm	24.8	2- slight	2- partly cloudy	9	Ambient conditions. Lots of cutgrass stands loose near SSG
MS2	11/11/2021	09:35	10:30	K. Chau, J. Doyal, P. Kean	6- none	1- brownish	2- ripple	19.3	1- calm	3- cloudy	7	Baseline data collection. No mats installed.
MS2	11/16/2021	09:37	10:10	J. Doyal, K. Chau	6- none	5- clear	1- calm	24.6	2- slight	2- partly cloudy	5	Baseline data collection. No mats installed. Ambient cond.
MS2	12/06/2021	13:03	13:39	G. Dennis, S. Lesher, K. Chau	6- none	1- brownish	2- ripple	24.6	2- slight	3- cloudy	2	Baseline data collection – no mats. Visible mixing of inflow waters with main waterbody observed upon arrival

Appendix Table 2

Sonde Water Quality Readings Measured During Sampling Events

MS	Date	Event	Sampling Station	Sample Time	Total Depth (m)	Secchi (m)	Temp. (°C)	Specific Conductivity (µS/cm)	Turbidity (NTU)	DO (% sat.)	DO (mg/L)	pH
MS1	07/17/2020	Pre-Wet 1	SS-A	12:28	0.543	0.2	27.7	212.5	N/A	61.2	4.81	7.55
MS1	07/17/2020	Pre-Wet 1	SS-D	13:35	0.458	0.208	30.8	331.6	N/A	114.2	8.54	8.91
MS1	08/13/2020	Pre-Dry 1	SS-A	11:35	0.815	0.295	32.1	323	13.19	107.4	7.84	8.41
MS1	08/13/2020	Pre-Dry 1	SS-D	11:55	0.605	0.332	33.7	289.8	28.4	147.4	10.5	8.82
MS1	09/04/2020	Pre-Wet 2	SS-A	09:21	0.65	0.341	27.7	746	24.01	30.7	2.41	7.32
MS1	09/04/2020	Pre-Wet 2	SS-D	10:23	0.404	0.323	31.5	407.2	35.33	59	4.34	7.38
MS1	06/03/2021	Post-Wet 3	SS-A	13:52	0.499	0.092	26.2	104.7	78.78	95.1	7.67	8.26
MS1	06/03/2021	Post-Wet 3	SS-E	14:37	0.889	0.166	27.5	239	44.2	101.6	8.03	8.35
MS1	06/03/2021	Post-Wet 3	SS-B	14:50	1.07	0.582	27.8	308.2	20.8	83.1	6.51	7.82
MS1	06/03/2021	Post-Wet 3	SS-C	15:00	1.375	0.504	27.8	302.5	17.04	88.7	6.97	7.73
MS1	06/03/2021	Post-Wet 3	SS-D	15:15	0.605	0.498	27.8	298.1	14.55	90.2	7.1	7.91
MS2	06/03/2021	Post-Wet 3	SS-F	15:53	0.37	0.148	26.2	225.7	10.74	50.3	4.05	7.09
MS2	06/03/2021	Post-Wet 3	SS-G	16:03	0.816	**0.6**	26.6	240.3	12.74	37.3	2.99	6.96
MS1	07/14/2021	Post-Wet 4	SS-A	14:26	0.533	N/A	29.3	211.5	24.14	81.2	6.2	7.76
MS1	07/14/2021	Post-Wet 4	SS-E	14:52	1.064	N/A	29.6	208.5	23.47	105.5	8.05	8.28
MS1	07/14/2021	Post-Wet 4	SS-B	15:00	1.046	N/A	29.8	209.7	14.73	91	6.88	7.96

