Project Title: Mission Library Low Impact Development Implementation

Final Report

Texas Commission on Environmental Quality

Nonpoint Source Program CWA §319(h)

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1. Introduction and Background

The Upper San Antonio River runs through the heart of downtown San Antonio and as such the water quality of the river is significantly impacted by urban runoff during rain events. The flow of the San Antonio River is dominated by effluent from water recycling centers such as Dos Rios Water Recycling Center (operated by the San Antonio Water System). Since the flow is predominantly effluent the water is high in nutrients such as nitrate, nitrite and phosphorus.

The Upper San Antonio River has been identified as impaired by the Texas Commission on Environmental Quality (TCEQ) due to elevated bacteria levels. In order to address this impairment a Watershed Protection Plan (WPP) was completed in 2006 by James Miertschin and Associates. This plan presented ways in which the bacteria impairment could be addressed in order to reduce the bacteria levels in the Upper San Antonio River. An update to the WPP was completed in 2014 and this plan was accepted by TCEQ and the Environmental Protection Agency in 2015. The updated plan included low impact development (LID) best management practices (BMPs)

San Antonio, the seventh largest city in the United States, grew by 6.6% between 2010 and 2015, and is projected to grow an additional 6.34% through 2020. The metropolitan area grew by 9.05% between 2010 and 2015 and is projected to grow an additional 7.64% through 2020 (San Antonio Economic Development Foundation). With such significant population growth taking place; redevelopment of existing properties is increasingly necessary to accommodate the growing population. The increasing population growth significantly impacts the water quality of the San Antonio River with increased amounts of impervious cover increasing stormwater runoff during rain events.

Bacteria and nutrients are washed into the San Antonio River during storm events. In order to decrease the amount of these substances being washed into the river, LID practices are being encouraged to capture/filter stormwater on site before the runoff is discharged into the storm drain system and ultimately the San Antonio River.

The Mission Drive-In was originally opened in March 1948 (See Figure 1). The facility had four screens and a total capacity of 760 vehicles and seating for 120 people. The facility operated for several decades until it was closed in 2007.

Figure 1. Mission Drive In 1995

In 2009, the property was sold to the City of San Antonio and plans were prepared to redevelop the property. Plans were made to build a public library on the site as well as other public amenities. The site's proximity to the San Antonio River made it a very desirable location to demonstrate stormwater Low Impact Development (LID) features and to educate the local development community on the feasibility of including LID features in future developments in the San Antonio Area.

The plans included (LID) features to address stormwater on site. These features consisted of surface detention/infiltration, Green Street/Bioswale areas, roof stormwater collection and rain gardens. See Figure 2, actual implementation of the features differed slightly from this plan.

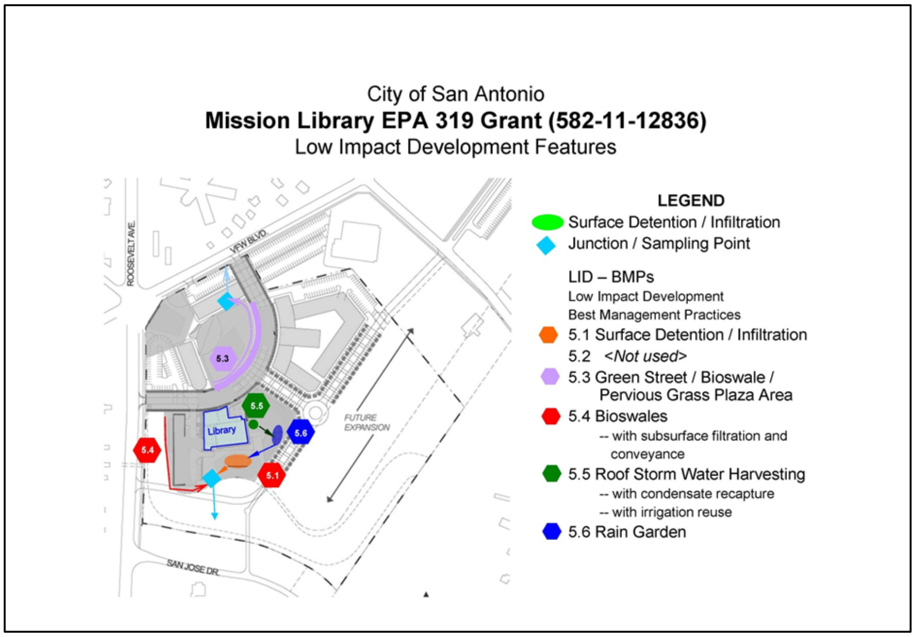

Figure 2. Original Plan for Mission Library LID Development Features

Once the library building was completed, the surrounding landscape and LID features were installed in stages. This is evident through the aerial photography images that follow. The building and parking lot were completed in the spring of 2012. At this time work was being performed to complete the playground and public fitness areas as well as the LID features. A permeable friction course (a porous pavement top layer that filters water and then discharges runoff laterally at the edge of the underlying impervious pavement) covers the ring road that encompasses the original marquee viewing area. The other BMPS in the area include rain capture system, rain garden, bioretention area, vegetated filter strip, and two bioswales.

Figure 3. Mission Library Development April 2012 and February 2013

Figure 4. Mission Library in 2015

The local match for this Section 319 grant project (40% of total costs) was provided by several cooperating entities including City of San Antonio, San Antonio Water System and the San Antonio River Authority. Each entity either directly funded installation of BMPs or provided in-kind services.

Table 1. Funding Sources for the Mission Library Demonstration Project

Funding Partners for Mission Drive-In Project
City of San Antonio • Project Administration • Design and Construction of LID features • Investigate feasibility of modifying the Uniform Development Code to incorporate LID BMPs • Design and Installation of Stormwater Monitoring Stations
San Antonio Water System • Design and Installation of roof Storm Water Harvesting/condensate Recapture /Irrigation System
San Antonio River Authority • Development of Quality Assurance Project Plan for Stormwater Quality Monitoring • Operations and Maintenance of the stormwater quality monitoring stations • Collection of water quality samples • Laboratory analysis of water quality samples • Submission of water quality data to TCEQ Surface Water Quality Database. • Submission of water quality data to EPA BMP National Database

2. Project Significance

The outputs of the project will enhance knowledge of effectiveness of porous pavements and bioretention areas in a humid subtropical climate.

The San Antonio area can be subjected to extreme temperatures. The mean annual temperature is 68.6°F, temperatures in excess of 100°F are common during the summer months, and winter temperatures can reach the upper teens on occasion. These conditions combined with occasional flooding events further complicate issues such as plant selection, surface runoff and infiltration rates. This installation will allow for the site to be monitored over time, if possible, to gather data specific to the San Antonio Area.

The Upper San Antonio River (Segment 1911) was identified as impaired due to elevated levels of bacteria in the 2012 Texas Water Quality Inventory. Concerns for nitrate, ammonia and total phosphorus have also been identified for this segment. The bacteria levels are the result of direct and indirect stormwater runoff, sanitary sewer overflows and potentially poorly maintained septic systems. The nitrate, ammonia and total phosphorus levels are likely due to wastewater treatment plant discharges, improper use of fertilizers and organic matter carried into the river as a result of storm events. With the Upper San Antonio river watershed being highly urbanized the primary source of pollution is likely the result of urban stormwater runoff. With little undeveloped land in the watershed available to implement large scale BMPs, the focus has been placed on treating or capturing stormwater onsite prior to the runoff leaving the property. This project focused on Nitrate, Nitrite, Total Phosphorus, Total Kjeldahl Nitrogen, Ammonia, Total Suspended Solids and *E. coli* bacteria.

The Upper San Antonio River Watershed Protection Plan (WPP) was completed in 2006 and updated in 2014. The WPP encourages the use of Low Impact Development (LID) features to improve water quality and reduce pollutants being transported to the San Antonio River. Stormwater Source BMPs are recommended in the 2014 WPP Update in order to positively impact water quality prior to runoff joining the Municipal Separate Storm Sewer (MS-4) System (JMA, 2014)

Several sites in the San Antonio area are being re-developed. In some cases these locations are completely torn down and a new development put in its place and in other cases some structures are kept and re-purposed as in the Mission Library Project site. A component of the Upper San Antonio River WPP involved the identification of properties that could possibly have BMPs implemented (JMA, 2013). The properties included local government owned parcels, school district parcels, as well as federal and state owned properties.

3. Best Management Practices

Storm water best management practices implemented onsite include one stand-alone bioswale and two treatment trains.

1. North Site Drainage
    a. North of the library, runoff passes laterally from a "permeable friction course" pavement overlay on a portion of the ring road and adjacent parking spaces into a bioswale, with any overflow treated by a vegetated filter strip on the slope leading down toward the amphitheater. An underdrain collects treated runoff from the bioswale and passes through a water quality monitoring station before discharging to the stormwater system. These features drain to the north site sampling station (See Figure 12 for locations of sample points).

Figure 5 Permeable Friction Course Pavement Parking Spaces

Figure 6 Vegetated Filter Strip

2. South Site Drainage
    a. West of the library, the stand-alone bioswale runs around the edge of the front parking lot.
    b. East and south of the library, any overflow from rooftop rainwater harvesting is treated by a rain garden and bioretention area which also drain the impervious features of the library's "backyard" (See Figures 5-8). Runoff filters through the bioretention media and an underdrain collects the exfiltrate. Drainage from the bioretention merges with treated flow from the front parking lot bioswale at a joint monitoring station, then discharges to the drainage feature on the property, which flows eastward to the San Antonio River.

Figure 5 Rainwater Harvesting System

Figure 6 Rainwater Harvesting First Flush Diversion

Figure 7 Bioretention/Rain Garden

Figure 8 Parking Lot Bioswale

Figure 9 Layout of BMPs at Mission Library

4. Methods

4.1. Sampling Design

Three sampling locations were identified by the City of San Antonio to monitor the BMP performance. A location was selected to quantify the baseline condition, or character of the runoff from the impervious surfaces. Theoretically this baseline site runoff would be representative of the inflow to the BMPs and could be used to estimate the mass of pollutants entering the BMPs (correcting for differences in the acreage of the drainage areas of the baseline site and the BMPs). The baseline location was a nearby library parking lot, Pan Am Library, with similar use patterns and physical conditions. The sampling locations to assess BMP performance were located at (a) the storm drain outlet receiving runoff from the permeable pavement overlay and bioswale system; and (b) the underdrain of the rain garden and bioretention feature and the front parking lot bioswale (combined flow). Sampling was conducted using automatic samplers installed by a contractor for the City of San Antonio with the samples collected and analyzed by the San Antonio River Authority.

Runoff events at the baseline sampling location, Pan Am Library, were monitored using an automatic sampler receiving runoff from the parking lot. Runoff from the parking lot is routed through a flume and exits to the street where it can enter the storm sewer system (See Figure 10 and Figure 11). The sampler was placed at the flume and a weir installed to allow a depth of flow sufficient for the sampler to draw the sample (See Figure 12).

