MEADOW CREEK STORMWATER MANAGEMENT

THE EFFECT OF GREEN INFRASTRUCTURE ON EQUITABLE ACCESS TO ECOSSYTEM SERVICES

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Civil Engineering

By
John Gore

November 1, 2021

Technical Team Members:
Neha Awasthi
Burke Haywood
Shreya Moharir
Annalee Wisecarver
Rachel Yates

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.

ADVISORS

Catherine Baritaud, Department of Engineering and Society

Teresa Culver, Department of Engineering Systems and Environment

Stormwater management is a critical component of every community's infrastructure that needs to be continuously evaluated and developed in order to respond to modern conditions. One such emerging condition is climate change and what that entails for environments across the globe. In Virginia, regional precipitation has already increased anywhere from 2 to 20 percent since 1901(U.S. Environmental Protection Agency, 2021, Figure 3). Howarth, Thorncroft, and Bosart (2019) found similar increases in regional precipitation in their study and an increase in the frequency of severe weather events such as hurricanes and extreme precipitation events. Therefore, the need to properly maintain and develop future stormwater infrastructure is crucial for communities to adapt to the inevitable effects associated with climate change. One emerging approach is the use of green infrastructure in managing urban stormwater runoff. As defined by the U.S. EPA (2021), green infrastructure includes a variety of natural and engineered systems that provide stormwater benefits related to runoff reduction, storage, infiltration, and treatment (What is green infrastructure, para. 3). Furthermore, established stormwater infrastructure has documented age-related deficiencies that are resulting in decreased stormwater capacity. In an effort to transition stormwater infrastructure into a time that requires climate resilience and adaptability, green infrastructure is being used to provide communities with stormwater management that is sustainable, resilient, and better for water quality than traditional "grey" infrastructure (Shade, Kremer, Rockwell, & Henderson, 2020).

With this knowledge in mind, the technical component for this project will consist of a site redevelopment of Fashion Square Mall within the Meadow Creek watershed. The watershed has experienced significant degradation due to urbanization and the increase in impermeable surfaces that accompanies that. As such, the watershed is now considered impaired and in need of intervention to restore the waterbody to a healthy state (Virginia Department of

Environmental Quality, 2020, p. 27). In order to improve the health of Meadow Creek, this technical project will use green infrastructure to redevelop Fashion Square Mall and retrofit it with needed stormwater infrastructure improvements that address modern climate. This site redevelopment will design and plan green infrastructure for Fashion Square Mall in order to improve the quality and volume at which stormwater runoff leaves the site. In conjunction with this work, a tightly-coupled research project will be undertaken detailing the consequences that community residents face due to the lack of green space and natural habitat that results from urban development. This research will also explore to what degree these consequences can be prevented and alleviated through the implementation of green infrastructure that can restore and mimic the ecosystem services provided by the original landscape and fauna. The research will be performed and studied using the Actor Network Theory model as outlined by Michel Callon, Bruno Lator, and John Law (Cressman, 2009).Furthermore, the technical portion of this project will be undertaken by a group of undergraduate students within UVA's Civil and Environmental Engineering department that includes Neha Awasti, John Gore, Burke Haywood, Shreya Moharir, Annalee Wisecarver, and Rachel Yates. This work will be advised by professor Teresa Culver of the Civil and Environmental Engineering department. Additional technical assistance will be provided by graduate student Seth Herbst and professional engineer Don Rissmeyer. In addition to this, the research component of this project will be advised by Catherine Baritaud from the department of Science, Technology, and Society.

As shown below in Figure 1 (Gore, 2021), the technical and research components of this project will be performed over the course of the 2021 fall and 2022 spring semesters. The technical work will focus on site design and planning in the fall and assess the performance of the interventions in 2022. Work related to the research component will be undertaken and completed in spring of 2022 through the STS 4600 course. Both the final technical and research projects will be completed and submitted for review at the end of the spring 2022 semester.

