# Water Quality Improvement and Pollutant Removal by Two Regional Detention Facilities with Constructed Wetlands in South Texas

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## Abstract

Stormwater runoff introduces several pollutants to the receiving water bodies that may cause degradation of the water quality. Stormwater management systems such as detention facilities and wetland can improve the water quality by removing various pollutants associated with the runoff. The objective of this research project is to determine the performance and efficiency of two major Regional Stormwater Detention Facilities (RSDFs) with different designs and structures in reducing pollutants based on various storm events in McAllen, Texas. The two sites are McAuliffe RDF and Morris RDF; each site was incorporated with a constructed wetland with different design and structure to enhance the pollutant removal process. McAuliffe RDF reduced the concentration and load of many stormwater constituents in comparison to Morris RDF. Observed concentrations and pollutant loads of suspended solids were much lower in the runoff of the inlet compared to the outlet for both sites. McAuliffe RDF showed better concentration and load reduction for nutrients, such as nitrogen and phosphorus, of different species. However, both sites did not show a significant improvement of organic material. Also, indicator bacteria concentration represents a fluctuation between the inlet and outlet at each site.

**Keywords**: Water quality, Stormwater, Load reduction, Detention facility, Wetland, South Texas

## Introduction

Urban stormwater runoff contains substantial loads of numerous chemical and physical constituents that may adversely affect the water quality of rivers, channels, and lakes. These constituent loads are caused by the rainfall wash-off of deposited material, such as vehicle emissions, trash, pet litter, fertilizers and pesticides applied to lawns, and atmospheric deposition. As a result, runoff carrying various pollutants, including sediments, nutrients, pathogenic bacteria, pesticides and herbicides, and heavy metals that cause a decline in aquatic biota and degradation of water quality, is discharged into untreated surface water (Bean, E. et al., 2007; Liu et al., 2014).

Recently, the rapid urbanization in the Lower Rio Grande Valley (LRGV) has increased the stormwater runoff and pollutant loading into the receiving water bodies through the region (Alam et al., 2019a). One of the affected waterbodies is the Arroyo Colorado watershed, which stretches for 90 miles and flows through Hidalgo, Cameron, and Willacy counties in the LRGV and into the Laguna Madre. The Arroyo Colorado serves as the main drainage system in that area and also as a freshwater source to the region. The watershed is considered the primary source of freshwater inflow to the Laguna Madre, which is an important estuary for many natural habitat species (Alam et al., 2019b). The transformation of the watershed from its natural state has contributed to a water quality problem. The watershed has been exposed to non-point source pollution from the extensive agricultural development that is interspersed with areas of rapid urban development. Henceforth, an overload of nutrients and oxygen demanding materials were transported across the river; both were associated with agricultural and stormwater runoff.

Since 2006, the Texas Commission on Environmental Quality (TCEQ) listed the Arroyo Colorado watershed as an impaired waterway due to depressed oxygen levels and high bacterial concentration (Flores et al., 2017). Therefore, local and regional efforts were initiated to curb the non-point source pollution to the watershed and to restore the river water quality. Local entities through the LRGV region started the adoption and implementation of Green Infrastructure (GI) as an effective management strategy to address the water quality issues. GI not only reduces runoff volume; it also increases water quality through structures such as detention basins, bioretention ponds and wetlands (Eckart et al., 2017; Mahmoud et al., 2019). Several studies also showed the water quality benefits of GI through the effective reduction of nutrients, biodegradable organic material, and bacteria from urban stormwater runoff (Lenhart and Hunt, 2011; Liu et al., 2017).

As mitigation of the adverse effects of urbanization on the quality of stormwater runoff becomes a major objective of planning and development of populated watersheds, detention basins can be incorporated into a site development plan to alleviate those effects. Detention basins are stormwater management structures that temporarily collect runoff and then release a reduced flow gradually to decrease the risk of flooding (Sinha et al., 2018). They can provide some economic benefits when incorporated in the watershed management program by reducing the cost of the drainage system. Detention systems provide effective low-cost, low-maintenance treatment of stormwater runoff from highways and other urban or industrial areas (Lee and Li, 2009). Their implementation is considered one of the most widely used management practices to reduce runoff volume.

Detention basins are stormwater management strategies that may also be used to improve water quality by maximizing sedimentation through chemical and biologic processes. Detention ponds with relatively simple design criteria can be used to provide excellent water quality benefits over a wide range of storm conditions (Caroline et al., 2005). Extended detention basins are constructed as modified conventional dry ponds to hold stormwater for at least 24 hours to allow solids to settle and to reduce local and downstream flooding. The basins are designed to detain smaller storms for a sufficient period of time to remove pollutants from the runoff. The water-quality improvement is optimized by maximizing the detention time of stormwater in a detention pond. The primary pollutant removal mechanism in detention basins is sedimentation through settling up the solid particles at the bottom of the basin. Some studies showed that detention basins are effective at removing solids from urban runoff. In addition, nutrients and heavy metals may also be removed  through flowing urban runoff in the detention systems (Middleton and Barrett, 2008; Simpson and Weammert, 2009). Nutrients such as nitrogen and phosphorus associated with solids are also removed through sedimentation. The two main components that affect system performance are retention time and influent concentration (Weiss et al., 2006; Middleton and Barrett, 2008).

A significant water quality improvement through settling is achievable by increasing the retention time of the water, removing suspended solids with associated pollutants and allowing UV disinfection from the sunlight during the day (Papa et al., 1999; Vallet, 2011; Vergeynst et al., 2012). In addition, mixing runoff with the base flow stored in the pond can significantly reduce the stormwater contaminates' loads through dilution in relatively small storms. It may be designed with either a fixed or adjustable outflow device. Pretreatment can be a fundamental design component of a detention pond to reduce the potential for clogging. Other components such as a micro pool or shallow marsh may be added to enhance pollutant removal. A properly designed detention basin is effective in reducing pollutant loads and may be used to meet the stormwater management standards. If it is maintained as shallow wetland, the lower stage of the detention basin incorporates natural biological removal processes to enhance the removal potential of soluble pollutants (USEPA, 1997).

Wetlands have grown in popularity as a cost-effective treatment for a variety of different types of wastewater, including municipal, industrial, urban and agricultural runoff (Sultana et al., 2014). Stormwater wetlands are engineered systems consisting of shallow ponds that have been planted with aquatic plants; they rely on the utilization of the natural functions of vegetation, soil, and microbials associated  with assembled processes to treat the wastewater (Wang et al., 2017). Additionally, in addition to stormwater management, wetlands provide other benefits, such as plant and wildlife habitat and recreational areas. Stormwater wetlands use physical, chemical and biological processes to treat urban runoff. Previous studies demonstrated that wetlands have efficiently removed sediment, nutrients and heavy metals associated with runoff through sedimentation, attachment of porous media, chemical and biological processes and plant uptake (Dorman et al., 2013; Vymazal and Březinová, 2015). Wetlands are classified into two types: either natural or constructed. Natural wetlands act as ecosystem filters by improving the water quality passing through the system. However, constructed wetlands are engineered systems designed to remove pollutants from contaminated water by using natural processes. Constructed wetlands have higher removal efficiency than a natural one due to the longer water circuits in the constructed system, which allows more retention time (Ingrao et al., 2020). Organic compounds are removed by the wetland through the microbial degradation under anaerobic conditions in the filtration bed where oxygen levels are very limited (Vymazal and Kröpfelová, 2008). Several studies showed that wetland is effective in reducing the suspended solids from stormwater runoff (Birch et al., 2004; Hathaway and Hunt, 2010; Lopardo et al., 2019). Wetlands are highly effective in removing suspended solids from runoff through the settling and filtration provided by dense vegetation (Vymazal, 2010). However, an upstream sedimentation process unit is suggested to enhance their performance by avoiding the premature clogging of the wetland by TSS (Kabenge et al., 2018). Moreover, stormwater wetlands provide flood control benefits by decreasing the flow velocity, reducing the peak discharge and slowly releasing the stored water over a period of time (Gill et al., 2017). Similar to detention basins and other GI systems, wetlands are installed to reduce the delivery of pollutants to surface waters, and their performance is commonly reported as being variable due to the site-specific nature of influential factors (Mangangka et al., 2013; Humphrey et al., 2014).

Nutrients such as nitrogen and phosphorus in urban runoff are pollutants of major concern for the Total Maximum Daily Load (TMDL) allocations (Mahmoud et al., 2019). Elevated levels of nitrogen and phosphorus from fertilizers in urban water can trigger algal growth in a process called eutrophication. This process contributes to the reduction of dissolved oxygen and leads to a decrease in aquatic biota that is associated with detrimental environmental impacts (Li and Davis, 2016; Goonetilleke and Lampard, 2019). Removal of nitrogen and phosphorus through wetlands is variable and depends on several factors, such as load variation, inflow concentration, hydraulic retention time, temperature, hydraulic efficiency and type of wetland (Land et al., 2013). Nitrogen can be removed through different independent processes, such as denitrification, volatilization, sedimentation, and plant uptake. However, denitrification is considered the major removal mechanism of nitrogen in the wetland. Studies showed that wetlands typically perform well for nitrate removal because the anaerobic conditions and organic material in wetland sediment create an ideal environment for denitrification. At the same time, due to lack of oxygen in the wetland filtration bed, removal of ammonia is limited (Vymazal, 2007). Significant nitrate reduction is commonly observed in stormwater wetlands, but total nitrogen reduction depends on the species and concentration of incoming nitrogen (Yu et al., 2019). Several studies demonstrated that wetland can effectively remove the total nitrogen (TN) with a median removal efficiency of 37%, and significantly correlated to the hydrological loading rate and temperature (Land et al., 2016).

