Thesis Portfolio

The Intersection of Public Utilities and Private Ownership in Stormwater Management: A Case Study of Localized Flooding in Charlottesville, VA

(Technical Report)

Communication and Learning Through Experience: An Autoethnography of a 4th Year Civil Engineer

(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Spring, 2020

Department of Civil Engineering

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Sociotechnical Synthesis

The following thesis is a combination of practical experience and personal reflection.

The technical report investigates a site experiencing flooding due to aging stormwater infrastructure and that is stuck in a web of disincentives that has inhibited a remedy. The report explores low impact development (LID) infrastructure such as rain gardens and infiltration trenches using stormwater modeling software. Under the tested parameters, the LIDs were not able to infiltrate enough water in a cost-effective manner. However, the data from the model still provides a framework for the infiltration effectiveness of LIDs under these conditions and still have potential under more favorable social and economic conditions.

The STS thesis uses autoethnography to explore the efficacy of the 4^{th} year engineering curriculum in imparting skills and acting as a stepping stone to “real world” engineering through the lens of my own experience. I reflect on what lessons and insights I gained from both my capstone and STS coursework and how I reached those insights. I felt ultimately my capstone and STS coursework together did provide my that “stepping stone” experience, however I do not think my all peers received the full benefit the STS courses had to offer. I compare my experience to literature on engineering education that emphasizes the importance of communication to professional engineers and the need to cultivate communication skills in the engineering curriculum. I believe if these communication skills had been emphasized as necessary to professional engineers prior to the STS course, both I and my peers would have been more receptive on the outset.

While separated into two sections, my experience with both my capstone and STS were tightly interconnected which I reflect on in my STS thesis. I believe there is a value to having the two linked in this way. I think that one without the other would be lacking. It was the interplay between the two that drove me to refine the technical work and more deeply understand the lessons taught in STS.

The Intersection of Public Utilities and Private Ownership in Stormwater Management: A Case Study of Localized Flooding in Charlottesville, VA

A Technical Report submitted to the Department of Civil Engineering

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In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Kevin "Connor" Corcoran
Spring, 2020

Technical Project Team Members:
Kevin "Connor" Corcoran
Jane Long

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Signature ____ Date __________
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The Intersection of Public Utilities and Private Ownership in Stormwater Management: A Case Study of Localized Flooding in Charlottesville, VA

A Capstone Report
presented to the faculty of the
School of Engineering and Applied Science
University of Virginia

by

Connor Corcoran and Jane Long

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Abstract

At a site in Charlottesville, VA, runoff from two upstream properties flows down to the downstream properties, resulting in flooding problems. The City's public utilities have previously looked into new underground stormwater conveyance that would only require maintenance of right of way through the private properties. With GIS and EPA SWMM models, this paper analyzes scenarios that instead change the surface of one or both upstream properties in order to reduce runoff. The three different low impact development (LID) scenarios (rain garden, infiltration trench, and vegetative swale) are computed based on area needed to infiltrate runoff and cost of implementation. The three infiltration objectives used were 50% and 100% infiltration of one property and 100% infiltration of both properties. The analysis showed that of the three LIDs, infiltration trenches were the most efficient in reducing the total runoff per square foot, with rain gardens nearly as efficient. Cost analysis showed, however, that infiltration trenches would be more expensive to implement than rain gardens. Vegetative swales were not found to be effective in reducing runoff from the site. As a result, it is recommended that, of three LIDs, rain gardens or infiltration trenches be used to reduce flooding at the site.

Introduction and Background

Throughout the city of Charlottesville, there exist several areas that are prone to flooding during periods of heavy rain. Large portions of the stormwater conveyance system that is in need of maintenance or repair lies outside the city's right of way. While the utility services of Charlottesville are ready to provide resources and recommendations to private property owners, the current incentives have failed to generate interest in solving these problems. In many cases, water from upstream private properties are creating problems for downstream private properties. Because the problems generated downstream do not directly influence upstream owners, there is little motivation for these owners to take any course of action.

This situation is exemplified at a site on St. Clair Avenue in Charlottesville, in which runoff from two uphill properties leads to flooding on a downstream property. The conveyance pipe that serviced the runoff from the upstream properties has collapsed causing water to overflow onto the street and flood the downstream property. Furthermore, the addition of driveways to the upstream properties further concentrated runoff going into the now collapse pipe. The city however does not have the right of way to fix the collapse. The project serves to observe and analyze different potential solutions to develop a recommendation that will result in flood mitigation at the site. Using Geographic Information System (GIS) and the Environmental Protection Agency's (EPA's) Stormwater management Model (SWMM), three low impact developments (LIDs) are analyzed using social factors, cost, and ability to reduce runoff at the site.

LIDs are management approaches using or mimicking natural processes that result in infiltration, evapotranspiration, or use of stormwater in ways that protect water quality and aquatic habitats, with an emphasis on preserving, restoring, or creating green space (US EPA, 2015). The three LIDs that were chosen for analysis in this project were rain gardens, infiltration trench, and a vegetative swale (Figure 1). Rain gardens and infiltration trenches use depressions and ditches filled with aggregate to collect and infiltrate stormwater into the ground (Shamsi, 2012). Vegetative swales, in contrast, are more broad and shallow channels that convey and infiltrate stormwater

(Shamsi, 2012). The objective of these LIDs is to minimize any runoff that would typically be directed to storm drains and removed using conventional stormwater management techniques.

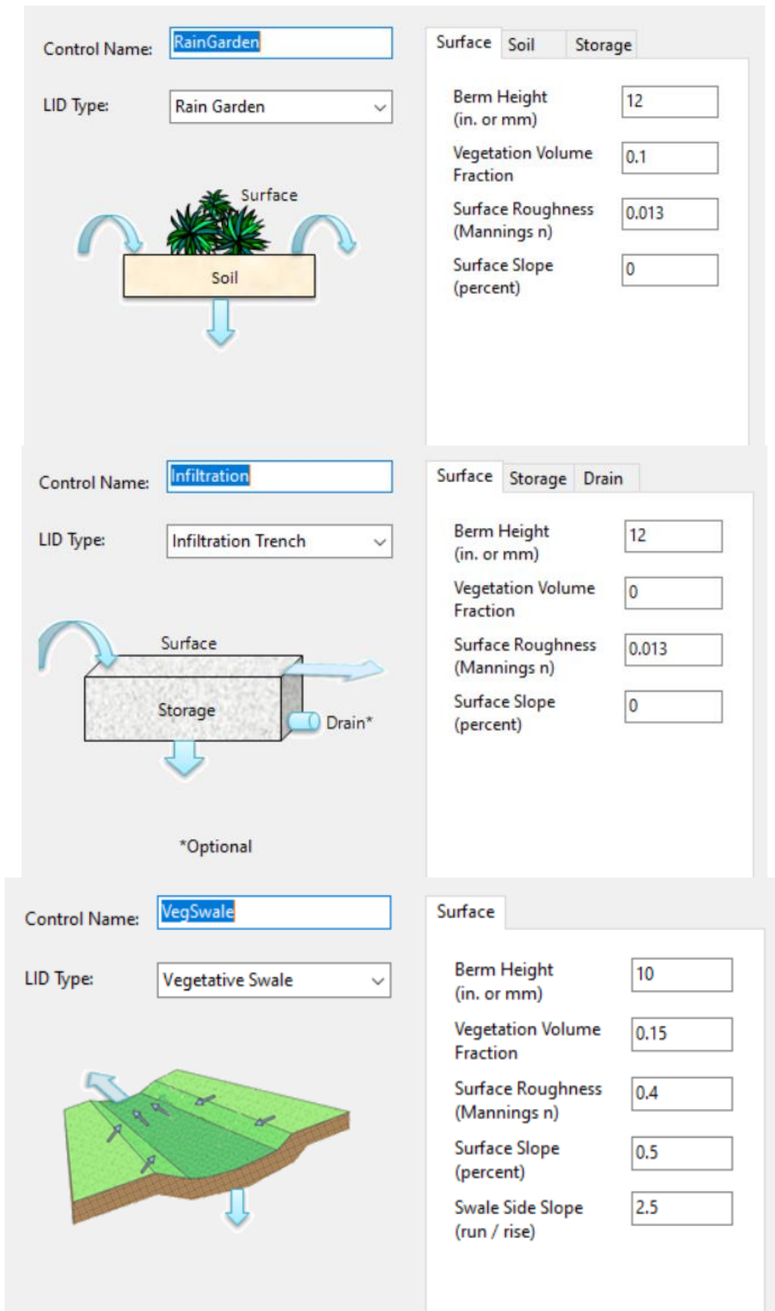

Figure 1. Visual representation of each LID according to EPA SWMM.