FALL SEMESTER: September, October, November, December | SPRING SEMESTER: January, February, March, April

	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION (DAYS)	PCT OF TASK COMPLETE
1	Project Conception and Initiation					
1.1	Background Research	All	9/1/21	9/30/21	29	100%
2	Project Definition and Planning					
2.1	Scoping	All	9/15/21	9/29/21	14	100%
2.2	Scheduling	All	9/29/21	10/6/21	7	100%
2.3	Site Selection	All	10/6/21	10/31/21	25	100%
3	Project Launch & Execution					
3.1	Green Infrastructure Planning	S C B	11/1/21	11/15/21	14	0%
3.2	Green Infrastructure Design	C B S	11/15/21	11/30/21	15	0%
3.3	iTree Model Creation	C B N	11/1/21	11/30/21	29	0%
4	Project Analysis					
4.1	Climate Impact Analysis	S C R	1/20/22	2/15/22	25	0%
4.2	Comparison of Alternatives	All	2/16/22	3/14/22	28	0%
5	Project Reports					
5.1	Fall Semester Final Report	All	10/15/21	12/7/21	52	0%
5.2	Final Report	All	3/15/22	4/30/22	45	0%
6	STS Thesis Deliverables					
6.1	Prospectus	Curtis	10/1/21	11/1/21	30	100%
6.2	STS Research Paper	Curtis	January	April		
6.3	Technical Report	Curtis	January	April		

Figure 1: Technical and STS GANTT Chart. The above figure outlines the schedule and pace of work for the technical capstone and STS thesis. (Gore, 2021)

MEADOW CREEK STORMWATER MANAGEMENT

The Meadow Creek watershed is located in Charlottesville, Virginia and is a tributary of the larger Rivanna River. The creek is currently ecologically impaired due to an excess of nitrogen, phosphate and sediment entering the stream from surface runoff. As such, Meadow Creek is now designated as impaired and requires total maximum daily load management (Virginia Department of Environmental Quality, 2020). Large amounts of impervious surfaces within the watershed create conditions optimal for fast moving runoff that carries pollutants and deteriorates downstream stream banks. According to Müller (2020), pollutants enter the watershed through a combination of atmospheric deposition and anthropogenic practices that introduce sediment, nitrogen, phosphorus, and a host of other substances onto the land surface. As Charlottesville and the greater community continue to develop, the increase in impervious surfaces and decrease in vegetation creates more strain on Meadow Creek to filter and manage stormwater runoff. Climate change will also affect stormwater runoff because as temperatures change and storms become more frequent and more intense, the amount of water flowing will increase, therefore increasing pollutant loads.

The health of the Meadow Creek is vital because it eventually flows into the Chesapeake Bay. The Chesapeake Bay is the largest estuary in the United States and is between the Mid-Atlantic region and Delmarva Peninsula, eventually opening into the Atlantic Ocean. The Chesapeake Bay is home to a plethora of unique animal and plant species. It also serves as the primary source of income for many people, through fishing, boating and the presence of seaports. The Chesapeake Bay is in ecological despair due to impairments further upstream. This puts the lives of many plants, animals, and humans at risk and could lead to the collapse of an entire watershed and associated ecosystems. The project team plans to address these upstream issues in the senior design capstone project.

Taking several factors into consideration, the Fashion Square Mall was chosen for a redeveloped stormwater management design. The Fashion Square Mall is located within the Meadow Creek watershed, directly off of Route 29 and approximately 5 miles from the University of Virginia (Figure 2). In June 2021, the mall was filed for bankruptcy by its owner, and it was auctioned off to Charlottesville JP a month later (Hirschheimer, 2021; Hammel, 2021). With the new ownership, the mall is expected to be redeveloped, so the team took this opportunity to create a redesign that met the stormwater management needs of Meadow Creek.

