Greater Edwards Aquifer Alliance
Lorence Creek HOA Retrofit Project and Water Quality Assessment

(Funded as Lorence Creek Stormwater Retrofit and Research Project under the Proposition 1 Edwards Aquifer Protection Projects within Urbanized Areas of Bexar County)

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EXECUTIVE SUMMARY

The purpose of this project is to assess the performance of a constructed treatment train of stormwater Best Management Practices (BMPs) that uses existing natural features with a minimum amount of new infrastructure for improving stormwater quality within the Edwards Aquifer Recharge Zone (EARZ). The site receives runoff from an approximately 33-acre portion of a residential subdivision. Stormwater runoff enters the treatment train beginning with a constructed sediment forebay within a modified bioswale. The first flush of stormwater runoff is then diverted into an offline bioinfiltration basin. From the basin's spillway, overflows then enter into the enhanced natural bioretention area. The system's size was limited due to site restraints and its design capacity was calculated through existing rainfall event data and predictive modeling to capture and treat approximately 0.5 inches from the first portion of the urban stormwater runoff before it enters Lorence Creek, a creek that provides recharge to the Edwards Aquifer.

Soil and water samples were collected at the concrete interceptor outfall where the subdivision's stormwater enters into the original earthen drainage channel that flowed directly into Lorence Creek. These samples taken before construction of the system aided in quantifying pollutants that could be commonly found in stormwater from urban residential runoff. Paired post-construction water samples were collected, again at the interceptor outfall and at the outfall of the bioinfiltration basin after treatment to determine effectiveness.

Utilizing the Wilcoxon analysis and addressing non-detect (ND) values, seven water quality parameters met the criteria to be statistically different at the 90% confidence interval (p-value < 0.1): Total Organic Carbon, Total Suspended Solids, Total Coliform, Escherichia coli (E. coli), and Terphenyl-d14 demonstrated improvement where Hardness and Total Nitrogen had increased levels after the bioinfiltration basin treatment. This observed statistical difference enabled calculating the percent removal for these seven water quality parameters. Percent removal calculations also resulted in an average loading decrease for five water quality parameters: E. coli (27% reduction), Total Organic Carbon (63% reduction), Total Suspended Solids (77% reduction), Total Coliform (24% reduction), and Terphenyl-d14 (13% reduction). Percent removal calculation also resulted in an average loading increase for two water quality parameters: Hardness (277% increase) and Total Nitrogen (35% increase).

ACRONYMS/ABBREVIATIONS

BMP	Best Management Practice
COSA	City of San Antonio
E. coli	*Escherichia coli*
EARZ	Edwards Aquifer Recharge Zone
GEAA	Greater Edwards Aquifer Alliance
GI	Green Infrastructure
HDPE	High Density Polyethylene
LID	Low Impact Development
MBC	Multiple Box Culvert
Mg/Kg	Milligrams per Kilogram
MPN	Most Probable Number
Mg/L	Milligrams per liter
MIL	1/1000 of an inch
NA	Not Available
ND	Non-Detect
NELAP	National Environmental Laboratory Accreditation Program
PVC	Polyvinyl Chloride
SARA	San Antonio River Authority
TCEQ	Texas Commission on Environmental Quality
TSS	Total Suspended Solids
USGS	United States Geological Survey

INTRODUCTION

The Lorence Creek subwatershed is located within the Upper Salado Creek watershed in Northeast San Antonio. The creek itself is categorized as a dry creek and a portion of it falls within the Edwards Aquifer Recharge Zone (EARZ) as shown in Figure 1.

Previous studies have indicated that there were increasing trends in several contaminants found in the urban stormwater runoff within the EARZ portion of Lorence Creek including Diazinon, volatile organic compounds such as polycyclic aromatic hydrocarbons, and certain metals including barium and zinc (USGS 1999). In addition, suspended sediment was identified as a concern. Such studies raised the issue of possible contamination of water that enters the aquifer (USGS 1999).

The project site was selected not only for its ability to improve the quality of stormwater runoff discharging into Lorence Creek and the aquifer, but also due to the ongoing community support and existing natural features that could be used withing the project design.

The drainage area for the project is approximately 26.1 acres within the Lorence Creek subdivision. This area consists primarily of residential development where rooftops, roadways, and driveways collect pollutants in stormwater runoff that flows into Lorence Creek as seen in Figure 1. Treating the first flush from this site will improve the water quality within the creek and the Edwards Aquifer as this portion of runoff typically has the highest concentration of pollutants during a rain event (City of Austin 1990).

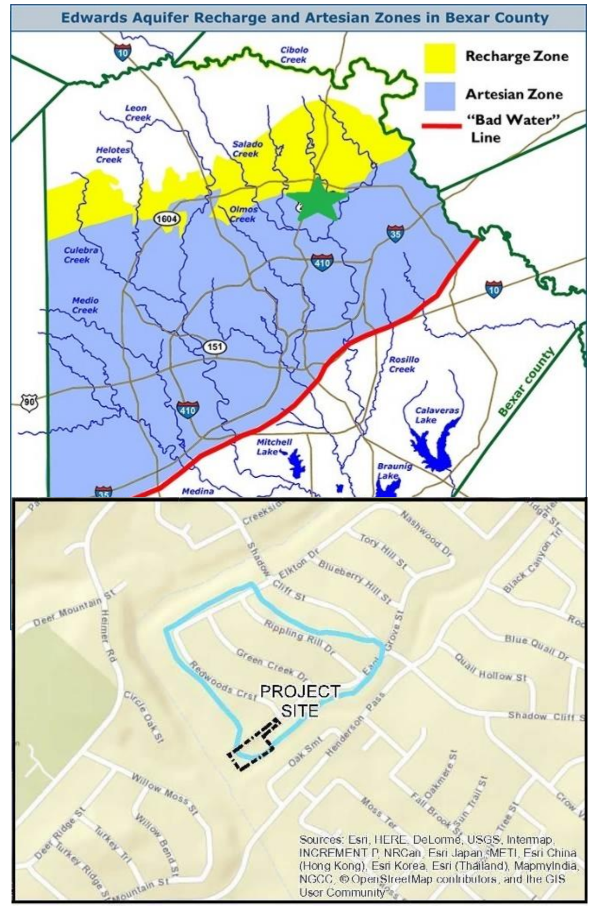


Figure 1: Project Location Overview
Top Photo: Salado Creek Within the EARZ
Bottom Photo: Lorence Creek HOA LID Retrofit Project Site

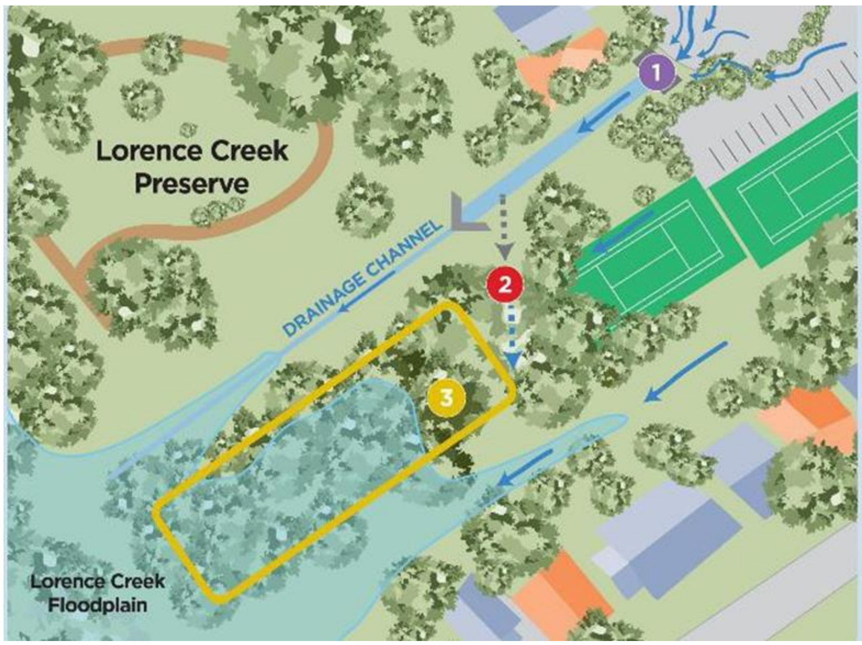
PROJECT DESCRIPTION AND OVERALL SITE LAYOUT

In October 2017, the City of San Antonio (COSA), San Antonio River Authority (SARA), and the Greater Edwards Aquifer Alliance (GEAA) signed a funding agreement to retrofit the existing trapezoidal drainage channel with a stormwater best management practice (BMP) treatment train. The treatment train system is comprised of a sediment forebay, modified vegetated swale, bioinfiltration basin and bioretention facility in the Lorence Creek neighborhood. The project as proposed included several unique and innovative components.

Since the subdivision was constructed before aquifer protection rules, there were no existing water quality stormwater BMPs in place. The project was designed as a "volunteer" retrofit; therefore, it was not required to meet the current aquifer protection requirements as mandated by the Texas Commission on Environmental Quality (TCEQ). This was crucial as the amount of treatment that could be accomplished was limited due to the size and condition of the project site. This designation also allowed the project to incorporate and utilize more of the existing natural features. Utilizing the site's natural features created a final project that not only protected water quality but also blended into the property's natural area and the abutting Lorence Creek Linear Park.

The greatest volume of water quality improvement provided by the project was due to directing stormwater runoff into an enhanced natural bioretention area after passing through a series of pre-treatment measures. The volume of the system was calculated in accordance with the San Antonio River Basin Low Impact Development Technical Design Guidance Manual (SARA 2019).

Figure 2: Lorence Creek HOA LID Retrofit Project Site and Treatment Train Overview



1 SEDIMENT FOREBAY – collects trash, sediment and organic debris for easy removal and disposal, preventing elevated nutrient levels and avoiding pollution from contaminants that adhere to sediment such as heavy metals.

2 BIOINFILTRATION BASIN – allows a portion of the diverted stormwater to filter through native plants and engineered soil (above a liner). Overflows enter directly into the enhanced natural bioretention area.

3 ENHANCED NATURAL BIORETENTION AREA – completes the stormwater BMPs treatment train, filtering stormwater through a natural system.

Sediment Forebay/Bioswale

A sediment forebay was installed between the interceptor at the street inlet and before the bioswale as shown in Figure 3

The sediment forebay captures sediment, trash, and debris. For the system to work efficiently, the sediment forebay needs to be cleaned periodically to ensure the lifespan of the bioretention facility will be prolonged. The design of the sediment forebay has provided an accessible location to remove accumulated sediment and debris.

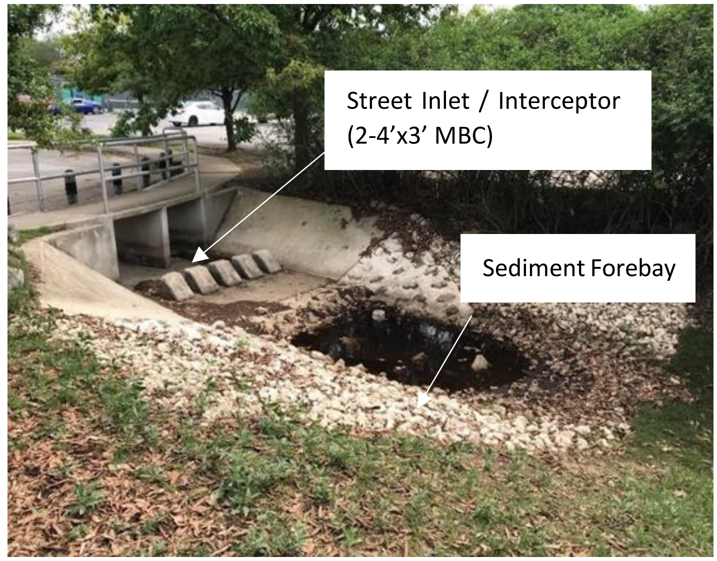


Figure 3: Sediment Forebay Located the Edge of Pavement

To begin the project, accumulate sediment was removed from the existing earthen channel, which was slightly reshaped to be maintained as a bioswale. It had been envisioned to re-vegetate this area with native grasses, but the concern for the establishment period led to the use of bermudagrass sod pinned to the existing channel to provide instant cover. The swale performs well in carrying stormwater to the diversion for the bioretention facility, and functions as additional pre-treatment by continuing to filter out sediment and debris.

Towards the end of the bioswale, a diversion system was installed as shown in Figure 4. The diversion consists of two 12 in. polyvinyl chloride (PVC) pipes that were installed through the side of the bioswale and existing berm of the bioretention area. This newly created structure controls the flow rate into the bioinfiltration basin and enhanced natural retention area while allowing the remaining flow to continue directly to Lorence Creek.