Methods

This project was conducted in three main parts: analysis of the area using GIS, determination of runoff with LIDs in SWMM, and analysis of external factors such as cost in determining a feasible solution.

GIS Analysis

For the GIS analysis, we selected to use ArcGIS, which includes a variety of tools, such as flow accumulation and pour point tools, used to determine the size of the watershed that was previously draining into the collapsed pipe. With this watershed delineated, the general percent slope of the area was determined by using the slope tool. Layers obtained from the city showing the roads, buildings, driveways, and land parcels were intersected with this watershed layer to find the amount of permeable and impermeable area on the entire site. Analysis of the site explored the options of implementing LIDs on just one property and on both properties. The size of the watershed for both of these options were calculated and applied to the models in SWMM.

EPA SWMM Modeling

The runoff and site conditions were modeled in EPA SWMM (Rossman, 2015). The watershed was assumed to be one subcatchment with one outlet. The parameter values of the subcatchment that were changed from the default values are listed in Table 1. Two storm return periods, 1-year and 10-year, each with a 24-hour duration, were considered. The rainfall depths for these synthetic storm events were obtained from the National Oceanic and Atmospheric Administration's (NOAA) website. For a 1-year storm, the rainfall depth was 3.03 inches and 5.55 inches for a 10-year storm.

Table 1. The values for the subcatchment parameters.

Subcatchment Parameters	
Width	140
% Slope	9
% Imperv	14.52
N-Imperv	0.01
N-Perv	0.2
Dstore-Imperv	0.05
Dstore-Perv	0.1
%Zero-Imperv	20

For the LIDs, the options were narrowed down to three possible scenarios: 1) rain gardens, 2) infiltration trench, and 3) vegetative swale. The setup of the SWMM model is shown in Figure 2. In analyzing each option, the typical parameter values (Table 2) according to the EPA SWMM guide for each LID were used as initial values and most parameters were held constant throughout each scenario and objective. Of the parameters, only berm height and soil media thickness were altered within a reasonable range as listed in the EPA SWMM guide to minimize the amount of runoff to the objective. These parameters were chosen because they are typically what is changed during design of the LIDs, as characteristics of the engineering soil and rip rap are more difficult to change. The ranges for these parameters are also listed in Table 2. In the first scenario, rain gardens, the berm height and thickness were altered between 6-12 inches and 18-36 inches, respectively. The second scenario, infiltration trenches, had alterations in berm height and thickness between the ranges of 6-12 inches and 36-100 inches. For the third scenario, vegetative swales, only the berm height was changed between a range of 6-12 inches.

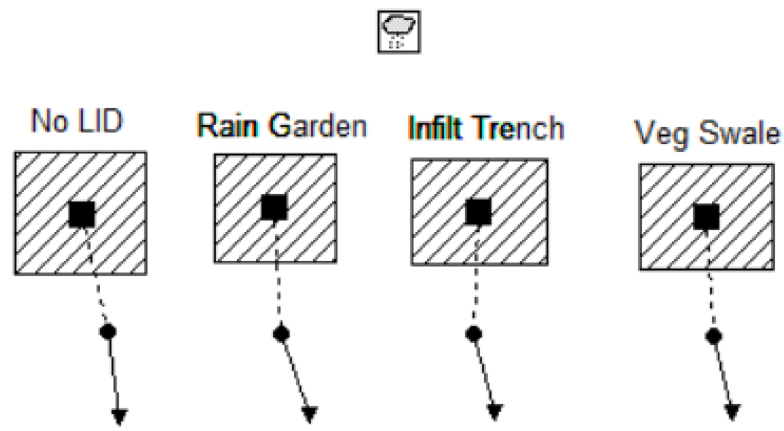

Figure 2. Setup of the SWMM model comparing each LID.

Table 2. Constant parameter values for each LID.

Constant Parameter Values					
Rain Garden		Infiltration Trench		Vegetative Swale	
Vegetation Volume	0.1	Vegetation Volume	0	Vegetation Volume	0.15
Surface Roughness	0.013	Surface Roughness	0.013	Surface Roughness	0.4
Surface Slope (%)	0	Surface Slope (%)	0	Surface Slope (%)	0.5
Porosity	0.52	Void Ratio	0.4	Swale Side Slope	3
Field Capacity	0.15	Seepage Rate (in/hr)	0.5	Berm Height (in)	6-12
Wilting Point	0.08	Clogging Factor	0.1		
Conductivity (in/hr)	1.6	Berm Height (in)	6-12		
Conductivity Slope	39.3	Thickness (in)	36-100		
Suction Head (in)	1.9				
Berm Height (in)	6-12				
Thickness (in)	18-36				

To determine how the different LID scenarios were able to mitigate flooding at the St. Claire site, the SWMM model was used and all LID parameters were then held constant except the area of the LID. Doing so, it was possible to determine the area necessary to achieve three objectives of 100% reduction of runoff from one property, 50% reduction of runoff from one property, and 100% reduction of runoff from both properties. The results for both peak runoff (cfs) and total runoff (gallons) were examined, both of which are zero for the objectives of 100% reduction of runoff. For 50% reduction of runoff, the aim of the LID was to reduce the total runoff (gallons) of the area by half, hence assuming that 50% of the runoff is infiltrated using the LID. While the area of the subcatchment and allowable peak flow changed to reflect each objective, the general procedures of analyzing each LID by changing different LID parameters were used for each LID scenario.

Analysis of Cost

For cost estimation, the costs of each LID were taken from various sources through research. The costs were approximated to reflect some of the characteristics known at the site. For rain gardens, the total cost mostly consists of excavating the site and filling it with soil. According to USDA's Web Soil Survey, the topsoil at the site is sandy loam and well drained soil, so the hydraulic conductivity of the soil is similar to what is modeled in SWMM. However, in order to ensure future performance of the rain garden, around 6 inches of compost soil and sand should be incorporated during construction to increase the infiltration rate and anticipate compaction. Displaced soil that is not returned to the rain garden is used to create the 12-inch berm as modeled in SWMM. Native plants to Virginia were chosen for the rain garden as they are adapted to local conditions, have deeper roots, and do not need extra care once planted (Fairfax County, 2009). For this project, seeds for plants that flourish in part sun- part shade conditions and are more tolerant of both drought and flooding were used to calculate the cost per square yard of the rain garden. To find the total cost, the amount of soil needed to fill the soil was found depending on the area of the rain garden and added to the cost of the surface layer of plants and mulch.

The vegetative swale has similar requirements to the rain garden. The native soil has 1adequate drainage and hydraulic conductivity. After excavation, a gravel layer is placed on the bottom along with a PVC underdrain that connects to the storm sewer. After the soil is backfilled in, the remaining soil can be used to build up a berm to allow for greater ponding. Grass is suitable vegetation on the swale, however, other vegetative covers can be used so long as they do not have high nutrient requirements.

