ABSTRACT

Title of dissertation: DECENTRALIZING STORMWATER MANAGEMENT: SHIFTING INFRASTRUCTURE AND EVOLVING HYDROSOCIAL RELATIONSHIPS

Matthew Wilfong, Doctor of Philosophy, 2022

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Stormwater management has historically remained in the technocratic realm of engineers and scientists disconnecting society from stormwater to protect public and environmental health. Despite incremental improvements, state and local governments are beginning to change their management practices and techniques in response to climatic changes, increased urbanization, and intensifying regulatory pressures. Scholars and practitioners have argued that this paradigm shift in stormwater management is required to continue to protect public and environmental health and reach regulatory goals. Despite the need for this paradigm shift, there continues to be slow progress towards decentralization. This shift is characterized by two key developments: the increased implementation of decentralized green infrastructure and increased involvement of individuals in managing stormwater. Broadly, this dissertation sets out to investigate two key aspects of this paradigm shift: (1) the hydrologic performance of these decentralized practices and (2) the social, political, cultural, and economic dynamics that are currently underpinning this paradigm shift.

This dissertation begins with a chapter investigating the hydrologic performance of decentralized, green infrastructure treatment trains in Clarksburg, MD. Using stormwater monitoring methodology, we analyze how effectively treatment trains can hydrologically manage stormwater and the effects of precipitation dynamics on the ability of these treatment trains to manage stormwater. This research suggests that these treatment trains are generally highly effective at managing stormwater volumes across a host of storm events with an average of 93% of discharge abated throughout the monitoring period. We also demonstrate that precipitation intensity was the most influential precipitation dynamic on the performance of each treatment train suggesting that designing these treatment trains with the potential higher prevalence of higher intensity storm events due to climate change.

To begin the social science portions of the dissertation research, we utilize an alternative framework, the hydrosocial cycle, to analyze how stormwater and society have and continue to shape each other over time. Building upon this work, we investigate the political, social, and cultural dynamics influencing and arising within this paradigm shift occurring within stormwater management. Through semi-structured interviews and Q-methodology within two urban watersheds in Maryland and Washington DC, we assess changes in the hydrosocial relationships between stakeholders and stormwater. Using these insights, we discuss the potential for alignment and cooperation among these diverging hydrosocial relationships and continuing the shift towards decentralizing stormwater management. Arising from this holistic and critical analysis, we seek to provide actionable recommendations focused on how, where, and who manages stormwater to reach more sustainable, resilient, and equitable outcomes. Additionally, we aim to demonstrate the effectiveness of these frameworks and methodologies to better attend to political and power dynamics involved in water governance and management, more broadly.

DECENTRALIZING STORMWATER MANAGEMENT: SHIFTING INFRASTRUCTURE AND EVOLVING HYDROSOCIAL RELATIONSHIPS

by

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2022

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Dedication

I would like to dedicate this dissertation to water. There is no other substance in this world that can conjure such a range of emotions. Water has this incredible power and dynamism - constantly adapting, transforming, and weaving itself into our lives. In an instant, water can turn from being beautiful and awe-inspiring to fearsome and deadly. This multiplicity of water drives and fuels the curiosity, attraction, and overall connection we have with water. Throughout my life and career, I hope to foster and explore my personal and our societal connection with water.

“I am haunted by waters”

Norman Maclean - *A River Runs Through It*

Acknowledgments

I want to personally thank Professor Mitchell Pavao-Zuckerman for the guidance and support throughout my Ph.D and dissertation. Your openness allowing me to explore new topics of research and perspective throughout the writing process was invaluable. I want to also thank Professor Michael Paolisso for bringing me into the world of environmental anthropology and political ecology. You have shaped my research and perspective on the world and now there is no going back. Finally, I want to thank my committee members, Professor Paul Leisnham, Dr. Kristina Hopkins and Amanda Rockler, for their collaboration and advice throughout this dissertation research and writing process. I am indebted to you all for your support over the past four years and I hope to emulate you all throughout my academic career.

In these acknowledgement, I would like to also personally thank all the people in my life who's support and guidance have made my academic career possible.

Firstly, my parents. None of this would have been even remotely possible without the support and love from you both. You both have sacrificed so much to provide me with opportunities I have and I cannot thank you enough for everything. Mom- I hope to emulate your kindness, patience, and time-management. Dad - I hope to emulate your curiosity, questioning, and work ethic. Both of you have made me the person I am today and by standing upon your loving and supportive shoulders, I hope to continue to make you both proud.

Secondly, my siblings. The support from all of you cannot be understated. Aubrey and Melissa - you both have always been there for me when I needed support. Your ever-presence in my life and positions as auxiliary "moms" have provided me the ability to become who I am today and I want you both to know that I am very grateful for everything. Tim and Brandon - you both have been mentors, friends, and exemplars in my life. From you both, I have had constant examples of proper work ethics and drive. The examples you both have set and the platforms you have foster for my success have made all of this possible. Jackson and Kassidy - you both have brought me a sense of youth and drive to be the best influence and mentor I can be. I hope that I have and can continue to return the favor by being someone who you can always look to for support and guidance in your life.

Thirdly, Gwen. These last four years and journey throughout this Ph.D was only possible with your love, friendship, and support. You have given me so much and I am eternally grateful that you're a part of my life. You have shown me what hard-work and sacrifice really mean and you continually influence my outlook on life, my career, and our lives together. This dissertation, this Ph.D, is for you.

Finally, all my friends. My teammates and friends from Washington College soccer are ever-present support system of laughs, love, and guidance that have made my life so enjoyable and fun over the past decade. Zach, Sam, Joey, Grosscup, Adam, Lew, Skyler, Vinny, Meir, and Brett - I am very grateful and thankful for your friendship and I hope to give you all the same support in your lives. I would also like to thank all my friends and lab-mates at UMD for their support over past four years, especially Sarah and Farshid.

Oh and, of course, my loving pup, Puck. You have brought so much love, energy, and fun into my life. The companionship you have given to me cannot be understated and I hope you know how much you are loved.

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Chapter 1: Review of Stormwater Management in the United States

1.1 Introduction

Throughout the United States, the ever-increasing urbanization over the past century has continued to create the need for effective and efficient stormwater management. Urbanization has three primary consequences that disrupts the natural hydrology of a landscape: the increase in impervious surfaces (buildings, roads, parking lots, etc.), the removal of vegetation, and the removal and/or compaction of topsoil across the landscape [1–4]. In combination, these three factors produce an environment where stormwater, or water that runs off the landscape during a precipitation event, can be hazardous to both public and environmental health. In urban areas, natural processes like infiltration, evapotranspiration, and interception of precipitation are reduced, producing a significantly larger proportion of stormwater remaining on the surface of the landscape during storm events [5]. As a result, urbanized areas are frequently exposed to larger volumes of stormwater resulting in higher incidences of flooding and increased degradation of local and downstream waterways [6–8]. Stormwater management has coincided and evolved over the past century with the overarching goal of reducing the adverse hydrological effects of urbanization across the landscape. This chapter and introduction to this dissertation will provide the needed historical and current context for the approaches to stormwater management in the United States. I will conclude this chapter by highlighting the theoretical approaches utilized throughout this dissertation research and overall objectives this work sets out to address.

1.2 Historical Approaches to Stormwater Management in the United States

Stormwater management in the United States has been a stepwise process over the past century, growing and adapting to address important and new concerns as scientists, policy-makers, and citizens alike begin to better understand the consequences and interactions between urbanization and stormwater. Initially, stormwater management was primarily concerned with protecting the public health of urban populations from potential flooding and water-borne diseases associated with sewage and stormwater [4, 9]. This style of stormwater management continued until the passing of the Clean Water Act in 1972 which created a legal requirement to manage stormwater to also protect environmental health [10]. Both management paradigms greatly improved how stormwater was managed in urban areas, but continue to leave room for improvement prompting the shift towards a new paradigm that is currently underway [2, 5, 11].

To discuss the historical approaches to stormwater management, I will utilize the Water Sensitive City framework [9, 10, 12]. The purpose of the Water Sensitive City framework (Figure 1.1) is to demonstrate the historical perspectives of urban water management systems, including stormwater management. We will use a simplified version of the Water Sensitive City framework to situate the various paradigms of stormwater management and how they have built upon one another over time.

1.2.1 Stormwater Management under "Drained Cities"

In the United States, prior to the passing of the Clean Water Act, urban stormwater management was primarily concerned with draining or conveying stormwater off the landscape as quickly as possible. The management paradigm, called "Drained Cities" under the Water Sensitive City framework, was focused on protecting urban populations from potential flooding associated with stormwater and, as a result, viewed stormwater as a "hazard"

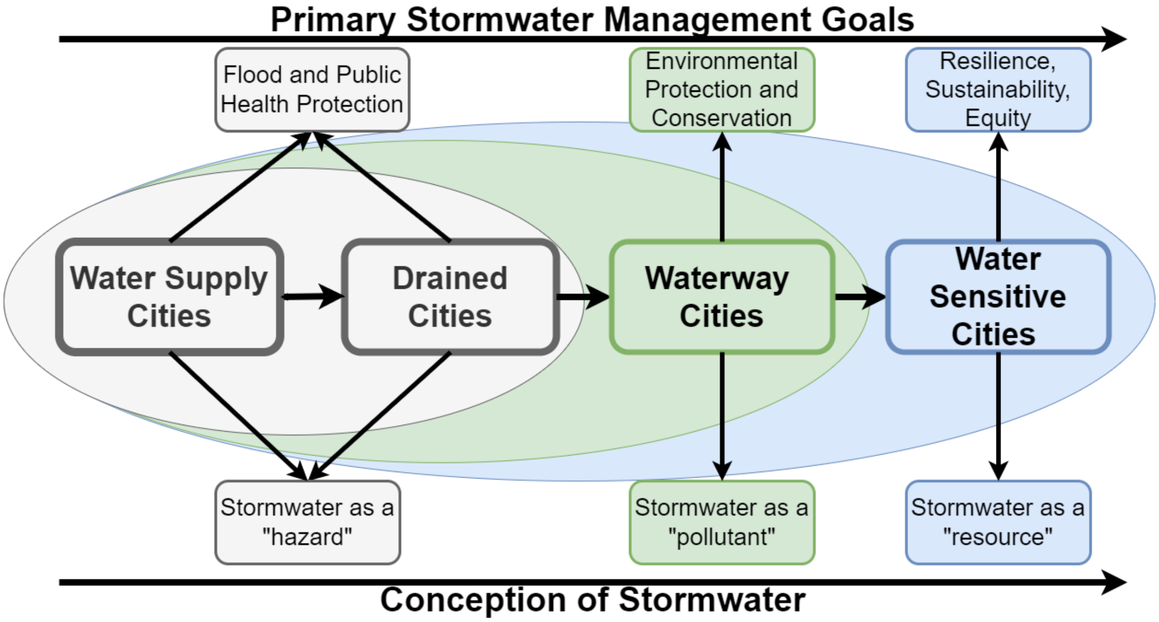


Figure 1.1: A conceptual diagram of the urban stormwwater management transitions and phases towards the Water Sensitive City. Adapted from [9].

to public health [10, 13]. The infrastructure that was built under this style of management was primarily complex systems of underground pipes that transported stormwater to larger, downstream bodies of water and even placed small, urban streams entirely underground. In addition, surface streams were concrete-lined, straightened, and constrained within retaining walls to ensure that flows during storm events were transported downstream rapidly, decreasing the propensity for flooding within urban areas [4, 14].

These complex networks of underground stormwater pipes are/were either combined with wastewater pipes or separated. Combined wastewater and stormwater pipe systems allow stormwater to be treated at wastewater treatment plants prior to release into surrounding waterways; however, during larger storm events, these systems can be overwhelmed causing untreated combined wastewater and stormwater to be released to neighboring streams (called combined sewer overflows) [15]. Separated storm and wastewater systems do not have the ability to cause combined sewer overflows but until the passing of the Clean Water Act did not require the treatment of stormwater prior to release [4]. As a result, in cities with separated systems, stormwater was transported directly into larger, downstream bodies of water untreated. Stormwater management under "Drained Cities" was primarily technocratic, using built infrastructure to protect cities from the adverse effects of urbanization, rather than attempting to re-implement or reintroduce the hydrological aspects of the natural environment that was lost.

Stormwater management under "Drained Cities" greatly decreased the occurrence of water-borne diseases associated with wastewater and stormwater and protected urban areas from flooding, more generally [4]. Also, these complex, built infrastructure networks allowed cities to grow and become more extensive as waterways and wetlands could be drained and placed underground with decreased concerns of flooding [13]. Despite these improvements, the techniques and infrastructure introduced within the "Drained Cities" paradigm caused a host of new concerns primarily focused on the environmental health impacts of stormwater. These concerns grew throughout the 1950s and 1960s and led to the passing of the Clean Water Act and subsequent shift in stormwater management paradigm.

1.2.2 Stormwater Management under "Waterway Cities"

The style of management under the "Drained Cities" paradigm, while protecting public health in urban areas, impacted the environmental health of urban waterways and downstream receiving bodies of water. As stormwater flows were quickly transported downstream, pollutants from the urbanized landscape (organics, metals, sediment) were also transported, causing stormwater to become a large non-source point pollutants to waterways across the United States [4, 7]. In addition, the hydrologic changes associated with urbanization and subsequent infrastructure built to manage stormwater, created a phenomenon called the "urban stream syndrome" [7, 8, 16]. The urban stream syndrome is characterized by urban waterways that tend to experience increased volumes of stormwater, higher peak flows, increased “flashiness” (or time between precipitation and increase in streamflow), and increased export of pollutants downstream [8, 17]. These issues surrounding the effect of stormwater on water quality and environmental health, prompted increased concerns by scientists, policymakers, and citizens towards protecting waterways across the United States from both point and non-point source pollutants, including stormwater.

The passing of the Clean Water Act in 1972 marked the beginning of the transition in stormwater management towards “Waterway Cities”. These new regulations, outlined by the Clean Water Act and subsequent amendments (301 and 402), introduced the National Pollutant Discharge Elimination System (NPDES) program. The NPDES programs issue Municipal Separate Storm Sewer System (MS4) permits at the county-level determining the amount of pollution that each county can export into surrounding waterways. These regulations place a legal requirement on state and local governments to manage stormwater quantity and quality prior to release into larger bodies of water. Following the legal and regulatory requirements stormwater began to be seen as a “pollutant”, in addition, to a “hazard” [4]. This marks a significant transition in how stormwater must be managed, to meet these stricter regulatory requirements. As a result, under the “Waterway Cities” paradigm, stormwater management is concerned with not only protecting public health, but also protecting and conserving the environment. The approach and infrastructure utilized in managing stormwater began to be updated as transporting stormwater directly into channelized streams or underground was no longer viable options for management.

“Waterway Cities” sought to improve the management of stormwater through two key infrastructural techniques: constructing large-scale detention basins and underground storage tanks and building/updating wastewater treatment plants to treat stormwater [2, 4, 5]. In highly urbanized cities, constructing above-ground detention basins is prohibitive due to space constraints, so many cities built underground storage tanks and chambers to temporarily detain and store stormwater during storm events that can be later transported to water treatment plants [4, 18]. In cities with combined stormwater and wastewater systems, these storage tanks cause lower frequencies of combined sewer overflows as water treatment plants are able to treat storm flows over a longer period of time [13]. Additionally, in cities with separated sewer systems, the networks of stormwater pipes were updated to transport stormwater to water treatment plants prior to release [18]. In conjunction, in more suburban areas with newer development, large-scale detention ponds were built to collect and detain stormwater from surrounding impervious surfaces. These centralized detention basins were designed to primarily increase time between precipitation and storm flows in surrounding waterways, but also promote infiltration of stormwater and lower the volume of storm flows, more generally [19, 20].

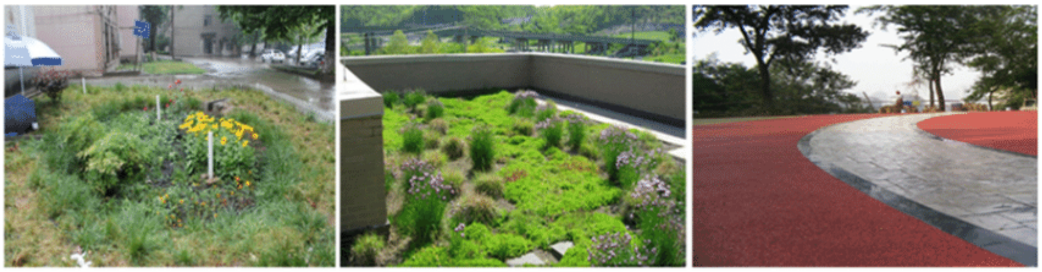
The infrastructural systems implemented during both “Drained Cities” and “Waterway Cities” were primarily “grey infrastructure”. Grey infrastructure can be defined as stormwater management practices that are designed to transport, retain, and treat stormwater through a complex network of pipes, storage tanks, and treatment facilities (Figure 1.2) [4, 13, 14, 21]. Additionally, “Waterways Cities” marked the beginning of the use of more “green infrastructure” to manage and treat stormwater. Green infrastructure can be characterized as small-scale, infrastructural practices that mimic natural ecosystem services and natural processes like infiltration and evapotranspiration (Figure 1.3) [21–26]. Centralized, grey infrastructure was implemented far more frequently than decentralized, green infrastructure due to the ability to reliable quantify and model the ability of these practices to manage and treat stormwater for both quantity and quality – needed requirements for MS4 permitting. In combination, these infrastructural and management changes have allowed state and local governments to more effectively meet requirements outlined by the MS4 permits.

Many cities and municipalities across the United States can still be characterized as

“Waterways Cities” concerning stormwater management with high variability, temporally and spatially in how and where stormwater is managed [2, 10, 27, 28]. Despite improvements in water quality across the United States, especially concerning stormwater, there continues to be issues surrounding the inability of state and local governments to protect public and environmental health from stormwater-related issues [2, 11, 26, 28].

Detention pond Pump station Drainage system

Figure 1.2: Examples of traditional grey infrastructure utilized for stormwater management in cities across the United States. These infrastructural systems were the primary techniques used throughout the “Drained Cities” and “Waterway Cities” paradigms [21].



Rain garden Green roof Permeable pavement

Infiltration trench Landscape water body Grassed swale

Figure 1.3: Examples of green infrastructure utilized for stormwater management in cities across the United States. These infrastructural systems are beginning to be implemented during the “Waterway Cities” paradigms [21].

1.3 Need for "Water Sensitive Cities" - Decentralizing Stormwater Management

Over the past decade across the United States, there has been a push towards transitioning stormwater management to a new, more decentralized paradigm [1, 2, 11, 28]. This need for a paradigm shift has been driven by scientists, policymakers, and citizens as the ability of primarily centralized, grey infrastructural systems to continue to manage stormwater effectively to protect public and environmental health becomes increasingly questioned [1, 2, 12]. These networks of underground storage tanks and stormwater pipes were built decades previously and due to increasing urbanization (higher percentage of impervious surfaces) and increasing precipitation variability due to climate change (more frequent, longer duration, higher intensity storm events), they are more frequently being overwhelmed [3, 4, 9, 14, 29, 30]. Cities across the United States are more frequently experiencing these infrastructural failures and, as a result, stormwater as a public health hazard and as an environment pollutant has returned to forefront of concerns [14, 16, 28, 31, 32].

Scholars have suggested that transitions towards a more "Water Sensitive Cities" paradigm will promote more effective stormwater management, even in the face of increasing urbanization and climatic pressures [10]. The "Water Sensitive City" "prioritizes livability, sustainability, and resilience in the design of its institutions and infrastructure" [33]. For stormwater management under the "Water Sensitive Cities", stormwater would be viewed more as a "resource" than a "hazard" or "pollutant" and more be more adaptable to variations and less reliant on centralized, grey infrastructural systems [11, 28]. To prompt this transition, state and local governments began to implement and enforce stricter stormwater regulations [4]. Some of these regulations were forced upon state and local governments through consent decrees from the federal government which allow state and local government to avoid paying costly fines associated with violating the NPDES program under the legally binding agreement that they will update existing infrastructure or implement new infrastructure to better manage stormwater for both quantity and quality [4, 34].An example of these new regulations are Total Maximum Daily Loads (TMDLs) which set the daily load limit of specific pollutants, typically nitrogen, phosphorus, and sediment, allowed to be exported into water bodies of any given watershed [35–37]. Other, new regulations require all stormwater to be treated on-site in areas of new development, typically through both grey and green infrastructure practices [36, 38].

To meet these stricter regulations and facilitate improvement in the public and environmental health outcomes associated with stormwater, state and local governments are beginning a new paradigm towards managing stormwater. Scientists, engineers, and policymakers have quickly acknowledged that to meet these new regulations, stormwater needs to be treated on-site through adoption of more decentralized, green infrastructural practices across the landscape [3, 11, 31, 39–41]. In addition to enforcing new regulations and constructing additional green infrastructure across urban areas, state and local governments are striving to involve individuals and communities in stormwater management. The involvement of individual citizens in stormwater management has been highlighted by policymakers and scholars as necessary due to the high percentage of privately-owned land across the landscape that state and local governments have no authority to build stormwater management infrastructure on but are still required to manage the stormwater emanating from these private lands [14, 26, 42].

Governments have begun programs and policies to promote the involvement of citizens in the management of stormwater, especially from privately-owned property [2, 11]. In particular, state and local governments are using educational outreach programs and a stormwater utility fee and rebate system to spark the involvement of private property owners into managing stormwater on their properties [36, 43, 44]. These programs and policies work, in tandem, to educate individuals about stormwater management, but also the ways in which they can manage stormwater on their property. In many municipalities across the United States, outreach programs were implemented to educate homeowners about stormwater and provide technical assistance on constructing landscape designs on their property to reduce stormwater runoff [37, 45].

The stormwater utility fee and rebate systems provide financial incentives for private property owners to manage stormwater on their own property, reducing the stormwater volumes that state and local governments are required to cope with. Typically, the stormwater utility fee is a charge added to a water bill that is calculated by the size and percent of impervious surfaces on a given property [36, 38]. To receive a rebate against this fee, property owners can implement stormwater best management practices on their properties. Using these approaches, state and local governments are hoping to push for an overall decentralization of stormwater management infrastructure across the landscape and diffuse the responsibility for managing stormwater onto individuals and communities.

1.4 Impediments and Barriers towards Decentralized Approach

Despite acknowledgement that this shift towards a "Water Sensitive Cities" paradigm in stormwater management is necessary, there has been slow, ineffective progress towards decentralizing stormwater management [2, 9–12, 14]. There are a host of impediments and barriers that various researchers have highlighted as significantly obstructing progress towards this decentralized paradigm including: a pro-grey infrastructure mindset, the "private vs. public" dilemma, and overall disconnect between stormwater and society [5, 9, 14].

1.4.1 Pro-Grey Mindset

Throughout the “Drained Cities” and “Waterway Cities” paradigm, grey infrastructure was the predominant type of infrastructure utilized to manage stormwater in urban areas due to the legal framing of stormwater management. The legal and regulatory requirements outline by the CWA, MS4 permits, and additional TMDLs are produced through complex modeling to determine quantitative numerical limits for counties, municipalities, and watersheds for pollutants associated with stormwater, like nitrogen, phosphorus, and total suspended sediments [4, 46]. To meet these ever-present quantitative regulatory limits, state and local governments must utilize infrastructural practices that can provide reliable, quantifiable, and modelable results. As a result, grey infrastructural practices, like storage tanks, large-scale detention ponds, water treatment plants, and complex networks of pipes, are typically employed [4, 9]. These grey infrastructural practices also allow scientists and engineers to maintain power and authority over where and how stormwater is managed as these large-scale projects require extensive knowledge of urban planning, hydrology, and engineering [4, 47].

Compounding this reliance on grey infrastructure is skepticism and insufficient knowledge on the effectiveness of more decentralized, green infrastructure which is still being extensively researched [3, 30, 48]. Many studies have shown that green infrastructure can effectively manage stormwater for both quantity and quality concerns; however, these practices are substantially more difficult to model - inhibiting their large-scale adoption and incorporation across the landscape due to continued and increasing regulatory requirements. In addition, green infrastructure brings additional challenges associated with maintenance, space needed for installation, and variability in performance due to ecological conditions [21–26]. Despite increasing research on green infrastructure, the perception around the ability and reliability of these styles of infrastructure are actively contested. In total, throughout past paradigms and currently within stormwater management, grey infrastructure remains preferred and a transition towards implementing more decentralized, green infrastructure is difficult [5, 11, 14].

1.4.2 “Private vs. Public” Dilemma

Arising from the CWA and subsequent stormwater regulations, a prominent regulatory hurdle and issue was created called the “private vs. public dilemma” [14, 26, 42]. This dilemma is produced as state and local governments are required to manage stormwater emanating from all lands, public or private, but only have the authority to construct and implement best management practices on publicly owned land. Newer regulations do require the construction of best management practices on privately owned land during new development; however, previously developed areas are protected from these new requirements [36, 46]. State and local governments are increasingly seeking to overcome this dilemma due to the small portion of publicly owned land available to governments for new stormwater management infrastructure. For example, in Maryland, only 7.6% of the land is publicly owned, while 92.4% is private and, on average across the United States, 39.8% of land is publicly owned, while 60.2% is privately-owned (US Bureau of the Census, Statistical Abstract of the United States: 2021). Exacerbating this issue, private lands are broken up into countless parcels with multitude of owners producing an even more difficult setting to overcome this dilemma [5, 14]. Collectively, the “private vs. public” dilemma creates a regulatory atmosphere were implementing more decentralized, green infrastructure across the landscape is difficult because state and local governments have little to no legal authority to do so [5, 13, 14]. As a result, the transition towards more decentralized stormwater management is obscured as decades of centralized, top-down management and the legal construction of the “private vs. public” dilemma prevent the large-scale adoption of these approaches [9, 10, 12, 13].

1.4.3 Disconnect with Stormwater

To overcome the “private vs. public” dilemma and shift towards “Water Sensitive Cities”, government officials, policymakers, engineers, and researchers have highlighted that the involvement of individuals and communities with stormwater management is necessary. This represents a momentous undertaking as, across the landscape, private property is divided into countless parcels with innumerable owners, all with varying perspectives and motivations towards stormwater and stormwater management [5, 28, 49, 50]. In addition, due to decades of centralized, technocratic management, the majority of individuals are unaware of issues surrounding stormwater and the current processes, techniques, and infrastructure utilized to manage stormwater [11, 14, 26]. This disconnect between individual citizens and stormwater was a purposeful separation to protect public health pre-CWA – typified by the immediate conveyance of stormwater underground and downstream away from communities using grey infrastructure. While this disconnect was designed for and implemented within the “Drained” and “Waterway Cities” paradigms, a transition towards the “Water Sensitive Cities” paradigm will require re-establishing a connection between individuals and stormwater - promoting their participation in management.

Various studies have demonstrated that the ongoing process of educating individuals about stormwater management and, especially the implementation of decentralized, green infrastructure on private property to manage stormwater, has been relatively ineffective, despite concerted efforts by state and local governments [13, 43, 44, 51–53]. It is clear; however, that a transition towards decentralized stormwater management and a more “Water Sensitive Cities” approach is significantly reliant on the contribution of individuals and communities, especially from privately owned lands [11, 12]. The current disconnect between individuals and stormwater is an impediment that is currently limiting progress towards a "Water Sensitive Cities" paradigm for stormwater management.

1.5 Dissertation Objectives and Approach

Broadly, this dissertation seeks to research and explore these present obstacles inhibiting progress towards a more decentralized approach to managing stormwater. This dissertation begins an understanding focused on the complex social, political, ecological, economic, and cultural dynamics influencing and underpinning the current paradigm transition in stormwater management.

1.5.1 Research Questions and Chapter Outline

Three primary research questions arise through this historical analysis of stormwater management and the current transition towards a decentralized, "Water Sensitive Cities" approach. In this dissertation, I investigate these research questions and promote needed progress within this paradigm shift.