MS	Date	Event	Sampling Station	Sample Time	Total Depth (m)	Secchi (m)	Temp. (°C)	Specific Conductivity (µS/cm)	Turbidity (NTU)	DO (% sat.)	DO (mg/L)	pH
MS1	07/14/2021	Post-Wet 4	SS-C	15:10	1.404	N/A	29.9	214	13.5	108.5	8.2	8.12
MS1	07/14/2021	Post-Wet 4	SS-D	15:17	0.711	N/A	29.9	240	10.98	112.8	8.5	8.27
MS2	07/14/2021	Post-Wet 4	SS-F	14:46	1.009	0.11	28.4	187.5	26.54	63.8	4.93	7.03
MS2	07/14/2021	Post-Wet 4	SS-G	15:00	1.026	0.632	28.9	206	16.98	39.3	3.08	6.94
MS1	07/27/2021	Post-Dry 2	SS-A	08:55	0.61	0.552	30.6	380.2	69.25	37.2	2.78	7.20
MS1	07/27/2021	Post-Dry 2	SS-D	10:00	0.546	0.516	32.1	278.2	10.77	67.1	4.89	7.60
MS2	07/27/2021	Post-Dry 2	SS-F	10:28	0.758	0.924	30.6	188	6.6	38	2.83	7.40
MS2	07/27/2021	Post-Dry 2	SS-G	10:40	0.78	0.702	30.7	179.1	6.38	33.5	2.5	7.17
MS1	08/03/2021	Post-Wet 5	SS-A	12:03	0.597	0.128	28.8	239.3	28.45	59.5	4.59	7.63
MS1	08/03/2021	Post-Wet 5	SS-E	12:27	0.931	0.384	31	344.8	9.33	92.8	6.89	8.15
MS1	08/03/2021	Post-Wet 5	SS-B	12:37	0.915	0.432	31.2	348.5	9.1	79	5.86	7.91
MS1	08/03/2021	Post-Wet 5	SS-C	12:44	1.204	0.444	31.3	345.5	7.9	82.3	6.08	7.95
MS1	08/03/2021	Post-Wet 5	SS-D	12:54	0.53	0.38	31.3	346	9.09	87.5	6.46	8.00
MS2	08/03/2021	Post-Wet 5	SS-F	12:15	1.19	0.754	30.4	190.2	4.9	26.2	1.97	6.99
MS2	08/03/2021	Post-Wet 5	SS-G	12:30	1.006	0.618	30.5	189.7	4.8	25.7	1.93	6.97
MS1	08/13/2021	Post-Dry 3	SS-A	14:09	0.46	0.416	30.6	607	41.4	97.9	7.37	7.83
MS1	08/13/2021	Post-Dry 3	SS-D	14:24	0.465	0.488	32.3	417.9	28.23	85.5	6.24	7.84
MS2	08/13/2021	Post-Dry 3	SS-F	14:38	0.505	0.6	31	237.9	2.82	29.9	2.21	7.03

MS	Date	Event	Sampling Station	Sample Time	Total Depth (m)	Secchi (m)	Temp. (°C)	Specific Conductivity (µS/cm)	Turbidity (NTU)	DO (% sat.)	DO (mg/L)	pH
MS2	08/13/2021	Post-Dry 3	SS-G	14:46	0.697	>1.2	31.4	232.7	1.94	33.3	2.44	7.05
MS1	09/01/2021	Post-Wet 6	SS-A	13:30	0.505	0.154	30.3	276.2	40.5	71.9	5.4	7.64
MS1	09/01/2021	Post-Wet 6	SS-E	13:58	0.975	0.42	32.0	290.2	8.32	132.2	9.72	8.63
MS1	09/01/2021	Post-Wet 6	SS-B	14:08	0.965	0.48	32.1	297.7	12.42	111.2	8.16	8.18
MS1	09/01/2021	Post-Wet 6	SS-C	14:16	1.126	0.532	32.3	288.1	6.83	122.5	8.93	8.35
MS1	09/01/2021	Post-Wet 6	SS-D	14:22	0.489	0.538	32.3	289	8.45	122.9	8.94	8.36
MS2	09/01/2021	Post-Wet 6	SS-F	14:43	0.679	0.434	31.1	205.5	5.7	63.5	4.72	7.16
MS2	09/01/2021	Post-Wet 6	SS-G	14:52	0.865	0.754	30.8	196.7	9.45	49	3.64	7.00
MS1	09/28/2021	Post-Wet 7	SS-A	09:11	0.462	0.222	25.9	238.7	21.9	59.7	4.84	7.67
MS1	09/28/2021	Post-Wet 7	SS-E	09:38	0.863	0.59	27.5	243.6	12.5	81.9	6.47	7.97
MS1	09/28/2021	Post-Wet 7	SS-B	09:47	0.903	0.616	27.4	242	7.33	63.8	5.05	7.53
MS1	09/28/2021	Post-Wet 7	SS-C	09:55	1.235	0.658	27.4	239.1	5.66	71.2	5.63	7.60
MS1	09/28/2021	Post-Wet 7	SS-D	10:05	0.52	0.65	27.3	238.5	6.76	75.7	5.99	7.69
MS2	09/28/2021	Post-Wet 7	SS-F	10:29	0.937	0.518	26.1	209.5	3.55	51.3	4.12	7.13
MS2	09/28/2021	Post-Wet 7	SS-G	10:39	0.79	1.15	27.0	153.7	1.98	52	4.13	7.10
MS1	10/11/2021	Post-Wet 8	SS-A	08:50	0.547	0.302	24.4	298.5	13	33	2.75	7.24
MS1	10/11/2021	Post-Wet 8	SS-E	09:14	1.05	0.61	26.6	225.9	5.9	75.2	6.05	7.55
MS1	10/11/2021	Post-Wet 8	SS-B	09:25	0.985	0.45	26.4	231	7.2	61.1	4.92	7.32

