Stormwater Best Management Practice (BMP) Testing at the Ghirardi Family WaterSmart Park

FINAL REPORT

582-16-60055

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Compiled by the

Texas Community Watershed Partners

A program of the Texas A&M AgriLife Extension Service

PREPARED IN COOPERATION WITH THE

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY AND

U.S. ENVIRONMENTAL PROTECTION AGENCY

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Executive Summary

In suburban communities, much of the land is covered by impervious surfaces including buildings, pavement and compacted landscapes. All of these impact stormwater drainage systems and increase runoff volume and velocity from rain storms. This runoff often carries pollutants called nonpoint source pollution. The Ghirardi Family WaterSmart Park[(GFWP), League City, TX] is a real world example of using green infrastructure best management practices to mitigate nonpoint source pollution. This study collected outflow water quality data from five rainfall events and showed overall positive percent reductions for rainwater harvesting, green roof, and bioswale for nitrogen, total suspended solids, and E. coli. No reductions were seen for total phosphorous for any of these practices.

Introduction

In suburban communities, much of the land is covered by impervious surfaces including buildings, pavement and compacted landscapes. All of these impact stormwater drainage systems and increase runoff volume and velocity from rain storms. This runoff often carries pollutants including: sediment; oil, grease and toxic chemicals from motor vehicles; pesticides and nutrients from lawns and gardens; viruses, bacteria and nutrients from pet waste and failing septic systems; heavy metals from roof shingles, motor vehicles and other sources. These pollutants, often referred to as nonpoint source pollution (NPS), can harm fish and wildlife, kill native vegetation, and make recreational areas unsafe and unpleasant.

Green infrastructure (GI) best management practices (BMPs) are site specific solutions that slow down stormwater runoff. These practices use plants and soil to remove pollutants from the water as it filters through the BMP. A number of BMPs have been used across the United States and are becoming more common in Texas.

The GFWP (1810 Louisiana Avenue, League City, TX) was completed in 2014 and provides local examples of GI BMPs. As part of the original Texas Commission on Environmental Quality (TCEQ) funded 319(h) grant project (582-11-13147), the Texas Community Watershed Partners (TCWP) established a sampling protocol to monitor outflow from these BMPs. This Galveston Bay Estuary Program (GBEP) funded project was a continuation of the original monitoring program. These two projects combined to provide local data over four calendar years and BMP percent removal rates.

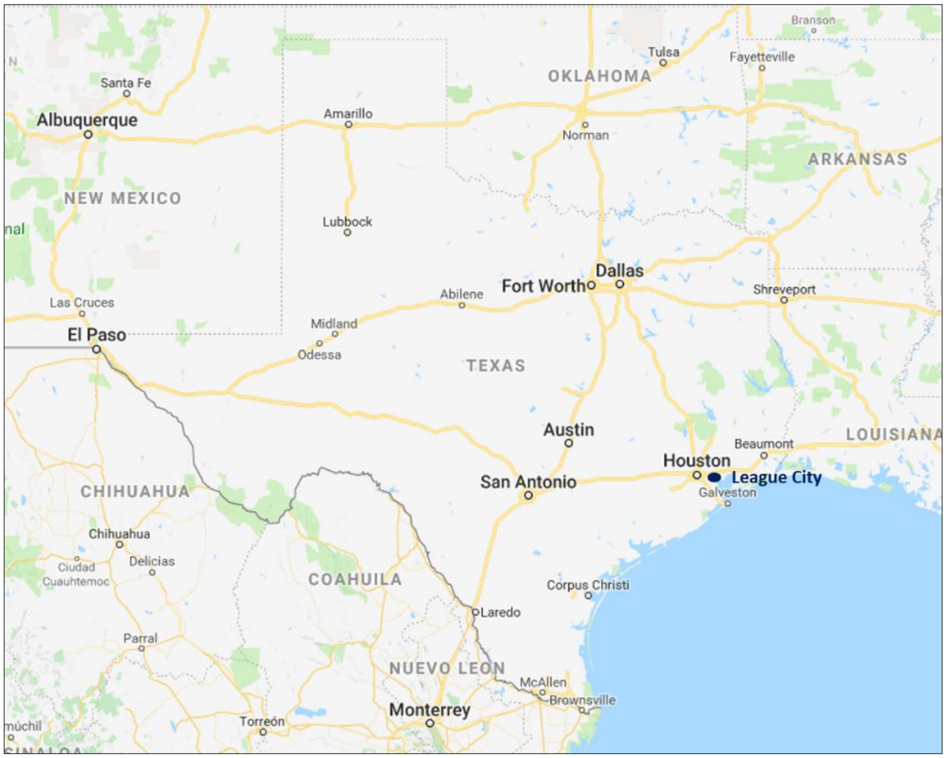

Figure 1. League City, TX is located south east of Houston, it straddles the Clear Creek and Dickinson Bayou watersheds both of which drain into Galveston Bay, the second largest bay ecosystem in the United States.

The GFWP is a public venue that showcases stormwater management techniques. The BMPs in the park serve both education and demonstration purposes. The park allows developers, city staff, community officials and residents to view functioning BMPs, learn how BMPs fit into the landscape, how BMPs can work together to form a treatment train, and how BMPs truly enhance the area while improving water quality. Five BMPs are showcased in this facility and were included in this study. They are:

- Rain gardens
- Bioswales
- Pervious pavers
- Rainwater harvesting
- Green roof

Each BMP was designed and engineered specifically for this space and represents best practices for the soil type and rainfall amounts typical of the Houston-Galveston region.

Figure 2. Ghirardi Family WaterSmart Park, League City, TX

Project Significance and Background

Numerous bayous, creeks and streams flowing through Coastal Texas, are considered impaired by the State of Texas for high levels of bacteria and low levels of dissolved oxygen.[1] In the Lower Galveston Bay watershed, major pollution sources include pets and livestock, feral hogs, sanitary sewer overflows and leaks, and malfunctioning on-site sewage facilities, as well as stormwater runoff. To address these issues, a number of Watershed Protection Plans, Total Maximum Daily Loads, and Bacteria Implementation Plans have been written. Many of these plans identify green infrastructure and stormwater best management practices as methods to mitigate the effects of stormwater runoff.

While there is a growing body of data worldwide that shows that stormwater BMPs are effective at removing pollutants, there is very little local data to show just how well these practices function in the soils and climate of the Texas Gulf Coast, or if the current design specifications are appropriate for our area. This study aimed to begin filling the knowledge gap by studying stormwater BMPs constructed at the Ghiradi Family WaterSmart Park in League City, TX.

Methods

Task 1: Project Administration

Objective: To effectively administer, coordinate, and monitor all work performed under this project including technical and financial supervision and preparation of status reports.

[1] https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/16txir/2016_303d.pdf

TCWP and GBEP staff coordinated throughout the course of the project to ensure technical and financial project needs were met and status reports were completed.

Task 2: Quality Assurance

Objective: To refine, document, and implement data quality objectives and quality assurance/quality control activities that ensure data of known and acceptable quality are generated by this project.

This project built upon the previous TCEQ funded sampling project. The Quality Assurance Project Plan (QAPP) from the original project was revised to meet the needs of the current project. The QAPP was amended throughout the project period to reflect changes to the project including staff changes. The most notable addition was the addition of soil sampling for infiltration BMPs to the project.

The quality assurance (QA) audits were performed by GBEP staff, field audits for both water quality samples and soil samples, and a desk audit for all aspects of the projects were completed in Fiscal Year 2018. Corrective Action Reports (CAR) were completed and submitted by TCWP project staff as needed.