How effective can decentralized, green infrastructure be to manage stormwater? – A pro-grey infrastructure mindset remains intact which substantially limits the large-scale implementation and funding for more green infrastructural practices. To push for more green infrastructure implementation, these practices must be proven effective at multiple scales. In part, this dissertation seeks to investigate the effectiveness of decentralized, green infrastructure through hydrologic monitoring in Clarksburg, MD. In Chapter 2, entitled; *"Investigating the Hydrologic Performance of Decentralized Stormwater Best Management Practices at the Treatment Train Scale,"* specifically researches the hydrologic effectiveness of green infrastructure treatment trains (chain of practices piped together to provide subsequent management of stormwater). These practices have been researched at the larger (watershed) and smaller scale (individual practice) scale, but little research has been conducted at the subwatershed-scale. These subwatershed-scale treatment trains are increasingly being built in newer development areas and provide an insight into how effective a largely decentralized approach can be. Through the research within this chapter, I will add to the literature and research on the effectiveness of decentralized, green infrastructure with the goal of promoting a more pro-green mindset, overcoming and eroding the current pro-grey mindset that is obscuring the current paradigm transition.

How are individuals and communities becoming involved with stormwater management? – The disconnect between individuals and stormwater is greatly constraining the push towards decentralization, especially due to the need for management of stormwater emanating from privately owned lands. In part, this dissertation investigates the political, social, and economic dynamics that are influencing and driving the involvement of individuals, with added emphasis on the power dynamics involved. This chapter entitled; *"Shifting Paradigms in Stormwater Management – Hydrosocial Relations and Stormwater Hydrocitizenship,"* uses semi-structured interviews amongst stormwater professionals and residents in two urban watersheds to explore how individuals are becoming involved within stormwater management. From this research, a more critical analysis of the ongoing recruitment of individuals to manage stormwater is undertaken. Using insights gained from this work, I highlight how the current processes and techniques are unsuccessful in reconnecting individuals with stormwater and provide recommendations and suggestions on how to progress forward.

What relationships between stakeholders and stormwater are being produced within the shift towards a more decentralized approach? – The obstacles and impediments previously emphasized arise from complex interactions between stakeholders, policies, infrastructures, and stormwater. To progress past these barriers, an assessment of the various relationships between stakeholder and stormwater within this transition is needed. In the chapter entitled; *"Diffusing Responsibility, Decentralizing Infrastructure: Hydrosocial Relationships within the Shifting Stormwater Management Paradigm,"* semi-structured interviews and Q-methodology are used to examine the current hydrosocial relationships between stakeholder and stormwater. Using this research, I convey how both converging perspectives demonstrate the need for decentralization, but divergent ideas remain on how to effectively and equitable achieve this goal. Through these insights, this chapter concludes by indicating the potential for alignment and cooperation among stakeholders and continuing the shift towards decentralized stormwater management.

Finally, I conclude by synthesizing the results from this dissertation to produce a guide towards advancing decentralized stormwater management. In addition, throughout this concluding chapter, I aim to demonstrate the need and pathways towards more critical research, like the research conducted within this dissertation, within water management and governance. With this conclusion, I hope to convey how effective and important interdisciplinary, holistic research can be, especially focusing on water.

1.5.2 Dissertation Approach

The research throughout this dissertation is interdisciplinary using both quantitative and qualitative methodologies ranging in disciplines including hydrology, ecology, anthropology, critical geography, and science and technology studies. This dissertation relies heavily on the hydrosocial cycle theoretical framework and approach to provide a critical and holistic perspective on the paradigm shift currently underway within stormwater management.

The hydrosocial cycle arises from the disciplines of anthropology, critical geography, and political ecology as a framework to understand water-society relationships, particularly the roles of power and technology. In contrast with the hydrologic cycle, which tends to disconnect humans from the flow of water across Earth's landscape, the hydrosocial cycle recognizes that water and society are closely and inextricably linked [54–57]. Under the hydrosocial framework, water is socionatural or a hybrid resulting from the internal relationship between society and water [54, 55]. Through internal relation, water and society are not distinct entities, but one, continuously changing function and relationship.

In practice, under the hydrosocial framework, water has both a physical and social meaning which is constantly shaped by sociocultural, political, and physical processes [58, 59]. These socionatural processes create distinct kinds of "waters" which need to be analyzed through the relations constituting these "waters" rather than as the relations between water and society [57]. Hydrosocial research attempts to investigate these internal relationships that give rise to distinct "waters" as socionatural entities with the goal of understanding how the "waters" manifest themselves over space and time. The primary goal of hydrosocial research is to understand how these "waters" are historically, culturally, socially, and politically produced and the resulting effect this has on the relationships with water and water management. A more in-depth discussion of the hydrosocial cycle and the application of this theoretical framework to analyze stormwater governance and management is covered in the dissertation chapter entitled; *"Rethinking Stormwater: An Analysis using the Hydrosocial Cycle."*

Chapter 2: Investigating the Hydrologic Performance of Decentralized Stormwater Best Management Practices at the Treatment Train Scale

2.1 Introduction

Stormwater management in the United States in currently undergoing a paradigm shift away from centralized infrastructure towards more decentralized management practices across the landscape [14, 16, 28, 31, 32]. These changes have been in response to growing concerns regarding maintaining public and environmental health in the face of increasing urbanization and increased climatic variation [5, 12, 60]. Accompanying and driving these infrastructural changes have been enhanced stormwater regulations, building on the Clean Water Act and National Pollution Elimination Discharge System, that seek to promote management of stormwater on-site, rather than primarily with centralized infrastructure [2, 4, 14]. An example of these new regulations are Total Maximum Daily Loads (TMDLs) which sets the daily load limit of specific pollutants, typically nitrogen, phosphorus, and sediment, allowed to be exported into water bodies of any given watershed [35, 36, 46]. Previously developed areas are not typically subjected to these new, stricter regulations and continue to rely on centralized, gray infrastructure to manage stormwater [3, 48, 61]. These stricter regulations require the management of stormwater on-site at new development, increasing the use of more decentralized, green infrastructure across the landscape.

Decentralized, green infrastructure is characterized by small-scale practices that mimic natural processes like infiltration and evapotranspiration usually lost or reduced due to urbanization [24, 50, 62–64]. By doing so, green infrastructure attempts to remedy the symptoms of the “urban stream syndrome” through reducing peak flows, increasing infiltration and residence time, and increasing nutrient and pollutant retention [7, 8, 17]. There are various types of green infrastructure including: bioretention rain gardens, green roofs, pervious pavements, above and below ground swales, and constructed riparian zones. Various studies have demonstrated that decentralized green infrastructure can better reduce the quantity and improve the quality of stormwater when compared to more traditional best management practices [30, 65–68]. These practices can provide stand-alone treatment or be arranged in a treatment train with a series of practices draining into each other providing redundant treatment [30, 69–73].

Treatment trains, or a series of green infrastructure or best management practices, that allow for the subsequent treatment of stormwater have recently begun to be implemented, especially in newly built urbanized areas [30, 69]. These treatment trains tend to be cost-prohibitive as stormwater management retrofits in established urban areas; however, in newly developed areas that can be both ecologically and economically effective and efficient [71]. Treatment trains incorporate a variety of infiltration, retention, and detention best management practices that are connected using stormwater pipes. By providing subsequent treatment, these treatment trains can increase the stormwater volume reduction and improve stormwater quality compared to centralized and single point decentralized best management practices [69]. These treatment trains, also called stormwater control measure networks, provide redundant retention, infiltration, and treatment of stormwater that better mimic natural flow regimes that tend to be lost due to urbanization [71]. They are typically designed and regulated as the additive benefits of the single best management practices incorporated into the train or network; however, this is likely not strictly accurate at the subwatershed and watershed-scale due to “differential time lags, SCM interaction, inconsistent water quality mechanisms, and spatial arrangement” [48].

Many studies have demonstrated the ability of distributed, decentralized stormwater best management practices, including treatment trains, to reduce stormwater volumes on the watershed level [30, 62, 65–68]. Most of the studies on the hydrologic effectiveness of stormwater control measure networks have been focused on the watershed-scale. Empirical studies have shown that the incorporation of infiltration and water-harvesting, green infrastructure-oriented best management practices, does decrease the peak discharge from storm events at the watershed-scale [74–76]. Additionally, modeling studies have shown similar results with a decrease in peak flow and discharge in watersheds with infiltration and water-harvesting best management practices [77–80]. Previous studies have primarily focused on opposite ends of the spectrum: the watershed-scale and site-scale. While these empirical and modeling studies demonstrate the important cumulative effects (watershed-scale) and specific best management practices stormwater volume and pollution reduction (site-specific), the intermediate-scale has not been explored as in-depth.

The intermediate-scale (the subwatershed, treatment train, or SCM network-scale) will allow for the investigation of variables that affect the hydrologic performance (stormwater volume reduction, peak discharge reduction, increased lag time) that are obscured in watershed or site-scale studies. As stated in Jefferson et al. (2017), “it is important to consider interacting effects of SCMs in series (e.g., treatment trains), age of practices, and effectiveness across a range of storm sizes and antecedent conditions” [48]. Research focusing on the stormwater hydrology at the treatment train scale allows for the analysis of variables including precipitation dynamics, arrangement of SCMs, connectivity of SCMs, storage volume of treatment trains, percentage of infiltration/water quality improvement best management practices, and percentage of impervious surfaces treated. All these variables are important in the hydrologic functioning of treatment trains and SCM networks and often overlooked both in watershed-scale empirical and modeling studies and regulations.

Treatment trains and SCM networks are increasingly being implemented for stormwater management, especially in newly urbanized area. Despite this, there is relatively little research into understanding the overall hydrologic performance of these treatment trains. In addition, there has been minimal research on how precipitation dynamics affects their hydrologic performance. To fill this knowledge gap, we aim to investigate the hydrologic performance of decentralized treatment trains with an additional focus on investigating how precipitation dynamics affects the performance of these treatment trains. To tackle these research questions, we performed stormwater monitoring within three decentralized stormwater treatment trains within a newly developed community in Clarksburg, MD. This stormwater monitoring allows for an investigation of both the hydrologic performance and the effects of precipitation dynamics on the overall effectiveness of these treatment trains at monitoring stormwater. Arising from this research, we seek to promote a better understanding of how these factors alter hydrologic performance of treatment trains allowing for better designing of treatment trains and SCM networks, as well as more accurate regulations for permitting.

2.2 Study Site and Methodology

The watershed for this field study, Tributary 104, is in Montgomery County, MD within the Piedmont physiographic region. Tributary 104 drains to the Little Seneca Creek tributary, and then to the Potomac River. Tributary 104 in Clarksburg, MD is a 1.2 km^2 watershed, and was primarily farmland and forest until 2004 [65]. Between 2004 and 2010 it was developed into a residential area with 30% impervious cover. Tributary 104 is within the Clarksburg Special Protection Area, which requires additional natural resource protection beyond existing environmental regulations for new development, including approval of a water quality plan (Montgomery County Code, 2001). During development, 121 hydrology and water quality stormwater green infrastructure practices were installed in the Tributary 104 watershed to meet these requirements [30]. Average annual precipitation at the nearby Damascus 3 SSW MD US station (1980-2010) is 1177.5 mm. Average annual daily maximum temperature is 17C and average annual daily minimum temperature is 6.9C at Damascus 3 SSW MD US (1980-2010). This watershed has undergone extensive study on the impacts of urbanization on baseflow, topographic changes in the watershed during development, and the impacts of the stormwater management on runoff quality and quantity at the watershed scale [30, 62, 65–68].

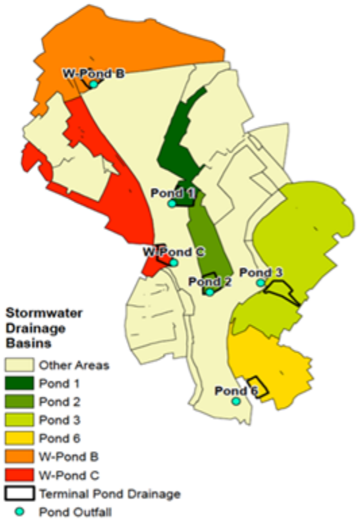


Figure 2.1: Map of Tributary 104 Watershed with the sub-watersheds for each terminal dry and wet retention pond denoted.

Tributary 104 watershed includes six stormwater BMP treatment trains (Figure 2.1). These treatment trains have substantially different drainage areas, arrangement of BMPs, storage capacities, BMP density, and proportion water quality BMPs (Table 2.1). For this study, three of the treatment train drainage basins were chosen for monitoring: Pond 1, Pond 2, and Pond 6 (Figures A.1,A.2,A.3). These three treatment trains were chosen due to the range in stormwater BMP infrastructure arrangement, connectivity, and storage capacity. Pond 6 has the highest degree of connectivity, distributed arrangement, and highest percentage of infiltration-based BMPs, while Pond 2 having the lowest degree of connectivity, distributed arrangement, and lowest percentage of infiltration-based BMPs (Table 2.1

and (Figures A.1,A.2,A.3). Importantly, each of these treatment trains are linked through stormwater pipes that out flow to separate dry detention ponds, so that the outfalls of each terminal dry detention pond release the majority of surface stormwater that has been conveyed within that drainage basin into Tributary 104. The architecture of these decentralized stormwater BMP treatment trains design allows for the sampling of each treatment train drainage basin separately, an important aspect of this study design.

Table 2.1: Subwatersheds and their respective BMP types, function, and drainage areas for Tributary 104. Each individual BMP in the subwatershed is mapped in GIS and their respective drainage area is known and the percentage of each drainage area comprised of impervious surfaces and green is reported (Sparkman et al. 2017). Storage capacity is the cumulative storage provided by each BMP within each treatment train calculated from BMP size data provided from as-builts [Hopkins, written communication, 2021]

Basin	**BMP Types**	**Drainage Area (ac)**	**Percent Built**	**Percent Grass**	**# of BMPs**	**BMP Density**	**Storage Capacity (cf)**
Pond 1	Bioretention Dry Swale Recharge Facility Oil/Grit Separator Sand Filter Dry Pond	9.0	39	56	7	0.78	21163
Pond 2	Dry Swale Sand Filter Oil/Grit Separator Filter Dry Pond	9.8	43	55	5	0.51	20188
Pond 6	Storm Drain Recharge Facility Dry Swale Oil/Grit Separator Sand Filter Underground Storm Filter Dry Pond	16.8	53	44	14	0.83	40527

Within each of these treatment trains drainage basin, stormwater monitoring was conducted at the outfall of the terminal dry detention ponds within each treatment train beginning in January 2020 and ending in October of 2021. To monitor stormwater volume exiting each treatment train, Thel-mar volumetric weirs, specifically fitted for the size of the outfall pipe, were installed at each terminal dry pond outfall. Behind the weir and within the outfall pipe itself, Onset HOBOware water level pressure transducers were placed within a protective PVC housing and mounted onto the bottom of the outfall pipe at least three feet upstream from the weir (Figure A.4). Using these water level pressure transducers, the water level within each outfall pipe could be continuously recorded at 5-minute intervals. Thel-mar volumetric weirs are provided within an empirically determined and field validated rating curve that can effectively convert the water level from the logger to discharge. As a result, when coupled with each other, the discharge from any given terminal dry detention pond and entire decentralized stormwater BMP treatment train can be calculated and monitored at 5-minute intervals.

Additionally, an Onset HOBOware pressure transducer and Onset HOBOware tipping bucket rain gauge were installed in an open field close to the outfall of Pond 6 to monitor barometric pressure at 5-minute intervals and rainfall, respectively (Figure A.5). The pressure transducer monitoring the atmospheric pressure is required to standardize the pressure readings from the water level pressure transducers. Using the HOBOware Pro software, the readings from the water level pressure transducers can be standardized using the atmospheric pressure readings to ensure accurate water depth measurements. The tipping bucket rain gauge monitored rainfall within the Tributary 104 watershed. These weirs and sensors were maintained and inspected monthly between January 2020 and October 2021. The data from these loggers (water level, atmospheric pressure, and rainfall) was downloaded bi-monthly. In the event of rain gauge failure during storm events, precipitation data was downloaded from a USGS rain gauge located on Ten Mile Creek (Latitude - 39°14’06.6”, Longitude - 77°17’39.9”), less than five miles from the study locations. Storm events were chosen for analysis when all water level pressure transducers were operational, and weirs were mounted firmly within the outfall pipes to ensure accurate discharge measurements. Importantly, storm events were also chosen only when precipitation was greater than 0.1 inches of rainfall.

For each storm event, several quantitative and qualitative variables were tracked to understand the overall hydrological performance including precipitation depth (in), precipitation length (hrs.), precipitation intensity (in/hr.), discharge (cubic feet), normalized discharge (cf/ac), discharge abated (%), lag time (hrs.), discharge duration (hrs.), antecedent dry days (days), distributed arrangement, connectivity, and water-quality/infiltration-based BMP percentage. Normalized discharge (cf/ac) was calculated by dividing the total discharge during a storm event from a treatment train by the total drainage area within that treatment train (drainage area in Table 2.1). Discharge abated (%) is the total amount of rainfall that is stored, infiltrated, and evapotranspirated by each treatment during a storm event. Duration Discharge is the total time (in hours) that a treatment train was exporting discharge during a given storm event. Lag Time is the total time (in hours) between when median precipitation occurred, and maximum discharge occurred.

All statistical analyses were conducted using R. The precipitation dynamics variables (precipitation amount, precipitation intensity, and antecedent dry days) are compared to normalized discharge and discharge abated across each treatment train and storm event using simple linear regressions. Multiple regression analysis was conducted to determine the effect that these precipitation dynamics have on the normalized discharge and discharge abatement for each treatment train. For these multiple linear regressions, normalized discharge was log-transformed. Additionally, logistic regressions were conducted to assess the precipitation dynamics needed to produce discharge within each a treatment train for the seventy storm events sampled throughout the monitoring period. For these logistic regressions, storm events that both produced and did not produce discharge were incorporated into the modeled logistic regressions. For each treatment train during each storm event a value of one was given if discharge was produced or a zero was given if there was no discharge produced. These statistical analyses will allow for some comparison across treatment trains on the effect that precipitation variables have on discharge during storm events and begin to assess the overall hydrologic performance of each treatment train.

2.3 Results: Hydrologic Stormwater Monitoring

Stormwater and rainfall monitoring took place between January 2020 and October 2021 with seventy storm events successfully monitored throughout the period (all precipitation and stormwater flow data is shown in Appendix Table B.1, Table B.2, Table B.3). A “successful” storm event sampled required that water level loggers, weirs, and rain gauge were all properly working to ensure accurate results for discharge and precipitation dynamics monitoring. Throughout the sampling period, there was twenty-nine storm events that produced discharge in, at least, one of the treatment trains, and thirty-one storm events that did not produce discharge in any of the treatment trains. For fourteen of the storm events in which discharge occurred, Pond 2 experienced failure due to a dislodged weir. The outlet pipe of Pond 2, where the weir and water level logger were placed, had a significantly smaller diameter compared to the other two treatment trains. As a result, during higher intensity storm events, the weir was placed under increased stress that often dislodged the weir, leading to inaccurate measurement of water level and discharge. Despite efforts to stabilize the weir after the initial discovery of this issue, the weir frequently became dislodged and resulted in the inability to accurately measure discharge from Pond 2 during fourteen of the twenty-nine storm events where discharge occurred. Summary values for hydrologic performance of each stormwater treatment train across the 70 storm events is shown in Table 2.2.

Table 2.2: Summary of mean values of hydrologic performance of each stormwater treatment train across the seventy storm events monitored between January 2020 and October 2021.

	Duration Discharge (hrs)	**Lag Time (hrs)**	**Discharge (cf)**	**Normalized Discharge (cf/ac)**	**Discharge Abated (%)**
Pond 1	2.53	1.92	1862	206.9	95.03
Pond 2	8.72	4.24	1863	190.1	93.38
Pond 6	9.46	1.59	4188	249.3	93.48

2.3.1 Analysis of Precipitation Dynamics on Discharge

Log-log scatter plots with linear regression were performed for each storm event for normalized discharge (cf/ac) versus each precipitation dynamic variable: precipitation amount (in), precipitation intensity (in/hr), and antecedent dry days (days). Figures A.6,A.7,A.8 portray these scatter plots and regressions demonstrating the relationship between normalized discharge and the precipitation dynamics of each storm event. Generally, all treatment trains exhibited similar and expected results for these simple regressions with normalized discharge increasing as precipitation amount and precipitation intensity increased and decreasing with increasing antecedent dry days. Multiple regression was performed on normalized discharge and precipitation dynamics to determine the influence and predictive ability of precipitation dynamics on the normalized discharge from each treatment train. The result from this multiple regression is shown in Table A.1. The multiple regression analysis conveys that for each treatment train, precipitation amount was the most important factor for normalized discharge; however, in general, precipitation dynamics had low correlation to the normalized discharge from each treatment train across storm events.

2.3.2 Analysis of Precipitation Dynamics on Discharge Abatement

Scatter plots with linear regression were performed for each storm event for discharge abatement (%) versus each precipitation dynamic variable: precipitation amount (in), precipitation intensity (in/hr), and antecedent dry days (days). Figures A.6, A.7, A.8 convey these scatter plots and regressions portraying the relationship between the discharge abatement and precipitation dynamics for each treatment train and each storm event. In agreement with the analyses on normalized discharge and precipitation dynamics, all treatment trains experienced lower discharge abatement as precipitation and precipitation intensity increased and slightly higher discharge abatement antecedent dry days increased. Multiple regression was performed on discharge abatement and precipitation dynamics to determine the influence and predictive ability of precipitation dynamics on the discharge abated from each treatment train. The result from this multiple regression is shown in Table **??**. The multiple regression analysis conveys that for each treatment train, precipitation amount was the most important factor for discharge abatement; however, in general, precipitation dynamics had low correlation to the discharge abatement from each treatment train across storm events.

2.3.3 Logistic Regressions of Precipitation Dynamics

Logistic regressions were conducted to assess the precipitation dynamics needed to produce discharge within each treatment train. For each precipitation variable, these logistic regressions demonstrate differences across treatment trains focused on the precipitation dynamics that will result in discharge for any given treatment train. Figures A.12, A.13, A.14 portray these logistical regressions and convey how precipitation dynamics affect the probability that each treatment train will generate discharge. As expected, the probability of discharge increased in each treatment train as precipitation and precipitation intensity increased. In general, these figures also demonstrate that Pond 6 would generate discharge during lower precipitation and intensity events compared to other treatment trains, followed by Pond 2, and finally Pond 1. Finally, Figure 10 demonstrates that antecedent dry days had little effect on whether a given treatment train would produce discharge.

2.4 Discussion: Hydrologic Performance and Effect of Precipitation Dynamics

2.4.1 Hydrologic Performance of Treatment Trains

The hydrologic performance of each of these decentralized stormwater management treatment trains can be conveyed through three key variables: discharge abated (%), lag time (hrs), and duration of discharge. The primary purposes of these treatment trains are to: decrease the total volume of stormwater runoff entering surrounding waterways during storm events (percent of discharge abated), increase the time between rainfall and stormwater entering surrounding waterways (lag time and duration discharge). An analysis of the total percent of discharge abated demonstrates that these treatment trains effectively evapotranspirate, intercept, and/or infiltrate over 93% of the total rainfall within the subwatershed, on average. In general, all subwatersheds had similar discharge abatement across storm events with Pond 1 having slightly higher discharge abatement compared to Ponds 2 and 6, on average. This could be due to the lower percentage of impervious surfaces and higher percentage of grass in the drainage area for Pond 1 compared to both Pond 2 and 6 which lowers the total amount of stormwater which must be managed by the BMPs within the treatment train. In general, the average discharge abatement across all three treatment trains and storm events demonstrates how effective these decentralized, green infrastructure-based treatment trains can perform at managing stormwater volumes, especially in suburban areas.

In addition, all treatment trains substantially slowed down the flow of stormwater within each subwatershed to neighboring Tributary 104 during each storm event. All three subwatersheds experienced lag times (time between median of rainfall and peak discharge) of nearly two hours, highlighting the ability of the BMPs within these treatment trains to detain and store stormwater, promoting a slower release of stormwater from each subwatershed into Tributary 104. In general, Pond 2 had a much longer lag time, nearly double that of Pond 1 and 6 on average. This is a particularly interesting result because Pond 2 was the only treatment train without designated underground storage tanks and recharge chambers designed to temporarily detain storm flows. Despite the lack of storage tanks and recharge chambers, Pond 2 generally prolonged the time between rainfall and peak discharge portraying that the addition of these types of BMPs may be less important on influencing lag time. These findings suggest that the layout, design, and connectivity of these treatment trains is likely as important as the BMPs incorporated into the treatment train, itself; however, the monitoring methodology uses within this study prohibits additional insights into these subtleties.

Finally, all treatment trains exhibited the ability to markedly prolong the total time of discharge during storm events. This measurement for hydrologic performance highlights the ability of these treatment trains to spread storm flows over a longer period allowing Tributary 104 to receive stormwater more gradually. Ponds 2 and 6 had discharge durations of over eight hours while Pond 1 only had durations of two hours, on average. In general, across all storm events, the discharge from Pond 1 exhibited “flashy” behavior meaning that discharge during a storm event would occur over a short period of time and have high peak flows. In contrast, both Ponds 2 and 6 would experience lower peak flows and gradual declines in discharge after peak flows, resulting in longer durations of discharge compared to Pond 1. This “flashy” hydrologic behavior within the Pond 1 treatment trains is likely caused by some aspect of the connectivity between the BMPs within the treatment train; however, as with the lag time differences, due to the monitoring methodology it is difficult to pinpoint how and why this occurs in Pond 1 more drastically compared to Ponds 2 and

6.

Overall, this monitoring demonstrates that these treatment trains can be highly successful at managing stormwater volumes during storm events. In general, within these subwatersheds containing these treatment trains, stormwater volumes were reduced, on average, by over 90%, and the time between rainfall events and storm flows entering the neighboring Tributary 104 was greatly increased. As a result, this research suggests that in areas where decentralized, stormwater BMP treatment trains can be built alongside of development, this style of management and infrastructure can be highly effective at mitigating the negative hydrologic effects associated stormwater runoff. In addition, this monitoring conveys the needs for more in-depth research to better understand how to better design, arrange, and connect the BMPs within these treatment trains to further increase lag times and discharge durations. Closer attention to these dynamics will help to prevent the “flashy” behavior as shown in Pond 1, which likely impacts the ability of the treatment trains to also manage the quality of stormwater – an important aspect of management, not covered within this research.

2.4.2 Influence of Precipitation Dynamics on Treatment Trains

Building upon the overall hydrologic performance of these treatment trains, another important aspect of these research was the effect of precipitation dynamics on their performance. Both the multiple linear regressions and logistic regressions analyzing how precipitation dynamics affect both normalized discharge and discharge abatement demonstrate similar results. Expectedly, across all treatment trains, the overall performance of these treatment trains was altered by changes in precipitation dynamics. Generally, as precipitation increased, precipitation intensity increased, and antecedent dry days decreases, the overall hydrologic effectiveness decreased (normalized discharge increases, and discharge abatement decreases).

The multiple linear regression analyses demonstrated that precipitation dynamics, while affecting hydrologic performance, were not highly correlated with normalized discharge or percent discharge abatement, as shown by the lower R^2 values in Table A.1 and **??**. The multiple regression analysis on precipitation dynamics compared normalized discharge suggests that precipitation amount was the most important predictor of normalized discharge within each of these treatment trains. Precipitation intensity and antecedent dry days were not statistically significant for normalized discharge across all treatment trains except for precipitation intensity for Pond 6. This suggests that the treatment trains can be hydrologically effective for a host of precipitation dynamics and are less reliant on “ideal” precipitation dynamics (high antecedent dry days and low precipitation intensity). Importantly, this analysis demonstrated that the hydrologic performance of these treatment trains was not highly correlated with antecedent dry days. Previous studies have suggested that low antecedent dry days could cause decreased hydrologic performance in green infrastructure due to lower rates of evapotranspiration and infiltration; however, within these treatment trains, antecedent dry days did not appear to affect the hydrologic performance of the green infrastructure BMPs [69, 71, 81].