MS	Date	Event	Sampling Station	Sample Time	Total Depth (m)	Secchi (m)	Temp. (°C)	Specific Conductivity (µS/cm)	Turbidity (NTU)	DO (% sat.)	DO (mg/L)	pH
MS1	10/11/2021	Post-Wet 8	SS-C	09:36	1.105	0.518	26.4	226.6	6.2	61.9	4.99	7.27
MS1	10/11/2021	Post-Wet 8	SS-D	09:47	0.636	0.59	26.3	224.6	7.8	62.9	5.07	7.30
MS2	10/11/2021	Post-Wet 8	SS-F	10:40	0.579	>1.2	26.0	170.3	3.6	34	2.76	6.82
MS2	10/11/2021	Post-Wet 8	SS-G	10:51	0.777	>1.2	26.2	167.6	3.1	32.1	2.6	6.84
MS1	10/20/2021	Post-Dry 4	SS-A	09:07	0.54	0.968	21.1	117	16	34.9	3.09	7.52
MS1	10/20/2021	Post-Dry 4	SS-D	09:30	0.51	0.73	22.7	311	6.69	52	4.47	7.42
MS2	10/20/2021	Post-Dry 4	SS-F	09:52	0.531	>1.2	23.2	187.3	2.71	29.7	2.52	6.98
MS2	10/20/2021	Post-Dry 4	SS-G	10:02	0.578	>1.2	23.2	187.4	2.41	26.5	2.24	6.97
MS2	11/11/2021	Pre-Wet 1	SS-F	10:07	0.914	0.186	18.8	111.1	18.62	76.6	7.19	7.18
MS2	11/11/2021	Pre-Wet 1	SS-G	10:27	0.753	0.332	19.3	161.3	8.11	61.5	5.67	7.19
MS2	11/16/2021	Pre-Dry 1	SS-F	09:44	0.691	>1.2	18.9	166.3	4.05	38.4	3.56	7.13
MS2	11/16/2021	Pre-Dry 1	SS-G	10:02	0.685	>1.2	19	165.7	3.2	37.3	3.44	7.11
MS2	12/06/2021	Pre-Wet 2	SS-F	13:20	0.57	0.1	21.2	214.8	10.46	52	4.63	7.19
MS2	12/06/2021	Pre-Wet 2	SS-G	13:35	0.868	>1.2	21.3	207.7	5.9	52.6	4.66	7.24

Appendix Table 3

Lab Analysis Results from Water Grab Samples and Composite Samples Collected During Sampling Events

