PRELIMINARY FINDINGS FOR SIZING A BIORETENTION POND AND AN ANALYSIS OF URBAN STORMWATER RUNOFF: SAN MARCOS, TX.

by

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ABSTRACT

The senior engineer for the City of San Marcos has designated an existing Stormwater Control Measure (SCM), a stormwater detention pond at the City of San Marcos City Hall, for improvements to better meet the stormwater quality standards of the Water Quality Protection Plan (WQPP), which has been drafted by the city. The WQPP is part of a larger objective, the Stormwater Master Plan (2018), that is geared toward managing non-point source (NPS) pollutants that accumulate in the stormwater runoff as it flows over impervious surfaces, like parking lots. This report will provide preliminary findings for sizing a bioretention (BR) pond that will replace an existing SCM that handles the runoff from the City Hall parking lot. The research utilizes the City of San Marcos Stormwater Technical Manual (CSM), which is an extension of the WQPP. The manual provides equations to calculate peak discharges, water quality volume (WQV), and the surface area for the BR pond related to Total Suspended Solids (TSS) loads. The WQPP contains equations to estimate Total Phosphorus (TP) and Fecal Coliform (FCOL) loads, which will be included separate from the TSS equations in the CSM. An analysis of urban stormwater runoff is conducted through the use of Event Mean Concentration (EMC) data from the City of Austin, TX, techniques used by the United States Geological Survey (USGS) to estimate pollutant loads and mean concentrations in the stormwater runoff, and the general stormwater quality categories listed in the WQPP. Peak discharges are based on a 2-year storm event (7 cubic feet per second) because they yield about an inch of precipitation, which is the most common type of rainfall that occurs annually and is the threshold to produce stormwater runoff from impervious surfaces. The TSS equations from the CSM estimate WQV to be 8,250 cubic feet, and the surface area is roughly 4,830 ft^2. An analysis of EMCs, pollutant loads, and mean concentrations have revealed a wide range of stormwater pollutants that commonly exist in urban runoff. The estimates calculated using techniques from the USGS will affect the WQV and surface area sizing of the SCM because the CSM equations only provide values for WQV and surface area based on TSS. Following this

USGS procedure, it is estimated that the proposed bioretention pond will reduce pollutants by 89 percent of the NPS pollutants from the first 1 in. precipitation event and thereby significantly reducing the NPS pollution entering the San Marcos River from this site

Key words: Stormwater management, bioretention, Event Mean Concentration (EMC), Stormwater Control Measure (SCM), urban stormwater quality

Problem Statement

In 2016, the City of San Marcos had a Water Quality Protection Plan (WQPP) prepared consistent with the criteria in the Habitat Conservation Plan (HCP). This plan was created, in part, to combat the non-point source (NPS) pollutants that negatively impact the local and regional natural environments, in which rapid urbanization is occurring. NPS pollutants can be defined as having no direct source of discharge or cannot be traced to an original source. The city has proposed retrofit solutions within the recommended areas of protection, but it is still early in the stages of development and the larger objective may take a few years to achieve.

The senior engineer for the City of San Marcos, Gregory J. Schwarz, has designated a stormwater management facility at City Hall to be improved, in order to better meet the goals of the WQPP, which require the city to reduce pollutant load sizes from NPSs. I will be providing preliminary values for the drainage area, impervious/pervious cover, water quality volume (WQV), and peak discharges. These values will provide the dimensions needed to roughly size a off-line bioretention (BR) pond.

I intend to analyze the drainage area by measuring its total area, and impervious/pervious surfaces. I will also investigate the WQV needed for the BR pond, this will help roughly size the pond's surface area (ft^2) and allow preliminary planning decisions on the placement and orientation of the SCM. The peak discharges can also be calculated to provide a threshold. This threshold is used for the off-line portion of the BR design. The off-line part consists of a channel that runs adjacent to the pond, so that only the calculated WQV enters the pond and the excess is bypassed through the channel once its at capacity. Also, Event Mean Concentration (EMC) data relevant to urban stormwater runoff is utilized from the Fundamentals of Urban Runoff Management issue, this will give preliminary evidence to the different types of pollutants that are commonly measured. Treatment planning for this Stormwater Control Measure (SCM) can be optimized when individual pollutant concentrations are calculated and included into the treatment design. However, the process involved in collecting water quality data is time intensive and costly (Driver 1990). Therefore, EMC data and estimation techniques for loads and mean concentrations will be used to determine the types and amount of pollutants on the City Hall parking lot. An EMC is defined as the total concentration of a single water parameter in a specified water volume (Kim 2007), and a post construction SCM, is a design that is used primarily to improve water quality and decrease stormwater runoff volume and peak flows from urban structures (CSM).

The Fundamentals of Urban Runoff issue described above has cited EMC values for water parameters related to stormwater runoff. Table 1 shows that various major cities have collected data for EMC computation; these values and list of pollutant parameters will help broaden the scope of treatment currently practiced in the San Marcos Stormwater Technical Manual (CSM) and the WQPP, which limits treatment to Total Suspended Solids (TSS), Total Phosphorus (TP), and Fecal Coliform (FCOL). Even though the general categories for water quality parameters exist in the WQPP, the equations for estimation of pollutant loads and mean concentrations are not available. So, a better understanding of the range of stormwater parameters and their estimated values regionally, can be obtained by using this EMC data.

The goals for the stormwater detention pond are based on the location within WQPP boundaries. The study location lies within the San Marcos River Corridor. The minimum treatment criteria included in the plan expects a SCM to capture 1.60 (inches) of stormwater runoff from a precipitation event and treat 89 percent of the pollutants in that runoff. These standards have been established by the Texas Commission on Environmental Quality (TCEQ) but have been modified to meet the TSS treatment level required by the San Marcos Land Development Code. The water quality volume and SCM size estimated using the CSM, is based only for TSS treatment. Although, TSS is seen as the primary constituent to determine the success rate of SCMs, concentrations for individual parameters can be used for additional estimations for SCM treatment planning.

Also, by capturing a WQV that represents the first flush effect, this SCM will collect the most concentrated runoff from the City Hall parking lot. When runoff begins, a duration of about 20-50 mins of flow can be characterized as the first flush. The effect is apparent in the water sample taken by Kim (2007). The offline channel will allow the less polluted water (runoff produced after a duration of 50 mins.) to bypass the system and enter the public drainage system. This will ensure that the WQV representing the first flush effect gets processed effectively through the filters, and turbidity, erosion, and additional sediments from the less polluted water will be diverted away from the pond. By using this BR technique, these pollutants are treated as they infiltrate into the pond's soil and engineered gravel media that create larger pore space underneath to soil layer, to allow for additional percolation and storage space of the stormwater. The water infiltrating into the pond, and out into the public drainage system or stored underground as groundwater, should meet the water quality goals defined in the WQPP.

The original SCM would have been composed of gravel and cobble stones, mostly limestone. This probably would have had an initial filtering effect, but there is no retention or detention of the water, so it is hard to say if infiltration occurs before it reaches the public drainage ditch during large storm events.

Figure 1. Location of original SCM at San Marcos City Hall. This SCM is designed for one of the few parking lots on the property.