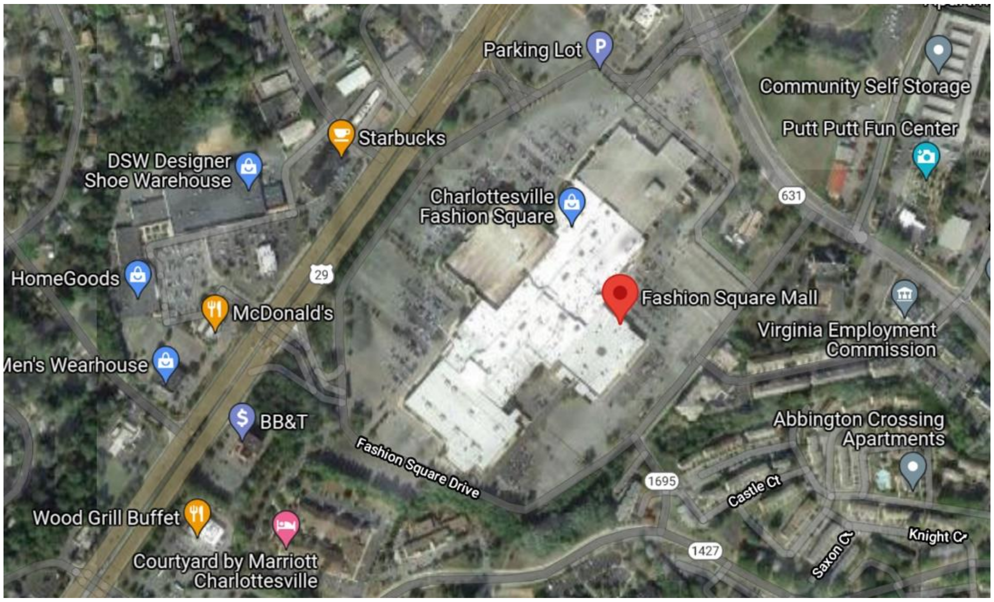

Figure 2: Ariel view of Fashion Square Mall. This figure displays the current mall site that has large amounts of impervious surfaces. (Gore, 2021)

A key component of the team's stormwater management design at Meadow Creek is the inclusion of green infrastructure (GI). GI is a method of integrating nature into the built environment through the placement of vegetated land and structures such as rain gardens, bioretention ponds, and green streets. It is recognized for its ability to conserve natural environmental systems and provide a variety of ecological benefits including water quality improvement, air temperature reduction, and habitat provisioning (Gagne & Tayouga, 2016, p. 1). It is particularly beneficial for stormwater management since it provides a method of naturally percolating and irrigating stormwater runoff before it is discharged into downstream water bodies. Additionally, green stormwater infrastructure controls excessive outflow by using precipitation to hydrate vegetation. For instance, green roofs can retain between 5 and 100 percent of rainfall (Gagne & Tayouga, 2016, p. 2). The goal of integrating GI into the stormwater management design of Meadow Creek is to reduce the impervious surface on which runoff travels, therefore reducing pollutant pickup and improving the water quality in the watershed.

The second key component in the team's design is a climate change analysis. As climate change worsens, storms grow in intensity and frequency. Over the past few decades, the Chesapeake Bay Watershed has faced an abundance of extreme weather events. In 2019, the watershed experienced a historic amount of rainfall and flash floods. The watershed is projected to have an eight to twenty percent increase in events that produce extreme precipitation by 2099 (DeGaetano et al., 2021). The team plans on evaluating how the GI design will be affected by potential extreme weather events in the future. Additionally, they plan to evaluate how the GI will potentially alleviate other side effects of climate change, for example, the urban heat island effect, which refers to the "phenomenon where temperature in urban areas is higher than that in rural areas" (Balany et al., 2020, p. 1). As climate change brings longer and stronger heat waves, urban areas grow warmer leading to health issues among the residents (US EPA, 2014). The GI design will incorporate design aspects that will lessen the heat island effect.

GREEN INFARSTRUCTURE AND THE SUPPLY OF ECOSYSTEM SERVICES IN URBAN AREAS

As urban areas grow and expand to accommodate growing populations, residents can lose access to green space and the greater benefits provided by greenery and nature. Beatley and Brown (2021) explore this topic deeply in their work and they explain how trends of urbanization and development have removed much of the original landscape and vegetation that allows an ecosystem to function healthily. This pattern is widespread and common throughout many cities as they require more space to be taken from native habitat. As native habitat is replaced with the urban build environment, the ecosystem services and benefits provided by soils, vegetation, and wildlife are no longer available to community residents. However, as

Figure 3 shows, urban spaces and systems such as parks, trails, and street tree canopies can combat this trend and provide urban residents with access to nature and the services provided by those natural systems. Unfortunately, the distribution of these systems often follows traditional patterns of investment and development that exclude less fortunate and disadvantaged social groups (Herreros-Cantis and McPhearson, 2021).