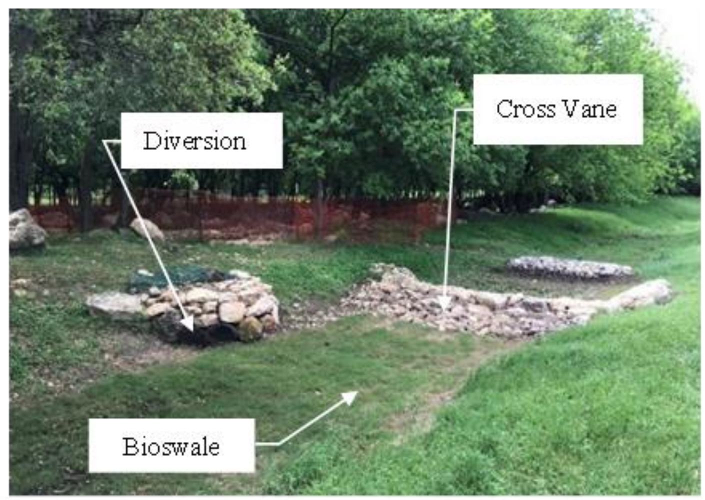


Figure 4: Flow Directed to Diversion with Assistance from Cross Vane.

Downstream within 12 ft. of this diversion, a cross vane was installed to create a slight rise in water elevation; thus, ensuring a minimum of 0.5 inches of the first flush of rain events is conveyed to the bioinfiltration basin even in short high-intensity rain events. It appears that more than 0.5 in. is diverted during long, low-intensity rain events. Flow meters would need to be installed to verify. Within the bioinfiltration basin overflows exit by a spillway into the enhanced natural bioretention area for treatment.

Bioinfiltration Basin

One of the initial primary uses of the bioinfiltration basin was to provide a site for water quality monitoring with the understanding that the enhanced natural bioretention area would provide the greatest volume of filtration due to size differences.

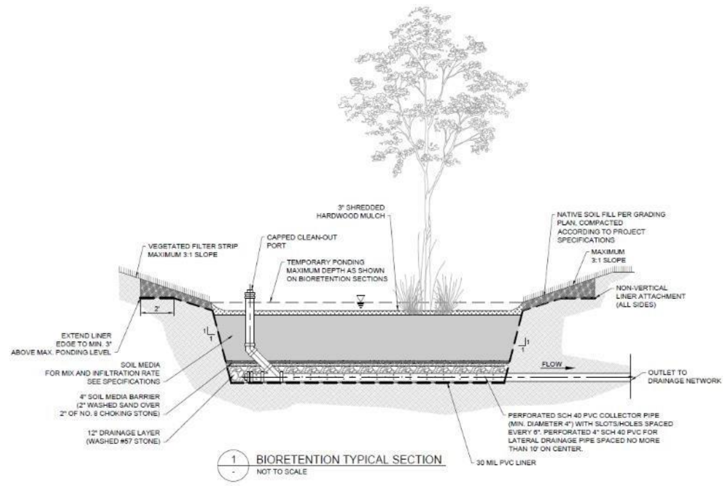


Figure 5: Construction Drawing of the 125 sq. ft. Bioinfiltration Basin.

This stormwater BMP was designed using the Low Impact Development design criteria as set out in the San Antonio River Basin Low Impact Development Technical Design Guidance Manual (SARA 2019) including the use of an engineered soil medium. The schematic used for the construction documents is shown in Figure 5.

Underneath the engineered soil, landscape fabric, and gravel layer, a 30 MIL PVC liner was placed not only to protect the aquifer but to also ensure that the filtered water was captured by a 4 in. perforated pipe that discharged the filtrate to the water quality sampling station located outside of the enhanced natural bioretention area but within the project site.

Figure 6: Completed Basin with Spillway That Overflows into the Enhanced Natural Bioretention Area

The bioinfiltration basin was then planted with a combination of shade-tolerant perennial and annual plants, such as Inland Seaoats, Missouri Violet, and Eastern Gammagrass, that would thrive in both cool and warm seasons, as shown in Figure 6. This combination promotes the system's ability to filter out pollutants year-round. A more detailed plant list can be found in Appendix C of this report

Sampling results indicate that the bioinfiltration basin could effectively treat small events as a stand-alone stormwater BMP. Additional observations on this portion of the system include:

1. During rain events of 0.5 in. or greater, a fine film of sediment would coat the topsides of the plant leaves. An investigation indicated that a source of this sediment was due to the separation of small particles within the engineered soil that was being picked up by the stormwater when the basin fills and resettled on top of the leaves, as shown in Figure 7. This observation was supported as the sediment film did not appear on the vegetation within the bioswale. This issue has been partially remedied by planting plants that grow larger.
2. The bioinfiltration system benefits by allowing some of the organic debris to remain on the surface to: assist in maintaining moisture levels in the media, reduce weeds, maintain organic matter and fertility levels within the media through decomposition, support the media's ability to remove

Figure 7: Sediment Settles on Basin Plants After Rain Event.

some pollutants through adsorption and dissipation (Harju, et al. 2021), and reduce maintenance as low levels of sediment are incorporated into media aggregates.

Therefore, for the past 2 years a maintenance strategy has been to allow some organic matter to accumulate, much like that in a natural system. As this material breaks down on the surface, it moves down through the soil profile, promoting plant growth, a robust soil microbial population, soil fertility, aggregate stability, adsorption and dissipation of stormwater pollutants and even carbon sequestration (Sustainable Agriculture Research and Education. 2020). Currently, maintenance focuses on removing only large debris and any excess sediment that could lead to infiltration reduction. Other on-going maintenance activities include weeding unwanted vegetation such as tree seedlings, removal of anthropogenic litter, and ensuring the rocks lining the sides of the basin are stabilized.

Enhanced Natural Bioretention Area

Figure 8: Completed 3:1 Berm on Northside of Area.

Once the bioinfiltration basin is filled to capacity, overflows spill into the enhanced natural bioretention area. This area had been a dumping site for excessive soil and the large boulders blasted and removed during the construction of the residential subdivision in the 1970s. The manner in which the materials were left in the area created a natural depression strewn with large boulders. This aspect, along with the trees that had grown through the boulders, provided an area that already encouraged increased infiltration. The facility was designed around these existing features and made use of on-site materials to enhance functionality for water quality and passive recreational use while protecting adjacent properties from flooding. The use of on-site materials eliminated the need for a floodplain permit as there was not an increase of material within the 1% floodplain area.

Tree removal was limited to several under-protected size trees (less than 6 in. diameter) and protection was provided for the remaining trees as seen in Figure 8. On one side of the original natural depression an existing partial low berm was extended by using boulders from the center of the area to create the core of a continuous 3:1 slope berm. The rock core was then covered with a liner that prevented water movement from the

Figure 9: Berm Showing Revegetation and Placement of Boulders at Toe and Walking Path to the Right

inside of the bioretention area to outside the project area where it could have increased flood risk to adjacent properties.

After the construction of the berm, some of the remaining boulders were moved to protect the toe of the berm and prevent vehicular traffic, thus allowed for a pedestrian walking path from the neighborhood through the area to the Lorence Creek Linear Park.

The berm was initially seeded with native grasses and wildflower seeds, including those that could thrive in deep shade. In addition, 4 in. shade-loving plants were planted throughout. The berm and its plantings were then protected with rocks and branches collected from the site as shown in Figure 9.

This effort not only reduced erosion but also gave some protection from deer, given their browsing and propensity to use the top of the berm as a trail. Vegetating and protecting the berm has been one of the greatest challenges due to:

1. Growing conditions consisting of intense shade and shallow (4 in. - 6 in.), poor quality soil and the 2-year plus drought,
2. The 3:1 slope for such conditions proved to be excessively steep; a 4:1 would be recommended,
3. The deer's ability to remove branches and rocks at the top of the berm that interfered with their mobility along the top of the berm, and
4. To a lesser degree, use of the berm area by local youths.

PROJECT SAMPLING PROTOCOL AND EQUIPMENT

Project soil and water samples were collected in accordance with the project QAPP. The sample location was at the point where the pavement of the street inlet/interceptor outfall ends and within the existing drainage channel as shown in Figure 11. The installation of the casing holding the mounting kit was into the soil where it could be secured and only the top 6 in. was above ground level. This required a modification from the photo shown in the QAPP. New holes had to be located at the top of the casing to receive stormwater flows to fill the sample bottles.

Soil samples were taken from the newly formed sediment deposits in this area. The water and soil samples were then analyzed by Alamo Analytical Laboratory, Ltd.[1] to determine levels of the targeted pollutants commonly found within the area's stormwater runoff (USGS 1999). Post-construction sampling consisted of five paired (pre-treatment and post-treatment) to assess the performance of the stormwater BMP

[1] Accredited through the Texas Laboratory Accreditation Program under the National Environmental Laboratory Accreditation Program standard for matrices, methods, and parameters of analysis.

treatment train system. Since the forebay, drainage channel, and bioinfiltration basin acted together for water quality improvement, they were treated as a unit for stormwater sampling.

The location for the pre-treatment sample site was again located at the end of the street inlet /interceptor pavement but in front of the sediment forebay. The post-treatment sample was collected at the bioinfiltration discharge outlet where the 4 in. perforated PVC pipe collected the filtered stormwater and discharged outside of the natural bioretention area but within the project site as shown in Figure 12. Post-construction sampling was limited to water quality analyses as there was no soil or sediment at the post-treatment sampling site. By comparing the concentrations of stormwater pollutants at the inlet and outlet and calculating the removal percentage, the pollutant removal efficiency was evaluated for stormwater runoff

Post-construction sampling was initiated only after a 70% or more vegetation cover within the entire system was achieved and a qualifying rain event occurred. For this project, a qualifying event is defined as a storm event with at least 0.1 in. precipitation, proceeded by at least 72 hours of dry weather or precipitation amounts less than 0.1 in. Precipitation data were monitored by the one functioning USGS station that was adjacent to the project site; USGS Station ID 08178700. This station provides real time data at 15-minute intervals. Table 1 shows the specifications of the precipitation station used for recording rainfall values and storm event characterization.

Table 1. Specifications of Precipitation Station Used for Storm Event Characterization

Station ID	**Station Name**	**Lat.**	**Long.**	**Distance from Station to the site**
08178700	Salado Ck at Loop 410	29.5161	-98.4311	4.71 mi (south)

For stormwater sampling, a Nalgene® Storm Water Sampler with White HDPE Sample Bottle (complying with U.S. Environmental Protection Agency National Pollutant Discharge Elimination System Multi-Sector General Permit regulations) was used to collect each stormwater sample. The sampler bottles collected stormwater runoff and once filled, a ball valve stopped water flow preventing additional stormwater from entering and diluting constituents. Each bottle held 1,000 ml of stormwater and was placed inside a mounting kit that secured the bottle in place. This system was then placed inside an 8 in. green PVC pipe (Sch. 80) with sufficient holes so that once placed in the ground, stormwater flowed to the inside and filled the bottles as shown in Figure 10. Stormwater sample collection was completed in accordance with

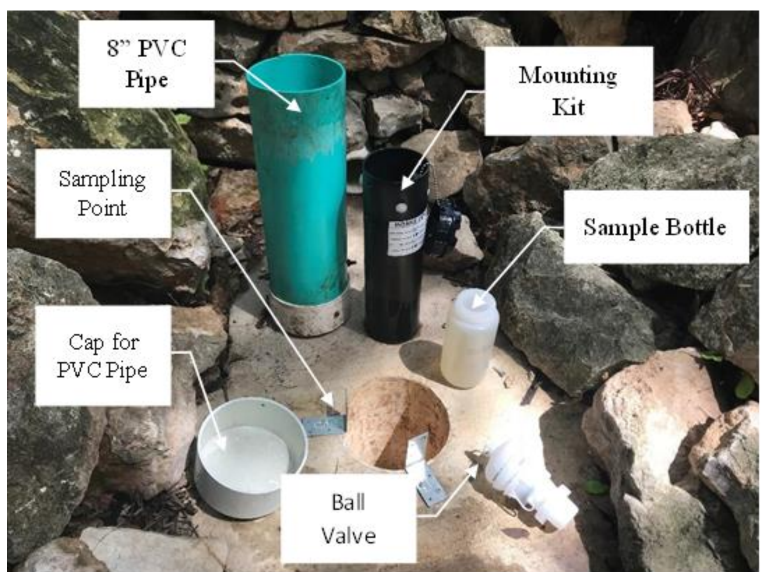


Figure 10. Stormwater Sample Collection Unit

the methods outlined in the Stormwater BMP Performance Monitoring Manual available online at www.BMPdatabase.org (Water Research Foundation, et al 2022).