Research Questions

Stormwater Runoff Pollutants

1. What are the most common pollutants in urban stormwater runoff that would be expected to be produced on the City Hall parking lot?
2. Why are event mean concentrations (EMCs) better than calculating only Total Suspended Solids (TSS) for water quality volume (WQV) and sizing the SCM?
3. How will using EMC data from Austin, TX, differ from a site-specific study to obtain EMCs from the City Hall parking lot in San Marcos, TX?
4. Why is having other parameters besides TSS, total phosphorus (TP), and fecal coliform (FCOL) important?

Design and Sizing of the Bioretention Pond

5. What is the volume of pollutants created by the parking lot per unit of time?

6. What are the design parameters for an effective bioretention (BR) pond to be installed at the City Hall parking lot?

7. How will the EMCs, estimated loads and mean concentrations, fit into the design of the pond?

Maintenance and Costs for the Bioretention Pond

8. What are the maintenance costs for the pond?

Background

The City of San Marcos senior engineer, Gregory J. Schwarz, who is a part of the Department of Engineering & Capital Improvements, has designated an existing SCM at City Hall for improvements. This SCM currently handles the stormwater runoff from one a the few parking lots on City Hall property. In the WQPP, this facility is visible on a map, and can be seen within the San Marcos River Corridor boundary line. The San Marcos River Corridor has been included in the plan so that it is protected against the runoff from the surrounding urban development. Urban stormwater runoff poses a threat to the critical habitat that provide shelter and food for the Endangered Species that are found within the WQPP boundaries (HCP 2012). Impervious cover increases the rate of precipitation runoff, reduces infiltration and groundwater recharge, and the pollutants that flow into the public drainage network and into the ground. In this case, the pollutants in the runoff will mix with the water of the San Marcos River as it flows down to lower elevations, and possibly into the Edwards Aquifer recharge zone, since the study site is located just East of the recharge zone. When impervious cover is near the river it increases risk of pollution, therefore stormwater management techniques should be implemented to reduce and mitigate exposure to NPS pollutants (Gleason 2016). The proximity of the project site is within a half-mile of the San Marcos River, this provides context for the necessity to implement an SCM that will address the problem of NPS pollutants in stormwater runoff.

Both suspended solids and dissolved solids have varying effects on a river's health when in excess. For example, excess phosphorus causes algae blooms in the river, which block sunlight and reduce oxygen levels for aquatic life (WQPP 2016).

The stormwater management literature includes discussion on SCMs that reduce pollution from NPSs (Osman 2013). Most of the pollution found in stormwater runoff comes from NPSs, which is why the correct structures should be in place for treatment before a water body becomes contaminated, and in danger of being designated on the TCEQ's 303(d) list, which is a list for impaired water bodies in the State of Texas.

The literature on SCMs will be utilized to define the design and cost parameters of the BR pond that will be replacing the existing stormwater management facility at the City Hall parking lot, which does not adequately filter the runoff from a 2-year storm event.

Table 1. Event Mean Concentration (EMC) Values for Various Major Cities in the U.S.

Table 3-9: Event Mean Concentration (EMC) Values for Stormwater Runoff Pollutants for Various U.S. Climatic Regions

Location	National	Phoenix, AZ	San Diego, CA	Boise, ID	Denver, CO	Dallas, TX	Marquette, MI	Austin, TX	MD	KY	GA	FL	MN
Mean Annual Rainfall (in)	N/A	Low (7)	Low (10)	Low (11)	Low (15)	Med (28)	Med (32)	Med (32)	High (41)	High (41)	High (41)	High (41)	Snow (*)
Pollutant													
TSS (mg/l)	78	227	330	116	242	663	159	190	67	98	258	43	112
TN (mg/l)	2.39	3.26	4.55	4.13	4.06	2.70	1.87	2.35	N/R	2.37	2.52	1.74	4.30
TP (mg/l)	0.32	0.41	0.70	0.75	0.65	0.78	0.29	0.32	0.33	0.32	0.33	0.38	0.70
SRP (mg/l)	0.13	0.17	0.40	0.47	N/R	N/R	0.04	0.24	N/R	0.21	0.14	0.23	0.18
Cu (ug/l)	14	47	25	34	60	40	22	16	18	15	32	1	N/R
Pb (ug/l)	68	72	44	46	250	330	49	38	13	60	28	9	100
Zn (ug/l)	162	204	180	342	350	540	111	190	143	190	148	55	N/R
BOD (mg/l)	14	109	21	89	N/R	112	15.4	14	14.4	88	14	11	N/R
COD (mg/l)	52	239	105	261	227	106	66	98	N/R	38	73	64	112
# Sample Events	3000	40	36	15	35	32	12	78	107	21	81	66	49
Reference	1	2	3	4	5	6	7	8	9	10	11	11	12

Notes: EMC = Event Mean Concentration; TSS = Total Suspended Solids; BOD = Biological oxygen Demand; COD = Chemical oxygen Demand; TP = Total Phosphorus; TN = Total Nitrogen; SRP = Soluble Reactive Phosphorus; N/R = Not Reported

References: 1 – Smullen and Cave, 1998; 2 – Lopes et al., 1995; 3 – Schiff, 1996; 4 – Kjelstrom, 1995; 5 – DRCOG, 1983; 6- Brush et al., 1995; 7 – Steuer et al., 1997; 8 – Barrett et al., 1995; 9 – Barr, 1997; 10 – Evaldi et al., 1992; 11 – Thomas and McClelland, 1995; 12 – Oberts, 1994

Source: CWP, 2004

(Source: Shaver 2007)

EMCs from Table 1 are based on regional stormwater data from major cities. One of the major cities included in the Table 1 is Austin, TX. EMC data from this table can be compared to the load and mean concentration estimated using the USGS engineering techniques (Driver and Tasker 1990).

The equations in steps 1,3,4, and 5 starting in section 3.2.2 of the San Marcos Stormwater Technical Manual (CSM), are used to calculate the required TSS removal, TSS load removed by SCMs, fraction of annual runoff to be treated, and WQV for TSS treatment, however, these equations only account for TSS load and not a range of loads and concentrations for individual water parameters, and because TSS is the target parameter in the CSM equations, this will limit the WQV and the size of the SCM to TSS. Although, equations exist to determine TP and FCOL, they will need to be included in a separate format, then synthesized with the TSS values. Other parameters besides TSS affect water quality, but do not have their own equations in the CSM. By using techniques from the USGS, loads and mean concentrations for pollutants can be estimated for the City Hall parking lot, along with TSS, TP, and FCOL (the target pollutant parameters in the CSM).

To further optimize treatment, the first flush effect is assumed for this project because small areas, like this parking lot, usually exhibit a first flush. The pollutants that exist in a first flush can include: TSS, TP, FCOL, Total Kjeldahl Nitrogen (TKN), Ammonium Hydroxide (NH_3-3), Nitrogen dioxide and Nitrate ($N0_2$-N and $N0_3$-N), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Lead (Pb), Zinc (Zn), Copper (Cu), Cadmium (Cd), which can be found as general categories in the WQPP (Solids, Nutrients, Metals, Bacteria, Petroleum hydrocarbons, Pesticides and herbicides, Trash and debris). However, three out of the seven categories are claimed to have insufficient data that would have otherwise been included in the estimation of WQV and SCM sizing, these categories are: Petroleum hydrocarbons, Pesticides and herbicides, Trash and debris. Having the offline channel will allow the first flush, along with the pollutants, to be diverted into the pond for treatment.