Similar to nitrogen removal mechanisms, phosphorus can be removed by sedimentation and plant uptake. In addition, phosphorus can be removed also by sorption or ligand exchange reactions; phosphate replaces hydroxyl or the water group from the surface of iron and aluminum hydrous oxide (Vymazal, 2007). (Land et al., 2016) compared the total phosphorus (TP) removal of 146 studies from the wetland. Results showed that the median removal efficiency of all studies of TP is 49%, and was significantly correlated with TP concentration, hydrologic loading rate and wetland area (Land et al., 2016). Similar to metals, phosphorus can desorb from sediments in the wetland under anaerobic conditions (Hathaway and Hunt, 2010). Humphrey et al., 2014 studied the stormwater water quality improvement in a constructed wetland in North Carolina. Results showed that high pollutants reductions efficiency is due to the relatively large size of the wetland area and below-average rainfall that likely contributed to improving the water quality performance (Humphrey et al., 2014).

Further investigations are needed to evaluate the sustainable removal performance of constructed wetland and detention basins that will contribute greater insights into the nutrient treatment process (Lee et al., 2009; Middleton and Barrett, 2008). Numerous studies have been conducted on detention basins in a wet climate, but its functionality in removing pollutants in arid/ semi-arid regions has not been widely investigated during a rain event for certain land-use types (Lodhi and Acharya, 2014). The best prospect of successful wetland treatment and pollutant removal should be in warmer regions of the world (Wang et al., 2017), which indicates that the

LRGV can be an ideal region for studying wetland performance and its effects on various pollutants. The previous studies showed the effectiveness of wetland and detention pond for improving stormwater quality separately under variable rainfall events. However, it is important to evaluate the performance of a regional detention facility incorporated with a combination of a constructed wetland and a detention pond to improve the quality of stormwater runoff during different rainfall events. The overarching goal of this study is to quantify the effectiveness of regional detention facilities in improving the quality of stormwater runoff. The main objectives of this study are to compare the performance of two regional detention facilities with a constructed wetland are: one with a detention pond and another without a detention pond to achieve a feasible pollutant load reduction. The second objective is to quantify the relationship between pollutant load reduction and hydrologic parameters.

## 2. Site Description

### 2.1. McAuliffe Elementary School RDF

Spanning 113,312 $m^2$, the McAuliffe RDF is located behind McAuliffe Elementary School. This RDF serves a drainage area of approximately 5 $Km^2$. It is a dual-purpose facility providing recreational opportunities during dry periods and stormwater detention during the wet weather. The RDF site boundaries are Nolana Avenue on the north and US 83 Business expressway. On the south boundary, Ware Road is on the west side, and an eastern boundary extends to N 23$^{rd}$ Street. Runoff generated in the watershed is delivered to the RDF by a man-made drainage channel located upstream of the RDF. The watershed is comprised mainly of urbanized landscapes (83%). The United States Geological Survey (USGS) land cover database showed that the majority of the urbanized area is either medium to low intensity (Figure 2A). The cultivated crops and developed open space cover about 0.75 $Km^2$ from the total drainage area.

The flow to the RDF mainly consists of stormwater runoff along with some groundwater seepage. The dominant hydrologic soil group B (92%) has moderately low runoff potential when thoroughly wet (Mockus, 2007). The soil in the watershed is mainly comprised of type B (92%) with type D (6%) and type C (2%) forming the rest. As shown in figure 1, the detention basin at McAuliffe Elementary School has gradually sloping banks.  A larger amount of urban runoff with sediment and nutrients during wet weather discharged to the man-made drainage channel located upstream of the RDF. There are two wet detention ponds that are considered permanent pools. They provide more residence time for the runoff, as they are aided by sedimentation and infiltration. The first wet pond starting from the upstream has an estimated area of 3400 $m^2$ and the second pool has an estimated area of 5,139 $m^2$. To maintain flow balance in between these two pools, a connection via the concrete pipe is established. The water from the second pool drains out to the wetland area at the end of the basin through another concrete pipe.

McAuliffe RDF was designed with a small channel wetland near the outflow monitoring point and the microscreen close to the inflow monitoring point on the upstream. The Coanda screen was installed in a concrete structure built parallel to the McAuliffe inlet (Figure 2C). There is an increasing need to screen water in surface water collection systems to remove floating debris and small aquatic organisms to protect receiving water bodies (Hosseini and Coonrod, 2011). Previous studies found that microscreen can remove solids by 3.5 times regardless of mesh size, but it is not effective in lessening the amount of dissolved substances (Fernandes et al., 2015). The main purpose of using microscreen in this study is to make the water free from debris or other larger particles, such as floatables, which may clog the channel by depositing on the channel bed. This screen is a self-cleaning apparatus, which performs without any power requirement. The microscreen used at the McAuliffe inlet RDF site operates based on the

Coanda screen principle. The Coanda effect is a hydraulic feedback circuit that produces a fluidic oscillator for which the frequency is linear with the volumetric flow rate of fluid (G. Fowles, 2010). This screen is a self-cleaning apparatus that does not require any power. The Coanda screen is installed perpendicular to the two concrete chambers for storing and diverting the overflow. The dimension of this microscreen is 7.6 m long and 0.76 m wide; it can handle a maximum flow of 2 cm/s. If the flow exceeds that maximum capacity, there will be an overflow, resulting in some debris being carried downstream. During normal operation, the incoming water flows over the screen and passes through the openings in the screen and falls into the outlet underneath; therefore, if the flow exceeds that amount, there will be an overflow, resulting in some debris being carried downstream. During normal operation, the incoming water flows over the screen and passes through the openings in the screen and falls into the outlet underneath, which is approximately 0.46 m deep. A headwall perpendicular to the channel is provided in order to increase the head by 0.37 m. The flow from the upstream of the Coanda screen flows through the screen aperture and the debris or other particles larger than the screen openings trapped upstream. The debris collection chambers assist to hold the debris for a certain time before periodic maintenance is carried out.

A small wetland was constructed just before the McAuliffe RDF outlet; this wetland consists of a channel wetland of primarily Olney Bulrush (*Schoenoplectus Americanus*) plants (Figure 1B and 1D). The *Schoenoplectus* species complex includes interesting and dynamic wetland species of ecological importance, and the growth of the stem largely depends on the combined nitrogen and phosphorus concentration present in the water (Escutia-Lara et al., 2008). This plant provides some biological treatment by nutrient uptake, infiltration, and reduction in the flow of stormwater from the McAuliffe RDF basin. The wetted area of the wetland is 170.94 $m^2$ with side slopes of 5:1 (H: V) on the left side and 4.5:1 (H: V) on the right side. The maximum width of the main wetted portion of the wetland is 11.89 m with an average depth of 0.55 m from the water level. The wetland water is flowing from a concrete outlet with a dimension of 3.3 m × 1.7 m.

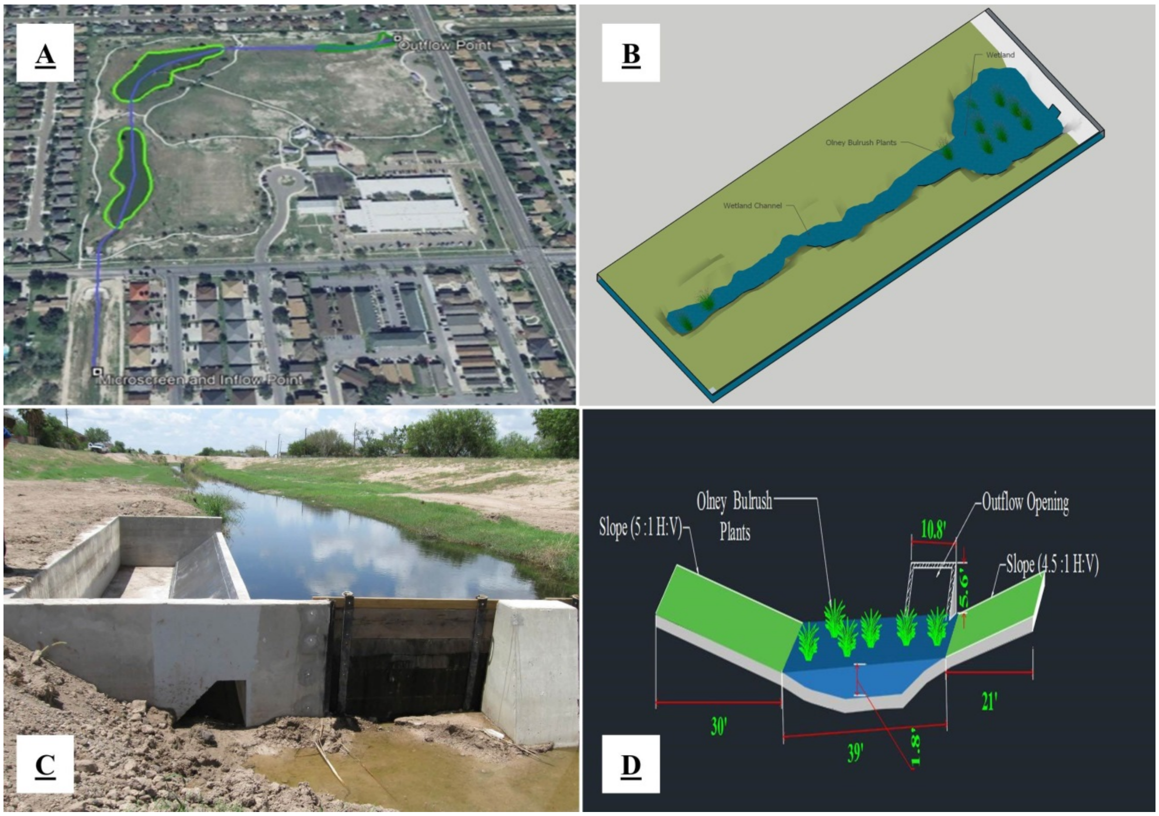



**Figure 1.** McAuliffe Regional Detention Facility (RDF) site: (A) site location showing the two wet detention and wetland locations, (B) wetland structure, (C) microscreen installed at the inlet, and (D) cross-section showing the depth and dimensions of the McAuliffe wetland.

