Urban Water Management Alternatives

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INTRODUCTION

The predominant role of cities in the global economy with the consequent over concentration of national and regional activities increases the pace of urbanization. According to Kolankiewicz and Beck "over a 20-year period, the 100 largest urbanized areas…sprawled out over an additional 14,545 square miles"[1]. As a consequence of the pace of urbanization, in other words the expansion of the urban footprint, we face environmental challenges such as increased stormwater runoffs and pollution.

In this essay, I will briefly illustrate the relationship between land use and its implications both to the quantity and quality of stormwater runoff. This paper will focus on commercial land use since according to the Storm Water Center[2] this is the land use with the greatest percentage of impervious cover (table 1) and "impervious surfaces are responsible for more stormwater runoff than any other type of land use"[3]. I will conclude by briefly illustrating the relationship between local urban policy and hydrology.

Table 1

Impervious Cover (%) for Various Land Uses	
Low Density Residential	10
Medium Density Residential	30
High Density Residential	40
Multifamily	60
Industrial	75
Roadway	80
Commercial	**85**

The objective of this paper is to evaluate the efficiency of permeable pavements in urban parking areas to reduce stormwater runoff and annual pollutant loads. I will assess three different paving materials on parking lots (porous concrete, porous asphalt and interlocking pavers) on five different commercial sites. The four commercial sites will be HEB locations in the Austin area.

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1 http://www.sprawlcity.org/studyUSA/USAsprawlz.pdf

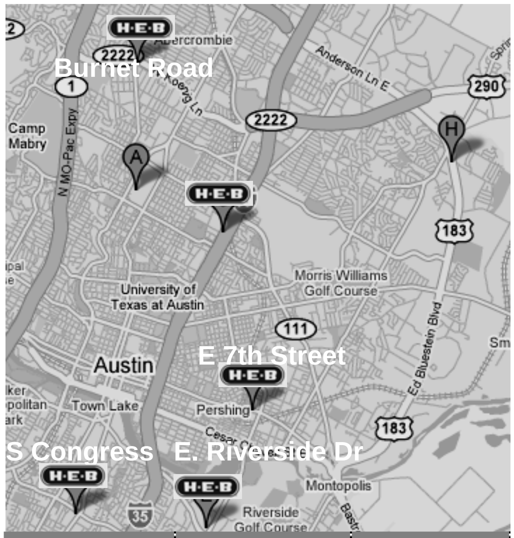
[2] http://www.stormwatercenter.net/monitoring%20and%20assessment/simple%20meth/simple%20imp%20table%205.htm

[3] EPA, 2000: Low Impact Development (LID) - A Literature Review. EPA-841-B-00-005, Office of Water, Washington, D.C.

STUDY SITE

1.1 *Assumptions:*

- The HEB parking lots are assumed to be medium volume parking lots.
- Parking lot slope is 1%. It slopes away from commercial buildings and towards the street.
- Parking lots are not fitted with pipe, gutters, etc. for stormwater conveyance.
- Green areas are considered negligible because of their higher elevation from parking lot surface.
- Loading dock areas in these sites were not considered covered with porous pavements because of their different load bearing requirements.
- Stormwater from loading dock areas was assumed not to flow towards parking lot pervious surface.
- Stormwater from the building roof is assumed to flow to the parking lot.



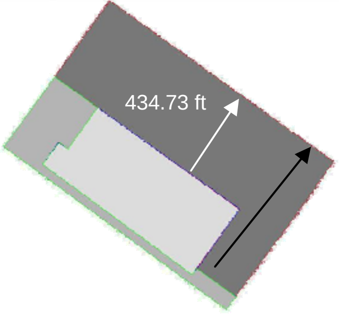
	Impervious buildings	Pervious parking lot	Total Area (ft2)
S Congress	303,390.77	632,397.80	1,075,468.43
Burnet Rd	429,662.55	621,467.95	1,482,349.34
E. Riverside Dr	243,247.18	658,754.68	1,034,427.11
E 7th St	409,184.25	667,667.02	1,076,851.27