In addition to the equations for TSS, the CSM has an equation for TP, a limiting nutrient, which can affect the river's health when in excess (Groeger et al. 1997). Another equation for FCOL can be found in the CSM. We can compare these equations with the regression models from the USGS.

A major component to understanding runoff for this site is determining its discharge rate. Knowing the peak discharge from the project site will allow for channel sizing. Channel sizing will include an intake structure that reduces runoff and creates an entry point at which the calculated WQV will flow into. Once the pond is at capacity (the calculated WQV and surface area), the less polluted water will bypass the BR pond through the adjacent offline channel. The water flowing through the channel flows to the public drainage without entering the pond. The Rational Method (Dunne and Leopold 1978) is acceptable by the city to estimate peak discharge for the drainage area. This is because the drainage area is under 100 acres (CSM). Any project site over 100 acres should use different hydrologic methods, such as those from the National Resources Conservation Service (formerly Soil Conservation Service). However, this equation has been modified in the CSM, where rainfall intensity (I) is represented by a time of concentration value equal to the amount of precipitation per hour (CSM).

Figure 2. Stormwater management site near City Hall designated for improvements.

Literature Review

Policy

Central Texas is one of the fastest growing regions in the US, and development is taking a toll on the health of its rivers, creeks, and streams (U.S. Census 2019). Most urban structures are constructed traditionally, using materials like concrete and asphalt. These materials are impervious, and usually cover a large portion of a project site to allow for facilities such as, parking lots or roadways. These facilities are heavily used by vehicles, which leave behind pollutants like grease and oil (Kim 2007). In order to address this problem, the City of San Marcos has created the WQPP, which has established rules based on the HCP, and will help protect the endangered species and their habitats within the San Marcos River and Edwards Aquifer. However, San Marcos is only one of the stakeholders participating in the various uses of water within the region, all stakeholders that fall within the Edwards Aquifer region are encouraged to apply for an Incidental Take Permit, that will allow a specified level of discharges from a property, but only with implementation of SCMs on those properties. The San Marcos WQPP is demonstrating the city's required participation by establishing professional standard goals for protecting the water quality in the area.

The San Marcos River is an important water body for the city because of its excellent water quality, which make it a recreational and aesthetic resource. The Upper San Marcos River has also been designated as critical habitat because of federally listed endangered species such as, the *Zizania texana* (Texas wild rice), Barton Springs salamander, fountain darter, Georgetown salamander, San Marcos salamander, and the San Marcos gambusia (TPWD 2019). Because of these species, the stakeholders of the San Marcos River and Edwards Aquifer, such as Texas State University, must apply for an Incidental Take Permit under the Endangered Species Act, and protect these species from anthropogenic activities, through implementation of SCMs. Although most of these species are small, and some nearly extinct, they may seem unimportant, but they have important ecological health implications for the river. For example, an indication of severe pollution or low water flows can be implied by the behavior or appearance of the fountain darters in the river.

The goals of the WQPP are based on achieving and maintaining excellent quality of the natural environment. The treatment standards in WQPP have been modified from the original TCEQ guidelines (WQPP 2016) and are expected to reduce NPS emissions entering the San Marcos River and Edwards Aquifer. A collaborative effort among stakeholders, who were guided by the Edwards Aquifer Recovery Implementation Program (EARIP), is needed to accomplish these goals because they all share the water within the Edwards Aquifer region. The EARIP prepared an HCP, which is a formal agreement that ensures associated parties within the Edwards Aquifer region (Edwards Aquifer Authority, San Antonio Water System, the City of San Marcos, the City of New Braunfels, and Texas State University) will lessen their impact on endangered species and their critical habitat in the receiving water bodies through the implementation of SCMs. So, the WQPP is an agreement that the City of San Marcos will follow the proposed regulations written in the HCP. In the plan, San Marcos focuses on their jurisdiction, the Upper San Marcos River and portions of the Edwards Aquifer.

Design, Maintenance Costs, and Construction Costs

Bioretention is a common low-impact development technique that manages pollutants in urban stormwater runoff. This technique will be applied to a filtration rain garden design, which is a practical choice for existing developments because the natural materials used can easily conform to the landscape (CSM). The ponding in the pool will detain the calculated water quality volume (step 5) for a period of up to 24-48 hours, then the EMC's of each stormwater pollutant will be treated as the water percolates through the filtration system underground.

A bioretention pond is constructed with a mixture of soil, gravel, rock, and drainpipes that will take pollutants through physical, chemical, and biological processes, which filter the water before it enters the underdrain or into the surrounding soil. The underdrain may or may not be needed. The TCEQ also recommends a 20 percent water quality volume increase to account for sediment accumulation and the required depth, which is applied in the stormwater technical manual in a equation that allows a bioretention pond to be roughly sized (CSM).

> A factor that can optimize the pond is accounting for the rainfall that lands on the pond, an adjusted EMC value is calculated to accommodate for precipitation that falls directly onto the pond (Erickson, Weiss, and Gulliver 2013).

The first flush effect can be handled with the offline BR pond design, which will be replacing the current SCM for the City Hall parking lot. Offline BR is a method that allows a certain water volume into the pond, then once the pond is at capacity, the overflow is sent through an adjacent channel (CSM). The overflow is usually diluted, and not a primary concern when considering the concentrations from the first flush effect. The diluted water is sent through the offline channel because of large and uncommon precipitation events. For example, 50, 100, and 500-year storm events are large and rare on an annual basis. So, 25, 10, 5, 2, and 1-year storm events more commonly yield rainfall quantities economically and architecturally manageable by stormwater infrastructure because there is less water volume flowing into the structures. If we did not have the offline system, the pond would still have an overflow mechanism, but most of the water from the storm event will enter the pond, causing turbidity, erosion, and the addition of sediments that clog the BR pond filters. This adaptive method has allowed for adjustments to cater to the first flush effect. The water volume necessary to cause runoff for this effect is between 5-10mm (.4 inches) (Kim et al. 2007) and 1 inch (the value given by the city). A value of 1 inch of rainfall more closely resembles that of a first flush from a 2-year storm event, and runoff from a 2-year storm event can be treated effectively with a BR pond. For a water quality volume to be accepted as a first flush, it will have to occur within the first 50 mins of the stormwater runoff.

The costs of SCMs can vary based on climatic conditions, drainage area, maintenance, construction machines and materials, land acquisition, excavation of the land, and unexpected costs. However, Brown and Schueler (1997b) have determined the ponds costs proportional to the total drainage area. So, in this case, a bioretention pond costs \$5.30 per cubic foot of volume that is related to the size of the catchment. Along with the construction of SCMs, annual maintenance costs must be factored into the budget. Depending on the type of SCM, the cost may vary according to the design. Although the EPA has not cited a reference, they estimated annual maintenance costs for a bioretention pond at 5-7 percent of its base construction costs (EPA 1999). Another cost factor is the disposal of the waste removed from the SCM's because of maintenance. In turn, a central location must be established, if not already, to dispose of this waste material that comes from a bioretention pond (EPA 1999). The literature also refers to costs of SCM construction to be affected by the economies of scale. Where the larger the construction project, the less money that is invested into overall costs. Lastly, the cost of land acquisition is an important factor because the prices for land range from region to region, according to the surrounding land-use types, and compared to a land parcels proximity to the urban centers of cities.