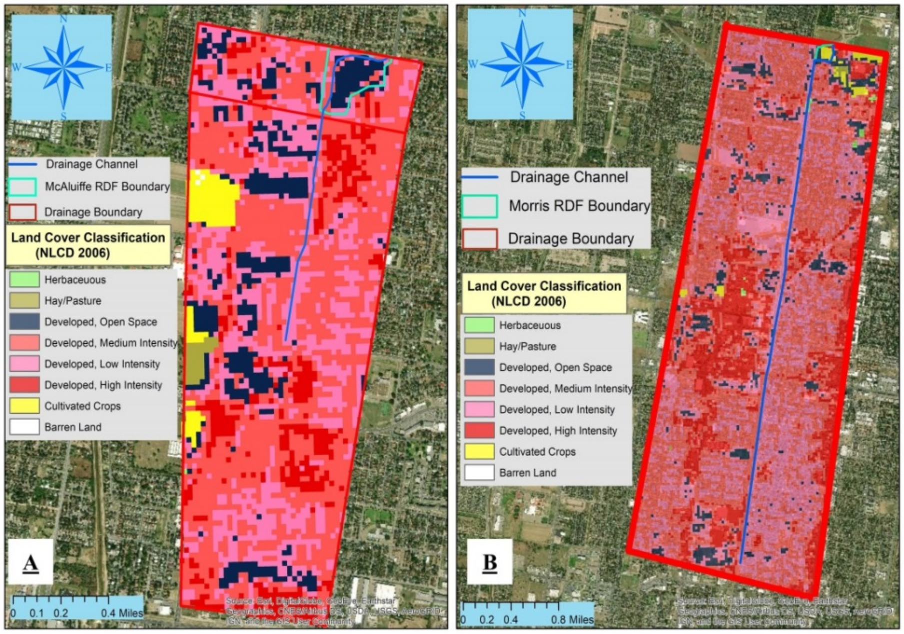



**Figure 2.** Land cover distribution for the watershed area at each site: (A) McAuliffe RDF, (B) Morris RDF.

### 2.2. Morris Middle School Regional Stormwater Detention Facility (RDF)

Morris RDF is located behind Morris Middle School at 1400 Trenton Ave, McAllen, Texas, spanning an area of 121,406 $m^2$. The RDF is elliptical in shape, and the slope within the RDF is ~1%. The RDF was intended to serve as a recreational facility during dry weather. The design includes a channel on the periphery that serves to drain some runoff from within the basin. No microscreen is installed at the upstream of this facility. However, Morris RDF has one wetland in the middle of the channel connecting inflow and outflow monitoring points. A constructed wetland was created near the midpoint of this channel (Figure 2). This wetland was planted with a mixture of vegetation, including California bulrush (*Schoenoplectus californicus*) and Olney bulrush (*Schoenoplectus Americanus*). The constructed wetland is elliptical in shape with a width of 22 m and average depth of 0.30 m. The side slope of this wetland is less than 1%. The average width of the incoming and outgoing channel is 4.87 m with a depth of 0.76 m. The total drainage area of the Morris RDF is over 20.6 $Km^2$, which is comprised of more than 93 % urbanized landscape. According to the National Land Cover Database (NLCD), the dominant percentage of land cover drainage area in the Morris RDF urbanized areas is developed between high to low intensity, like in parking lots and on pavements; the remaining 7% is either cultivated crops or developed open space. The Morris RDF drainage area has more urbanized area and less cultivated crops in comparison to McAuliffe RDF. The dominant percentage for the Morris RDF drainage area lies with hydrologic soil group B soil (97%). The dominant soil type in this watershed is type B soil (97%).

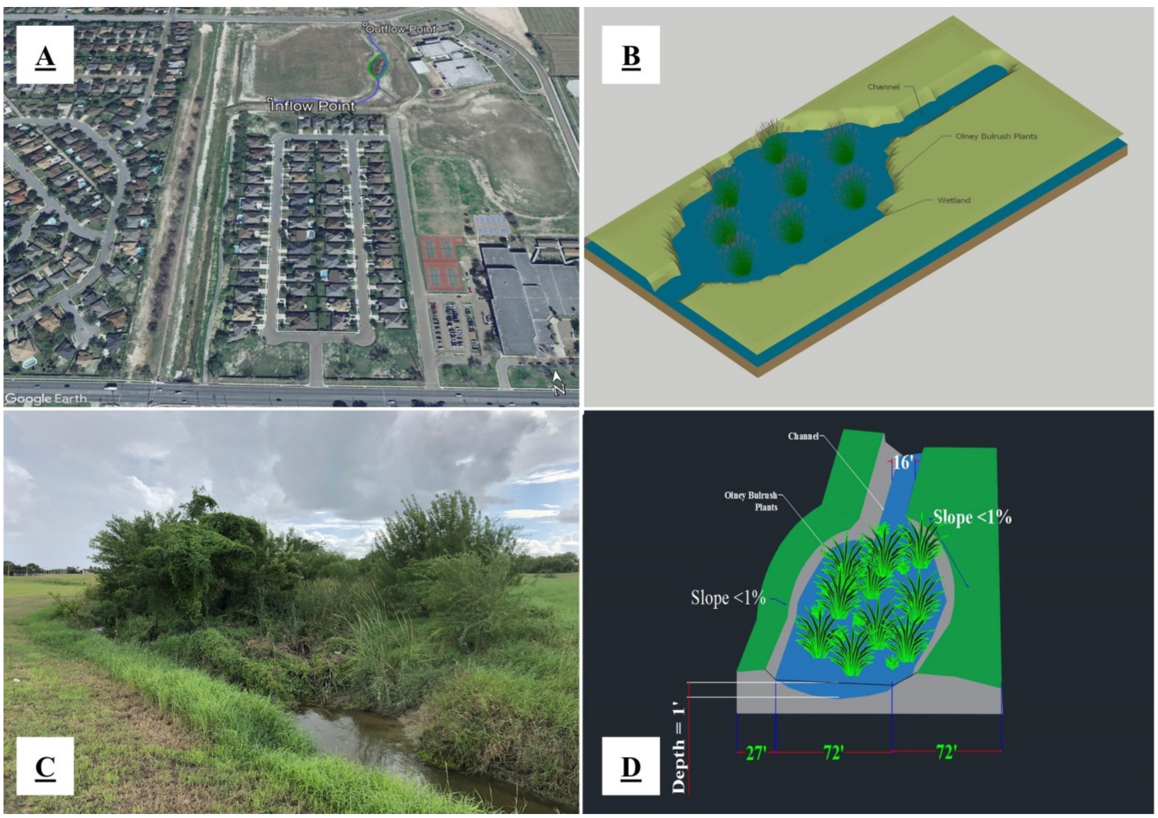



**Figure 3.** Morris Regional Detention Facility (RDF) site: (A) aerial view for the site location, (B) wetland structure, (C) vegetation on the wetland, and (D) cross-section showing the depth and dimensions of Morris wetland.

### 3. Sampling, monitoring and analysis

The ISCO 2150 Area Velocity Flow Module was used to measure stream velocity and the stream level. These two parameters can be used, along with the cross-sectional area of the stream, to calculate the flow rate. The velocity sensors installed in each of the stormwater monitoring sites work based on the Doppler Effect. The ultrasonic waves transmitted by one transducer are picked up by another transducer after the waves are reflected off particles and air bubbles in the water stream. Based on the Doppler Effect, the difference in frequency between transmitted and reflected wave describes the water velocity. The flow sensor also detected the flow in both the forward and reverse directions. For example, if there was some reverse flow in a stream, then the velocity sensor would record negative velocity readings. The level of the stream was detected based on the difference in atmospheric and hydrostatic pressures acting on an internal transducer. The velocity and level measurements were recorded by the sensor on a second-by-second basis. However, the data were saved once every 15 seconds to 24 hours, depending on the requirement. According to the manufacturer, the memory would last for a total of 270 days if level and velocity readings were stored every 15 minutes along with the total flow and input voltage every 24 hours. The flow modules at the two RDFs were programmed to store data every 5 minutes. Velocity and level data were retrieved by the 2150c Module to a computer running the FLOWLINK program (a software program developed by ISCO) to calculate flow using the velocity and level readings from the velocity sensor. Data recorded by the ISCO field instruments were retrieved and viewed on the FLOWLINK software. Retrieved flow data were imported into Excel software to draw the inflow and outflow hydrographs for each rainfall-runoff event and calculate the flow volume. RDFs Residence time for each event was estimated based on the time between the inflow and outflow peak.