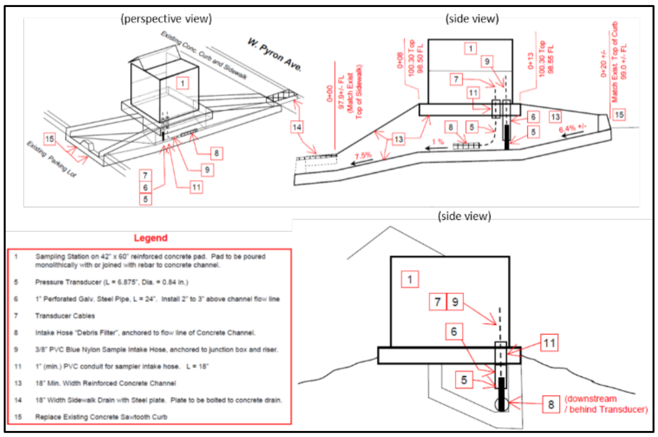

Figure 10 Design of Sampler for Pan Am Library

Figure 11 Sampler at Pan Am Library

Figure 12 Flume from which sampler pulls sample at Pan Am Library

The bioretention performance was monitored by a sampler that drew samples from the underdrain of the bioretention and front parking lot bioswale (See Figure 13). The sampler was located in a job box with sample collection tubes placed in the outfall pipe of the underdrain (See Figure 14).

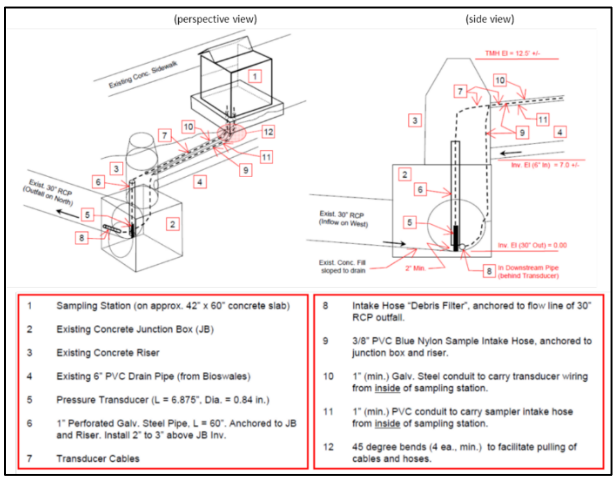

Figure 13. Design of Sampler for bioretention at Mission Library.

Figure 14. Sampler for monitoring south site runoff at Mission Library.

Rainfall flows through the permeable pavement overlay and drains to a bioswale. Once runoff enters the bioswale, it filters through the porous media and collects in a perforated underdrain pipe, which is connected to the storm sewer. The automatic sampler pulls samples through a line placed in the storm sewer pipe (See Figure 15 and 16).

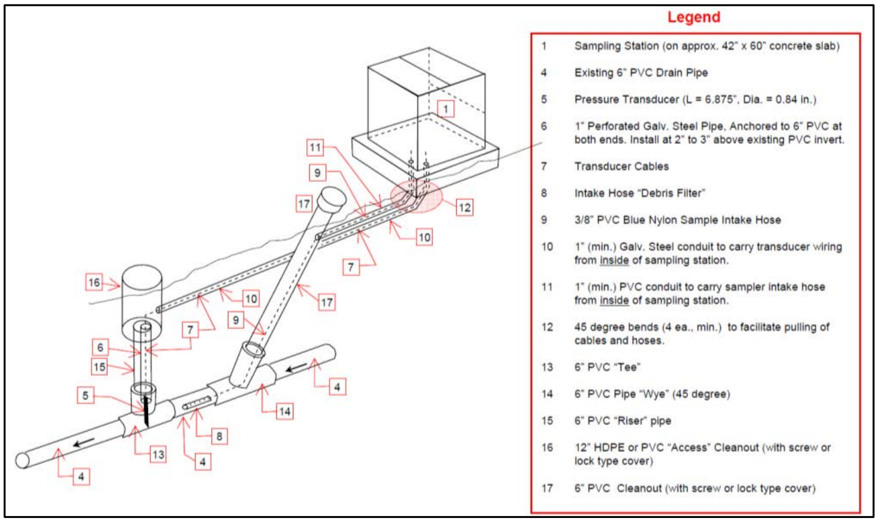

Figure 15. Design of Sampler for permeable pavement and vegetated filter strip at Mission Library.

Figure 16. Sampler monitoring for north site runoff at Mission Library.

The automated samplers are triggered by the presence of water with a sensor in the pipe or weir structure. Samples are pulled from the runoff stream and into sample bottles within the sampler at equal intervals throughout the runoff event. Field staff from the San Antonio River Authority collected the samples within a specified holding time and transported the samples to the San Antonio River Authority Regional Environmental Laboratory. One flow weighted composite sample was created for each monitoring station from the individual samples collected there at intervals throughout each storm event.

4.2. Analysis Methods

4.2.1. Laboratory

The collected samples were analyzed via laboratory methods to determine the concentration of the constituents of focus; sediment, nutrients, and bacteria. The San Antonio River Authority Regional Environmental Laboratory is NELAP accredited for the analysis methods reported in Table 2 to determine the event mean concentration of the constituents commonly found in runoff.

Table 2. Laboratory methods used to analyze runoff.

Analysis	Method
Ammonia as N - Distilled	SM 4500 NH3BD-1997
E. coli	SM 9223B-2004
Nitrate as N	EPA 300.0-1993
Nitrite as N	EPA 300.0-1993
Total Hardness, Calculated	SM 2340B-1997
Total Kjeldahl Nitrogen	EPA 351.2-1993
Total Phosphorus	EPA 365.3-1978
Total Suspended Solids	SM 2540D-1997

4.2.2. Flow Monitoring

In addition, the flows were monitored to determine the depth of flow and then translated to a volumetric flow rate using standard engineering equations. For the two BMP sample locations at Mission library the configurations of the sampler apparati were used to parameterize Manning's equation for pipe flow in a circular PVC pipe.

$$Q = \frac{1.49}{n} AR^{2/3}\sqrt{S}$$

Where Q is the flowrate (cfs), A is the cross sectional area of the pipe (ft^2), R is the hydraulic radius (ft), S is the slope (ft/ft). The sampler at Pan American Library pulls samples from behind a weir from a rectangular channel, so the depth of flow was translated to flow rate using the weir equation (Lindburg, 2011).

$$Q = \frac{2}{3} C_1 b\sqrt{2g}H^{3/2}$$

Where Q is the flowrate, C_1 is an empirically derived coefficient dependent on the characteristics of the weir, b is the width of the weir (ft), g is the gravitational constant 32.1 ft/s^2, and H is the height of the weir (ft).

4.3. Data Analysis

The performance of the BMPs was evaluated using a mass balance approach, where the average mass export of the baseline site was compared to the average mass export from the BMPs. To do this the loading of each constituent from each site was calculated for each event. Then the two BMP groupings were compared to the PanAm (baseline) to calculate the percent removal and total pollutant removal.

4.3.1. Loading

The mean concentration of each monitored event was used to calculate the estimated mass of constituents that were exported from each site by multiplying by the volumetric flow rate or

$$Loading = C * Q * Unit\ Conversion$$

where C is the concentration of the constituent being analyzed (either in mg/L or MPN/dL) and Q is the volumetric flow rate of the runoff (in cfs), and *Unit Conversion* is the factor necessary to convert between the appropriate units (*28.316* for nutrients and TSS or *283.16* for *E. coli*). For comparison between the baseline and the BMP sites, the average loading was then divided by the estimated drainage area to each outlet (made by visual observation and spatial analysis) in order to calculate the export of load per unit area. This allows the BMP sites to be compared to the baseline because it normalizes by the drainage area for each observation point.

4.3.2. Performance Evaluation

The performance of the BMPs was then evaluated by determining the percent removal of the constituent on a mass per unit area comparison. The basic export of the constituent from a conventional surface was assumed to be equivalent to the measured values from the Pan American Library, a site of similar character as the impervious surfaces of the Mission Library Campus. The treated effluent was then taken from either the permeable pavement or bioretention BMP outflows. Percent removal is calculated as

$$\%Removed = 100 * \left(\frac{(PanAm - BMP)}{PanAm}\right)$$

where *PanAm* is the mass export from the Pan American Library (in either mg or MPN), *BMP* is the mass export from the BMP at Mission Library (in either mg or MPN). This was calculated on a per unit area basis by dividing the mass export by the drainage area of the sample locations; 6,098 sf for Pan Am, 121,818 sf for the permeable pavement and bioswale, and 194,020 sf for the bioretention, bioswale, and rain garden. These reduction factors are later applied to project annual performance of the BMPs under the cost benefit analysis.

4.3.3. Cost Aversion for Water Quality Treatment

Without the best management practices, nutrients, sediment, and bacteria would enter the municipal separate storm sewer and eventually enter the receiving body, the San Antonio River. In order to maintain the integrity of the water resources, either BMPs or water treatment are required. Therefore in order to quantify the averted cost of water treatment estimates of the costs of conventional water treatment processes to remove nutrients are required (Russell et al., 2013). However, there is limited data for water treatment costs of specific nutrients on a mass basis. From the available literature, estimates range from $268 to $1,348 per kg of phosphorus (Sano et al., 2005). The cost to remove nitrogen ranges from $2.71 to $96.00 per kg (Compton et al., 2011). Abatement costs for reducing nitrogen from point sources are estimated to be $18.00 per kilogram an average across national studies (Birch et al., 2011).

Due to the wide variety of water treatment costs for suspended sediment, rather than using a water treatment cost for suspended sediment for a cost aversion estimate, an estimate of stormwater infrastructure capacity was used to estimate the cost of suspended sediment. The stormwater infrastructure regional projects from the Upper San Antonio River Watershed Master Plan have an average cost of $7.92 per cubic foot of capacity (SARA, 2011). Using a mineral density of 2.65 g/cc, the cost of suspended sediment decreasing capacity of stormwater infrastructure is $9.48 per kg. Bacteria, measured by the indicator species *E. coli*, can be removed from water by a wide variety of mechanisms with a variety of costs. However, there are few local estimates or applicable national estimates available that quantify the cost on a per MPN or mass rate.

Using the estimates of export from the baseline site, Pan American Library, which had conventional asphalt treatment, estimates of the averted costs for TSS, total nitrogen, and total phosphorus were calculated for each BMP scenario using annual estimates of pollutant exports as a flux (i.e. a mass of pollutant export per area per time, mg/sf/year) with the following approach:

$$Annual\ Nutrient\ Mass\ Export\ \frac{kg}{sf \cdot yr} = Average\ Concentration \frac{mg}{L} * \ Annual\ Rainfall \frac{32\ in \frac{Rainfall}{yr}}{12\ in / ft} * 28.316 \frac{L}{cf} * \frac{kg}{10^6 mg} * Design\ Volume\ Factor$$

Where *Average Concentration* is the average concentration of constituent from the baseline location in mg/L, and *Annual Rainfall* was the average rainfall depth reported by the National Weather Service (NWS) rain gauge at the San Antonio International Airport, 32 in/yr, and the Design Volume Factor was the percent of annual runoff volume captured by a BMP designed to capture 2 inches. The Design Volume Factor was calculated using the Water Quality Capture

Optimization Statistical Model (UWRI, 2012). Historical rainfall from the San Antonio International Airport was analyzed to determine the percent of total runoff volume that would be captured and retained by a BMP designed to treat 2 inches of runoff. It was found that this design standard would account for 85.4% of runoff annually. The results were then extrapolated to estimate the load reduction that could be accomplished by incorporating practices over the area expected to be redeveloped or retrofitted within the Upper San Antonio watershed. Using planning documents from the City of San Antonio, estimates regarding likely development patterns and policy were made. From this characterization, it was estimated that 5% to 25% of the commercial areas could potentially be redeveloped within the next 25 years (410 to 2,050 acres). This allowed for future projections on a wider spatial scale of implementation of the studied BMPs.