Stormwater Quality Parameters

The existing SCM at City Hall in San Marcos does not adequately reflect current stormwater practices that would allow achievement of WQPP treatment goals. So, to meet these goals, a rain garden design will replace the current SCM. However, the city's stormwater technical manual (CSM) provides only an equation to determine removal of TSS, TP, and FCOL, which limits standards to the scope of those three stormwater quality parameters and their relation to other constituents as they interact through a variety of chemical and biological processes. There are a few other categories listed in the city's WQPP that are not factored into the equations in the manual, but rather assumed because TSS represents a large percentage of the WQV. Although, the remaining parameters still need to be estimated because of their effects on the river's health is harmful to humans, aquatic organisms, and natural river processes. Therefore, EMCs for pollutants relative to the categories in the WQPP are included into the analysis of the SCM. An analysis of EMCs will optimize treatment by understanding the large range of pollutants found in the stormwater runoff and how they also critically affect the river's health. Water parameters besides

TSS, TP, and FCOL, qualify for monitoring because of their impacts. For example, Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP), Copper (Cu), Lead (Pb), Zinc (Zn), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). These parameter concentrations can be estimated for San Marcos with the data on Table 1.

A vehicle can pollute a parking lot in several ways. For example, antifreeze, hydrocarbons, oil and grease, rust, metals from brake pads or engine parts, rubber particles from tires, and nitrous oxide from a car's exhaust (EPA 2008). The United States Geological Survey (EPA 1999) has even found parking lot sealants to release polycyclic aromatic hydrocarbons into the stormwater runoff, which are toxic to fish and wildlife (EPA 2008). This problem has been acknowledged by the City of Austin; they have banned the use of parking lot sealants indefinitely (CSM).

Aquatic life is highly vulnerable in urban areas with high traffic volumes, so it may be necessary to select a pre-treatment option to address the severity of pollution from vehicle pollutants. For example, street sweeping, and oil grit separators can treat pollutants before they accumulate in runoff and enter the pond. Pre-mixed biotreatment soils are recommended, as the mixture is designed to handle pollutants associated with stormwater runoff (EPA 1999).

The WQPP defines some general categories for stormwater runoff, such as, TSS and Total Dissolved Solids (TDS), Dissolved Oxygen/Oxygen-demanding Substances, Nutrients, Pathogens, Petroleum Hydrocarbons, Metals, Synthetic Organic Compounds, and Physical Parameters, but in order to estimate specific pollutant concentrations, EMC data from the Fundamentals of Urban Runoff Management issue are utilized. For Austin, TX, EMC data is available for TSS, TN, TP, SRP, Cu, Pb, Zn, BOD, COD, which are measured in milligrams per liter (mg/l) and micrograms per liter (µg/l) for the metals (Shaver et al. 2007). Therefore, these EMC values can be used for analysis of determining target constituents in the runoff, and to understand how these parameters react with TSS, TP, and FCOL, since these parameters have been chosen as the target pollutants in the CSM. Understanding how the other pollutants react with TSS, TP, and FCOL will help distinguish the pollutants that are not being treated effectively, due to the limited range of pollutants calculated for treatment in the CSM. In this way, a geographical perspective is further introduced into the engineering design of the BR pond.

Literature on Methods

The literature on stormwater has various sources for EMC data, but no data exists for the City Hall parking lot. So, an estimation will have to be extrapolated using techniques from the United States Geological Survey (Driver 1990). Table 1 shows the estimated EMCs for Austin, TX, provided by an article by Shaver et al. (2007). The EMC data in this table reflects the stormwater runoff categories presented in the WQPP. The WQPP does not have EMC data, but has the modified TCEQ equations to determine TSS, TP, and FCOL loads. The TCEQ estimated TSS by using data from the City of Austin's historical water monitoring datasets (Barrett 2005). This is important because considering the proximity of Austin to San Marcos, the climatic conditions and vehicular activities may be similar, allowing for accurate estimations of pollutant loads and mean concentrations for the relevant water quality parameters. The USGS techniques extrapolate estimations for a few stormwater pollutants (DP, COD, SS, DS, TN, TKN, TP, CD, Cu, Pb, Zn, and RUN). These techniques do not cover all parameters of interest, but they allow estimates of these parameter loads and concentrations for a given drainage area, based on a large stormwater runoff dataset.

Figure 4. This is the primary parking lot outlet (left side), and the secondary outlet (right side), which channel the runoff from the parking lot.

Research Methods

Epistemology/Paradigm

This study uses a mix methods approach combining qualitative methods and quantitative methods. The quantitative methods are expressed through a positivist epistemology, in which the scientific method is used to derive measurements for sizing a BR pond, and for estimating stormwater pollutant loads and mean concentrations. A spatial science component will also be added to the quantitative methods approach, as GIS (Geographic Information Systems) will be used to help understand the topography of the drainage area. I will quantify the drainage area and impervious/pervious cover of the parking lot in Google Earth, in order to produce an estimate, based on the TSS equations in the CSM, of the potential WQV (cubic feet) that will enter the BR pond. This BR pond is assumed to replace the SCM currently in place at the City Hall parking lot. It will be designed with a offline channel feature, which will divert the first flush into the pond, which will filter the pollutants of the most concentrated runoff that occurs at the beginning of a storm event. The first flush will enter the pond before it enters the public drainage or infiltrates into the ground and into the aquifer. The offline channel handles the less polluted water from the bigger storm events (5, 10, 25, 50, 100, 500-year), or the WQV that is not calculated into the sizing of the pond. The pond will be sized for a volume that a 2-year storm event would yield. Without the offline design, the pond would ultimately require more maintenance, such as sediment removal, because any runoff from the parking lot would enter the pond not matter the magnitude of the storm (5, 10, 25, 50, 100, 500-year). The offline channel reduces erosion from turbidity caused by intense flows from large storm events and reduces sediments from entering the BR pond that would otherwise clog its filters.

A qualitative approach is expressed in this research through the analysis of images and observations from site-visits. I will use deductive reasoning and focus on optimizing treatment of urban stormwater runoff for one of the City Hall parking lots in San Marcos. Preliminary measurements for sizing the BR pond, analysis of pollutant loads and mean concentrations, and EMC values based on data from the City of Austin, TX, are compiled into a report for the City of San Marcos to use for project development purposes.

Methodology

Overview

The scientific method is used to answer the research questions. This methodology provides the opportunity to quantify data to produce a logical answer based on the available information. Since the study will involve the quantification of the drainage area and impervious/pervious cover, Google Earth is used to make the measurements that will be used to calculate WQV, surface area of the pond, and peak discharge. The scientific method provides a model where observations are explored, and questions can be tested. This model is used to answer eight research questions related to urban stormwater runoff and a BR pond.