At the end of a sample collection activity and after each non-qualifying event, both PVC pipe and mounting kit were cleaned using tap water and, a new HDPE Sample Bottle sterilized from the manufacturer was installed to be prepared for the next event. In addition, the general functionality of the surrounding site and sampling locations were inspected to make sure that no debris or trash was located in the water sampling areas that could clog PVC pipe holes.

Samples were labeled in the field, stored in an ice chest cooled with frozen cold packs, and delivered to Alamo Analytical Laboratory, Ltd as directed within 12 hours from the initiation time of a qualifying event as per the QAPP (Pope, et al. 2003). At the time of delivery to the lab, a chain of custody record was filled out for each sample which contained information regarding project name, lab ID#, date and time of sampling, sampling method (composite/grab), matrix, and type of analyses being undertaken. Alamo Analytical Laboratories performed all experiments and tests consistent with NELAP accreditation. After completion of analyses, test results were reported back which included sample results, units of measurement, sample matrix, date and time of collection, and date of analyses.

Tables 2 and 3 list the measurement specifications for each parameter analyzed for soil and stormwater testing. Parameters analyzed included metals such as lead and silver, hydrocarbons, and nutrients such as nitrogen and phosphorus. For this project, Total Nitrogen was analyzed for both soil and stormwater for pre-construction sampling, Phosphate as P was analyzed for soil sampling, and Total Phosphorus was analyzed for stormwater sampling. Additional parameters included bacteria such as *E. coli* and Total Coliform, Total Organic Carbon, Diazinon, and hydrocarbon surrogates such as 1-Chlorooctadecane and 2-Fluorobiphenyl.

Table 2. Measurement Performance Specifications for Soil Sampling

Parameter	Units	Test Code
Arsenic	mg/L	SW6010B
Barium		
Cadmium		
Chromium		
Lead		
Selenium		
Mercury	mg/Kg	SW7471A
Hydrocarbons, C6-C12	mg/Kg	TX1005
Hydrocarbons, >C12-C28	mg/Kg	TX1005
Hydrocarbons, >C28-C35	mg/Kg	TX1005
Hydrocarbons, >C6-C35	mg/Kg	TX1005
Phosphate as P	mg/Kg	M4500-PD
Total Nitrogen	mg/Kg	M4500
Hardness	mg/L	SM2340B

Table 3. Measurement Performance Specifications for Stormwater Sampling

Parameter	Unit	Method	Test Code	Limit of Quantitation (LOQ)	Minimum Detection Limit
Arsenic	mg/L	EPA 6010	SW6010B	0.01	0.014
Barium	mg/L	EPA 6010		0.01	0.002
Cadmium	mg/L	EPA 6010		0.03	0.0017
Chromium	mg/L	EPA 6010		0.01	0.0044
Lead	mg/L	EPA 6010		0.015	0.014
Selenium	mg/L	EPA 6010		0.01	0.016
Silver	mg/L	EPA 6010		.007	0.0061
Mercury	mg/L	EPA 7470	SW7470A	0.0002	0.00012
Hydrocarbons, C6-C12	mg/L	TCEQ 1005	TX1005	5.0	0.68
Hydrocarbons, >C12-C28	mg/L	TCEQ 1005		5.0	0.79
Hydrocarbons, >C28-C35	mg/L	TCEQ 1005		5.0	0.79
Hydrocarbons, >C6-C35	mg/L	TCEQ 1005		5.0	1.47
Total Phosphorus	mg/L	M4599-P D	E365.4	0.01	0.0111
Total Nitrogen	mg/L	SM 4500-NH3 C	M4500	0.5	0.5
Total Suspended Solids	mg/L	SM 2340 D	SM2540D	5.0	2.11
Hardness	mg/L	SM 2340 B	SM2340B	5.0	2.38
*E. coli**	MPN/100 mL	Colilert	E_COLI	0	0
Total Coliform*	MPN/100 mL	Colilert	E_COLI	0	0
Total Organic Carbon*	mg/L	EPA 415	E415.1	1.0	0.21
Diazinon*	mg/L	EPA 8270	SM5310B	.1	0
Nitrobenzene-d5 *(Surrogate)**	% Recovery	NA	SW8270C	NA	36
2-Fluorobiphenyl *(Surrogate)**	% Recovery	NA		NA	49
Terphenyl-d14 *(Surrogate)**	% Recovery	NA		NA	10
1-Chlorooctadecane *(Surrogate)**	% Recovery	NA	TPH1005_W	NA	70
1-Chlorooctane *(Surrogate)**	% Recovery	NA	TPH1005_W	NA	70

*Denotes additional parameters included for stormwater analysis

PRE-CONSTRUCTION PROJECT SAMPLING

Pre-construction sampling was conducted before the installation of the stormwater BMP treatment train system from December 2017 to July 2018. The sampling point was located at the edge of pavement where the street outlet/interceptor discharged into the drainage channel as shown in Figure 11. A total of five storm events were analyzed for stormwater and four storm events for soil. Collection dates for pre-construction project sampling were:

1. Pre-Construction Collection #1 – December 6, 2017
2. Pre-Construction Collection #2 – December 16, 2017
3. Pre-Construction Collection #3 – February 21, 2018
4. Pre-Construction Collection #4 – March 28, 2018
5. Pre-Construction Collection #5 – July 5, 2018

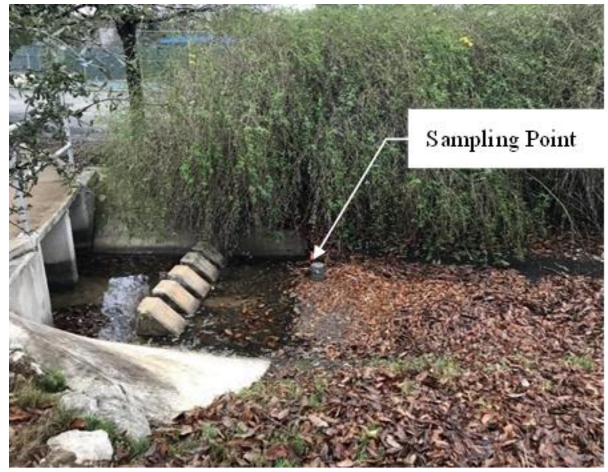


Figure 11: Inlet Sampling Point for Pre-Construction Soil and Stormwater and Post-Construction Stormwater

Rainfall data for each post-construction storm event was collected and is displayed in Table 4. Precipitation data was taken from USGS Station 08178700.

Table 4: Pre-Construction Rainfall Data

Storm Event Date	Rainfall (inches)
Storm 1: December 6, 2017	1.29
Storm 2: December 16, 2017	1.16
Storm 3: February 21, 2018	0.25
Storm 4: March 28, 2018	5.00
Storm 5: July 5, 2018	1.37

POST-CONSTRUCTION PROJECT SAMPLING

Post-construction sampling was conducted after the stormwater BMP treatment train installation and its revegetation, from March 2020 to June 2021. The paired samples were collected at two points:

1. Pre-treatment point at almost the same pre-construction sampling point shown in Figure 11; at the end of the concrete interceptor and before the sediment forebay, and
2. Post-treatment point at the bioinfiltration basin discharge outlet as indicated in Figure 12.

Figure 12: Basin Outlet Sampling Point for Stormwater

A total of five storm events were analyzed for stormwater. Collection dates for post-construction sampling were:

1. Post-Construction Collection #1 – September 4, 2020
2. Post-Construction Collection #2 – September 22, 2020
3. Post-Construction Collection #3 – December 31, 2020
4. Post-Construction Collection #4 – February 12, 2021

5. Post-Construction Collection #5 – May 12, 2021

Rainfall data for each post-construction storm event was collected and is displayed in Table 5. Precipitation data are taken from USGS Station 08178700

Table 5: Post-Construction Rainfall Data

Storm Event Date	Rainfall (inches)
Storm 1: September 3-4, 2020	0.39
Storm 2: September 21-22, 2020	0.10
Storm 3: December 30-31, 2020	0.15
Storm 4: February 11, 2021	0.92
Storm 5: May 11-12, 2021	0.48

ANALYSIS OF PROJECT SAMPLING RESULTS

Stormwater sampling results collected throughout the project were used to evaluate and assess the overall effectiveness of the stormwater BMP treatment train system in its ability to remove pollutants and potentially improve the quality of stormwater before it enters the Edwards Aquifer.

Pre-Construction Sampling Results

Pre-construction samples provided background and baseline information for water quality parameters prior to the stormwater BMP construction. The soil sample results highlighted what pollutants could be expected to be found within this residential drainage area. Summary results are given in Appendix A and averages and standard deviations are listed in Table 6. Note: A non-detect (ND) result indicated the concentration of a particular parameter was deemed to be lower than could be detected using the method employed by Alamo Analytical. A not available (NA) result indicated a lack of data available when parameter data was analyzed.

Table 6: Average Concentration of Stormwater and Soil Parameters

Parameter	Average	Standard Deviation	Parameter	Average	Standard Deviation
Stormwater			**Soil**		
Total Phosphorus (mg/L)	0.21	0.20	Phosphate as P (mg/Kg)	18.34	11.53
Barium (mg/L)	0.26	0.01	Barium (mg/Kg)	40.23	32.23
Hardness (mg/L)	49.42	31.36	Chromium (mg/Kg)	8.97	10.74
Total Nitrogen (mg/L)	1.88	0.61	Total Nitrogen (mg/Kg)	18.25	0.75
E. coli (MPN/100mL)	944.73	961.95	Lead (mg/Kg)	9.91	12.03
Total Coliform (MPN/100mL)	2912.70	4162.88	Total Organic Carbon (mg/Kg)	23,357.50	15,411.58
Total Suspended Solids (mg/L)	76.10	100.69	Hardness (mg/L)	1049.50	727.86
Total Organic Carbon (mg/L)	30.15	20.65	Barium (mg/Kg)	40.23	37.22
Hardness (mg/L)	49.42	31.36	Chromium (mg/Kg)	8.97	10.74

Hydrocarbons, C6-C12 (mg/L)	ND	NA	Hydrocarbons, C6- C12 (mg/Kg)	ND	NA
Hydrocarbons, > C12-C28 (mg/L)	ND	NA	Hydrocarbons, > C12-C28 (mg/Kg)	ND	NA
Hydrocarbons, > C28-C35 (mg/L)	ND	NA	Hydrocarbons, > C28-C35 (mg/Kg)	ND	NA
Hydrocarbons, C6-C35 (mg/L)	ND	NA	Hydrocarbons, C6- C35 (mg/Kg)	ND	NA
1-Chlorooctadecane (% Recovery)	100.60	20.86	1-Chlorooctadecane (% Recovery)	106.25	14.62
1-Chloroooctane (% Recovery)	98.40	12.34	1-Chloroooctane (% Recovery)	86.25	12.62
2-Fluorobiphenyl (% Recovery)	34.47	22.40			
Nitrobenzene-d5 (% Recovery)	33.14	16.94			
Terphenyl-d14 (% Recovery)	71.19	26.94			

Post-Construction sampling Results

Post-construction samples provided a detailed look into the effectiveness of the Lorence Creek stormwater BMP treatment train system for improving water quality within the project area. Summary results for stormwater samples are included in Appendix B and more detailed tables and graphs are given below on individual constituents. Note: A non-detect (ND) sample result indicated the concentration of a particular parameter was deemed to be lower than could be detected using the method employed by Alamo Analytical.

Hardness

According to the EPA (1986), water hardness is caused by the polyvariant metallic ions dissolved in water. In freshwater, these are primarily calcium and magnesium although other metals such as iron, strontium, and manganese contribute to the extent that appreciable concentrations are present. Hardness commonly is reported as an equivalent concentration of calcium carbonate (CACO3). Natural sources of hardness principally are limestones which are dissolved by percolating rainwater and made acidic by dissolved carbon dioxide.

Figure 13 depicts, and Table 7 shows that hardness increased in the effluent sample for each storm. As shown in Table 8, the average hardness from the storm samples was higher in the effluent samples than in the pre-construction samples. Pre-construction average hardness appears to be similar to the average influent hardness from the storm events.