In contrast, for the multiple regression analysis on percent discharge abated compared to precipitation dynamics conveyed that precipitation intensity was the most important factor for determining the percentage of discharge that would be abated. For these treatment trains, their ability to detain and slow stormwater and facilitate ecosystem processes, like evapotranspiration and infiltration, greatly increase their hydrologic performance and ability to abate stormwater [70, 71]. During high intensity storm events, the ability of these green infrastructure BMPs to detain stormwater can be compromised and simply convey stormwater to the following BMP within the treatment trains, rather than promote infiltration and evapotranspiration. As the results from this monitoring suggests these treatment trains' hydrologic performance can be affected by the precipitation intensity – highlighting that the design of the BMPs within these treatment trains needs to able to account for high intensity storm events, especially in the face of climate change [3, 82]. Similarity with the normalized discharge analysis, antecedent dry days did not significantly contribute to the discharge abatement of these treatment trains. This demonstrates the ability of the BMPs within these treatment trains to quickly recover after storm events

Finally, the logistical regression analyses conveyed similar results to both multiple regression analyses. Across all treatment trains, increases in precipitation and precipitation intensity correlated to higher probability of discharge. Notably, the logistical regression for antecedent dry days portrays that increasing antecedent dry days produced slightly higher probabilities of discharge which is counter-intuitive and contrary to the previous research [71, 83–85]. This is likely due to the overall low correlation between discharge probability and antecedent dry days, rather than a trend itself – demonstrating the ability of these treatment trains to recuperate and adapt after each storm event to mitigate stormwater for following events. The logistic regressions also show that increased in precipitation intensity (log-scale) tend to have a higher influence on the probability of discharge compared to precipitation amount. This again portrays the need to design BMPs and treatment trains to cope with higher intensity storm events.

Between each treatment train, the logistic regression analysis conveys that Pond 1 appears to be the less affected by precipitation dynamics for discharge compared to Pond 6 and Pond 2. Pond 6 generally appears to be more affected by the precipitation dynamics compared to Pond 2, expect at low precipitation intensities (¡ 0.08 in/hr) where the storage and recharge chambers within the Pond 6 subwatershed can effectively detain stormwater. At greater precipitation intensity, Pond 6 has higher probabilities of discharge than Pond 2 indicating that these recharge and storage chambers are less effective at higher precipitation intensities. Pond 1 is likely less affected by precipitation dynamics due to a combination of storage capacity within the treatment train and low percentage of impervious surfaces within the subwatersheds compared to Ponds 2 and 6. In contrast, Pond 6 has substantially higher percentage of impervious surfaces within the watershed and lower storage capacity compared to total subwatershed area than both Ponds 1 and 2 which likely results in the higher influence of precipitation dynamics on probability of discharge shown in the logistical regressions.

In total, these analyses on precipitation dynamics demonstrate two key takeaways. The hydrologic performance of treatment trains is most readily affected precipitation intensity compared to other precipitation dynamics. This suggests that treatment trains must be designed to more effectively store and detain stormwater, even during high intensity storm events, in order to ensure effective performance across a host of storm events and in the face of increasing higher intensity storm events due to climate change [3, 82]. In addition, this monitoring demonstrated that total storage capacity of BMPs within a treatment train and percentage of impervious surfaces within a subwatershed are important factors in determining the hydrologic effectiveness of treatment trains. As a result, treatment trains should be designed to ensure higher storage capacities in subwatersheds with higher percentages of impervious surfaces.

2.5 Conclusions and Future Research Needs

Treatment trains consisting of decentralized, green infrastructure BMPs are increasingly being implemented in newly developed areas and, to a lesser extent, as retrofits in more urbanized areas. This research demonstrates that treatment trains can effectively manage stormwater volumes,especially rainfalls under 1 inch, across a host of storm events with a range of precipitation amounts, intensities, and antecedent dry days. Our research also indicates that despite some treatment trains containing recharge chambers and storage tanks that temporarily detain stormwater, treatment trains are susceptible to decreases performance during higher intensity storm events. This suggests that as higher intensity storm events become more frequent due to climate change, these treatment trains and green infrastructure BMPs, in general, should be designed to detain and store rapid influxes of stormwater during high intensity events. Failure to design BMPs and treatment trains with these high intensity storm events in mind will result in greatly diminished hydrologic performance and likely decreased ability to remove pollutants from stormwater, like organics, metals, and sediments. From this research, we also suggest that treatment trains be designed and built to ensure that drainage areas containing higher percentage of impervious surfaces contain additional storage ability to mitigate the effects of precipitation dynamics, like precipitation amount and intensity. Our monitoring conveyed that subwatersheds with the highest percentage of impervious surfaces within the drainage area were more sensitive to precipitation dynamic variations, despite increases in storage capacities of BMPs. This highlights that increasing storage capacities of treatment trains as drainage areas increases is not sufficient, especially if the percentage of impervious surfaces increases within the drainage area. Overall, our research demonstrates that treatment trains can be effective at managing stormwater quantity, but continued attention needs to be directed towards designing and planning these treatment trains to withstand and cope with both higher volume and intensity storm events.

This research begins to investigate performance of the decentralized, green infrastructure at the subwatershed or treatment train scale. While our monitoring project provides a good platform for their hydrologic effectiveness, additional research is needed. Research focused on how each individual BMP functions within a treatment train performs and how each BMP contributes to the overall performance of the treatment train can provide some important insights for planning and development of future treatment trains. Similar methodology will also allow for a better understanding of how these treatment trains react to high intensity storm events when storm flows inundate and overwhelm BMPs resulting in rapid transport of stormwater throughout the treatment train, as seen in this research. Finally, sampling accompanying the stormwater monitoring will allow for insights into the ability of these treatment trains to manage stormwater quality, especially nitrogen, phosphorus, and sediments. As treatment trains and decentralized BMPs become more readily adopted, it is important to ensure that these infrastructural practices are planned and built to withstand an ever-changing landscape and climate and ensuring sustainable, resilient, and equitable stormwater management outcomes.

Chapter 3: Rethinking Stormwater: An Analysis using the Hydrosocial Cycle[1]

3.1 Introduction

> "The fundamental problem with conventional stormwater management may be the mindset. It does not treat water as a valuable resource but more like a problem to be solved, or even worse, it as a waste product" [13].

Water is a substance that is inextricably linked with life. It is a "non-substitutable flow resource essential for life and ecological health" but also "of deep spiritual and aesthetic significance" [86]. Water and society are deeply connected with water leaving a trace of its historical, political, and social influence on society as it flows over the landscape [54, 55, 87–90]. The "social nature" of water is the idea that water's materiality, conceptual significance, and meaning is the direct result of the social relations that produce it [91]. Social nature reflects Cronon's ideas where, "what we mean when we use the word 'nature' says as much about ourselves as about the things we label with that word" [92]. What people mean when they talk about water, the different names, meanings, and values they place on water are created by socio-natural processes. These socio-natural processes being

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[1] This dissertation chapter was published on April 30, 2020 in the journal, *Water*. Matthew Wilfong and Mitchell Pavao-Zuckerman were co-authors for this journal article. Matthew Wilfong contributed conceptualization, methodology, investigation, writing, review, and editing of the manuscript. Mitchell Pavao-Zuckerman contributed funding and review and editing of the manuscript. This research was funded by NSF-CHN/AGS Grant no. 1518376 and a USDA NIFA Hatch project through the Maryland Agricultural Experimentation Station. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution [28].

the internal relations that materially and discursively shape water and society, blurring and abstracting the separation between the two [93].

The idea that water is “inescapably social” [94] is in direct contrast with the preeminent Western epistemology where nature and society are separate entities. This dominant cultural ideology has allowed water to become an object of management, governance, and commodification. As a result, command-and-control practices and technocratic solutions dominate water management and are the primary mechanisms to control natural hydrologic processes [9, 10, 33, 95]. These technocratic solutions struggle to reach resilient, sustainable, and equitable outcomes due to disregarding and overlooking the social nature of water [54, 55]. Moving past the command-and-control, engineering-based model is essential to address the complex and wicked problems for a growing population and in an ever-changing climate [2, 9, 96].

This desocialization and depoliticization of water management under the prevailing Western epistemology is extremely evident in stormwater management in the United States. Stormwater management has been a public health, public safety, and environmental issue throughout the history of mankind, exacerbated by the drastic increase in urbanization within the last century [4]. In the United States, stormwater management remains in a technocratic realm of engineers and hydrologists due to the separation of humans from the hydrologic cycle. Most stormwater management and governance decision-making is based solely on hydrologic variables and analyses, rather than utilizing more holistic approaches [1, 2, 5, 14, 95].

Despite this, there has been progress towards more resilient stormwater management – from solely flood control towards treating stormwater prior to release into surrounding waterways. One example of this progress is the utilization of green infrastructure, rather than traditional gray infrastructure, to help manage stormwater volume and quality in urban and suburban areas [9]. Currently though, stormwater management in the United States continues to struggle with changing climatic conditions while maintaining human and environmental well-being [1, 5, 12]. Many urban water and stormwater management scholars suggest that climate change requires a complete rethinking and overhaul of water management, including stormwater management, especially in urban areas [11, 26].

Most engineers, hydrologists, and ecologists alike acknowledge that understanding the social, political, and economic factors driving stormwater management is important, but typically these factors are discounted and not incorporated into decision-making and governance [2, 5]. One approach that can help bring these factors into decision-making is the hydrosocial framework, which stresses that water and society exist in an integrated system. So, rather than people affecting hydrologic systems from the outside, the hydrosocial cycle views water and people as an integrated system with internal connections between humans and water [55]. The hydrosocial cycle as a framework for stormwater management can provide the ability to assess and understand the political, economic, social, and cultural dimensions. The hydrosocial cycle promotes a critical analysis of water-society relationships, positioning humans within the hydrologic cycle, where humans and water co-construct themselves based upon complex interactions of social, political, historical, economic, and hydrological factors.

The goal of this article is to explore how the hydrosocial cycle, as a framework for analysis, can provide the platform to investigate the social and natural relations of stormwater. We begin by showing that a hydrological framework that does not integrate the socio-natural aspects of water and stormwater heavily influences most stormwater management thinking and programs. Next, we present details of two case studies to illustrate the application of the hydrosocial cycle through which broader cultural, social, and political factors are linked to water management, in one case rainwater harvesting and the other stormwater management. The insights and lessons learned from these two different case studies are useful and suggestive to what a hydrosocial approach to stormwater management might look like or consider. Finally, we suggest some implications and provide recommendations focused on how hydrosocial analysis of stormwater management can increase the understanding of the socio-natural aspects of stormwater and how stormwater engineers and managers can begin to think within a hydrosocial framework.

3.2 History of Stormwater Management in the United States

Stormwater management is not a modern invention in response to urbanization. Ancient civilizations, like the Romans and Mesopotamians, constructed rather sophisticated water drainage infrastructure throughout their cities [97]. Historically, “pave and pipe approaches” were used to move stormwater off the landscape as quickly as possible with a “slow and soak” approach being utilized currently where stormwater is slowed down and allowed to remain and soak into the landscape over a longer period [4]. As populations continue to grow within the United States and throughout the world, a larger proportion of the landscape will be developed into suburban and urban environments. Development of the landscape can have a drastic effect on stormwater hydrology through a host of mechanisms including removal of vegetation, compaction of soils, and construction of impervious surfaces [14]. The processes of development significantly reduce the ability of the landscape to maintain proper hydrologic functioning [3, 7, 17, 22, 65, 98]. As urbanization has continued and the construction of impervious surfaces increased, it has become glaringly evident that stormwater management is necessary to maintain public and environmental health.

The concept of a hydrosocial contract or unwritten contract between society and their government to provide potable drinking water, water sanitation, management of stormwater, and flood protection begins to highlight how society and water have co-evolved over time. This coevolution can be seen through alterations in the hydrosocial contract, especially through the outcomes and goals of stormwater management. Stormwater management in the United States has undergone transitions; however, these transitions have been slow and ineffective at responding to the changing conditions and delivering management outcomes that align with the public and environmental concerns posed by stormwater [2, 5, 9]. Stormwater management began in urban areas with the primary goal of protecting public health from waterborne diseases that were prevalent due to the dumping of human waste into surrounding waterways. To combat this, some urban areas constructed combined wastewater and stormwater pipes which transmitted stormwater and wastewater to a central water treatment plant before release into local waterways. These combined sewers work well during dry conditions, but during wet weather, these combined sewers overflow resulting in the direct release of untreated sewage and stormwater directly into surrounding waterways [99]. Additionally, public safety became a primary concern due to flooding resulting from a host of landscape alterations associated with urbanization. To provide flood protection, the dominant view has been to transport stormwater off the landscape as quickly as possible, resulting in the technocratic solution of concrete lining or placing of streams into pipes to expedite the movement of stormwater to larger, receiving bodies of water. This paradigm in stormwater management characterized primarily by the expedited movement of stormwater off the landscape and into receiving bodies of water have been called “drained or sewered cities” [1, 9, 12, 83].

This paradigm dominated until the beginning of the environmental movement, where society wished to rethink the hydrosocial contract, leading to the subsequent passing of the Clean Water Act (CWA) in the 1970’s [2, 14]. The passing of the Clean Water Act in 1972 and the subsequent amendments (301 and 402) in 1987 placed legal requirements on state and local governments to control and treat stormwater prior to release into waterways [4]. These policies caused a distinct shift in stormwater management towards stormwater control measures that not only managed the volume, but also the quality of stormwater. Cities and municipalities have aligned with these legal requirements following both traditional gray infrastructure (centralized conveyance systems and water treatment plants) and GI (decentralized infiltration systems and practices) with the implementation of either varying spatially and temporally [2, 4, 14]. Stormwater management during this era has been called "waterways cities" [9, 10, 96] where the primary goal of stormwater management is to reduce pollutants entering waterways via stormwater through water volume reduction and water quality improvement practices. This is the current paradigm in the United States, but with a vast spectrum of implementation both within cities and throughout the country. Some cities have invested greatly in decentralized GI while others have continued to rely on gray infrastructure to meet the requirement of the CWA, but the large majority have implemented a complex combination of both gray and GI [31].

While there is agreement that decentralized GI practices will promote more sustainable and resilient stormwater management, the adoption and implementation of these practices has been slow mostly due to social, economic, and political factors [1, 5, 14]. Engineers, hydrologists, and ecologists who often make stormwater infrastructure and management decisions frequently overlook these factors [2, 60]. This tends to result in the implementation of traditional gray infrastructure rather than the adoption of new, GI practices. To compound these issues, climate change has prompted scholars to suggest that a "complete reworking of urban water governance" is required to cope with the public health, public safety, and environmental issues [11, 60]. In the United States, stormwater management must adapt to the changing climate, population growth, and increased urbanization towards more resilient, sustainable, and equitable outcomes. This would require stormwater management to incorporate the socio-natural aspects of stormwater into management and governance decision-making. This will also require a conceptual shift away from the hydrologic cycle and towards understanding of stormwater and society more holistically – this transition can be done using the hydrosocial cycle.

3.3 Transition from Hydrologic to Hydrosocial Cycle

Water management and governance has lacked a holistic perspective, when attempting to provide water for societal health, well-being, and prosperity resulting in the tendency to view water as a resource or commodity. This material view of water and water infrastructure has been reinforced by the hydrologic cycle. In the hydrologic cycle, the flow of water throughout the biosphere is a phenomenon pertaining to the "natural circulation of water in, on, and over the Earth's surface" [100]. The hydrologic cycle was first depicted by Robert Horton, an American hydrologist, with the purpose of providing a framework for the continued study of water within the biosphere [100] (Figure 3.1).

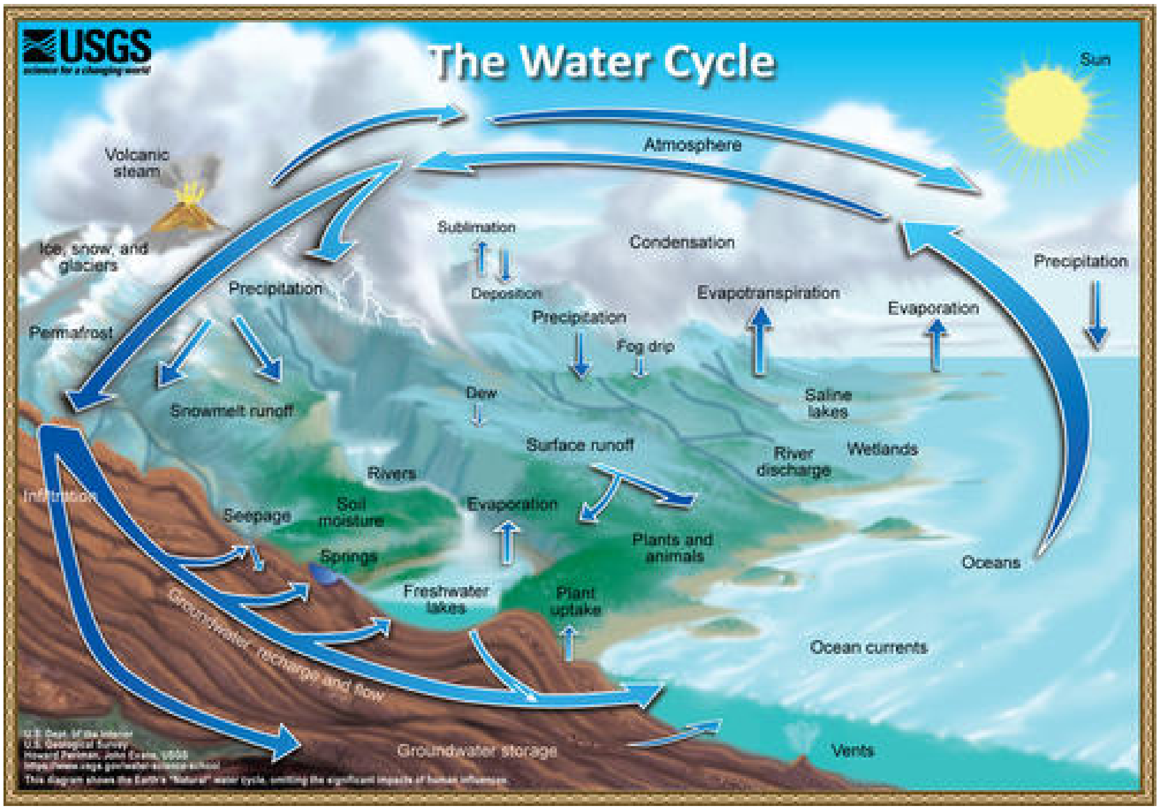

Figure 3.1: An example depiction of the hydrologic cycle seen in most textbooks and taught in introductory environmental classes. The purpose of this figure is not to convey the scientific principles of the hydrologic cycle, but to demonstrate the separation of humans from the hydrologic cycle. Produced by the United States Geological Survey.

The separation of humans from the hydrologic cycle has persisted despite many scholars identifying the problematic discourse of humans' separation from nature [55, 88]. This persistence may be connected to the general lack of representation of humans in hydrologic conceptual models. For example, a recent study reviewed 464 water cycle diagrams from around the world and found only 15% conveyed any type of human interaction within the cycle and only 2% showed any potential effects of human-induced climate change[101, 102]. Excluding human interactions from conceptualizations of water cycles may contribute to mismanagement of water resources and ineffective and inequitable water governance.

The hydrologic cycle leads to the separation of hydrologists from the other stakeholders and variables affecting water management and governance. The reliance on the hydrologic cycle reduces the ability to understand the historical, political, and social dimensions that give meaning, value, context, and power to water in, on, and over Earth's surface. Effectively, the hydrologic cycle "represents water in a way that erases its own social content and operates akin to a mirror of nature, wherein no image of society is reflected back" [55].

The hydrosocial cycle [55] provides an alternative to the widely accepted hydrologic cycle (Figure 3.2) and broadly conveys how "water" is situated within a continuously adapting cycle shaped by social, physical, and technological drivers. This general framework provides a stark contrast to depictions of the hydrologic cycle. In contrast with the hydrologic cycle, the hydrosocial cycle attempts to understand and account for the historical, political, and social factors that shape water and water management. Rather than separating humans from the flow of water, the hydrosocial cycle captures the reality that "water is simultaneously a physical flow (the circulation of H2O) and a socially and discursively mediated thing implicated in that flow" [88]. The hydrosocial cycle can be defined as "a socio-natural process by which water and society make and remake each other over space and time" [55]. This dialectical relationship between water and society suggests tracing every alteration within the hydrologic cycle to a societal shift of power or structural change is possible [87]. The hydrosocial cycle insinuates that water and society as related internally, each providing meaning, context, and power to the other [54].

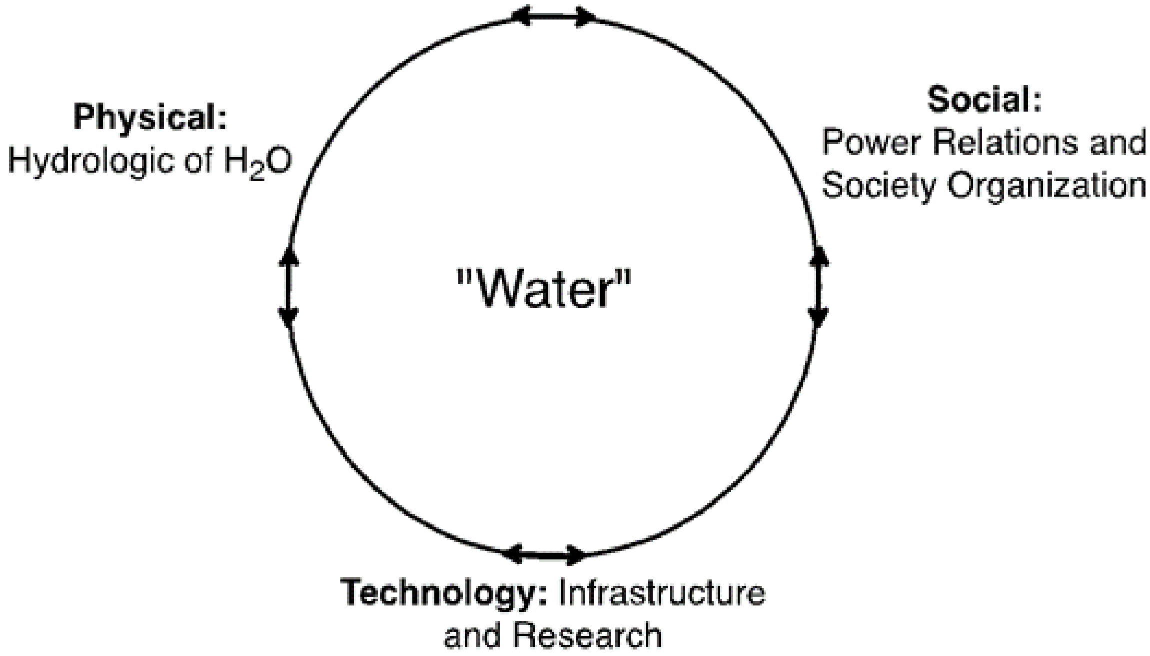

Figure 3.2: A conceptual diagram of the hydrosocial cycle by which the materiality of water, social power and structure, and technology and infrastructure make and re-make "water". Adapted from [55]

The hydrosocial cycle emphasizes the socio-natural aspects of water, particularly where "particular kinds of social relations produced different kinds of water" [103]. These different kinds of "water" arise due to different sociocultural meanings and water-society power relations that produce significant symbolic and material implications. For example, the sociotechnical processes that create bottled water as an alternative to tap water that citizens would be willing to pay for demonstrates how social, political, economic, and historical factors can create different kinds of water with different values and meanings [88]. In short - the hydrosocial cycle reframes the Western epistemology that divorces nature and society, and it allows the analysis of water and society as “the transformations of, and in, the hydrological cycle at local, regional and global levels on the one hand and relations of social, political, economic, and cultural power on the other”. The hydrosocial cycle seeks to understand the socio-natural processes that drive water-society relationships over time and across space.

The hydrosocial cycle can be a powerful framework to analyze the social, political, and historical dimensions of water-society relationships. The key aspects to utilizing the hydrosocial cycle to understand these relations are: (1) water management is necessary to maintain society, and as such, has a substantial driving effect on organizing society and power relations, which then in turn affects the hydrologic flows of water; (2) water and society are internally related – so that different sociopolitical relations give rise to different kinds of water; and (3) water’s material, hydrologic flow, despite being socio-politically altered, still provides important and active processes in the hydrosocial cycle that cannot be discounted [55]. Using the hydrosocial cycle can illuminate previously hidden or obscure nature-water-society relations that when integrated convey how water’s production, meaning, value, and context is the product of the coevolution of water and society.

3.4 Methodology: Using the Hydrosocial as Framework for Analysis

The research done throughout this article consisted of a literature review, in-depth analysis of stormwater-related hydrosocial case studies, and a synthesis of implications that a hydrosocial framework can bring to stormwater management. This research began with a literature review of applications of the hydrosocial framework to analyze water-society relationships in various sociocultural, political, and economic contexts. The literature reviewed spanned a multitude of spatial, cultural, and political settings [59, 104–112]. This literature review not only provided a basis for understanding applications of the conceptual framework and theory behind the hydrosocial cycle, but also, a platform to assess and expand into other water-society relationships, like stormwater management.

We formulated a set of questions based upon the literature review that all case studies provided the information to answer. These questions can be used as the basis for assessing the hydrosocial relations for any given water-society relationship. Additionally, they help explore the coevolution of water and society and unveil the internal processes and relationships shaping one another:

1.) What is the definition or conception of water amongst different stakeholders? Do these stakeholders have differing definitions or conceptions?

2.) What is the primary mechanism or driver behind the conception of water for each stakeholder group (i.e., social, historical, economic, political, spiritual, etc.)?

3.) In each instance, how has water and society been co-constructed and internally related to create "different waters in different water-society relationships" [55]?

4.) What are the management and livelihood implications and consequences of the hydrosocial relations between stakeholders and their and their "waters"?

Each of these questions can be answered differently depending on the hydrosocial relations present in any location, but they can have a profound effect on the water-society relationship and the overall goals and outcomes of water management and governance. These questions, derived from the literature review, are the foundation of any hydrosocial research and the backbone of beginning to question novel water-society relationships, like stormwater management.

Two case studies were chosen to explore the application of the hydrosocial cycle to analyzing stormwater management in the United States. Each case study analyzed with the above questions demonstrates how water and society continuously make and remake each other through sociocultural and sociopolitical processes. These two case studies concerning rainwater harvesting in the arid southwest [113] and the political atmosphere surrounding the implementation of green infrastructure (GI) implementation [34] were chosen to be illustrative and representative of the power of the hydrosocial cycle as an analytical framework. Additionally, both case studies were closely related to stormwater and could be utilized to explore what a hydrosocial approach would bring to an analysis of stormwater management. These case studies were utilized as steppingstones to draw equivalents into stormwater management. These parallels allowed for the formulation and articulation of key questions that a hydrosocial framework reveals for stormwater management in the United States.

3.5 Results: Bridging the Hydrosocial into Stormwater Management

3.5.1 Rain Harvesters as "Ethical Desert Dwellers"

In a study of rainwater harvesting programs in Arizona, Lucero Radonic documented how rainwater harvesting produced an intimate connection between residents and rainwater [113]. The city of Tucson instituted a rainwater harvesting ordinance in 2008 where residents received a $2,000 rebate for the installation of cisterns on their property. These rainwater harvesting practices were readily implemented with nearly two thousand residents installing cisterns in the first six years of the program [113]. The primary goal of the ordinance was to reduce the potable water consumption by residents of Tucson by incentivizing the use of harvested rainwater for irrigation and other household uses. This research revealed that despite the widespread installation of rainwater harvesting practices, potable water consumption by residents did not significantly decline. Radonic analyzed the hydrosocial relations altered and created through the rainwater harvesting program and determined how and why potable water consumption remained consistent [113].