1.2 *Methodology:*

Each site was outlined in AutoCAD using an aerial photograph. The sites were observed at an elevation of 385ft above the ground. Three sections were delineated in each site: parking lot, buildings' footprint with peripheral sidewalks and loading dock areas. Areas were classified through visual recognizance of the aerial photograph. For example, the presence of trailers evidenced loading dock areas while an area with cars only indicated a parking lot. Then using AutoCAD in each site, the area of each section was calculated, the representative length of flow was visually identified and measured. The criterion for choosing a representative length of flow also results in conservative travel time estimates given that alternative larger flow lengths are disregarded. In the case of the HEB located in South Congress the chosen length of flow is 434.73ft long.

S Congress

S Congress



□ Building's foot print with peripheral sidewalks

▨ Loading dock areas

■ Parking Lot

QUANTITY

1.3 Rational Method

The peak flow was calculated using the Rational Method[4]. This method was chosen because it is the "most widely used method for urban drainage design"[5], because of its wide applications for small drainage areas as well as the fact that it requires limited data. This method is particularly appropriate due to the small size[6] of HEB lots in Austin. The average area of the case study sites is approximately 1,167,274ft^2 (0.041870193 mi^2) which complies with the requirement that "the rational method should not be used on areas larger than about 1 square mile".

A 2year storm was used to estimate the peak discharge. The following parameters where estimated in order to use the Rational Method:

- Runoff Coefficient
- Time of Concentration
- Rainfall Intensity

1.3.1 Runoff Coefficient

As part of the Rational Method, the runoff coefficient will be computed. The Runoff Coefficient is the "ratio of surface runoff to rainfall".[7] In calculating the runoff coefficient only two distinctions where made regarding parking lot pavement surface: porous pavement and interlocking pavers. "Porous pavement is a permeable asphalt or concrete surface that allows stormwater to quickly infiltrate to an underlying stone reservoir".[8] The category porous pavement, which combines porous asphalt and porous concrete, has the runoff coefficient range: 0.18 to 0.29[9]. In order to get conservative estimates, 0.18 was used as the runoff coefficient value. The runoff coefficient for interlocking pavers ranges from .30 to .50. Again the lower coefficient was used in the estimates: .30.

In the proposed scenario I assumed that impervious areas are disconnected. The composite value for the runoff coefficient incorporates the values of impervious areas from the roof of the commercial buildings and peripheral sidewalks along the buildings. It also includes the values from pervious areas namely the proposed porous surfaces of the parking lot areas. Green areas will be assumed negligible because of their higher elevation with respect to the parking surface and the small areas covered in sites. Similarly, the impervious area of sidewalks along the perimeter of the lot will not be accounted for due to their higher elevation in relation to the parking lot's surface.

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[4]" http://www.ems-i.com/wmshelp/Hydrologic_Models/Models/Rational/Equation/Basic_Equation.htm

[5] http://www.ems-i.com/wmshelp/Hydrologic_Models/Models/Rational/Equation/Basic_Equation.htm

[6] http://www.ems.com/wmshelp/Hydrologic_Models/Models/Rational/Equation/Important_Limitations.htm

[7] Ferguson, B. 2005. *Porous Pavements.* CRC Press

[8] Pennsylvania Stormwater Management Manual

[9] Ferguson, B. 2005. *Porous Pavements.* CRC Press.

The equation used to compute the weighted runoff coefficient for each site is:

$$C_{DEV} = IC_1 + (1 - I)C_2$$

	Developed Conditions	
	Interlocking Pavers	Porous Pavements
	CDEV	CDEV
S Congress	0.475	0.394
Burnet Rd	0.521	0.450
E. Riverside Dr	0.446	0.358
E 7th St	0.505	0.431

The weighted runoff was calculated by taking both the impervious and pervious areas as percentages of the drainage area, in other words the lot size in these case studies. Two weighted runoff coefficients were estimated for each lot. Each estimate accounted for different pavements materials in the parking lot area: porous pavement or interlocking pavers.

1.3.2 Time of Concentration

Time of concentration is the time “when the entire watershed is contributing to the flow at the outlet”[10]. The time of concentration was estimated for each case study considering a 2 year storm and six different storm durations. Next these values were used to estimate the intensity parameter (i) employed in the Rational Method.