The infiltration trench first needs to be excavated, and the soil will ultimately need to be hauled away as well. Filter fabric should be draped over the sides of the trench, going 2 feet in from the bottom edges. There should be 2 feet over coverage for any sections that overlap. An 8" layer of sand must be placed at the bottom to meet specifications covering the filter fabric base. The aggregate is then filled in on top and the filter fabric covering the top as well. Finer aggregate is added over the filter fabric and then finally a layer of sod. Observation wells are required every 50 feet for maintenance. The total cost was found by finding the amount of each aggregate needed to fill the infiltration trench according to the specifications.

The overall budget for the materials of constructing a rain garden is shown in Table 6. Cost of materials for an infiltration trench is shown in Table 7, and Table 8 for vegetative swale.

Table 3. Unit prices of each item for the rain garden.

Item	Unit	Unit Price
Compost soil/sand mix	yd^3	$30.50[a]
Earth excavation	yd^3	$15[b]
Mulch (2-inch layer)	yd^3	$20[c]
Plants	yd^2	$10[d]

Table 4. Unit prices of each item for the vegetative swale.

Item	Unit	Unit Price

Earth excavation	yd^3	$15[b]
1-½" Gravel Aggregate (AASHTO #57)	yd^3	$25[g]
PVC underdrain	10 ft	$10
Grass Seed	1000 ft^2	$15

Table 5. Unit prices of each item for the infiltration trench.

Item	Unit	Unit Price
Earth excavation	yd^3	$15[b]
½" Filter Gravel (AASHTO #8)	yd^3	$30[g]
1-½" Gravel Aggregate (AASHTO #57)	yd^3	$25[g]
Drainage Sand	yd^3	$50[i]
Non-woven Filter Fabric	yd^2	$1.40[f]
Sod	yd^2	$4.50[e]
PVC Observation Well (4"x10')	Per 50ft of trench	$75[h]

[a] Cost from https://cedar-grove.com/store/soil/60-40-lawn-mix
[b] Cost from https://www.homeadvisor.com/cost/landscape/excavate-land/#grading
[c] Cost from https://www.homeadvisor.com/cost/landscape/mulch-delivery-install/
[d] Cost from https://www.ufseeds.com/product/virginia-wildflower-seed/
[e] Cost from https://www.homeadvisor.com/cost/landscape/sod-prices/
[f] Cost from https://www.agriculturesolutions.com/agricultural-fabrics/drainage-filtration-and-weed-fabric?p=2
[g] Cost from https://www.paturnpike.com/Procurement/Purchasing/docs/BID%20TAB%20Aggregates%20801023_2015.pdf
[h] Cost from https://www.shop-esp.com/4-x-10-PVC-Well-Screen-020-Sch40-brMale-x-Female-Threads-P276.aspx?gclid=EAIaIQobChMImKeK7YjI6AIVBpyzCh2MYQtcEAQYASABEgKC4PD_BwE
[i] Cost from https://homeguide.com/costs/fill-dirt-sand-topsoil-cost#sand

Results

The total watershed area discharging to the property downstream was found to be 3.3 acres. The watershed area for just the south property was 1.58 acres (Figure 3). The total area consisted of 0.48 acres of impermeable area, resulting in 14.52% impermeable areas on the site. The site was determined to have a 9% slope, and a width (the area of the subcatchment divided by the longest flow length) of approximately 140 ft.

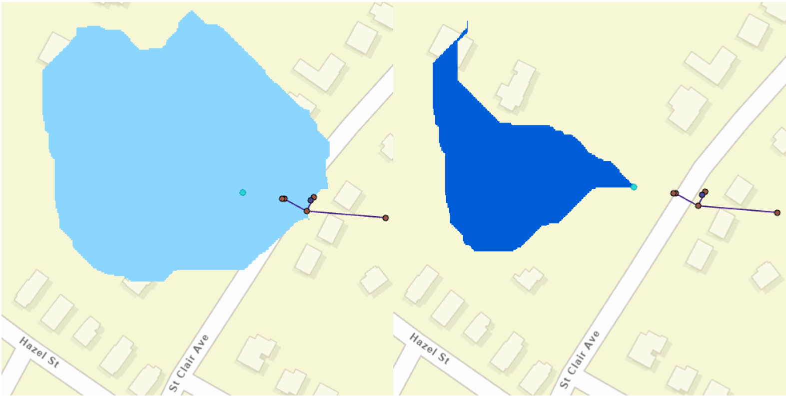

Figure 3. Watershed for both properties (left) and watershed for the south property.

Using EPA SWMM, the peak runoff for a 1-year storm and a 10-year storm for both of the properties are 3.19 and 9.84 cubic feet per second (cfs), respectively. The total runoff volume for a 1-year storm is 0.06×10^6 gallons and 0.17×10^6 gallons for a 10-year storm. Meanwhile, the peak runoff for the south property for a 1-year storm and a 10-year storm are 2.15 and 6.33 cfs, respectively (Figure 4). Similarly, the total runoff volume for just the south property given a 1-year storm is 0.03×10^6 gallons and 0.09×10^6 gallons given a 10-year storm.

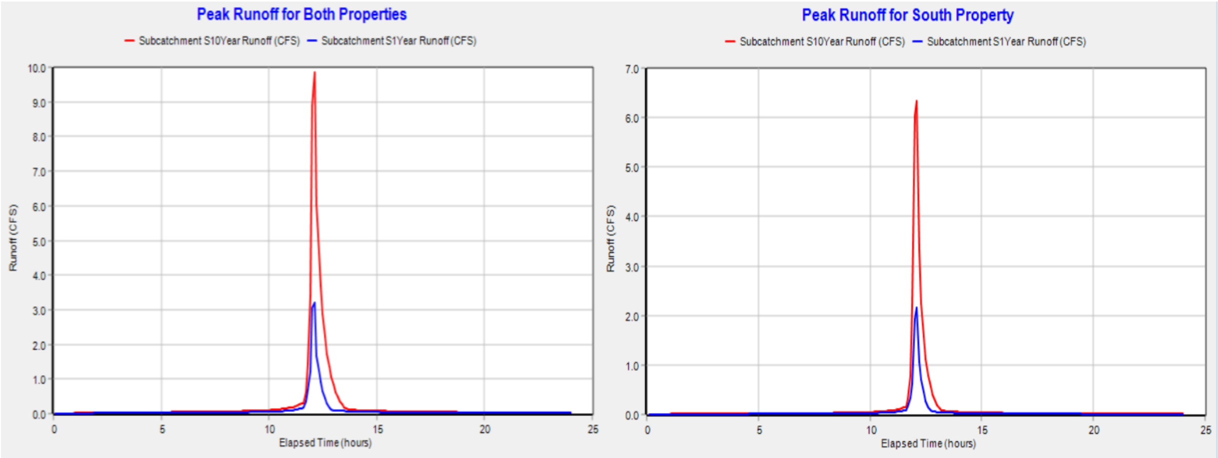

Figure 4. Runoff prior to LIDs for 1-year storm (blue) and 10-year storm (red) for both properties (left) and just the south property (right).