Task 3: Execute Water Quality Monitoring Protocol

Objective: Implement the water quality sampling protocols as outlined in the QAPP.

A combination of ISCO automated samplers and grab samples were used, field parameters (dissolved oxygen, air and water temperature, pH, and conductivity) were measured, and additional parameters (nitrate + nitrite, phosphorous, orthophosphate, total suspended solids, and *E. coli*) were measured at Eastex Environmental, a NELAP certified laboratory. A minimum rainfall of 0.29 inches was needed for sampling, as the BMPs were designed to capture and treat the 90^{th} percentile storm, which is 0.29 inches locally. Rainfall events under 0.29 inches do not produce enough outflow from BMPs for sampling. Soil sampling was completed in the spring of 2018 for the two infiltration BMPs, rain garden and swale, as well as control sites around the park.

Water quality data was submitted to the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database, where it is available for download and use for further analysis.

Task 4: White Paper

Objective: Summarize findings and conclusions in a white paper.

Water quality and soil data were analyzed and presented in a white paper (Appendix A) for dissemination to interested parties. Data from both water quality sampling projects was included in the white paper as were percent reduction values from similarly designed BMPs at the Texas A&M AgriLife Dallas Urban Center (funded by TCEQ project 582-14-40155). This was done to provide context and relevance for the data collected.

Results and Observations

Task 2: Quality Assurance

The QAPP was amended two times during the course of the project: June 2017 and December 2017.

Corrective Action Reports (CARs) were needed to address issues with the ISCO automated samplers for the following sampling dates: 12/17/2017, 12/19/2017, 1/8/2018, 2/22/2018, and 3/29/2018.

Quality Assurance Audits were completed per the contract requirements, the water quality field audit was conducted 3/29/2018, field audit for soil sampling was conducted on 4/9/2018, and the desk audit on 5/29/2018. No negative findings resulted from the desk audit, only one comment was received ("Records of educational credentials, training, demonstrations of competency, assessments, and corrective actions are retained by project management and are available for review" were not available for all TCWP project staff.) This information was later provided to the GBEP project manager.

Task 3: Execute Water Quality Monitoring Protocol

Water Quality

Five sampling dates yielded sufficient rainfall for outflow from the BMPs. Figures 3, 4, 5, and 6 show measured values for nitrogen, total phosphorous, total suspended solids, and E. coli by BMP for each sampling date.

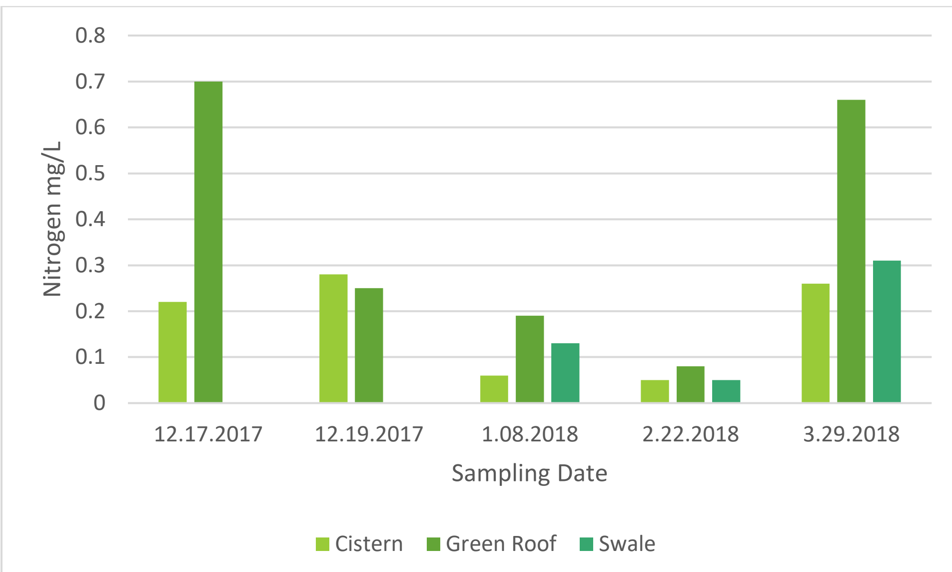

Figure 3. Measured nitrogen in BMP outflow by sampling date

Nitrogen levels were highest for the green roof on most sampling dates, but these levels are not high enough to raise concern.

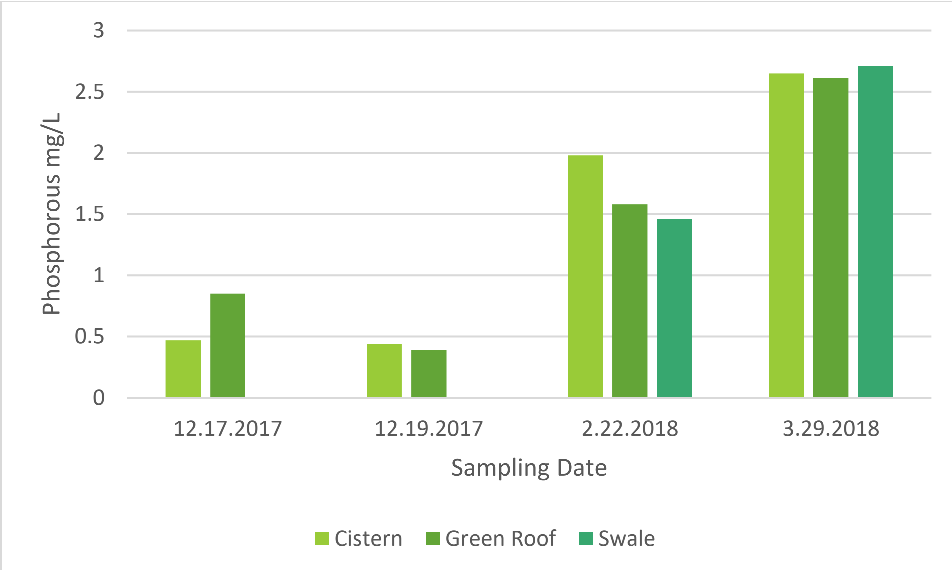

Figure 4. Measured phosphorous in BMP outflow by sampling date

Total phosphorous levels in the outflow were similar for all BMPs across all sampling dates. The values for 2/22/2018 and 3/29/2018 are higher than the other sampling events, but are not outside of the normal range.

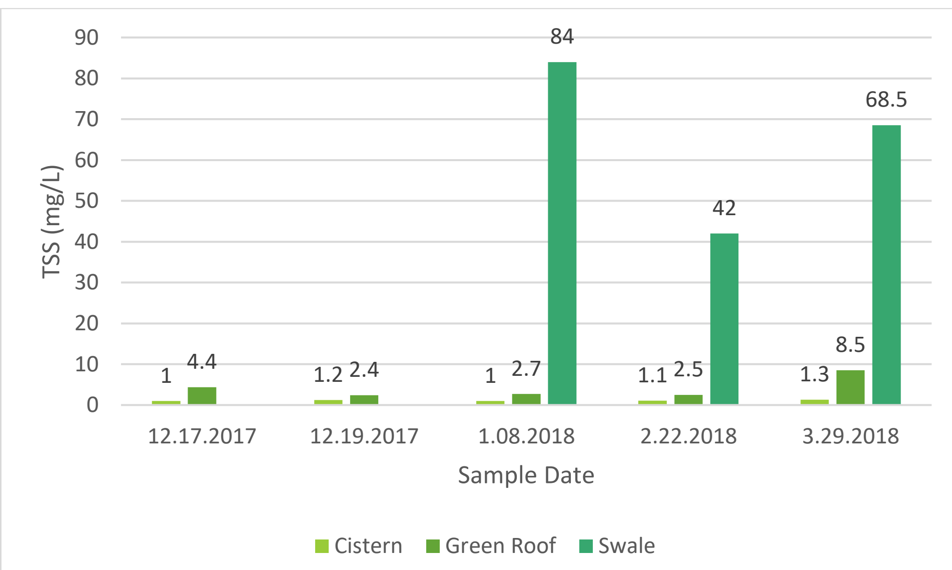

Figure 5. Measured total suspended solids in BMP outflow by sampling date

TSS levels across all sampling dates were low with the exception of the bioswale on 1/8/2018, 2/22/2018, and 3/29/2018. There was a large amount of sediment build up at the mouth of swale that was washed back into the pipe during large rain events, this likely is the reason for high TSS values, not soil washing in from the BMP watershed. The sediment was due to the theft of rock used to stabilize the swale outflow pipe, when the rock was in place, the lower TSS values were observed. Since sampling has ended, the rock has been replaced.

