Technical Topic:
Using Green Infrastructure to Manage Stormwater in the Meadow Creek Watershed

STS Topic:
Addressing Inequities in the Experience of Green Infrastructure Benefits

A Thesis Prospectus
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By
Burke Haywood

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Technical Team Members:
Annalee Wisecarver, Curtis Gore, Neha Awasthi, Rachel Yates, Shreya Moharir

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.

Signed: ____________________________

ADVISORS

Kathryn A. Neeley, Department of Engineering and Society

Teresa B. Culver, Department Engineering Systems Environment

Introduction

Since it first appeared in early civilizations like Ancient Egypt and the Roman Empire, urban stormwater management has evolved very little until recent times. Much like the world's first cities, the majority of the developed world still relies on so-called "gray infrastructure" – the routing of stormwater (and in some cases wastewater) directly into surface water bodies using gutters, channels and pipes (Batts, 2020). This approach to management curtails natural groundwater recharge, results in dramatically altered flow regimes, and subjects ecosystems to a deluge of harmful chemicals and excess sediment (Subramanian, 2016). Because of the interconnectedness of surface waterways, these negative impacts can often be felt hundreds of miles downstream of cities with poor stormwater management, putting even some coastal ecosystems at risk.

In recent years, implementing green infrastructure (GI) – stormwater management techniques that use or mimic natural processes of infiltration, detention and filtration – has become a priority in many cities to improve the health of their surface water ecosystems and to address climate change resilience (Shade et al., 2020). GI has proven to be a cost-effective alternative to gray infrastructure, but it has not yet been implemented at an adequate scale, and failures in both policy and communication with the public about the importance of GI, have made it difficult to implement GI in specific locations that need it (Noe et al., 2020). In addition, the distribution of GI has been inequitable (with benefits favoring white affluent communities) and low-income neighborhoods inhabited by people of color where GI has been implemented have suffered from green gentrification (William, Endres & Stillwell, 2020).

Meadow Creek in Charlottesville, Virginia has a watershed which contains much of the developed land within the city. As a result of the watershed's high percent impervious land cover and the use of primarily gray stormwater infrastructure, stormwater runoff has caused substantial physical and ecological damage to the creek. The technical portion of the project aims to propose a GI design that remediates some of the watershed's stormwater management shortcomings and improves the health of Meadow Creek, while taking into consideration the implications that location, design and community engagement have on the overall sociotechnical outcome of the project. In the form of a literature review, the STS portion will summarize and draw from current STS research on the sociotechnical shortcomings of GI implementation, and ultimately serve as a guide to successful future GI initiatives.

Using Green Infrastructure to Manage Stormwater in the Meadow Creek Watershed

Meadow Creek flows through northern Charlottesville, Virginia draining an approximately 5,800-acre watershed into the Rivanna River – a system that eventually connects with the Chesapeake Bay on Virginia's coast. As shown in Figure 1, in the south end of the watershed, water drains into the system from the University of Virginia campus, and to the north along U.S. route 29, much of the contributing drainage area is composed of impervious cover associated with shopping centers and housing developments. Poor water quality and ecological health assessments by both local entities and the Virginia Department of Environmental Quality (DEQ) came to a head in 2012 when over a mile stretch of Meadow Creek was restored by the City of Charlottesville in conjunction with the Nature Conservancy and U.S. Army Corps of Engineers. Before the restoration took place, the stream had been listed as one of Virginia's "impaired waterways." The culprit for the stream's poor health, according to The Nature Conservancy, was "excess sedimentation due to uncontrolled stormwater runoff" (The Nature Conservancy, 2013). Excess sedimentation occurs when uninhibited runoff picks up large amounts of debris from unvegetated patches of soil, streambanks, parking lots, etc. These debris later settle to the stream bottom in a process called sedimentation. The result is severe negative impacts on stream biota via a plethora of mechanisms including but not limited to: elevated water temperatures, increased contaminant concentrations, buried stream-bed habitat, and decreased allowance of sunlight passage to submerged photosynthetic organisms (Noe et al., 2020, p. 2-4).