Then using the percent removal, the annual cost averted by pollutant removal via use of BMPs was calculated by

$$Averted\ Cost\,\frac{\$}{yr} = Annual\ Nutrient\ Mass\ Export\,\frac{kg}{sf \cdot yr} * Cost\ of\ Pollutant\ Removal\,\frac{\$}{kg} * \%Removal * Area\ sf$$

Where the *%Removal* was calculated from the average load from the baseline and outflow of the BMP and *Cost of Pollutant Removal* was the estimated pollutant treatment costs taken from literature estimates, and *Area* was the impervious area that was draining to each BMP (sf). Only the impervious area of the drainage area of each BMP is used, because this is the area that would be exported from the area if the BMP was not in place. Pervious areas would infiltrate and thus under the target design storms would not contribute runoff to the BMP.

5. Results and Observations

5.1. BMP Performance

The concentrations of the constituents within the samples are reported in Table 3. The modeled runoff estimates, monitored flow through of BMP outflow, and estimated runoff reduction are reported in Table 4. In this table, the monitored runoff was the volume calculated from the logging of flow depths throughout each event; the monitored runoff depth was this volume divided by the estimated drainage area; and the percent reduction was the difference of the volume per unit area from the BMP site and the baseline site for each event (See equation in 4.3.2). The average mass of the pollutants in the monitored outflow, the average export of pollutants, and estimated percent removal by the BMPs are reported in Table 5.

Note that a number of sampling events did not result in flow sufficient for sample collection, indicating that the BMP captured flow to an extent which minimized pollutant export from the site. In addition, some events resulted in observations of E. coli above the limit of quantification, 24,000 MPN/dL. For purposes of loading calculation, the upper limit of quantification was used

Table 3. Observed concentrations of runoff constituents.

Sample Location	Date	TSS (mg/L)	*E. coli* (MPN/dL)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Baseline	7/18/2014	15.3	52	**	0.103	0.697	4.42	0.434
	10/11/2014	54	1400	***	***	***	***	***
	10/31/2014	***	410	***	***	0.771	***	***
	11/4/2014	****	****	****	****	****	****	****
	1/22/2015	****	****	****	****	****	****	****
	4/22/2015	29.4	*	0.05	0.137	0.332	1.49	0.452
Permeable Pavement and Bioswale	7/18/2014	42	2300	**	1.1	0.1	2.68	0.905
	10/11/2014							
	10/31/2014	192	450	***	***	***	***	***
	11/4/2014	12.1	320	**	4.86	0.168	3.95	0.722
	1/22/2015	44.6	***	0.05	0.093	0.1	1.3	0.373
	4/22/2015							
Bioswale, Bioretention, Rain Garden	7/18/2014	5.8	5800	**	0.316	0.965	3.96	0.356
	10/11/2014							
	10/31/2014							
	11/4/2014							
	1/22/2015							
	4/22/2015	34.8	*	**	0.089	***	***	***

*	Above Quantification Limit
**	Below Limit of Detection
***	Insufficient Sample Volume for Laboratory Testing
****	Sampler Malfunction
(shaded)	Insufficient Outflow through Feature for Sample

Table 4. Runoff characteristics from sampling events.

Sample Location	Date	Rainfall (in)	Monitored Runoff (cf)	Monitored Runoff Depth 'Volume / area' (cf/sf)	% Runoff Reduction
Baseline	7/18/2014	3.5	393.34	0.0645	
(6,098 sf)	10/11/2014	0.53	133.19	0.0218	
	10/31/2014	1.4	47.21	0.0077	
	11/4/2014	1.98	247.19	0.0405	
	1/22/2015	1.4	71.16	0.0117	
	4/22/2015	0.89	154.53	0.0253	
Permeable	7/18/2014	3.5	686.20	0.0056	91.26
Pavement and	10/11/2014	0.53	29.79	0.0002	98.88
Bioswale	10/31/2014	1.4	0.05	0.0000	99.99
(121,818 sf)	11/4/2014	1.98	2,091.55	0.0172	57.61
	1/22/2015	1.4	1,262.87	0.0104	11.08
	4/22/2015	0.89	2,148.65	0.0177	30.34
Bioswale,	7/18/2014	3.5	1,421.49	0.0073	88.64
Bioretention and	10/11/2014	0.53	487.14	0.0025	88.50
Rain Garden	10/31/2014	1.4	65.56	0.0003	95.64
(194,020 sf)	11/4/2014	1.98	1,979.18	0.0102	74.84
	1/22/2015	1.4	423.45	0.0022	81.30
	4/22/2015	0.89	535.07	0.0028	96.86

Table 5. Pollutant export characteristics at monitoring locations.

	BMP	Average Pollutant Mass in Outflow	Export/Area	% Removal
		(mg)	(mg/sf)	
Total Suspended Solids	Baseline	167,574	27.48	
	Permeable Pavement	625,583	5.14	81.30
	Bioretention	253,578	1.31	95.24
		(MPN)	(MPN/sf)	
E. coli	Baseline	278,564,427	45,681.28	
	Permeable Pavement	212,147,351	1,742.95	96.18
	Bioretention	2,985,485,814	15,387.49	66.32
		(mg)	(mg/sf)	
Nitrate as N	Baseline	873	0.14	
	Permeable Pavement	104,179	0.86	-497.62
	Bioretention	7,034	0.04	74.69
		(mg)	(mg/sf)	
Ammonia as N - Distilled	Baseline	3,416	0.56	
	Permeable Pavement	5,156	0.04	92.44
	Bioretention	38,843	0.20	64.26
		(mg)	(mg/sf)	
Total Kjeldahl Nitrogen	Baseline	27,875	4.57	
	Permeable Pavement	110,835	0.91	80.08
	Bioretention	159,398	0.82	82.03
		(mg)	(mg/sf)	
Total Phosphorus	Baseline	3,406	0.56	
	Permeable Pavement	24,562	0.20	63.87
	Bioretention	14,330	0.07	86.78

5.1.1. Permeable Pavement and Bioswale

The permeable pavement overlay was not designed to hold runoff, but rather to filter the water and convey the runoff to bioswales. This combination of BMPs is designed in a flow through configuration. The permeable pavement and bioswale treatment train captured an average of 65% of the runoff that would otherwise flow from the parking lot. Minimal outflow from the BMP occurred in the monitored events with less than 1 inch of rainfall. Also on average, this BMP removed approximately 96% of the *E. coli*, 80% of the total nitrogen, 64% of the total phosphorus, and 81% of the TSS. It should be noted that the average concentration of *E. coli* in the outflow from the BMP is above the primary contact recreation standards, 126 MPN/dL.

5.1.2. Bioretention Areas

The bioretention area receives runoff from the library rooftop and adjacent impervious surfaces. On average, 88% of the runoff volume was infiltrated and did not outflow from the BMP. The concentration of *E. coli* of the first observed overflow event was over an order of magnitude above the primary contact standard and one overflow event was above the concentration that can be quantified. Despite this, because the overflow from the bioretention features was significantly reduced the total load of *E. coli* was reduced by an estimated 66%. On average, the percent removal of the TSS is around 95%, total nitrogen is 82% and total phosphorus is 86%.

5.1.3. Rainwater Harvesting

The rainwater harvesting system was designed to capture and use 30,000 gallons of rainwater as well as capturing condensate from the library air conditioning system. This system had a capacity to irrigate 20,000 square feet of landscape for approximately 4 weeks. However, it is understood that due to challenges with maintaining the pump which pressurized the irrigation system, staff at the facility have requested that the irrigation use be discontinued. In effect the cisterns provide storage in conjunction with landscaping around the library which would ultimately overflow to the bioretention facility. There is currently no available usage data for the rainwater harvesting system. Although there is no measurement of the collection of the rainwater, in effect the cisterns act to provide additional storage for an infiltration BMP, thus increasing the depth of rainfall that would be managed by the BMP treatment train. When managed to minimize off site runoff this effectively decreases the volume of runoff leaving the Mission Library site and increases the opportunity for additional runoff to be treated.

5.1.4. Watershed Estimates

This project was a redevelopment of a site with over 90% impervious cover. A formerly commercial site was redeveloped to an institutional land use with on –site stormwater management. The average annual load reduction for each BMP train was estimated using the Annual Nutrient Mass Export equation and comparing to the estimated export from the baseline site. The estimated load reductions for TSS, total nitrogen, and total phosphorus are shown in Table 6. The estimated average annual reduction in export of *E. coli* from the permeable pavement to bioswale treatment train is 4.69×10^{10}, and on average the bioretention, bioswale, and rain garden BMP cluster and treatment train removed *E. coli* at an estimated rate of 5.15×10^{10} per year.

To extrapolate this study's results to an estimate of the impact of watershed wide adoption of on-site stormwater management, estimates of anticipated redevelopment, retrofitting, and on-site stormwater management adoption is required. However a comprehensive estimate for the Upper San Antonio River Watershed is not available at this time. In the absence of this data, the City of San Antonio provided information (COSA, 2013) regarding community planning documents which identified patterns of development preferences elicited from residents and stakeholders. From those documents, it was assumed that between 5% and 25% of commercial properties were likely to be redeveloped within the next 25 years in the Upper San Antonio River Watershed. Currently 8,202 acres of the watershed is impervious commercial land use and cover (SARA, 2011). This means that between 410 acres and 2,050 acres could potentially incorporate BMPs such as those utilized in this study.

Were 5% of the commercial areas in the Upper San Antonio River Watershed redeveloped with BMPs such as permeable pavement overlay and bioretention then approximately 39,000 kg of TSS, 3,000 kg of total nitrogen, and 450 kg of total phosphorus could be prevented from reaching the river annually. If 25% of the commercial properties were redeveloped with either of the BMPs then 195,000 kg of TSS, 16,000 kg of total nitrogen, and 2,000 kg phosphorus could be prevented from reaching the river annually. If permeable pavement overlay were implemented then between $8.05X10^{12}$ MPN *of E. coli* and $4.03x10^{13}$of MPN of *E. coli* would be prevented from entering the river with the 5% and 25% redevelopment scenarios, respectively. This represents 0.048% and 0.24% (for 5% and 25% implementation, respectively) of the required load reduction in the existing stormwater load (MS4) reported in the USAR Watershed Protection Plan (Miertschin, 2014) in order to achieve compliance with primary recreation standards.