Using these values, the three LID scenarios as outlined in the Methods section were analyzed with the objectives of 100% reduction of runoff from one property and hence no peak flow, with results shown in Table 3 and 4. Required area for a rain garden and an infiltration trench during a 10-year storm is 0.156 acres and 0.122 acres, respectively (see Figure 5, values can be found in the appendix). The vegetative swale did not successfully infiltrate 100% of the runoff even when it occupied the entire property, so the result for the vegetative swale is the value of the entire property. For the rain garden, the final value used for the berm height was 12 inches, and the thickness of the soil was 24 inches. The infiltration trench had the same berm height but a thickness of 60 inches, as infiltration trenches can typically be deeper than rain gardens. When analyzing peak flow using a vegetative swale with a berm height of 10 inches, it was found that peak flow could not be reduced to zero even if it occupied the full subcatchment. Changing the berm height did not alter the results significantly and still required the entire subcatchment to be the vegetative swale to reduce peak flow.

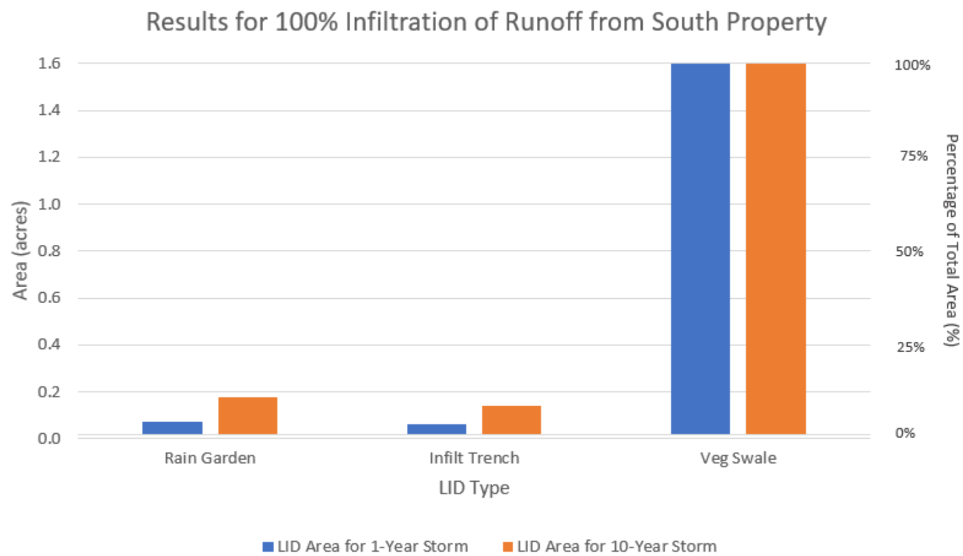

Figure 5. The results for 100% infiltration of runoff from the south property by LID type.

In the second objective, 50% reduction of runoff from only the south property, the volume of runoff should not exceed $0.02x10^6$ gallons for the 1-year storm and $0.05x10^6$ gallons for the 10-year storm. Given these values, the results for each LID are displayed in Figure 6. The third and final objective, 100% reduction of runoff from both properties, resulted in the values shown in Figure 7. The berm heights and thickness for each LID were not changed throughout the three objectives and were maximized within a range of values typical for each LID scenario. After looking at the effect of the two parameters on the runoff amount, it was found that berm height and thickness played an important role in infiltration and therefore the highest reasonable values were chosen for each parameter. For a rain garden, the berm height is typically 6-12 inches with a thickness of 24-48 inches (Rossman, 2015). Infiltration trenches have the same range for berm heights but thicknesses can range from 36-144 inches, but in order to keep the bottom of the trench a reasonable distance from the water table, the maximum depth of the infiltration trench was set to 60 inches.

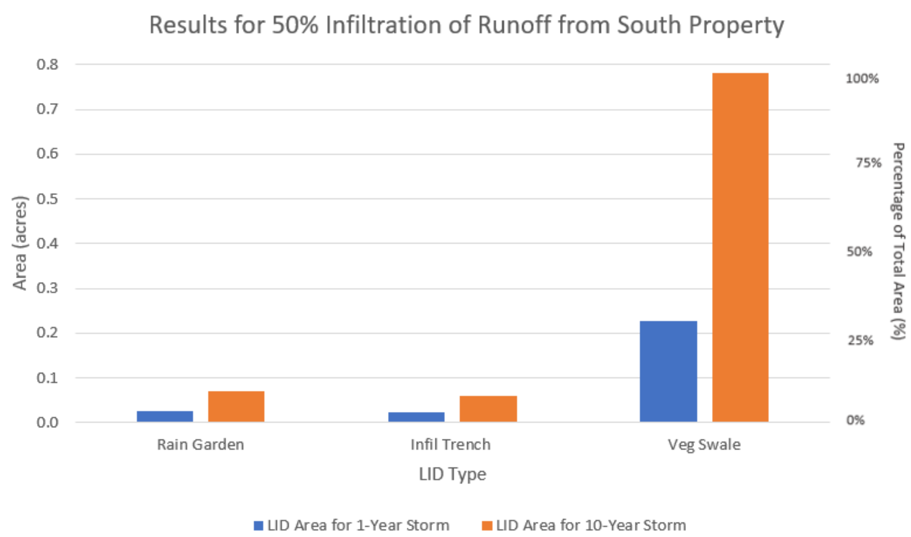

Figure 6. The results for 50% infiltration of runoff from the south property by LID type.

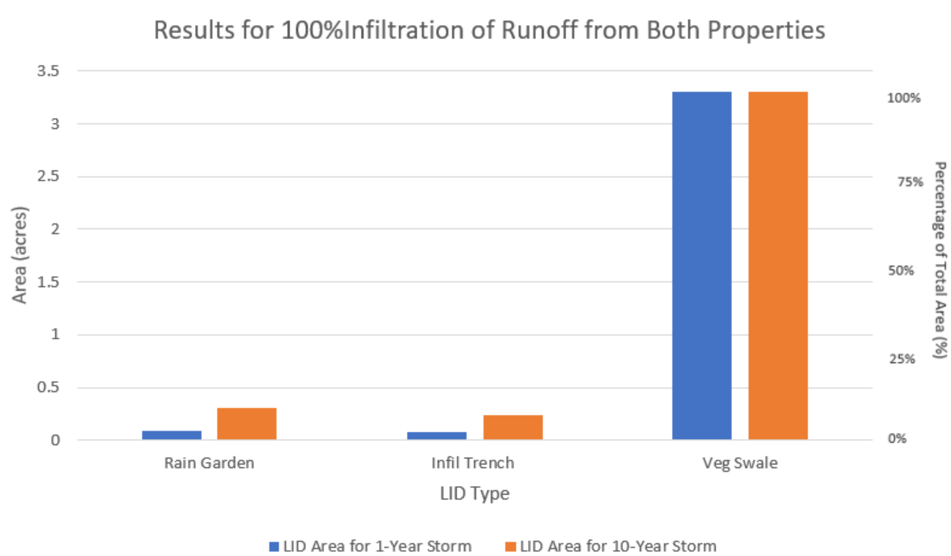

Figure 7. The results for 100% infiltration of runoff from both properties by LID type.

Cost Factors

The costs for the rain garden and infiltration trench for each scenario using the costs from the Methods section are shown in Table 9 and 10. The costs for a vegetative swale were not calculated as it did not fully infiltrate runoff even when it occupied the entire subcatchment.

Table 6. Cost for a rain garden for each scenario.

	100% infiltration - 1 property		50% infiltration - 1 property		100% infiltration - both	
	1-year storm	10-year storm	1-year storm	10-year storm	1-year storm	10-year storm
Cost	$5,400	$16,500	$2,700	$7,500	$9,800	$32,000

Table 7. Cost for an infiltration trench for each scenario.