The water quality sampling protocol adopted in the initial Texas Commission on Environmental Quality (TCEQ) approved the Quality Assurance Protocol Plan (QAPP) for collecting composite samples for every 41 $m^3$ of flow. Automated composite samplers were set up at the inlet and outlet of the McAuliffe and Morris RDFs. The samplers used at the McAuliffe and Morris RDFs were Teledyne ISCO 6712 Portable samplers that collected composite samples based on a user-programmed frequency in a 15 L bottle. The sampling interval was based on flow-pacing and was the same for both sites initially. Compositing a sample through the entire duration of the runoff event depends on the selection of an ideal sampling interval. A peristaltic pump was mounted on the control console that was housed in a protective ABS plastic casing. The pump purged the suction line before and after collecting the sample to ensure that the suction line was not plugged. The pump was also programmed to retry sampling up to a maximum of 3 times. The sampler’s memory was capable of storing five different sampling programs. The autosampler was connected to 2105 via cable, and the 2105 acts as the primary controller for the 6712. All samplers were programmed to enable themselves when certain level-rise conditions are satisfied. Prior to May 2012, the samplers were initially programmed to draw a fixed aliquot (100 mL) for every 41 $m^3$ of flow once the event started; this decision was based on a preliminary evaluation of historical rainfall data and drainage areas and estimated runoff coefficients.

From the 2011-2012 data, a new sampling protocol was developed based on an event of 17,000 $m^3$ of design inlet flow to fill up a 3L volume or one 100 ml aliquot for each 567 $m^3$ of flow. This protocol would still allow for an accurate composite sample for an event only ½ as large – only 8,500 $m^3$ to achieve a volume of the 1.5 L minimum for the lab sampling. Also, since the sample bottle has a much larger capacity of 15 L, this protocol could also representatively sample an event up to 5 times as large (85,000 $m^3$). This range of sampling would encompass over 90% of the 24-hour storm events for this area based on the historical data. The minimum and the maximum runoff events that resulted in measurable increases in flow rate at the inlet and the outlet were identified. For the McAuliffe RDF, water quality samples at the inlet and outlet point were collected over 22 months, from June 2011 through April 2013, and they were analyzed (approximately 8 events). During the same monitoring period, approximately 12 samples were collected from the Morris RDF. After collecting, composite samples were transferred to a NELAC certified lab contractor (Ana-Lab Corp facility) and concentration data were obtained after the analysis.

Rainfall events were sampled and analyzed for nutrients, suspended solids, and bacterial concentration, which were used to calculate the pollutants load reduction on an event-by-event basis. The inflow and outflow volume for each event was obtained from FLOWLINK software. All samples were analyzed for five nutrient components: Nitrate-Nitrite Nitrogen ($NO_x$), Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN) and Total Phosphorus (TP), Total Suspended Solids (TSS), *Escherichia coli* (*E. coli*), and Biochemical Oxygen Demand ($BOD_5$). The percentage load reduction of pollutants achieved by the RDF for each monitored rainfall event was calculated using following a mass balance equation:

$$\textit{Removal Efficiency: } RE_i = 1 - \frac{C_{i-Outlet}}{C_{i-Inlet}} \quad (1)$$

*where i = event 1,2,3…n*

$$\textit{Total Pollutant Mass: } M = \sum_{i=1}^{n} V_i \times C_i \quad (2)$$

$$\textit{Summation of Pollutant Loads: } SOL = 1 - \frac{\sum_{i=1}^{n} M_{Outlet}}{\sum_{i=1}^{n} M_{Inlet}} \quad (3)$$

*where,* $C_{outlet}$ = *Concentration at the outlet for event i = 1,2,3…n*

$C_{inlet}$ = *Concentration at the inlet for event i = 1,2,3…n*

*V = Event Volume*

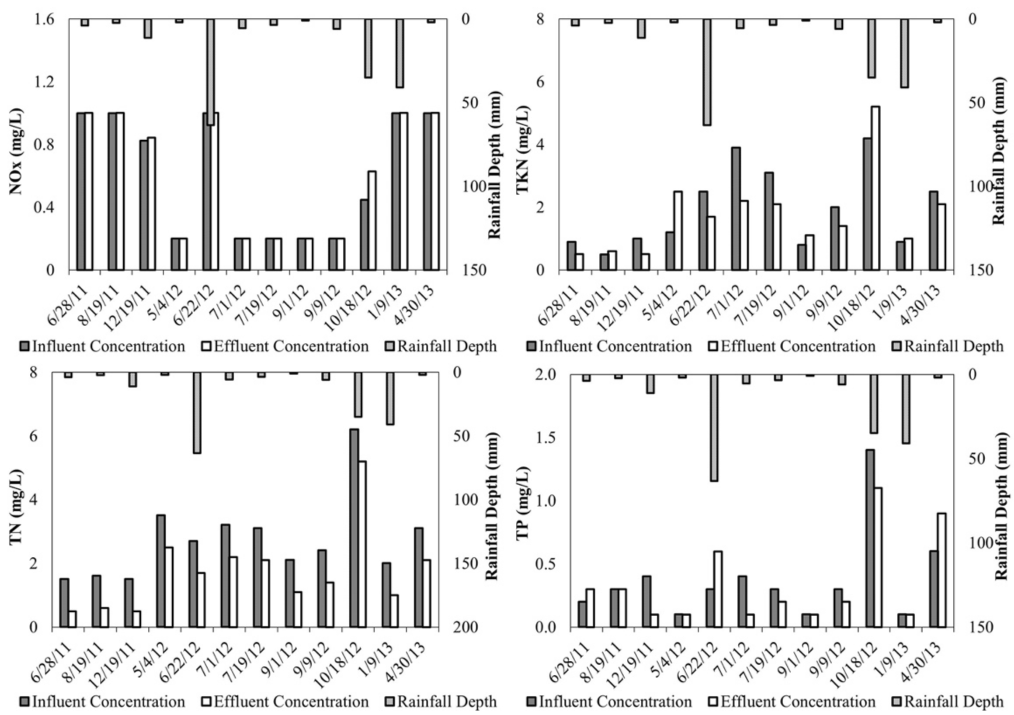
## 4. Results and Discussion

### 4.1. Water Quality Sampling and Analysis

Figure 1-2 represents the comparison of the influent and effluent concentrations at the Morris and McAuliffe RDF sites for different rainfall magnitudes, which were recorded during the monitoring timeframe. Results from the Kolmogorov-Smirnov Test suggest that our concentration data do not differ significantly ($p > 0.1$) from that which is normally distributed. The pollutant concentrations for both RDFs were compared to those reported by the USEPA National Urban Runoff Program (NURP) for mixed land-use settings.

Figure 4 demonstrates the concentration of pollutants and the corresponding rainfall depth from the Morris RDF. Samples were collected from 12 rainfall events throughout the monitoring period. The concentration of all pollutants was relatively higher from May 2012 to October 2012. The median concentration of $NO_x$, TKN, TP, TSS, $BOD_5$ was observed much closer to the NURP standard, which was approximately 1.1 to 1.6 times higher than the typical values. However, the mean *E. coli* concentration (15,079 MPN/100 mL) was below the average (25,000 MPN/100 mL), approximated from the NURP typical range (Strassler et al., 1999). Our paired *t*-test results indicate that the observed influent and effluent concentrations from the Morris RDF is not significantly ($p > 0.05$) different for the parameters analyzed. The $NO_x$ intake concentration was around 0.99 or 0.197 mg/L for most of the events; thus, those values were approximated to 1.0 & 0.2 mg/L. The maximum influent concentration of $NO_X$ (1.0 mg/L), TKN (4.20 mg/L), TN

(5.20 mg/L), TP (1.4 mg/L), *E.coli* (61,310 MPN/100mL), and TSS (2,270 mg/L) were reported on October 18, 2012, induced from 35 mm of rainfall depth, which were depleted to 5.20, 6.20, 1.1, 853, and 12 mg/L prior to reaching the outlet, respectively. Surprisingly, the *E.coli* concentration was also observed higher at the outlet (57,940 MPN/100 mL) for the same event. The maximum BOD intake (57 mg/L) was observed from 4 mm rainfall depth (occurred on July 1st, 2012), which was depleted to 29 mg/L at the outlet. An increase in the effluent concentration was observed for TP, TSS, and *E.coli* for about 25% times of total sampling events. Although there was no significant change observed in $NO_x$ concentration, less than 60% of total rainfall events were reported with lower TKN, TN, and $BOD_5$ concentrations at the outlet. However, reliable BOD and bacterial data were cumbersome due to their shorter holding time.