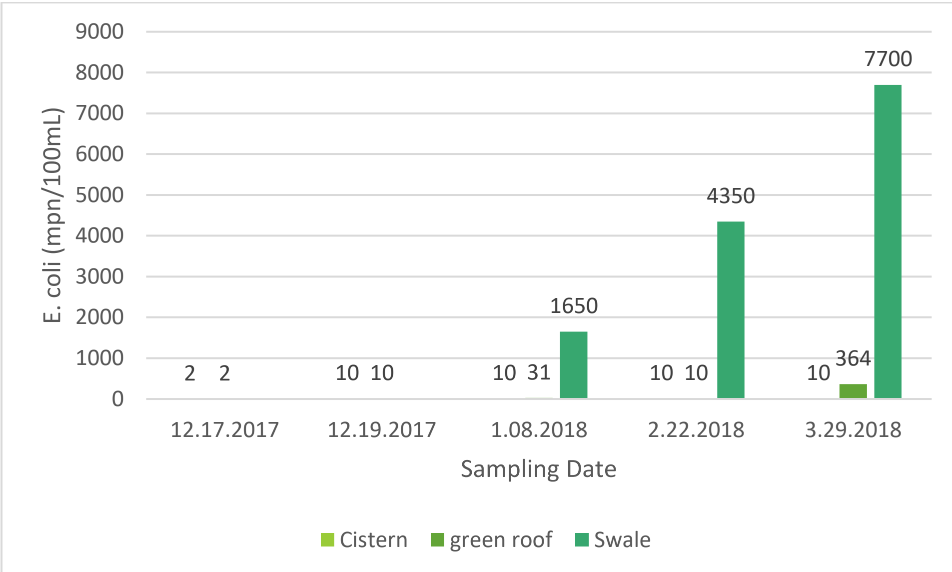

Figure 6. Measured E. coli in BMP outflow by sampling date

Overall, the bacteria levels in outflow were very low, and under the limit for contact recreation standards (126 mpn/100mL). For the swale, high E.coli levels were seen in 1/8/2018, 2/22/2018, and 3/29/2018. These are the same dates as high TSS levels. This indicates a possible connection between those two parameters. Levels about the standard were also seen on 3/29/2018 for the green roof.

Soil

Particle-size Distribution

Soil texture is shown on the soil triangle in Figure 7. The United States Department of Agriculture (USDA) classifies clay as anything finer than two micrometers, whereas the United States Geological Survey boundary is at four micrometers. The plotted points therefore may be clayier than the actual values. Nonetheless, the plot does show relationships between the samples very well. The Control Site points were tightly clustered right in the middle of the Silty Clay Loam texture. Both the Rain Garden (RG) and Bioswale (BS) points had a much greater spread across the texture diagram. The control sites contain soils native to the area, the rain garden contains a rain garden soil mix that contains sand and compost, the swale is also composed of native soil but has been manipulated to create the gradient of the swale.

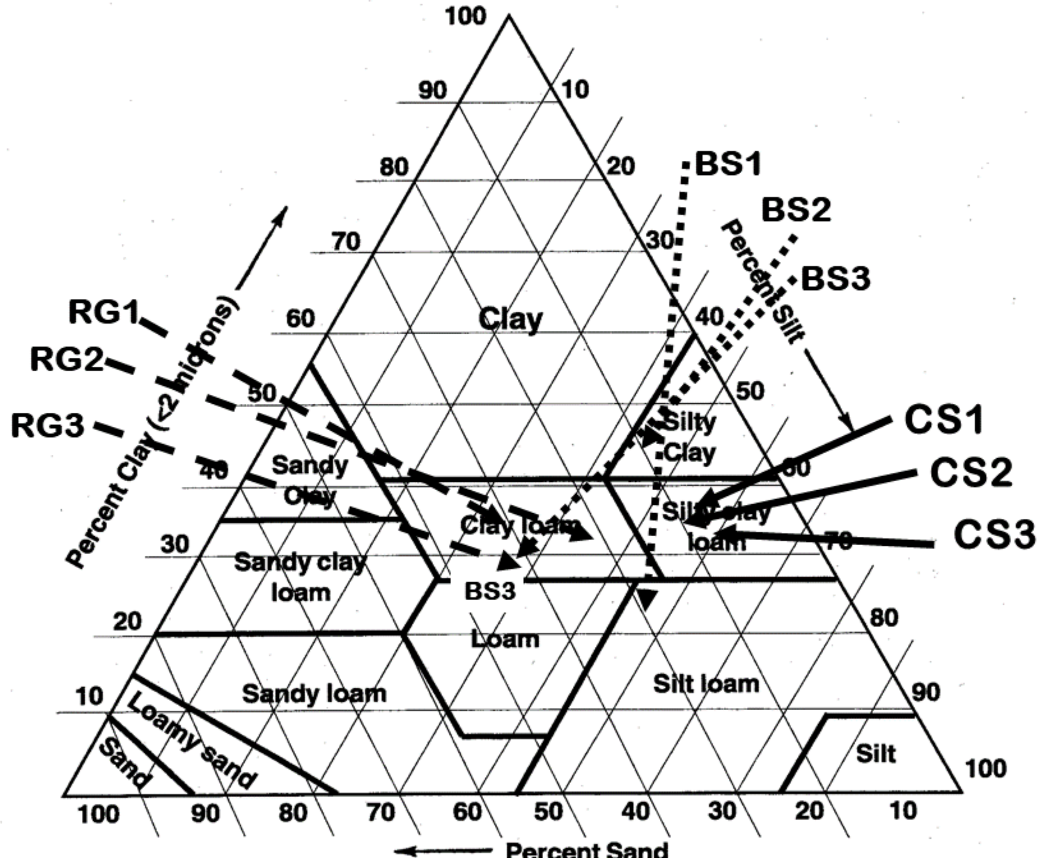

Figure 7. Soil textures of each sampling site plotted on the USDA texture triangle. CS=control sites; RG=rain garden; BS=bioswale.

Heavy Metals

Heavy metal concentrations varied widely across all sites at the GFWP (Table 1), but all of the values are within expected values. The values for the control sites had approximately the same spread for each element as was found in the bioswale and the rain garden. No patterns were observed for any of the other analytes.