The goal of decreasing the potable water consumption was not achieved through the rainwater harvesting ordinance; however, the hydrosocial relationships between the residents, rainwater, and their surrounding environment were transformed. For residents, the rainwater-harvesting program altered their relationship with the surrounding environment, providing a deep connection with the local landscape and water resources. Understanding the hydrosocial relations affords a look into the more nuanced ramifications of the rainwater harvesting program that go beyond simply lowering potable water consumption.

The rainwater-harvesting program allowed residents to feel as though they were working alongside the natural environment, and they managed their livelihood within the desert landscape. For example, nearly all residents were utilizing the harvested rainwater to decrease the use of potable water for irrigation purposes. Residents shifted to manually watering the landscape or setting up automated drip irrigation connected to their cisterns, despite being both time and labor intensive compared to typical household watering practices [113]. This alteration in everyday irrigation practices helped produce a tangible connection between the harvested rainwater, the landscape, and the residents, themselves. Additionally, many rainwater-harvesting residents began to replace high water using ornamental plants with more drought-resistance native plants to allow the harvested rainwater to be more efficiently utilized [113]. Residents began to take responsibility for, not only harvesting rainwater, but effectively and efficiently utilizing the rainwater for the betterment of their landscape and to decrease their impact of living within a desert environment. Ultimately, this connection prompted a new socio-natural relationship between the residents and their environment, altering how residents viewed their place on the landscape.

Rainwater is now also conceptualized as a new "resource" within the urbanized environment [113]. Many residents, after partaking in the rainwater-harvesting program, uprooted their beloved "tropical paradise" landscaping to prevent wasting harvested rainwater [113]. Residents also began citing healthier plants and soil conditions due to rainwater irrigation [113]. Residents started viewing rainwater as higher quality compared to tap water, the result of their intimate relationship with harvesting practices (like how a tomato grown in your own garden always tastes better than one that was store bought). Rainwater became socially and culturally constructed as a valuable resource that residents could take advantage of and utilize for their own personal benefit and the betterment of the environment.

The hydrosocial relations that arise because of the water conservation program do not align with the goals and outcomes of the state conversation program, but still provide important, useful insights for future water conservation and management in the face of increased urbanization and climate change in a desert environment. For example, by understanding the hydrosocial relations, one identifies that the usage of harvested rainwater for irrigation is an avenue to promote more efficiency. Most residents use their harvested rainwater purely for landscape irrigation; however, many residents cited that this practice is inefficient, labor and time-intensive, and particularly wasteful. This wastefulness is due to the inability of residents to closely monitor pumping systems distributing rainwater and/or the forgetfulness of residents to close valves and move hoses and pipes when manually distributing collected rainwater. A hydrological viewpoint may deem the program a failure or advocate for additional rainwater harvesting by residents to lower potable water consumption, but through understanding the hydrosocial relations, the state could help lower potable water consumption through outreach for irrigation practices and promoting the usage of different, more efficient irrigation technologies. This outreach could help residents more efficiently and effectively utilize harvested rainwater and decrease the use of potable water for irrigation purposes when rainwater is either wasted or scarce. Additionally, though, this analysis conveys the socio-natural processes and hydrosocial relationships that arise because of the rainwater harvesting program. These insights are important to understand and assess to determine how residents relate to water resources and their surrounding environment.

3.5.2 Co-option of Green Infrastructure by Gray Epistemologies

In a second case study, Michael Finewood demonstrates how water management and governance stakeholders have co-opted the conversation around GI for stormwater management to maintain control and power [34]. The city of Pittsburgh, subjected to Consent Decree in 2008, required Allegheny County Sewer Authority (ACSA), in collaboration with municipalities, to improve the quality of water entering the surrounding streams and rivers. The Consent Decree would require large-scale improvements in the stormwater infrastructure within the city costing ACSA approximately 2-4 billion dollars. Stormwater management infrastructure in Pittsburgh would primarily be classified as "gray infrastructure" where combined stormwater and sewage pipes convey water to water treatment facilities prior to release into local waterways. Moving away from gray infrastructure and limiting combined sewer overflows, GI or source-control practices have gained widespread acceptance as a more ecologically friendly and "green" method for stormwater management.

In 2013, ACSA released a "Wet Weather Plan" that detailed how primarily gray infrastructure approaches would be constructed to help meet the Consent Decree that was roundly opposed by a large contingent of the community. Community members instead supported the institution of GI practices across the city to help cope with stormwater during rain events and potentially provide more equitable distribution of benefits from the large-scale infrastructure projects necessary to meet the Consent Decree [34]. The Wet Weather Plan was rejected by the Environmental Protection Agency (EPA), providing community advocates an inroad for the institution of GI practices into the Wet Weather Plan. After the rejection of the gray infrastructure-dominated plan and the backlash faced from the community over the lack of GI, ACSA began to acknowledge the importance of GI to manage stormwater. ACSA understood that the incorporation of GI within the city would be more expensive, require additional planning, and necessitate involvement with the community. To avoid this and maintain the status quo of stormwater management in Pittsburgh, ACSA used their position of power and perceived expertise to control the gray versus GI narrative and how GI was conceptualized.

Controlling the narrative began when the ASCA began using model analysis to pinpoint "hot spot" areas for GI implementation, allowing ACSA to be viewed as supportive of GI, demonstrating their expertise for stormwater management, and controlling GI implementation, in general. ASCA also worked alongside community partners to find shovel-ready GI projects. These shovel-ready projects for GI implementation were chosen based on which projects would be most visible to the community, rather than which would provide the highest stormwater management and overall community benefit. ACSA rebranded themselves as "green by mission, green by choice" [34] and began to attend community meetings organized by GI proponents to convey how they were supportive of GI institutions. Additionally, ASCA incorporated GI into their revised Wet Weather Plan, but strategically failed to set any specific GI goals or targets. ASCA appeared to the public as honestly incorporating GI into their plan while only superficially endorsing and supporting GI implementation. This could be seen in discussions around construction of GI within low-income neighborhoods where engineers "asked if there was an effective size or type of GI that would not need community feedback" [34].

All these steps taken by ASCA were to increase their involvement within the GI discussion. Then they began shaping the narrative surrounding GI implementation for stormwater management. ASCA shifted to a more technical narrative for GI implementation centered on hydrology that GI advocates had to embrace to be incorporated within the debate. Community advocates speaking about GI in terms of "water quality compliance" and "long term-maintenance and monitoring," where prior to ASCA involvement, the narrative was centered on broader, less technical ideas, like job creation, economic development, and community improvement. This demonstrates co-opting of the GI narrative by ASCA. ASCA utilized their position of power and control to infiltrate the GI discussion, shift the narrative to benefit their viewpoint, and ultimately, converge the narrative more towards their preferred gray infrastructure, technological-dominated views. By doing so, ASCA could not only control what infrastructure is built (gray vs. green), but where it is built and who it benefits. Here, stormwater and society co-construct each other to reconceptualize GI through political, economic, and socially distinct narratives.

ASCA was not only shaping the narrative surrounding stormwater management, but also around larger, more broad urban governance issues. The converging of ASCA's engineering-based ecohydrological narrative with community-based involvement in stormwater management through GI did not result in collaboration and erosion of epistemological difference, it simply reframed the city as slightly greener but the dominant existing command-and-control, technocratic regime remained in control and power [34]. This results in the same stakeholders "shaping, controlling, and reproducing the city" [109] to align with their interests, benefiting themselves, and neglecting others, but behind the shroud of collaboration with community groups. Community members wanted GI to be incorporated into the Wet Weather Plan to provide multi-functional benefits, especially for low-income neighborhoods, who disproportionately are affected by the multitude of environmental harms of urban living [34]. This shift would entail a reworking of urban water management within Pittsburgh and potentially a removal of powerful actors, like ASCA. To prevent this, ACSA co-opted the messages and views of GI proponents and community members, using their position of power and expertise to control the narrative. This allowed ASCA to maintain the status quo for urban water management, and more largely, produce a city designed to advantage certain actors and stakeholders, and neglect others which has distinct management and livelihood implications.

A hydrosocial lens allows an analysis that better understands the sociopolitical drivers that maintained a gray epistemology within Pittsburgh water governance and management. The dominant ecohydrological view allows for the perpetuation of dominant management practices and outcomes and the co-option of the GI narrative. Through an analysis of the hydrosocial relations, it becomes evident that GI advocates and community members must change how they approach GI implementation and adoption to achieve their goals. GI advocates must begin to ask deeper, more complex questions of urban power dynamics, human-nature integration, and capitalistic endeavors, and if progress towards GI adoption wishes to overcome the dominant, deeply ingrained technocratic management, especially surrounding urban water management.

3.5.3 Synthesizing Case Studies

These case studies demonstrate the significance of understanding the hydrosocial relations concerning stormwater management and governance. When used as an analytical tool, approach, or lens, the hydrosocial cycle illuminates previously obscured or invisible social, political, historical, and/or economic interactions that shape how the framing of stormwater and how governance and management is undertaken and supported. The findings and implications of each case study and how each case study answers the guided hydrosocial questions mentioned previously is depicted in Table 3.1. We summarize the insights from the hydrosocial analysis, the implications of these insights, and how these insights are different from typical hydrologic or ecohydrological research in the following section.

In Tucson, Arizona, state-sponsored rainwater harvesting programs fostered an intimate connection for residents with their desert landscape; however, it did not produce the desired outcome of lowering potable water consumption. At first glance, the rainwater-harvesting program was a failure; however, by understanding the changing hydrosocial

Table 3.1: Comparative Insights from Applying Hydrosocial Framework

	Pittsburgh, Pennsylvania	**Tucson, Arizona**
Definition or Conception of Water	Stormwater Water as “hazard”	Rainwater Water as “resource”
Primary Mechanism or Drivers	Political Social Physical Economic	Social Physical Political
Co-construction of Water and Society	City needed to adhere to the Consent Decree to manage stormwater within Pittsburgh. Conflict between GI proponents and ASCA on how to best address stormwater and adhere to Consent Decree.	State rainwater harvesting program designed to promote decrease in potable water consumption by residents. Program alters residents’ connection with rainwater, tap water, and surrounding landscape.
Insights of Traditional Ecohydrological Analysis	Gray infrastructure is the most cost-efficient choice to manage stormwater in Pittsburgh, but GI implementation in “hotspot” areas for ecological benefit.	Rainwater harvesting program failing to decrease potable water consumption among residents. Increased adoption could decrease potable water usage.
Insights using Hydrosocial Analysis	The co-option of GI for stormwater management by those in power to maintain authority over water management. GI narrative controlled by traditional technocratic, command-and-control water management regime.	Rainwater harvesting program failing to decrease potable water consumption among residents. Residents as “ethical desert dwellers,” not as economic rational decision makers that use rainwater harvesting to validate their decision to live in a desert environment.
Management and Livelihood Implications	GI advocates should acknowledge how they have lost control of the GI narrative. Begin to ask larger questions of urban power dynamics to unseat traditional institutions, power dynamics, and epistemologies.	The implementation of future conservation programs towards more efficient, effective usage of collected rainwater and other programs to decrease public potable water usage.

relations, future management decisions and programs can be more successful. In Pittsburgh, Pennsylvania, the co-option of GI by engineers and hydrologists to maintain the status quo and perpetuate environmental inequality within the city's stormwater management plan is significant to acknowledge. The hydrosocial configurations, despite appearing to favor a shift to supporting GI and the management of stormwater as a "resource" were purely superficial. To truly progress towards the implementation of GI, co-option must be understood through hydrosocial relations and avoided and overcome. These case studies provide valuable information on how the hydrosocial framework illuminated the often hidden social, cultural, and political factors underlying water-society relationships. Importantly, these case studies provide direct relations to implementing a hydrosocial framework into stormwater management in the United States and what questions would arise from doing so and the implications of those questions.

3.6 Discussion: Applying the Hydrosocial to Stormwater Management

Stormwater management in the United States is distinctly a socio-eco-technical issue [1, 9]; however, the current solely hydrology-focused paradigm depoliticizes the management and governance of stormwater. Within the past decade, there has been substantial pressure from environmental and social advocates to transition stormwater management towards more sustainable, resilient, and equitable goals and outcomes [2, 14, 33]. Despite this pressure, the paradigm shift and evolution has been markedly slow and, in some cases, non-existent [7, 10, 114]. There is substantial knowledge that social, political, economic, and historical factors underpin and affect stormwater management; however, they are rarely incorporated into management and governance, maintaining the status quo of stormwater management being an apolitical, asocial, and ahistorical process [2, 5, 9–11, 34, 97, 113].

These case studies provide interesting and useful parallel insights for the application of into the hydrosocial cycle framework to stormwater management. For example, in Arizona, the way in which the residents related, viewed, and conceptualized rainwater and their place on the landscape shifted due to rainwater harvesting. Socially and culturally rainwater began to be seen as a significant resource in the desert landscape that should be efficiently harvested and utilized by the residents living there. Similarly, how stormwater is socially and culturally constructed highly dictates how it is managed across the United States. By understanding the social and cultural factors influencing how stormwater is viewed and conceptualized, infrastructure and management plans can be tailored to help shift the conceptualization or simply work within the bounds of a given conceptualization [8]. In Tucson, by providing a tangible, intimate relationship between the residents and rainwater, rainwater was elevated into a socially and culturally important resource. Perhaps doing the same for stormwater will help shift the narrative away from "stormwater as a pollutant" and towards "stormwater as a resource." Undoubtedly, understanding the social and cultural factors influencing stormwater are important and answering the question of "what is stormwater?" both socially and culturally is paramount to successful transitions in management paradigms.

In Pittsburgh, the ability of powerful stakeholders to control the narrative around infrastructure choices, particularly for stormwater management, demonstrated the importance of political and economic drivers. ASCA could utilize their seat of power and influence to dictate what infrastructure was built, where it was built, and who it was built to benefit. The power and influence of ASCA arises due to their positioning within the hydrosocial relations and ability to control the narrative to frame their positions and discount others. Only through an understanding of these hydrosocial relations could the discursive framing employed by ASCA be assessed and potentially overcome. This case study draws strong connections with stormwater management in the United States, especially the political and economic aspects that are often overlooked. In Pittsburgh, the stormwater management infrastructure choices were controlled through co-option of narratives to keep certain stakeholders in power and remake the city in the image of their desires. Similarly, stormwater management across the United States provides a platform for actors to control what infrastructure is built for stormwater management, where they are built, who reaps the benefits of the infrastructure, and who is neglected. Stormwater management in the United States is highly political and investigates the hydrosocial relations, answering questions like, "where are stormwater management practices built and why?" will begin to promote a transition away from the technocratic management paradigm dominating stormwater management throughout the United States.

Stormwater management provides an excellent platform for the application of the hydrosocial cycle framework of analysis to better understand why the paradigm shift in management has faltered and identify opportunities for progressing stormwater management to the more desired state towards sustainability, resilience, and equity. Engaging with the hydrosocial framework for stormwater management raises some important questions that will undoubtedly shape the ecological, social, political, and economic outcomes for the future of stormwater management in the United States. These questions are related to the framing questions we identified from the literature review and include:

1. Conception and Definition of Stormwater - What is stormwater? Is it a natural resource or a pollutant? - Stormwater tends to be seen as a nuisance, hazard, or "a problem to be solved" [13] rather than a natural resource that can be a "remedy to ongoing water resource challenges and constraints" [27]. How will climate change (increase in droughts, flash flooding, etc.) affect this? Can stormwater be "re-made" as a natural resource, and if so, will this reconceptualization begin a new paradigm in stormwater management [8]?

2. Co-construction of Stormwater and Society - How does the legal structure frame stormwater? - The Clean Water Act has been described as a "liability, not a tool to manage stormwater – giving cities the responsibility, but not the authority to control stormwater from private property" [2]. Can changing the CWA or introducing new legislation shift the discursive framing of the management of stormwater from a "liability" to an "opportunity" for cities and communities?

3. Co-construction of Stormwater and Society - Where are stormwater management practices built and why? - Stormwater does not occur uniformly across the landscape, and it "is rarely a medium of rigid social structures" [55]. As a result, there is a disconnection between political and hydrologic boundaries for management, including public versus private land. Is integration of political and hydrologic units possible? Will shifting the responsibility to "private landowners who generate stormwater by changing their land features," [2] provide integration?

4. Management and Livelihood Implications - Who benefits from stormwater management? - Centralized and decentralized GI stormwater best management practices as more sustainable, equitable solutions for stormwater management have garnered considerable attention. Are governments utilizing GI, along with neoliberal ideology, to maintain power and authority over the landscape of urban areas? Can we provide truly sustainable and equitable solutions for stormwater management?

Each of the questions above arise through an analysis of the hydrosocial relations of stormwater management in the United States. These questions are primarily social, political, or economic, obstacles or impediments rather than scientific knowledge gaps or concerning the physical nature of water (hydrology). Many ecologists understand that "we already have many of the technologies to address the problem of stormwater runoff" [5]; however, it is an insufficient understanding and accounting for the socio-natural processes of stormwater that hinder progress. The hydrosocial cycle as an analytical framework provides the foundation to begin to answer these questions. Each of these questions requires an in-depth analysis of the internally related processes between stormwater and society that have shaped stormwater, socially and discursively. The goal of employing the hydrosocial as a framework for analysis is to understand how stormwater socially, politically, and historically and the implication this can have on future management decisions. By understanding the different stormwater-society relationships that give rise to the different definitions and conceptions of stormwater, a better understanding of the obstacles and identification of potential avenues to alter these relations is possible.

For stormwater managers, these questions prompt a re-thinking of the management of stormwater. If stormwater is a resource, how can stormwater managers provide infrastructure to best utilize the potential of stormwater for homeowners, industry, government, and businesses alike? If the goal of stormwater management is resilience and equity, how can stormwater managers incorporate environmental and social equity into their management plans to be sure that decisions and implementation of stormwater management practices are equitable? An adoption of the hydrosocial framework will create stormwater managers who think more critically, holistically, and collaboratively with the communities. Stormwater management in the United States is strongly dictated by power and authority, potentially through this framework, inequalities and injustice that tend to dominate environmental management can be identified and avoided for stormwater management.

For hydrosocial researchers, stormwater can provide a new avenue to understand more complex nature-society relationships. For example, stormwater is difficult to manage, as with other environmental issues, due to the dispersed nature of stormwater across the landscape and the difficulty in managing private versus public lands. By understanding the hydrosocial dynamics that prevent the management of stormwater on private lands, hydrosocial researchers can begin to, more broadly, investigate the nature-society relations that arise due to private land. Additionally, stormwater can be a means for hydrosocial researchers to investigate how the framing of water in different contexts, alters how it is managed (i.e., stormwater/rainwater as a hazard, pollutant, nuisance versus as a natural resource). A hydrosocial framework for stormwater management has significant implications for both stormwater managers and hydrosocial researchers and provides a platform for collaboration between the two.

3.7 Conclusions

Many ecologists and engineers suggest that the technology to achieve more sustainable, resilient, and equitable water management in cities is available through stormwater GI, low-impact development, and best management practices [2, 5]. However, they understand that implementing these technologies is relatively futile without social, political, and economic acceptance and support [7, 31, 115, 116]. Hydrosocial research provides the foundation to increase the successful implementation of stormwater management technologies and practices within a diverse range of hydrosocial configurations. Natural and social scientists alike can utilize the hydrosocial cycle, bringing stormwater management out from behind the technocratic shroud of the hydrologic cycle and past the nature-society dualistic relationship.

Stormwater provides the basis to understand, more broadly, urban life and inequity through a hydrosocial framework. For hydrosocial researchers, stormwater is a medium within water-society relationships that has immense research potential, specifically for improving the resiliency, sustainability, and equity of stormwater management in the United States. Stormwater provides an excellent platform to see how application of the insights and implications from research can be utilized for meaningful and relevant changes to stormwater management outcomes [57]. Stormwater managers often encounter political, social, and economic obstacles, which are difficult to address when attempting to provide the best stormwater management outcomes for public and environmental health. The hydrosocial cycle provides the foundation to place ecohydrological research into a more holistic setting, promoting reflexivity in research, framing advances in technologies or management within the appropriate and necessary social, political, and economic climates.

Stormwater and the management of stormwater is highly cultural, social, and political in nature and only through incorporation of these factors into management decision-making and governance, can a transition towards more sustainable, resilient, and equitable stormwater management be reached. It is suggested here that in the short-term, hydrosocial analyses on stormwater management will be necessary in promoting a more resilient, sustainable, and equitable stormwater management paradigm. Ultimately, the hope is that stormwater will become an environmental flow within the hydrosocial cycle assessed, understood, and managed by engineers, ecologists, hydrologists, political ecologists, economists, and geographers alike.

Chapter 4: Shifting Paradigms in Stormwater Management: Hydrosocial Relations and Stormwater Hydrocitizenship[1]

4.1 Introduction

Stormwater management in the United States of America (USA) typifies expert-based, technocentric governance where decision-making, discourse, and practices are shaped predominately by scientists, engineers, and policymakers [2, 5, 28, 60]. Arising from this top-down governance, stormwater has typically been managed using centralized, built infrastructure. This infrastructure, referred to as gray infrastructure, is designed to transport, retain, and treat stormwater through a complex network of pipes, storage tanks, and treatment facilities [4, 13, 14]. This style of management separates individuals from stormwater, primarily with the aim to protect the environment and public health from the potential adverse effects posed by uncontrolled stormwater runoff. Gray infrastructure remained the status quo until the early 2000's, when stormwater flooding and non-point source pollution concerns returned to the public purview due to climatic changes, increasing urbanization, and a resurgence in environmental advocacy [2, 5, 11, 34].

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[1] This dissertation chapter is currently in the second round of reviews in the journal, *Journal of Environmental Policy and Planning*. Matthew Wilfong, Michael Paolisso, Debasmita Patra, Mitchell Pavao-Zuckerman, and Paul Leishnam were co-authors for this journal article. Matthew Wilfong and Michael Paolisso contributed conceptualization, methodology, investigation, writing, review, and editing of the manuscript. Debasmita Patra contributed with methodology, investigation, and review and editing the manuscript. Mitchell Pavao-Zuckerman and Paul Leishnam contributed funding and review and editing of the manuscript. This research was funded by NSF-CHN/DEB Grant no.1824807 and a USDA NIFA Hatch project through the Maryland Agricultural Experimentation Station.

There is currently the beginning of a paradigm shift in how stormwater is managed across the USA [5, 9, 12, 114, 115, 117]. This paradigm shift is characterized by two key developments: the implementation of additional decentralized green infrastructure, and the practice of individuals managing stormwater from their privately-owned property. In contrast with centralized, gray infrastructure - green infrastructure is characterized by small-scale, decentralized practices that mimic natural processes like infiltration and evapotranspiration [22–24, 118]. This paradigm shift also focuses on expanding the participation of individuals into stormwater management and governance [119, 120]. Individuals' participation in managing stormwater is a necessity, especially in urbanized areas, where public land available for stormwater management infrastructure is often minimal [2, 9–11]. Currently, however, many individuals have little knowledge of where, how, and who manages stormwater due to the decades of centralized management [5, 11, 14, 26, 28]. As a result, a reframing of how individuals view their responsibilities and duties to manage stormwater is required. In this paper, we analyze individuals' involvement with stormwater management and governance as stormwater hydrocitizenship [121–124].

Building upon existing hydrocitizenship scholarship, we explore how processes and mechanisms of governance help to produce specific hydrosocial relationships, specifically drawing on Foucauldian concepts of biopower, the mechanisms through which governance shape the lives individuals [121, 124–126]. The overall goal of our paper is to better understand the hydrosocial processes that influence, shape, and control how and why individuals partake in stormwater management and the shaping of stormwater hydrocitizenship more generally. We analyze how emerging hydrosocial relationships are influenced by the techniques and processes of stormwater governance that can be characterized by Foucauldian concepts of biopolitics and discipline, two modalities of biopower used by governments to influence the behaviors and ideals of individuals [121, 124–126]. We argue that the modalities of biopower employed by governments shape the hydrosocial relationships with stormwater, including the emergence of stormwater hydrocitizenship. The result is tension and conflict among stakeholders as individuals and communities are limited in their ability to define their role within stormwater management and governance. We contend that these conflicts surrounding hydrocitizenship will continue to limit the ability of stormwater governments to bring individuals into the management of stormwater. We show that the current shift in stormwater management paradigm remains predicated on top-down governance and struggles to provide the needed changes within stormwater governance and management to cope with climatic changes, increased urbanization, and heightened focus on environmental health, justice, and equity [1, 2, 5, 11, 28].

We structure this paper by presenting the theoretical framework for this research connecting the hydrosocial to power and political dynamics, specifically using the Foucauldian concepts of biopolitics and discipline. Next, we describe the historical context for stormwater management focusing on the Mid-Atlantic region, specifically within our study watersheds, Watershed 263 in Baltimore, MD and Watts Branch watershed in Prince George's County, MD and Washington D.C. We then discuss the research methodology utilized to investigate the hydrosocial relationships and hydrocitizenship within our study watersheds. The remainder of the paper describes the emergence of hydrocitizenship within these study locations, specifically through the hydrosocial and Foucauldian lens. The paper concludes by providing some actionable recommendations and steps towards re-imaging stormwater management beyond the technocratic, top-down form of governance and management firmly in place.

4.2 Theoretical Frameworks: Hydrosocial and Foucauldian Biopower

4.2.1 Hydrosocial Cycle and Hydrocitizenship

The hydrosocial cycle, as a theoretical framework of analysis, has gained popularity as a tool to better understand and assess the socio-natural dimension of water management, especially the role of power relations [54, 55, 88]. Within the hydrosocial framework, "water" is situated within a continuously adapting cycle shaped by social, physical, and technological drivers. The hydrosocial cycle emphasizes that water and society are related internally, each providing meaning and context to each other [55, 86, 88]. Using the hydrosocial cycle can illuminate previously hidden or obscured water-society relations that when integrated convey how water's production, meaning, value, and context is the product of the co-evolution of water and society [28, 55, 86, 113]. These co-evolutionary processes between water and society produce distinct hydrosocial relationships and can highlight how specific power dynamics shape, define, and reinforce these relationships [55, 108, 109, 127, 128].

Of particular interest in research on hydrosocial relationships is subject formation or subjectivity. Subjectivity has been described as the way in which individuals reflexively understanding themselves [113, 121, 126, 129]. Under the hydrosocial cycle framework, this subjectivity represents a distinct hydrosocial relationship and shaped by political, social, and cultural factors alongside the ever-present materiality of water. Scholars have begun to study how subjectivities between individuals and water relate to and are influenced by dominant discourses and institutions, typically imposed by state and local governments [10, 113, 121, 130]. Recent research has also focused on the ways in which water, technology, and citizenship co-evolve producing distinct relationships between citizens and water, typically resulting in inequities in water access, quality, and health [131, 132]. This subjectivity between individuals and water and citizenship arising from water infrastructure has also been described as hydrocitizenship. Branching from environmental citizenship, hydrocitizenship is the rights, duties, responsibilities of individuals within water management and governance [121–124]. Hydrocitizenship describes the way in which citizens subjectively envision or position themselves within the water management and governance structures and represents a newly identified hydrosocial relationship [55, 86, 90, 121, 124, 133, 134].

Most of the research on hydrocitizenship has not investigated the drivers (sociopolitical, socioeconomic, and sociotechnical) that influence the "rights, duties, practices and identities" of hydrocitizenship [135]. Under the predominantly Western epistemology of technocratic, top-down forms of water governance, hydrocitizenship is typically shaped through techniques of governance that individuals [121–124]. As a result, hydrocitizens actively engage within water management and governance; however, this participation is based upon the pre-existing structures and existing power relationships. The use of the Foucauldian concept of biopower can help to assess and understand the mechanisms through which governments influence hydrocitizenship [125, 126].