In this section I used the Kinematic wave formula. “This method has been adopted by the FHWA [Federal Highway Administration part of the U.S. Department of Transportation] for general use”. The equation used was:

$$t_c = \frac{0.93L^{0.6}N^{0.6}}{i^{0.4}S^{03}}$$

There is a linear relationship between length of flow and time of concentration. In other words, the results show that as the length of flow increases the time of concentration increases as well. In a 15 min duration storm as the flow length increases by 1 foot the time of concentration increases on average by 5.06min. In a 30 min storm the same increase in length flow results on average in a 5.92min increase in time of concentration.

It is relevant to note that S Congress with 10,929.85ft^2 more parking lot area than Burnet Rd has a lower time of concentration. The difference between the two sites ranges from 1min to 2.39min from a 15min to 6 hour storm duration respectively.

2yr Storm Duration		Length of flow path L (ft)	Time of Concentration Tc (min)
15 min	S Congress	434.73	10.01
	Burnet Rd	509.67	11.01
	E. Riverside Dr	632.33	12.53
	E 7th St	695.10	13.26
30 min	S Congress	434.73	11.72
	Burnet Rd	509.67	12.90
	E. Riverside Dr	632.33	14.68
	E 7th St	695.10	15.54
1 hr	S Congress	434.73	13.91
	Burnet Rd	509.67	15.31
	E. Riverside Dr	632.33	17.42
	E 7th St	695.10	18.44
2 hr	S Congress	434.73	16.76
	Burnet Rd	509.67	18.44
	E. Riverside Dr	632.33	20.99
	E 7th St	695.10	22.21
3 hr	S Congress	434.73	19.16
	Burnet Rd	509.67	21.08
	E. Riverside Dr	632.33	23.99
	E 7th St	695.10	25.39
6hr	S Congress	434.73	23.90
	Burnet Rd	509.67	26.29
	E. Riverside Dr	632.33	29.92
	E 7th St	695.10	31.67

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[10] .Maidment, R. D. 1998. *Applied Hydrology*,.McGraw Hill.

1.3.3 Rainfall Intensity

The rainfall intensity value was calculated using the time of concentration.

2yr Storm Duration		Rainfall Intensity (in/h)
15 min	S Congress	4.84
	Burnet Rd	4.65
	E. Riverside Dr	4.37
	E 7th St	4.24
	E. 41st St	5.02
30 min	S Congress	4.52
	Burnet Rd	4.31
	E. 41st St	4.69
	E. Riverside Dr	3.98
	E 7th St	3.87
1 hr	S Congress	4.12
	Burnet Rd	3.89
	E. 41st St	4.33
	E. Riverside Dr	3.71
	E 7th St	3.63
2 hr	S Congress	3.77
	Burnet Rd	3.63
	E. 41st St	3.95
	E. Riverside Dr	3.41
	E 7th St	3.30
3 hr	S Congress	3.56
	Burnet Rd	3.40
	E. 41st St	3.69
	E. Riverside Dr	3.15
	E 7th St	3.03
6hr	S Congress	3.16
	Burnet Rd	2.96
	E. 41st St	3.27
	E. Riverside Dr	2.65
	E 7th St	2.59