	100% infiltration - 1 property		50% infiltration - 1 property		100% infiltration - both	
	1-year storm	10-year storm	1-year storm	10-year storm	1-year storm	10-year storm
Cost	$21,800	$64,100	$11,800	$31,500	$40,300	$124,000

Discussion

A large amount of area is required to reduce the peak runoff to zero for a 10-year storm. Designing to a 10-year storm would require around 10% and 8% of the total property area for a rain garden or infiltration trench, respectively. In comparison, designing the LID to a 1-year storm is more feasible since the areas are two to three times smaller, while still diverting runoff to alleviate flooding problems in more common rain events. Designing to a 1-year storm would require only around 3% and 2.5% of the total property area for rain gardens and infiltration trenches, respectively. Due to the ineffectiveness of a vegetative swale to reduce runoff during a 10-year storm, it is unlikely to be used as a means of reducing flooding at the site.

Using the cost estimate for the components of a rain garden, the cost for materials for a rain garden for each scenario ranged from $5,400 to $124,00. While the costs for a 1-year storm are lower, the rain garden would only help with flooding in more common, smaller rain events. If the property wishes to alleviate some flooding but is more limited in budget, an available option would be to choose to design the rain garden to a 1-year storm or aim for 50% infiltration instead of 100% infiltration. Overall, the costs for a rain garden are lower than for an infiltration trench, but also require more area for each scenario.

The infiltration trench performs best in the models and requires the least amount of area, however, it also has higher construction costs. Even for the most limited case with half runoff reduction for a 1 year storm, the cost still comes out to be approximately $11,800 for materials and excavation not including other labor costs. There is also the added factor of maintenance to ensure the pore spaces of the aggregate do not get overly clogged. Budget permitting, using an infiltration trench on the south property to reduce runoff is a feasible option.

The vegetative swale was the poorest performer in the model requiring the most area of any of the options; in the 100% infiltration cases a vegetated swale would require an area greater than the site itself. Given that it has comparable material costs to a rain garden but performs much more poorly, it should not be considered.

The quality of data going into the model could be improved. The soil data was gathered from the USGS Web Soil Survey and the NRCS synthetic hydrograph along with NOAA local precipitation data was used to create time series for design storms. The topographical data gathered from GIS was not very granular in the context of the size of the site, however, the general slope, shape, and size of the catchment were the important aspects that served the purposes of the model. The primary output variable used for sizing and optimization was peak runoff (cfs). The intent was by reducing the peak flow rate, the constrained flow through the damaged storm sewer would have more time to dissipate. Precipitation data was gathered from the Albemarle airport for one of the past storms on the site which was known to cause flooding. A time series was created from the data and found to be comparable to a 1-year storm. This time series was intended to be used as a baseline, however given the knowledge that there have been record storms in the past few years at the site, it was unlikely that the storm was the largest which could have caused flooding.

While none of the proposed scenarios may be the chosen solution for this site, the model can still offer useful insights for future stormwater management practices. While retrofitting LIDs has shown to be land intensive and costly, the LIDs' performances were demonstrated within the model with rain gardens infiltrating 1.7 cubic feet of stormwater per square foot and infiltration trenches 2.2 cubic feet per square foot. Trying to accomodate all the runoff was difficult in a finite space, so to avoid such cases in the future, less-intensive application of LIDs could reduce the load across the whole system. However, there are currently no incentives in place for private properties to landscape in a way that improves infiltration at the St. Claire site.

Conclusion

Stormwater management requires coordination between the City's public utilities and private property owners. While the City's public utilities have found ways to manage stormwater and reduce flooding without the help of private property owners, there are solutions that could be more effective in mitigating flooding with the cooperation of the private property owners. This is shown in a case study at St. Claire Avenue, where runoff from upstream properties is flooding downstream properties during rain events. The problem has been exacerbated by broken pipes that had previously diverted the runoff and the addition of impermeable area upstream. In order to address the problem, three LIDs were analyzed in the hopes of determining a potential solution that reduces runoff from the upstream properties. We found that the most effective way to reduce runoff at the site is through an infiltration trench, with rain gardens nearly as effective. However, in order for runoff to be zero during 10-year storms using the infiltration trench or rain garden, a large area of the property will need to be used for the LID. It may not be feasible or realistic to design a rain garden or infiltration trench to accomodate a 10-year storm due to requiring large amounts of area and resulting high prices of implementing the LID. If there is a desire to alleviate some flooding during more common 1-year storms, the rain gardens and infiltration trenches would be relatively small in size and could reduce the peak flow to zero. Vegetative swales were found to be inefficient in infiltrating runoff from the site.

Currently the greatest limitation is the lack of data on site specific hydrology. The rainfall data used in the model was a synthetic storm based on NOAA rainfall intensities. The topographical model was derived from city-level GIS data, not at the scale of the site. Opportunities for future research could include obtaining GIS data and rainfall data that more closely reflects what is observed at the present site. Further investigation into dates when the site has flooded previously would clarify what the threshold for flooding is and the scenarios could be adjusted. In addition, installation of sensors to log both local precipitation and water level in the flooding storm drains would create a baseline for the model and would allow for further optimization of LID solutions. In addition, more research can be conducted so that costs include life cycle costs such as maintenance fees, replacement parts, etc.

Appendix

The results for 100% infiltration of runoff from the south property by LID type.

LID	Berm Height (in)	Soil Thickness (in)	LID Area for No Runoff (1-year storm) (sqft)	LID Area for No Runoff (10-year storm) (sqft)
Rain Garden	12	24	2,200	6,800
Infiltration Trench	12	60	1,800	5,300
Vegetative Swale	10	-	MAX	MAX

The results for 50% infiltration of runoff from the south property by LID type.

LID	Berm Height (in)	Soil Thickness (in)	LID Area for Half Runoff (1-year storm) (sqft)	LID Area for Half Runoff (10-year storm) (sqft)
Rain Garden	12	24	1,100	3,100
Infiltration Trench	12	60	975	2,600
Vegetative Swale	10	-	9,900	34,000

The results for 100% infiltration of runoff from both properties by LID type.

LID	Berm Height (in)	Soil Thickness (in)	LID Area for No Runoff (1-year storm) (sqft)	LID Area for No Runoff (10-year storm) (sqft)
Rain Garden	12	24	4,050	13,175
Infiltration Trench	12	60	3,330	10,315
Vegetative Swale	10	-	MAX	MAX

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Communication and Learning Through Experience: An Autoethnography of a 4th Year Civil Engineer

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Kevin "Connor" Corcoran
Spring, 2020

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Signature ____ Date __________
Kevin Connor Corcoran

Approved ____ Date __________
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A Mindfulness Exercise for Engineering Students

To any engineering students entering or in their 4th year at UVA, I hope this paper can offer some perspective to you. My experience is my own, but I believe we can always learn from sharing our experiences with one another.

Before reading this paper, I'd like you to pause and reflect on your own engineering experience so far. The following are questions and reflections I regularly contemplated and that regularly frustrated me, but were nonetheless important to my personal growth:

What is an engineer to you? What would you say an engineer's defining characteristics are? Think about the people and experiences that informed this image of what an engineer is in your mind. Hold this image in your mind as you contemplate the subsequent questions.

How much do you match your image of an engineer now? Has your academic career guided you towards that image? Think back to various lectures, assignments, and projects in your curriculum: for each of those things considered how much or how little it contributed to helping you match your image of an engineer.

What is most important to a practicing engineer? This can be skills, knowledge, ethics, or a mindset. Think about person or experience gave you this insight into what is valuable to practicing engineers. Ask yourself why you believe it to be true.

What are your values? This has nothing to do with being an engineer. What is important to you? Think slowly and without effort. Let any past experience not matter how trivial, any part of your life no matter how distant, answer this question. Sit with the thoughts that come to you for a few moments. Compare your values to your image of an engineer. Ask yourself how you can integrate your values into that image.

I hope this was helpful. I wish you all the best in finishing out your time at UVA!