5.2. Cost Benefit Analysis

The cost benefit comparison was made using the averted cost of water treatment costs using the baseline average pollutant loading rate, removal efficiency, and the water treatment cost for the constituents of concern. The annual averted costs are reported in Table 6. Monetization of water treatment benefits of investigated BMPs.

Table 6. Monetization of water treatment benefits of investigated BMPs.

		Permeable Pavement & Bioswale		Bioretention, Bioswale, & Rain Garden	
Total Drainage Area (sf)		121,818		194,020	
Baseline Loading		**Average Annual Averted Export**	**Averted Cost**	**Average Annual Averted Export**	**Averted Cost**
	(kg/sf yr)	(kg/yr)		(kg/yr)	
TSS	2.48E-03	210.11	$ 1,991.81	392.05	$ 3,716.61
TN	2.23E-04	18.59	$ 334.60	30.33	$ 545.88
TP	3.35E-05	2.22	$ 5.96	4.55	$ 12.18

Assuming a 25 year life span the total averted costs in terms of water quality treatment, the permeable pavement overlay with a bioswale and bioretention provide a total benefit of $58,309 and $106,867, respectively.

5.2.1. Estimations of Maintenance

Maintenance costs estimates were taken from the *San Antonio River Basin Low Impact Development Technical Guidance Manual* (SARA, 2013) for the bioretention system, which were approximately $1.91 per square foot for routine maintenance (SARA, 2013) every two years. The bioretention area is approximately 5,956 square feet, therefore there is an approximate annual maintenance cost of $5,687.98 that funds weeding, mulch replacement, refreshing infiltration media, cleanout of the underdrain, and plant replacement as necessary. However it needs to be noted that much of these costs would be present in a conventional design, to provide maintenance to the landscaping.

For the permeable pavement overlay (permeable friction course), research has shown that maintenance is not needed between replacement cycles (Winston, 2014).

5.2.2. Comparison to Conventional Maintenance

Local estimates, given environmental factors, indicate that conventional asphalt treatments will require crack repair and seal coat every three years at a price of $0.40 per square foot. Therefore an approximate annual maintenance cost of $5,909 is estimated for conventional asphalt parking lots.

6. Discussion

6.1. Discussion of Results

The performance of the BMPs was determined by calculating the percent removal of pollutants by the BMPs in comparison to a baseline condition as measured at a comparable alternative site. Then the cost benefit was derived from the performance data by calculating annual mass prevented from entering the San Antonio River and applying a cost rate of conventional treatment.

6.1.1. Permeable Pavement

The permeable pavement overlay and bioswale treatment train had significant reductions of runoff in events less than 1 inch. The outflow events had rainfall depths greater than 1 inch, exceeding the design capacity of the permeable pavement/bioswale BMP. Furthermore, it should be noted that the concentration of many constituents for outflow events were greater than the concentrations observed at the baseline location.

Nutrient removal efficiencies reported in literature for total nitrogen are generally below 88% (MWCOG, 1983; Schueler, 1987; CWP, 2007; Collins et al., 2010) and total phosphorus are generally below 78% (MWCOG 1983; Schueler 1987; Rushton 2001; Gilbert and Clausen 2006; Bean et al. 2007; CWP 2007; Toronto and Region Conservation Authority 2007; Roseen et al. 2009, 2011; Yong et al. 2011). The performance of this study, which is a lesser removal efficiency than literature values for both total nitrogen and phosphorus, is within reported ranges. It should be noted that a single event skewed the average to an export of nitrate.

6.1.2. Bioretention

The bioretention BMP reduced runoff rates from rainfall events less than 2 inches in the first year of monitoring, but had increases in outflow rates in an event less than an inch in the second year of monitoring. This shift in performance indicates a change in the configuration of BMP. It was observed that the overflow spillway of the bioretention was allowing runoff to bypass the BMP and limited the treatment. By addressing this, the runoff capture characteristics are more fully observed. In addition, flows were observed in events where the flow was not sufficient for collection of the sample. Both of these issues resulted in incomplete observation of the BMP's performance. Furthermore, the results indicate that compared to the baseline location, that when the bioretention feature does overflow it exports bacteria at concentrations higher than the baseline condition. Runoff is captured by the BMP decreasing the number of times bacteria will flow off the library site and into the Upper San Antonio River, but when outflow events do occur they export a greater concentration of bacteria. However, on a site visit dated March 7, 2014, it was observed that 3 dogs were bedding down near the bioretention. This would indicate that fecal material containing bacteria is being deposited directly into the feature, contributing to the bacterial export when runoff overflow does occur and diminishing the performance of the BMP.

The estimated reduction in nutrients ranged from 82% for total nitrogen to 87% for total phosphorus. There is a wide variety of performance of bioretention reported in scientific literature. Total phosphorus removal has been reported as efficient as 85% (Davis et al., 2006). The performance of this study, which is a slightly greater removal efficiency than literature values for total phosphorus is within expected performance ranges.

6.1.3. Limitations of Sampling Design

This study focused on sediment, bacteria, and nutrients as the constituents of concern. However, there are many more pollutants associated with parking lots and rooftops, such as petroleum hydrocarbons and heavy metals that were not investigated. Due to the impacts and high risk of such constituents, future evaluation of BMP performance would benefit from inclusion of these pollutants.

The sampling design was limited by the selection of the baseline condition. Monitoring a nearby, but off-site location, introduces error to the study, because of the inherent spatial variation in rainfall. Even more, the characteristics of the baseline site may not be the best comparison to the study location. For instance, the parking lot baseline may not be characteristic of the drainage area (rooftop and adjacent impervious surfaces) of the bioretention BMP. Future efforts could benefit from monitoring the inflow and outflow of the evaluated BMPs.

Additional error was introduced into the study by monitoring rainfall offsite, which was used to model runoff from the drainage area. Because of spatial variation, the magnitude and timing of rainfall could vary between the study and the rainfall monitoring location thus skewing the total runoff and the calculated total loading for each event. Future efforts would benefit from on-site monitoring of rainfall.

Furthermore, uncertainty was introduced by the sampler capabilities. Multiple events had minor flows observed but the samplers were unable to collect a sample, because the flows were not sufficient for the collection to be pulled. These events were not accounted for within the analysis, potentially skewing the results. It is anticipated that such low flow events would have low load export due to the low flows flowing offsite. However, due to the sampling limitations this bears further study.

Estimates of pollutant removal were made based on a average loading over all events, in order to account for the fact that monitoring events at each site did not necessarily overlap. This is a result of the fact that spatial variation in rainfall and the design of the BMPs did not allow for all BMPs to be monitored for all events. A better comparison would result from being able to evaluate the removal that occurs in each event. This could most successfully be accomplished by monitoring the inflow and outflow of each BMP rather than use of an offsite baseline site.

6.2. Discussion of Cost Differences

The LID design implemented within this demonstration project varied from a conventional design in the mechanisms by which runoff is conveyed through the site. The LID design eliminated curbs in some locations and created curb breaks in other locations. Instead runoff was allowed to flow overland over flush curbs to BMPs before it was discharged to the ultimate receiving body. Without these BMPs and LID design elements such as flush curbs, traditional stormwater infrastructure would be required to convey the runoff offsite and eliminate localized flooding using features such as curb and gutter, storm drain inlets, and culverts. Therefore, the cost differences between a conventional design and the utilized LID design is a trade between these structural controls and the LID BMPs. Furthermore, with the use of permeable pavement, no additional space is required to achieve the water quality goals and by using bioretention to manage runoff, stormwater infrastructure is "hidden" within landscaping. Costs are offset by using the bioretention in place of the landscape areas, thus requiring no additional space and utilizing budget normally allocated for landscaping.

Additionally, there are cost differences within the maintenance of the LID and conventional designs. The permeable paving surface utilized was permeable friction course, which does not require maintenance in between replacement cycles. In contrast crack repair and seal coating are required for traditional asphalt treatments. The replacement cycles for both the permeable paving surface and traditional asphalt treatment are similar at 20 to 25 years.

The maintenance of bioretention requires regular examination to ensure there is no clogging of the infiltration surface, replacement of the mulch, and weeding or replacement of plants as necessary. Replacement of mulch, weeding, and plant replacement would be required within a conventional design for maintenance of the landscaping. It should also be noted, that with limited weeding the aesthetic appeal is diminished but not the stormwater function. A conventional design would require that sediment and debris be removed from stormwater culverts and inlets at regular intervals.

6.2.1. Cost Aversion for Water Quality Treatment

The benefits of the pollutant removal include reduced human health effects of exposure to pathogens, improved ecological integrity of the receiving body, security of the water resource for downstream users, and improved recreational access to the stream. Measuring these benefits of improved water quality of runoff is challenging due to the lack of data and the complexity of the interconnected processes which influence these functions. Therefore, a cost aversion approach was used to simplify this task. In order to achieve these functions, it was assumed that conventional water treatment would be required. Literature values of conventional water treatment were applied to estimate the benefit of water treatment by the BMP.

It was estimated that over a 25 year lifespan, the permeable pavement overlay/ bioswale and bioretention provide a total benefit of $58,309 and $106,867, respectively. This was estimated by the cost of removing an equivalent amount of nitrogen and phosphorus using conventional water treatment technologies. One of the challenges of trying to estimate the value of pollutant removal is that there is a wide range in the cost of water treatment costs owing to great variability in the physical conditions. For this study, the lowest reported cost of phosphorus, the point source removal cost for nitrogen removal, and local capacity costs for TSS was used. By using the lower range of costs, conservative estimates were made. Improved estimates could be made with more local data regarding the costs of nutrient removal. A major gap in the analysis is lack of an estimate of the benefit derived from the removal of bacteria. In order to estimate this benefit using the cost aversion methodology, local data of the cost of treating stream flow to remove bacteria is required. It should be noted that it is not common practice to treat stream flow in order to meet recreational standards. However, the aversion of such a requirement, by treating the runoff using BMPs before it enters the stream, is a benefit that can be monetized using the cost of water treatment in the absence of BMPs, even if it is not standard practice (Russell et al., 2013).

6.2.2. Intangible Benefits

The best management practices provide other benefits in addition to runoff reduction and water improvement many of which are "intangible" in that they are not well quantified or have not been well studied or observed. In this study, benefits that have been specifically identified for further observation include groundwater recharge, shading, improved aesthetics, benefits to pollinator species, and education opportunity.

6.2.2.1. Groundwater Recharge

The BMPs demonstrated notable runoff reduction through infiltration and evaporation with an average of 76% of runoff reduced in comparison to the baseline site. The demonstrated BMPs utilized infiltration, which increases water movement into groundwater recharge or hyporrheic flow into surface water (which in turn improves the function and sustainability of surface water resources). In order to quantify the effect of BMPs and specifically identify the physical pathways by which runoff is reduced and the ultimate fate of the water, further study must be conducted. This is a highly important benefit, because of the increased exploitation of groundwater resources to maintain population and economic growth within the San Antonio and south Texas region.