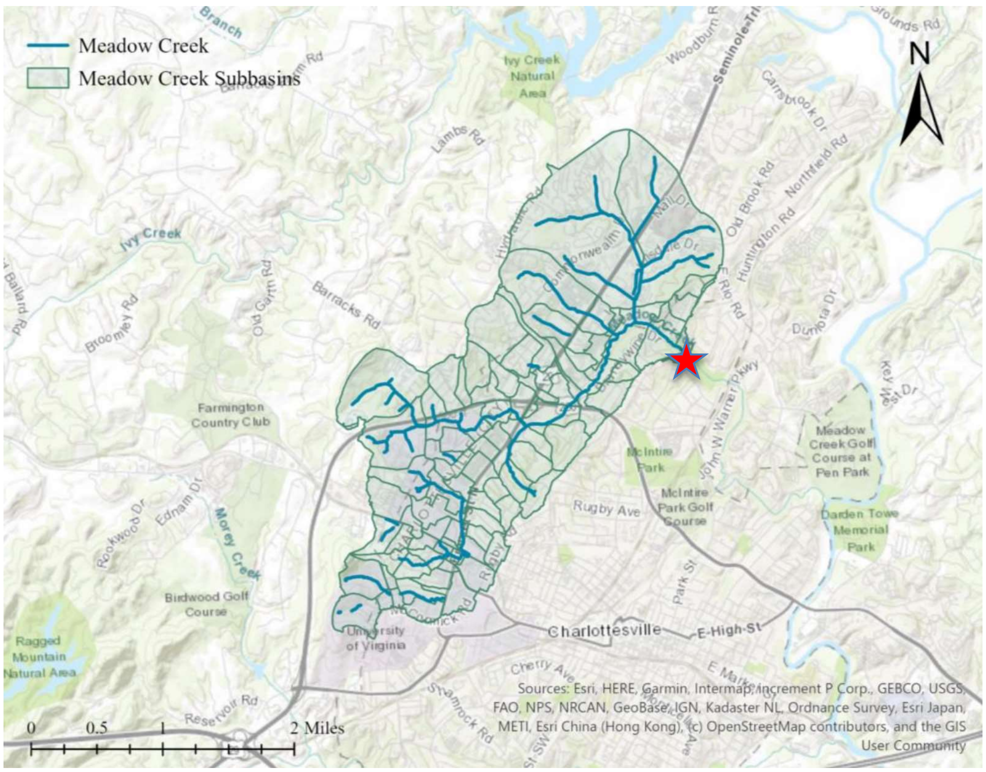

Figure 1. Meadow Creek Watershed in Charlottesville, VA (Stephens et al., 2021, pg. 4). All precipitation that falls within the watershed boundaries drains to a single outlet point indicated by the red star. Blue lines indicate where significant amounts of precipitation runoff accumulate to form Meadow Creek and its tributaries.

While the length of stream that was restored in 2012 appears more natural and is less likely to contribute to excess sedimentation due to its newly stabilized state, the restoration did not directly address the root cause of the problem – uncontrolled stormwater runoff. In addition, the majority of the stream remains unrestored and is just as vulnerable to excess sedimentation due to accelerated runoff and pollutants in runoff. Long-term monitoring of benthic macroinvertebrates downstream of the restored stream reach has shown improvement since the project, however, this part of Meadow Creek still scores below Virginia DEQ's impaired status threshold for aquatic life (Pence et al., 2021, p. 5). Beyond its local negative effects on the health of Meadow Creek, excess sedimentation in this watershed is contributing to the detriment of the Chesapeake Bay – the country's largest estuary. In fact, because upland urban streams like Meadow Creek are so susceptible to erosion, they are among the most important target areas to manage in order to restore sustainable sediment dynamics in the bay (Noe et al., 2020).

GI is becoming more and more common in highly developed watersheds like Meadow Creek because of its ability to reduce total suspend solids (TSSs), total runoff, and speed of runoff (Xing et al., 2021). In addition, filtration processes associated with many GI techniques can remove significant amounts of target pollutants including nitrogen and phosphorous (Xing et al., 2021). Figure 2 shows several typical GI practices as well as the beneficial processes that are associated with them. By implementing site-scale GI within the watershed, the project team intends to reduce total runoff and peak discharge in Meadow Creek, thus reducing excess sedimentation and pollutant loading.

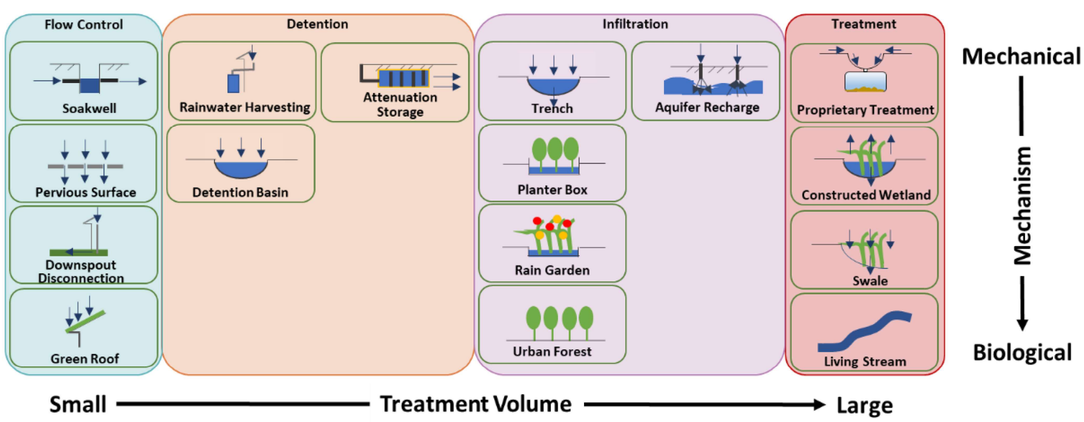

Figure 2. Green Infrastructure Practices (Xing et al., 2021). Differing GI techniques can provide a variety of different stormwater benefits like reducing TSSs and pollutant loading (Infiltration, Detention and Treatent), total runoff (Infiltration), and speed of runoff (Flow Control, Detention, and Infiltration).