Thesis Statement

Our 4th year prepares us students for engineering work in two ways that are different from our previous years' curricula: First, we take part in a year-long capstone project to exercise the technical principles we've learned up until that point. Second, we work on our STS thesis, which along with the associated courses provides us with ethical and social context for our work as engineers. These parts of our education are valuable stepping stones to between our studies and the professional world. How well are the goals of these course achieved though? In this autoethnographic paper, I will explore my evolving perspectives as I worked on my capstone and in my STS course and share some insights I've gained. It is now my belief that communication and engagement with a client and a project's social context is an equally foundational pillar as technical rigors and due diligence to engineering.

4th Year Experience

Before 4th year even began, I was quite idealistic (and I don't think I was alone). Up until that point I had been given lots of technical engineering education and was confident I could solve "real world problems" by applying engineering principles to them. It was a continuation of the mindset instilled at a young age of, when you're given a math or science problem, there is a solution, you need to find it.

The capstone project I selected at the end of 3rd year was for the City's Stormwater Utility where a site was experiencing localized flooding. I chose this project for three reasons: Frist, it was most similar to my coursework, so I felt I would be there most useful on that project rather than another. Second, it was local meaning we could see the site we were working on; this tangibility was important to me. Finally, it was related to existing work the advising professor was doing and had students from other departments; these were factors I felt made it seem more like "real work".

When 4th year began, our team met and we learned more about the project site: The issue causing the flooding was a collapsed pipe running under a private property. The owner did not want to grant an easement to the City to repair and maintain the pipe. While the Stormwater Utility explored the option of an alternate pipe construction and easement, they tasked us UVA students with exploring alternatives. My initial reaction to this situation was confusion. I found it strange there was flooding so far from the river. I doubted the severity of the problem. The situation felt like a contrived scenario for which the local University students could work some calculations.

Over the next few weeks, we had some site visits and meetings with the Utility. Our aim was to define the scope and constraints of the project so we could get to work on a technical solution:

> "So we can't affect the property with the collapse, what about the one with flooding?"
>
> "We've tried to reach out to the landlord who lives out of state, but we haven't heard back from them."
>
> "Have you talked to the tenants? Have they reached out to the landlord?"
>
> "The tenants don't speak English well. Despite the severity of the flooding, we only know because the neighbor across the street reached out to us."
>
> "Okay… So, what about the properties up-slope across the street? Are those part of the workable area?"
>
> "The neighbor that contacted us has expressed willingness, however we don't know about the other neighbor. There's not much of an incentive, but they might help out of the goodness of their heart."
>
> "Right…"

I found myself frustrated with the lack of a clear path ahead. Even more frustratingly, the simplest solution wasn't even technical, but social, and by contrast, the technical solution was caught in that social quagmire bound by all manner of non-technical constraints.

In in parallel with our capstone was our STS coursework. I had enrolled in a new version of the course with a focus on community engagement, a global perspective, and mindfulness. I tried to keep an open mind about how this would work out since those all sounded like good things. To me what was important was to get some useful tools for shedding light on these “social problems” that were currently frustrating me in my capstone.

I think the course spooked quite a few of my peers from the very start. In the first week, there were guided meditations and talk of a project that to many sounded like a second capstone. I had a friend who switched into a different section after the first week. Many, including myself, were very unsure of what to expect and unfortunately that set the tone for many for the remainder of the fall semester. The projects were topics we could choose from suggested list, or make our own, that we would explore with STS frameworks and create an ePortfolio as a means of visual storytelling. The intent was a compelling multimedia portfolio is better to engage the people in the communities where these projects would be.

I selected a project topic about an augmented reality (AR) sandbox where the sand could be pushed around under a projector and storms could similar waterflow across the topography. While the AR part I was a bit wary of, it seemed to involve stormwater which was the closest to my capstone, and I like many others wanted to have as much crossover as possible between my capstone and STS prospectus to minimize the workload. The rest of my group was drawn towards the topic because it mentioned AR or because it was what was available. As we learned STS frameworks like value sensitive design and actor network theory, we found we were having trouble tying it to our AR sandbox in a meaningful and compelling way. This only compounded on the initial frustration we had with the course and I noticed some of my groupmates becoming apathetic to not just the project, but the content of the class as well.

In addition to the main STS section, we were also enrolled in a lecture. It was a joint effort between our STS professors and the provost of academic outreach that aimed to included community engagement principles into the engineering curriculum. I was especially interested in this section because it seemed like it could be very relevant to my capstone. Country to the main course, this discussion section being more relaxed fostered more frequent participation from the students. Though very interesting conceptually, I found myself struggling to crystallize frameworks into thoughts I could readily apply to my capstone. Throughout the semester we would learn local, conceptual models, and listen to many guest speakers on the topic of community engagement. It all seemed like valuable information albeit removed from both my STS project and my capstone. The discussion section offered great material; however, we were a bit fatigued some days from the main lecture part of the course and didn't always absorb as much as we could've.

By the end of the semester I had completed my prospectus and we had presented our final STS digital project. It certainly felt like pulling teeth sometimes to motivate myself and my group to reach this point. My prospectus focused on NIMBYism which is when people deny works that serve the public good because there is a cost to them individually. This seemed to fit the social situation in my capstone. Additionally, I did my best to use what I learned from that writing as a guide of what not to do for our project. We ended up scraping the AR sandbox idea in favor of a collection of murals that would be made by local artists that would be spread across town. There would be an app inspired by the We Are Martinsville app which overlays information when scanning over landmarks. We felt this would be a good way to "engage the community". However, during our poster presentation, I had an epiphany while answer questions about getting school kids involved in making the murals. That made perfect sense; kids are very receptive to new ideas and communities love things made for kids. It was then I realized the value of the AR sandbox we had tossed aside which would have been a fantastic children's activity. It was almost laughable how we had spent so much time spinning our wheels frustrated and not understanding where the course material was taking us and why, only to have it all click at the end. At that time, I wondered if the journey had to be so painful, but was nonetheless grateful I had come to some realization from all of it. There was still uneasiness however, as I still didn't feel I had the full picture.

In the spring semester, I noticed many in my previous STS section had switched out. It seemed the deviation from the norm was too great for a lot of people. We shifted focus towards ethical systems, specifically contrasting Eastern and Western engineering ethics. At first most of this content felt similar to the principles of community engagement that emphasized context matters. However, we were also paired with Chinese students to discuss some ethical prompts from class. I found that when discussing them with my Chinese partner I intuitively began to grasp the concepts better being forced to communicate across cultural lines. This experiential synthesis happened when I went to the City's town hall meeting just to observe. I saw the differing groups advocating for themselves in the context of land and housing development much like the community engagement seminar described. I saw elements of NIMBYism that I had researched for my prospectus. I was given these and other opportunities to watch these real-world systems play out and connect the dots. I remember getting a thrill off of having these concepts begin to click.

Throughout the fall semester and more so throughout the spring, we were given the opportunity to listen to many professional engineers share their experience. It was interesting to see how the work they talked about differed from mine, but also how it was similar. I wondered what experienced were it that would fill that gap. I wondered how they applied the concepts of ethics and community engagement to their practice. Overall, those workshops and guest lectures were encouraging with respect to dealing with challenges, like what I was facing in my capstone, pragmatically. They also instilled a sense of individuality to my conception of being an engineer and I began to believe that solutions engineers find will necessarily vary person to person in some way or another.

Meanwhile, work on the capstone had begun to feel sluggish. Our results were not what we were hoping for. On top of that it was still hard to shake the frustration had from the social dynamics that formed our constraints. These two factors made our project feel like an absurd and futile effort at points. I had begun to sense that the community engagement principles would gain the most traction by interacting with people, but what if the people involved didn't want to engage? Thankfully, our advisor gave us some very useful advice:

> "Focus on creating a narrative even if your data isn't doing what you expected it to do. And remember that you're providing this information for a decision maker, so think of the presentation from their perspective."