Methods Used

The reason why the Rational Method is used is because an off-line bioretention design is being proposed. The off-line channel will divert the runoff past the pond once its at capacity. The pond's capacity is based on a 2-year storm event, which reflects a rainfall intensity of about 1 inch. An inch is enough to produce runoff from the parking lot and create a first flush effect. Therefore, the pond will be designed to treat the first flush effect. The Rational Method (Dunne and Leopold 1978), uses Google Earth measurements for the drainage area (A), the runoff coefficient (C) is based on table 3.1 in the CSM, and a time of concentration value is used, instead precipitation frequencies, for rainfall intensity (I). The CSM uses Depth-Duration-Frequency, Intensity-Duration-Frequency, and a Intensity-Duration-Frequency curve table to modify the variable I from the original Dunne and Leopold version.

$$Q_{peak} = CIA.$$

Where, Q_{peak} represents the peak discharge rate of the stormwater runoff in cubic feet per second (cfs). Runoff coefficient (C) is a variable to account for the type of landscape the water will be interacting with as it flows down to lower elevations (Table 3.1 in the CSM), the value is generally based on proportion of impervious to pervious cover. Peak rainfall intensity (I) is measured in inches per hour based on the time of concentration in the CSM (equation 3.8). Lastly, area (A) is the measured drainage area in acres.

The measurements that represent drainage area and impervious/pervious cover are calculated using Google Earth (2019). Also, ArcMap, version 10.6.1 (ESRI 2018), was used to observe the contour lines and elevation point shapefiles for San Marcos, in order to help delineate the drainage basin. Greg Schwarz provided the elevation point shapefile for which to study the topography of the catchment.

For understanding and estimating pollutant concentrations of the City Hall parking lot, EMC data from the City of Austin, TX provides a range of stormwater quality parameters, besides TSS, TP, and FCOL, and their calculated average concentrations for the region (Table 1). An EMC will give a concentration value for a single stormwater quality parameter. By understanding the EMCs for a range of stormwater quality parameters, a better representation of the total pollutant mass loads and mean concentrations in the stormwater runoff is achieved. This new representation will help optimize treatment for the BR pond by influencing it's WQV (cubic feet) and surface size (ft^2).

Table 2. Water Quality general categories included in CSM WQPP.

Categories	Parameters	Parameters	Parameters	Parameters
Solids (TSS, TDS)	Suspended Solids (SS), Dissolved Solids (DS)	Turbidity, Gross solids		
Nutrients	Nitrogen	Phosphorus species		

	(NH3, NO3, NO2, & TKN)	(TP)		
Metals	Copper, Lead, Zinc, Arsenic, Nickel	Cadmium, Silver, Mercury		
Bacteria	E. coli	Fecal coliform	Streptococci	Enterococci
Petroleum hydrocarbons	PAHs	Oil and grease	VOCs	SVOCs
Pesticides and herbicides	landscaping	household	industrial	
Trash and debris				
Temperature	Changes			
pH	Changes			

I used the equations in the CSM, beginning with the information in section 3.2.2. Preliminary values obtained from the CSM equations will allow the quantification of WQV and surface area, as it relates to TSS. This will provide opportunity for modifications to the methods used in the CSM, as EMC data compiled by Shaver et al. in Table 1 (2007), and the estimated loads and mean concentrations from using the USGS techniques may alter the WQV and surface area dimensions of the BR pond.

The City of San Marcos WQPP has listed general water quality categories, which will be used as guidelines to determine the relevant stormwater quality parameters chosen for analysis and to estimate their concentrations in the City Hall parking lot. The Fundamentals of Urban Runoff Management issue (Table 1) has region-specific EMC data that will be used to estimate the related pollutant concentrations, as they are defined in the WQPP.

A few EPA documents, the TCEQ RG-348 (Barrett 2005), San Marcos Stormwater Technical manual (CSM), and the WQPP are used to determine design, cost, limitations, and benefits of the BR pond.

Table 3. Region-specific Event Mean Concentration (EMC) values for Austin, TX.

Location	Austin, TX
Mean Annual Rainfall (in)	Med (32)
Pollutants	
TSS (mg/l)	190
TN (mg/l)	2.35
TP (mg/l)	0.32
SRP (mg/l)	0.24
Cu (µg/l)	16
Pb (µg/l)	38
Zn (µg/l)	190
BOD (µg/l)	14
COD (µg/l)	98
# Sample Events	78

(Source: Shaver 2007)

Figure 5. Roof drainage pipe on City Hall building (side closest to parking lot).

Results

Employing the Rational Method, the following variables and values were used. Runoff coefficient (C), rainfall intensity (I), and area (A) are equal to 0.73 (2-year storm event based on Table 3.1 in the CSM), 10.11 inch, 0.91 acres, respectively. The answer for peak runoff discharge is estimated at 7 cfs (cubic feet per second). The runoff coefficient is found by using the Water in Environmental Planning literature, or in table 3.1 in the CSM. Rainfall intensity is found by using the inches per hour value (NOAA 2019a) equal to the time of concentration of water from the parking lot. The time of concentration was equal to 4.7 mins. However, for any drainage area, the minimum time allotted is 5 mins for the equation in the CSM. Therefore, the value was rounded to 5 mins. Google Earth was used to determine area (A), which was 39, 518.09 ft^2, but rounded to 39,500 ft^2, then converted into acres (0.91). Google Earth has a measurement feature that was used to delineate the catchment via satellite imagery. The quality of the satellite imagery suggests better resolution, therefore yielding a more accurate measurement of the drainage area and the impervious/pervious cover, which is provided in ft^2 on the software.