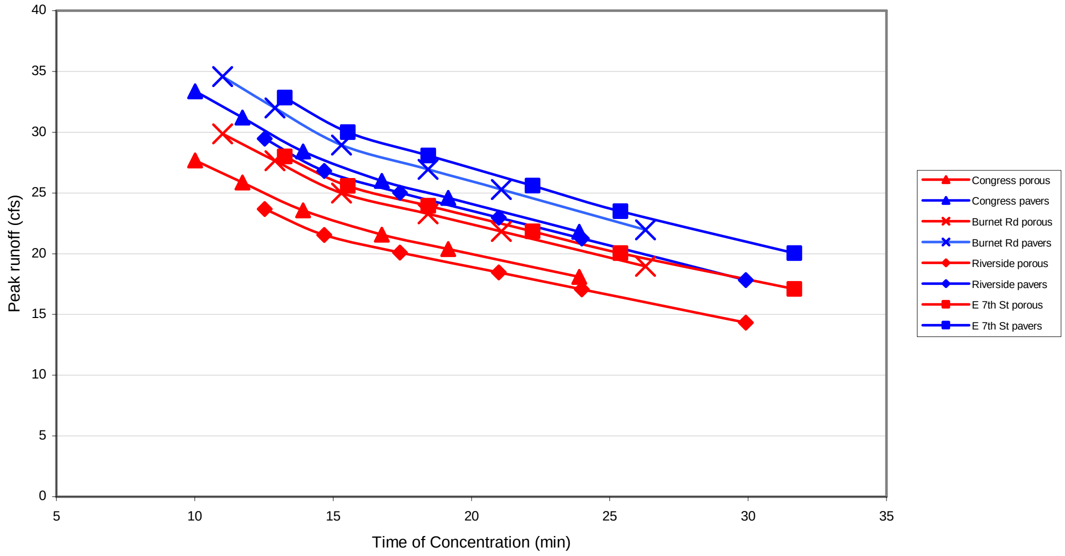
1.3.4 Peak Flow

In calculating peak discharge the following formula was used:

$$Qp = CiA$$

	Peak Runoff Porous Pavement			
2yr rStorm Duration	S Congress (cfs)	Burnet Rd (cfs)	E. Riverside Dr (cfs)	E 7th St (cfs)
0.25	27.67	29.87	23.68	27.99
0.5	25.87	27.64	21.54	25.58
1	23.56	24.99	20.10	23.94
2	21.56	23.27	18.46	21.82
3	20.39	21.83	17.07	20.03
6	18.08	18.97	14.33	17.09

	Peak Runoff Interlocking Pavers			
2yr Storm Duration	S Congress (cfs)	Burnet Rd (cfs)	E. Riverside Dr (cfs)	E 7th St (cfs)
0.25	33.37	34.58	29.48	32.83
0.5	31.19	32.00	26.82	30.00
1	28.41	28.93	25.02	28.08
2	26.00	26.94	22.97	25.59
3	24.59	25.27	21.25	23.49
6	21.80	21.97	17.84	20.05



The results show that as time of concentration increases peak discharge decrease. The graph clearly shows that all sites with porous pavement parking lots (red lines) have a lower peak discharge than the same site areas using interlocking pavers (blue lines). It can also be observed that all sites with porous pavement in parking lot surface, regardless of their size, have lower peak flows than smaller sites using interlocking pavers. For example the HEB on E 7th St (the largest site both in terms of overall area, parking lot area and length of flow) using porous pavement has a lower peak flow than any other smaller site using interlocking pavers.

2 QUALITY

2.1 ANNUAL POLLUTANT LOAD

The annual pollutant load was estimated for each site using the Simple Method. Five pollutant loads were estimated: zinc (Zn), copper (Cu), total suspended solids (TSS), total nitrate (TN) and total potassium (TP).

Simple Method

L = 0.226 * R * C *

L= Annual load (lbs)
C= Pollutant Concentration
A= Area (acres)
R= Annual Runoff (inches)

R = P * Pj * Rv

P= Annual Rainfall (in)
Pj= Fraction of year rainfall events that produce runoff 0.9
Rv= Runoff Coefficient

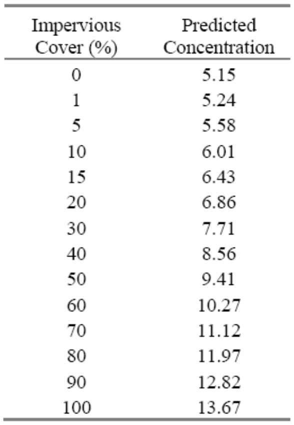
Rv=0.05+0.9I

Ia= Fraction of impervious cover

	Annual load (L)				
	TN (lbs)	TP (lbs)	TSS (lbs)	Zn (lbs)	Cu (lbs)
S Congress	51.00	9.66	4404.03	1.39	0.23
Burnet Rd	63.83	12.08	5511.53	2.13	0.31
E. Riverside Dr	38.27	7.25	3304.65	0.89	0.16
E 7th St	70.70	13.38	6104.58	2.21	0.33

The annual load pollutant concentration of each case study was calculated according to the percentage of impervious cover at each site. In this calculation data from the City of Austin's small watershed pollutant concentration [11], predicted according to the site's percentage of impervious cover, was used. In this calculation the percentage of impervious cover of each site was interpolated between the corresponding lower and upper values of the City of Austin's small watershed pollutant concentration tables (see example Table 4.7).