6.2.2.2. Improved Aesthetics

The bioretention features around the library provide vegetation that improves the aesthetics of the library parking lots and associated areas. This enhances the library user experience, thus improving utilization of the library resources.

6.2.2.3. Pollinator Species Benefit

The bioretention areas utilized native species appropriate to the area. Pollinator species, such as butterflies, bees, and hummingbirds, have been observed within the BMPs on multiple occasions. Pollinator species are important to both ecological integrity and agricultural production. A primary limiting factor for stable populations of such species is the appropriate habitat and food sources, which can be limited in time and space for urban environments. The bioretention areas, with appropriate plant species selection, can provide pockets of habitat for pollinator species and thus improve prevalence of target species.

6.2.2.4. Education Opportunity

The Mission Library has served as an educational tool for the San Antonio engineering community to learn about best management practice design and maintenance. Multiple tours were given to public employees in order to educate them about how to implement and maintain LID best management practices. A report detailing these training events is included in Appendix A. Workshops cumulatively addressed a broad range of topics including national regulations, innovators, and trends; LID design basics; design and construction issues resulting in increased maintenance; operations and maintenance of LID features, construction inspection related to future performance, and performance inspection; budgeting, staffing, and comparison of LID to traditional staffing and costs; maintenance on public and private property; and lessons learned and hands-on activities. Field trips exposed government agents to the following local and regional LID/GI features: green street with bioswale; bioretention; pervious grass plaza and rock-pave parking lot; bioswales; rain water harvesting, condensate recapture, and irrigation; vegetated swale and vegetated filter strips; disconnected downspouts; missed/future opportunities for additional LID features; and BMP maintenance. Additional information regarding the education efforts that were made possible by the BMP installation can be found in Appendix A. In addition, prominent signage in the high traffic area of a library provides education to improve awareness of the hydrologic cycle, runoff, water quality, and rainwater harvesting among a wide variety of demographics from young students to adults.

7. Summary

Through work-in-kind efforts and funding through a Section 319(h) grant from the TCEQ, the City of San Antonio, SAWS, and SARA, BMPs were installed to treat runoff from the Mission Library. This effort was made to address the bacterial impairment of the San Antonio River. BMPs including permeable pavement overlay, vegetated filter strip, rainwater harvesting, bioretention features, and bioswales were installed to treat runoff from the library parking lot, rooftop, and other impervious features.

The performance of the BMPs was evaluated by monitoring runoff in the outflow of the BMPs in comparison to a baseline condition or location of similar character to the runoff entering the BMP. Based on average pollutant export through the BMPs, the absolute and percent removal of the constituents of concern was calculated. This was then used to estimate the monetized benefit in terms of water quality treatment. Together the site BMPs will provide a conservative estimate of $165,176 of water quality treatment over the lifespan of the features. Overall, the USAR LID BMPs for the Redevelopment of the Mission Drive-In Demonstration Project enhanced the Mission Library campus by improving on-site hydrology and water quality runoff. In addition, the features will provide many other benefits including intangible benefits which were not monetized, including groundwater recharge, improved aesthetics, improved habitat for pollinator species, and educational opportunities.

The project contributes to the restoration of the Upper San Antonio River. In addition, it provides an example of multiple BMPs that were monitored to disseminate local estimates of runoff treatment performance, demonstrate operation and maintenance as part of building local expertise and familiarity of LID concepts, and develop policy and educational materials to further acceptance and implementation of on-site stormwater treatment.

References

Bean, E.Z., W.F. Hunt, and D.A. Bidelspach. 2007. Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts. Journal of Irrigation and Drainage Engineering 133(6):583–592.

Birch, M.B.L., B.M. Gramig, W.R. Moomaw, O.C. Doering III, and C.J. Reeling. 2011. Why metrics matter: evaluating policy choices for reactive nitrogen in the Chesapeake Bay watershed. Environmental Science and Technology 45: 168-174.

Collins, K.A., W.F. Hunt, and J.M. Hathaway. 2010. Side-by-side comparison of nitrogen species removal for four types of permeable pavement and standard asphalt in eastern North Carolina. Journal of Hydrologic Engineering 15(6):512–521.

Compton, J.E., J.A. Harrison, R.L. Dennis, T.L. Greaver, B.H. Hill, S.J. Jordan, H. Walker, and H.V. Campbell. 2011. Ecosystem services altered by human changes in the nitrogen cycle: a new perspective for US decision making. Ecology Letters 14: 804-815.

COSA. 2013. Lonestar Community Plan. Available at http://www.sanantonio.gov/Portals/0/Files/Planning/NPUD/LoneStarCP_2013.pdf. Accessed on April 30, 2015.

CWP (Center for Watershed Protection). 2007. National Pollutant Removal Performance Database. Center for Watershed Protection, Ellicott City, MD.

Davis, A. M. Shokouhian, H. Sharma, C. Minami. 2006. Water Quality Improvement through Bioretention Media: Nitrogen and Phosphorus Removal. Water Environment Research. 78(3):284-293.

Fassman, E.A., and S.D. Blackbourn. 2011. Road runoff water-quality mitigation by permeable modular concrete pavers. Journal of Irrigation and Drainage 137(11):720–729.

Gilbert, J.K., and J.C. Clausen. 2006. Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut. Water Research 40:826–832.

Miertschin, J. 2014. Upper San Antonio River Watershed Protection Plan. Available at http://www.bexarfloodfacts.org/watershed_protection_plan/FinalWPP_7242014.pdf. Accessed June 12, 2015.

MWCOG (Metropolitan Washington Council of Governments). 1983. Urban Runoff in the Washington Metropolitan Area: Final Report, Urban Runoff Project, EPA Nationwide Urban Runoff Program. Metropolitan Washington Council of Governments, Washington, DC.

Pagotto, C, M. Legret, and P. Le Cloirec. 2000. Comparison of the hydraulic behaviour and the quality of highway runoff water according to the type of pavement. Water Research 34(18):4446–4454.

Roseen, R.M., T.P. Ballestero, J.J. Houle, P. Avellaneda, J.F. Briggs, G. Fowler, and R. Wildey. 2009. Seasonal performance variations for storm-water management systems in cold climate conditions. Journal of Environmental Engineering 135(3):128–137.

Roseen, R.M., T.P. Ballestero, J.J. Houle, J.F. Briggs, and K.M. Houle. 2011. Water quality and hydrologic performance of a porous asphalt pavement as a stormwater treatment strategy in a cold climate. Journal of Environmental Engineering 138(1):81–89.

Russell, M. A. Teague, F. Alvarez, D. Dantin, M. Osland. J. Harvey, J. Nestlerode, J. Rogers, L. Jackson, D. Pilant, F. Genther, M. Lewis, A. Spivak, M. HJarwell, and A. Neale. 2013. Neighborhood scale quantification of ecosystem goods and services. EPA/600/R-13/295. Dec 2013.

Rushton, B.T. 2001. Low-impact parking lot design reduces runoff and pollutant loads. Journal of Water Resources Planning and Management 127(3):172–179.

Sano, D., A. Hodges, and R. Degner. 2005. Economic Analysis of Water Treatments for Phosphorus Removal in Florida. EDIS document FE576. Available at http://edis.ifas.ufl.edu/fe576. Accessed on May 7, 2015.

SARA. 2011. Upper San Antonio River Watershed Master Plan. Available at https://www.sara-tx.org/public_resources/watershed_master_plans/Upper_SA_River.pdf. Accessed May 7, 2015.

SARA. 2013. San Antonio River Basin Low Impact Development Technical Design Guidance Manual. Available at https://www.sara-tx.org//wp-content/uploads/2015/05/Full-LID-Manual.pdf Accessed May 7, 2015.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Toronto and Region Conservation Authority. 2007. Performance Evaluation of Permeable Pavement and a Bioretention Swale. Interim Report #3. Seneca College, King City, Ontario.

UWRI. 2012. Water Capture Optimization Statistical Model. Version 2.0.0.29.

Winston, R. 2014. Use of Permeable Friction Course (PFC) to Improve Runoff Quality. ODOT Stormwater Workshop -12 Dec 2013. Available http://www.dot.state.oh.us/Divisions/Engineering/Hydraulics/2014%20NCSU%20Roadway%20Stormwater%20Control%20Workshop/5.%20Perm%20Friction%20Course.pdf. Accessed May 7, 2015.

Yong, C.F., A. Deletic, T.D. Fletcher, and M.R. Grace. 2011. Hydraulic and treatment performance of pervious pavements under variable drying and wetting regimes. Water Science and Technology 64(8):1692–1699.

Appendix A Public Outreach and Education Report

Combined Report on Site Tours and Education/Outreach

Background

In the spring of 2012, the San Antonio River Authority released the *Low Impact Development/Green Infrastructure in the San Antonio Area Implementation Plan* to the Water Quality Focus Group of the Bexar Regional Watershed Management consortium. This Plan highlighted opportunities and community need for LID/GI, assessed barriers to LID/IG implementation, and recommended a number of next steps toward elimination of the barriers, most of which have links to deliverables under this 319 grant: 1) Local ordinance and regulation revisions (Task 6); 2) Public outreach and education (Task 7); 3) LID design guidance manual; and 4) Pilot projects, with direct mention of the Mission Drive-in/Library project as follows:

> SARA, in coordination with the BRWM partners, should seek opportunities for pilot projects in the San Antonio region. Ongoing initiatives such as the proposed LID Design competition, City of San Antonio Mission Drive-in project, SARA's administration building stormwater retrofits, and COSA's appropriate 2012 bond projects can serve as data-generating pilot projects (p. 28).

Following the release of these recommendations, BRWM partners requested SARA to take the lead in developing a LID design guidance manual tailored to San Antonio's climate and geology. By fall 2012, SARA was holding brainstorming and scoping sessions with the BRWM partners (City of San Antonio, Bexar County, and SARA) as well as the San Antonio Water System (SAWS), CPS Energy, and a number of interested representatives of the private sector—all focusing on BMP selection, content, and format for the manual.

Throughout these brainstorming and scoping sessions, both the public and the private representatives stressed the importance of continued community education, with a recurring theme from both camps being concern over the operations and maintenance (O&M) of LID/GI features. Another key issue was implementation related to the City of San Antonio's Unified Development Code. These topics were of such significance to the participants that they requested SARA to create a LID Implementation Group, separate from but functioning simultaneous and parallel to the LID manual process, to address policy and implementation issues.

Development of the LID Implementation Group (LID IG) commenced in December 2012. By February 2013, a committee consisting of management- and supervisory-level staff of the City of San Antonio's stormwater and development services departments, Bexar County's stormwater and development services departments, the San Antonio River Authority's LID/GI program and intergovernmental relations department, SAWS' conservation department, CPS Energy's environmental education department, and the Edwards Aquifer Authority were identifying implementation challenges and developing strategies to address them.

O&M continued to be a recurring theme. Thus, the LID IG scoped a workshop and field trip series that, cumulatively, would educate the spectrum of government functions that would affect or be affected by increased LID projects in the San Antonio area, from planning and budget staff to construction inspection and field maintenance crews. All workshops and field trips were required to link content to operations and maintenance. For instance, the workshop that addressed LID design for improved water quality had to address common design and construction flaws that result in reduced performance and increased maintenance costs.