It seemed quite obvious once I heard it. Our job is to collect data with consistent and reliable methods and communicate our results clearly. There was no solution we should be trying to force. The narrative is to give context to our findings. This was an important perspective shift for me and one instilled in me a sense of confidence much like I had at the beginning of the year, but this time with a more resilient mindset.

At the beginning of 4th year, I thought that engineers found solutions to problems, however, social factors seemed to muddy that simplicity. When STS and community engagement concepts were firsts introduced, I learned my initial mindset was in fact potentially harmful. My perspective changed to believing that one must apply this STS principles to a problem in the same manner you would engineering principles, however, while this broadened the context and promised a more nuanced solution, it was still forcing a solution. It was only once I began observing my local community on matters similar to my capstone that I started to synthesize the knowledge being handed to me by my professors. I realized the frameworks can describe behavior, not predict it. Finally, in writing my capstone report, I learned the value of communicating for the sake of the client who is the one actually making the decisions. I now see engineers as navigators whose education is a collection of maps and tools. It's the people we work for that decide what the start and end points are and the engineering determines how to get there with their input along the way. Because engineering is necessarily a back and forth relationship, I believe now that being able to communicate the technical, ethical, and social frameworks that inform a design is just a foundational to the practice as proficiency in said frameworks.

A Retrospective

In recounting my 4th year experience to others, I talk about my struggle in figuring out what engineers actually do. What's our role to society as a whole and tow the communities we operate in? How do our professional and personal ethics interact with our design process and our relationships with our clients and the community? I know myself as a person who ruminates on matters of meaning and value and this process was a prime example of that. I feel as though I went in one great circle, starting from a high point of confidence, plummeting into confusion, and then crawling my way back up with a new, richer perspective informed by the journey. I hold my beliefs now on the importance of communication and social context for engineers because I experienced and participated in my capstone and STS courses and was exposed to a broader community than my normal peer group. It was the process of finding my way along that path with the guidance of my professors that was so valuable to my growth.

While I consider my education experience in 4th year extremely valuable and transformative, I know that my experience is only my own. I was aware of this through out the year as well and continually wondered if my peers were getting the same value out of their work that I was. Rulifson et al (2019) did a longitudinal study over 4 year measuring engineering students' view of the social responsibility of engineers. Factors such as socially minded parents, high school teachers, and volunteering correlated with a high social responsibility (SR) score while emphasis on technical course work and corporate internships correlated to a more "confided" view of social responsibility. This tracks with my experience of apathetic groupmates in the fall semester; they were very technically oriented, had internship experience, and were very focused on apply for jobs throughout the semester, but they were uninterested in the content of our STS course beyond meeting deliverables. However, Rulifson et al also noted that students with low SR scores did see significant increases over the course of the study. In my interactions with these groupmates, understanding their feelings on the course was often the determinate of if a discussion was productive or not. This leads me to believe that understanding a person's initial awareness of social responsibility is the first step to getting them to at least interact with the theoretical frameworks of social responsibility.

Regardless of initial awareness, how students process new information can run into difficulties. Plemmons et al (2006) used a qualitative metric to evaluate students' perceived efficacy of ethics courses. The three aspects that course was measure to improve were knowledge, skills, and attitude. It was found that most often students reported they gained new knowledge, rather than new skills or a change in attitude. It was also noted that students by then have well formed attitudes and confidence in their skills. My frustrations with my ethics and community engagement coursework were from the difficulty in synthesizing knowledge into new skills and attitudes. I believe without catalyzing experiences or guidance people will default to their known skills and attitudes. McGinn (2003) investigated students' perceptions of ethical issues in professional settings; they found that they varied greatly in what they considered ethical issues and how to approach them, and many defaulted to moral relativism. I shared a similar habit of assuming subjectivity before I went to the town hall meeting and had a clear example of individuals being affected by design choices of housing developments. In person experiences were powerful tools to help me digest the abstract concepts.

Once students gain proficiency with theoretical frameworks, there is still the matter of communicating these ideas in their designs. In a study of six different engineering firms of varying sizes, Anderson et al. (2010) found that communication skills were the most highly valued. On interviewee from the firms even went as far as to say that communicating plans to those outside the field was what separates engineering from hard science. Not only was communication valued for interacting with non-technical individuals, but also for interacting with teammates. It was stated that the individual engineers most valued their proficiency with an array of communication and coordination abilities in their work.

Regardless of what understanding professors may have of their students or ways in which they wish to prepare them, there is still a very real time restriction. How much theory should be covered and how many interactive experiences should there be? Edström (2018) reflects on the ongoing tension between focus on academic, theoretical content and professional, pragmatic content in engineering curricula. They say the balance should not be determined by "how much" of each should receive focus, but rather how to have a tight relationship between theoretical and practical education. Looking back, I see my 4th year as full of both practical and theoretical content, however they were not tightly linked. I was fortunate to be given time and space to bounce between the two. From my vantage point now, I don't think the theoretical knowledge I gained would have been meaningful without the practical experiences and vice versa.

Looking back on my 4th year experience, my courses and capstone project succeeded in teaching important lessons and providing valuable experiences. However, the specific path I took was challenging and stressful to say the least and downright painful at times. My capstone project while frustrating at times, offered great practical, tangible experience of working in a real setting with complex social dynamics and requiring use to observe and navigate them. My one criticism is that there wasn't much structured overlap with the STS section: most of that thought and reflection was done on my own. I think my peers similarly had valuable capstone experiences as well. My STS portion of 4th year was a challenge. While it succeeded in imparting so much meaningful insight to me, it was only after frustration and confusion of working my way through it and having to will myself into finding meaning in it. More importantly though, I feel the particular STS courses I took failed to impart the insights I gained onto many of my peers. There were attempts made to check in with us, but the initial shock of differentness made so many reluctant to engage for most of the semester. I feel the format has a lot of important content to offer, but can only be successful if successful if an active and open dialog is maintained between the instructors and students. I think the class size was a detracting factor. I believe had the class been smaller, similar to the size of capstone groups, that open channel of communication would be easier to maintain. Regardless, despite some failures, I hope such a course continues and improves so that students can gain the full benefit of it. I believe if the value and importance of communication and engagement are made clear both in the STS course and in engineering education as a whole, students will be able to associate those skills with their idea of a “real world” engineering and be more receptive to knowledge offered by STS courses like in my experience.

Conclusion

My journey through 4th year was not a simple or easy one, however, the experience as a whole was essential to my growth as an engineer. I was presented with a variety of practical experiences and new knowledge that enhanced on another and together shaped my perception on what it means to be an engineer. I now believe that effective communication and engagement with the social context of projects is just as foundational as technical skill and ethical conduct. Echoing Edström’s sentiment, I believe these pillars should be taken as whole and cultivated in a way that each reinforces the other. It is because of how meaningful this experience has been to me that I’ve shared and analyzed it in this autoethnographic format. I hope for this to be a useful perspective for my professors, my peers, and most importantly for future students. The journey does not need to take the same path as mine, but I believe such a journey is necessary to foster a full appreciation for all that is taught at our University and to set the stage for engineering work in the “real world”.