Figure 13: Post-Construction Stormwater Sample Results: Hardness

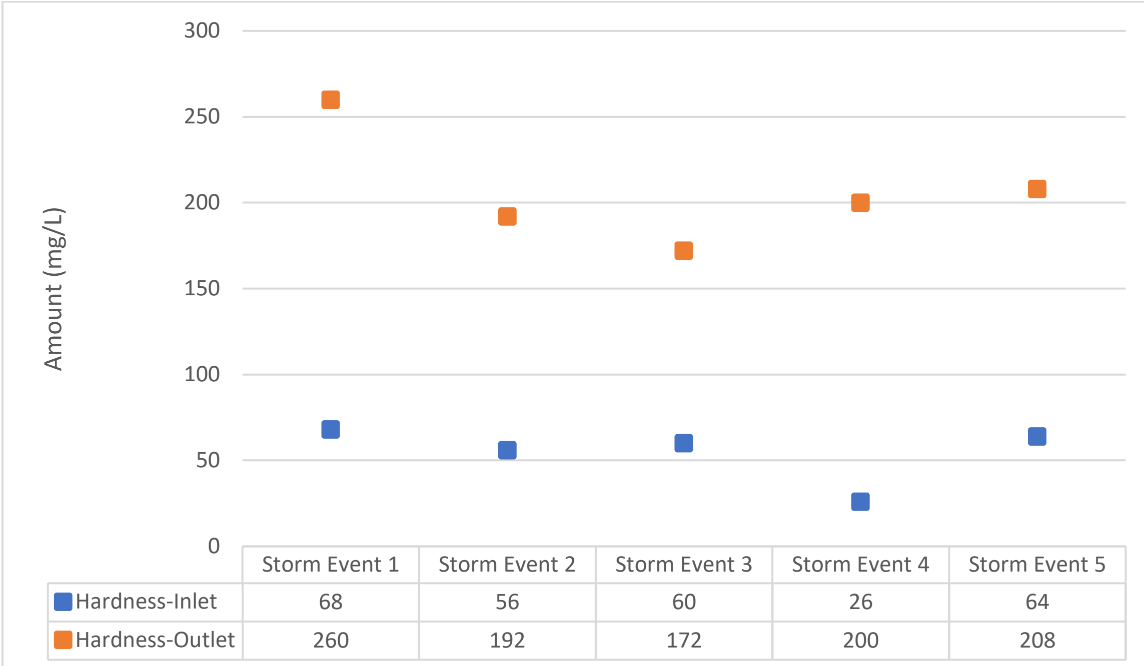


Table 7: Post-Construction Stormwater Sample Results: Hardness (mg/L)

Location	Storm					Average	Geometric Mean
	1	2	4	4	5		
Inlet	68	56	60	26	64	54.8	52.0
Outlet	260	192	172	200	208	206.4	204.4

Table 8: Pre- and Post-Construction Hardness Data (CaCO3) (mg/L)

Sample	Average	Geometric Mean	Standard Deviation	# of Samples
Pre-Construction	49.4	37.6	31.4	5
Post-Construction (Outlet)	206.4	204.4	29.4	5

The post-construction results for hardness were unexpected. The hypothesis is that the increased hardness was due to constituents included in the bioinfiltration media. San Antonio soil vendors sell ground limestone or "fines" as structured sand, as a standalone product, or as used in their mixes. It is hypothesized that the bioinfiltration soil media contained sufficient quantities of this material to cause the increased hardness results. Results from a media sample taken on April 20, 2022, show an elevated hardness level at 5,9600 mg/L (CaCO3), almost 2 years after the first post-construction sample was collected. These results indicate the need for more research and testing into the most appropriate soil media for use in LID and stormwater BMP projects in the San Antonio area.

Total Suspended Solids (TSS) and Sediment Analysis

Sediment and its deposition in the urban environment affect aesthetic, economic, and other aspects of city life, including reducing the capacity of drainage infrastructure and impairing surface water quality and aquatic habitat. Urbanization results in a number of pressures on our watersheds because development affects local runoff and sediment loading rates (Jordan et al. 2014).

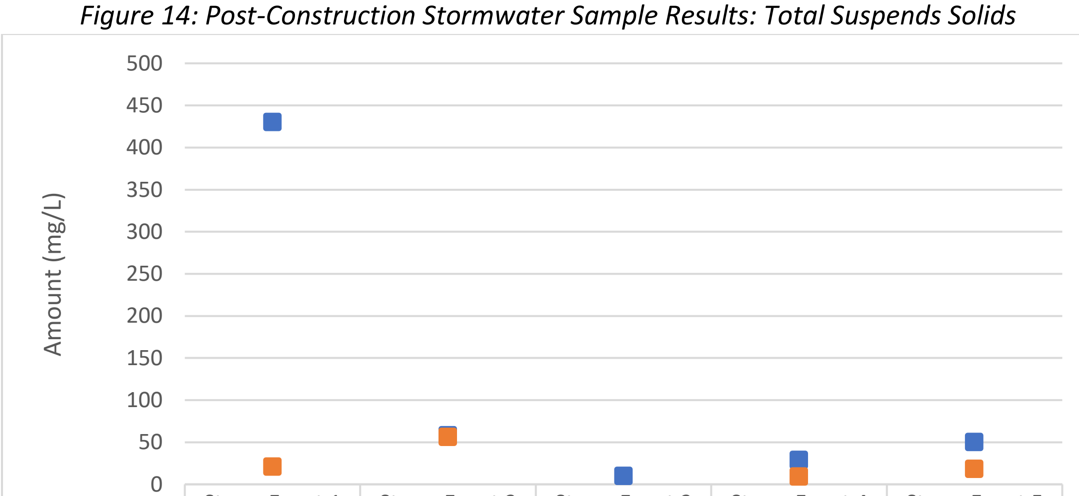
Two major characteristics of urbanized areas, impervious surfaces, and nonpoint source pollution, have been noted to adversely affect local water and land quality along with water quantity due to the excessive amount of sediment entering our local watershed areas. Sediment is the most common pollutant found in our waterbodies and 70% of total sediment is attributed to accelerated erosion from human use of land (Mid-Atlantic Regional Council 2022).

Sediment also provides a medium for the accumulation, transport, and storage of nutrients and metals. It can be organic, or inorganic derived from wind and water erosion and can arrive from sources outside the watershed by atmospheric deposition (Shaver, et al. 2007). Stormwater transports sediment of varying particle sizes depending on its discharge and availability within the watershed.

Total Suspended Solids (TSS) is the parameter most frequently measured and refers to any waterborne particle that exceeds 2 microns in any size. TSS can be anything that floats, or "suspends" in water, including clay particles, grass clippings, and limestone dust. TSS affects a waterbodies' clarity, impacting dissolved oxygen levels and increasing water temperature. In addition, sediments in stormwater runoff from urban areas, and metals and hydrocarbons associated with these sediments, are a substantial source of pollution to receiving waters and associated toxic effects on aquatic organisms (Water Research Foundation 2020).

Figure 14 and Table 10 show that suspended solids were lower in the effluent sample. The effluent sample from Storm 1 had a far greater reduction than the other storms analyzed. There was only a reduction of 2 mg/L for Storm 2. The average of suspended solids was lower in the post-construction analysis as shown in Table 11.

Figure 14: Post-Construction Stormwater Sample Results: Total Suspends Solids



	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
TSS-Inlet	430	58	10	29	50
TSS-Outlet	21	56	ND	9	18

Table 10: Post-Construction Stormwater Sample Results: Total Suspended Solids (mg/L)

Location	Storm					Average	Geometric Mean
	1	2	4	4	5		
Inlet	430	58	10	29	50	115.4	51.5
Outlet	21	56	ND	9	18	26.0	20.9

ND: Non-Detect

Table 11: Pre- and Post-Construction Total Suspended Solids Data (mg/L)

Sample	Average	Geometric Mean	Standard Deviation	# of Samples
Pre-Construction	76.1	31.4	100.7	5
Post-Construction (Outlet)	26.0	20.9	17.9	5

During project monitoring, it was noted that the amounts of sediment collected within the sediment forebay exceeded expectations for this type of residential development where construction had been completed approximately 40 years ago with established and well-maintained landscapes. To better understand this phenomenon, rates of sediment deposition were initiated and recorded from April 1, 2022, to July 4, 2022. Results indicate that sediment loading rates are variable and depend not only on the intensity of rain events in the drainage area but also on other erosion-causing events as seen in Table 12.

Observations were also noted on the type of sediment that settled out of the stormwater in the basin. While a large portion was organic matter such as grass clippings and even mulch, there was also a substantial amount of fine-particle material that could be attributed to road and roof dust along with some larger grain, crushed rock particles from composition roof shingles. Most of these pollution sources could be reduced by residents disposing of grass clippings properly versus blowing them into the street and more frequent street sweeping operations by Public Works. Additional control could be realized by promoting the practice of disconnecting impervious surfaces with green space areas and the use of LID practices such as rain gardens and bioswales installed within existing residential landscapes

Table 12: Rates of Sediment Collected in Sediment Forebay:

Date of Collection	Amount of Sediment Collected (Liters)*	Amount of Rain Between Collection Times
April 17, 2022	3.7	No recorded rain. Sediment deposition due to a water main break in the drainage area.
May 3, 2022	208.2	16 days between collection events. 1.52 in. of rain was reported during this timeframe from USGS Gauge 08178700.
May 12, 2022	13.7	8 days between collection events. 0.58 in. of rain was reported during this timeframe from USGS Gauge 08178700.

June 14, 2022	45.4	34 days between collection events. 0.50 in. of rain was reported during this timeframe from USGS Gauge 08178700.
July 4, 2022	63.4	20 days between collection events. 1.21 in. of rain was reported during this timeframe from USGS Gauge 08178700.
Average Amount of Sediment/Event:	66.9 L	

* = Larger pieces of debris, (larger than approximately 1" in size) were removed from the volume measurement.

Fecal Indicator Bacteria

Fecal indicator bacteria, although not generally pathogenic, indicate feces levels present in waterbodies. Their presence increases the risk of contracting a waterborne illness for humans who come in contact with such water. Recreational contact and non-contact criteria are based on indicator bacteria rather than direct measurements of pathogens.

The analysis of the Lorence Creek stormwater BMP treatment train system included bacteria parameters for *Escherichia coli* (*E. coli)* and fecal coliform. *E. coli* is a subgroup of fecal coliform bacteria that are part of the normal intestinal flora in humans and animals used as indicators of fecal contamination. Fecal coliform is a subset of total coliform bacteria that are present in the intestines or feces of warm-blooded animals. Fecal coliform was historically used as an indicator of the sanitary quality of water. Today, most modernized freshwater water quality standards are based on *E. coli* levels. Criteria are expressed as the number of bacteria per 100 mL of water, either as colony-forming units per 100 mL (CFU/100mL) or Most Probable Number per 100 mL (MPN/100ml), a statistical probability used to represent CFU/100ml.

For the state of Texas, the TCEQ utilizes *E. coli* as an indicator for freshwater quality standards as shown in Table 13. A standard is set based on the recreational use of the waterbody that consists of five categories: primary contact recreation 1, primary contact recreation 2, secondary contact recreation 1, secondary contact recreation 2, and noncontact recreation waters.

Table 13: TCEQ Recreational Use Standard for E.coli

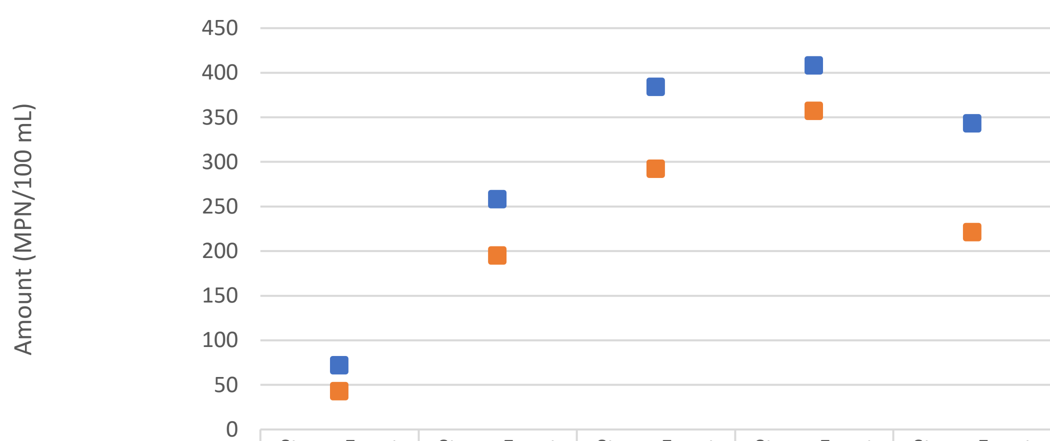
Category	**Geometric Mean Criteria (Bacteria/100mL)**
Primary Contact Recreation 1	126
Primary Contact Recreation 2	206
Secondary Contact Recreation 1	630
Secondary Contact Recreation 2	1,030
Noncontact Recreation	2,060

Figures 15 and 16 and Table 14 show that bacteria levels, *E. coli* and Total Coliform, were lower in the effluent samples. Non-detect sample results were identified for Total Coliform for Storms 3 and 4. When examining the average *E coli* levels from the water quality sampling results, averages would not meet the TCEQ Primary Contact Recreation 1 Criteria. All samples were above that limit except for the influent and effluent from Storm 1. Table 15 shows a comparison of pre-and post-construction bacteria levels. A more effective removal may be realized with a more microbially robust bioinfiltration medium. In addition, laboratory analysis of collected sediment from the project forebay during the May 3, 2022 event resulted in an exceptionally high *E. coli* result of 4,720,000 MPN/g (4,720,000 bacteria/100mL).