The workshop/field trip series is described below:

1. Workshop 1

   July 19, 2013, 1 – 5:00 p.m.

   Presenters: Steven Carter, PE, and Troy Dorman, PhD, PE, and CFM, Tetra Tech

   Audience: Agency directors, managers, and supervisors over functions affecting or affected by LID projects

   Agenda

   a. State of practice in national regulations and local impacts
   b. National examples of LID innovators and their regulatory drivers
   c. National trends to address regulatory drivers and cost-effective LID design and O&M
   d. San Antonio River Basin LID Design Guidance Manual
   e. O&M considerations
   f. Lessons learned

2. Workshop 2

   September 30, 2013, 1 – 5:00 p.m.

   Presenters: David Dods, URS; Rusty Schmidt, Water Drop Design

   Audience: Field inspector/construction oversight, maintenance staff and supervisors, program planners, and policy developers

   Agenda

   a. O&M of LID Best Management Practices (BMP) features
   b. BMP construction inspection (related to future performance and O&M)
   c. BMP performance inspection
   d. Budgeting and staffing for O&M
   e. Traditional vs. LID O&M costs
   f. Handling O&M requirements on public and private property
   g. Case studies
   h. Q&A

3. Workshop 3

January 24, 2014, 8 a.m. – Noon (modified to 10:00 a.m. – Noon due to ice storm)

Presenters: Daivd Dods; Michael Barrett, PhD, UT-Austin Center for Research in Water Resources

Audience: Municipal and County staff involved in public capital improvement projects or review of private proposals. Planning, Community Development, Public Works, Parks Departments: staff who may be involved in planning or review of new or redevelopment projects.

Agenda

a. Introduction
b. LID basics
c. Design & construction issues resulting in increased O&M
d. Class exercise
e. Wisdom circle discussion

Due to a delayed start time for two of the governmental agencies and a need to compress the content into a two-hour time-slot, the LID basics component incorporated the O&M discussion and the class exercise was eliminated. Most of the attendees' schedules were clear through 1:00 p.m., so, during the wisdom circle discussion, most agreed to stay until 12:45 p.m. to give more time for group discussion.

Despite the day's obstacles and light attendance, this workshop yielded one of the most valuable exchanges of the workshop series. The facilitator, David Dods, asked the attendees to provide detail on how they currently budgeted, scoped, staffed and managed capital projects. He then used that information to address all of the missed opportunities represented through that process to utilize LID to 1) offset construction costs, 2) minimize the pressures placed on receiving regional storm water infrastructure through increased development, 3) improve storm water quality, 4) reduce localized street flooding, and 5) increase aesthetics and provide other quality of life amenities.

4. Mini-Site Tour (A non-scoped tour requested by City of San Antonio as a direct result of Workshop 3)

February 21, 2014, 2:30 – 4:30

Audience: City of San Antonio Transportation and Capital Improvements, Storm Water Division: Assistant Director, Managers, and Superintendents

Presenter: Troy Dorman

BMP Site Visit List:

1. Mission Library's suite of BMPs.
2. Bioretention at Wyndham Garden Inn (9th Street at Arden).

3. 600 E. Euclid, San Antonio River Authority's rain garden.

San Antonio River Authority Euclid facility rain garden, San Antonio, Texas.

Purpose: Discuss BMP design and maintenance in a smaller setting with key Storm Water Division leaders and to allow for SARA and the consultant who will lead the site visit series discussed below to understand TCI Storm Water concerns prior to the tour series.

5. Site Tour 1: Introduction to LID O&M in San Antonio through Site Visits

March 7, 2014, 8:00 a.m. - Noon

Presenter: Troy Dorman

Audience: All audiences from Workshop Series

BMP Site Visit List:

1. Port San Antonio: Rainwater harvesting, vegetated swale, vegetated filter strips, disconnected downspouts, and opportunities for additional LID features

Port of San Antonio, Texas. Agency staff observing opportunities for LID retrofits

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2. Mission Library, EPA 319 Grant LID BMPs: Green street with bioswale and pervious grass plaza; bioswales; rain water harvesting, condensate recapture, and irrigation; and rain garden.

Mission Library, San Antonio Texas. Agency staff viewing bioswale.

Learning Objectives

This tour provided attendees with an overview of ongoing LID BMP O&M practices in San Antonio.

San Antonio River Basin LID Manual Sections Discussed

a. Chapter 1 Section 6 – Example LID Site Design
   Discussed information needed to locate LID BMPs within a construction project site.
b. Chapter 3 – LID Selection; Structural BMPs
   Discussed how the BMPs for each site were selected and what information was used to select them; also discussed what information from the LID manual would have been useful to select BMPs for the site had the manual been available pre-design.

Mission Library, San Antonio Texas. Agency staff viewing green street: permeable pavement and bioswale.

c. Chapter 4 Section 3 – BMP Operation and Maintenance
   Discussed what types of maintenance are required for typical BMPs, what is needed at the sites we visited, and what could be changed to make maintenance easier?
d. Appendix B – BMP Design Guidance
   Discussed whether the BMPs were consistent with the design standards/guidance in the manual, whether there were maintenance considerations that should have been included in the designs, and whether there is access available for the long-term maintenance at each site.

Site Tours 2 and 3 below were not held at the Mission Library site, but, for comparison purposes, at each location references were made to site planning and features at the Mission Library site.

6. Site Tour 2: BMP Maintenance in Northern Bexar County and Kendall County

   March 21, 2014, 8:00 a.m. – Noon

   Audience: All audiences from Workshop Series

   Presenters: Troy Dorman; Paul Barwick, City of Boerne

   BMP Site Visit List:

   1. The Rim Shopping Center: sand filters and bioswales

The Rim, San Antonio, Texas. Curb cuts to green infrastructure.

2. Patrick Heath Public Library: bioswale, cistern, permeable pavements

Paul Barwick providing introductory remarks regarding LID site assessment and BMP selection discussions held in advance of the design and construction of Patrick Heath Public Library, Boerne, Texas. Barwick in front of a storm water cistern outside the library. Photo courtesy of Troy Dorman, Tetra Tech.

3. Boerne
Stage Subdivision: vegetated swale and sand filters

Learning Objectives
This tour provided attendees a focused look at sand filters, bioswales, and a library site that fully integrated LID into its site planning and design processes. The tour also addressed how traditional landscaping functions in commercial developments and maintenance activities at the library site.

LID Manual Sections Discussed

e. Chapter 3 – LID Selection Structural BMPs
   For the library site, the tour addressed how and why the constructed BMPs were selected for that particular site. For the shopping center, the tour

addressed the BMPs that had been constructed and improvements that could be made based upon current knowledge and to avoid maintenance challenges observed at the site. Reference was made to the bioswales at the Mission Library and differences at The Rim resulting from its location within the Edwards Aquifer Recharge Zone.

f. Chapter 4 Section 3 – BMP Operation and Maintenance
Questions addressed were what types of maintenance are required for typical BMPs; what is needed at the sites visited; and what could be changed to make maintenance easier?

g. Appendix B – BMP Design Guidance
The tour addressed whether the BMPs followed the design standards/guidance found in the LID manual; whether there were maintenance considerations that should have been included; and whether there was adequate access available for long-term maintenance.

7. Site Tour 3: BMP Maintenance in Parks, Schools and Infrastructure Settings

March 28, 2014, 8:00 a.m. – Noon

Audience: All audiences from Workshop Series

Presenters: Troy Dorman and Jason Wright, PE, Tetra Tech

BMP Site Visit List:

1. Phil Hardberger Park: Pervious pavement and rainwater harvesting
2. Madison High School: Green roof, pervious pavement, rock pave system, rainwater harvesting, bioretention

Green roof and outdoor learning space, James Madison High School Agricenter, San Antonio, Texas. Photo courtesy of Troy Dorman, Tetra Tech.

Learning Objectives

This tour provided attendees a focused look at pervious pavement, green roofs, and biorentention. At each site, attendees looked at how traditional landscaping functions and at opportunities to retrofit with LID.

LID Manual Sections Discussed

h. Chapter 3 – LID Selection Structural BMPs
   Attendees learned how the BMPs for each site were selected and what information was used to select them. Where this information was lacking, attendees discussed information that would have been useful in BMP selection and site design.

i. Chapter 4 Section 3 – BMP Operation and Maintenance
   The tour addressed what types of maintenance are required for the BMPs at the site and what could be changed to make maintenance easier.

j. Appendix B – BMP Design Guidance
   Questions addressed were do the BMPs follow the design standards/guidance; are there maintenance considerations that should have been included; is access available for long-term maintenance?

The three educational offerings/site tours below, all of which incorporated Mission Library, were in addition to the LID Implementation Group's scope:

8. Combined Workshop and Site Tour

   April 14, 2014, 8:00 a.m. – 5:00 p.m.

   Audience: San Antonio Housing Authority Staff and Design Consultants

   Presenter: Troy Dorman, Tetra Tech

   a. Workshop Session (4-hours): LID Overview and Local Implementation Strategies for Redevelopment

      The workshop addressed the planning, design, and sizing requirements for the LID Best Management Practices that are most applicable to multi-family redevelopment sites in San Antonio. The following general topics were discussed:

      i. Why is LID the preferred approach for stormwater management in San Antonio?
      ii. What LID practices best fit with SAHA's ongoing and near future projects to improve aesthetics, increase multi-use benefits, and improve water quality?
      iii. How can bioretention, permeable pavement, and rainwater storage be designed using the San Antonio River Basin LID manual.
      iv. What approaches are effective to make LID cost-neutral or a cost savings?

b. LID BMP Tour (4-hours)
SARA and Tetra Tech led a field tour to local sites with BMPs that are similar to the design guidelines presented in the SARB LID Manual:

i. Bioretention:
   1. Mission Branch Library
   2. Wyndham Garden Inn (9th Street at Arden)

   At each site, construction and O&M needs were discussed and related to O&M and construction costs. The tour helped SAHA staff understand what LID looks like after installation and how the SARB LID manual checklists are used to assess maintenance needs. O&M deficiencies were noted and options to meet LID goals were discussed.

ii. Site Assessment for Potential BMPs: The Wheatley Courts redevelopment site was also toured to discuss options for including LID in the project design.

9. Mission Library Site Tour for Commissioner Tommy Adkisson, Bexar County Precinct 4

June 30, 2014, 5:00 – 6:00 p.m.

Presenter: Karen Bishop, SARA

Purpose: Commissioner Adkisson requested and was provided information on each of the BMPs at the site: what they were called, how they functioned, what their water quality and quantity benefits were, and whether any provided water conservation benefits.