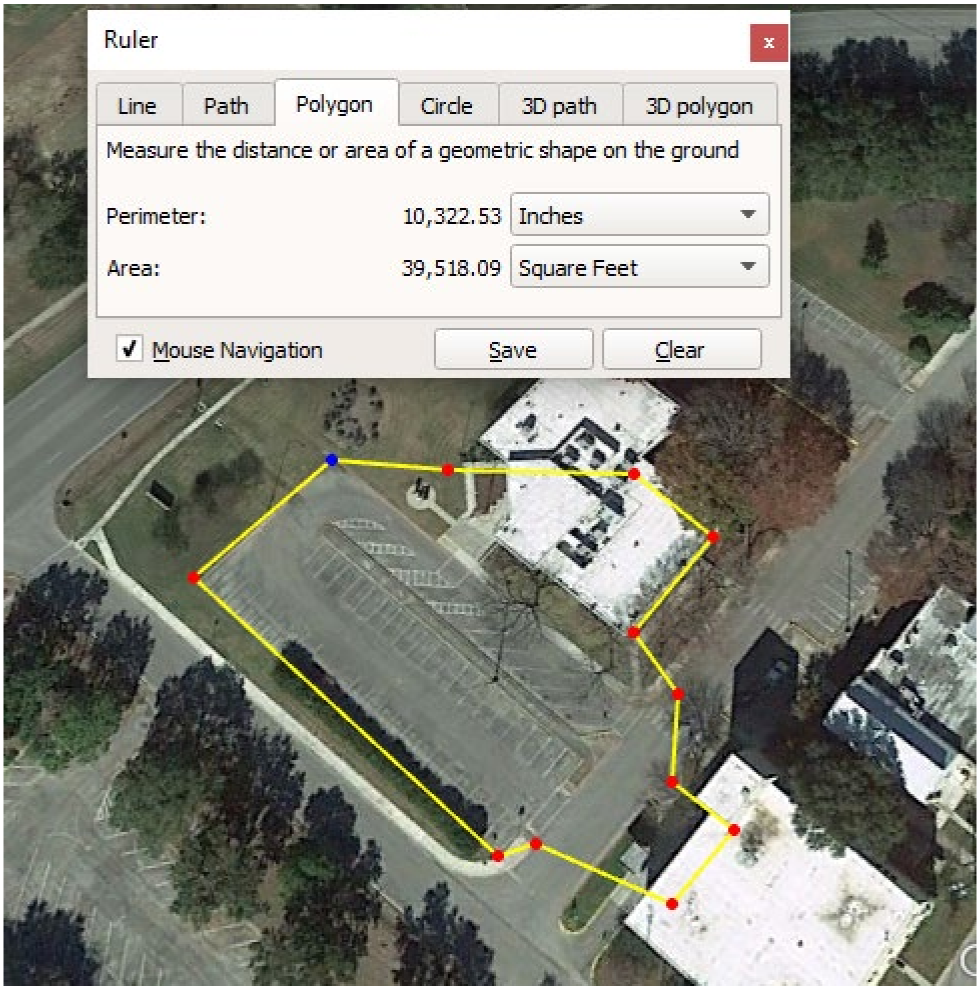

Figure 6. Satellite image of the drainage area delineated with Google Earth measurement tool. (Source: Google Earth 2019)

In the CSM, beginning in section 3.2.2.1, the equations provided will help estimate the required TSS removal, SCM and TSS removal efficiency, TSS load removed by an SCM, fraction of annual runoff to be treated, expected water quality volume for TSS treatment, and surface area for the bioretention pond.

The location of the project site is within the San Marcos River Corridor boundaries. The criteria for this location can be seen in a table in section 3.2.2 of the stormwater manual. It shows the minimum water quality volume required for the site (1.60 inches) and the desired treatment level (89 percent). Step 1 will determine the required TSS removal for the parking lot.

$$L_M = T \times 34.0 \times A_T \times P \qquad (1)$$

After calculation, the determined TSS removal is 799 (Pounds). Where, L_M is the required TSS removal in pounds, T is the water quality treatment level (89 percent or 0.89), A_T is the impervious cover to be treated (34,700 ft^2 or 0.80 acre), and P is the average annual precipitation (33 inch). Also, the constant 34.0 is included in the equation to help estimate the required TSS removal.

In Step 2, an appropriate stormwater control measure will need to be selected. By looking at table 3.9 of the stormwater manual, a variety of SCM with their determined percent of TSS reduction. In this case, the SCM best fitted to meet WQV treatment level goals of the WQPP would be a bioretention (aka biofiltration) facility. This SCM is deemed appropriate due to the percent TSS reduction on table 3.9 and the designs capability of adapting to existing structures. A bioretention facility is expected to have an 89 percent of TSS reduction rate.

For Step 3, assuming the 89 percent of TSS reduction rate from the SCM chosen in Step 2, the TSS load removed by this SCM is determined at 815 pounds.

$$L_R = (\text{SCM efficiency}) \times P \times (A_I \times 34.6 + A_P \times 0.54) \qquad (2)$$

Where, L_R is load removed by the chosen SCM from Step 2, the SCM efficiency is 89 percent (0.89) based on Step 2 and is multiplied by the average annual precipitation (P) of San Marcos (33 inch). Then, the equation factors in impervious (A_I = 34,700 ft^2 or 0.80 acre) and pervious (A_P = 4,809 ft^2 or 0.11 acre) tributary areas, multiplied by two constants (34.6 and 0.54), which help estimate TSS load removed by an SCM.

So, with this information, the equation in Step 4 is utilized to calculate the fraction of annual rainfall expected to be treated by the SCM, which is calculated at 0.98.

$$F = L_M / \sum L_R \qquad (3)$$

Where, F is the fraction of the annual rainfall treated by the SCM, ΣL_R (815 Pounds) is the load removed for each SCM from Step 3 calculation in pounds, and L_M (799 pounds) is the required load reduction from step 1 calculation in pounds.

With the F value obtained in Step 4, water quality volume for TSS treatment can be calculated in step 5, by first using table 3.10 to convert F = 0.98 to equal a rainfall depth of 3.33 (inches). The water quality volume is the product of the rainfall depth from table 3.10 (3.33 in.), a runoff coefficient of 0.75, and an area of 0.91 acres.

$$\text{Runoff Coefficient} = 1.72(IC)^3 - 1.97(IC)^2 + 1.23(IC) + 0.02 \qquad (4)$$

Where: IC = fraction of impervious cover

This is calculated to be 8,250 cubic feet of water quality volume. The minimum WQV was also calculated at 4,070 cubic feet. Since, the determined WQV of 8,250 cubic feet is larger than the minimum value needed for the pond, it will be used to size the pond.

$$\text{WQV} = \text{Rainfall depth} \times \text{Runoff Coefficient} \times \text{Area} \qquad (5)$$

In section 3.2.2.3.4, an equation to roughly size the bioretention area is provided. In this equation the surface area is determine for the pond. The determined surface area for the pond is 4,830 ft^2 based on the equation below.

Bioretention Area (surface area) = 1.2 x (WQV in cubic feet) / 2.05 (6)

Based upon the equations in steps 1, 3, 4, and 5, the BR pond would need to have a water quality volume of 8,250 cubic feet. This would result in a pond with a surface area of 4,830 ft^2, because the required depth (ft), porosity (%), and volume per ft^2 have been pre-determined in a table in section 3.2.2.3.4 of the CSM, that follow the construction criteria in the San Marcos Land Development Code. The volume per ft^2 is equal to 2.05, based on the depth and porosity of the ponding, media, and underdrain components. A constant of 1.2 is multiplied by the estimated water quality volume (8,250 cubic feet), then divided by 2.05 (the volume per ft^2). A factor of 1.2, represents the additional 20 percent added to the surface area to account for sediment accumulation and the required depth. From these calculations and using the cost of $5.30 cubic foot capacity, the construction cost of the pond would be approximately $43,700 (Brown and Schuler 1999b).

EMC values in Table 2. by Shaver (2007) shows data for Austin, TX starting with TSS in mg/l, to be estimated at 190, TN 2.35 mg/l, TP 0.35 mg/l, SRP 0.24 mg/l, Cu 16 µg/l, Pb 38 µg/l, Zn 190 µg/l, BOD 14 µg/l, and COD 98 µg/l. These concentrations are supported by a frequency of 78 samples.

Analysis and Discussion

The EMC data can be estimated for each stormwater quality parameter in Table 1 that is related to the stormwater quality categories in the WQPP, so that treatment can be further optimize because, "A point of diminishing returns can be envisaged for BMPs that are sized on the basis of flow rate, or total volume treated. Each subsequent volume fraction provides less opportunity for removal" (Kim et al. 2007). So, additional estimations of the constituents in the parking lot runoff can be made to improve its design and ultimately reduce the amount of maintenance visits related to sediment clogging and erosion.

The constants found in the CSM for the equations in steps 1,3, and for the BR surface area are based off an analysis made by the TCEQ that included water monitoring data from the City of Austin, TX. The TCEQ states in the RG-348 document, that the average TSS concentrations for paved surface areas in Austin have been determined at 170 mg/l and 80 mg/l for undeveloped surfaces. These values have been factored in as constants into the equations in steps 1, 3, and for surface area in the CSM.