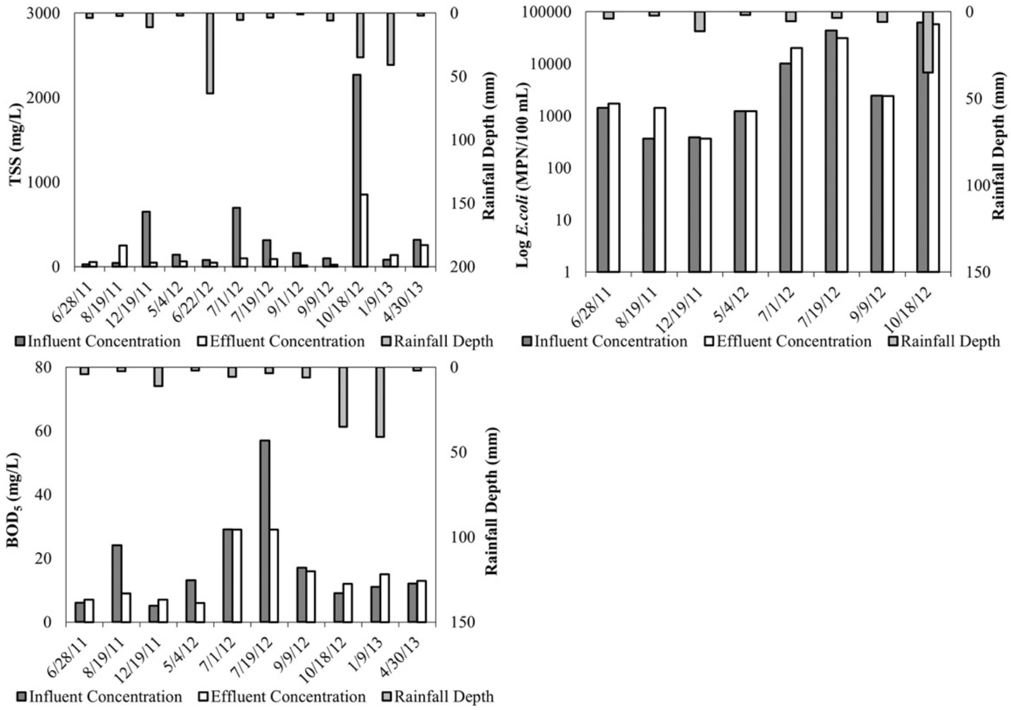



**Figure 4.** Influent and effluent concentrations (mg/L) for different pollutants collected at Morris RDF at different rainfall depths.

Table 1 demonstrates the water quality results summary for the Morris RDF for all parameters of analysis. Although there was some depletion observed for TKN (11%), TN (7%), & TP (9%), and BOD (22%) on average, the median TKN, TSS, and BOD concentration at the outlet slightly exceeded NURP typical values by 1.2, 1.1, and 1.6 times, respectively. Despite the relatively higher median than the NURP standard, the median TSS depletion efficiency was achieved by 49%, which was the maximum among all the pollutants analyzed. However, an expected TSS removal efficiency from a conventional detention facility is 75% (Barrett, 2005; Middleton and Barrett, 2008).

**Table 1** Summary of the water quality results summary for the Morris RDF

| Parameters | Flow type | Mean | S.D. | Min. | 25% | Median | 75% | Max. | % Reduction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Mean | Median |
| NOx | Inflow | 0.61 | 0.39 | 0.20 | 0.20 | 0.64 | 1.00 | 1.00 | -3 | -16 |
| | outflow | 0.62 | 0.39 | 0.20 | 0.20 | 0.74 | 1.00 | 1.00 | | |
| TKN (mg/L) | Inflow | 1.96 | 1.28 | 0.50 | 0.90 | 1.60 | 2.95 | 4.20 | 11 | 3 |
| | outflow | 1.74 | 1.30 | 0.50 | 0.70 | 1.55 | 2.18 | 5.20 | | |
| TN (mg/L) | Inflow | 2.96 | 1.28 | 1.50 | 1.90 | 2.60 | 3.95 | 5.20 | 7 | 2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | outflow | 2.74 | 1.30 | 1.50 | 1.70 | 2.55 | 3.18 | 6.20 | | |
| TP (mg/L) | Inflow | 0.38 | 0.35 | 0.10 | 0.13 | 0.30 | 0.40 | 1.40 | 9 | 33 |
| | outflow | 0.34 | 0.34 | 0.10 | 0.10 | 0.20 | 0.53 | 1.10 | | |
| TSS (mg/L) | Inflow | 406 | 629 | 25 | 79 | 150 | 565 | 2270 | 60 | 49 |
| | outflow | 161 | 232 | 15 | 46 | 76 | 222 | 853 | | |
| *E.coli* (MPN/100mL) | Inflow | 15,079 | 23,735 | 361 | 595 | 1917 | 35,140 | 61,310 | 4 | -8 |
| | outflow | 14,511 | 20,860 | 365 | 1,269 | 2,076 | 28,250 | 57,940 | | |
| $BOD_5$ (mg/L) | Inflow | 18.3 | 15.6 | 5.0 | 8.3 | 12.5 | 25.3 | 57.0 | 22 | 0 |
| | outflow | 14.3 | 8.5 | 6.0 | 7.0 | 12.5 | 19.3 | 29.0 | | |

Figure 5 demonstrates the results of the water quality analysis of composite samples collected at the inlet and outlet point of the McAuliffe RDF. A total of 8 rainfall events were considered for the analysis. The last two samples (for events that fell on January 09, 2013, and April 30, 2013) were taken after the installation of the Coanda microscreen. The depletion of nutrient constituents was found inconsistent for the samples analyzed from unprotected inlet conditions. Results from the paired *t*-test suggested that there was no significant ($p > 0.1$) difference between the inlet and outlet concentration of pollutants analyzed from the McAuliffe RDF. It appears that the effluent concentration of nutrients and organic solids (TKN, TN, TP, $BOD_5$) was reported higher in less than 50% of total sampling events prior to installing the microscreen. The maximum $NO_x$ inlet concentration (2.55 mg/L) appeared on August 19, 2011, which was depleted to 1.0 mg/L at the outlet. The maximum inlet concentration of TKN (8.09 mg/L), TN (8.29 mg/L), TP (1.47 mg/L), and $BOD_5$ (135 mg/L), and *E. coli* (86,640 MPN/100 mL) appeared on May 04, 2012, which was depleted to 2.40, 2.6, 0.25, 78 mg/L, and 2180 MPN/100 mL, respectively, prior reaching to the outlet.

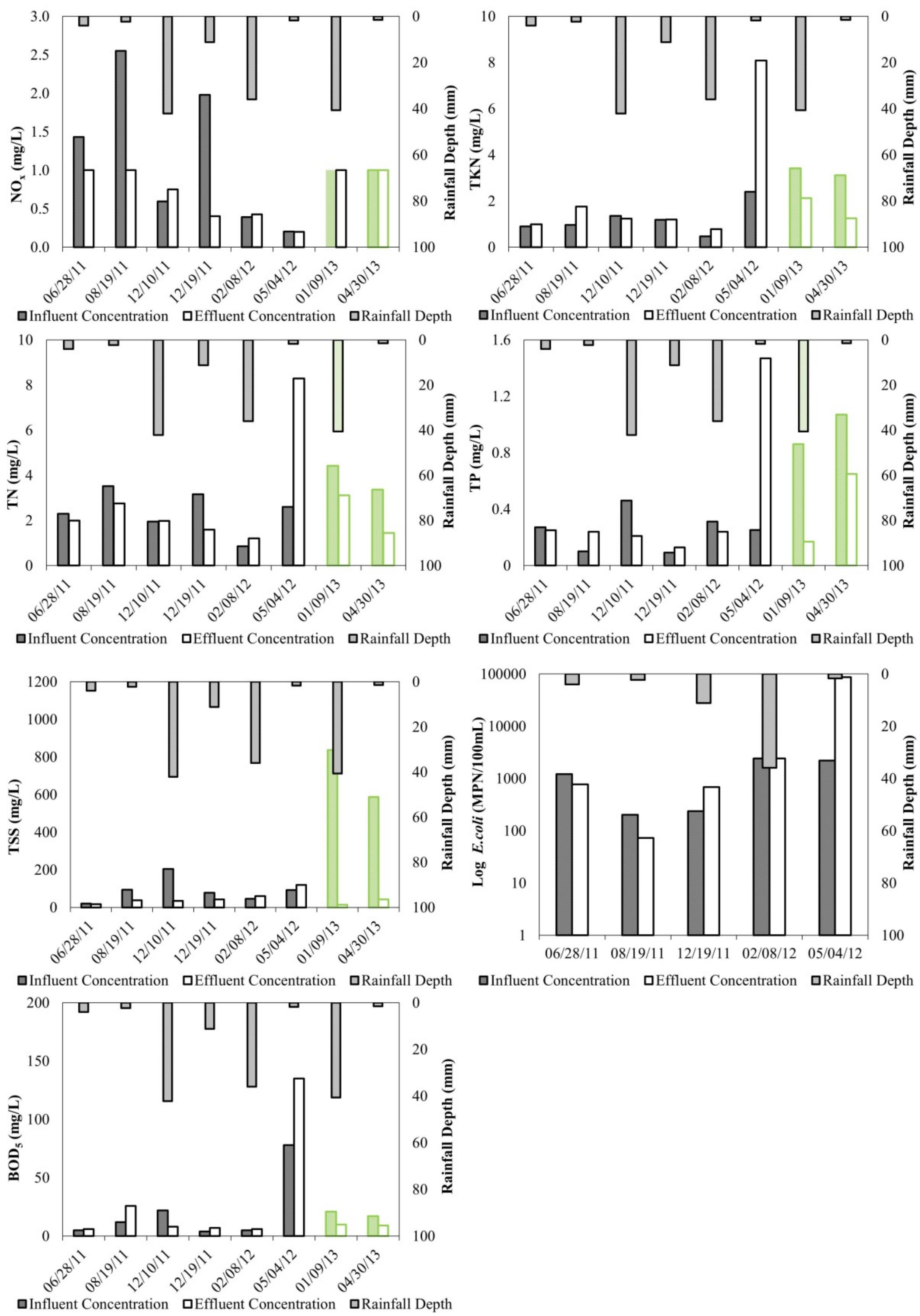



**Figure 5.** Influent and effluent concentrations (mg/L) for different pollutants collected at McAuliffe RDF at different rainfall depths, green bars indicate the samples collected after the microscreen installation.