Table 1. Soil heavy metal data for control sites, rain garden, and bioswale

	Control Site 1	Control Site 2	Control Site 3	Rain Garden Inflow	Rain Garden Midpoint	Rain Garden Outflow	Bioswale Inflow	Bioswale Midpoint	Bioswale Outflow
Arsenic (mg/Kg dry)	4.43	2.64	3.03	2.88	2.97	3.71	2.51	2.74	2.5
Cadmium (mg/Kg dry)	1.29	1.25	0.967	0.932	0.959	1.25	1.1	1.17	1.1
Chromium (mg/Kg dry)	24.2	25.3	16.9	20.5	18.1	25.8	20.2	23.9	23.2
Copper (mg/Kg dry)	8.13	8.97	13.2	11.3	12.2	13.8	6.08	7.22	6.14
Lead (mg/Kg dry)	29.9	7.5	8.47	5.35	5.46	8.45	9.46	10	8.23
Mercury, Total (mg/Kg dry)	0.0788	0.0239	0.0371	0.0474	0.0215	0.033	0.0296	0.0201	0.0183
Molybdenum (mg/Kg dry)	<0.0119	<0.0119	<0.0114	<0.0153	<0.0137	<0.0148	<0.0116	<0.0125	<0.0119
Nickel (mg/Kg dry)	12.9	9.68	7.3	9.16	9.54	11.8	7.86	9.34	8.73
Percent Solid (%)	83.8	84.1	87.8	65.4	72.9	67.5	86.1	80.2	84.2
Phosphorus (mg/Kg dry)	57.9	31.5	29.6	128	263	200	24.4	22.4	34.4
Potassium (% dry)	0.196	0.221	0.139	0.166	0.141	0.214	0.195	0.202	0.193
Selenium (mg/Kg dry)	<0.0119	<0.0119	<0.0114	<0.0153	<0.0137	<0.0147	<0.0116	<0.0125	<0.0119
Zinc (mg/Kg dry)	34.1	36.2	21.3	42	32	39	33	28.8	25.7

Task 4: White Paper

The project White Paper (Appendix A) focused on the bioswale, rainwater harvesting, and green roof BMPs due to limited data for the rain garden and pervious pavers. It also assessed the percent removal rates for the GFWP and the Texas A&M AgriLife Dallas Urban Center (Table 1). There are no overall similarities or discernable patterns between the two sites. Overall, at GFWP nitrogen was removed from BMPs. Phosphorus had a negative percent reduction, meaning P values were larger in outflow data than those calculated for inflow. TSS was removed by all three BMPS, and E. coli values were less in measured outflow than in calculated inflows. In Dallas, all BMPs showed positive percent removals except for the green roof for nitrogen. However, the percent increase was still smaller than the percent increase at the GFWP by an order of magnitude. Additional sampling results are included in Task 3 above.

Table 2. Percent Reductions for Nitrogen, Phosphorous, Total Suspended Solids, and E. coli for both the Ghirardi Family WaterSmart Park and the Dallas AgriLife Reserach Center

	Percent Reduction GFWP				Percent Reduction Dallas Center[2]			
	Nitrogen	**Phosphorous**	**Total Suspended Solids**	**E. coli**	**Nitrogen**	**Phosphorous**	**Total Suspended Solids**	**E. coli**
Bioswale	93	-1200*	17	99.9	NS	NS	NS	NS
Green Roof	81	-800*	93	99.9	-11*	49	75	89
Rainwater Harvesting	20	-1100*	68	99.9	50	79	52	NS

*A negative value for percent reduction, indicates that the measured level in the outflow was greater than the calculated expected value for inflow

NS- Not sampled

Discussion

Water quality data for the GFWP does not show a clear overall pattern but is still part of telling the larger story of GI BMPs in Coastal Texas. As more practices are implemented, and additional data collected, the value of these BMPs will be more discernable. Data for the park does show positive percent reductions for nitrogen, TSS, and E.coli, though some are only small reductions. These results are consistent with BMPs across the United States as reported in the 2016 International Stormwater BMP Database Summary Statistics Report[3]. Based on these findings, TCWP staff feel comfortable continuing to recommend these BMPs for use in the Lower Galveston Bay watershed.

At the GFWP, through field observations, TCWP staff saw that rain gardens and swales do positively impact infiltration. Areas of the park without BMPs routinely held standing water after rainfall events, especially large or heavy rainfalls. Areas of the park with BMPs did not have standing water, indicating

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[2] Jaber, F. 2015. Dallas Urban Center Stormwater BMPS Final Report. https://www.tceq.texas.gov/assets/public/waterquality/nps/projects/40155_FinalReport.pdf

[3] WERF, 2016. Final Report International Stormwater BMP Database 2016 Summary Report. http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf

that the BMPs were infiltrating runoff. Despite a lack of pollutant removal data for rain gardens, these are still one of the best practices for use in the Houston-Galveston Region, provided sufficient space is available for the garden.

A logical next step for the GFWP is a long-term data set to better understand the BMPs as they mature and age. The GFWP is an excellent location for longer term monitoring, however, this project is not a good fit for the TCWP and another partner should be sought to take on this project. This partner should also work with the City of League City to allow the ISCO samplers to be onsite at the park on a more permanent basis, reducing staff time to move samplers around before and after storm events, and allow more rainfall events to be captured.

Sampling logistics for the GFWP protocol are overly complicated. For a long-term sampling location, the protocol should be robust, transferable, and simple. At the request of League City staff, the GFWP protocol was developed such that ISCO samplers were not kept on site. Because the BMPs are so prominent at the GFWP, Parks Department staff were concerned that sampling equipment kept on site would detract from the facility. This decision was made before the park construction was complete. Now that the park has been open to the public for four years, there are obvious locations where small boxes housing ISCO samplers could be integrated into the park design without impacting the visual appeal of the park. For example, the rain garden sits in a corner of the park separated by the parking lot from the most used spaces. A small concrete pad and shed to house the ISCO could easily be installed without most park visitors even noticing. For locations like the pervious pavers where a sampler box would be difficult to situate long term, the box could be integrated into the park design. Interpretive signage for the BMP could be mounted directly onto a small shed-like structure with the ISCO sampler inside and solar panels for battery charging; this design could also contain Plexiglas windows to show the samplers at work.

ISCO samplers can also connect to a cellular modem to notify field staff by text message of site conditions and considerations. This technology also allows program changes to be made remotely. Due to cost, these were not originally employed for this project, but are highly encouraged for any future studies at the GFWP or other future BMP sampling sites.

Summary

Five sampling events for green infrastructure best management practices at the GFWP in League City, TX show overall positive percent reductions in outflow from rainwater harvesting, green roof, and bioswale for nitrogen, total suspended solids, and E. coli. No reductions were seen for total phosphorous for any of these practices.

References

Jaber, F. 2015. Dallas Urban Center Stormwater BMPs Final Report. https://www.tceq.texas.gov/assets/public/waterquality/nps/projects/40155_FinalReport.pdf

Shacklette, H.T. and J.G. Boerngen. 1984. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States. U.S. Geological Survey Professional Paper 1270. USGS, Alexandria, VA

Water Environment & Reuse Foundation, 2016. Final Report International Stormwater BMP Database 2016 Summary Report. http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf

Appendix A – Water Quality Data

Table 3. Measured Outflow Data (Nitrogen, Phosphorous, & Total Suspended Solids measured in mg/L, E. coli measured in cfu/100 ml)