The mean number of days with precipitation greater than or equal to 1 inch between the years 1981-2010 is 10.7 (NOAA 2019b). This is based on monthly precipitation averages greater than or equal to 1 inch. An inch is the amount to rainfall needed to produce runoff and reflects 2-year storm event conditions in which the capacity of the BR pond will be designed to handle. So, the mean number of days with precipitation equal to 1 inch or greater (10.7) can be divided by the number of days in a year, the dividend of this procedure determines 34 antecedent dry days (ADD). ADD will represent the number of dry days between each rainfall event that produces runoff from the City Hall parking lot.

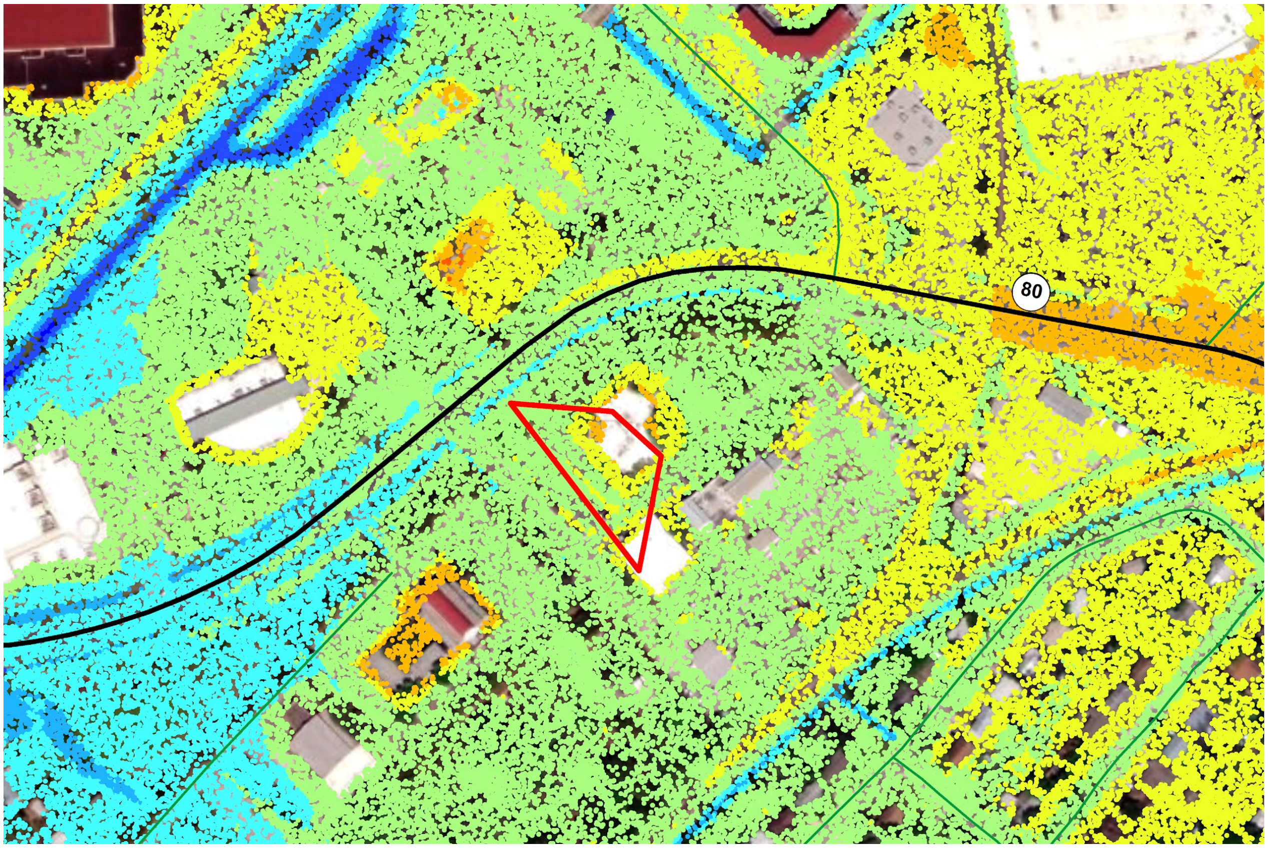

Figure 7. LiDAR imagery showing elevation points. The green and yellow points within the red outline reveal the relatively flat topography of the study site.

The drainage area was difficult to delineate with software because of its flat topography. In turn, field observations of the site were conducted to better understand the hydrology of the catchment. Using software, such as ArcMap, the catchment was analyzed through the addition of shapefiles. Using the layers provided in the shapefiles, contours and elevation points revealed a relatively flat topography. The contour layer shows large spacing between each line, meaning the slope is not steep in this area. The elevation points layer has LiDAR data associated with the raster image. Each point has associated elevation data assigned to it and is organized by color depending on the different measurements. Similar elevations are group together and put into different classes. However, the LiDAR image still did not reveal major variations in the topography. Therefore, the

LiDAR data was reclassified into groups with a smaller range of values, thus creating more color groups that show the fine gradients that exist in this flat catchment.

Field observations, such as, pictures were taken to show the site and to help visualize how the hydrology may behave and how to show how many cars can typically be seen at this parking lot. This allowed for accurate drainage area delineation on the Google Earth software.

The time of concentration adds different analysis to the original Rational Method variable I by calculating 3 types of flow: sheet flow, shallow concentrated flow, and channel flow. The time of concentration represents the process of rainfall as it accumulates on a surface feature during a storm event. The rain begins to accumulate and concentrate on the surface, then flows down the path of least resistance. Values were obtained for the 3 types of flows, then plugged into an equation in the CSM (Equation 3.8), which is based off the San Marcos Region intensity-duration-frequency curve coefficients (table 3.5 in the CSM). Equation 3.8 will ultimately yield the time of concentration value use for variable I in this modified version of the Rational Method.

Because of the variable nature of EMC values, data with many samples is necessary for accurate estimations (Table 3), especially since no site-specific data exist for San Marcos. The EMC values determined for the City of Austin is based on 78 water quality samples. Data with too few sample sizes do not provide enough information to determine spatial patterns of the stormwater pollutants.

The literature on EMC values describe how they vary based on location, ADD, and rainfall intensity. ADD measures the number of days between each rainfall event. The location affects values because of varying climatic conditions, especially between arid and humid regions. The volume of rainfall does not affect the mass of pollutant loads, but rather their concentration as the dilution effect is introduced. The dilution effect occurs because large amounts of precipitation spread pollutants further apart from each other because of the increase in runoff volume. Therefore, the concentration of pollutants is lessened by the increase in water volume created by intense rainfall events.