Table 2 demonstrates the results summary of the influent and effluent concentrations for all water quality parameters of analysis for the McAuliffe RDF. Nutrient and $BOD_5$ showed somewhat contradictory concentration results at the outlet. Among all nutrient constitutes, $NO_x$ depletion was relatively better with 37% mean and 13% median reduction. However, a noticeable depletion of TSS concentration was observed in 83% of the first six samples collected during the monitoring period. Before installing the microscreen, the overall depletion efficiency of TSS concentration was moderate (50%), and the median concentration (41 mg/L) in the effluent remained below NURP guidelines (67 mg/L). A substantial improvement in the TSS mean depletion (up to 98%) was noticed just after the installment of the Coanda microscreen (last 2 sampling events). The maximum TSS concentration (836 mg/L) was observed on January 9, 2013, which was substantially depleted to 13 mg/L. Also, the nutrient constituents (TKN,TN, TP) and BOD were moderately depleted (30-80%) by the Coanda microscreen. However, a further assessment would be important to ensure its long-term performance of the microscreen. Alike, Morris, the *E.coli* concentration, was observed exceedingly higher (86,640 MPN/100mL) at the McAuliffe outlet; it was spiked by one very large accumulation on April 5, 2012. Overall, *E.coli* reduction was poor for about 40% times of the total monitoring events with an intense accumulation near the outlet.

**Table 2** Summary of the water quality results summary for the McAuliffe RDF

| Parameters | Flow type | Mean | S.D. | Min. | 25% | Median | 75% | Max. | % Reduction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Mean | Median |
| NOx | Inflow | 1.14 | 0.81 | 0.20 | 0.44 | 1.00 | 1.84 | 2.55 | 37 | 13 |
| | outflow | 0.72 | 0.33 | 0.20 | 0.41 | 0.88 | 1.00 | 1.00 | | |
| TKN (mg/L) | Inflow | 1.72 | 1.11 | 0.46 | 0.91 | 1.27 | 2.93 | 3.42 | -27 | 2 |
| | outflow | 2.18 | 2.43 | 0.78 | 1.04 | 1.24 | 2.03 | 8.09 | | |
| TN (mg/L) | Inflow | 2.77 | 1.10 | 0.85 | 2.03 | 2.88 | 3.47 | 4.42 | -1 | 31 |
| | outflow | 2.80 | 2.31 | 1.20 | 1.49 | 1.99 | 3.03 | 8.29 | | |
| TP (mg/L) | Inflow | 0.43 | 0.36 | 0.09 | 0.14 | 0.29 | 0.76 | 1.07 | 1 | 17 |
| | outflow | 0.42 | 0.45 | 0.13 | 0.18 | 0.24 | 0.55 | 1.47 | | |
| TSS (mg/L) | Inflow | 245 | 301 | 20 | 54 | 93 | 491 | 836 | 81 | 56 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | outflow | 46 | 33 | 13 | 21 | 41 | 56 | 120 | | |
| *E.coli* (MPN/100mL) | Inflow | 1,248 | 1,044 | 201 | 219 | 1,203 | 2,300 | 2,419 | -1,352 | 36 |
| | outflow | 18,118 | 38,315 | 73 | 380 | 770 | 44,530 | 86,640 | | |
| $BOD_5$ (mg/L) | Inflow | 20.5 | 24.3 | 4.0 | 5.0 | 14.5 | 21.8 | 78.0 | -26 | 41 |
| | outflow | 14.3 | 8.5 | 6.0 | 7.0 | 12.5 | 19.3 | 29.0 | | |

Overall, Both of the RDFs showed a relatively better removal of TSS than other pollutants analyzed. In our study, the mean depletion efficiency of TSS concentration (81%) by the McAuliffe RDF was achieved 21% higher than that from Morris. This result was closer to the desired removal efficiency (80%) achieved by BMP controls (Barrett, 2005). The depletion of TSS concentration was more consistent in the McAuliffe for most of the sampling events. However, the median TSS influent concentration in Morris (150 mg/L) was substantially higher than the McAuliffe (93 mg/L) since it serves a relatively bigger basin (4 times higher than McAuliffe) with a higher percentage of high-density impervious cover (17.1%). For the rainfall that occurred on January 9, 2013, the lowest TSS effluent concentration achieved from the Morris and McAuliffe RDF was 15 and 13 mg/L, respectively, which were considerably below the normally-expected discharge concentration from a conventional facility (30 mg/L) (Lampe et al., 2005; Middleton and Barrett, 2008). It is important to note that the inlet modification with the installation significantly enhanced the depletion of TSS concentration.

In conventional detention facilities, the primary mechanism of pollutant removal is sedimentation resulting from the gravitational settling (Birch et al., 2006). Several factors might influence the variability in the quality of effluents achieved in RDFs through the sedimentation process. Among them, three important hydrologic variables might have a possible impact on the RDFs settling mechanism: residence time, the volume of feed, and temperature (Middleton and Barrett, 2008). Both RDFs are hydrologically connected to a vegetated wetland to improvise the overall retention and settling process. The water holding depth and aerial footprint of the

McAuliffe RDF are much higher than that of Morris, including the drainage channels, two sequential wet ponds, and a wetland. These act like wet ponds, and they offer more residence time for the runoff, thus aiding sedimentation. For the same rainfall event that occurred on January 09, 2013, the residence time of the McAuliffe RDF (4 hours) was estimated almost 8 times higher than that for Morris (0.5 hours). This event could account for the McAuliffe RDF being 98% in terms of TSS concentration removal while Morris RDF was 70%. In addition, the greater depth of McAuliffe's downstream wetland might have improved the storage volume for larger storm events and increased the overall residence time in the McAuliffe RDF. Temperature also affects the viscosity of the sediment particles in contact with water and thereby improves the settling process (Middleton and Barrett, 2008). During our monitoring period, the local temperature varied in a range between 24° - 31°C, which might enhance dynamic viscosity and particle settling velocity. Apart from the hydrologic benefits, the inlet modification by the installation of Coanda microscreen resulted in enhanced TSS concentration (81% on average), which slightly exceeded the acceptable removal efficiency (80%) from other BMP controls (Barrett, 2005). It is possible that a polluted stream entering the McAuliffe RDF generated from the watershed passes through a rigorous prescreening of large suspended solid particles and later receives direct rainfall volume (cleaner than the stormwater runoff), which contributes to the significant depletion of concentrations in some cases. Thus, it can be said that the Coanda screen might be used in the RDF when comparable performance is required.

In terms of nutrients, the mean effluent concentration of TKN, TN, and TP is similar or slightly lower than the influent concentration for both RDFs. A smaller portion of nutrients was apparently removed from both RDFs. For Morris RDF, a slight depletion of nutrients concentration was observed for most of the rainfall events. The side-slope drainage area surrounding the RDF is mostly vegetative or agricultural land cover that might lead to being a potential source of the organic and nutrient load generation through the erosion of the topsoil. During heavy rainfall events, these excess nutrients could possibly be carried out by the agricultural runoff (i.e., fertilizers). This condition might induce a potential nutrient recharge near the RDF. Comparatively, the McAuliffe site covers a higher percentage of cultivated croplands (3.2%), which might lead to a significant amount of nutrients generation in the facility. Besides the negative value of the percentage, BOD mean and median reduction in the McAuliffe RDF indicates that there is a chance of organic solid accumulation in the wetland bed.