Table 4.7: Predicted copper (Cu) concentrations (ug/l).



Impervious Cover (%)	Predicted Concentration
0	5.15
1	5.24
5	5.58
10	6.01
15	6.43
20	6.86
30	7.71
40	8.56
50	9.41
60	10.27
70	11.12
80	11.97
90	12.82
100	13.67

The relevance of TSS, TN and TP annual load estimates for each site is uncertain. The following limitations where observed: either the pollutant had no relationship with the percentage of impervious cover (TSS) or the range of impervious cover was broad enough as to not be site-specific (TN and TP). First, "no significant relationship was found for total suspended sediment based on impervious cover or development condition". For TSS the average recommended concentration: 153.7mg/l was used regardless of the percentage of imperviousness of each of the sites. Second, the tables show two values of TP and TN concentrations for two ranges of impervious cover. The value of TP concentration for a 0 to 1 % impervious cover is 0.122 while the

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[11] Pollutant concentration: STORMWATER RUNOFF QUALITY AND QUANTITY FROM SMALL WATERSHEDS IN AUSTIN, TX, City Of Austin, Watershed Protection Department, Environmental Resources Management Division, Water Quality Report Series, COA-ERM/WQM 2006-1, November 1, 2006

concentration of a 5 to 100% impervious cover is 0.337. TN predicted concentrations are 0.90 and 1.78 for a range of 0 to 1% and 5 to 100% respectively. As a result, it may be inferred that the most relevant site-specific estimates are those for Zn and Cu annual pollutant loads. The results show there is approximately 6% more zinc annual pollutant concentration than copper. Zinc because of cars' brake pad wear is found in parking lot's surface while copper is found because of tire wear.

The value of annual rainfall (P) used, while estimating annual runoff (R) a variable in the Simple Method, is the average annual rainfall of the last eighteen years (from 1990 to 2007). Two possible outliers are 1991 and 2004 with an annual rainfall of 52.21 and 52.27 respectively.

The percentage of pollutant removal is the average value of two different sources[12]. It is important to note that TN and TP were the only two consistent pollutant categories in the three sources. The categories were pooled and the average value for each category estimated. The estimates in table 2 were the results of multiplying the annual pollutant load for each site by its percentage of removal. Overall, porous pavements have a high pollutant removal performance. It is particularly effective in removing metals such as Zn and Cu: 95% removal.

	Annual rainfall
	P (in)
1990	28.44
1991	52.21
1992	46.05
1993	26.05
1994	41.16
1995	33.98
1996	29.56
1997	47.04
1998	39.11
1999	23.93
2000	37.96
2001	42.9
2002	35.98
2003	21.43
2004	52.27
2005	22.33
2006	34.6
2007	46.95
	36.775

Estimated Pollutant Removal of Porous Pavement

Pollutant	% Removal	S Congress (lbs)	Burnet Road (lbs)	E Riverside Dr (lbs)	E 7th St (lbs)
TSS	0.89	3897.56	4877.70	2924.61	5402.55
TP	0.65	6.28	7.85	4.71	8.70
TN	0.89	45.14	45.14	33.87	62.57
Zn	0.95	1.31	2.01	0.84	2.09
Cu	0.95	0.21	0.29	0.15	0.31

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[12] The sources were EPA and the Minnesota Stormwater Manual.