MS	Date	Event	Sampling Station	Sample Time	Oil & Grease (mg/L)	TSS (mg/L)	Ammonia (mg/L)	Kjeldahl Nitrogen (mg/L)	Nitrate + Nitrate (mg/L)	Orthophosphorus (mg/L)	BOD (mg/L)	Total Phosphorus (mg/L)	*E. coli* (mg/L)
MS1	07/17/2020	Pre-Wet 1	SS-A	12:28	2	33.2	0.1	2.65	0.396	0.586	4.8	0.404	>2419.6
MS1	07/17/2020	Pre-Wet 1	SS-A-FF	12:32	N/A	82.4	0.557	2.93	2.49	1.49	N/A	0.621	N/A
MS1	07/17/2020	Pre-Wet 1	SS-D	13:35	1.4	24.4	0.0675	2.6	0.0236	0.151	4.8	0.235	104.6
MS1	08/13/2020	Pre-Dry 1	SS-A	11:35	1.5	26.3	0.36	2.13	0.084	0.429	4.97	1.56	16.9
MS1	08/13/2020	Pre-Dry 1	SS-D	11:55	2.1	12.4	0.0675	1.79	0.0229	0.277	4.8	1.3	7.5
MS1	09/04/2020	Pre-Wet 2	SS-A	09:21	2.1	17.6	0.186	1.81	0.582	2.25	4.8	0.667	1119.9
MS1	09/04/2020	Pre-Wet 2	SS-A-FF	09:21	N/A	2.6	0.123	1.41	0.204	0.759	N/A	0.308	N/A
MS1	09/04/2020	Pre-Wet 2	SS-D	10:23	2.2	15	0.137	1.67	0.017	0.77	4.8	0.292	52
MS1	06/03/2021	Post-Wet 3	SS-A	13:52	4.6	131	0.0912	0.751	0.385	0.116	4.36	0.159	24196
MS1	06/03/2021	Post-Wet 3	SS-A-FF	14:00	N/A	799	0.121	1.37	0.908	0.276	N/A	0.447	N/A
MS1	06/03/2021	Post-Wet 3	SS-E	14:37	4.1	44	0.0345	1.27	0.131	0.14	5.06	0.249	594
MS1	06/03/2021	Post-Wet 3	SS-B	14:50	4.1	12	0.0345	1.38	0.0396	0.146	8.88	0.281	5
MS1	06/03/2021	Post-Wet 3	SS-C	15:00	3.4	13.5	0.335	1.69	0.0494	0.143	9.46	0.276	10
MS1	06/03/2021	Post-Wet 3	SS-D	15:15	4.67	18.9	0.0345	1.54	0.0412	0.149	8.11	0.298	20
MS2	06/03/2021	Post-Wet 3	SS-F	15:53	3.6	22.1	0.196	0.881	0.734	0.424	3	0.508	2909