Figure 15: Post-Construction Stormwater Sample Results: E. coli

	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
E.coli-Inlet	69.7	239	360	342	343
E.coli-Outlet	37.9	190	250	290	221

Figure 16: Post-Construction Stormwater Sample Results: Total Coliform



	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
Total Coliform-Inlet	71.7	258	384	408	343
Total Coliform-Outlet	42.8	195	292	357	221

Table 14: Post-Construction Stormwater Sample Results: E. coli & Total Coliform (MPN/100mL)

Parameter	Location	Storm					Average	Geometric Mean
		1	2	4	4	5		
E. Coli	Inlet	69.7	239	360	342	343	270.7	234.1
	Outlet	37.9	190	250	290	221	197.8	163.1
Total Coliform	Inlet	71.7	258	384	408	343	292.9	250.9
	Outlet	42.8	195	292	357	221	221.6	180.6

Table 15: Post-Construction Stormwater Sample Results: E. coli & Total Coliform (MPN/100mL)

Parameter	Sample	Average	Geometric Mean	Standard Deviation	# of Samples
E. Coli	Pre-Construction	944.7	427.5	962.0	5
	Post-Construction (Outlet)	197.8	163.1	86.5	5
Total Coliform	Pre-Construction	2912.7	770.0	4162.9	5
	Post-Construction (Outlet)	221.6	180.6	105.8	5

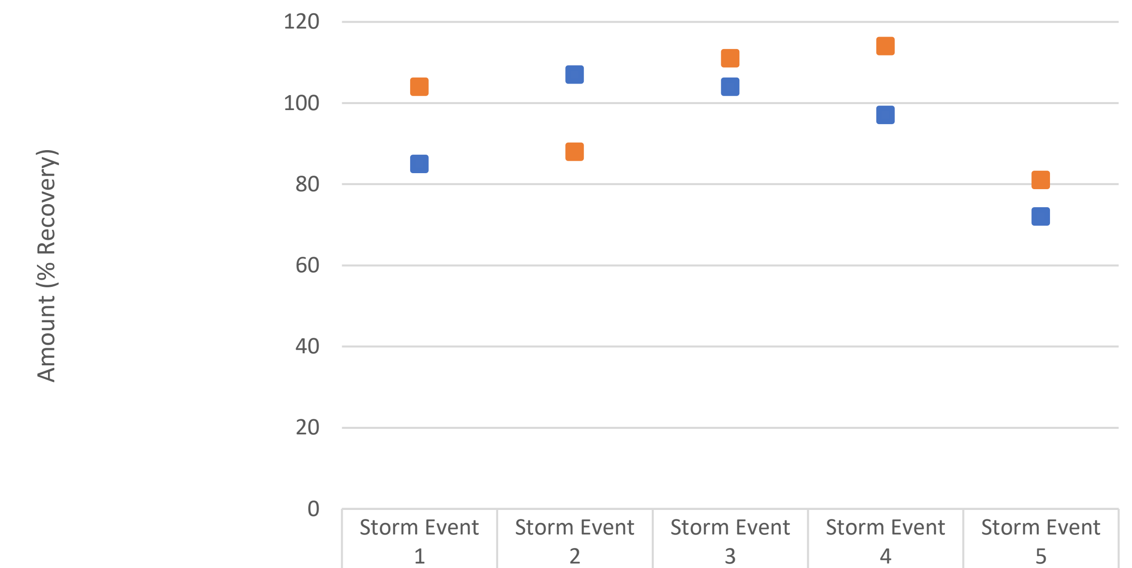
Hydrocarbons

One of the main sources of hydrocarbons in surface waters is the discharge of urban stormwater from roads, parking lots, and driveways. These sites frequently contain gasoline, oil, grease, and other petroleum products on their surfaces. During rainfall events, these pollutants are carried by stormwater runoff, enter our waterbodies and threaten overall water quality.

Samples for the Lorence Creek stormwater BMP treatment train system project were analyzed for the following hydrocarbon chains: C6-C12, >C12-C28, >C28-C35, and C6-C35. Further, the following hydrocarbon surrogates were also analyzed: 1-Chlorooctadecane, 1-Chlorooctane, 2-Fluorophenyl, Nitrobenzene-d5, and Terphenyl-d14. Figures 17-21 show the comparison of inlet and outlet samples of the hydrocarbon surrogates. Table 16 shows the tested inlet and outlet hydrocarbon results for the five storm events. The comparison between pre-and post-construction is shown in Table 17.

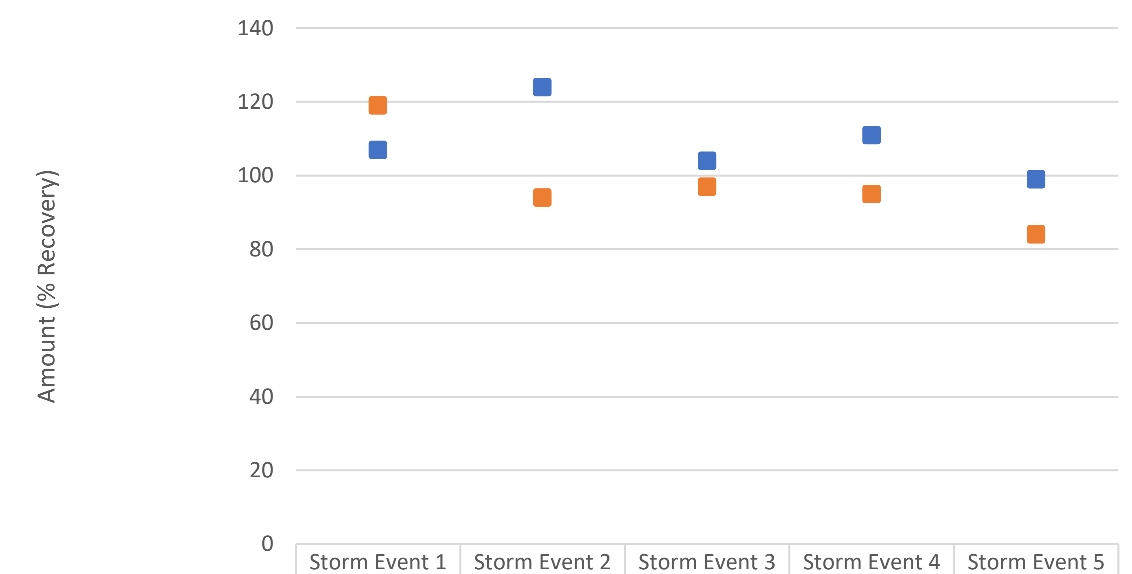
Examining stormwater sample results for the hydrocarbon chains, 92.5% of samples yielded a non-detect result from the inlet and outlet sampling points. Hydrocarbon surrogates yielded more numerical results that can be used to analyze the stormwater BMP treatment system's effectiveness. When examining post-construction stormwater sample results for hydrocarbon surrogates, 1-Chlorooctance, 2-Fluorobiphenyl, and Terphenyl-d14 were observed to have decreased average pollutant loading when comparing inlet vs. outlet results. Comparing pre-and post-construction hydrocarbon data, decreased average pollutant loading was observed for the following hydrocarbon surrogates: 1-Chlorooctadecane and 1-Chlorooctane.

Figure 17: Post-Construction Stormwater Sample Results: 1-Chlorooctadecane



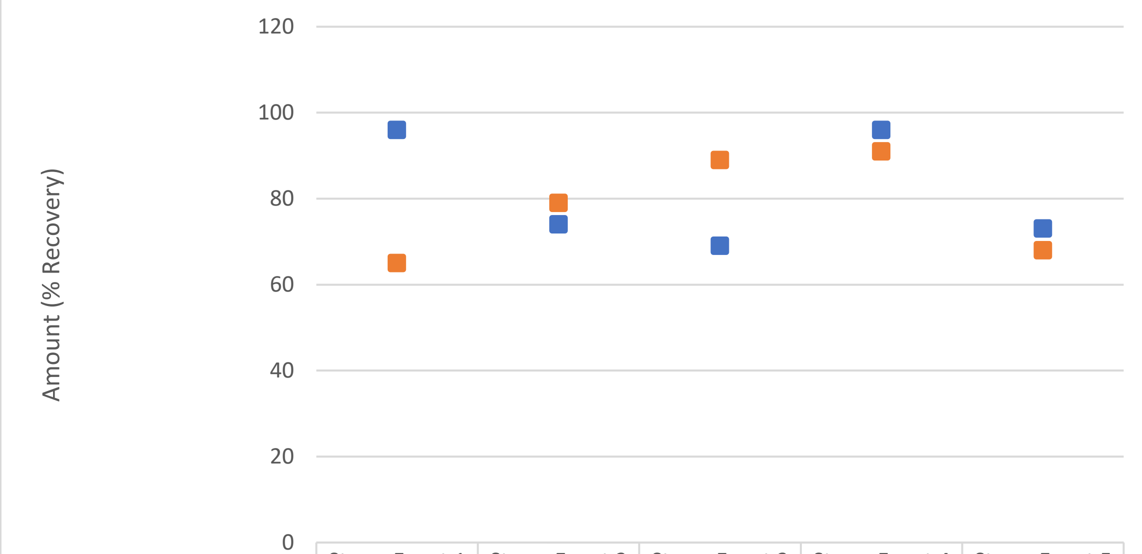
	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
1-Chlorooctadecane-Inlet	85	107	104	97	72
1-Chlorooctadecane-Outlet	104	88	111	114	81

Figure 18: Post-Construction Stormwater Sample Results: 1-Chlorooctane



	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
1-Chlorooctane-Inlet	107	124	104	111	99
1-Chlorooctane-Outlet	119	94	97	95	84

Figure 19: Post-Construction Stormwater Sample Results: 2-Fluorobiphenyl



	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
2-Fluorobiphenyl-Inlet	96	74	69	96	73
2-Fluorobiphenyl-Outlet	65	79	89	91	68

Figure 20: Post-Construction Stormwater Sample Results: Nitrobenzene-d5

	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
Nitrobenzene-d5-Inlet	61	91	86	67	71
Nitrobenzene-d5-Outlet	59	85	98	72	68

Figure 21: Post-Construction Stormwater Sample Results: Terphenyl-d14

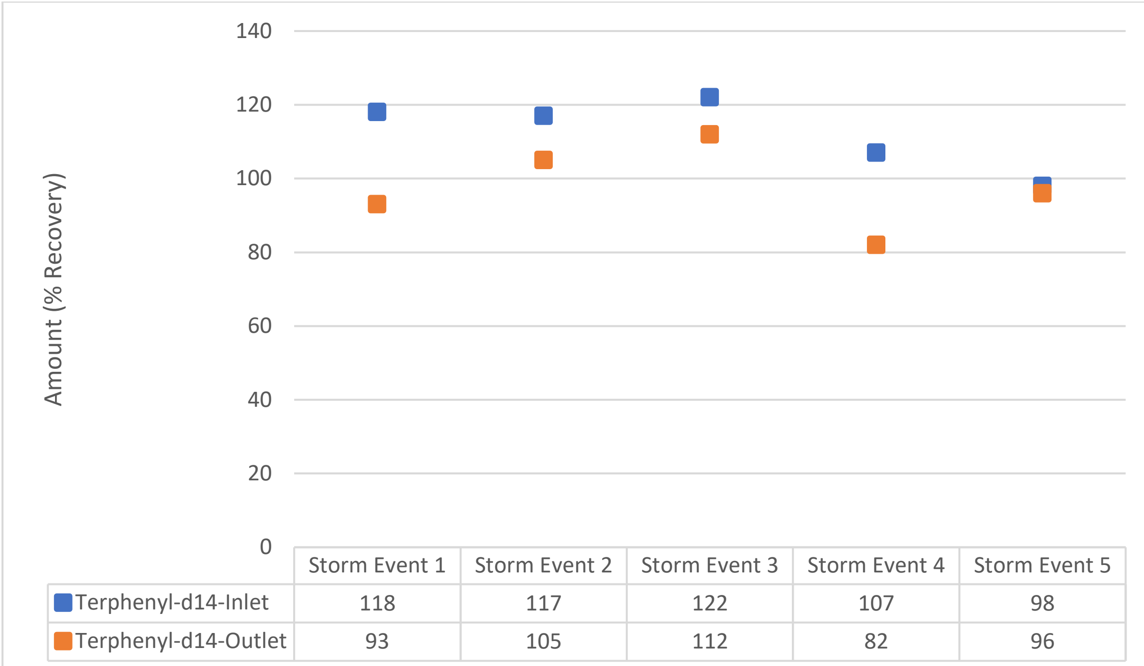


Table 16: Post-Construction Stormwater Sample Results: Hydrocarbons (mg/L)