4.2.2 Foucauldian Biopower and Hydrocitizenship

Building and refining upon his work on governmentality, which is the ability of those in power to govern the conduct of subjects, Foucault introduced the concept of biopower [125, 126]. Alongside the generalized and abstracted force of biopower, he introduced two distinct modalities of governmentality: biopolitics and discipline [121, 124–126]. Biopolitics can be defined as the power consisting of practices and techniques that govern and regulate behavior at the population-scale [121, 124–126]. In contrast, discipline is the mode of governmentality where governments seek to produce behaviors and practices by individuals through influencing the ways in which they relate to and view the world [121, 124–126]. Biopolitical governmentality aims to separate management from social variables and reduce the complexity of the system to quantifiable values and statistics. Alternatively, disciplinary governmentality seeks to reintroduce those same social variables into the system but controlling the range of possibilities and extent as to which those social variables manifest themselves. In combination, biopolitics is "impersonal and totalizing" and discipline is "intimate and individualizing" [124]. These two forms of governmentality operate in tandem to constitute biopower.

Within environments characterized by expert-based, top-down governance and management, hydrocitizenship is arguably shaped, in part, by the governmentalities of biopolitics and discipline practices [86, 90, 124, 129]. For example, drought management and planning in England relies on complex, quantitative risk-based computer models [124]. This biopolitical governmentality coincides with disciplinary practices where authorities install water usage monitors on households throughout the region to encourage citizens and water users to be more cognizant of their water use, especially during times of drought [124]. In combination, the biopolitical governmentality works to create a system through which drought management is a quantifiable, modellable system while the disciplinary governmentality shapes the ways in which individuals understand, relate to, and behave within the predefined system [121, 124–126, 129]. These two modes of governmentality represent a portion of the hydrosocial cycle through which distinct relationships are being produced and controlled, typically benefiting those governments in power [32, 88]. As a result, hydrocitizenship can be understood through a hydrosocial lens where Foucauldian ideas of biopower, biopolitics, and discipline play integral roles in defining hydrocitizenship. Using these theoretical approaches, we assess the hydrosocial relationships within the shifting stormwater management paradigm and the emergence of stormwater hydrocitizenship.

4.3 Framing Stormwater Management and Governance in the Mid-Atlantic

4.3.1 Historical Approach to Stormwater Management and Government

In the United States, stormwater management and governance are regulated through the Clean Water Act (CWA) and the subsequent amendments (301 and 402), which place the legal requirements on state and local governments to control and treat stormwater prior to release into waterways [4]. As a result, state and local governments, through the National Pollutant Discharge Elimination System (NPDES) program, issue Municipal Separate Storm Sewer System (MS4) permits, and total maximum daily loads (TMDLs) permits at the county-level that dictate the amount of pollution that each county can export into surrounding waterways. MS4 permits and TMDLs place numerical limits on the amount of pollution allowed to be released, typically nitrogen, phosphorus, and total suspended sediments, from a given county or municipality [46]. These values are determined through quantitative modeling and stormwater management infrastructures are assessed on their performance using similar modeling approaches. This legal structuring of stormwater management promotes the use of quantifiable monitoring and statistical models to enact and enforce stormwater regulations. This permitting scheme requires stormwater infrastructure to provide quantifiable, modellable management that is reliable and consistent [4, 9].

As a result, state and local governments typically employ gray infrastructure, characterized by technocentric, centralized conveyance systems that temporarily detain or slow the flow of stormwater prior to treatment at large-scale treatment plants, to manage stormwater from urban areas These systems are typically complex networks of underground pipes and storage tanks that transport stormwater to treatment plants or into larger bodies of water and have mostly proven effective in managing stormwater. Additionally, gray infrastructure systems can be readily modeled and calculated, a necessity to fulfill legal requirements outlined within the NPDES [4, 15]. Overall, this management paradigm has greatly improved stormwater management throughout the United States, reducing the hazardous impacts of stormwater flooding and pollution in cities compared to pre-CWA management [4, 16].

Despite these improvements, centralized gray infrastructure struggles to cope with increasing urbanization and climatic changes occurring throughout cities across the USA. These infrastructural systems were built under scenarios and criteria that are frequently surpassed due to higher proportions of impervious surfaces and more intense precipitation dynamics. As a result, stormwater flooding is increasingly becoming a public health and safety concern in cities along with stormwater pollution concerns in surrounding waterways. Stemming from these concerns, there has been a substantial shift, within the past two decades, towards more decentralized, green infrastructure for stormwater management.

4.3.2 Shifting Paradigm: Towards Decentralized, Green Infrastructure

Beginning in the early 2000's, many states began implementing stricter stormwater management regulations in response to consent decrees by the EPA because of violations of the CWA and NPDES programs. These consent decrees act as an agreement between state and local governments and the EPA to begin actions towards improving stormwater treatment, rather than paying the costly fines associated with violating the CWA and NPDES program. In addition, climatic change, increased urbanization, and heightened environmental advocacy prompted increased and more stringent stormwater regulations [4, 15]. Both Maryland and the District of Columbia (D.C.), passed enhanced stormwater management acts in 2007 and 2013, respectively [4]. These new regulations require the management of stormwater on-site through more decentralized, green infrastructure, specifically from new development. Previously developed areas were not required to adhere to these new, stricter regulations and typically continued to rely on centralized, gray infrastructure to manage stormwater [3, 23, 48, 61]. The passing of these more stringent regulations marks the beginning of a shift in the stormwater management paradigm across the region.

In most urbanized watersheds, including Watershed 263 and Watts Branch, public spaces and new development are a small portion of the total area producing stormwater [2, 5, 11, 13, 14]. As a result, the enhanced stormwater management regulations are insufficient to create noticeable changes in how and where stormwater is managed in highly urbanized watersheds. The majority of stormwater emanates from privately-owned property where governments do not have the authority to implement stormwater best management practices (BMPs), due to the legal framework of the CWA and state stormwater regulations [2, 5, 11, 14, 61, 114]. This issue, coined the "private vs. public dilemma", prevents governments from directly regulating stormwater emanating from private property and places the responsibility to manage this stormwater onto state and local governments, rather than the landowner (unless new development occurs on the privately-owned land) [2, 5, 11, 14, 61, 114]. This dilemma, coupled with the need to improve the quantity and quality of stormwater being managed, has pushed governments to begin fee and rebate systems and coupled outreach programs to influence private landowners to partake in the management of stormwater on their own properties [43, 44, 52, 53].

In 2012, there were almost 1,400 jurisdictions where a stormwater utility fee was in place across 39 states, including Maryland and D.C. [35, 36]. Initially in Maryland, this stormwater fee was enacted through the passing of a House Bill (HB 987) in 2012. HB987 required the ten most populous jurisdictions in the state to enact a stormwater utility fee to help fund stormwater management infrastructure improvements. In Maryland, HB987 was overturned in 2015, but despite this many municipalities continue to charge and collect a stormwater utility fee from residents, as a part of their overall water bill. The purpose of this fee is two-fold: provide a source of revenue for municipalities solely for the construction and maintenance of publicly owned stormwater infrastructure and to incentivize individuals to manage their stormwater from their property through the adoption of BMPs.

The stormwater utility fee is typically calculated based on the total impervious surfaces (typically roofs, driveways, patios) on a given property. In Baltimore, there is a sliding pay-scale for single family properties ranging from $3-10 per month depending on the total impervious surfaces on the property [37, 38]. In Washington D.C, all property owners pay $2.67 per month per ERU which is 1,000 square feet of impervious surface (Stormwater Fee Background, 2021; Stormwater Management, 2020; Water Supply and Demand Study Executive Summary, 2012). Overall, a typical individual homeowner in both Washington D.C and Baltimore pays between $2-10 per month towards the stormwater utility fee [37, 38].

Alongside of the stormwater utility fee, municipalities introduced a rebate system to provide credits against homeowners' stormwater utility fee if they adopt BMPs on their properties. The rebate system allows individuals to decrease their monthly fee by installing stormwater BMPs on their properties (like rain barrels, rain gardens, and bioretention cells) based upon their size. Importantly though, very few programs provide any financial support towards the implementation of these BMPs, so the adoption, construction, and future maintenance of these BMPs falls upon the homeowner. Additionally, individual property owners can only adopt and receive the rebate on BMPs that are approved by a given municipality and must be inspected by a governmental official prior to acceptance. Despite these stipulations, the rebate system provides a financial incentive for property owners to manage the stormwater emanating from their property. While this does not give the government authority to manage stormwater from private property, it does begin to circumvent the "private vs. public" dilemma by increasing stormwater management on private properties.

4.4 Methodology: Study Watersheds and Semi-Structured Interviews

For stormwater governance and management, reshaping hydrocitizenship is a primary goal of governments and highlighted by scholars as a necessity towards the decentralization of stormwater management [2, 5, 11]. A major question and challenge facing state and local governments is how to motivate individuals to partake in stormwater management. Many scholars have and are currently researching the effectiveness of government-led outreach and education programs to recruit individuals to manage stormwater [43, 44, 51, 53]. Importantly though, stormwater hydrocitizenship is shaped by specific political, social, and cultural factors that produce distinct hydrosocial relationships. These hydrosocial relationships arise due to the internal relationship between water and society and must be understood through a holistic and critical assessment of the power dynamics shaping these relationships. Despite this, there is little research on the underlying hydrosocial relations that are embedded within and driving the shifting stormwater paradigm and the resulting production of stormwater hydrocitizens. Drawing upon historical research, policy document reviews, and semi-structured interviews, we attempt to delineate the influence of biopower within the stormwater hydrosocial cycle. We focus particularly on the reliance on quantitative, technocratic management (biopolitics) and emergence of hydrocitizenship resulting from fee-rebate systems and educational outreach programs (discipline).

4.4.1 Study Watersheds

Our research focused on two Mid-Atlantic urban watersheds: Watts Branch watershed and Watershed 263 (Figure 4.1). Watershed 263 resides within Baltimore City, Maryland and Watts Branch watershed straddles between Prince George's County, Maryland and Washington, District of Columbia (DC) [44]. These two watersheds were chosen through community-based participatory planning alongside local nonprofit organizations, government organizations, and University of Maryland Extension (UME). These study watersheds are also the sites for broader, collaborative Coupled Human and Natural Systems research project focused on the role of community engagement within stormwater management and the broader realm of ecological restoration, community development, and environmental equity within urban landscapes. Watts Branch watershed and Watershed 263 differ in socio-economic and physical characteristics, but both contain predominantly African American populations (Table 4.1) [44]. Watershed 263 is significantly more urbanized compared to Watts Branch watershed as measured by higher population density and impervious surface coverage. Additionally, Watershed 263 has lower median household incomes, education attainment, and a higher proportion of vacancy parcels as compared to Watts Branch.

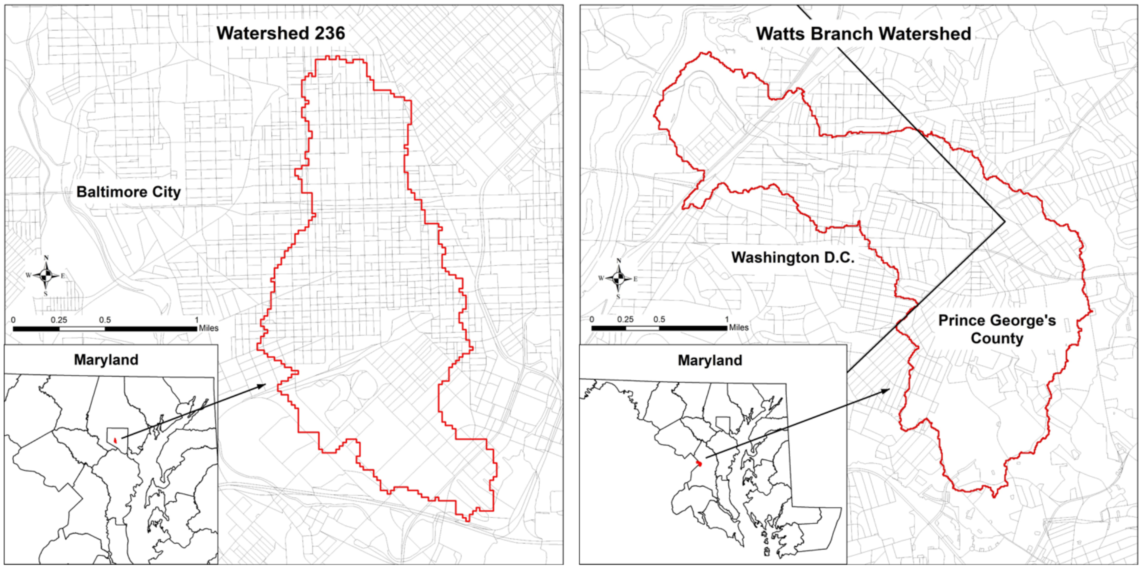

Figure 4.1: Map depicting the geographical location of each of the two study watersheds. Watershed 263 located on the southeastern side of Baltimore City and Watts Branch watershed located on the northeastern side of Washington D.C, straddling Washington D.C and Prince George's County in Maryland. The red line outlines the watershed boundaries for each watershed [44].

Both Watershed 263 and Watts Branch watershed primarily utilize centralized, gray infrastructural systems to manage stormwater by conveying and transporting stormwater to wastewater treatment plants using complex systems of underground pipes and storage

[4, 9]. Watershed 263 has a separated sewer system, meaning that household wastewater and stormwater pipes are separated from one another, while Watts Branch watershed uses a combined system where stormwater and wastewater are transported together in the same pipes. In both watersheds, these centralized systems are frequently being overwhelmed during storm events due to a host of synergistic factors including increasing urbanization and more frequent high intensity storms. As a result, incidences of flooding, stormwater pollution, and combined sewer overflows (when combined sewer systems overflow during a storm event leaking raw sewage into nearby waterways prior to treatment) have increased significantly over the past decade in these watersheds and other urbanized areas throughout the Mid-Atlantic.

Table 4.1: Physical and socio-economic characteristics of Watershed 263, Baltimore, Maryland and Watts Branch, Prince George's County, Maryland and Washington, District of Columbia (Source: www.census.gov; 5-year estimated, 2014-18) [44].

	Watershed 263	**Watts Branch**
Environmental Characteristics		
Size (mi^2)	1.78	4.02
Percent residential land use	92.10%	64.65%
Percent impervious surface	65%	33%
Stormwater and sewer system	Separated	Combined
Social Characteristics		
Population density (mi^2)	10,843	7,669
Percent 10-yr population change	-7.17%	14.04%
Percent population African American ethnicity	73.85%	90.44%
Median household Income	$27,181	$46,260
Percent of residents with a college Degree or higher	12.79%	14.51%
Percent of vacant lots	36.95%	10.61%

As a result of the added stress on these centralized, gray infrastructural stormwater management systems, there has recently been an increase within these watersheds towards implementing additional decentralized, green infrastructure and heighted outreach efforts by governmental groups and Non-Government Organizations (NGOs) to educate, empower, and recruit residents and communities into stormwater management efforts [43, 44, 51, 53]. These watersheds are currently undergoing a shift towards decentralizing stormwater management and governance providing an excellent platform to explore the evolving hydrosocial relationships and emerging stormwater hydrocitizenship.

4.4.2 Research Methodology

A Community Advisory Board consisting of residents and stormwater professionals from local nonprofit organizations, government organizations, and University of Maryland Extension was formed [44]. The purpose of this Community Advisory Board was to understand stakeholder's perspectives about stormwater management before and during the project. Purposive sampling methodology was used to recruit stormwater 22 professionals, including government officials, university researchers, stormwater experts with nonprofit organizations, funding agency officials, policy makers, and environmental activists, and 20 household residents for interviews (42 total), split evenly across each study watershed [44]. Semi-structured interviews were conducted by Debasmita Patra between March and November 2019 and lasted between 45 and 90 minutes each.

These interviews employed questions to understand the conceptualizations surrounding stormwater and stormwater management of stakeholders from these watersheds. The open-ended questions that were asked of each respondent throughout the interviews are in Table 4.2. Otter.ai was used to transcribe each coded interview and all identifying information was removed to maintain confidentiality (Version 2.1.6; [136]). In this article, we use the term stakeholder to denote stormwater professionals and residents alike, as all are actively invested and concerned with stormwater management.

This research focused on hydrosocial processes in this paper began after the interviews were completed and transcripts were made available for additional analysis. Following

IRB approval (University of Maryland Institutional Review Board - 1709048-2), content analysis of each transcript was conducted in MAXQDA (VERBI Software, 2021) using coding techniques to extract overarching themes and conceptualizations of stormwater described by each interviewee [137–139]. For the content analysis, each of the 42 interview transcripts was read thoroughly and statements were coded into a total of seven themes which were deemed pertinent to hydrosocial and Foucauldian theoretical perspectives: (i) Motivation for Managing Stormwater, (ii) Definition of Stormwater Management, (iii) Responsibility to Manage Stormwater, (iv) Stormwater Management Practices, (v) Opportunities for Stormwater Management, (vi) Obstacle for Stormwater Management, and (vii) Personal Management of Stormwater. The codebook and description of each code can be found in Appendix C.1. After sorting, each theme yielded anywhere from 13 - 300 coded segments. These seven themes were chosen as they focused on topics which were frequently discussed across respondents and provide avenues to explore the various hydrosocial relationships between stakeholders and stormwater and instances where biopolitical and disciplinary governmentalities arise through the discourse.

Table 4.2: Open-ended Questions asked during the Semi-structured Interviews

1.	How has the residential stormwater been managed in your area?
2.	Who or what entity is responsible for managing stormwater in your area?
3.	How do you manage stormwater on your own property?
4.	What is the best way to manage residential stormwater?
5.	Do you see any barriers to stormwater management?
6.	What is the future of stormwater management?

From above content analysis, coded segments were further sorted to highlight specific hydrosocial relationships, the processes driving these relationships, and the implications of these relationships. These 8 sub-themes included: (i) Equity, (ii) Biopolitical Policy, (iii) Tax and Rebate, (iv) Disconnect from Stormwater, (v) Educational Outreach, (vi) Discipline, (vii) Responsibility, (viii) Motivation. This added layer of sorting allowed for a more pointed analysis of prominent hydrosocial relationships and the processes shaping them. Through this methodology, we set out to identify the hydrosocial relationships underpinning and forming within the ongoing paradigm shift in stormwater management.

4.5 Results: Stakeholder Perspectives, Knowledge, and Concerns about Stormwater Management

Throughout the interviews, stakeholders discussed how stormwater has been traditionally and currently managed in these watersheds. Both stormwater professionals and residents described the technocratic, top-down style dominating stormwater management and the ongoing decentralization through targeted governmental programs. These perspectives and knowledge highlight the current hydrosocial setting and the underlying power and political dynamics driving the shifting paradigm in stormwater management. The following sections will present the perspectives of these stakeholders on the technocratic, top-down style of stormwater management within their watersheds with particular interest on the role of governments.

4.5.1 Technocratic, Top-Down Stormwater Management

Throughout both study watersheds, local and state government actions towards managing stormwater revolve around meeting regulatory requirements outlined by the CWA, MS4 permitting, and TMDLs limits. Many of the stakeholders interviewed understood current stormwater management as using a top-down approach focused on meeting quantitative regulatory goals. One stormwater professional who works with NGOs to implement stormwater BMPs in Watershed 263 and one watershed restoration professional from Watts Branch Watershed described the dominance of MS4 permits and credits in stormwater management decision-making:

"It's very much a top-down sort of decision making and some of that is driven by the fact that Baltimore City, like many cities, has an MS4 permit that they have to meet the requirements for. And so, they're looking for where they can get the most credit. I think that we could potentially start managing more of our water upstream... instead of just taking the 'Oh there's a stream restoration we can get X number of credits will just throw the money at it'. You know that that seems like a very top-down approach, and I don't think it's good for the city in the long term."

"Quite frankly, I think that the driver for stormwater management, [is] compliance with permits, [with] MS4 permit in particular."

Stakeholders repeatedly discussed how this top-down approach focuses solely on reaching permit requirements, creating a technocratic atmosphere that is difficult to understand and interact with. It was clear from most interviews that the technical knowledge and requirements needed by individuals to understand and participate in stormwater management were a substantial hurdle for residents' engagement with the process. For example, two residents reported:

"The first time I ever heard TMDL, I had no clue what it was. I was reading about it, you know, and I had no clue until I finally met someone and asked them what the hell is..."

"I think that stormwater management seems complicated to folks sometimes because I remember the first time I heard of an impervious surface, I'm like oh my goodness, what does that mean?"

As a result of this technocratic knowledge barrier, many residents and stormwater professionals discussed how most of the public had little-to-no knowledge of stormwater and its management. For example, three residents described how many individuals are mostly unaware of stormwater and stormwater management:

"I know that most people don't even know what stormwater is."

"And so, I think most people don't think about it."

"Well, people don't know what a big problem it is. They don't know what they can do about it."

The above quotes suggest that most interviewees are either: 1) disengaged with stormwater management, or 2) primarily learning about stormwater management through the technocratic language and approach utilized by state and local governments. The latter process contributes to the emergence of a stormwater hydrocitizenship.

4.5.2 Decentralization and Emerging Stormwater Hydrocitizenship

Despite these technocratic barriers, as one outreach coordinator from the Watts Branch watershed expertly described, local governments need individual and community involvement:

"All of the jurisdictions are reaching out to private property owners because they have to. There is not enough public property in any of these jurisdictions. If they managed every drop of the storm water coming off their public property, they would still be short of what they are required to do for their MS4 permits. So, from that point of view, they just they have to reach out"

Respondents discussed how the "reaching out" by local jurisdictions has resulted in a shift in perception of who is responsible for managing stormwater. For example, one program coordinator at a prominent NGO focused on outreach, education, and community engagement from Watts Branch watershed argued for shared responsibilities and duties:

> *"So, whoever is responsible for the maintenance of that property, I think is responsible for the stormwater management associated with it. In terms of residential stormwater management, I think that some of the responsibility does lie on the homeowner. But I think that it is the responsibility of whatever the governing body is, whether it's municipality, county, whatever, to educate and provide solutions."*

Some residents believed that managing stormwater was a universal responsibility. One resident from Watts Branch watershed echoed this sentiment in stating:

> *"And so, it's everybody's responsibility. When people have properties like that, they need to understand that they're responsible. . . all the water is running off, and it's not hurting you, but it's hurting everybody else, and you have a responsibility. Everybody's yard, everybody's property should be viewed as a sub watershed"*

Evidence of the emergence of stormwater hydrocitizenship can be seen in the above quotations, as stakeholders discussed the shared responsibility among individuals, communities, and governments to manage stormwater. While this perceived responsibility was not shared among all respondents, this general shift towards universal responsibility to manage stormwater marks a significant starting point for stormwater hydrocitizenship.

The shifting responsibility for stormwater management is further reinforced by fee-rebate systems and educational outreach programs organized by state and local governments and partnered NGOs. One resident from Watts Branch watershed, one governmental official from Watershed 263, and one outreach specialist at a prominent NGO from Watershed 263, each discussed the roles that these governmental and NGO-partnered educational outreach programs play in establishing stormwater management practices on private lands:

> *"I think the local government is trying to implement programs...to help homeowners implement practices because they know that as a local government, you're not going to be able to meet your water quality goals without residential practices."*

"I think what we're thinking, and I think this is part of that community outreach is that we're promoting what we're trying to understand from residents like what are those simple actions that they could be taking that help improve water quality and understand the relevance that those have to what we're trying to do with this particular facility"

"Somewhere around that time, [a local NGO] implemented a project, working at the residential scale, trying to get residents involved with installing stormwater best management practices on their property."

Additionally, two Watershed 263 residents and one grant specialist from a large NGO within Watts Branch watershed, respectively, discussed how the fee-rebate system uses financial incentives to recruit individuals:

"Basically, there's a stormwater fee, and there's a program that exists to basically refund some of that stormwater fee back to residents for being involved in certain projects."

"So, for example, that [rebate] program, that they set up to reimburse people for taking stormwater management into their own hands."

"[A local municipality] has a [rebate] program which is kind of like seven small practices that homeowners and business owners can install on their property...and then they install the practice per the guidelines, and they get a rebate, an offset of the cost, which is great."

Residents and outreach professionals discussed the specific purpose of these programs to involve individuals in managing stormwater on their own properties. As a result, most residents talked about stormwater management based on the knowledge they gained either through outreach programs or from engaging with the fee-rebate system. Arising from this predominantly technocratic but progressively decentralizing paradigm of stormwater management comes a host of conflicts, tension, and inequity in who, how, and where stormwater is managed.

4.5.3 Stormwater Conflicts, Tension, and Inequity

Throughout the interviews, it became apparent that within the shifting stormwater management paradigm, there was significant tension, conflict, and inequity among stakeholders and state and local governments. These conflicts were mainly centered around the quantitative approach to stormwater management, the implementation of the fee-rebate system, and the overall recruitment of individuals to manage stormwater.

Quantitative Management and Outcomes

Throughout the interviews, it was evident that the continued technocratic, quantitative outcomes from stormwater management created tension and conflicts among local governments, communities, and individuals. As one resident from Watts Branch watershed stated:

"We're just trying to solve the problem of how we get to the right MS4 number, as opposed to how do we create a healthy ecosystem in our space."

Another Watts Branch resident voiced similar concerns, describing how the quantitative endpoints and outcomes of stormwater management do not appear to benefit individuals and communities:

"I think in this case though it has really backfired, sort of really sours people on the whole idea of mitigating stormwater. If one of your policy goals is to better manage stormwater and better make your community resilient to flooding - this [prioritizing quantitative indicators] is a really bad way to do it because it deters people from even engaging in the process because they think oh well it doesn't help me any."

Rather than creating healthy ecosystems or livable communities, stormwater management remains primarily concerned with adhering and meeting quantitative regulatory endpoints. Many residents discussed this underlying theme throughout their interviews and repeatedly voiced their frustration with the management choices of state and local governments towards stormwater. One resident from Watershed 263 exemplified this when discussing the lack of benefits residents receive from stormwater management:

> *"We don't see the benefits of [stormwater management] coming back to the residents of Maryland. Like you take my money [through stormwater utility fees] but you're not street sweeping for me, you're not taking care of [and protecting] properties."*

Importantly, residents frequently discussed their vision and goals for how stormwater should be managed in their communities within the broader context of improving their livelihoods and health of the community - in stark contrast with the technocratic, regulatory driven goals of state and local governments.

Fee-Rebate System Implementation

The fee-rebate system was the crux of many discussions and irritations for stakeholders within the study watersheds. One urban ecologist from Watershed 263 described the process through which rain gardens could be implemented on residential properties to receive the rebate:

> *"They have a rain garden program where they'll come out to your home, and they'll look at how much impervious cover you have. And they will say, "Okay, this is how much rain garden you need and square feet," and show you some plans that are pre-done with all the plants and everything."*

A government official from Watts Branch watershed described a similar process:

> *"So they can either go through the [governmental agency] and sign up online to participate in [rebate program], and that's when they do their formal audit with a [rebate program] representative, they go to the homeowner's house, they walk the property with them, talk to them about what practices are suitable for their property, and then the auditor comes back, writes down their report, and then sends the name of the homeowner."*

Stakeholders viewed the fixed and narrow options available to participate in the rebate programs as frustrating constraints. Additionally, other respondents during the interviews discussed how ineffective and arduous the rebate system was due to institutional and technical barriers. Two Watershed 263 residents described how the rebate system was difficult to interact with and utilize:

> *"It's onerous and difficult, and frankly, I've given up on even trying it, but I just pay the fee because the difficulty, the prior consent, and the documentation the city requires to go through the process is just too difficult to make it work."*

> *"I think the discount we would get on our bill would be a couple of dollars or something. So, we don't pay much, we pay like $5 a month. And so, it might save us $20 a year if we went through the paperwork, but it just hasn't been high on our to do list. Yeah, the permitting and the paperwork, which is why I haven't registered mine, is very difficult."*

The fee-rebate system was designed to financially reward individuals who partake in the management of stormwater on their property; however, due to technical and institutional obstacles, many individuals feel overburdened by the process and either just pay the stormwater utility fee or implement stormwater BMPs and never apply for the rebate. This issue created significant tension as residents repeatedly cited the rebate system as ineffective, unduly burdensome, and did not provide sufficient rebates to offset the time, labor, and materials needed to implement certain BMPs.