Maintaining low organic levels and adequate plant support are important to maintain the aerobic condition in the water for the effective oxidization of $NH_4^+$ or other organic nitrogen to produce more mineral $NO_3$ form, which is later consumed by the roots of most plants (Kant, 2018). The mean depletion of TKN (11%), TN (7%), TP (9%), and BOD (22%) was relatively better in Morris. For most nutrient constituents, the percent average depletion was negative in the McAuliffe RDF, which indicates an elevation concentration prior to reaching to the RDF outlet. Several studies have found that higher BOD and TN (predominantly present as $NH_4^+$) removal is possible when wetland bed is vegetated with plants of bulrush genus (*Schoenoplectus*) as because of its deeper root penetration (30-60 cm), which results in aeration and microbial nitrification (Tanner, 1996). From our visual inspection of the site, the density of bulrush plants was observed comparatively higher in Morris, which might lead to a relatively better depletion of all organic nitrogen sources (TKN, TN & BOD) near the outlet. However, the mean depletion efficiencies of $NO_x$ (37%) was much better in McAuliffe RDF. The *E. coli* result exemplifies a large variability in both RDF results for different sizes of rainfall events. Considerably higher bacterial accumulation appeared near the outlet of RDFs. Surprisingly, the number of *E. coli* per

100 ml of the effluent was highly spiked in the McAuliffe on May 04, 2012. The maximum *E. coli* depletion efficiency was observed 64% and 29% by the McAuliffe and Morris RDF, respectively. Nonetheless, the interaction between different water quality parameters might affect the performance of one another, which is explained by determining Pearson Multiple Correlation Coefficient (PMCC) values between different variables among all parameters analyzed and tabulated in Table 3. The significance of the correlations was validated by the regression hypothesis test.

**Table 3** Correlation coefficients for outflow water quality results in both sites

| | | Inflow Volume ($m^3$) | outflow volume ($m^3$) | $NO_x$ | TKN | TN | TP | TSS | BOD | E. coli | Temp. | Rainfall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| McAuliffe RDF | Inflow Volume ($m^3$) | 1.00 | | | | | | | | | | |
| | Outflow volume ($m^3$) | 0.63 | 1.00 | | | | | | | | | |
| | $NO_x$ | 0.01 | -0.37 | 1.00 | | | | | | | | |
| | TKN | -0.48 | -0.23 | -0.55 | 1.00 | | | | | | | |
| | TN | -0.54 | -0.27 | -0.47 | 0.99 | 1.00 | | | | | | |
| | TP | -0.41 | -0.32 | -0.48 | 0.91 | 0.86 | 1.00 | | | | | |
| | TSS | -0.32 | -0.09 | -0.80 | 0.84 | 0.80 | 0.87 | 1.00 | | | | |
| | BOD | -0.54 | -0.25 | -0.58 | 0.99 | 0.97 | 0.92 | 0.88 | 1.00 | | | |
| | E. coli | -0.40 | -0.18 | -0.62 | 0.99 | 0.98 | 1.00 | 0.93 | 0.99 | 1.00 | | |
| | Temp. | -0.64 | -0.45 | 0.07 | 0.49 | 0.51 | 0.51 | 0.39 | 0.55 | 0.40 | 1.00 | |
| | Rainfall | 0.61 | 0.46 | -0.01 | -0.32 | -0.29 | -0.47 | -0.32 | -0.38 | -0.34 | -0.77 | 1.00 |
| Morris RDF | Inflow Volume ($m^3$) | 1.00 | | | | | | | | | | |
| | Outflow volume ($m^3$) | 0.99 | 1.00 | | | | | | | | | |
| | $NO_x$ | 0.19 | 0.11 | 1.00 | | | | | | | | |
| | TKN | 0.70 | 0.70 | -0.28 | 1.00 | | | | | | | |
| | TN | 0.70 | 0.70 | -0.28 | 1.00 | 1.00 | | | | | | |
| | TP | 0.48 | 0.40 | 0.39 | 0.67 | 0.67 | 1.00 | | | | | |
| | TSS | 0.63 | 0.61 | 0.18 | 0.80 | 0.80 | 0.80 | 1.00 | | | | |
| | BOD | -0.80 | -0.78 | -0.55 | 0.19 | 0.19 | -0.15 | -0.11 | 1.00 | | | |
| | E. coli | 0.26 | 0.24 | -0.20 | 0.88 | 0.88 | 0.80 | 0.82 | 0.41 | 1.00 | | |
| | Temp. | -0.01 | 0.05 | -0.50 | 0.34 | 0.34 | 0.15 | 0.16 | 0.25 | 0.34 | 1.00 | |
| | Rainfall | 0.19 | 0.22 | 0.43 | 0.24 | 0.24 | 0.36 | 0.25 | -0.04 | 0.79 | -0.18 | 1.00 |

The positive correlations between pollutants and inflow volume in the Morris suggest that much of the nutrient and TSS generation was triggered beyond the RDF inlet, perhaps because of the basin area serves a high-intense impervious land cover (17%). Conversely, the negative correlations between McAuliffe inflow volume and outlet pollutant concentration suggested that much of the pollutant generation was not triggered by the total feed volume; rather their concentration underwent potential changes through subsequent retention and sedimentation process throughout the RDF length, improvised by two sequential wet ponds. The same explanation can be appropriate for the negative correlation ($R$ = -0.8) between inflow volume and outlet BOD concentration in the Morris.

Possibly, the progression of nutrients throughout the RDFs was associated with sediment transportation, perhaps because of the ability of sediment particles to adhere to nitrate and phosphate onto its surface. In McAuliffe RDF, this hypothesis is strongly supported by the positive correlation ($R \geq 0.80$, $p < 0.05$) between nutrient constituents (TKN, TN & TP) and TSS concentration. For McAuliffe, strong positive correlations (R > 0.85, $p < 0.05$) were observed between BOD and the rest of the probable organic sources (TKN, TN, TP, & TSS), perhaps because of a large number of organics were carried by the solids. Adversely, high sediment concentration can interrupt $NO_x$ generation because it raises the issues of DO depletion and nitrification (Mitchell et al., 1999); the hypothesis can be supported by the strong negative correlation (R = - 0.80) between TSS and $NO_x$ concentration in the McAuliffe RDF. In general, high organic compounds are highly associated with the escalated bacterial population. Bacteria consume organic compounds for their growth and reproduction and deplete oxygen from the water (Bouteleux et al., 2005). This hypothesis can be supported by the strong correlation ($R$ > 0.8) between *E. coli* and all probable organic sources (TKN, TN, TP, TSS & BOD). However, the bacteria-nutrient interaction was more dominant ($R$ > 0.95) in McAuliffe as compared to Morris ($R$ > 0.8). There is a close association ($R$ = 0.91) between TKN and TP in the McAuliffe RDF.

However, the analysis of variation of event-specific concentration does not really explain the differences observed in pollutant load reduction. The following section of the paper discusses the results in terms of load reduction estimates for all pollutants analyzed from both RDFs.

### 4.2. Pollutant Mass Load Reduction

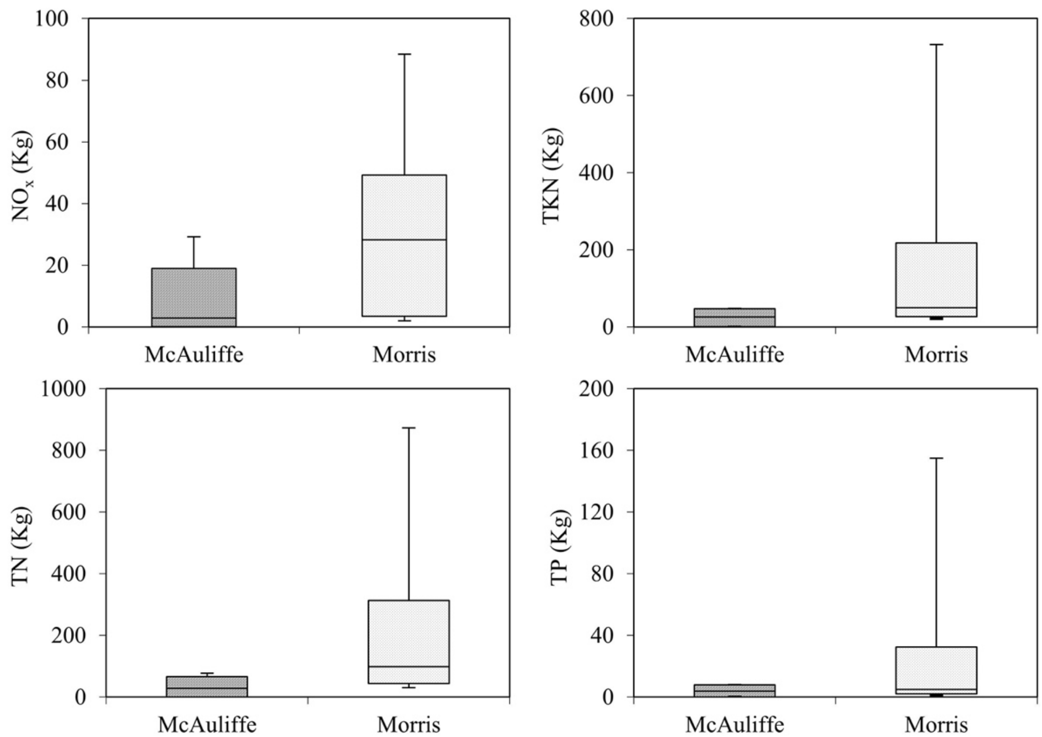
Water quality data was collected for concentration along with the flow data at the inlet and outlet from each site to calculate the pollutant load reduction. For all-over the monitoring period, McAuliffe RDF exhibited better load reduction in comparison to Morris RDF. A summary of load reduction at the inlet and outlet for each site for the different pollutants is presented. Figure 6 shows the box and whisker plot of the total load for all collected samples of each pollutant at the outlet monitoring station in each site.