	12/17/2017 0.45 inches of rain				**12/19/2017** 0.27 inches of rain			
	Nitrogen	**Phosphorous**	**E. coli**	**Total Suspended Solids**	**Nitrogen**	**Phosphorous**	**E. coli**	**Total Suspended Solids**
Bioswale	ns	ns	ns	ns	ns	ns	ns	ns
Green Roof	0.7	0.85	10	4.4	0.25	0.39	31	2.4
Cistern	0.22	0.47	10	1.0	0.28	0.44	10	1.2
	01/08/2018 0.45 inches of rain				**02/22/2018** 0.82 inches of rain			
	Nitrogen	**Phosphorous**	**E. coli**	**Total Suspended Solids**	**Nitrogen**	**Phosphorous**	**E. coli**	**Total Suspended Solids**
Bioswale	0.13	ns	4350	84	0.05	1.46	7700	42
Green Roof	0.19	ns	10	2.7	0.08	1.58	364	2.5
Cistern	0.06	ns	10	1.0	0.05	1.98	10	1.1
	03/29/2018 0.32 inches of rain							
	Nitrogen	**Phosphorous**	**E. coli**	**Total Suspended Solids**				
Bioswale	0.31	2.71	66	68.5				
Green Roof	0.66	2.61	3	8.5				
Cistern	0.26	2.65	0	1.3				

ns = no sample due to sampler error

Appendix B – White Paper

Green Infrastructure Practices at the Ghirardi Family WaterSmart Park

Compiled by the

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Introduction

In suburban communities, much of the land is covered by impervious surfaces including buildings, pavement and compacted landscapes. All of these impact stormwater drainage systems and increase runoff volume and velocity from rain storms. This runoff often carries pollutants including: sediment; oil, grease and toxic chemicals from motor vehicles; pesticides and nutrients from lawns and gardens; viruses, bacteria and nutrients from pet waste and failing septic systems; heavy metals from roof shingles, motor vehicles and other sources. These pollutants, often referred to as nonpoint source pollution (NPS), can harm fish and wildlife, kill native vegetation, and make recreational areas unsafe and unpleasant.

In Texas, many of the creeks, bayous, rivers, lakes and streams are listed as impaired in the Texas Integrated Report of Surface Water Quality (303(d) List). The most common impairment is for fecal coliform bacteria with over 50% of the impaired waterbodies under this classification. Other common impairments include dissolved oxygen and total suspended solids. Many of the pollution sources that lead to these impairments are the same NPS issues listed above. These cannot be addressed through traditional permits and regulations like point source pollution. Many communities in the U.S. and throughout the world are using stormwater Best Management Practices (BMPs) to address NPS pollution.

This report reviews the BMPs installed at the Ghirardi Family WaterSmart Park (GFWP) in League City, TX as a very real solution for reducing NPS loading into local waterbodies. It also evaluates water and soil data from the park and compares percent reduction values to those found for a North Texas site with similarly designed BMPs and comparable soil types.

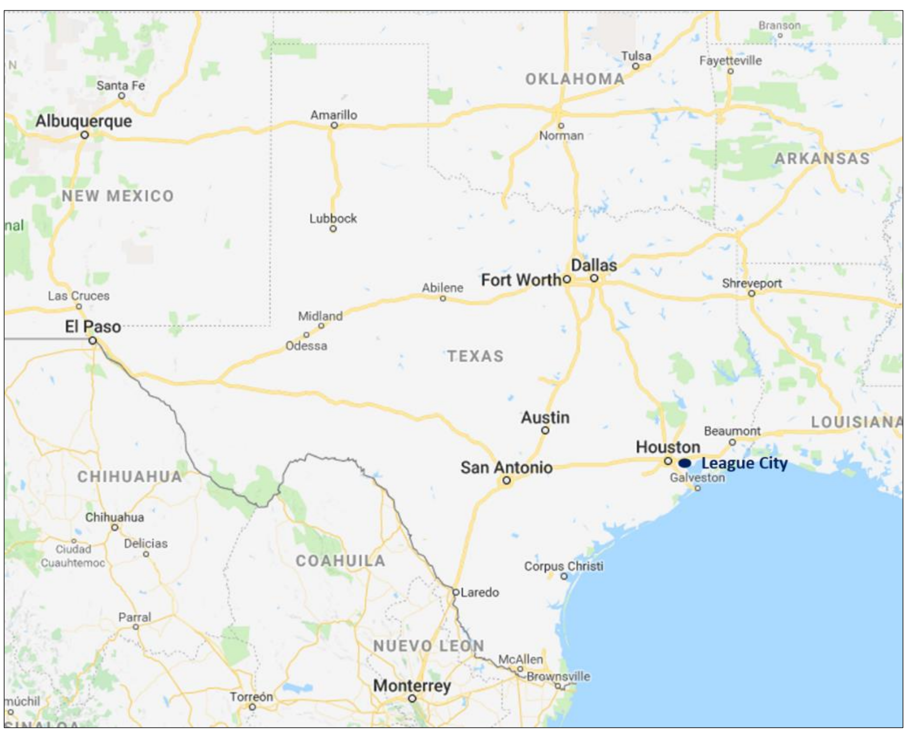

Figure 8. League City, TX is located on the Gulf Coast in Galveston County, on the banks of Clear Lake, a sub-bay of Galveston Bay.

The 3.75 acre Ghirardi Family WaterSmart Park is located on Louisiana Street in the Meadows Subdivision of League City (Figure 2). The Park was substantially completed and opened for public use in March of 2014. It contains amenities such as shaded walking trails, a playground, picnic area, and restroom facilities as well stormwater BMPs. It is first and foremost a public park and recreation area but it is so much more.

Figure 9. Ghirardi Family WaterSmart Park is located within a suburban neighborhood of League City, TX

The GFWP is a very public venue that showcases stormwater management techniques. The BMPs in the park serve both education and demonstration purposes. The park allows developers, city staff, community officials and residents to view functioning BMPs, learn how BMPs fit into the landscape, how BMPs can work together to form a treatment train, and how BMPs truly enhance the area while improving water quality. Five BMPs are showcased in this facility and were included in this study. They are:

- Rain gardens
- Bioswales
- Pervious pavers
- Rainwater harvesting
- Green roof

Each BMP was designed and engineered specifically for this space and represents best practices for the soil type and rain fall amounts typical of the Houston-Galveston region. This facility is also a living laboratory, where all of the BMPs can be studied throughout their lifecycle.

Best Management Practices

Five BMPs were selected for monitoring at the GFWP; however, limited data was collected for the rain garden and pervious pavers, so this white paper will focus primarily on three practices: bioswale, rainwater harvesting, and green roof.

All BMPs at the GFWP are sized to collect the 90th percentile storm which for this location is up to 0.29 inches of rainfall

BioSwale

The bioswale (Figure 3) is completely vegetated with Bermuda grass, and collects overland flow from within the park, only grassed areas contribute runoff, there are no impervious surfaces in this watershed.

Figure 10. Bioswale vegetated with turf grass. Sampling point for this BMP is the pipe pictured.

Green Roof & Rainwater Harvesting

The green roof and rainwater harvesting cistern are situated to collect runoff from the roof of the park pavilion (Figure 4). The pavilion has a split roof design so each practice has a discrete watershed contributing to the BMP. The green roof is a system of interlocking tray filled with engineered soil due to the pitch of the roof.

Figure 11. Pavilion at GFWP, the roof is split into two sections, allowing for both a green roof and rainwater harvesting practices on the same structure.

Sampling

Two rounds of data collection were completed for the park. The first in 2014 & 2015 funded by 582-11-13147 from the Texas Commission on Environmental Quality. The second in 2017 & 2018 funded by 582-16-60055 from the Galveston Bay Estuary Program. All sampling was completed under a Quality Assurance Project Plan (QAPP) as required by TCEQ.

Water quality

Wet weather sampling protocols were used for both projects. Inflow volumes were calculated using the curve number method, and outflow samples were collected to measure water quality parameters.

Outflow samples were collected and submitted to a NELAC accredited laboratory for processing for Nitrite + nitrate, total phosphorous, orthophosphate, total suspended solids (TSS), and E. coli. Field parameters collected were water temperature, dissolved oxygen, pH, and conductivity. These were measured using a hand-held YSI unit.