Defining the Role of Stormwater Hydrocitizens

A clear theme that emerged from the interviews was the role of individuals within stormwater governance and management as a source of significant contention despite the efforts by local governments to promote their involvement. While many interviewees discussed the responsibility of individuals within stormwater management, some suggested that the government was still solely responsible, including one biologist who had worked with multiple NGOs within Watershed 263 and one Watts Branch watershed resident, respectively:

> *"The public agencies. I mean we pay taxes first of all, and they have their MS4 to meet, and they are counting the stormwater practices towards their MS4 to meet their permit requirements and so they are responsible for it. It's not the residents' responsibility."*

> *"So, the thing about it is, the government has made the issue...I would say that the government's responsible."*

These differences in perceived responsibility highlight the conflict and tension within stormwater management and defining the role of stormwater hydrocitizens more generally. While governments are attempting to recruit and enlist individuals to manage stormwater, there are still uncertainties among residents about their perceived responsibilities.

Another frequent theme throughout the interviews among residents was concern about how these new duties and responsibilities would manifest within their everyday lives. One resident from Watts Branch watershed highlighted potential issues of these new responsibilities towards managing their environment, like stormwater:

> *"When you live in communities that are traumatized by poverty and violence and crime... we're generally always fearful...What do they want from me? And we don't have anything*

> *else to give. We're overwhelmed, we're stressed out. And the environment. Why should I clean the environment? My house isn't clean."*

Individuals are concerned that they are being tasked with increased responsibility towards safeguarding the well-being of their home, communities, and surrounding environment - responsibilities that some suggest remaining with the state and local governments. Stormwater hydrocitizenship while being actively promoted is still being met with considerable pushbacks and concerns.

4.6 Discussion: Stormwater Hydrosocial Relations and Foucauldian Biopower

The shifting paradigm and emergence of stormwater hydrocitizenship can be observed within these two urban watersheds. These changes are accompanied by and embedded within distinct power and political dynamics. The following discussion aims to assess how these dynamics produce and shape specific hydrosocial relationships, especially stormwater hydrocitizenship. We particularly focus on the role of governments and their use of biopolitical and disciplinary governmentalities within the evolving stormwater management paradigm.

4.6.1 Biopolitics of Technocratic Management

Stormwater is incredibly heterogeneous across the landscape and rarely aligns with political and social boundaries. Using MS4 permits and TMDLs, governments attempt to reduce this complexity using quantitative endpoints. This reliance on quantitative modeling for stormwater management produces a process through which planning, and decision-making must be done with MS4 and TMDL requirements at the forefront. As a result, extensive knowledge of urban planning, hydrology, engineering, water chemistry, and stormwater regulations is required to participate in stormwater governance and management. The implications of this are two-fold: solidifying the position of "experts" within management and decision-making and producing a knowledge barrier for individuals and communities to participate in the process. Using a quantitative approach to management, stormwater governments can greatly reduce the complexity of the system all while controlling how stormwater management is understood and perceived by using technocratic language.

Through these approaches and style of management, stormwater governments can partially shape the hydrosocial relationships between individuals and stormwater. This was shown throughout the interviews as residents with intimate knowledge of stormwater discussed management using technocratic, regulatory languages that they had adopted through interactions with state and local governments and NGOs. Most residents also acknowledged that many individuals had little to no knowledge of stormwater management, due to a combination of hidden gray infrastructure that sequesters, stores, and transports stormwater underground or out of sight and technocratic language that stifles the involvement of many individuals. From this technocratic dominance, two distinct hydrosocial relationships arise between individuals and stormwater - one where individuals are completely removed from stormwater management and another where individuals relate to and participate in stormwater management through the technocratic lens of the expert-led governments in power. The expert-based, gray infrastructure-dominated paradigm in stormwater governance empirically illustrates Foucauldian biopolitical techniques explaining how state and local governments maintain control and power over management and decision-making

Furthermore, this technocratic approach continues to partially dictate how, where, and why stormwater is managed. Within the shifting decentralized, green infrastructure paradigm remains the continued focus on quantitative, modeling endpoints of management to align and reach the ever-increasing MS4 and TMDL permitting requirements. This biopolitics structuring continues to prefer a more scientific, engineering approach to stormwater management and reifies the power of technocratic forms of governance. In our two study watersheds, residents placed their goals of managing stormwater more within the broader realm of producing livable, healthy, resilient communities, prompting significant frustrations with how stormwater is currently being managed. We are not suggesting that meeting MS4 and TMDL permits to improve downstream water quality is not an important goal of stormwater management, but instead highlighting that these endpoints do not always align with the needs of individuals and communities. Individuals and communities are aiming to promote stormwater management that includes benefits outside of flood, public safety, and environmental health protection towards outcomes that directly benefit their everyday livelihoods. As a result, progress with the shifting stormwater management paradigm will remain heavily debated, as residents and communities perceive disconnected from any potential progress towards meeting regulatory requirements.

4.6.2 Disciplining Stormwater Hydrocitizens

It was evident from the interviews that all stakeholders understood that governments, without the recruitment of private property owners, would "still be short of what they are required to do" to meet increasingly strict MS4 and TMDL permits. There was widespread agreement that the necessity to overcome this "private vs. public" dilemma has increased efforts to involve individuals in managing stormwater with the subsequent shaping of stormwater hydrocitizenship. This emergence of stormwater hydrocitizenship, including the new responsibilities, duties, and practices placed upon individuals towards managing stormwater, are still currently being actively contested. Residents cited how these added responsibilities should not fall upon them, how their involvement provided little to no benefit to them, and how the systems in place promoting their involvement can produce inequity.

Within this shifting decentralized stormwater paradigm, we argue that stormwater hydrocitizenship is being actively promoted by and through specific governmental actions and programs. We propose that the fee-rebate system and accompanying outreach programs are designed by stormwater governments to promote the internalization of knowledge and goals of stormwater management by individuals. Residents discussed how the fee-rebate system and outreach programs shaped their knowledge of and involvement within stormwater management. From a Foucauldian perspective, these techniques represent disciplinary processes where state and local governments attempt to align the knowledge, beliefs, and actions of individuals towards stormwater with their own [121, 124–126, 129]. These programs promote a distinct hydrosocial relationship where individuals are internalizing the knowledge, goals, and outcomes of stormwater governments while participating in stormwater management on their own property.

As these governmental practices shape stormwater hydrocitizenship, they also significantly limit how individuals can be involved within stormwater management. Throughout the interviews, residents who are actively engaging with stormwater management and adopting stormwater hydrocitizenship voiced their frustration with implementation of the fee-rebate system and outreach programs that are in place to facilitate their involvement. One issue was how the fee-rebate system promotes inequality as those with the inability to pay the stormwater utility fee and wish to implement stormwater BMPs to receive the rebate are often met with substantial time, institutional, financial, and technical barriers that prevent them from doing so. In contrast, those that can pay have the luxury of implementing stormwater BMPs on their property, receive the auxiliary benefits of doing so, and possibly not register for the rebate because the process is too “difficult”. This produces uneven benefits throughout cities as higher income communities can implement more stormwater BMPs on their properties, benefitting from the increased stormwater management and auxiliary ecosystem services. On the other side, lower-income communities are left to pay the stormwater utility fee and rely on governmental interventions and infrastructures to be built in their neighborhoods to protect against stormwater. Coupled within this uneven dynamic is the added unevenness in how local and state governments implement stormwater BMPs, using revenue from the stormwater utility fee within cities, preferentially choosing higher-income neighborhoods for new and retrofitting projects [140–143].

In addition to the equity issues, a major theme throughout the interviews were the technical and institutional constraints created by the guidelines and bureaucracy of local government regulations towards interacting with the rebate system. The fee-rebate system is designed to financially encourage stormwater management from private property, but only using techniques and infrastructure approved by local governments. We acknowledge that state and local governments have more specialized knowledge about how to manage stormwater compared to the average landowner but want to highlight how the rebate system preferentially rewards certain BMPs over others - indirectly shaping the behavior of individuals. Tensions arise here as individuals are constrained in their options for engaging with and managing stormwater by the guidelines and bureaucracy of local government regulations. These constraints significantly limit how stormwater hydrocitizens can be involved within stormwater management and dictate what benefits they can gain from their involvement.

From this research, we suggest that stormwater hydrocitizenship is being actively adopted within these watersheds but shaped by the disciplinary governmentalities of the fee-rebate system and outreach educational programs. Stormwater governments utilize their positions of power and expertise to produce stormwater hydrocitizens whose knowledge and actions surrounding stormwater management align with government needs. Our research demonstrates that while individuals are engaging with stormwater management, the avenue for their involvement is greatly constrained by both the biopolitical and disciplinary governmentalities. These constraints and the overall lack of autonomy felt by individuals in defining their role, duties, responsibilities, and desired outcomes within stormwater management results in significant conflicts, tensions, and inequity within the shift towards a more decentralization paradigm in stormwater management.

4.7 Conclusions: Reimaging Stormwater Governance and Management

Stormwater governances and management are including more green infrastructure and increasing citizen involvement. However, top-down technocratic systems of governance and management continue to exert a disproportionate effect on hydrosocial relations and constrain greater participation of stormwater hydrocitizens. Consequently, the emerging stormwater management paradigm is at risk of not meeting its sustainability, resilience, and equity goals. To help meet these goals, a more critical conversation about knowledge and power within stormwater governance is needed. Drawing on the findings presented above, we seek to contribute to a reimagining of stormwater management and a reworking of the hydrosocial relationships among governments, communities, individuals, and stormwater. We offer the following next steps as actions that can help advance this reimagining.

We suggest adopting more holistic approaches to stormwater management that will allow individuals and communities to better advocate for their goals and desires for stormwater management infrastructure and decision-making. We have shown how the dominantly technocratic approach to stormwater management continues to significantly shape how, where, and who manages stormwater. We contend that stormwater management must move past these technocratic forms of management and governance towards more participatory, collaborative planning and decision-making [28, 113, 144]. Stormwater is not uniform spatially or temporally throughout cities and requires specific, local actions. Within this transition, the views, needs, and concerns of all stakeholders need to be incorporated into decision-making and planning. Additionally, a more holistic approach will allow stormwater hydrocitizens to participate in defining their roles, responsibilities, and rights within stormwater management, especially deciding the outcomes and goals of their involvement.

Through this approach to management, we can begin to implement stormwater management that serves the localized interests of individuals and communities, as well as the government.

We suggest placing stormwater research and management within the broader context of socio-ecological systems, particularly accounting for the multitude of ecosystem services provided by decentralized, green infrastructure [2, 11]. This approach will promote the use of multi-purpose stormwater infrastructure that can help to re-envision how stormwater should be managed, away from large-scale, centralized projects and towards smaller, decentralized infrastructures. Through a more accurate representation and accounting of ecosystem services, residents and communities will also be able to better advocate for stormwater management that not only protects the environment and public health but also improves the health and livelihood of communities and cities. Additionally, as more individuals can visualize and access the benefits of these decentralized, green infrastructure practices, individuals will likely be more willing to participate in stormwater management as the benefits of doing so will be more readily accessible.

We suggest that there should be new regulations that approach stormwater management as an “opportunity” rather than a “liability” and stormwater as a “resource” rather than a ”hazard” [2, 11, 28]. Framing stormwater as a “resource” rather than a “hazard” will open more possibilities for how stormwater is managed and a wider, more holistic variety of desired regulatory outcomes and goals for stormwater management. Regulations should also be more adaptive and less reliant on quantitative outcomes, further allowing for more integrative, collaborative planning and decision-making across the diverse range of stakeholders within urban areas. Improving the accessibility of regulations will promote more involvement of individuals to partake in the decision-making process and promote more accountability for how and where governments decide to manage stormwater.

Finally, we need to better attend to the power and political dimensions of stormwater management and governance to highlight conflicts, tensions, and inequities within these systems. We have found Foucault's concepts of biopower, biopolitics and discipline useful in sharpening our research focus on the power and politics of stormwater management. Other political ecology approaches can offer additional and complementary approaches [55, 121, 124–126]. Through similar research, important and powerful questions regarding stormwater governance can be further investigated, such as: What does a non-technocratic approach to stormwater management look like? How can stormwater hydrocitizenship become a tool for improving the livelihood of individuals and communities? How can governments and citizens share decision-making power within a more decentralized form of stormwater governance? These questions and others are important starts to a more holistic effort to reimagine stormwater governance.

In conclusion, we must move past the technocratic approach to managing stormwater. We need clearer articulation of the goals and outcomes of stormwater management and employ a more participatory approach to promote a robust and diverse stormwater hydrocitizenship. Through a more critical approach where these considerations are assessed and acted upon, more sustainable, resilient, and equitable stormwater governance and management can be implemented that protects and improves public and environmental health, as well as the overall livability of our cities.

Chapter 5: Diffusing Responsibility, Decentralizing Infrastructure: Hydrosocial Relationships within the Shifting Stormwater Management Paradigm[1]

5.1 Introduction

Stormwater management in the United States of America (USA) is currently undergoing a paradigm shift, especially within urban areas [2, 9, 11, 115, 117]. This shift has been driven by increasing concerns surrounding the public and environmental health issues caused by stormwater, more frequent severe storm events, and an overall increase in urbanization across the USA [5, 12, 28, 60]. To address these growing concerns, stormwater governments have begun rethinking how and where stormwater is managed, as well as who partakes and is responsible for stormwater management [44]. Two important developments underpin these evolving changes - the implementation of more decentralized infrastructure and the practice of recruiting residents and communities to manage stormwater from privately-owned property.

Historically in the USA, stormwater management and governance has been highly top-down and technocratic where planning and decision-making was conducted entirely by

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[1] This dissertation chapter is currently in review in the journal, *Journal of Environmental Planning and Management*. Matthew Wilfong, Debasmita Patra, Mitchell Pavao-Zuckerman, and Paul Leishnam were co-authors for this journal article. Matthew Wilfong contributed conceptualization, methodology, investigation, writing, review, and editing of the manuscript. Debasmita Patra contributed with methodology, investigation, and review and editing the manuscript. Mitchell Pavao-Zuckerman and Paul Leishnam contributed funding and review and editing of the manuscript. This research was funded by NSF-CHN/DEB Grant no.1824807 and a USDA NIFA Hatch project through the Maryland Agricultural Experimentation Station.

scientists, engineers, and policymakers [13, 26, 34]. As a result, state and local governments have used gray infrastructure, characterized by centralized conveyance systems that temporarily detain or slow the flow of stormwater prior to treatment at large-scale treatment plants [14, 145–147]. These systems are complex networks of underground pipes and storage tanks that transport stormwater away from populated areas to treatment plants or directly into larger, downstream bodies of water. This technocratic, centralized management style primarily aimed to protect public and environmental health from the potential adverse effects posed by uncontrolled stormwater runoff. Overall, centralized stormwater management infrastructure has improved stormwater management throughout the USA, reducing the hazardous impacts of stormwater flooding and pollution in cities [4, 148].

Over the past few decades, however, there has been significant concerns raised surrounding the ability of these centralized systems to continue to protect public and environment health [2, 117, 149]. Across the USA, centralized stormwater management systems, which were built upwards of seventy years ago, are frequently overwhelmed during storm events due to higher proportions of impervious surfaces and more intense precipitation dynamics within urbanized areas [1, 4, 14, 30]. These infrastructural failures and impacts on public and environmental health have prompted increased concerns about improving and rethinking stormwater management and governance in urban areas [16, 28, 31, 32].

In response, beginning in the early 2000’s, a shift away from the established centralized infrastructural systems and towards a more decentralized approach began. This shift was accompanied by stricter stormwater regulations at the federal, state, and local levels building on the Clean Water Act (CWA) and National Pollutant Discharge Elimination System (NPDES) [4]. One example of these new regulations is the introduction of Total Maximum Daily Loads (TMDLs) for impaired watersheds which set the daily load limit of specific pollutants, typically nitrogen, phosphorus, and sediment, allowed to be exported into water bodies of any given watershed [36, 46]. These stricter regulations require the management of stormwater on-site at new development, increasing the use of more decentralized, green infrastructure across the landscape. Decentralized, green infrastructure is characterized by small-scale practices that mimic natural processes like infiltration and evapotranspiration [24, 48, 50, 62, 150]. Previously developed areas are not typically subjected to these new, stricter regulations and continue to rely on centralized, gray infrastructure to manage stormwater [3, 48, 61].

The stricter stormwater regulations that were introduced in the early 2000s only began to address the need for improved stormwater management for decreasing stormwater volume and improving stormwater quality entering downstream bodies of water. One major issue that continues to trouble stormwater management, especially in highly urbanized areas has been coined the "private vs. public dilemma" [2, 14, 26, 42]. This issue in stormwater management, created by the CWA, is characterized by the inability of the governments to directly regulate stormwater emanating from private property; however, the responsibility for the management of this stormwater is still placed onto state and local governments, rather than the local landowner (unless new development occurs on the privately-owned land). In urbanized areas, public spaces and new development, where state and local governments have authority to implement stormwater infrastructure, are a small portion of the total area producing stormwater [2, 13, 151]. For example, in Maryland, only 7.6% of the land is publicly owned, while 92.4% is private and, on average across the United States, 39.8% of land is publicly owned, while 60.2% is privately-owned (US Bureau of the Census, Statistical Abstract of the United States: 2021). Coupled with this disparity in land ownership, private lands are broken up in countless parcels with separate and distinct owners, making management on private property even more complex and difficult. As a result, these enhanced stormwater regulations remain insufficient to create noticeable changes in how and where stormwater is managed in urbanized watersheds.

Many stormwater professionals actively acknowledge that meeting stormwater regulatory requirements is highly reliant on residents' participation on privately-owned land; however, this represents a significantly large undertaking due to the large amount and diverse set of private property owners within urban and suburban areas [5, 28, 49, 152]. To begin to overcome this "private vs. public dilemma," state and local governments are actively engaging with residents and communities to promote their involvement in the management of stormwater. State and local governments have begun implementing outreach programs to educate residents and communities about stormwater management. For example, in Montgomery County, Maryland, a RainScape program was implemented designed to educate homeowners about stormwater and provide technical and financial assistance to property owners who wish to implement landscape design techniques on their property to reduce stormwater runoff [45]. Most counties in Maryland have similar programs, as well as the District of Columbia [35]. In addition, local governments have begun enacting a stormwater utility fee and rebate system to engage residents and communities with stormwater management [36]. The stormwater utility fee is a charge added to a water bill that is calculated by the size and percent of impervious surfaces on a given property. This fee is used to fund stormwater infrastructure improvements throughout cities and to provide a financial incentive for property owners to mitigate the stormwater emanating from their properties [37, 38, 38, 153]. Property owners can implement stormwater best management practices on their properties to receive a rebate against these stormwater utilities fees. The outreach programs and stormwater utility fee and rebate system are currently the two primary techniques that state and local governments are using to increase the management of stormwater on privately owned land.

Despite these programs, most urban and suburban residents continue to have little knowledge of where, how, and who manages stormwater due to the decades of centralized, underground, and top-down management and infrastructure [26, 49, 53, 154]. As a result, there continues to be many questions and concerns among residents and communities about their roles, responsibilities, and duties towards managing stormwater [43, 44, 51, 52, 155]. Additionally, most stormwater professionals and government officials acknowledge that individual involvement on private property through the implementation of household-scale best management practices is necessary, but there are questions about the most effective and equitable policies and techniques to recruit and enlist their involvement. These questions and concerns within this evolving paradigm continue to severely limit the progress towards decentralizing stormwater management and the involvement of residents in managing stormwater [1, 5, 14, 28].

To address these questions, we use the hydrosocial cycle framework to explore various perceptions across stormwater professionals and urban residents concerning the shifting decentralization of stormwater management. The hydrosocial cycle, as a theoretical framework, promotes the assessment of water management and governance as socionatural, where specific social relationships produce specific kinds of "water." [55, 88]. Through these socionatural processes, the hydrosocial framework promotes increased attention and consideration to the role of power relations in shaping and defining "water" [32, 86, 90, 134]. The hydrosocial cycle emphasizes that water and society are inherently related where each provides meaning and context to one another [55]. Within the cycle, water-society relations are shaped and constructed that convey how water's production, meaning, value, and context is the product of the co-evolution of water and society [55, 113, 114, 128, 156]. These co-evolutionary processes produce distinct hydrosocial relationships and can highlight how specific economic, social, cultural, and political dynamics shape, define, and reinforce these relationships [55, 106, 127, 157].

This study aims to investigate hydrosocial relationships that arise within this shifting paradigm with particular interest in assessing stakeholder perspectives on the roles and responsibilities of varying entities, including state and local governments, communities, and residents within stormwater management, and the policies and techniques used to initiate and sustain their involvement. We use Q-methodology to group responses across two key stakeholder groups, stormwater professionals and residents, on their perceptions about the decentralization of stormwater governance and management. Q-methodology is a way to determine a person's subjective understanding of a particular topic [158]. The method is increasingly being used by social scientists interested in evaluating stakeholders' understanding of environmental issues [159–163]. Rather than measure responses to variables between people (i.e., how many people agree with a statement or set of statements), a Q analysis is meant to examine the interrelation of many different statements across individual stakeholders. This approach allows for a coherent "discourse" or set of beliefs about a particular topic, to emerge [158, 163]. Researchers can then gauge which actors tend to align with particular discourses [164–166]. We use Q-methodology to assess potential differences and similarities in the hydrosocial relationships across stormwater professionals and residents, specifically towards the role of residents in stormwater management and how individual involvement should be mediated through specific policies or techniques.

We employ the hydrosocial framework to characterize and assess political, economic, social, and cultural factors that influence and shape hydrosocial relationships. We explore potential drivers (political, economic, social, and cultural) that influence differences in hydrosocial relationships, and the implications within the decentralizing stormwater management paradigm. We then aim to provide recommendations towards remedying divergent perspectives, if any, to facilitate the decentralization of stormwater management and to ensure more sustainable, resilient, and equitable outcomes. Finally, we use this research to demonstrate the effectiveness of hydrosocial and Q-methodology to situate and understand varying perspectives within environmental governance and management, more broadly.

5.2 Study Location and Methodology

Our research focused on two Mid-Atlantic urban watersheds: Watts Branch watershed and Watershed 263 (Figure 5.1). Watershed 263 resides within Baltimore City, Maryland and Watts Branch watershed crosses between Prince George's County, Maryland and Washington, District of Columbia (DC) [44].

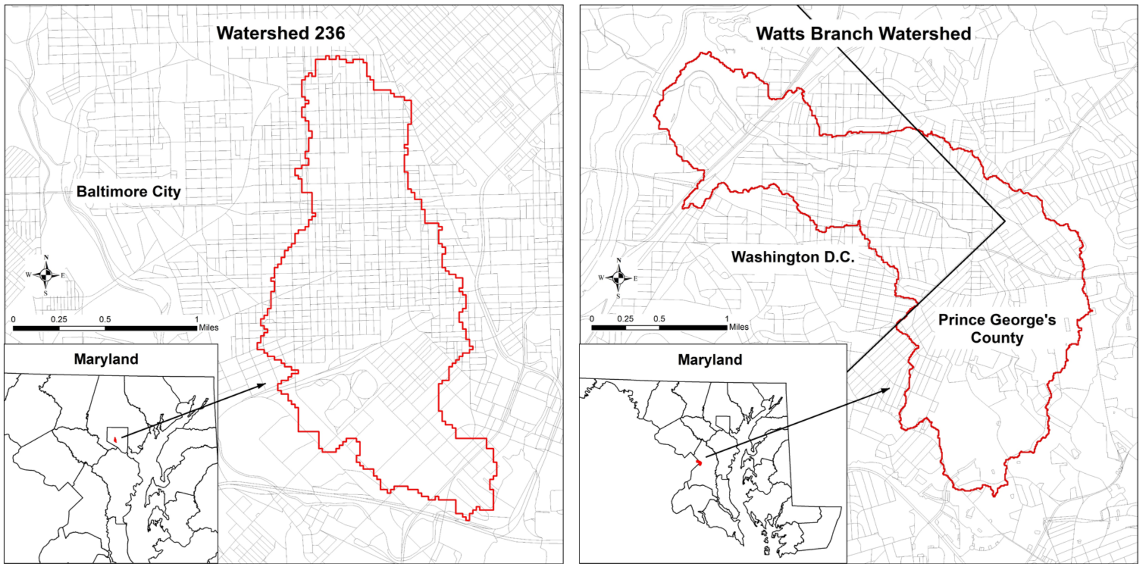

Figure 5.1: Map depicting the geographical location of each of the two study watersheds. Watershed 263 located on the southeastern side of Baltimore City and Watts Branch watershed located on the northeastern side of Washington D.C, straddling Washington D.C and Prince George's County in Maryland. The red line outlines the watershed boundaries for each watershed [44].

These two watersheds were chosen through community-based participatory planning alongside local nonprofit organizations, government organizations, and University of Maryland Extension (UME). Watts Branch watershed and Watershed 263 differ in socio-economic and physical characteristics, but both contain predominantly African American populations (Table 4.1) [44].. Watershed 263 is significantly more urbanized compared to Watts Branch watershed as measured by higher population density and impervious surface coverage. Additionally, Watershed 263 has lower median household incomes, education attainment, and a higher proportion of vacancy parcels as compared to Watts Branch.

Both Watershed 263 and Watts Branch watershed primarily utilize centralized, gray infrastructural systems to manage stormwater by conveying and transporting stormwater to wastewater treatment plants using complex systems of underground pipes and storage. Watershed 263 has a separated sewer system, meaning that household wastewater and stormwater pipes are separated from one another, while Watts Branch watershed uses a combined system where stormwater and wastewater are transported together in the same pipes. In both watersheds, these centralized systems are frequently being overwhelmed during storm events due to a host of synergistic factors including increasing urbanization and more frequent high intensity storms. As a result, incidences of flooding, stormwater pollution, and combined sewer overflows (when combined sewer systems overflow during a storm event leaking raw sewage into nearby waterways prior to treatment) have increased significantly over the past decade in these watersheds and other urbanized areas throughout the Mid-Atlantic.

To combat these public and environmental health issues related to stormwater, local governments are focused on decentralizing stormwater management due to the prohibitive costs of repairing, replacing, and/or updating centralized systems and the overall lack of sufficient publicly owned property to implement new infrastructure [35, 167]. As a result, local and state governments are increasing community engagement efforts to promote more effective stormwater management, including educating, empowering, and recruiting residents to partake in managing stormwater on their properties. Due to this ongoing shift in stormwater management, these two urban watersheds provide an excellent platform to investigate the evolving hydrosocial relationships between stormwater professionals, residents, and stormwater.

The Q-methodology research in this study was conducted in three main phases following usual procedures. Phase one consisted of forty-two semi-structured interviews with (22) stormwater professionals (government officials, university researchers, stormwater experts with nonprofit organizations, funding agency officials, policy makers, and environmental activists) and (20) residents, both groups split evenly across Watts Branch watershed and Watershed 263. Respondents were chosen through purposive sampling working alongside of a Community Advisory Board consisting of residents and stormwater professionals from local nonprofit organizations, government organizations, and University of Maryland Extension working within these watersheds [44]. These interviews employed questions to understand the perceptions of stormwater management and governance of stakeholders from these watersheds. The open-ended questions that were asked of each respondent throughout the interviews are in Table 4.2. These semi-structured interviews were conducted between March and November 2019 and lasted between 45 and 90 minutes each. Otter.ai was used to transcribe each interview and all identifying information was removed to maintain confidentiality (Version 2.1.6; [136]). A thematic analysis of these interviews was published by Patra et al. (2021), and more details can be found there [44].