10. City of San Antonio Municipal Storm Water Program: LID/GI Workshop

October 3, 2014

8:00 a.m. – Noon

Presenters: Arthur (Art) E. Reinhardt IV, PE, CFM, and Stacy Geiger, City of San Antonio; Scott Halty, Martin Miller, and Philip Handley III, SAWS; Karen Bishop and Aarin Teague, PhD, PE, CSM, SARA

Audience: Brent E. Larsen, NPDES Permits and Technical Assistance, and Claudia V. Hosch, Associate Director, Water Quality Protection, U.S. EPA Region 6

Agenda:

1. Presentations
   a. Introductions and Overview
   b. SARA's LID Projects and Efforts
      I. UDC Amendment Project
      II. COSA Pilot Project Pre-construction Stormwater Monitoring
      III. LID Training Series
   c. SAWS' Aquifer Protection Program

i. Edwards Aquifer Regulations
ii. Construction Control Measures Training Program
iii. BMP Inspection Program
iv. Watershed Implementation Plan

d. COSA
    i. MS4 Permitting Program Components
    ii. LID Pilot Projects
        1. Hausman Road
        2. Ray Ellison
        3. Hemisfair

2. Site Visits
    a. Mission Library Suite of BMPs
    b. Rain Garden at SARA's Euclid Facility

Agenda:

Presentations

- Introductions and Overview
- SARA's LID Projects and Efforts
    - UDC Amendment Project
    - COSA Pilot Project Pre-construction Stormwater Monitoring
    - LID Training Series
    - LID Design Manual
- SAWS' Aquifer Protection Program
    - Edwards Aquifer Regulations
    - Construction Control Measures Training Program
    - BMP Inspection Program
    - Watershed Implementation Plan
- COSA
    - MS4 Permitting Program Components
    - LID Pilot Projects
        - Hausman Road
        - Ray Ellison
        - Hemisfair

Site Visits

- Mission Library Suite of BMPs (including discussion of site's use in Site Tour Series)
- Rain Garden at SARA's Euclid Facility

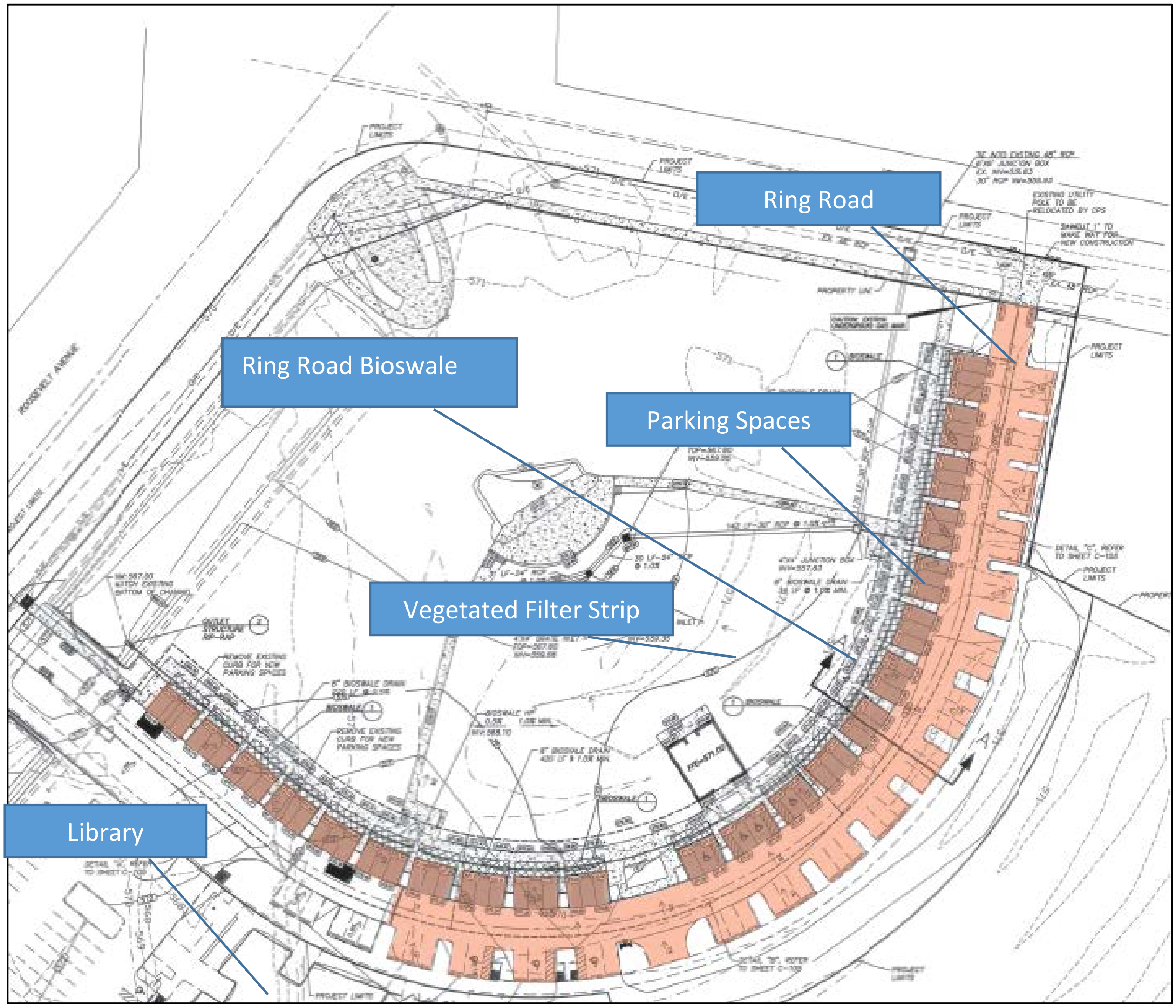
Appendix B LID Resources

- San Antonio River Basin Low Impact Development Technical Guidance Manual http://www.sara-tx.org/lid_services/documents/Full%20LID%20Manual.pdf

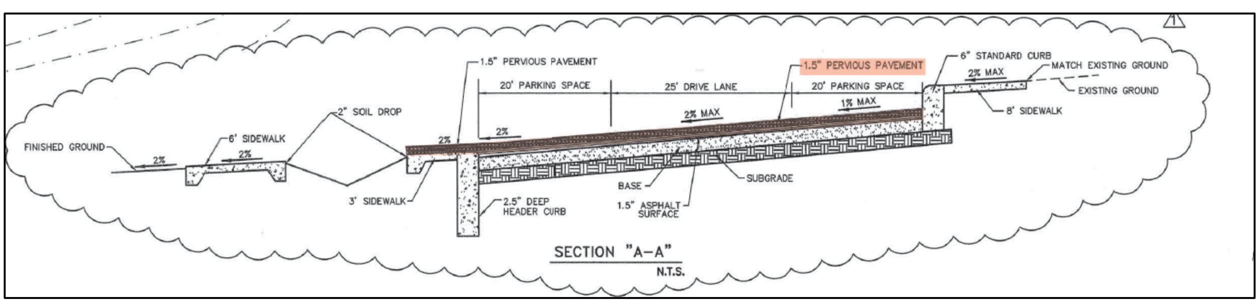
- Low Impact Development / Green Infrastructure in The San Antonio Area Implementation Plan http://www.sara-tx.org/sustainability/documents/120626__ImplementationPlan-Draft_Distribution.pdf

Appendix C BMP Schematic Renderings

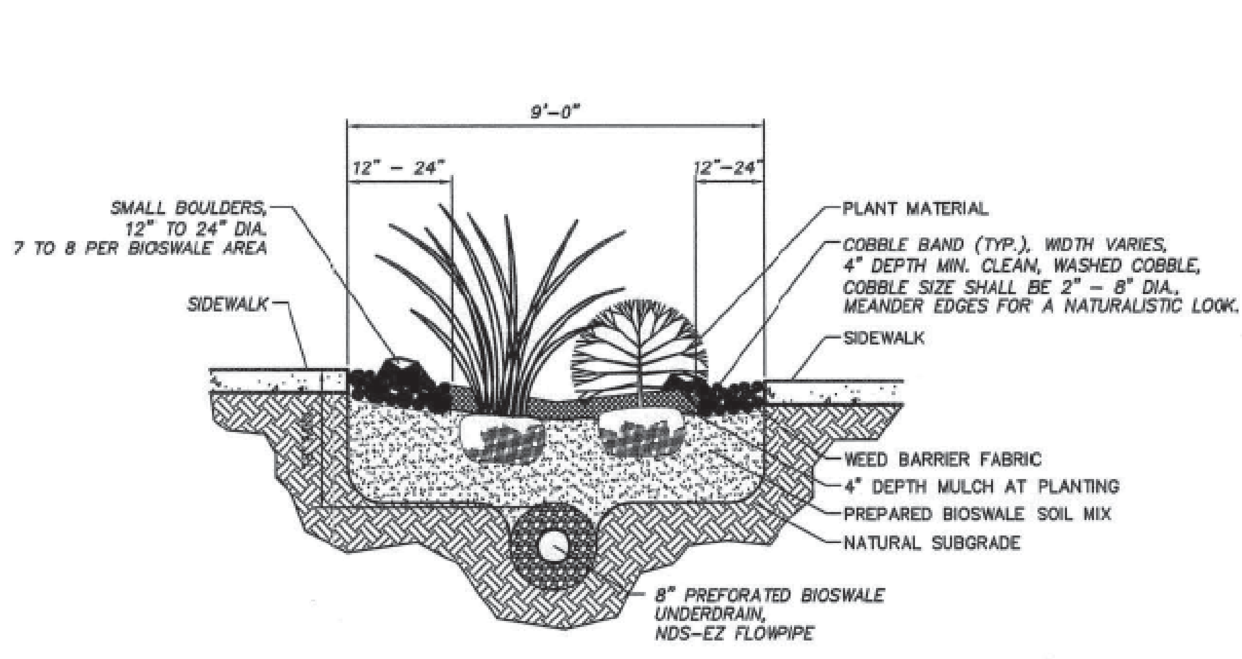
Ring road and adjacent parking spaces with permeable friction course overlay (plan view)