Parameter	Location	Storm					Average	Geometric Mean
		1	*2*	*3*	*4*	*5*		
Hydrocarbons, C6-C12 (mg/L)	Inlet	ND	ND	11.4	ND	ND	11.4	11.4
	Outlet	ND	ND	ND	ND	ND	NA	NA
Hydrocarbons, >C12-C28 (mg/L)	Inlet	ND	ND	ND	ND	ND	NA	NA
	Outlet	ND	ND	ND	ND	ND	NA	NA
Hydrocarbons, >C28-C35 (mg/L)	Inlet	ND	ND	7.1	ND	ND	7.1	7.1
	Outlet	ND	ND	ND	ND	ND	NA	NA
Hydrocarbons, C6-C35 (mg/L)	Inlet	ND	ND	18.5	ND	ND	18.5	18.5
	Outlet	ND	ND	ND	ND	ND	NA	NA
1-Chlorooctadecane (% Recovery)	Inlet	85	107	104	97	72	93.0	92.0
	Outlet	104	88	111	114	81	99.6	98.7
1-Chlorooctane (% Recovery)	Inlet	107	124	104	111	99	109	108.7
	Outlet	119	94	97	95	84	97.8	97.2
2-Fluorobiphenyl (% Recovery)	Inlet	96	74	69	96	73	81.6	80.8
	Outlet	65	79	89	91	68	78.4	77.7
Nitrobenzene-d5 (% Recovery)	Inlet	61	91	86	67	71	75.2	74.3
	Outlet	59	85	98	72	68	76.4	75.2
Terphenyl-d14 (% Recovery)	Inlet	118	117	122	107	98	112.4	112.0
	Outlet	93	105	112	82	96	97.6	97.0

ND: Non-Detect NA: Not Applicable

Table 17: Pre- and Post-Construction Hydrocarbons Data (mg/L)

Parameter	Sample	Average	Geometric Mean	Standard Deviation	# of Samples
Hydrocarbons, C6-C12	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
Hydrocarbons, C12-C28	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
Hydrocarbons, C28-C35	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
Hydrocarbons, C6-C35	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
1-Chlorooctadecane	Pre-Construction	100.6	98.5	20.9	5
	Post-Construction (Outlet)	99.6	98.7	12.9	5
1-Chlorooctane	Pre-Construction	98.4	97.6	12.3	5
	Post-Construction (Outlet)	97.8	97.2	11.5	5
2-Fluorobiphenyl	Pre-Construction	34.5	9.0	22.4	5
	Post-Construction (Outlet)	78.4	77.7	10.6	5
Nitrobenzene-d5	Pre-Construction	33.1	8.5	16.9	5
	Post-Construction (Outlet)	76.4	75.2	13.7	5
Terphenyl-d14	Pre-Construction	71.2	20.0	26.9	5
	Post-Construction (Outlet)	97.6	97.0	10.3	5

NA: Not Applicable

Metals

Metals are among the most common stormwater pollutants and can be present at potentially harmful concentrations in urban runoff (Shaver et al. 2007). Metals in urban stormwater originate primarily from automobile-related activities and the exposure of building materials to rain (WERF 2003). Atmospheric deposition of metals may also be an issue, particularly in the case of mercury, as a result of air emissions from coal-fired power plants, waste incinerators, certain manufacturing facilities, and other sources (U.S. EPA 2005). Most metals that were included in the sampling tests for this project were below the reportable limit. Only barium was present at testable levels in all samples. Mercury and chromium were present above the reportable limit in a few samples.

Barium compounds are used in a variety of industrial applications including the metallurgic, paint, glass, and electronics industries. Experimental data indicate that the soluble barium concentration in fresh and marine water generally would have to exceed 50 mg/L before toxicity to aquatic life would be experienced (EPA 1986). Chromium is used in electroplating, paints, and cement. Of the tested metals, mercury could be considered the greatest concern as it is a bioaccumulating neurotoxin that could lead to adverse health effects (EPA 1986).

Figure 22 shows a comparison of barium in the post-construction inlet and outlet sample results. Table 18 shows the comparison of metals of the storm samples. Pre- and Post-construction barium levels are shown in Table 19. It is unclear why barium levels were higher after treatment in samples from Storm Events 1 and 3 than those in the inlet samples. Additional sampling would be required to determine if these results were an anomaly or if there is another as yet unidentified source.

Figure 22: Post-Construction Stormwater Sample Results: Barium

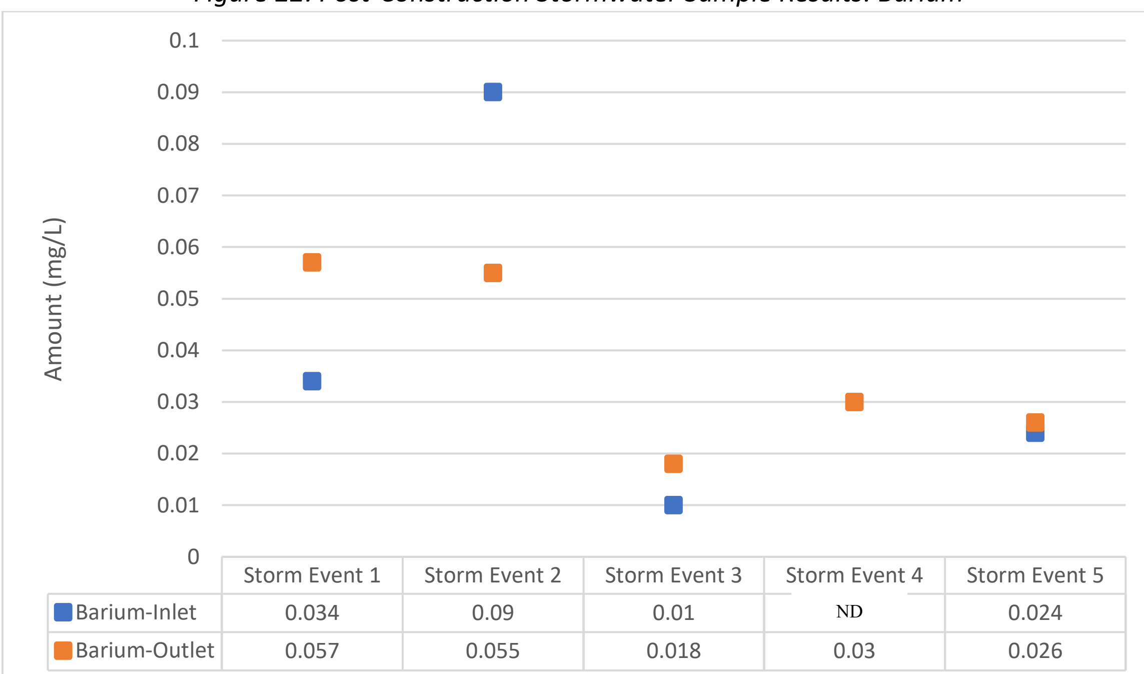


Table 18: Post-Construction Stormwater Sample Results: Metals (mg/L)

Parameter	Location	Storm					Average	Geometric Mean
		1	2	3	4	5		
Arsenic	Inlet	ND	ND	ND	ND	ND	NA	NA
	Outlet	ND	ND	ND	ND	ND	NA	NA
Barium	Inlet	0.034	0.09	0.01	ND	0.024	0.04	.03
	Outlet	0.057	0.055	0.018	0.03	0.026	0.04	.03
Cadmium	Inlet	ND	ND	ND	ND	ND	NA	NA
	Outlet	ND	ND	ND	ND	ND	NA	NA
Chromium	Inlet	ND	ND	ND	0.01	0.011	0.01	.01
	Outlet	ND	ND	ND	0.01	0.013	0.01	.01
Lead	Inlet	ND	ND	ND	ND	ND	NA	NA

	Outlet	ND	ND	ND	ND	ND	NA	NA
Mercury	Inlet	ND	ND	ND	ND	ND	NA	NA
	Outlet	0.005	ND	ND	0.0011	ND	0.01	.01
Selenium	Inlet	ND	ND	ND	ND	ND	NA	NA
	Outlet	ND	ND	ND	ND	ND	NA	NA
Silver	Inlet	ND	ND	ND	ND	ND	NA	NA
	Outlet	ND	ND	ND	ND	ND	NA	NA

ND: Non-Detect, NA: Not Applicable

Table 19: Pre- and Post-Construction Metals Data

Parameter	Location	Average	Geometric Mean	Standard Deviation	# of Samples
Arsenic	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
Barium	Pre-Construction	0.03	0.03	0.01	5
	Post-Construction (Outlet)	0.04	0.03	0.02	5
Cadmium	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
Chromium	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	0.01	0.01	0.002	5
Lead	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
Mercury	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	0.01	0.01	.003	5
Selenium	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5
Silver	Pre-Construction	NA	NA	NA	5
	Post-Construction (Outlet)	NA	NA	NA	5

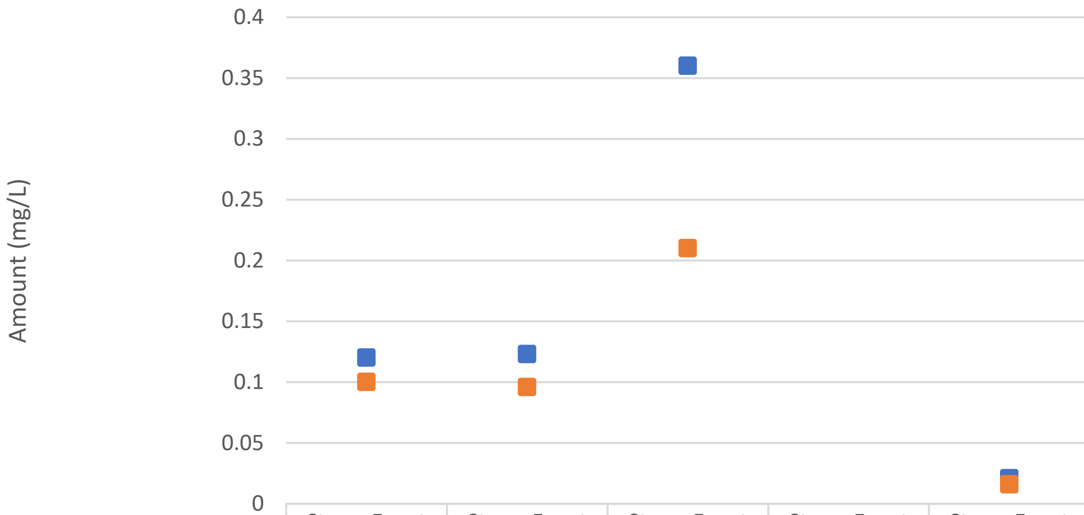
NA: Not Applicable

Nutrients

Nutrients occur naturally and are necessary for the health of terrestrial and aquatic systems; however, excessive nutrients in surface waters can result in the accelerated growth of macrophytes and phytoplankton and potentially harmful algal blooms which lead to declines in oxygen, aquatic species imbalances, public health threats, and general declines in aquatic resource value (Clary et al. 2020). Excessive nutrients in water bodies typically result from fertilizers and animal and human, treated, and untreated waste.