The second phase of the research was a content analysis to extract concourse statements from within each interview using MAXQDA [168]. Each of the forty-two interview transcripts was read thoroughly and potential concourse statements were extracted that specifically provided a respondent's perspectives or thoughts on one of the following statements: (i) Who or what entity is responsible for managing stormwater in your area? (ii) How is stormwater currently being managed? (iii) What is the best way to manage residential stormwater? or (iv) What is the future of stormwater management? The content analysis produced a list of approximately 750 statements across all respondents that reflected the range of perspectives for each of the questions. We organized these quoted statements based on the question they respectively answered and the broader perspective they provided on each question. From these groupings, we developed a concourse of nineteen paraphrased statements that effectively covered the range of perspectives for each expressed throughout the interviews amongst all respondents (Table D.1).

The third phase consisted of a Q-sort survey whereby respondents ranked concourse statements from strongly disagree to strongly agree on a quasi-normal distribution ranking system (Figure 5.2). A total of twenty participants completed the Q-sort survey, consisting of fourteen stormwater professionals and six residents. Due to the ongoing COVID-19 pandemic, the Q-sort process was conducted entirely online using QMethod software during November and December 2021 [169]. The online QMethod software allows participants to conduct the entire Q-sort survey online and confidentially. Through the software, respondents were asked initial survey questions to help identify their watershed affiliation and resident or professional status (Table D.2). The respondents were then presented with the Q-sort survey itself, where they were asked to rank the concourse statements (Table D.1) on the quasi-normal distribution ranking system (Figure 5.2).

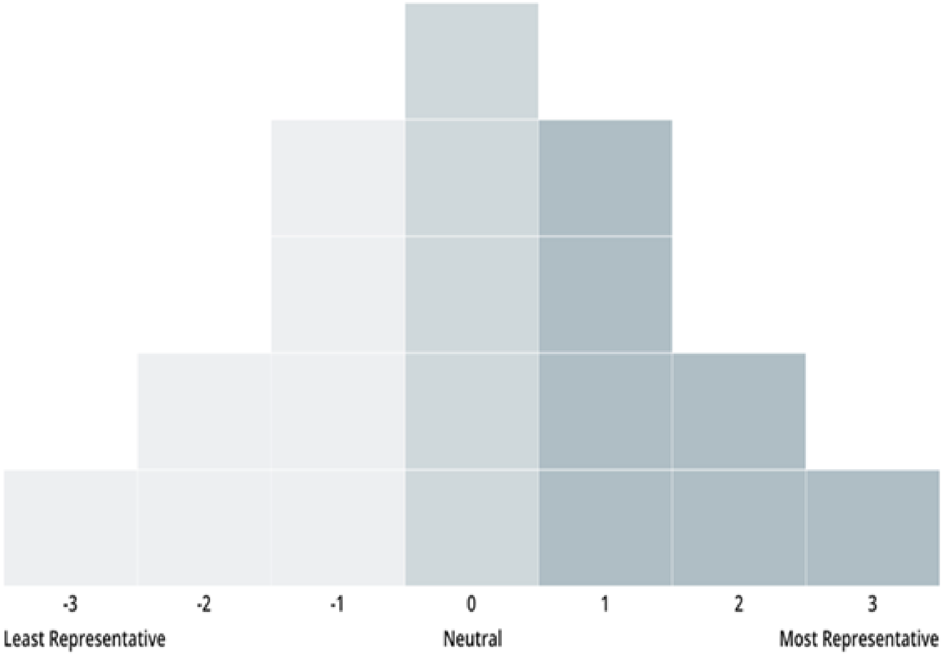

Figure 5.2: Quasi-normal distribution chart used for the online Q-sort survey through online QMethod software. Participants place one concourse statement within each box, ranking whether they agree or disagree with each statement on a 7-point scale [169].

Following completing the Q-sort survey, respondents were asked optional follow-up questions that could be used to better understand how and why each respondent ranked the concourse statements (Table D.2). All participants were contacted via email and were from the pool of forty-two interviewees from Phase two and twenty other participants identified from interviews during Phase one, but due to time restraints were not interviewed [44]. The response rate was 32.25%; however, smaller, purposefully chosen survey populations typically provide a sufficiently diverse range of perspectives in Q-methodology [160, 161, 163]. Importantly, Q-methodology is more focused on identifying the groups or clusters in perspectives than the prevalence of the perspectives in the broader population.

The fourth and final phase of the research involved a correlation and factor analysis of the resultant Q-sorts. These analyses were conducted within the online QMethod software [169]. The correlation and factor analysis mathematically works by creating "new variables" or factors that group together consistent rankings of statements. Pearson correlation and Principal Component Analysis (PCA) were conducted producing eight distinct factors. It is typical in Q-methodology for any factor with an eigenvalue greater than one to be kept for analysis if those factors represent a socially significant perspective and/or account for significant variance among the Q-sorts [158, 159, 163]. Of the eight factors in our PCA analysis, three were kept for varimax rotation due to their higher eigenvalues (>2) and substantial percentage of explained variance within the Q-sorts ($>10\%$). These three factors represented distinct and significant perspectives that identify and explain significant hydrosocial relationships present within the changing stormwater management and governance paradigm in these two urbanized watersheds.

5.3 Results: Identified Hydrosocial Relationships

Three factors emerged from the factor analysis that portray significant thoughts, perceptions, and knowledge of stormwater governance and management within these two watersheds. The summarized statistics for the factor analysis are shown in Table 5.1. Importantly, stormwater professionals and residents were identified within each of the three factors with the distribution of respondents for each factor shown in Table 5.2. Two respondents (one Watts Branch watershed resident and one Watts Branch watershed professional) were not assigned a factor due to their high correlation with multiple factors and inability to distinguish an appropriate single factor. The factor analysis produces an "idealized" sort where statistically significant statement rankings represent important divergence views and perspectives across each factor. These idealized sorts for each factor and factor rank for each statement are shown in Table 5.3. We defined each of the three factors as (1) Market Decentralists, (2) Anti-Market Decentralists, and (3) Technocratic Opportunists. Each of these factors represent "descriptive archetypes" and perspectives on stormwater management and governance. These archetypes correspond to distinct hydrosocial relationships that arise due to varying influence of social, economic, cultural, and political factors on how these archetypes know, interact with, and view stormwater governance and management.

Table 5.1: Summarized statistics from the varimax-rotated factor analysis conducted using online QMethod software [169].

		Factors	
Factor Characteristics	**1**	**2**	**3**
Eigenvalue	5.440	3.080	2.584
# of Defining Variables	8	5	5
% Explained Variance	27	15	13
Composite Reliability	0.970	0.952	0.952
Standard Error of Factor Scores	0.174	0.218	0.218

Table 5.2: Distribution of stormwater professionals and residents from each watershed within each of the three identified factors. WB stands for Watts Branch Watershed and B stands for Baltimore or Watershed 263.

Factors	WB Residents	B Residents	WB Professionals	B Professionals
1	0	1	5	2
2	2	1	0	2
3	1	0	0	4

Across all the three factors, certain concourse statements were mostly agreed with or disagreed with, regardless of their assigned factor (Figure D.1). Statements were identified where greater than half of the respondents had a shared ranking of the statement. For example, concourse statement one had thirteen respondents agree (ranked +1, +2, or +3) with the statement, while only two respondents disagree (ranked -1, -2, or -3) – demonstrating agreement with this statement broadly across all respondents. Additionally, concourse statements 2 and 14 were regularly agreed with, while statements 3, 5, and 16 were consistently disagreed with. Using a similar approach, statement rankings were compared across stormwater professionals and residents (Figure D.2). Key differences arose surrounding statements 9, 12, and 17 that portray potential divergent perspectives between stormwater professionals and residents. These two figures portray convergences in hydrosocial relationships demonstrating shared perspectives on stormwater management and governance. These areas of convergence are important to further situate and explain differences between the identified factors. While these areas of convergence are important, investigating the differences across respondent groups and using factor analysis highlights the distinct hydrosocial relationships arising within the shifting stormwater management paradigm.

Table 5.3: Identified factors and idealized rankings for each concourse statement for each factor: **(F1) Market Decentralists**, **(F2) Anti-Market Decentralists**, and **(F3) Technocratic Opportunists**. Values in bold and with * are distinguishing statements that are statistically significant at $p < 0.05$.

Statements	**F1**	**F2**	**F3**
1. Stormwater is an important resource in urban environments.	**0***	**1***	**2***
2. Stormwater is a hazard to public and environmental health.	3	3	**-1***
3. Stormwater is most effectively managed through large-scale centralized projects that capture and treat stormwater.	-2	-3	-2
4. Stormwater is most effectively managed through small-scale, decentralized green infrastructure.	1	0	1
5. The government should be solely responsible to manage stormwater.	-3	**-1***	-3
6. All property owners should be responsible for the stormwater emanating from their property.	1	**-2***	0
7. Local landowners lack the knowledge to effectively participate in stormwater management planning.	0	0	0
8. All stormwater planning and management decisions should be made with direct and continuous input from local landowners.	**1***	**1***	**2***
9. Stormwater fees are necessary to ensure that cities and local governments have the funding required to effectively manage stormwater.	**1***	-1	0
10. Stormwater fees have a negative connotation due to the inequity in who pays, how much each landowner pays, and how the revenues from the fees are utilized.	**-2***	1	0
11. The stormwater fees, and rebates system promotes the implementation of stormwater management practices on private land.	**2***	-1	-2
12. Stormwater fee and rebate systems are unjust and inequitable due to the inability for lower income landowners to either pay the fee or implement practices to receive rebates.	**-1***	2	1
13. The future of stormwater management must be driven by technological innovations and scientific research.	0	0	**3***
14. The future of stormwater management must contain a mixture of centralized and decentralized infrastructure.	2	2	1
15. The future of stormwater management must be decentralized and use small-scale infrastructural practices.	0	1	**-1***
16. The best way to improve stormwater management is through updating existing large-scale, centralized infrastructure.	-1	**-2***	-1
17. The best way to improve stormwater management is through adoption of small-scale, decentralized practices.	-1	0	0
18. The best way to improve stormwater management is through increased regulations and market-based approaches.	-1	-1	-1
19. The best way to improve stormwater management is through education and outreach.	0	0	1

5.3.1 Factor 1 – Market Decentralists

The market decentralists group was composed of eight respondents, seven stormwater professionals from both Watts Branch watershed and Watershed 263, and one resident from Watershed 263. Market decentralists, along with the other two factors, identify closely with the need to shift stormwater management infrastructure away from large-scale centralized infrastructure and towards smaller-scale, decentralized management practices. This perspective believes that decentralization also involves shifting the sole responsibility of managing stormwater off the government and onto private landowners and communities. Uniquely, this group considers market-based approaches, like the stormwater fee and rebate systems, to be an effective mechanism to shift responsibility onto residents and communities while promoting the implementation of more decentralized, small-scale management practices across the landscape. For this factor, market-based approaches are important for state and local governments to raise funds dedicated to improving stormwater management and provide residents and communities with the financial incentive to partake in the management of stormwater on private properties.

Market decentralists strongly view stormwater as a hazard for public and environmental health. One Watts Branch watershed stormwater professional, assigned to the market decentralists factor, conveyed this viewpoint during the post Q-sort survey responding explaining which concourse statement they most agreed with:

> *"Stormwater is a hazard to public health and environmental health. I don't think there is any way you can dispute or argue with this statement."*

This perspective believes that the primary goal of stormwater management is to protect society and the environment from the adverse effects of stormwater. Within this group, the responsibility to protect the health and safety of society and environment is not entirely that of the local governments, but also of all private landowners. Market decentralists place the most responsibility onto private landowners compared to other factors but suggest that market-based approaches and financial incentives are the best way to impart this responsibility onto all landowners. One resident from Watershed 263, during the semi-structured interviews, exemplified a market decentralists perspective on the ability of market-based techniques, like the stormwater fee and rebate system, to shift responsibility onto private landowners when stating:

> *"So, for example, that [rebate] program that they set up to reimburse people for taking stormwater management into their own hands. That's a policy and it works, that's a great idea."*

For this perspective, state and local governments have specific expertise and knowledge needed to make decisions on how and where to manage stormwater, but direct input from local landowners is necessary and important. Market-based approaches allow and promote state and local governments to use their expertise and knowledge to maintain control over decision-making and planning for managing stormwater. Collectively, market decentralists can be described as residents who view stormwater as a hazard that must be dealt with by the government, communities, and residents, alike. Market decentralists recognize that individual involvement and decentralization of management practices is necessary and suggest that market approaches, like the stormwater fee and rebate system, can be a successful mechanism to begin this process.

5.3.2 Factor 2 – Anti-Market Decentralists

This factor group contained two stormwater professionals, both from Watershed 263, and three residents, two from Watts Branch watershed and one from Watershed 263. As with the other two factors, anti-market decentralists describe the importance of decentralizing stormwater management through the implementation of smaller-scale management practices. During the post Q-sort survey, one stormwater professional from Watershed 263, describes the pitfalls of large-scale centralized systems:

> *"Large-scale centralized solutions, they can't handle the loads. [Stormwater flows] often overwhelms the system (especially combined sewer/stormwater systems) causing sanitary overflows that are potentially more harmful than stormwater effects alone. No centralized system is large enough to handle it, and no centralized system can disperse the resulting clean water over the landmass from which the water originated"*

This factor takes the perspective that decentralization is needed and the responsibility to support this shift in stormwater infrastructure lies primarily with state and local governments. Anti-market decentralists keep most of the responsibility on the government, while acknowledging that residents and communities should play a role. Notably, anti-market decentralists do not believe all property owners should be responsible to manage stormwater on their own property. Particularly, this group also strongly opposes market-based approaches, like the stormwater fee and rebate system, to involve private landowners into managing stormwater. Anti-market decentralists universally agree with the statement that a stormwater fee and rebate system is inherently unjust and inequitable, especially for lower-income residents and communities. During the post Q-sort survey one anti-market decentralist, a resident from Watts Branch watershed, explained this perspective by stating that:

> *"[Placing responsibility onto all landowners promotes] unfairness to low-income landowners. There should be a greater sense of equity across the board."*

Like Market Decentralists, this factor perceives stormwater as a hazard for public and environmental health, ranking this statement the highest in the idealized factor sort. One

Watts Branch watershed professional, assigned as an anti-market decentralist, echoed this viewpoint during the post Q-sort survey stating:

> *"Stormwater is a source of environmental harm. We need clean water. Period."*

Anti-market decentralists perceive managing stormwater as one of the responsibilities of state and local governments to ensure protection of the public and environment against the hazard of stormwater. This perspective identifies implementing new, decentralized management practices alongside the existing centralized infrastructure as the best way forward to improve stormwater management towards protecting society and the environment. Crucially, while anti-market decentralists agree that governments should not be solely responsible, the current market-based mechanisms to recruit communities and residents to manage stormwater on private properties is inefficient, unsuccessful, and inequitable. Anti-market decentralists seek to begin programs that work with and alongside residents and communities to connect them with the benefits and risks of implementing small-scale stormwater management practices on their properties – a more equitable and integrated approach than market-based techniques, like the stormwater fee and rebate system.

5.3.3 Factor 3 – Technocratic Opportunists

The technocratic opportunist factor contained one resident from Watts Branch watershed and four stormwater professionals from Watershed 263. Technocratic opportunists align with the other two factors suggesting that the decentralization of stormwater management is necessary – specifically, using more decentralized infrastructure and the involvement of communities and residents into the stormwater management paradigm. In contrast with the other two factors, technocratic opportunists suggest that this decentralization needed to be structured around and driven by technological innovations and scientific research. During the post Q-sort survey, one stormwater professional from Watershed 263 typified this perspective by stating that they most agreed with the statement that:

> *"Technology and research are needed to better manage stormwater and increase the implementation of GSI [green stormwater infrastructure]."*

Technocratic opportunists identify that better infrastructure and technology is needed to treat stormwater, especially smaller-scale decentralized technologies. This factor acknowledges that the government, and stormwater expert therein, typically has more technical knowledge and expertise needed to implement and utilize these infrastructures. Despite this, technocratic opportunists highly agree that stormwater planning, and management decision-making must be made with direct and continuous input from local landowners. Along with this collaborative process, this group acknowledges that the government alone cannot manage stormwater effectively, especially in urban areas, and suggests that residents and communities should play a role in managing stormwater.

Most uniquely, technocratic opportunists regard and perceive stormwater as a potential "resource" rather than a "hazard," as compared to the other two factors. This factor suggests that stormwater is an under-harnessed and underutilized opportunity and potential resource in urban areas. One stormwater professional and technocratic opportunist from Watershed 263 exemplified this perspective by stating during the post Q-sort survey that:

> *"Stormwater is not necessarily dangerous to people and the environment. [If] harnessed/captured it can be beneficial for such things as irrigation and alternative energy production."*

Technocratic opportunists identify that a reform of how stormwater is managed and governed is necessary to view stormwater as a "resource" rather than a "hazard." By doing so, stormwater has the potential to become a valuable resource that can supply numerous benefits in urban areas, like irrigation and alternative energy production. This factor represents a unique way of managing stormwater compared to the other two factors.

5.4 Discussion: Convergences and Divergence Perspectives across Hydrosocial Relationships

These three identified factors represent distinct hydrosocial relationships between stakeholders and stormwater. Across these factors, there are converging views and perspectives that highlight the growing support for decentralizing stormwater management. Despite these similarities, substantial differences remain between perspectives on the best path forward towards this overarching goal of decentralization. Additionally, there appears to be areas of divergent perspectives between stormwater professionals and residents that are valuable to identify as significant hurdles that are slowing the decentralization of stormwater management, more broadly. We discuss these converging and diverging perspectives within the broader hydrosocial cycle of stormwater management and governance to identify areas where the decentralization of stormwater management remains heavily contested. We conclude by highlighting these areas of tension with the goal of suggesting policies and practices that can help to bridge these perspectives and progress stormwater management.

5.4.1 Convergent Perspectives towards Decentralization

Across all respondent groups and identified factors, there were two critical perspectives on the evolving stormwater management paradigm that were shared universally: the need to transition away from large-scale centralized infrastructure and the view that the government should not be burdened with the sole responsibility for stormwater management. Both views are at the root of the continuing push towards decentralizing stormwater management and are key areas of convergence across these hydrosocial relationships.

Across all three factors, the need for more decentralized, green infrastructure was highly recognized. Respondents acknowledged that continued reliance on centralized, gray infrastructure will be insufficient to protect public and environment health, as well as, meeting the increasingly strict regulatory requirements of the CWA and NPDES. For each factor and respondent groups, statements regarding the effectiveness of centralized, gray infrastructure (statements 5 and 16) were mostly disagreed with (Table 5.3 and Figure D.1 and Figure D.2). In contrast, all three factors and both respondent groups recognize that the future of stormwater management must contain a mixture of centralized and decentralized practices (statement 14). One Watts Branch watershed professional and market decentralist conveyed this shared perspective by suggesting that:

“The future of stormwater management must contain a mixture of centralized and decentralized infrastructure. We will never be able to effectively manage stormwater if we rely solely on one or the other. We need a mixture of practices.” Coupled with the common perspective, all three factors and respondent groups agreed that the government should not be solely responsible for managing stormwater (statement 5). Respondents suggest that the responsibility must be shared across stakeholders due to the inability of the government to effectively manage stormwater alone. Another Watts Branch watershed professional and market decentralist explained this perspective by stating: “While the government has some responsibility, we all contribute to stormwater issues in some way, and the problem will never be resolved without everyone playing a role.”

These common views across stakeholders represent progress towards decentralizing infrastructure and diffusing responsibility that has been the goal of state and local governments over the past decade. For these entities, this decentralization was a political and economic necessity due to increasingly stringent regulations and higher costs of repairing or upgrading aging centralized infrastructure [5, 11, 14, 26]. We suggest that outreach programs and the stormwater utility fee and rebate system, utilized by most state and local governments, have been successful in educating residents and communities about stormwater management, but fall short of engaging residents to begin to implement household-scale management practices on their properties [24, 43, 44, 51–53]. These two shared perspectives across all three factors and both respondent groups represent a significant transition in how stormwater management is viewed and further identifies the paradigm shift currently underway.

We argue that these hydrosocial relationships are commonly shaped by the political power dynamics that remain from decades of top-down, expert-based management [32, 86, 89, 133, 134]. State and local governments are harnessing their position as "experts" to promote decentralization that will both benefit public and environmental health, but also their political and economic bottom-line. We acknowledge that decentralizing infrastructure and diffusing responsibility will benefit stormwater management, more broadly; but it also portrays the continued political influence and power that state and local governments have on how, who, and where stormwater is managed. While these identified hydrosocial relationships are uniformly influenced by these dynamics, significant differences arise when investigating how these factors view the policies and techniques utilized to promote this decentralization.

5.4.2 Divergent Perspectives on Achieving Decentralization

These areas, where hydrosocial relationships diverge, provide an important view into the varying perspectives on the shifting stormwater management paradigm. Across these three identified hydrosocial relationships and respondent groups, three primary differences arose that have substantial effects on overall transition towards decentralization: (1) how stormwater is viewed and defined, (2) the role and responsibilities of residents in managing stormwater, and (3) the most effective policies to engage with residents and communities.

Hazard or Resource

Stormwater has effectively been managed and defined as a "hazard," "pollutant," and "liability" throughout the top-down, centralized management paradigm [9, 12, 114, 115, 117]. In response to the growing transition towards decentralized management, many scholars have suggested that redefining stormwater as a "resource" will benefit stormwater management [11, 13, 28, 144, 170]. For market decentralists and anti-market decentralists, stormwater remains predominantly a "hazard" to public and environmental health. In contrast, technocratic opportunists identify stormwater as a potential "resource" and "opportunity" for different techniques and policies for managing stormwater. For both stormwater professionals and residents, stormwater remained more strongly defined as a "hazard," but across both groups, the majority agreed that stormwater can also be a "resource" in urban environments. This transition in how stormwater is conceptualized and defined is still actively contested across stakeholders.

We argue that this transition towards redefining stormwater is primarily affected by political, social, and economic drivers [5, 11, 14]. For stormwater professionals: regulations, existing centralized infrastructure, and the political necessity to protect the public from flooding reinforces stormwater as a "hazard." In contrast, stormwater professionals tend to have highly technical knowledge that could influence their ability to envision infrastructure and practices that utilize stormwater as a "resource" – this could be influencing the perspectives of the technocratic opportunists, which were predominantly stormwater professionals from Watershed 263. For residents, whether stormwater is viewed as a hazard or resource is impacted by economic standing. Lower-income communities are more likely to be negatively impacted by stormwater issues and, as a result, view stormwater as a hazard. Oppositely, residents in higher-income neighborhoods and communities, protected against flooding and pollution issues, can take advantage of stormwater as a resource [140–

143, 171]. We highlight these potential influences to demonstrate that, while redefining and managing stormwater as a resource is an ideal goal, there remains multiple convergent hydrosocial perspectives that limit this transition.

Role and Responsibility of Residents and Communities

A major aspect of this shifting paradigm is the increasing involvement of residents implementing best management practices on their properties to manage stormwater. This push for the involvement and engagement of residents and communities has been led by state and local governments as they perceive these efforts as necessary to meet increasingly stringent regulatory requirements [24, 43, 44, 51–53]. Despite active outreach efforts and policies, our research suggests that there continues to be a lack of agreement and tension surrounding the role and responsibilities of residents and communities within stormwater management. Across the identified factors, there were substantial differences in their perspectives towards the involvement of residents. Market decentralists perceive that residents have a responsibility to manage stormwater from privately-owned property. Technocratic opportunists have a similar perspective; however, they suggest that the role of residents is, less of a responsibility to manage stormwater, and more of increased participation through direct and continuous input throughout the decision making and planning process. In contrast, anti-market decentralists perceive residents as having little to no responsibility to manage stormwater from privately-owned property.

We contend that currently, within this evolving stormwater paradigm, the diffusion of responsibility for managing stormwater is being prompted by political drivers which seek to shape the social and cultural perspectives on stormwater and stormwater management, reminiscence of other forms of environmental citizenship [121–124]. Despite these political influences, the involvement of residents in stormwater management remains mostly a novel approach due to decades of top-down, centralized infrastructure and management and a lack of political and legal authority to mandate residents to manage stormwater emanating from their properties. As a result, the involvement, responsibility, and role of residents remains highly contentious. This is highlighted by the anti-market decentralists perspective, which importantly, is the factor which contains the highest number of resident respondents. This suggests that while political influences have been successful in educating residents about stormwater, the social and cultural transition towards universal responsibility is still debated and contested. We convey these discrepancies to suggest that political, social, and cultural factors are influencing and driving these factors separately and differently creating distinct hydrosocial relationships between people and stormwater. Consequently, the overall diffusion on responsibility of managing stormwater remains primarily on state and local governments and the role that residents and communities can and will play in stormwater management continues to be questioned.

Policies to Engage Residents and Communities

The final area of distinguishable differences between the factors was their perception of the most effective policies to engage with residents and communities for stormwater management. State and local governments are currently employing outreach programs coupled with stormwater fees and rebate systems to educate and promote the involvement of those outside the government. The perception of these policies was the most recognized difference between the factors and conveys how influential these policies are in shaping and defining the hydrosocial relationships between people and stormwater. Market decentralists perceived the stormwater utility fee and rebate system as an effective and equitable policy to increase the involvement of residents and communities and increase the implementation of decentralized management practices across the landscape. Technocratic opportunists do not believe that the stormwater utility fee and rebate system is an effective mechanism to promote the involvement of residents, and instead, propose that continued educational outreach programs and more technological innovations can be more successful.

Anti-market decentralists assert that the stormwater utility fee and rebate system, in its current iteration, is inequitable and unjust. For anti-market decentralists, the stormwater utility fee and rebate system are simply a policy used by state and local governments to strong-arm residents and communities to implement decentralized management practices, diffuse responsibility onto others, and increase funding for stormwater management. This factor perceives market-based policies as ineffective due to the overall small "return on investment" meaning that, residents either have little financial incentive to receive the rebate, regard the time and labor necessary to do so as prohibitive, and/or do not recognize other personal or universal benefits of doing so. These perceptions suggest that for anti-market decentralists, the factor containing the most resident respondents, economic policies will be insufficient to alter their perspectives and beliefs, and other, more sociocultural-oriented techniques are needed to solicit their involvement.

Our research demonstrates that the current policies and outreach utilized by state and local governments to engage residents and communities will continue to limit the overall involvement of the public, especially private property owners. Importantly, the identification of the anti-market decentralists perspective suggests that these market-based approaches can be detrimental to progress and promote inequality. We argue that the stormwater fees and rebate systems can produce uneven benefits throughout cities as higher income communities can implement more stormwater BMPs on their properties (benefitting from the increased stormwater management and auxiliary ecosystem services); while, lower-income communities primarily pay the stormwater utility fee, rarely become involved in managing stormwater, and continue to rely on governmental interventions to be protect against stormwater that are often insufficient ([140–143, 171]. Collectively, these insights convey that the policies driving individual and community involvement with stormwater management are highly impactful on shaping the hydrosocial relationships between people and stormwater. As a result, current and future policies must be focused on influencing sociocultural aspects of these relationships and continued economic approaches must consider equity and justice concerns to ensure that the benefits of these policies are felt equally across all stakeholders. Our research illustrates that the current approaches produce divergent hydrosocial relationships and progress towards decentralization will continue to be hindered unless newer policies are introduced.