MS	Date	Event	Sampling Station	Sample Time	Oil & Grease (mg/L)	TSS (mg/L)	Ammo nia (mg/L)	Kjeldahl Nitrogen (mg/L)	Nitrate + Nitrate (mg/L)	Orthopho sphorus (mg/L)	BOD (mg/L)	Total Phosph orus (mg/L)	*E. coli* (mg/L)
MS2	06/03/2021	Post-Wet 3	SS-G	16:03	2.89	18.7	0.116	0.895	0.131	0.411	3	0.462	20
MS1	07/14/2021	Post-Wet 4	SS-A	14:26	5.62	42.6	0.0345	0.417	0.177	0.121	6.2	0.183	9804
MS1	07/14/2021	Post-Wet 4	SS-A-FF	14:26	N/A	347	0.0345	0.98	0.651	0.172	N/A	0.373	N/A
MS1	07/14/2021	Post-Wet 4	SS-E	14:52	6.3	28.5	0.106	0.614	0.114	0.0415	16.1	0.163	1106
MS1	07/14/2021	Post-Wet 4	SS-B	15:00	4.1	22.1	0.0345	0.456	0.109	0.0518	6.89	0.147	1850
MS1	07/14/2021	Post-Wet 4	SS-C	15:10	3.1	26	0.0345	0.546	0.119	0.0671	4.78	0.174	1529
MS1	07/14/2021	Post-Wet 4	SS-D	15:17	4.74	22.8	0.0345	0.758	0.0416	0.054	7.34	0.175	556
MS2	07/14/2021	Post-Wet 4	SS-F	14:46	3.3	37.7	0.0914	0.768	0.336	0.204	8.49	0.252	24196
MS2	07/14/2021	Post-Wet 4	SS-G	15:00	4.1	20.9	0.151	0.637	0.17	0.238	7.92	0.344	5475
MS1	07/27/2021	Post-Dry 2	SS-A	08:55	1.57	19.3	0.0345	1.15	0.121	0.132	3	0.174	23.1
MS1	07/27/2021	Post-Dry 2	SS-D	10:00	1.57	10.3	0.0345	0.653	0.0283	0.0987	3	0.173	7.4
MS2	07/27/2021	Post-Dry 2	SS-F	10:28	1.67	4.8	0.0345	1.9	0.0283	0.253	3	0.307	125
MS2	07/27/2021	Post-Dry 2	SS-G	10:40	1.65	6.1	0.0345	2.45	0.0283	0.265	3.96	0.315	21.8
MS1	08/03/2021	Post-Wet 5	SS-A	12:03	1.74	48.3	0.0627	1.13	0.496	0.277	26	0.416	<2419.6
MS1	08/03/2021	Post-Wet 5	SS-A-FF	11:58	N/A	56	0.0754	1.07	0.686	0.3	N/A	0.382	N/A
MS1	08/03/2021	Post-Wet 5	SS-E	12:27	1.74	18.1	0.0345	0.741	0.0316	0.0798	4.9	0.234	35
MS1	08/03/2021	Post-Wet 5	SS-B	12:37	1.74	18	0.0345	0.46	0.0306	0.0969	3.97	0.198	52.1

MS	Date	Event	Sampling Station	Sample Time	Oil & Grease (mg/L)	TSS (mg/L)	Ammonia (mg/L)	Kjeldahl Nitrogen (mg/L)	Nitrate + Nitrate (mg/L)	Orthophosphorus (mg/L)	BOD (mg/L)	Total Phosphorus (mg/L)	*E. coli* (mg/L)
MS1	08/03/2021	Post-Wet 5	SS-C	12:44	1.74	16.4	0.0345	0.586	0.0283	0.0892	4.45	0.235	64.4
MS1	08/03/2021	Post-Wet 5	SS-D	12:54	1.57	17.4	0.0345	0.994	0.0283	0.0938	4.2	0.251	36.4
MS2	08/03/2021	Post-Wet 5	SS-F	12:15	1.57	7.79	0.0345	0.308	0.0471	0.199	3.95	0.285	37.4
MS2	08/03/2021	Post-Wet 5	SS-G	12:30	1.57	10.1	0.0345	0.359	0.0283	0.209	4.61	0.291	18.5
MS1	08/13/2021	Post-Dry 3	SS-A	14:09	1.57	16.6	0.066	0.934	0.263	0.241	3.86	0.294	75
MS1	08/13/2021	Post-Dry 3	SS-D	14:24	1.57	31.3	0.0345	1.07	0.134	0.131	4.61	0.201	30
MS2	08/13/2021	Post-Dry 3	SS-F	14:38	1.57	8	0.0663	0.872	0.152	0.281	3.6	0.32	<10
MS2	08/13/2021	Post-Dry 3	SS-G	14:46	1.57	6.8	0.0615	0.839	0.143	0.284	4.15	0.344	41
MS1	09/01/2021	Post-Wet 6	SS-A	13:30	2.6	51.1	0.0694	0.668	0.846	0.22	6.35	0.281	9208
MS1	09/01/2021	Post-Wet 6	SS-A-FF		N/A	60.2	0.0345	0.466	0.816	0.223	N/A	0.296	N/A
MS1	09/01/2021	Post-Wet 6	SS-E	13:58	1.57	15.5	0.0345	0.872	0.163	0.0917	4.04	0.217	20
MS1	09/01/2021	Post-Wet 6	SS-B	14:08	2.1	12.2	0.0345	1.02	0.106	0.0863	3.58	0.192	10
MS1	09/01/2021	Post-Wet 6	SS-C	14:16	3.2	12	0.0345	0.773	0.155	0.0795	3.2	0.186	5
MS1	09/01/2021	Post-Wet 6	SS-D	14:22	2.9	16.4	0.0345	0.617	0.162	0.0834	4.01	0.185	10
MS2	09/01/2021	Post-Wet 6	SS-F	14:43	2.5	13.6	0.0345	1.09	0.21	0.205	3	0.283	171
MS2	09/01/2021	Post-Wet 6	SS-G	14:52	3	38.8	0.0345	0.771	0.19	0.194	3	0.262	41
MS1	09/28/2021	Post-Wet 7	SS-A	09:11	1.74	16.4	0.0345	0.586	0.0283	0.0892	4.45	0.235	64.4