Soil

The GBEP funded project also added a soil sampling component. Soils are not routinely sampled as part of stormwater BMP monitoring. However, because several of the most commonly used BMPs encourage soil infiltration as a means of removing pollutants, preliminary soil data was collected for both the rain garden and bioswale at the GFWP, as well as three control sites. One sampling was conducted in April 2018; a soil particle size analysis was completed as well as arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, phosphorus, potassium, selenium, and zinc.

Results

Water quality

The data described here is from both projects, and therefore spans four years. The concentrations for outflow pollutant volumes for nitrogen, phosphorous, total suspended solids, and bacteria are shown in Figures 5, 6, 7 and 8.

Measured outflow for nitrogen is fairly similar for all sampling events across all three BMPs (Figure 5, Table 2). The exception being the green roof on two events (12.17.2017 and 3.29.2018), while these levels are higher than the other BMPs, they are not high enough to raise concerns.

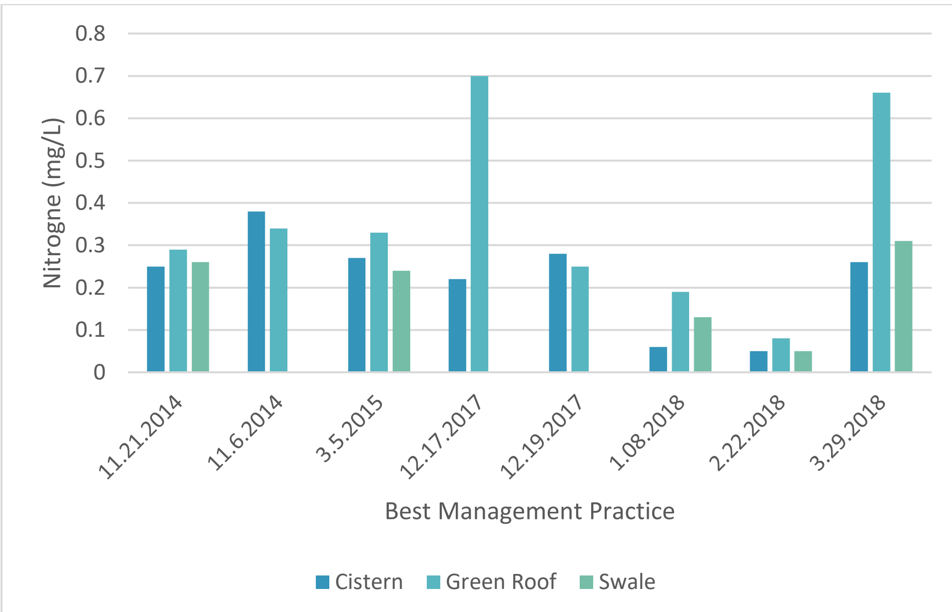

Figure 12. Measured outflow values for Nitrogen for all three BMPs

Measured outflow for phosphorous is fairly similar for all sampling events across all three BMPs (Figure 6, Table 3). Data for the 1.08.2018 sampling event for phosphorous is not included due to a sample preservation error. The final two sampling events (2.22.2018 and 3.29.2018) have higher measured phosphorous levels across all three BMPs than the other five events. Fertilization would be an obvious cause of the increased phosphorous levels, and could be the explanation for the bioswale, however neither the green roof nor the cistern watershed was fertilized, making this an unlikely explanation.

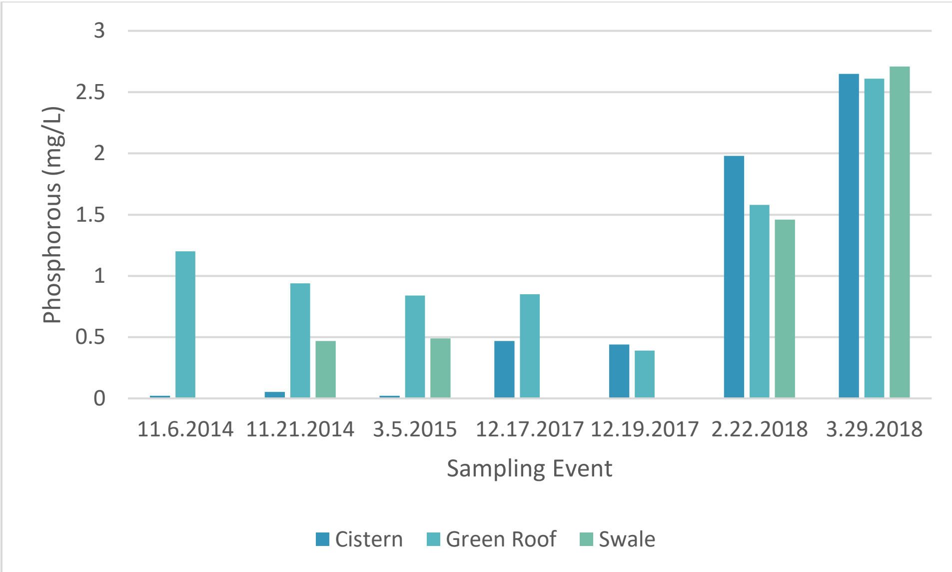

Figure 13. Measured phosphorus in outflow for all three BMPs

Overall, TSS values for all BMP outflows are relatively low. The highest values were for the bioswale in the spring/winter and spring of 2017 and 2018 (Figure 7, Table 4). There was a large amount of sediment build up at the mouth of swale that was washed back into the pipe during large rain events; this likely is the reason for high TSS values, not soil washing in from the BMP watershed. The sediment was due to the theft of rock used to stabilize the swale outflow pipe, when the rock was in place, the lower TSS values were observed. Since sampling has ended, the rock has been replaced.

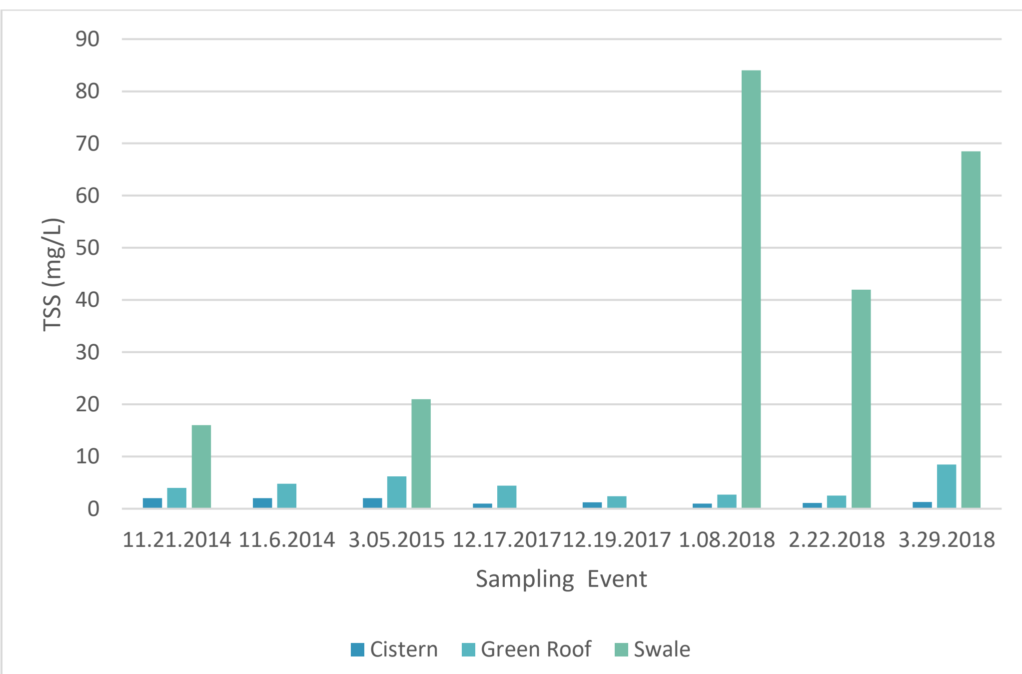

Figure 14. Measured Total Suspended Solids in outflows for all three BMPs

E. coli values are fairly similar across sampling dates, except for the bioswale (Figure 8, Table 5). During the winter/spring of 2018 high outflow values were observed for three sampling events. A large number of local residents walk their dogs in the park. While there is a pet waste station in the park, it is not near the watershed for the swale, a grassy area where pets can run and play. On more than one occasion dog waste was seen in the area near the sampling location for the bioswale which was likely the cause of high bacteria counts. No stormwater from outside of the park drains into the GFWP or the swale, therefore typical sub-urban sources of bacteria such as leaking sewer pipes are unlikely the cause of the elevated E. coli values.