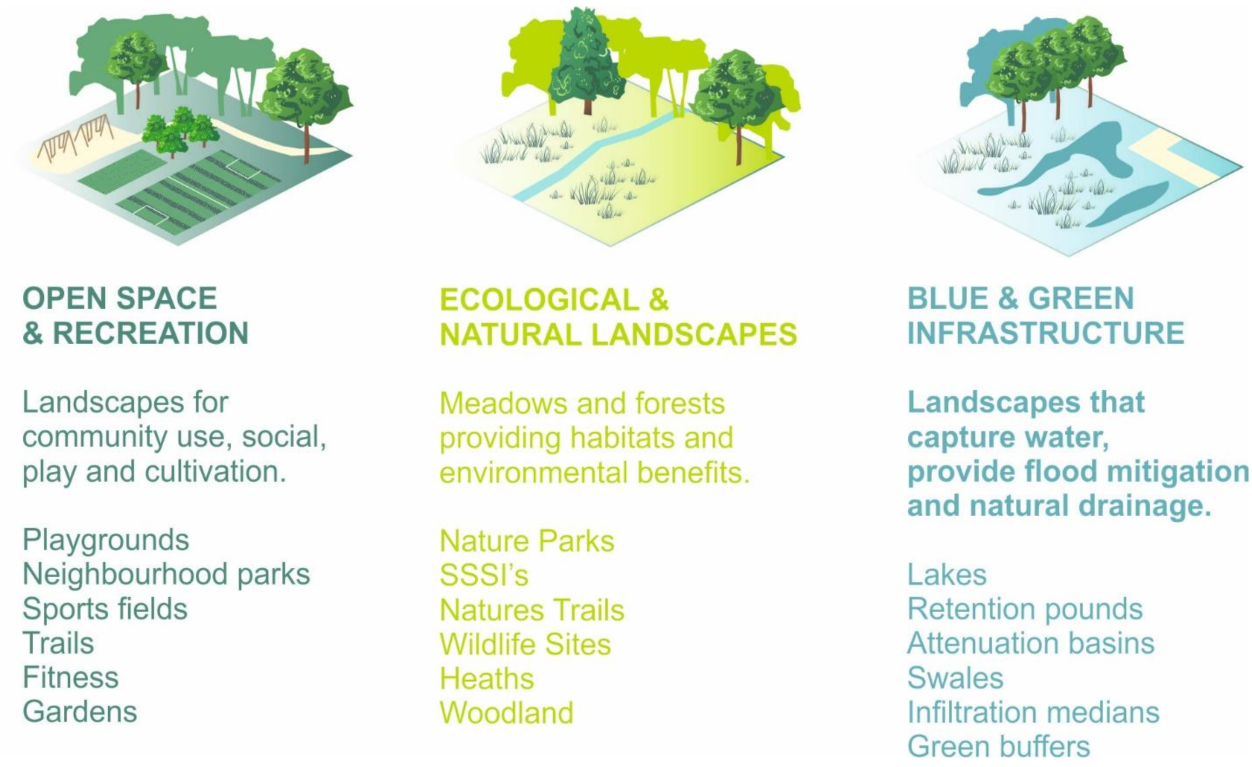

Figure 3: Types of public space that includes green infrastructure. The above figure provides examples as to where green infrastructure is commonly located in a community. (North Norfolk District Council, 2018)

Current research into green infrastructure has focused significantly on the relationships between implementing green infrastructure and ensuring that all social groups have access. This research has revealed that there are existing mismatches in the supply and demand for green infrastructure between different community groups (Herreros-Cantis and McPhearson, 2021). The existence of this trend and its continuation form the basis of the argument that many social groups in urban areas are experiencing environmental injustice through a lack of access to green infrastructure. For instance, Mandarano and Meenar (2017) found that the city of Philadelphia was perpetuating this pattern by promoting the inclusion of green infrastructure in new developments, while failing to retrofit existing communities. While the lack of service to these communities is researched and published, the associated effects that this lack of service has on a community is less understood.