2.2 WATER QUALITY VOLUME

In this section, the methodology used to estimate water quality volume is the one employed by the New York State Stormwater Management Design Manual.

$$WQ_v = \frac{(P)\ (R_v)(A)}{12}$$

WQv=Water Quality Volume (ft3)
A= Total Area (ft2)
P= 90% Rainfall event (inches) 1.4 in for Austin

Rv=0.05+0.9Ia

Ia= Fraction of impervious cover

In estimating the water quality volume the total area of the site was included (parking lot, building's foot print and loading dock areas). The P value is 1.4 inches for Austin[13] (see table 4). The results show that changing the surface materials from dense concrete/asphalt to porous pavements and so reducing the percentage of impervious cover, decreases water quality volume to be treated by 20%.

	Water Quality Volume WQv	
	Proposal (ft3)	Actual (ft3)
S Congress	5,777.33	6,441.34
Burnet Rd	6,582.74	7,235.28
E. Riverside Dr	5,517.09	6,208.78
E 7th St	6,711.28	7,412.33

Table 1.
90% Rainfall Event for Select U.S. Cities

City	Rainfall (in)
Columbus, OH	1.00
Albany, NY	0.90
New York, NY	1.20
Frederick, MD	1.10
Washington, D.C.	1.20
Boise, ID	0.50
Phoenix, AZ	0.80
Denver, CO	0.70
Austin, TX	**1.40**
Savannah, GA	1.50
Montpelier, VT	0.90
Los Angeles, CA	1.30

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[13] http://www.stormwatercenter.net/Manual_Builder/Sizing_Criteria/Water%20quality/Options%20for%20Water%20Quality%20Volumes.htm

The bed depth is a determinant factor in porous pavement water treatment. “The pores [of the gravel bed] house a microsystem that filters and biodegrades the pollutants that occur generically on…pavements; the underlying soil ecosystem is a backup treatment system that assures high treatment levels”.[14] There is some controversy about the minimum depth of the gravel bed. Some sources specify 6 in as the minimum bed depth while other sources state it is 12 in. “Infiltration beds are typically sized to handle the increased volume from a 2-yr storm”[15].

In order to calculate the porous pavement surface for each site’s drainage area “based on the water quality volume required to treat this area” the following equation was used:

$$A_p = WQv / (n \times d_t)$$

Ap= Porous Pavement Surface (ft2)
n=Porosity of bed gravel (0.4)
dt=Depth of gravel bed/reservoir (ft)
WQv=Water Quality Volume (ft3)

The results show that as bed depth increases the porous pavement surface required to treat the required water volume decreases. In other words, the bed depth is inversely proportional to the porous pavement surface. The following equation evidences on average, for all sites, this inverse relationship:

$$y = 15368x\text{-}^{1}$$

	Porous Pavement surface Ap	Depth of gravel bed/reservoir
	Proposal	
	(ft2)	(in)
S Congress	28,886.63	6
	14,443.32	12
	9,628.88	18
	7,221.66	24
	5,777.33	30
	4,814.44	36
Burnet Rd	32,913.70	6
	16,456.85	12
	10,971.23	18
	8,228.43	24
	6,582.74	30
	5,485.62	36
E. Riverside Dr	27585.44	6
	13792.72	12
	9195.15	18
	6896.36	24
	5517.09	30
	4597.57	36
E 7th St	33556.38	6
	16778.19	12
	11185.46	18
	8389.09	24
	6711.28	30
	5592.73	36

Next, in order to estimate the volume of water treated by each site’s parking lot area (with the proposed porous pavement surface) the following equation will be used:

$$WQv = A_p \ (n \times d_t)$$

To have a conservative estimate the minimum bed depth will be used in this computation. On average, the case studies’ porous surface parking lots will treat 21% more water volume than the amount required by the drainage area (see table 2).

Depth of gravel bed/reservoir	S Congress	Burnet Rd	E. Riverside Dr	E 7th St
(in)	(ft3)	(ft3)	(ft3)	(ft3)
6	126,479.56	124,293.59	131,750.94	133,533.40
12	252,959.12	248,587.17	263,501.87	267066.81

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[14] Ferguson, B. 2005. *Porous Pavements.* CRC Press.