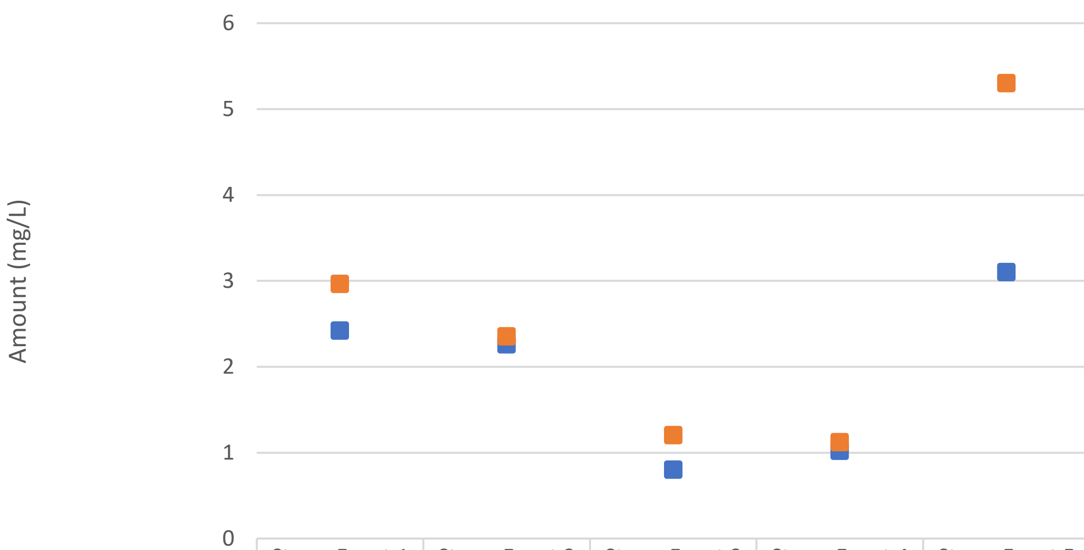
A comparison of inlet and outlet samples of tested nutrients is shown in Figures 23-25 and Table 20. The results indicate that the stormwater BMP was effective in removing some nutrients below the stormwater BMP. Total Phosphorus and dissolved organic carbon were lower in the effluent, and Total Nitrogen was higher in the effluent. Pre- and post-treatment nutrient parameter levels are shown in Table 21

Figure 23: Post-Construction Stormwater Sample Results: Total Phosphorus



	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
Total Phosphorus-Inlet	0.12	0.123	0.36	ND	0.021
Total Phosphorus-Outlet	0.1	0.096	0.21	ND	0.016

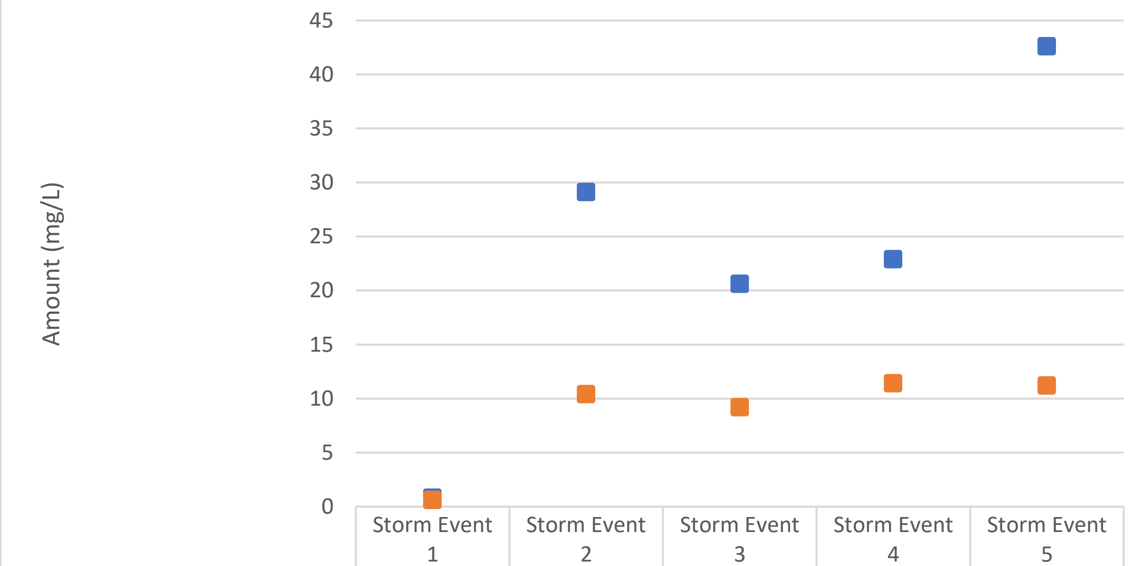
Figure 24: Post-Construction Stormwater Sample Results: Total Nitrogen



	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
Total Nitrogen-Inlet	2.42	2.26	0.8	1.02	3.1
Total Nitrogen-Outlet	2.96	2.35	1.2	1.12	5.3

The overall higher nitrogen levels at the outfall after treatment are most likely due to the elevated nitrogen levels of 5% in the bioinfiltration basin soil medium which has been documented in its use within other local LID projects using the same media. It is recommended that the nitrogen content for media to be used in LID projects be between 2-3% maximum, providing sufficient nutrients for plant growth, and with a healthy microbial population, any excess is held in a slow- release form. Results of media sampling on April 20, 2022, indicated that the Total Nitrogen level within the media was below the limit of detection, 1 mg/L. Other contributing factors leading to elevated nitrogen levels at the outfall could include the intense use of the area by deer. It is unclear the cause of the spike shown for Storm Event 5. This event occurred at the end of a very hot and dry summer and could reflect changes in vegetation or even in deer usage of the area but, still seems excessive and indicates that there was a specific source of additional nitrogen near the outlet area. Further, laboratory analysis of collected sediment from the project forebay during the May 3, 2022 event yielded a high level of Total Organic Carbon (9,450 mg/Kg) and a non-detect result for Total Nitrogen.

Figure 25: Post-Construction Stormwater Sample Results: Total Organic Carbon



	Storm Event 1	Storm Event 2	Storm Event 3	Storm Event 4	Storm Event 5
Total Organic Carbon-Inlet	0.8	29.1	20.6	22.9	42.6
Total Organic Carbon-Outlet	0.6	10.4	9.2	11.4	11.2

Table 20: Post-Construction Stormwater Sample Results: Nutrients (mg/L)

Parameter	Location	Storm 1	2	3	4	5	Average	Geometric Mean
Total Phosphorus (mg/L)	Inlet	0.12	0.123	0.36	ND	0.021	0.16	0.10
	Outlet	0.1	0.096	0.21	ND	0.016	0.11	0.08
Total Organic Carbon (mg/L)	Inlet	0.8	29.1	20.6	22.9	42.6	23.20	13.62
	Outlet	0.6	10.4	9.2	11.4	11.2	8.56	5.93
Total Nitrogen (mg/L)	Inlet	2.42	2.26	0.8	1.02	3.1	1.92	1.69
	Outlet	2.96	2.35	1.2	1.12	5.3	2.59	2.18

Table 21: Pre-and Post-Construction Nutrients Data (mg/L)

Parameter	Location	Average	Geometric Mean	Standard Deviation	# of Samples
Total Phosphorus	Pre-Construction	0.21	0.14	0.20	5
	Post-Construction (Outlet)	0.11	0.08	0.07	5
Total Organic Carbon	Pre-Construction	30.15	21.29	20.65	5
	Post-Construction (Outlet)	8.56	5.93	4.05	5
Total Nitrogen	Pre-Construction	1.88	1.78	0.61	5
	Post-Construction (Outlet)	2.59	2.18	1.53	5

Pesticides

Pesticides are chemicals used to control undesirable plants, animals, and insects. While toxicity to humans has always been a concern, long-term impacts on the environment from pesticides have become an issue that needs to be addressed. For the Lorence Creek stormwater BMP treatment train system project, the pesticide Diazinon was examined and analyzed from pre-and post-construction stormwater samples. Diazinon was used for agriculture, industry, and residential insect control. Diazinon is no longer available for residential use and is more limited for other uses, but Diazinon is persistent and remains highly mobile in soils. Diazinon impacts aquatic life in surface waters and continues to enter surface waters in runoff from landscapes.

From collected samples, Diazinon was not detected above the reporting limit in any of the storm event samples, nor during the sampling before the construction of the stormwater BMP.

STATISTICAL ANALYSIS

Post-construction stormwater samples were used to examine if a statistical difference was observed between inlet and outlet concentration values across tested water quality parameters in Table 3. For this analysis, the nonparametric Wilcoxon matched-pair signed ranks test was performed to verify a statistical difference between tested water quality parameters' inlet and outlet concentration values at a 90% confidence level (p-value < 0.1). To conduct the Wilcoxon statistical analysis accurately, water quality parameters must include five-paired numerical results (ten results total) at the inlet and outlet levels, yielding an n-value of five for this analysis. If a statistical difference was observed in the analysis, the percent removal was also calculated to assess the Lorence Creek stormwater BMP treatment train system's effectiveness in improving stormwater quality across the project site. Table 22 displays statistical analysis results for qualified post-construction stormwater sample parameters

Table 22: Statistical Analysis of Qualified Post-Construction Stormwater Parameters

Parameter	Inlet		Outlet		P-Value	Percent Removal (%)
	Average	Standard Deviation	Average	Standard Deviation		
Hardness (mg/L)	54.80	14.95	206.40	29.35	.0625	-277%
Total Nitrogen (mg/L)	1.92	0.87	2.59	1.53	.0625	-35%
E.coli (MPN/100 mL)	270.74	109.26	197.78	86.48	.0625	27%
Total Organic Carbon (mg/L)	23.20	13.56	8.56	4.05	.0625	63%
Total Coliform (MPN/100 mL)	292.94	121.82	221.56	105.80	.0625	24%
Total Suspended Solids (mg/L)*	115.40	115.19	26.00	17.87	.0625	77%
Terphenyl-d14 (% Recovery)	112.40	8.73	97.60	10.29	.0625	13%
2-Fluorobiphenyl (% Recovery)	81.60	11.88	78.40	10.57	.8125	NA
Nitrobenzene-d5 (% Recovery)	75.20	11.43	76.40	13.66	.9999	NA
1-Chlorooctadecane (% Recovery)	93.00	12.95	99.60	12.94	.5000	NA
1-Chlorooctane (% Recovery)	109	8.46	97.80	11.51	.1875	NA
Barium (mg/L)*	0.04	0.03	0.04	0.02	.6250	NA
Total Phosphorus (mg/L)*	0.16	0.12	.11	.07	.1250	NA

*Parameter had a ND lab result for an inlet and/or outlet sample. 1/2LOQ was used for any ND result for analysis. NA: Not applicable

During lab analysis, it was observed that results yielded a ND value for three parameters; Barium, Total Phosphorus, and Total Suspended Solids. To address this, ND values were given an estimated value for statistical analysis, taking one-half of the Limit of Quantitation (LOQ) found in Table 3 for the particular parameter. Further, a 90% confidence level was the highest confidence level that could be used for this analysis due to the number of paired samples collected during this study.

Utilizing the Wilcoxon analysis and addressing ND values, seven water quality parameters met the criteria to be statistically significant at the 90% confidence interval (p-value < 0.1): Hardness, Total Nitrogen, E. coli, Total Organic Carbon, Total Suspended Solids, Total Coliform, and Terphenyl-d14. This observed statistical difference enabled calculating the percent removal for these seven water quality parameters. Percent removal calculations resulted in an average loading decrease for five water quality parameters; E. coli (27% reduction) Total Organic Carbon (63% reduction), Total Suspended Solids (77% reduction), Total Coliform (24% reduction), and Terphenyl-d14 (13% reduction). Six water quality parameters did not meet the criteria to be statistically significant at the 90% confidence interval (p-value < 0.1): 2-Flurobiphenyl, Nitrobenzene-d5, 1-Chlorooctadecane, 1-Chlorooctane, Barium, and Total Phosphorus. Therefore, percent removal calculations for these six water quality parameters could not be effectively calculated, resulting in a not applicable (NA) percent removal result

Statistical difference was also observed for Hardness and Total Nitrogen water quality parameters. However, percent difference calculations yielded a percent increase result for these two parameters.

Examining these two parameters, the increase in Total Nitrogen and Hardness across the system could be attributed to the following:

1. The soil media used during the development of the bioinfiltration basin. The analysis for the recommended soil media used for the bioinfiltration was 5% Nitrogen.
2. Existing limestone presence in the media mix as supported by the April 2022 media analysis.
3. Hardness reading often increase during drought conditions.

DISCUSSION

A key lesson gained from the project was an improved understanding of the impact of sediment and organic debris on the BMP treatment train system. A key finding included the need to effectively capture the entering sediment and debris at the beginning of a treatment train in order to ensure its removal in a timely manner. Further, an increase in the sediment basin size would have facilitated improved maintenance to ensure the direct functioning of the entire system.

In addition, the prevalence of a high deer population in the area created some unexpected results, especially during the two-plus years of drought conditions when their numbers increased in this project location. Not only was there a negative impact on vegetation, but the high excrement concentration in the bioretention area could affect the system's ability to improve water quality. However, a positive outcome that resulted from the increased deer population was that no pruning of vegetation was necessary; thus, reducing overall maintenance needs. It is anticipated that the impact of this matter will decrease when climate conditions improve.