In selecting a site for site-scale GI design, the project team will use GIS models of the Meadow Creek watershed that characterize sub-watersheds - or small watersheds within the greater watershed - based on a variety of technical and social criteria. Technical criteria include percent treated acreage, percent imperviousness and feasibility of GI implementation – based on slope, percent imperviousness and current land use. Social criterion including key demographic information like race, income, education etc. will be drawn from Environmental Justice Screening and Mapping Tool developed by the Environmental Protection Agency (EPA). Once a site is selected, land use and elevation data will be used to create models in two watershed and GI modeling software – iTree and SWMM. These models will enable the project team to consider many different GI implementation scenarios, allowing them to observe how each implementation affects the runoff parameters of the sub-watershed. This information will then aid in decisions regarding which and how much of each GI type should be implemented in the final design. Because one of the key co-benefits often associated with GI is added climate change resilience to both ecosystems and surrounding cities in which they are implemented, the project team also seeks to quantify how the final GI design will make both Meadow Creek and the city of Charlottesville more resilient to climate change (Shade et al., 2020).

Addressing Inequities in the Experience of Green Infrastructure Benefits

Along with benefits regarding stormwater management, analyses of the efficacy of GI often report the positive effects that GI can have on the quality of life of people living in nearby communities. For instance, a study conducted in Portland, Oregon concluded that increased tree canopy resulted in reduced violent crime, property crime and overall crime (Donovan & Prestemon, 2010). "The combination of environmental, societal, and economic benefits of [GI]…", Chini et al. (2017) posits, "requires… evaluation within the context of a sociotechnical system" (pg. 4).   As shown in the Portland study and others like it, when GI implementation is viewed as a sociotechnical system, the costs, benefits and tradeoffs associated with it stretch far beyond stormwater management (Donovan & Prestemon, 2010; Kondo et al., 2015). Suddenly, a system like the Meadow Creek watershed becomes much more than a drainage area where GI might be useful for controlling stormwater and improving stream health. Rather, it is a complex array of community members, businesses, perceptions, existing infrastructure, natural organisms and an endless chain of downstream implications. While the stormwater benefits of GI have been quantified and well-documented, in order for engineers to facilitate equitable implementation of this technology, they must understand the complex flows of benefits from the GI to the stakeholders (Xing et al., 2021).

To holistically appreciate the complex flows associated with GI, engineers must not turn a blind eye to the inadequacies and negative impacts associated with past GI implementation. Perhaps the most well-documented shortcoming of GI is its inequitable distribution and variation in maintenance across communities of differing socioeconomic status. Tony Arnold and Resilience Justice Project Researchers at William and Mary University (2021) describe "Low-income communities of color in the United States…" as routinely having "…disproportionately less quantity, worse quality, thinner or more uneven spatial distribution, and/or limited access to green and blue infrastructure than do other communities in the region" (p. 678). In addition, they point out that in those low-income communities of color - as opposed to in wealthy, white communities - GI sees a lower overall investment of resources, less maintenance and is less likely to be restored. Well-intended, deliberate attempts to place GI in these underserved communities have also resulted in the displacement of low-income communities of color by driving up property values such that residents can no longer afford to live in the area where GI was located. While other shortcomings of GI exist, this prospectus will focus on understanding and addressing these social inequities and environmental justice issues.

The resultant research of this prospectus will aim to provide a literature review of recent STS research and frameworks developed to analyze the flow of benefits from and the sociotechnical shortcomings of GI that may be used to advise future GI projects like that of the technical portion of this paper. Literature of particular interest includes, "The Green Experiment: Cities, Green Stormwater Infrastructure, and Sustainability" by Chini et al. (2017) and "The Thorny Path Toward Greening: Unintended Consequences, Trade-offs, and Constraints in Green and Blue Infrastructure Planning, Implementation, and Management" by Kronenberg et al. (2021). "The Green Experiment" proposes "an experimental framework for policy, implementation, and subsequent evaluation of green stormwater infrastructure within the context of sociotechnical systems and urban experimentation" (Chini et al., 2017). They argue that this multi-faceted framework for experimentation with urban GI is critical in order for a necessary urban stormwater regime overhaul to occur. Kronenberg et al. (2021) suggests constant monitoring of GI projects through three sociotechnical lenses – infrastructure, institutions and perceptions – in order to mitigate unintended consequences of implementation.

Conclusion

From the technical portion of our work, the project team will produce two hydrological models (one in iTree, one in SWMM) of the sub-watershed that is determined to be both in technical and social need of GI. Advised by these models, the team will produce a site-scale design of GI for that sub-watershed and quantify its improvement to the site's runoff parameters. Successful implementation of these would ultimately result in a more physically and ecologically stable Meadow Creek and perhaps make Charlottesville a more climate change resilient city. The work done by the project team will also be a step towards the more equitable implementation of GI and its perceived successes and failures can be further used to inform GI projects in the future. Last, the STS literature review should provide succinct, holistic and robust recommendations for GI implementation strategies that mitigate unintended consequences and distribute costs, benefits and tradeoffs in an equitable fashion.

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