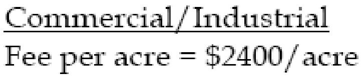
[15] Pennsylvania Stormwater Best Management Practices Manual, Section 6 Comprehensive Stormwater Management: Structural BMPs.

3 COSTS

In the case of surface pavements for parking lots in commercial developments a 33% average increase per square feet of porous asphalt versus dense asphalt may deter land developers, who seek to reduce costs in order to maximize their profits, from using porous pavements[16].

	Porous Concrete	Dense Asphalt	Porous Asphalt	Interlocking Pavers
	$4.00	$0.75	$1.00	$3.50
S Congress	$2,529,591.20	$474,298.35	$632,397.80	$2,213,392.30
Burnet Rd	$2,485,871.79	$466,100.96	$621,467.95	$2,175,137.82
E. Riverside Dr	$2,635,018.70	$494,066.01	$658,754.68	$2,305,641.37
E 7th St	$2,670,668.08	$500,750.27	$667,667.02	$2,336,834.57

Additionally, the city of Austin charges as part of the Regional Stormwater Management Participation Fees a fee for "the number of impervious acres…based on the maximum allowable impervious cover" for commercial development using the formula[17]:



Commercial/Industrial
Fee per acre = $2400/acre

	Impervious cover		Savings
	w/ porous pavement	w/o porous pavement	Reduced imperviousness
S Congress	443,070.63	1,075,468.43	$ 34,842.85
Burnet Rd	860,881.39	1,482,349.34	$ 34,240.66
E. Riverside Dr	375,672.43	1,034,427.11	$ 36,295.02
E 7th St	538,870.69	1,206,537.71	$ 36,786.06

"Many municipal stormwater "utilities" and stormwater management departments impose taxes of fees based on impervious coverage. Converting pavements to porous, pervious materials reduces the basis for the tax of fee"[18]. On average, the savings from the Participation Fee could amount to $35,541.15.

There are also additional savings, "from not having to build a separate stormwater infrastructure in addition to paving, the overall project costs are often reduced".[19] For example, savings might come from the opportunity cost of:

- Storm drainage pipes
- Storm reservoirs
- Drainage inlets
- Cost of land for stormwater management facilities

In sum, "porous pavement with little or no drainage structures is commonly less expensive than a dense pavement with the large drainage and treatment system it requires"[20]

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[16] Average price per ft2 from EPA, Dr. Barrett, City of Seattle Department of Planning and Development and City of New York ;base/storage bed not included in cost estimate.

[17] http://www.ci.austin.tx.us/watershed/rsmp_fee_com-mf.htm

[18] Ferguson, B. 2005. *Porous Pavements.* CRC Press

[19] New York State Stormwater Management Design Manual Chapter 9: Redevelopment

4 CONCLUSIONS

Ferguson states that “paradoxically, we have specified impermeable pavements that flush away runoff, [and] then paid for detention basins to counteract the pavement’s runoff and pollution…”.[21] Porous pavements’ effectiveness in removing pollutants as well as the capacity to treat high water volumes makes them an attractive on-site solution. This is particularly relevant for two reasons. First, the multiplicative effects of porous pavements solutions in all commercial sites in an urban area. Second, large surface area parking lots tend to occupy in commercial lots.

- Further research is necessary to implement land use policies that require the use of porous pavements when the length of flow is smaller than a certain benchmark.

- Social marketing strategies for policy makers as well as citizens might be necessary to make known the benefits of porous pavements. This might in turn create at the local/state level incentives for the use of these materials.

- Local solutions like the one presented may decrease the size of stormwater infrastructure not only the land developer’s costs but perhaps also the local and/or state government. Future research would be required to prove this hypothesis as well as the best balance between local and centralized infrastructure.

- Using porous pavement/interlocking pavers for stormwater management may require government supervision after a certain period of installation to ensure maintenance hence effectiveness in infiltration and water treatment.

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[20] Ferguson, B. 2005. *Porous Pavements.* CRC Press.
[21] Ferguson, B. 2005. *Porous Pavements.* CRC Press.

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6. http://www.dsi.gov.tr/sozlukler/hidrosozluk/en.cfm?SozcukID=0887
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