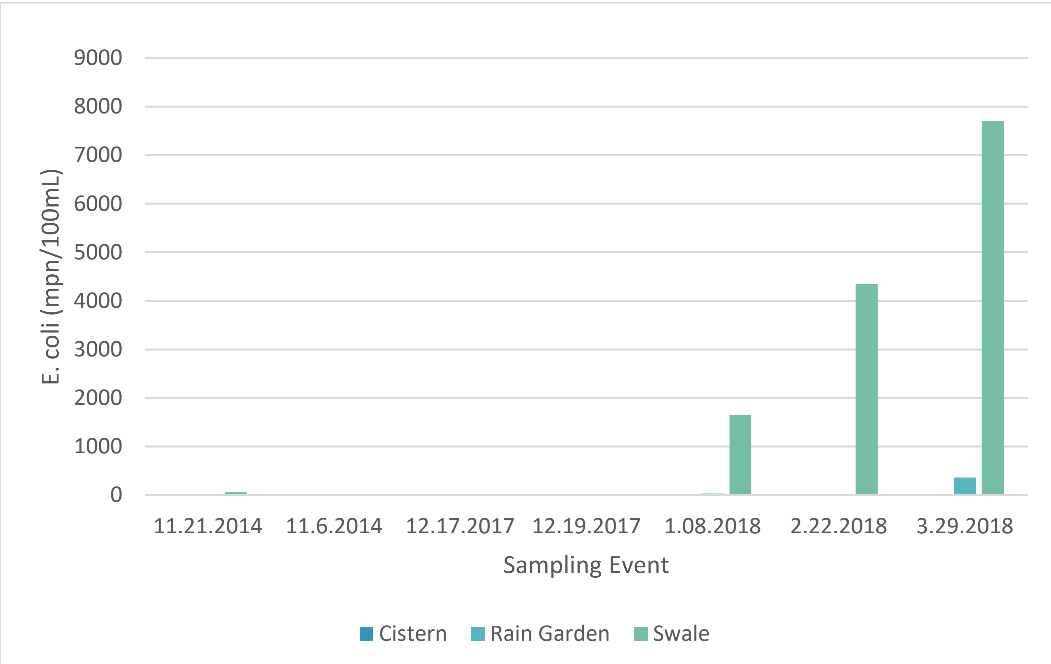

Figure 15. Measured bacteria in outflows for all three BMPs

Percent Reductions

Table 1 shows the percent reduction for the pollutants in each BMP for both the GFWP and the Dallas AgriLife Extension Center. There are no overall similarities or discernable patterns between the two sites. Overall, at GFWP nitrogen was removed from BMPs. Phosphorus had a negative percent reduction, meaning P values were larger in outflow data than those calculated for inflow. TSS was removed by all three BMPs, and E. coli values were less in measured outflow than in calculated inflows (Inflows were calculated using the Simple Method[4] and locally derived even mean concentrations[5], this method may have overestimated the inflow values, therefore showing higher than expected percent reductions). In Dallas, all BMPs showed positive percent removals except for the green roof for nitrogen. However, the percent increase was still smaller than the percent increase at the GFWP by an order of magnitude.

[4] Schueler, T. (1987) Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments. Washington, DC.
[5] Newell, C.J., Rifai, H.S., and Bedient, P.B. (1992) Characterization of Non-Point Sources and Loadings to Galveston Bay, GBNEP-15. Prepared for the Galveston Bay National Estuary Program, Houston, TX.

Table 4. Percent Reductions for Nitrogen, Phosphorous, Total Suspended Solids, and E. coli for both the Ghirardi Family WaterSmart Park and the Dallas AgriLife Reserach Center

	Percent Reduction GFWP				Percent Reduction Dallas Center[6]			
	Nitrogen	Phosphorous	Total Suspended Solids	E. coli	Nitrogen	Phosphorous	Total Suspended Solids	E. coli
Bioswale	93	-1200*	17	99.9	NS	NS	NS	NS
Green Roof	81	-800*	93	99.9	-11*	49	75	89
Rainwater Harvesting	20	-1100*	68	99.9	50	79	52	NS

*A negative value for percent reduction, indicates that the measured level in the outflow was greater than the calculated expected value for inflow

NS- Not sampled

Soil

Particle-size Distribution

The soil textures of each sample are plotted on Figure 9. The soil texture triangle in Figure 9 is based on the United States Department of Agriculture (USDA) particle size criteria, whereas as the data is reported with the United States Geological Survey (USGS) criteria. The USDA classifies clay as anything finer than two micrometers, whereas the USGS boundary is at four micrometers. The plotted points therefore may be clayier than the actual values. Nonetheless, the plot does show relationships between the samples very well.

The Control Site (CS) points were tightly clustered right in the middle of the silty clay loam texture. Both the Rain Garden (RG) and Bioswale (BS) points had a much greater spread across the texture diagram. The CS points were from undisturbed areas and appear to be reflective of the native soils. The RG samples, on the other hand, were taken from areas where additional soil materials were added, particularly compost and mulch. The RG samples did cluster somewhat tightly in the clay loam texture area. The RG samples in fact had about the same percentage of clay as the CS sites, but about 20% more sand and 20% less silt. The landscapers may well have added significant sand to the RG sites.

The most variable samples were those taken from the bioswale. The bioswale is a much longer depressional feature than the rain garden, and thus we might expect more soil variation along the bioswale.

All of the samples clustered fairly tightly in the silty clay, silty clay loam, and clay loam texture fields. This pattern is consistent with a silty clay loam initial soil across the park, modified by landscaping construction.