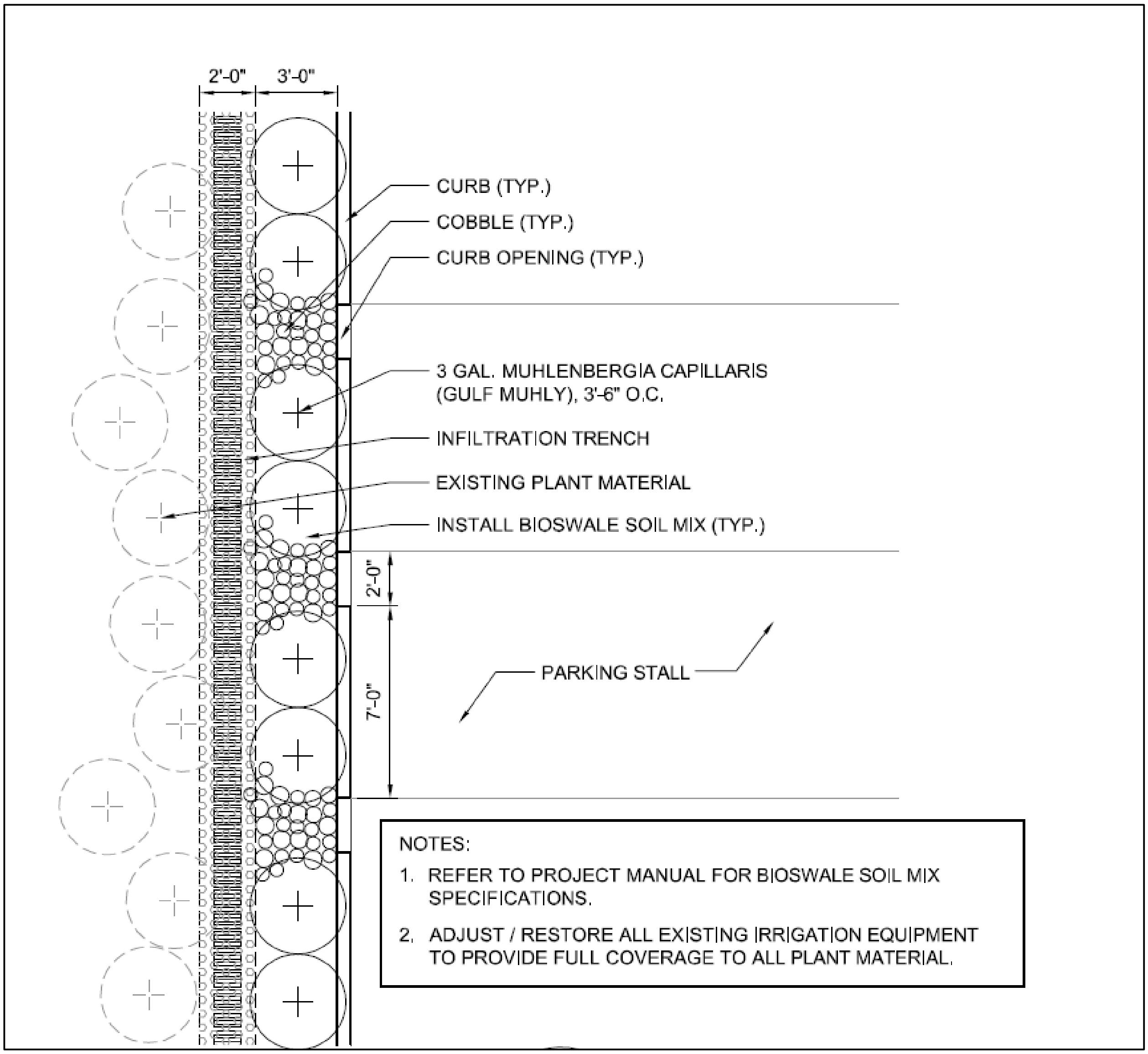
Ring Road with overlay (cross section)



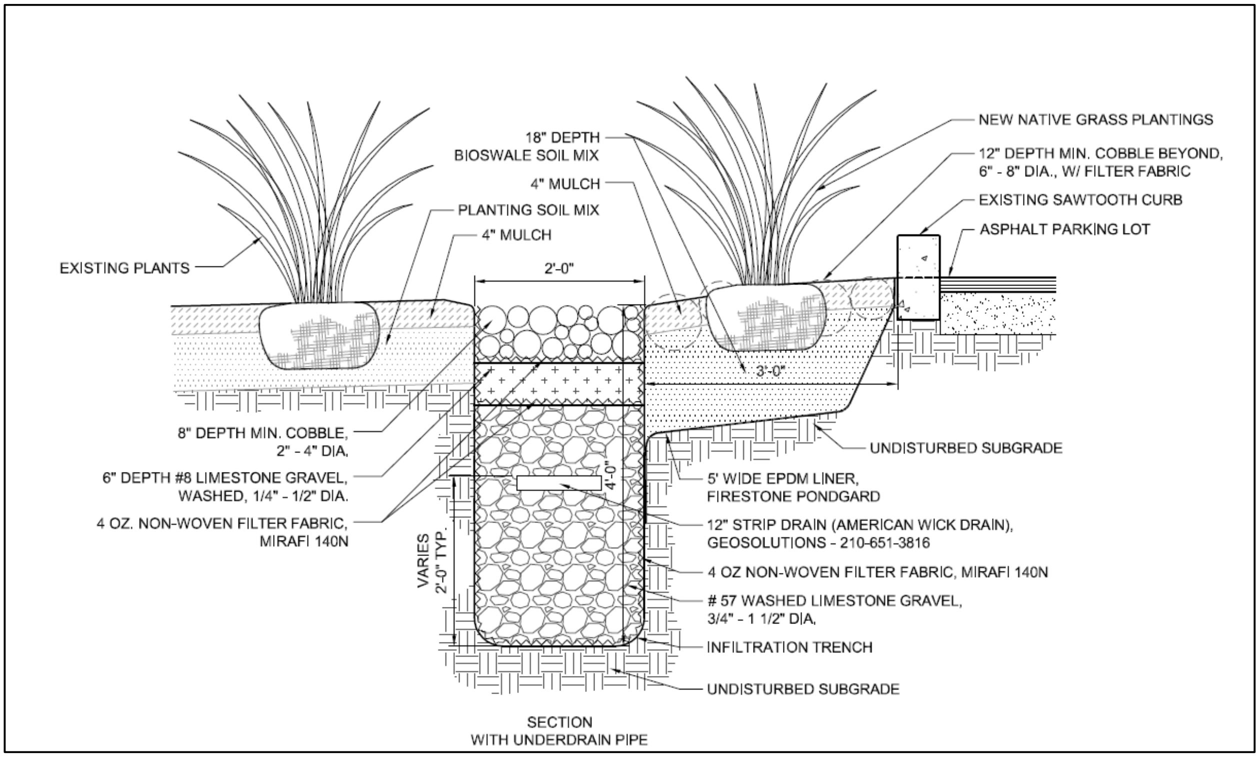
Bioswale receiving runoff from ring road and parking spaces with permeable friction course overlay (typical cross section)



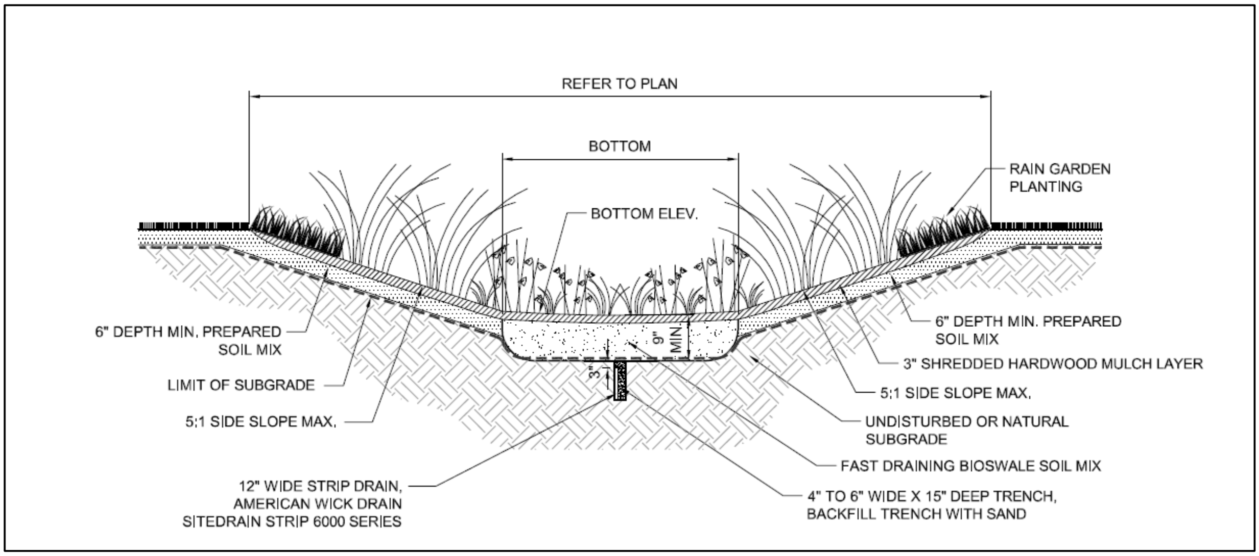
Typical section of bioswale to capture runoff from impervious parking area to the west of the library (plan view)



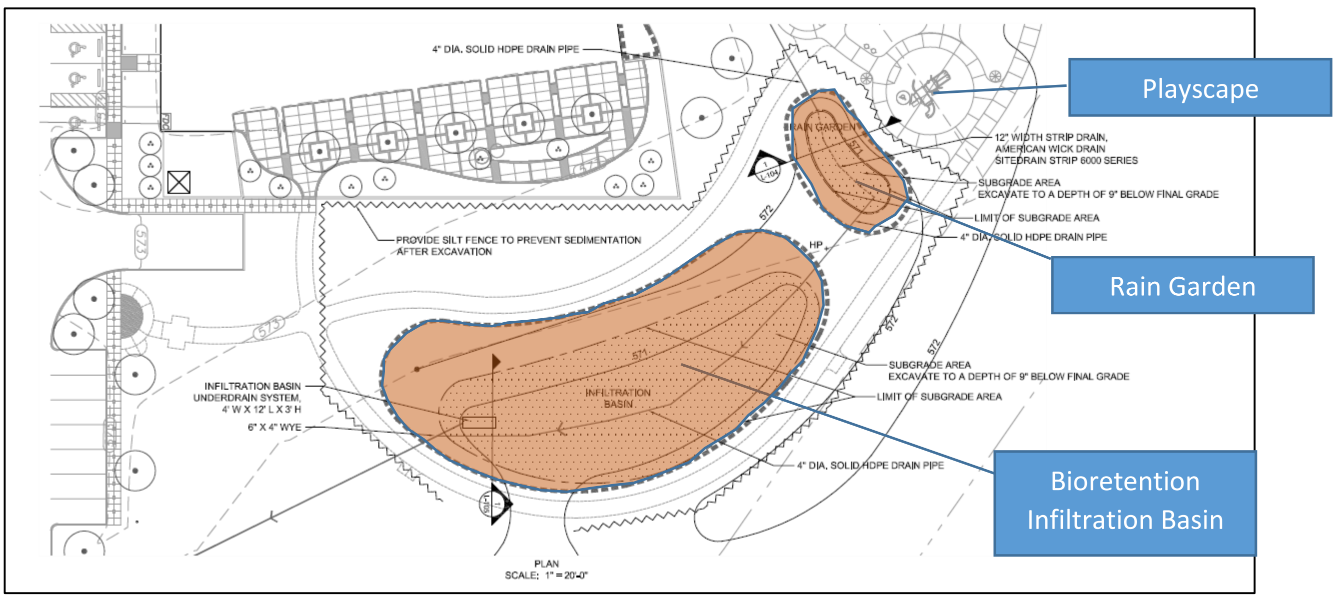
Typical cross-section of bioswale to capture runoff from impervious parking area to the west of the library



Rain garden on south side of library building (typical cross section)



Rain garden and bioretention infiltration basin on south side of library building (plan view)



Bioretention infiltration basin on south side of library building (typical cross-section)