Therefore, it is the goal of this research project to better understand how green infrastructure can play a role in providing communities with ecosystem services in urban areas devoid of their original landscape. Depietri and McPhearson (2017) explain, green infrastructure can aid a city by combatting the urban heat island effect, providing habitat that promotes biodiversity, and providing open, public green space that many residents lack access to. Moreover, Figure 4 demonstrates that the benefits go beyond improving natural space and extend into the realms of public health and safety (EPA, 2017)

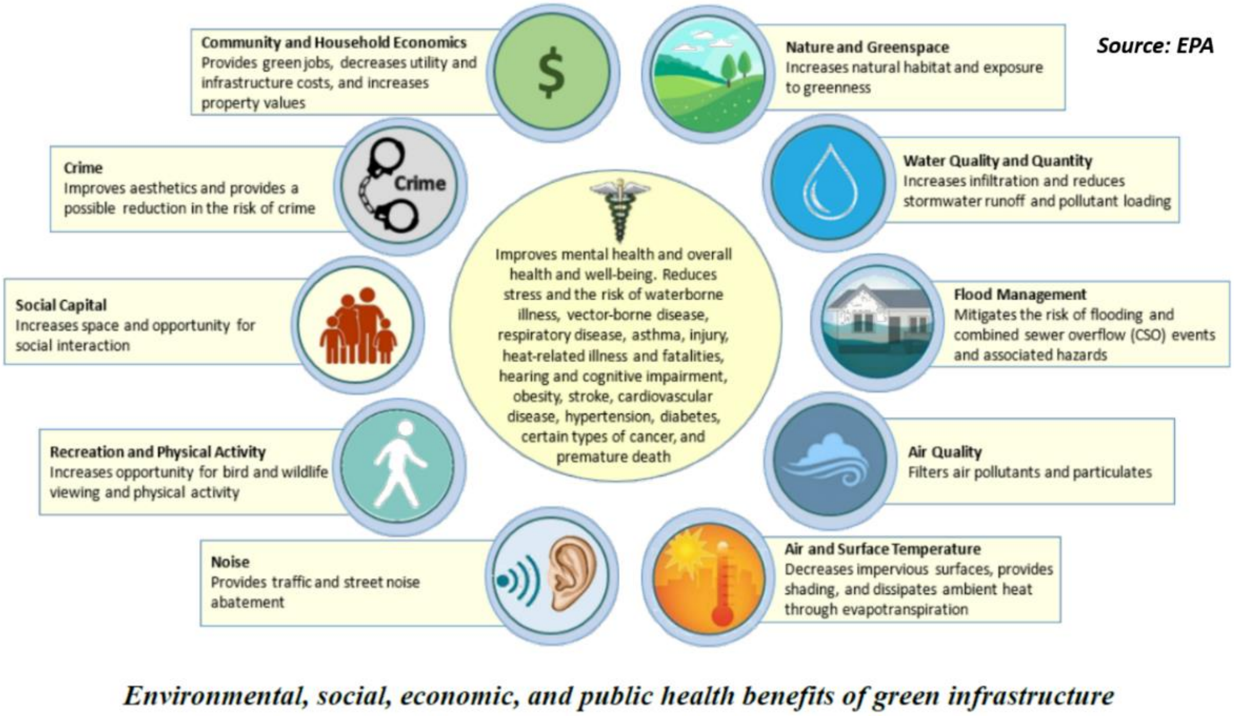

Figure 4: Ecosystem services provided by green infrastructure. The infographic displays the many different services green infrastructure can perform in a community. (EPA, 2017)

If it is possible for green infrastructure to provide these benefits while appropriately managing urban utility needs, then it makes sense to pursue developing these projects to address the threats of climate vulnerability that urban residents face now and increasingly in the face of climate change. Moreover, this research will show how green infrastructure can be used as multi-objective systems that can restore and promote greater community access to the ecosystem services that have been lost from past urbanization.