[6] Jaber, F. 2015. Dallas Urban Center Stormwater BMPS Final Report. https://www.tceq.texas.gov/assets/public/waterquality/nps/projects/40155_FinalReport.pdf

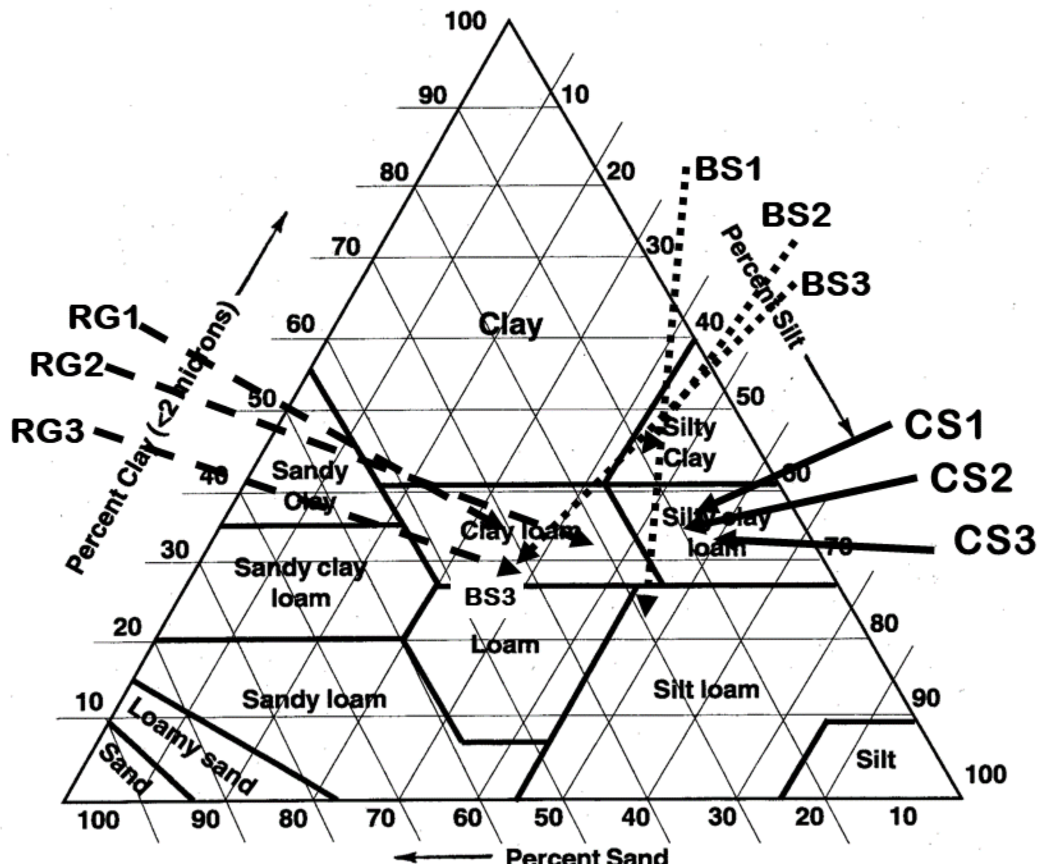

Figure 16. Soil textures of each sampling site plotted on the USDA texture triangle. CS=control sites; RG=rain garden; BS=bioswale.

Heavy Metals

A standard profile of heavy metals was run on all sites. Heavy metal concentrations varied widely across the entire site, but all of the values are within the range of values for "normal" soils as reported in the literature.[7]

The values for the control sites had approximately the same spread for each element as was found in the bioswale and the rain garden. No patterns were observed for any of the other analytes.

Conclusions

Overall, there is additional data needed to fully understand the functionality of the BMPs at the GFWP. Data from the two studies included in this paper show a general trend for pollutant removal for grassed bioswales, green roofs, and rainwater harvesting practices, with the exception of phosphorous. Results do indicate that the BMP designs used are functional for the soil type and climate in League City, TX.

[7] Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States. U.S. Geological Survey Professional Paper 1270. 1984. Shacklette, H.T. and J.G. Boerngen. USGS, Alexandria, VA

Water quality

No unusual results were seen in this study. The percent increase for phosphorous increases instead of reductions could be an artifact of the estimated inflow values instead of using measured inflow. Calculated values could underestimate the actual amounts seen at the GFWP. Or, there could be high phosphorous levels that cannot be adequately addressed by these BMPs. A mesocosm experiment could be designed to better understand inflow values. These results could be used to reevaluate the GFWP data to better understand the actual percent removals for pollutants.

The 2016 International Stormwater BMP Database Summary Statistics Report[8] compiles results from a number of studies in the database. This report shows an overall increase in phosphorus levels for grassed bioswales, this is in line with the results of this study at the GFWP. The Summary Report also found an increase in nitrogen values for grassed bioswales, a result contrary to that at the GFWP. There was not a sufficient number of studies for green roofs for inclusion in the Summary Report.

The 2017 and 2018 sampling events were after Hurricane Harvey ravaged the Texas Gulf Coast and dropped record setting rainfalls in League City, which submerged large portions of the community, including the GFWP. Increased levels of TSS for the swale could be related to this flooding, as a large amount of sediment was moved and re-deposited by flood waters. After Harvey, the area went several months without rainfall, therefore, transported sediments could be a source of measured TSS during the sampling period.

Soil

No unusual results were found during the soil analysis. However, this study has provided baseline data for the infiltration BMPs at the GFWP. It is recommended that soil sampling be repeated in several years time to see if any noticeable changes have occurred, especially for the rain garden. This rain garden collects run off from the park driveway and overflow parking area. It is a site where heavy metals would likely wash into the system and build up in the soil layer slowly over time. Normal values were observed during this sampling, but that could change with time.

Recommendations

At the request of League City staff, the GFWP water quality sampling protocol was developed such that ISCO samplers were not kept on site. Because the BMPs are so prominent at the GFWP, Parks Department staff were concerned that sampling equipment kept on site would detract from the facility. Therefore, ISCO samplers were kept offsite, transported to the park and set up prior to each sampled storm event, then removed after each rainfall. Thelmar weirs in hard to reach pipes and some other pieces of sampling equipment were maintained on site. The ISCO samplers selected for this project are labeled by the manufacturer as “portable”, but AgriLife staff feel that transporting the samplers, disconnecting and reconnecting hoses, batteries, etc. led to some of the sampling issues. If the samplers had been maintained on-site, charged with solar panels, and connections

[8] WERF, 2016. Final Report International Stormwater BMP Database 2016 Summary Report. http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf

contained continuously, we anticipate that less sampler errors would have occurred. We recommend using this approach on future projects.

Appendix A – Data Tables

Table 5. Measured outflow values for Nitrogen (mg/L) for all three BMPs by sampling date

	Cistern	Green Roof	Bioswale
11/06/2014	0.38	0.34	NS
11/21/2014	0.25	0.29	0.26
03/05/2015	0.27	0.33	0.24
12/17/2017	0.22	0.7	NS
12/19/2017	0.28	0.25	NS
01/08/2018	0.06	0.19	0.13
02/22/2018	0.05	0.08	0.05
03/29/2018	0.26	0.66	0.31

NS- No sample

Table 6. Measured outflow values for Phosphorous (mg/L) for all three BMPs by sampling date

	Cistern	Green Roof	Bioswale
11/06/2014	0.021	1.2	NS
11/21/2014	0.053	0.94	0.47
03/05/2015	0.021	0.84	0.49
12/17/2017	0.47	0.85	NS
12/19/2017	0.44	0.39	NS
02/22/2018	1.98	1.58	1.46
03/29/2018	2.65	2.61	2.71

NS- No sample

Table 7. Measured outflow values for total suspended solids (mg/L) for all three BMPs by sampling date

	Cistern	Green Roof	Bioswale
11/06/2014	2	4.8	NS
11/21/2014	2	4	16
03/05/2015	2	6.2	21
12/17/2017	1	4.4	NS
12/19/2017	1.2	2.4	NS
01/08/2018	1	2.7	84
02/22/2018	1.1	2.5	42
03/29/2018	1.3	8.5	68.5

NS- No sample

Table 8. Measured outflow values for E. coli (mpn/110mL) for all three BMPs by sampling date

	Cistern	Green Roof	Bioswale
11/06/2014	1	6	NS
11/21/2014	0	3	66
03/05/2015	2	2	NS
12/17/2017	10	10	NS
12/19/2017	10	31	NS
01/08/2018	10	10	4350
02/22/2018	10	364	7700
03/29/2018	0	3	66

NS- No sample