MS	Date	Event	Sampling Station	Sample Time	Oil & Grease (mg/L)	TSS (mg/L)	Ammonia (mg/L)	Kjeldahl Nitrogen (mg/L)	Nitrate + Nitrate (mg/L)	Orthophosphorus (mg/L)	BOD (mg/L)	Total Phosphorus (mg/L)	*E. coli* (mg/L)
MS1	09/28/2021	Post-Wet 7	SS-A-FF	08:58	N/A	39.3	0.0345	0.92	2.96	0.541	N/A	0.574	N/A
MS1	09/28/2021	Post-Wet 7	SS-E	09:38	1.57	10.5	0.0345	0.523	0.149	0.0754	3	0.114	5
MS1	09/28/2021	Post-Wet 7	SS-B	09:47	1.6	9.87	0.0345	0.488	0.144	0.079	3	0.129	5
MS1	09/28/2021	Post-Wet 7	SS-C	09:55	1.6	10.2	0.0345	0.535	0.146	0.0735	3	0.127	5
MS1	09/28/2021	Post-Wet 7	SS-D	10:05	1.8	12.3	0.0345	0.547	0.126	0.074	3	0.131	20
MS2	09/28/2021	Post-Wet 7	SS-F	10:29	1.7	7.2	0.0345	0.555	1.45	0.273	3	0.377	1576
MS2	09/28/2021	Post-Wet 7	SS-G	10:39	1.57	4	0.0345	0.444	0.139	0.173	3	0.2	5
MS1	10/11/2021	Post-Wet 8	SS-A	08:50	1.57	20.8	0.0746	1.51	1.62	0.488	4.2	0.524	1439
MS1	10/11/2021	Post-Wet 8	SS-A-FF	08:46	N/A	8.89	0.0414	0.875	3.69	0.909	N/A	1.27	N/A
MS1	10/11/2021	Post-Wet 8	SS-E	09:14	1.57	9	0.0345	0.592	0.134	0.738	3	0.178	135
MS1	10/11/2021	Post-Wet 8	SS-B	09:25	1.57	12	0.0345	0.991	0.168	0.0883	3	0.17	31
MS1	10/11/2021	Post-Wet 8	SS-C	09:36	1.87	12.2	0.0345	0.716	0.145	0.0856	3	0.174	20
MS1	10/11/2021	Post-Wet 8	SS-D	09:47	1.87	10	0.0345	0.845	0.124	0.0843	3	0.181	20
MS2	10/11/2021	Post-Wet 8	SS-F	10:40	1.57	4	0.037	0.67	0.147	0.221	3	0.364	10
MS2	10/11/2021	Post-Wet 8	SS-G	10:51	1.57	4	0.0407	0.544	0.153	0.217	3	0.312	20
MS1	10/20/2021	Post-Dry 4	SS-A	09:07	1.57	27.9	0.0703	1.31	4.69	0.553	3	0.865	96
MS1	10/20/2021	Post-Dry 4	SS-D	09:30	1.57	43.8	0.0345	0.72	0.171	0.0666	3	0.131	<10