Expanding on other lessons learned from this project's efforts, it appeared that several issues originated from the engineered soil mix including nitrogen and water hardness levels within the affluent samples. On-going issues with any commercial media include types of ingredients and holding times that directly affect its quality and pricing. Current research highlights the need for soil media products to focus on an increased organic matter level which can require longer holding times to stabilize the organic matter, improve structure and promote aggregate stability (a strong indicator of microbial robustness). This process could also lower nitrogen levels to a more ideal level within a 2-3% range. Such a process can shift the media to a healthier loamy sand with a robust microbial population promoting its ability to incorporate and digest small amounts of additional sediment and organic matter in low-impact development features. This capability would not only reduce maintenance but could better maintain soil fertility and porosity, reduce surface crusting and assist in the media's effectiveness in removing contaminants. (US Composting Council)

The results from the sample analysis also revealed the need for more sampling events for future BMP treatment train systems. Data for several of the constituents contained outliers that might have been better understood with additional sampling. In addition, it would be recommended to use field blanks and duplicates as they would provide improved controls in relation to the laboratory results. Also recommended would be the installation of area velocity flow sensors that could be used in an open channel or culvert to better quantify the capacity and effectiveness of the system.

Overall, this demonstration project resulted in sufficient effectiveness for improving the quality of urban runoff to explore the possibility of developing a similar project with recommended improvements and under the protocol that TCEQ would require in developing a “model project” to encourage and streamline their process for similar projects within the EARZ. It should also be noted that one of the innovative aspects of the project was the public outreach component, professional and general public. To promote the effectiveness of public education, an interpretive sign was designed and installed on the project site.

CONCLUSION

Maintaining water quality within the Edwards Aquifer remains a high priority across the San Antonio area, and one way to assist in its protection would be to continue retrofitting existing sites with water quality stormwater BMPs. The funding and construction of this retrofit project have increased the understanding regarding the design, functioning, and maintenance of stormwater BMPs not only within the EARZ, but for any site in other areas with similar climate, soil, and social regime.

While current design criteria for low impact development features within the City of San Antonio development code requires the capture and treatment of 1.5 in., this project did show that significant improvement in the quality of stormwater runoff can be accomplished with smaller systems. the results for the project were significant for the percent removal of seven water quality parameters including TSS, Total Coliform, E. coli, Total Organic Carbon, and several types of hydrocarbons. It is reasonable to expect that effectiveness could be increased and maintenance reduced with improved design and soil media mixes. It is recommended that mixes should have nitrogen levels within 2-3% and for the mix to be aged for a longer period of time to promote and stabilize soil aggregates.

The project’s innovative design of utilizing site’s existing natural features (topography, boulders, trees, and plants), while enhancing to function as a water quality stormwater BMP, could be used as a model and duplicated throughout the area as a “volunteer” retrofit. To utilize such concepts in new development within the ERZD would not only require an increase in the ratio of the BMP treatment size to the drainage area but also coordination with TCEQ to meet their criteria for substantiating effectiveness to quality as a “model project”. The criteria to set new standards would require a longer and more detailed monitoring and sampling period with stormwater flow data.

Similar type projects that provide not only water quality benefits but also much needed green space for recreational use will become more important not only in the ERZD but throughout the area as the projected population increases and impacts of urbanization on urban watershed areas are expected to increase as well. According to population figures from the Texas Demographic Center, the San Antonio-New Braunfels, TX metropolitan area is anticipated to increase 99% between 2020 and 2050, from 2.2 million to 4.4 million (2018). With this expected population increase, significant land use conversion for commercial, residential, and industrial purposes will occur causing significant impacts on the area’s ecological footprint.

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APPENDIX A: PRE-CONSTRUCTION STORMWATER AND SOIL SAMPLE RESULTS

Pre-Construction Stormwater Sample Results Sample Location: Inlet					
Parameter	Storm Event 1: 12/06/2017	Storm Event 2: 12/16/2017	Storm Event 3: 02/21/2018	Storm Event 4: 03/28/2018	Storm Event 5: 07/05/2018
Arsenic (mg/L)	ND	ND	ND	ND	ND
Barium (mg/L)	ND	ND	0.016	0.033	0.028
Cadmium (mg/L)	ND	ND	ND	ND	ND
Chromium (mg/L)	ND	ND	ND	ND	ND
Hardness (mg/L)	28.6	39.2	73.3	96.5	9.52
Hydrocarbons, C6-C12 (mg/L)	ND	ND	ND	ND	ND
Hydrocarbons, >C12- C28 (mg/L)	ND	ND	ND	ND	ND
Hydrocarbons, >C28- C35 (mg/L)	ND	ND	ND	ND	ND
Hydrocarbons, >C6-C35 (mg/L)	ND	ND	ND	ND	ND
Lead (mg/L)	ND	ND	ND	ND	ND
Mercury (mg/L)	ND	ND	ND	ND	ND
Selenium (mg/L)	ND	ND	ND	ND	ND
Silver (mg/L)	ND	ND	ND	ND	ND
Total Phosphorus (mg/L)	0.205	0.185	0.582	0.064	0.036
Total Nitrogen (mg/L)	1.2	1.4	2.7	2.2	ND
Total Suspended Solids (mg/L)	7.8	16.7	12	272	72
1-Chlorooctadecane (% Recovery)*	92	124	78	127	82
1-Chloroooctane (% Recovery)*	88	106	80	105	113
Diazinon (mg/L)*	0	ND	0	ND	ND
E. coli (MPN/100mL)*	218	2490	1010	ND	60.9

2-Fluorobiphenyl (% Recovery)*	54.1	45	56.8	16.4	0.0258
Nitrate (mg/L)*	ND	ND	NA	NA	NA
Nitrite (mg/L)*	ND	ND	NA	NA	NA
Nitrobenzene-d5 (% Recovery)*	46	44.1	39.8	35.8	0.0155
Terphenyl-d14 (% Recovery)*	72.2	87.5	103	93.2	0.0534
Total Coliform (MPN/100mL)*	467	10100	1010	NA	73.8
Total Organic Carbon (mg/L)*	7.34	32.9	6.92	59.8	43.8

*Denotes additional parameters included for detailed stormwater analysis
ND: Non-Detect, NA: Not Available

Pre-Construction Soil Sample Results Sample Location: Inlet					
Parameter	Storm Event 1: 12/06/2017	~~Strom~~ Event 2: 12/16/2017	Storm Event 3: 02/21/2018	Storm Event 4: 03/28/2018	Storm Event 5: 07/05/2018
Arsenic (mg/Kg)	ND	ND		ND	ND
Barium (mg/Kg)	95.4	20.9		15.4	29.2
Cadmium (mg/Kg)	0.58	ND		ND	ND
Chromium (mg/Kg)	27.5	3.63		3.41	1.34
Hardness (mg/L)	1810	1740		399	249
Hydrocarbons, C6-C12 (mg/Kg)	ND	ND		ND	ND
Hydrocarbons, >C12-C28 (mg/Kg)	ND	ND		ND	ND
Hydrocarbons, >C28-C35 (mg/Kg)	ND	ND		ND	ND
Hydrocarbons, >C6-C35 (mg/Kg)	ND	ND		ND	ND
Lead (mg/Kg)	30.7	2.72		4.08	2.12
Mercury (mg/Kg)	ND	ND		ND	ND
Selenium (mg/Kg)	ND	ND		ND	ND
Silver (mg/Kg)	ND	ND		ND	ND
Phosphate as P (mg/Kg)	24.8	34		7.04	7.51
Total Nitrogen (mg/Kg)	17.5	19		ND	ND
1-Chlorooctadecane (% Recovery)	124	117		89	95
1-Chloroooctane (% Recovery)	88	105		70	82
Total Organic Carbon (mg/L)	31300	42700		18100	1330

APPENDIX B: POST-CONSTRUCTION STORMWATER SAMPLE RESULTS

Post-Construction Stormwater Sample Results						
Parameter	Location	Storm Event 1: 09/04/2020	Storm Event 2: 09/22/2020	Storm Event 3: 12/31/2020	Storm Event 4: 02/12/2021	Storm Event 5: 05/12/2021
Arsenic (mg/L)	Inlet	ND	ND	ND	ND	ND
	Outlet	ND	ND	ND	ND	ND
Barium (mg/L)	Inlet	0.034	0.09	0.01	ND	0.024
	Outlet	0.057	0.055	0.018	0.03	0.026
Cadmium (mg/L)	Inlet	ND	ND	ND	ND	ND
	Outlet	ND	ND	ND	ND	ND
Chromium (mg/L)	Inlet	ND	ND	ND	0.01	0.011
	Outlet	ND	ND	ND	0.01	0.013
Hardness (mg/L)	Inlet	68	56	60	26	64
	Outlet	260	192	172	200	208
Hydrocarbons, C6-C12 (mg/L)	Inlet	ND	ND	11.4	ND	ND
	Outlet	ND	ND	ND	ND	ND
Hydrocarbons, >C12-C28 (mg/L)	Inlet	ND	ND	ND	ND	ND
	Outlet	ND	ND	ND	ND	ND
Hydrocarbons, >C28-C35 (mg/L)	Inlet	ND	ND	7.1	ND	ND
	Outlet	ND	ND	ND	ND	ND
Hydrocarbons, >C6-C35 (mg/L)	Inlet	ND	ND	18.5	ND	ND
	Outlet	ND	ND	ND	ND	ND
Lead (mg/L)	Inlet	ND	ND	ND	ND	ND
	Outlet	ND	ND	ND	ND	ND
Mercury (mg/L)	Inlet	ND	ND	ND	ND	ND
	Outlet	0.005	ND	ND	0.011	ND
Selenium (mg/L)	Inlet	ND	ND	ND	ND	ND
	Outlet	ND	ND	ND	ND	ND
Silver (mg/L)	Inlet	ND	ND	ND	ND	ND
	Outlet	ND	ND	ND	ND	ND
Total Phosphorus (mg/L)	Inlet	0.12	0.123	0.36	ND	0.021
	Outlet	0.1	0.096	0.21	ND	0.016
Total Nitrogen (mg/L)	Inlet	2.42	2.26	0.8	1.02	3.1
	Outlet	2.96	2.35	1.2	1.12	5.3
Total Suspended Solids (mg/L)	Inlet	430	58	10	29	50
	Outlet	21	56	ND	9	18
1-Chlorooctadecane (% Recovery)*	Inlet	85	107	104	97	72
	Outlet	104	88	111	114	81
1-Chlorooctane (% Recovery)*	Inlet	107	124	104	111	99
	Outlet	119	94	97	95	84
Diazinon (mg/L)*	Inlet	0	0	ND	ND	0
	Outlet	0	0	ND	ND	0
E. coli (MPN/100 ml)*	Inlet	69.7	239	360	342	343
	Outlet	37.9	190	250	290	221
2-Fluorobiphenyl (% Recovery)*	Inlet	96	74	69	96	73
	Outlet	65	79	89	91	68
Nitrobenzene-d5 (% Recovery)*	Inlet	61	91	86	67	71
	Outlet	59	85	98	72	68
	Inlet	0.8	29.1	20.6	22.9	42.6

Total Organic Carbon (mg/L)*	Outlet	0.6	10.4	9.2	11.4	11.2
Terphenyl-d14 (% Recovery)*	Inlet	118	117	122	107	98
	Outlet	93	105	112	82	96
Total Coliform (MPN/100 ml)*	Inlet	71.7	258	384	408	343
	Outlet	42.8	195	292	357	221

*Denotes additional parameters included for detailed stormwater analysis

ND: Non-Detect

APPENDIX C: PLANT LIST FOR LORENCE CREEK HOA RETROFIT PROJECT

Plant	**Seed**	**Plant**
Chile pequin*, Capsicum annuum ‘Pequin’*	X	X
Frogfruit, *Phlya nodiflora*		X
Horseherb, *Calyptocarpus vialis*		X
White or Fragrant mist flower, *Eupatorium havanense*		X
Pigeonberry, *Rivina humilis*		X
Lyre leaf sage, *Salvia lyrata*		X
Zexmenia, *Wedelia texana*	X	X
Inland seaoats, *Chasmanthium latifolium*	X	X
Texas persimmon, *Diospyros texana*		X
Heart leaf skullcap, *Scutellaria ovata*		X
Missouri violet, *Viola soroia*		X
Webberville sedge, *Carex perdentata*		X
Woodland sedge, *Carex blanda*		X
Cherokee sedge, *Carex cherokeensis*		X
Eastern gammagrass, *Tripsacum dactyloides*		X
Texas lantana, *lantana urticoides*		X
Virginia wildrye, *Elymus virginicus*	X	
Purpletop tridens, *Tridens flavus*	X	
Red seeded plaintain, *Plantago rhodosperma*		X
Baby blue eyes, *Nemophila phacelioides*	X	
Turkscap’s, M*alvaviscus dummondii*		X
Bushy bluestem, *Andropogon glomeratus*	X	
White heath aster, *Symphyotrichum ericoides*		X
Obedient plant, *Physostegia virginiana*		X

Frostweed, *Verbesina virginica*	X	
Texas little barley, *Hordeum pusillum*	X	
White germander, *Teucrium cubense*		X
Wild petunia, *Ruellia drummondiana*	X	X