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Prospectus

Reasons to Infiltrate: A Case Study of Localized Flooding in an Aging Stormwater System

(Technical Report)

The Many Faces of NIMBYism and Their Roles in the (Re-)Development of the Built Environment

(STS Research Paper)

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Kevin “Connor” Corcoran

Fall, 2019

Department of Civil Engineering

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Introduction

The capstone project is focused on identifying a range of potential solutions to mitigating localized flooding caused by a collapsed pipe on private property. The site has a variety of social dynamics at play that the physical solution must take into account. The City has limited right-of-way in which to implement solutions without the cooperation of owners to acquire easements. Some owners are willing to work while other are not or are just unresponsive. The technical solution aims to reduce the flow as much as possible before it gets to the pipe, however this comes with its own costs. The STS thesis dives deeper into the social dynamics around NIMBYs (Not In My Back Yard) to potentially provide insights as to why certain owners are willing to help and others are not. In this research, frameworks describe NIMBY behavior as a reaction to burden that would be place on subgroups or individuals, however that reaction differs in its effectiveness depending on the power the aggrieved party has. Finding ways to incorporate benefit into design solutions therefore becomes very important in gaining the cooperation of resistant parties. The technical solution seeks to not only mitigate the flooding in this locality, but also serve as a case study for the greater benefits of runoff reductions strategies over traditional conveyance as a stormwater management practice.

Technical Topic

The stormwater utility of the City of Charlottesville has asked our capstone team to investigate and provide input on a site that has experienced flooding during heavy rain events. The site is located on St. Clair Ave. just south of the US-250 bypass. The cause of the flooding is a collapsed pipe which causes a storm drain to back up, overflow, and flood a rental home. The civil engineering majors, Jane Long and I, were specifically tasked with modeling the existing hydrology of the catchment flowing into the collapsed pipe and use that model to provide potential solutions to mitigate the flooding.

Our investigation began with a site visit with the stormwater utility. They explained the nature of the collapse and their current options in more depth and provided us with GIS topographic and utilities data. We were able to ask clarifying question in later meetings with them as well. Not only is the pipe collapsed but also collecting substantial debris as well. The collapsed pipe goes under a retaining wall of the house adjacent to the home that gets flooded. The owner of that property is unwilling to grant the City and easement to repair the pipe, however they are open to the possibility of an easement for a new conduit on the opposite side of the property provided the City goes under an existing retaining wall on that side. The two up-slope properties contributing the most to the catchment flowing into the blocked storm drain have both recently added in new driveways. The new grade may not be accounted for in the existing GIS topographic data. The south property was the one that brought the flooding to the City's attention and seems willing to help implement solutions. The north property has not been contacted yet.

With this data and information, we have created a preliminary model of the catchment using GIS and SWMM, a stormwater hydrology modeling software. We have determined that the majority of the up-slope catchment is on the south property and offers the greatest potential for infiltration BMPs (stormwater Best Management Practices). We modeled heavy rain events for 1, 2, 5, and 10-year design storms and found the highest peak flow to be approximately 19 cubic feet per second. Currently the peak flow value lacks context since we do not know how much flow would cause the pipe to flood.

Going forward we plan to focus on proposed designs that infiltrate as much water as possible before it reaches the blocked pipe. While this does address the issue of the of the blockage itself or the collecting debris, we believe that this site could serve as a valuable example of the merits of retention and detention-based stormwater management versus the tradition conveyance method.

Specific tasks going forward will include the following:

- Sensitivity analysis of our preliminary hydrology model.
- Determine the flooding threshold of the collapsed pipe by looking at precipitation conditions around the times of reported flooding.
- Additional site visits to verify the topographic data of key locations in the catchment.
- Preliminary design of BMPs and testing capacity for flow reduction in our hydrology model.
- Cost estimation of proposed BMPs, to in include research into state and local programs that will partially fund them.
- Cost comparison to the possible alternate conveyance route underneath the retaining wall.

STS Thesis

Communities have two spatial components: the social connections that tie its members together and the geographic locations in which its members reside. It is incredibly common, especially in urban areas, for multiple communities to anchor themselves in the same geographic location. However, because these geo-spatially overlapping communities have different values and resources, they don't necessarily always agree on how to manage their common spaces. Constituent communities might all agree that there is an issue that needs to be address in their common spaces, but if one or more groups does not want the solution near them then they are NIMBYs (Not In My Back Yard).

Ideally there is some equitable solution that reconciles the varied values and resources of constituent communities when managing their common spaces. However, it becomes increasingly difficult to strike a balance the larger the constituency of a common space gets. Government and markets are two systems that attempt to find this balance. For stormwater in particular however, the methods for dealing with it in common spaces are embedded in infrastructure like roads and sewers which are managed by local governments. Therefore, to achieve equitable stormwater solutions, governments need to have a solid understanding of constituent communities' values and resources and facilitate inclusivity in their decision-making process.

In striving to implement these values in governance however, NIMBYism will inevitably arise. NIMBYs can bring policy and projects to a halt if they have the numbers and resources. But what does the appearance of NIMBYs indicate for the efficacy of the decision-making process? And is NIMBYism a natural part of the dialog or is it something that needs to be mitigated?

Infrastructure, such as stromwater systems, aim to provide some service to the common good. NIMBYs value the service in theory, but oppose the proposed location. However, R. W. Lake points out that "Rather than necessarily and inherently fulfilling a societal need, LULUs [Locally Unwanted Land Uses] represent a particular solution to a problem." (Lake, 1993). By decoupling the solution's theoretical value to society from the implementation itself, we can better see all the values that informed to the design of the implementation. Through value sensitive design, we can see that while "serving the common good" is a value, so too were "economic efficiency" and "political support". From this we see that NIMBYs do not necessarily arbitrarily oppose solutions near their communities. Instead, they with the allocation of resources to provide that solution because it does not align with their values.

Value sensitive design done well should be able to create designs that do not spawn any NIMBYism, however there are other social factors that prioritize some communities' values over others. Different demographics can be categorized along two axes: power and social construction (either positive or negative sentiment) which describe how benefits and burdens are applied to different those groups (Ingram and Schneider, 1993). Groups with more power and positive construction have their values prioritized in informing design solutions. They design is such that they receive benefits and disproportionately few of the burdens. Those that do take on the burdens are likely to protest and be labeled NIMBYs. To complicate the matter however, the NIMBY label has been applied to both powerful groups that want to avoid any burdens and powerless groups that have already been saddled with them, which “makes it difficult to reconcile with radical and progressive intentions” despite being accurate (DeVerteuil, 2013). For both versions however, NIMBYism is an indicator of exclusivity in decision-making.

As environmental health becomes a growing public concern and existing stormwater infrastructure continues to age, there is a need to improve stormwater systems in common spaces. With the need for infrastructure improvements however, NIMBYism is likely to arise. The technical topic above for example outlines how some property owners do not want to allow the City to make repairs. The values of the City, the tenants, and the property owners all vary. Traditional conveyance designs are not sufficiently supported by these collective values to move forward with implementation. Another example is the ongoing discussion in Albemarle County on how to fund improvements to the stormwater infrastructure. Their first implementation of a stormwater utility fee, dubbed “the rain tax”, was a complete failure after huge backlash from the rural population and “125 farmers with tractors showed up to protest at a County meeting say the rain tax would threaten their livelihoods” (Baars, 2018). The same policy however, was implemented in the City of Charlottesville without any NIMBY backlash, so how did the two differ? Over a year after that incident in a debate for Board of Supervisors, incumbent Ann Mallek stated: “the grand majority of [stormwater] work was going to be done in the urban ring, and two, the grand majority of the money was going to come from the rural area” when explaining why she removed her support for the rain tax (Wrable, 2019). The inequitable allocation of burdens and benefits of the rain tax caused it to get shot down because the County made an effort to be inclusive.

Going forward, I will to investigate instances of NIMBYism in the Charlottesville are as it relates to stormwater to determine the underlying values of the design and the groups that oppose them. Specifically, I will attempt to determine the value commonalities between rural and urban citizens of Albemarle as well as their differences. These shared values can be brought forwards to create value sensitive designs that are of use to these communities.

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