The methodology and framework in which this research will be undertaken will align with Actor Network Theory (ANT) as set forth by Michel Callon, Bruno Lator, and John Law (Cressman, 2009). By analyzing the different influences and social groups involved in green infrastructure and its creation, this research will demonstrate how current needs are met at varying levels of access across different social groups. This Actor Network Theory framework will allow the research to show why certain groups lack access to the benefits of green infrastructure and what causes these patterns of development and investment. As demonstrated by Figure 5, green infrastructure's development centers around the standards and rules of various institutions across society. Furthermore, by orienting the research around the needs and wants of different social groups, the project will be able to identify specific services that green infrastructure can provide to underserved communities.

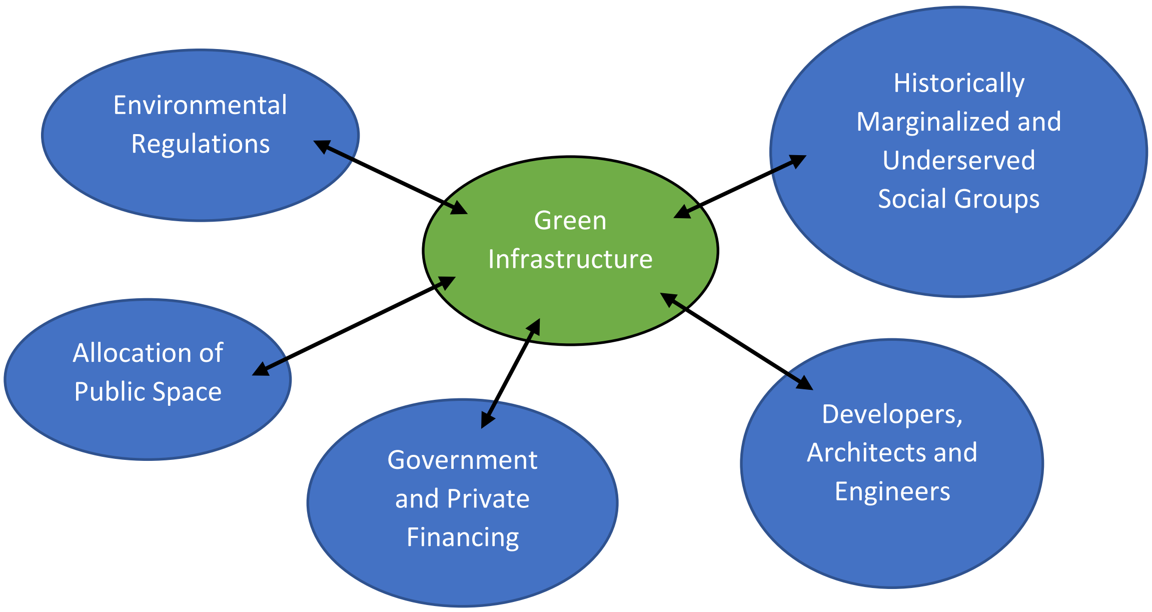

Figure 5: Green infrastructure ANT model. Green infrastructure's development is centered around the balancing of various environmental, planning, design, and financial considerations that can affect who has access to the benefits provided. (Adapted by Gore (2021) from Cressman 2009)

Ultimately, this research is being performed with the idea that it will demonstrate that green infrastructure provides far more to a community than just stormwater management. As such, the development of green infrastructure should be utilized to address the climate vulnerabilities that currently and will soon exist in society's dense, populous regions. By thoroughly researching and communicating these benefits, it is hoped that green infrastructure will be seen as a tool that can address the many issues within communities during a period of time that demands access and protection of marginalized groups. This research will be compiled in a scholarly article that seeks to both inform and promote the use of green infrastructure in addressing community needs.

THE GREEN TRANSITION

The technical and research components of this project are aimed at understanding and effectively using green infrastructure to solve issues of stormwater and beyond. Through the design for redeveloping and retrofitting Fashion Square Mall, the technical work will demonstrate the tangible stormwater benefits provided by green infrastructure. By exploring the community services provided by this infrastructure, the research project will demonstrate that green infrastructure is a solution to broad issues of public health, biodiversity, and overall quality of life. As these topics closely align, it is hoped that aspects and knowledge gained from the research will aid the technical design in providing an effective multi-objective plan that serves as many of the community needs possible. Ultimately, this work seeks to advance the knowledge and body of literature related to green infrastructure so that society may benefit from and maintain infrastructure that is resilient, inclusive, and efficient.

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