MS	Date	Event	Sampling Station	Sample Time	Oil & Grease (mg/L)	TSS (mg/L)	Ammo nia (mg/L)	Kjeldahl Nitrogen (mg/L)	Nitrate + Nitrate (mg/L)	Orthopho sphorus (mg/L)	BOD (mg/L)	Total Phosph orus (mg/L)	*E. coli* (mg/L)
MS2	10/20/2021	Post-Dry 4	SS-F	09:52	1.9	5.3	0.0944	0.681	0.175	0.262	3	0.306	10
MS2	10/20/2021	Post-Dry 4	SS-G	10:02	1.94	4	0.101	0.79	0.154	0.264	3	0.312	<10
MS2	11/11/2021	Pre-Wet 1	SS-F	10:07	1.57	28.9	0.0448	0.349	0.393	0.169	3.4	0.166	57940
MS2	11/11/2021	Pre-Wet 1	SS-G	10:27	1.57	5.2	0.0353	0.405	0.227	0.136	3	0.143	573
MS2	11/16/2021	Pre-Dry 1	SS-F	09:44	1.6	5.2	0.0345	0.315	0.127	0.146	3	0.192	20
MS2	11/16/2021	Pre-Dry 1	SS-G	10:02	1.57	4	0.0345	0.361	0.188	0.148	2.4	0.159	20
MS2	12/06/2021	Pre-Wet 2	SS-F	13:20	2	24.6	0.0345	0.548	0.0283	0.218	3	0.219	3654
MS2	12/06/2021	Pre-Wet 2	SS-G	13:35	1.57	6.5	0.0345	0.536	0.0283	0.16	3	0.157	213

APPENDIX C:

VEGETATION SURVEY DATA

Appendix Table 4

MS1 Vegetation Monitoring Results Average Occurrence and Height from 10/28/2020 through 12/21/2022

Common Name	Scientific Name	Average % Cover Total (all 3 mats)	Average Height (cm) Total (all 3 mats)	Average % Cover Beemats	Average Height (cm) Beemats	Average % Cover BioHaven	Average Height (cm) BioHaven	Average % Cover PhytoLinks	Average Height (cm) PhytoLinks
Alligatorweed	*Alternanthera philoxeroides*	7.54%	10.33	3.12%	10.97	2.88%	6.52	10.48%	11.19
Cuman ragweed	*Ambrosia psilostachya*	0.68%	19.5	0.5%	16.2	0.5%	6.5	0.86%	25.57
Asters	*Aster spp.*	1%	35.33	1.1%	36.4	0%	N/A	0.5%	30
Lemon Bacopa	*Bacopa caroliniana*	2.26%	7.87	3.25%	7.75	2.68%	6.78	1.47%	8.68
Bare/Duff	N/A	46.32%	N/A	37.96%	N/A	61.19%	N/A	42.30%	N/A
Erect Spadeleaf	*Centella erecta*	0.56%	3.63	0.5%	2	0%	N/A	0.57%	3.73
Wild Basil	*Clinopodium spp.*	6.31%	11	6.31%	11	0%	N/A	0%	N/A
Swamp Lily	*Crinum americanum*	1.96%	15.41	2.96%	17.47	1.7%	14.27	1.60%	15.03
Pond Flatsedge	*Cyperus ochraceus*	0.97%	15.08	0.82%	18	0.75%	9.5	1.09%	14.17
Rosette grasses	*Dicanthelium spp.*	15%	60	0%	N/A	0%	N/A	15%	60
Ponysfoot	*Dichondra spp.*	0.52%	4.94	0.52%	5.71	0.5%	2	0.5%	2.33
Hairy Crabgrass	*Digitaria sanguinalis*	0.9%	47.6	0.5%	47	0%	N/A	1.5%	48.5
False Daisy	*Eclipta prostrata*	1.66%	5.12	0.87%	2.75	2.56%	5.77	1.53%	5.82