For the McAuliffe site, $NO_x$ compounds the load, which includes nitrate and nitrites. They were significantly ($p < 0.05$) different between the inlet and outlet. However, the load for the total nitrogen, total suspended solids (TSS) and total phosphorus (TP) were significantly less at the outlet than the inlet. However, there was a significant difference ($p < 0.05$) between loads of biological oxygen demand ($BOD_5$), total Kjeldahl nitrogen (TKN) and *E.coli* between the two monitoring stations at McAuliffe RDF. On the other hand, for the Morris site, only TSS loads were significantly ($p < 0.05$) different between the inlet and outlet. While the load for the total nitrogen, total suspended solids, total phosphorus biological oxygen demand ($BOD_5$), total Kjeldahl nitrogen (TKN) and *E.coli* was not significantly less at the outlet than the inlet.

Statistically significant reductions in loads of TSS were observed from both of the RDFs. In McAuliffe RDF, the median value of the inflow and outflow for the TSS load was 1,173 ± 3,581 and 637 ± 681 Kg, respectively, for 8 collected samples. The average and median load reductions were 48% and 75%, respectively. The median average indicated a higher removal since only one event occurred on May $4^{th}$, 2012; the TSS load at the outlet was higher than the inlet. This event TSS load reduction was negative due to both the TSS concentrations, and outflow flow volume was higher at the outlet. While for the Morris RDF, the median value of the inflow and outflow for the TSS load was 4,309 ± 97,388 and 2,316 ± 38,130 Kg, respectively, for 8 collected samples. The average and median load reductions were 53% and 60%, respectively. Similar to McAuliffe RDF, only one stormwater event showed a negative reduction with a value of -64%. Results from both sites indicate that TSS can be removed from the detention basin in the semi-arid coastal under certain conditions, such as concentration, rainfall depth, and flow reduction. TSS is removed in detention facilities through sedimentation of the solid particles at the bottom of the basin. The removal mechanisms are achieved by reducing the water velocity and hence give an opportunity to the solids for settling before reaching the outlet.

In McAuliffe RDF, for nutrients such as nitrogen and phosphorus, the nitrate-nitrite ($NO_x$) total load at the outlet was significantly ($p > 0.05$) less than the outlet. However, Morris RDF did not show any significant difference for $NO_x$ species. There are two ways for $NO_x$ depletion to occur; it is either absorbed by plants as a form of nitrate, or it is biologically converted to nitrogen gas through the denitrification process. However, the detention time between the inlet and outlet was short and may not be enough to trigger the denitrification process. It is possible that $NO_x$ reduction was achieved through plant assimilation in the wetland section. This process can be supported by the difference in the wetland area between both sites. The wetland area in McAuliffe RDF was 258 $m^2$, and the average load reduction was 47%; the wetland in Morris RDF was 9.3 $m^2$ with an average reduction of 6%. McAuliffe RDF's large wetland area could enhance the $NO_x$ uptake from the urban stormwater runoff. Due to the relatively small area of the Morris wetland minimum, $NO_x$ removal was observed. Both sites did not show any significant difference in TKN load reduction between the inlet and outlet at each monitoring station. However, McAuliffe RDF showed better performance due to the runoff reduction volume. From 8 storm events, the TKN load at the outlet was lower than inlet in 7 events; the average pollutant load was 24 and 25 Kg, respectively. In Morris RDF, the TKN load was higher at the outlet in 4 storm events. The average load at the outlet and inlet was 156 and 137 Kg, respectively. TN and TP loads showed significant reductions in McAuliffe only. Since the McAuliffe RDF showed better performance in $NO_x$ and TKN removal than the Morris RDF, the TN total load at the McAuliffe outlet was expected to be lower than the inlet and the Morris RDF because the TN comprises all the nitrogen species, including $NO_x$ ad TKN. Several studies showed that the detention basin can reduce the TP in stormwater runoff (Middleton and Barrett, 2008; Simpson and Weammert, 2009). Detention basins improve runoff water quality through settling out of suspended particles that may carry contaminants such as phosphorus (Lodhi and Acharya, 2014). Both McAuliffe and Morris RDFs showed reductions in TP load reduction in comparison to the inflow load at each site. However, McAuliffe RDF has an extended retention time compared to the Morris RDF due to the larger wetland volume and presence of two wet basins. Therefore, McAuliffe RDF showed an enhanced removal of solids and phosphorus.

Similar to the TKN load reduction, both sites did not show any significant difference between the $BOD_5$ and *E.coli* outlet and inlet loads for each site. The average $BOD_5$ load reduction for McAuliffe and Morris RDFs was 22 and 19, respectively. Some events showed a negative reduction for $BOD_5$. The main constituents for TKN and $BOD_5$ are organic compounds that require a microbial activity for its degradation. However, the major mechanism for water quality improvement is sedimentation. However, the microbial activity may not achieve the desired results due to the short distance between the inlet and outlet monitoring stations. This distance might not be enough to enhance the microbial activity to breakdown the organic compounds. Five samples were collected for the bacterial reduction in the RDFs from each site. *E.coli* load showed fluctuation between the outlet and the inlet. Both sites showed a negative removal of bacteria. There are several factors that control bacterial concentration, such as temperature and presence of organic matter. *E.coli* can be removed in green infrastructure either by adsorption or filtration (Peng et al., 2016; Mahmoud et al., 2019) since none of the previous mechanisms were introduced in the detention basin or the wetland. *E.coli* showed the lowest removal values among the other pollutants.



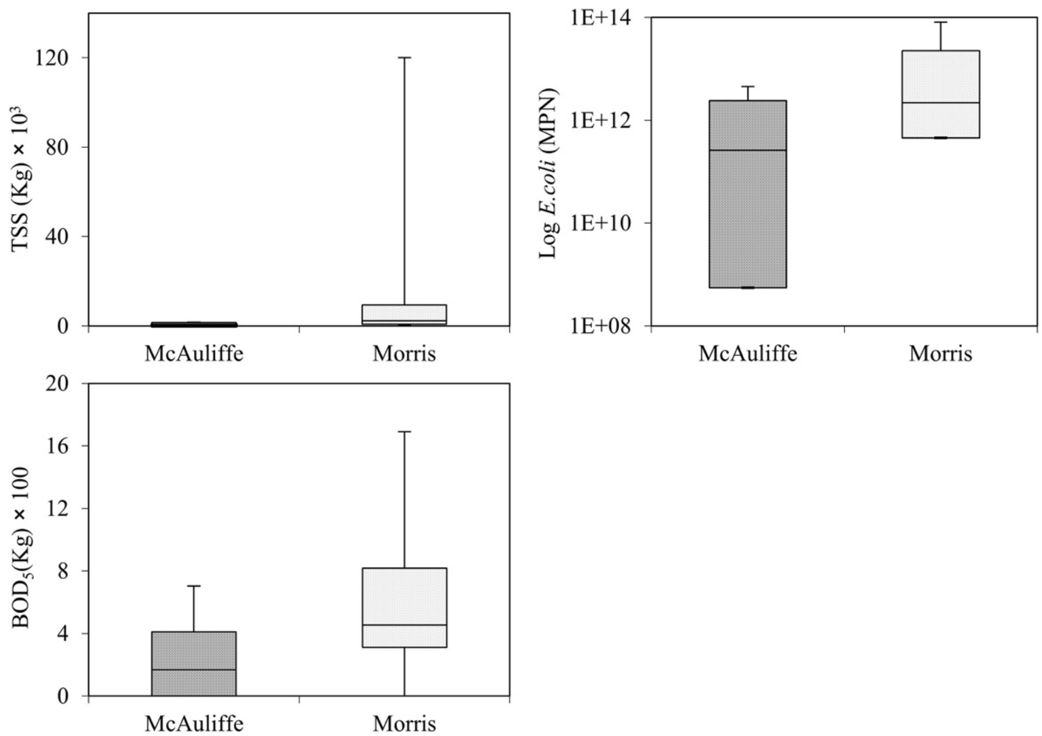



**Figure 6.** Box and whisker plot for different pollutant load at the outlet at McAuliffe and Morris RDFs.

## 5. Summary and conclusions

The analyses used in evaluating the performance and efficiency of the two RSDFs in McAllen Texas, were able to give some insight into pollutant reduction in the constructed facilities. Both the McAuliffe and the Morris RDFs were incorporated with constructed wetland to enhance the urban runoff water quality by reducing some pollutants. Both sites showed a significant ($p > 0.05$) reduction of the suspended solids at different storm events. On the other hand, the McAuliffe RDF showed a better reduction in the pollutant concentration and load between the inlet and outlet in comparison to the Morris RDF. The outlet pollutant load for NOx, TN and TP were significantly ($p > 0.05$) lower than the inlet monitoring site at the McAuliffe RDF. This result could be attributed to the different design and structural enhancement incorporated with the McAuliffe RDF, which effectively contributes to improvement of the water quality. The

McAuliffe RDF had a larger constructed wetland that could utilize more nutrients through the plant uptake and sedimentation. Also, the site was constructed with two wet detention ponds that probably worked in augmenting the sedimentation process in the McAuliffe site. In addition, installation of the Coanda microscreen at the McAuliffe site was proven to be effective in the reduction of part of the solids and associated particles before entering the site channel. On the other hand, neither of the sites showed a significant contribution in lowering either the organic compounds or the bacteria. In particular, *E.coli* as indicator bacteria demonstrated an obvious fluctuation in the concentration at various rainfall events.

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