Referencing to the specific research questions the following findings were determined:

Stormwater Runoff Pollutants

1. What are the most common pollutants in urban stormwater runoff that would be expected to be produced on the City Hall parking lot? The most common pollutants that would be expected to be produced on the City Hall parking lot are: TSS, TN, TP, SRP, Cu, Pb, Zn, BOD, and COD based on table 1. Table 1 represents stormwater quality parameters related to those categories listed in the WQPP.
2. Why are event mean concentrations (EMCs) better than calculating only TSS for WQV and sizing the SCM? EMCs are important to include because they will contribute to the WQV determined and may increase the surface area of the BR pond.
3. How will using EMC data from Austin, TX, differ from a site-specific study to obtain EMCs from the City Hall parking lot in San Marcos, TX? Using stormwater monitoring data from Austin, TX is limiting because there are a few factors that will affect EMC values. EMC values vary from region to region, ADD, rainfall intensity, and storm duration. Having data from Austin should yield values like what would be expected with a site-specific study in San Marcos. Austin is roughly 30 miles from San Marcos, so climatic conditions are similar enough to make assumptions based on the EMC data, and load and mean concentrations.
4. Why is having other stormwater quality parameters besides TSS important? It's important to have other stormwater quality parameters because creating treatment criteria based on only TSS will give only a general representation of the pollutant loads in the stormwater. If the pond is to be optimized, additional related stormwater quality

parameters and their concentrations should be determined, as they affect the WQV needed to treat the pollutants, and the surface area size of the BR pond.

Design and Sizing of the Bioretention Pond

5. What is the volume of pollutants created by the parking lot per unit of time? The volume of pollutants created by the parking lot per unit of time can be found using techniques used by the USGS. The techniques based the pollutants on a pounds per year scale.
6. What are the design parameters for an effective bioretention (BR) pond to be installed at the City Hall parking lot? The bioretention pond should use non-leachable organic matter and limestone in its design. Phosphorus is a limiting nutrient in the San Marcos River, in part, because it's a freshwater system (Groeger et al 1997). This means that the river is sensitive and will react to additional amounts of phosphorus entering the system. Algae blooms are possible with excess nutrients available in the water, and in turn, block sunlight and deplete oxygen levels for aquatic life. Limestone is effective at removing TP.
7. How will the EMCs, estimated loads and mean concentrations, fit into the design of the pond? The EMCs, loads, and mean concentrations will modify the WQV needed for treatment and will in effect increase the surface area for the pond.

Maintenance and Costs for the Bioretention Pond

8. What are the maintenance costs for the pond? Annual maintenance costs for a BR pond is estimated in an EPA document (1999) to be 5-7 percent of its base construction cost or \$2200 to \$3100/year.

Conclusions

San Marcos has prepared the WQPP as part of the city's larger Stormwater Master Plan (2018) objective. Stakeholders within the Edwards Aquifer region are bound by the Endangered Species Act to implement SCMs in developed and developing areas to mitigate the effects of runoff from impervious surfaces. The current SCM in place at one of the City Hall parking lots, has been designated for improvements by the city senior engineer, Gregory J. Schwarz, to meet the goals of the WQPP. Therefore, a report of preliminary findings for the dimensions needed to construct a bioretention (BR) pond has been produced to address this problem for the City of San Marcos. The BR pond is considered a retrofit solution because it will replace the existing SCM. The retrofit SCM will treat the polluted stormwater as it runs off the parking lot, and inevitably into the Upper San Marcos River. The contaminant loads, and concentrations were calculated for additional estimations of water parameters related to stormwater runoff other than TSS, TP, and FCOL.

The CSM has already provided the means of designing a BR pond, but the equations in the manual do not cater to the wide range of stormwater quality parameters (only TSS, TP and FCOL), and they also assume a constant concentration of TSS in the runoff, which does not reflect the first flush effect. In order to optimize treatment, an off-line design is being introduced to handle for the first flush effect. This will ensure that the most concentrated runoff, the initial 20-50 mins a storm event begins producing runoff, is treated before entering the public drainage system. So, although an EMC for TSS is not accounted for in the CSM equations, the high concentrations of TSS assumed to be in the first flush effect, will be treated effectively because the off-line channel will be diverting excess water away from the pond, allowing the WQV to infiltrate through the pond's filtration system.

Google Earth was used to measure the drainage area and impervious/pervious cover of the project site. ArcMap version 10.6.1, was used to export a map displaying the topography contours and LiDAR elevation points for the catchment.

The first flush effect is catered to by adding the offline technique to the BR design, but additional estimations of the pollutant loads and mean concentrations for the site are useful and may further optimized the treatment criteria by modifying the WQV and surface areas of the pond.

Benefits of the Study/Summary

This project should improve the existing SCM at City Hall by treating the TSS that runs off the parking lot and explaining how a range of pollutants in the stormwater runoff affect the health of the surrounding environment, like the Upper San Marcos River. Having multiple SCMs will have an impact on a larger regional scale and will help meet obligations of the HCP. This project will assist the City of San Marcos by completing a report on the preliminary findings for sizing a BR pond that will replace the existing SCM at City Hall and include an analysis on the stormwater pollutants running off the parking lot. This research could prove to be beneficial to stormwater managers and engineers in a similar project development scenario in the South-Central Texas area.

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Appendix: Abbreviations and Acronyms used in this report

ADD - Antecedent Dry Days

BMP - Best Management Practice

BOD - Biochemical oxygen demand

BR - Bioretention pond

Cd - Cadmium

COD - Chemical oxygen demand

CSM - City of San Marcos Stormwater Technical Manual

Cu - Copper

DP - Dissolved Phosphorus

DS - Dissolved Solids

EARIP - Edwards Aquifer Recovery Implementation Program

EMC - Event Mean Concentration

FCOL - Fecal Coliform

GIS - Geographic Information Systems

HCP - Habitat Conservation Plan

LiDAR - Light Detection and Ranging

NH_3-3 - Ammonium Hydroxide

NO_2-N - Nitrogen dioxide

NO_3-N - Nitrate

NPS - Non-Point Source

Pb - Lead

SCM - Stormwater Control Measure

SRP - Soluble Reactive Phosphorus

SS - Suspended Solids

TCEQ - Texas Commission on Environmental Quality

TDS - Total Dissolved Solids

TKN - Total Kjeldahl Nitrogen

TN - Total Nitrogen

TP - Total Phosphorus

TSS - Total Suspended Solids

USGS - United States Geological Survey

WQPP - Water Quality Protection Plan (San Marcos)

WQV - Water Quality Volume

Zn - Zinc

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SUMMARY OF QUALIFICATIONS

- Knowledge of Water Resources
- Knowledge of nonpoint source pollution management
- Field Experience
- Positive attitude and good personal discipline
- Good team player

EDUCATION

Master of Applied Geography, Resource & Environment Studies – May 2019

Texas State University, San Marcos, TX

Preliminary Findings for Sizing a Bioretention Pond and An Analysis on Urban Stormwater Runoff: San Marcos, TX

Bachelor of Science, Geography-Water Resources – May 2017

Texas State University, San Marcos, TX

Minor in Geology – May 2017

Texas State University, San Marcos TX

Relevant Coursework: River Basin Management, Environmental Management, Managing Urbanization

EXPERIENCE

Field-Methods: *08/18 – 12/18* - Texas State University, San Marcos, TX

- Conducted 7 field exercises related to Geography
- Gathered, analyzed, and interpreted data
- Worked in groups for each exercise

SCA Alaska Corps Team: *05/18 – 08/18* - Glacier Bay National Park, AK

- Worked with an SCA Corps team and a partner agency, the National Park Service. A 12-week work season, the first half we worked in Dry Bay doing trail widening using chainsaws and brush saws. The second half we worked delineating the park boundary in Gustavus, using brush saws and post hole diggers.

Red Lobster: *06/15 – 02/18* – San Marcos, TX

- Worked in a team environment
- Maintained, organized, and cleaned machines
- High volume restaurant