Common Name	Scientific Name	Average % Cover Total (all 3 mats)	Average Height (cm) Total (all 3 mats)	Average % Cover Beemats	Average Height (cm) Beemats	Average % Cover BioHaven	Average Height (cm) BioHaven	Average % Cover PhytoLinks	Average Height (cm) PhytoLinks
Spikerushes	*Eleocharis spp.*	0.84%	15.36	0.64%	14.79	0.5%	9	1.09%	16.27
Dog Fennel	*Eupatorium capillifolium*	2%	60	0%	N/A	0%	N/A	2%	60
Hairy Crabweed	*Fatoua villosa*	3.49%	20.47	1.83%	16.39	2.61%	13.89	4.5%	25.97
Catchweed bedstraw	*Galium aparine*	0.75%	25.5	0.75%	25.5	0%	N/A	0%	N/A
Carolina geranium	*Geranium carolinianum*	0.5%	2.75	0.5%	6	0.5%	2.1	0%	N/A
Pennywort	*Hydrocotyle spp.*	10.60%	7.62	7.89%	7.22	10.37%	7.89	12.67%	7.86
Waterleaf	*Hydrolea spp.*	0.5%	3	0.5%	3	0%	N/A	0%	N/A
Morning-glory Vine	*Ipomoea spp.*	4.66%	8.77	1.31%	6.5	16.07%	7	2.63%	9.57
Virginia Iris	*Iris virginica*	4.71%	40.74	6.01%	41.12	4.66%	42.91	4.06%	39.14
Common Rush	*Juncus effusus*	6.72%	49.71	11.81%	62.27	2.57%	39.36	6.45%	49.18
Poverty Rush	*Juncus tenuis*	0.5%	12	0%	N/A	0.5%	12	0%	N/A
Mexican Primrose-willow	*Ludwigia octovalvis*	2.73%	8.04	3.08%	15.32	7.67%	6.67	2.26%	5.07
Dallisgrass	*Paspalum dilatatum*	0.75%	9	0%	N/A	0%	N/A	0.75%	9
Paspaluum	Paspaluum spp.	0.94%	8.13	0.70%	8.36	0.51%	4.16	1.20%	9.43
Turkey Tangle Frogfruit	*Phyla nodiflora*	2.46%	16.58	0%	N/A	0.5%	6.17	4.42%	27
Swamp Smartweed	*Polygonum hydropiperoides*	3.90%	29.49	1.85%	25.15	1.14%	18.55	5.70%	34.63
Pickerelweed	*Pontederia cordata*	3.10%	22.26	4.45%	24.01	2.35%	21.96	2.87%	21.49

Common Name	Scientific Name	Average % Cover Total (all 3 mats)	Average Height (cm) Total (all 3 mats)	Average % Cover Beemats	Average Height (cm) Beemats	Average % Cover BioHaven	Average Height (cm) BioHaven	Average % Cover PhytoLinks	Average Height (cm) PhytoLinks
Marsh mermaidweed	*Proserpinaca palustris*	0.5%	4.5	0.5%	4.5	0%	N/A	0%	N/A
Dock or Sorrel	*Rumex spp.*	1.19%	12.2	0.91%	12.07	0.5%	2.5	1.52%	13
Swamp dock	*Rumex verticillatus*	0.59%	3.55	0%	N/A	0%	N/A	0.59%	3.55
Black willow	*Salix nigra*	3.5%	94.33	0.5%	150	5%	66.5	0%	N/A
Canada goldenrod	*Solidago canadensis*	0.8%	53.8	0.75%	72.5	0%	N/A	0.83%	41.33
Bald cypress	*Taxodium distichum*	0.5%	6	0.5%	6	0%	N/A	0%	N/A
Inch plant	*Tradescantia spp.*	0.5%	5.91	0.5%	5.91	0%	N/A	0%	N/A
White clover	*Trifolium repens*	1.23%	4.29	0%	N/A	0.1%	10	1.42%	3.33
Cedar elm	*Ulmus crassifolia*	0.5%	4	0%	N/A	0.5%	4	0.5	4
Elm tree variety	*Ulmus spp.*	0.2%	9	0%	N/A	0.2%	9	0%	N/A
Broadleaf signalgrass	*Urochloa platyphylla*	0.62%	8.30	0.49%	9.04	0.5%	6	0.77%	8.23
Hairypod cowpea	*Vigna luteola*	5.23%	15.86	1.89%	11.33	8.42%	5	6.55%	17.29