5.5 Conclusions

This research and use of Q-methodology and hydrosocial framework has allowed for some important insights into the social, cultural, political, and economic factors influencing and shaping stormwater-society relationships within the shifting stormwater management paradigm. Our research indicates that there is acknowledgement and acceptance that this transition towards decentralization is necessary and essential. Across the identified hydrosocial relationships, there were converging perspectives on the need for the implementation of additional, decentralized green infrastructure and the involvement of residents and communities in the management of stormwater. Despite this broad-scale agreement, the use of Q-methodology allowed us to recognize and highlight areas where stakeholders' perspectives diverge. These differences across hydrosocial relationships convey areas where changes are needed to promote alignment and cooperation between the currently divergent perspectives. We argue that until these areas of conflict and tension are ameliorated, there will continue to be overall slow progress towards an overall decentralization of stormwater governance and management. We briefly highlight two important aspects within the shifting paradigm that can help to begin marrying the divergent hydrosocial relationships: valuing stormwater and promoting more collaborative involvement of residents and communities within planning and decision-making for stormwater management.

The process and transition through which stormwater is valued can help progress stormwater away from being conceptualized as a "hazard" and more towards a "resource". To value stormwater as a "resource" in urbanized areas, there needs to be substantial changes to types of infrastructure built and the legal structures in place regulating stormwater [11, 28]. The implementation of decentralized, green infrastructure that manage and treat stormwater on-site allow for the harvesting and beneficial utilization of stormwater, especially at the household, residential-scale [52, 58]. Additionally, green infrastructure can provide multitudes of auxiliary benefits, or ecosystem services, (urban heat mitigation, access to green space, air pollution abatement, etc.) that when effectively valued can push stormwater management infrastructure to be viewed as an important resource in urban areas, rather than a liability or necessity [24, 172, 173]. Along with decentralized, green infrastructure, updating the legal and regulatory framework for stormwater, will be important in this transition towards stormwater as a "resource". This will be a significant undertaking as decades of legal structuring and resulting infrastructure has been built to manage stormwater as a "hazard". There have been a few examples of reworking water rights around stormwater or rainwater; however, successful examples required years of concerted legislative efforts and this overall re-conceptualization of stormwater as a "resource" will require an complete overhaul of existing regulations [11, 113]. We argue though that until major changes are made to the legal framework for stormwater management, the divergent hydrosocial relationship across stakeholders and stormwater will remain.

The current policies and techniques through which residents and communities are becoming engaged with stormwater management must be re-evaluated and adjusted. The current policies and programs promote divergent perspectives on how individuals and communities should be involved in stormwater management. As a result, the needed decentralization and participation of individuals in managing stormwater remains actively disputed. To overcome this, there must be more collaborative, participatory programs and policies through which residents and communities can discuss their views and needs within stormwater management to ensure that the process is not entirely technocratic and allows for more bottoms-up approaches. This change will allow individuals to participate in defining their roles, responsibilities, and rights within stormwater management and begin to decide the outcomes and goals of their involvement. We argue that until the involvement of individuals and communities is designed to primarily serve the localized interests, the involvement of those outside of the government and partnered NGOs in stormwater management will remain insufficient to progress towards broad decentralization. In conclusion, this research has demonstrated that there needs to be significant changes within the shifting stormwater management paradigm, to overcome the differences among the emergent hydrosocial relationships between stakeholders and stormwater. Our research highlights that the need for this decentralization is agreed upon across stakeholders, but the techniques and policies to achieve this transition is not. Two important aspects that can help to overcome these disparities is the beginning of valuing stormwater as a “resource” effectively and promoting more collaborative policies and techniques to engage individuals and communities with stormwater management. The process towards decentralizing stormwater management will remain inadequate to protect public and environmental health in the face of these divergent hydrosocial relationships, unless substantial regulatory and policy changes are supported and enacted.

Chapter 6: Conclusions: Towards Decentralized Stormwater Management and Applied Hydrosocial Research

6.1 Summary and Contributions

This dissertation has broadly been focused on investigating and exploring the ongoing shift within stormwater management towards a more decentralized approach. The interdisciplinary research conducted throughout this dissertation seeks to better understand the two key evolving aspects of stormwater management within this paradigm shift: the implementation of decentralized, green infrastructure and the involvement of individuals and communities in managing stormwater. This dissertation utilizes a hydrosocial framework to assess the social, political, and cultural dynamics underpinning this paradigm shift, especially understanding the relationships between stakeholders and stormwater. In this chapter, I will use my findings to promote more attention and discussion surrounding the political and power dynamics within stormwater governance and management and water governance and management, more broadly. In addition, this chapter will highlight how the use of hydrosocial research can promote critical and useful analyses into the power dimensions underlining water management. Finally, I use this chapter to demonstrate how hydrosocial research can be utilized to provide actionable recommendations and applied outcomes towards improving water management and governance, later referred to as applied hydrosocial research.

6.1.1 Chapter 2: Investigating the Hydrologic Performance of Decentralized Stormwater Best Management Practices at the Treatment Train Scale

This chapter, the only non-hydrosocial research chapter, investigated the hydrologic performance of decentralized, green infrastructure treatment trains in Clarksburg, MD. The research within this chapter was focused on using stormwater monitoring methodology to analyze how effectively treatment trains can hydrologically manage stormwater and the effects of precipitation dynamics on the ability of these treatment trains to manage stormwater. From this research, we demonstrated that these treatment trains are generally highly effective at managing stormwater volumes across storm events with an average of 93% of discharge abated. We also demonstrate that precipitation intensity was the most influential precipitation dynamic on the performance of each treatment train. This suggests that designing these treatment trains with the potential higher prevalence of higher intensity storm events is important to ensure consistent and reliable hydrologic performance. Overall, this chapter highlights that areas of newer development where primarily decentralized, green infrastructure is built to manage stormwater can provide effective management. This also suggests that the implementation of additional decentralized, green infrastructure in urban areas can help to better hydrologically manage stormwater.

6.1.2 Chapter 3: Rethinking Stormwater: Analysis using the Hydrosocial Cycle

This chapter introduces the hydrosocial cycle to analyze how water and society shape each other over time. This synthetic review provides the theoretical framework for the following two chapters which are focused on applying the hydrosocial framework to investigate sociopolitical factors of stormwater management and governance. In particular and most importantly, this chapter explores how the hydrosocial framework can be applied to stormwater management in the United States. To conduct this review, two hydrosocial case studies centered on rain and stormwater were investigated to highlight how stormwater management can benefit from a hydrosocial approach. The insights and implications from these case studies are then applied to stormwater management by formulating key questions that arise under the hydrosocial framework. These key questions are significant to progressing stormwater management to more sustainable, resilient, and equitable outcomes for environmental and public safety and health. Additionally, these key questions provided the research hypotheses and questions for Chapters 4 and 5 of this dissertation. Finally, this chapter frames a conversation for incorporating the hydrosocial framework into stormwater management and demonstrates the need for an interdisciplinary approach to water management and governance issues.

6.1.3 Chapter 4: Shifting Paradigms in Stormwater Management – Hydrosocial Relations and Stormwater Hydrocitizenship

Arising from the hydrosocial synthetic review, questions surrounding the role and responsibility of individuals within stormwater management arose. To explore the sociopolitical dimensions behind the increased involvement of individuals and communities in managing stormwater, this dissertation chapter utilized semi-structured interviews among residents and stormwater professionals from two urban watersheds within the Maryland-D.C metro region. Using insights from Watershed 263, Baltimore, MD and Watts Branch, Prince George's County, MD and Washington, DC, we assess changes in the hydrosocial relationships underpinning this paradigm shift including the emergence of stormwater hydrocitizenship. We investigate stormwater hydrocitizenship as the role and responsibilities of individuals within stormwater management. We focus on the role of government at several levels, drawing insights from the concept of biopower. The most important and impactful finding from this chapter is that this paradigm shift and the emergence of a stormwater hydrocitizenship remains embedded in top-down governance, which in turn creates significant tension among different stakeholders such as residents, communities, and governments. Arising from this critical analysis, we demonstrate how the current processes and techniques utilized by state and local governments to involve individuals and harness stormwater hydrocitizenship are both unsuccessful and insufficient, but also, produce inequities and conflicts in how, where, and who manages stormwater. This dissertation highlights the usefulness of critical hydrosocial research, especially Foucauldian biopower, to illuminate the power dynamics within dominant discourses and institutions and the way they shape the broader water management regimes and paradigms.

6.1.4 Chapter 5: Diffusing Responsibility, Decentralizing Infrastructure: Hydrosocial Relationships within the Shifting Stormwater Management Paradigm

Building upon Chapters 3 and 4, this chapter seeks to explore additional hydrosocial relationships between stakeholders and stormwater within the evolving paradigm. Through semi-structured interviews and Q-methodology within the same two urban watersheds (Watershed 263 and Watts Branch watershed), perspectives on the evolving stormwater paradigm among residents and stormwater professionals such as nonprofit organizations, funders, policy makers, researchers were investigated. We evaluated differences in stakeholder perspectives related to who is responsible for management, the best ways to do it, and the future of stormwater management. We identified three hydrosocial relationships that stakeholders have with stormwater: Market Decentralists, Anti-Market Decentralists, and Technocratic Opportunists. Across these hydrosocial relationships, we demonstrate that there is agreement for decentralizing stormwater management through infrastructural changes and involvement of residents and communities. Nevertheless, there remain substantial differences in how stormwater is viewed, the role and responsibilities of residents, and the most effective policies to engage with residents and communities. Importantly and most impactfully, this chapter highlights how these differences represent significant hurdles towards implementing decentralized infrastructure and involving residents and communities in managing stormwater. Using these insights, this chapter focuses on the need for collaborative decision-making and planning in stormwater management and governance to overcome these divergent hydrosocial relationships.

Throughout this dissertation, a hydrosocial approach was utilized to investigate the political and power dynamics underpinning the evolving stormwater management paradigm, particularly in the Mid-Atlantic region of the United States. This dissertation was primarily focused on applying insights derived from this research to provide actionable recommendations and suggestions towards improving stormwater management towards more sustainable, resilient, and equitable outcomes. As a result, this dissertation provides an ample platform to discuss how applied hydrosocial research can be conducted and lessons learned throughout this research process.

6.2 Need for Future Applied Hydrosocial Research

A recent editorial entitled “Too Much and Not Enough” published in Nature Sustainability and written by the editors-in-chief discusses the current status of water research [174]. This brief op-ed opens by establishing the historic progress achieved within the studies of water and acknowledges the current epistemological position across critical water research that water is “dynamic resource that is as much a function of social, economic and political choices as it is a geological and hydrological reality of life". This is a sharp contrast from the predominant perspectives of previous academic queries on water that divorced water and society and siloed water solely within the hydrologic cycle. While this is progress, the editorial suggests that even within this updated epistemological setting, water research remains "stagnant" [174]. The editors use the repetitive and thematically, methodologically, and factually, consistent submissions over the past five years to Nature Sustainability, a highly recognized and impactful journal, as their primary evidence. They suggest that while water research has become "more quantified and technically driven, it has also become less grounded" and, as a result, rarely "invest[s] in new questions and theoretical approaches" [174]. This creates an atmosphere where the majority of water research strives to create "engineering solutions to water problems" that "ignore the messy institutions, norms, and processes that underlie our relationship, as individuals and as a society with water in the first place" [174]. The editorial concludes by asking the readers to think about the future of water research and how we can move away from this "untenable model" and begin the needed and intensely important research that will push the boundaries and illuminate novel approaches and ideas on our relationship as a society with our most important resource, water.

This dissertation provides an example of how applied hydrosocial research can begin to push the boundaries and investigate novel approaches to understand water governance and management. Building upon the editorial call for more critical research in water management and governance, and using examples from this dissertation, the following section will outline some highly important avenues for future applied hydrosocial research.

6.2.1 Decentralization of Water Management

This dissertation research primarily centered on the overall push towards decentralizing stormwater management in the Mid-Atlantic region through more decentralized infrastructure and diffusion of responsibility of management onto individuals and communities across the landscape. This process mirrors a larger push towards the decentralization of water management both across various types of waters and geographic regions [42, 59, 120, 175]. As shown throughout this dissertation, the process of decentralization raises a host of questions concerning the techniques and policies utilized to transition towards a more decentralized form of management. In Chapters 4 and 5, we demonstrated that within stormwater management, the governmental-based policies enacted to increase decentralization tend to produce conflicts, tensions, and inequities. It is important that as more decentralized forms of water governance and management arise, we consider the ways in which power and politics dictate who benefits from this decentralization, who is burdened, and why. Applied hydrosocial research can begin to investigate and unearth these processes and ensure that as water management and governance become more decentralized, we find processes and outcomes that benefit everyone and the environment, equally.

6.2.2 Neoliberalization of Water Resources

Alongside the broad decentralization of water governance and management is the complementary push towards neoliberal forms of management. As a result, there has been an increase in recent scholarship focused on the neoliberalization of water resources [86, 121, 133, 170, 176–178]. To a lesser extent throughout this dissertation, we have demonstrated how market-based mechanisms and overall neoliberal techniques have been primarily utilized to transition stormwater management into the new decentralized paradigm. Within

Chapters 4 and 5, we have shown how these neoliberal policies are ineffective, but also, have the potential to create public and environmental health inequities, especially in urban landscapes which are highly heterogeneous in how and where stormwater is managed. These insights demonstrate that neoliberalization of water resources tends to entail distinct adjustments in power dynamics and relationships between stakeholders and water. This tends to further reinforce dominant structures of management which scholars have shown to be detrimental to public and environmental health [133, 176]. As more neoliberalized forms of water governance and management evolve, applied hydrosocial research is needed to examine the geometries of power at play and the potential for these policies and processes to exacerbate inequities and obfuscate environmental damages [133, 176].

6.2.3 Citizenship and Hydrocitizenship

Coupled with decentralizing and neoliberalizing water governance has been an increase in citizenship related individuals' involvement with water resources and management. Research focused on the techniques and policies influencing and shaping these forms of hydrocitizenship has recently increased in prevalence [10, 113, 121, 123, 124]. Within Chapter 4 of this dissertation, we concentrated our research on understanding the hydrosocial dynamics involved in the production and influx of stormwater hydrocitizens. This analysis demonstrated that, while the production of hydrocitizenship can be highly beneficial and favorable for stormwater management, the current processes and techniques utilized by state and local governments are highly ineffective and are the source of significant tensions and conflicts. As citizenship becomes more and more intimately linked with water management, we must be aware and cognizant of how hydrocitizenship is controlled and dictated by entities in power [11, 32, 131, 132, 179, 180]. Applied hydrosocial research provides an excellent platform and framework to investigate how, where, and why hydrocitizenship arises. In addition, through this research we can suggest how hydrocitizenship improves the livelihood of individuals and communities and how can governments and hydrocitizens can share decision-making power within a more decentralized form of water governance?

6.3 Final Thoughts

Overall, these three areas convey the need for more critical, interdisciplinary water research and highlight how research within these avenues can begin the process towards more sustainable, resilient, and equitable water governance and management. As the authors of the Nature Sustainability editorial suggests only by engaging with these “messy institutions, norms, and processes” can we begin to make meaningful and impactful change. I am highly optimistic that there will be a greater influx of applied hydrosocial research, like this dissertation, and that research like this will be more readily incorporated into decision-making and planning. I hope that this dissertation can be motivation and a template for those wishing to embark in similar research.

Appendix A: Treatment Train Monitoring Maps, Figures, and Tables

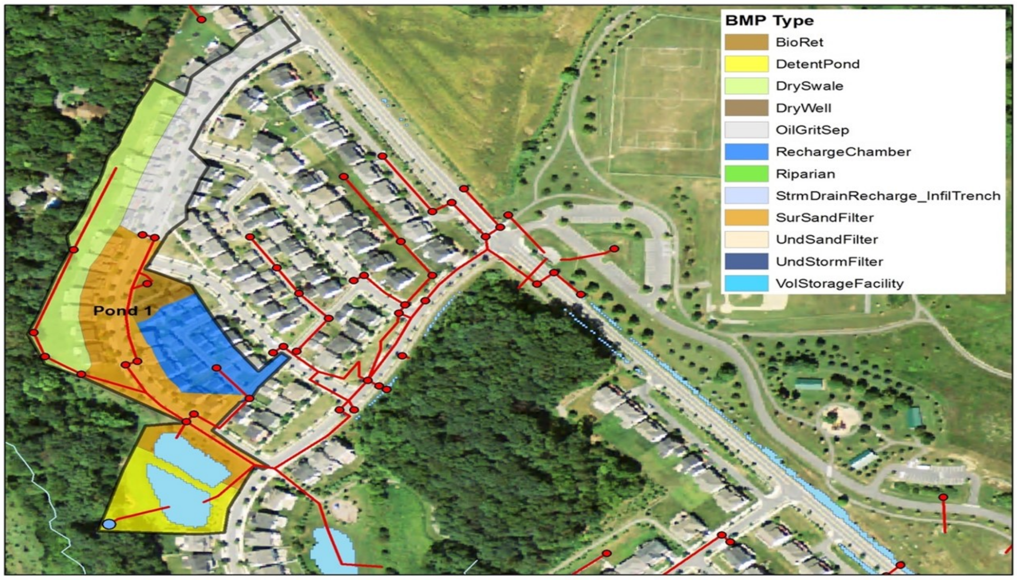

Figure A.1: GIS map of Pond 1 subwatershed that depicts the drainage area for each stormwater BMP, the arrangement, and the connectivity of the BMPs within each subwatershed. This maps also highlight the flow paths or sewershed within each subwatershed where all stormwater that does not evapotranspirate or infiltrate into the soil surface and groundwater exits the subwatershed via the outfall of the terminal dry detention pond of that subwatershed.

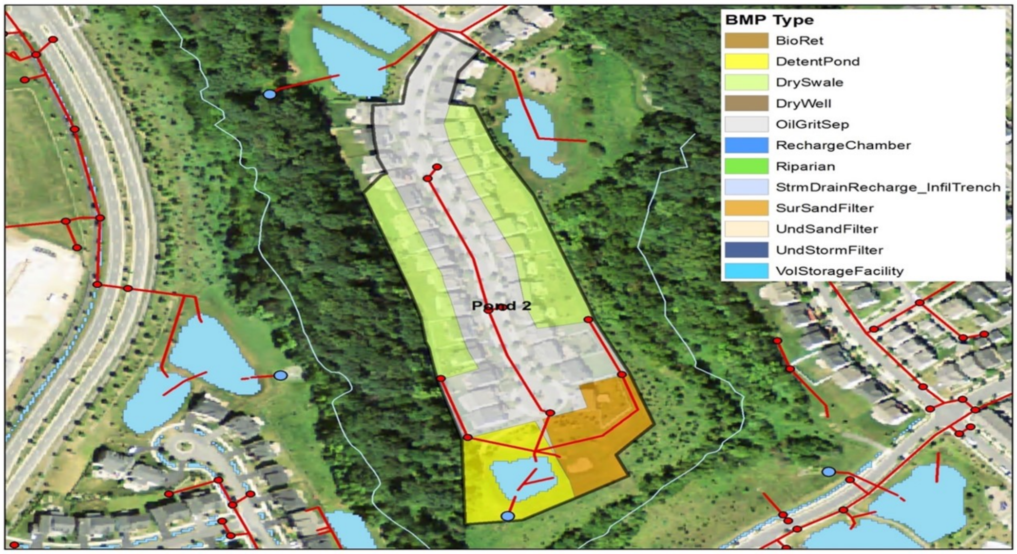

Figure A.2: GIS map of Pond 2 subwatershed that depicts the drainage area for each stormwater BMP, the arrangement, and the connectivity of the BMPs within each subwatershed. This maps also highlight the flow paths or sewershed within each subwatershed where all stormwater that does not evapotranspirate or infiltrate into the soil surface and groundwater exits the subwatershed via the outfall of the terminal dry detention pond of that subwatershed.

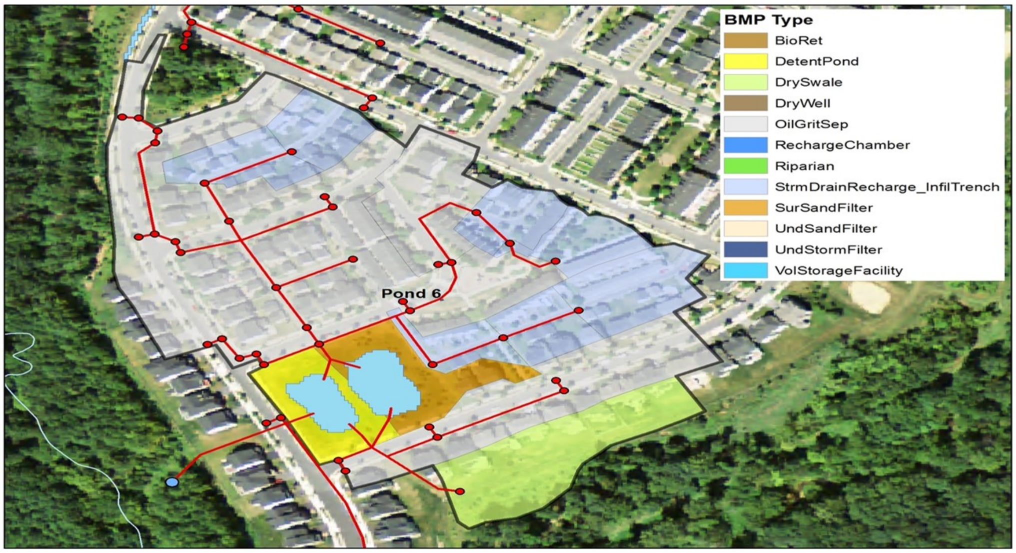

Figure A.3: GIS map of Pond 6 subwatershed that depicts the drainage area for each stormwater BMP, the arrangement, and the connectivity of the BMPs within each subwatershed. This maps also highlight the flow paths or sewershed within each subwatershed where all stormwater that does not evapotranspirate or infiltrate into the soil surface and groundwater exits the subwatershed via the outfall of the terminal dry detention pond of that subwatershed.

Figure A.4: A Thel-Mar volumetric weir mounted within the outfall pipe of terminal dry detention Pond 6 along with the water level pressure transducer, within a protective PVC housing, mounted six feet into the pipe behind the volumetric weir.

Figure A.5: A tippet bucket rain gauge and atmospheric pressure transducer, placed within a protective PVC housing, mounted to a fence post within an open field approximately 100 yards from the outfall of terminal dry detention Pond 6.

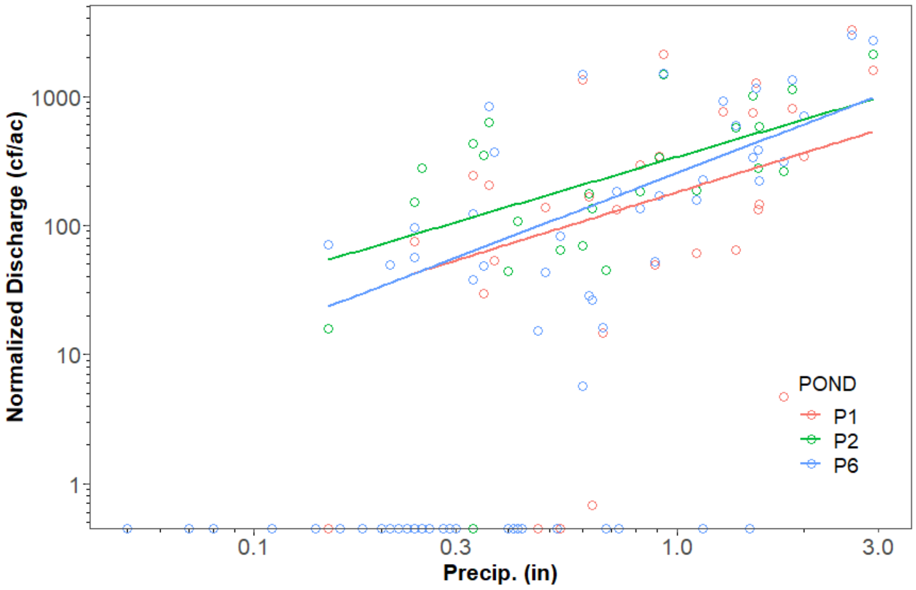

Figure A.6: Log-Log Scatter Plots and Linear Regressions of Normalized Discharge (cf/ac) versus Precipitation Amount (in) for each storm event across each treatment train. Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

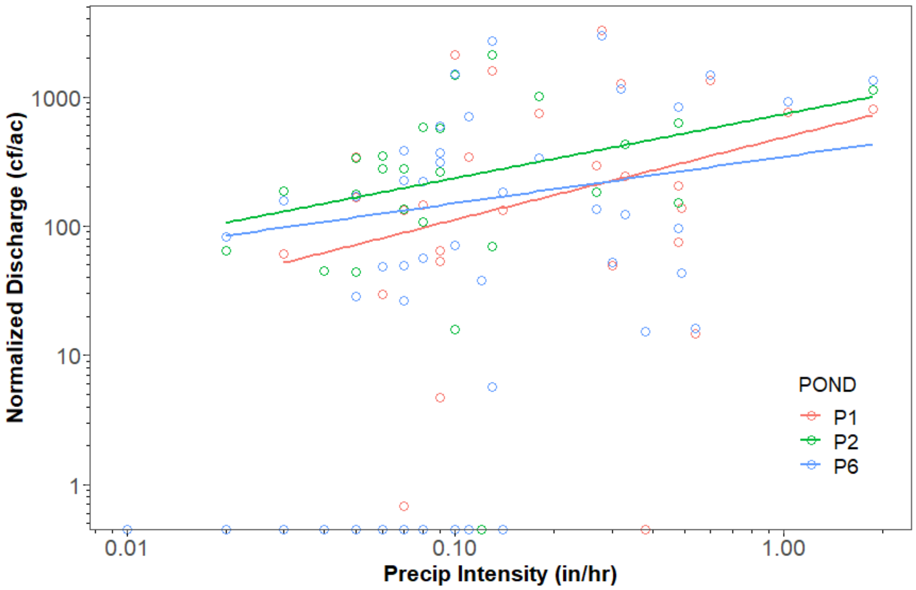

Figure A.7: Log-Log Scatter Plots and Linear Regressions of Normalized Discharge (cf/ac) versus Precipitation Intensity (in/hr) for each storm event across each treatment train. Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

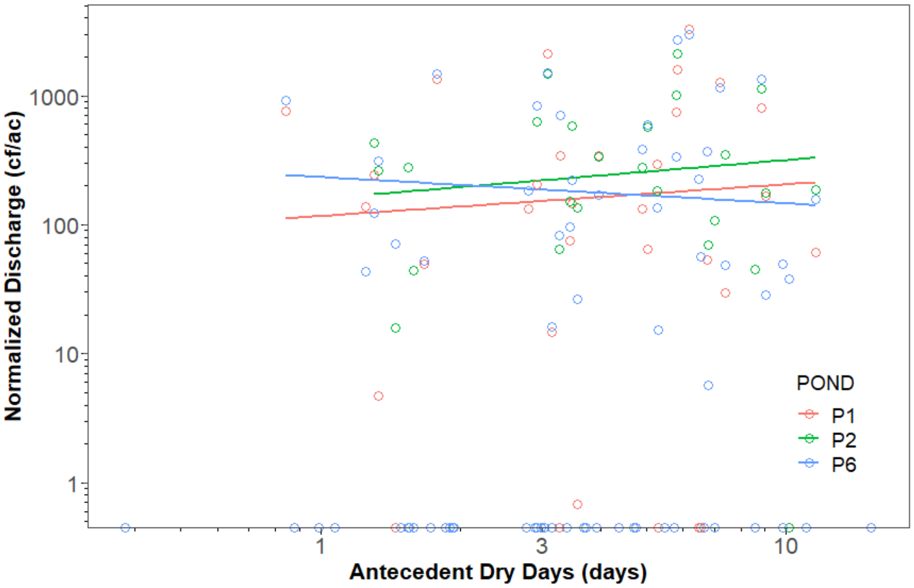

Figure A.8: Log-Log Scatter Plots and Linear Regressions of Normalized Discharge (cf/ac) versus Precipitation Amount (in) for each storm event across each treatment train. Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

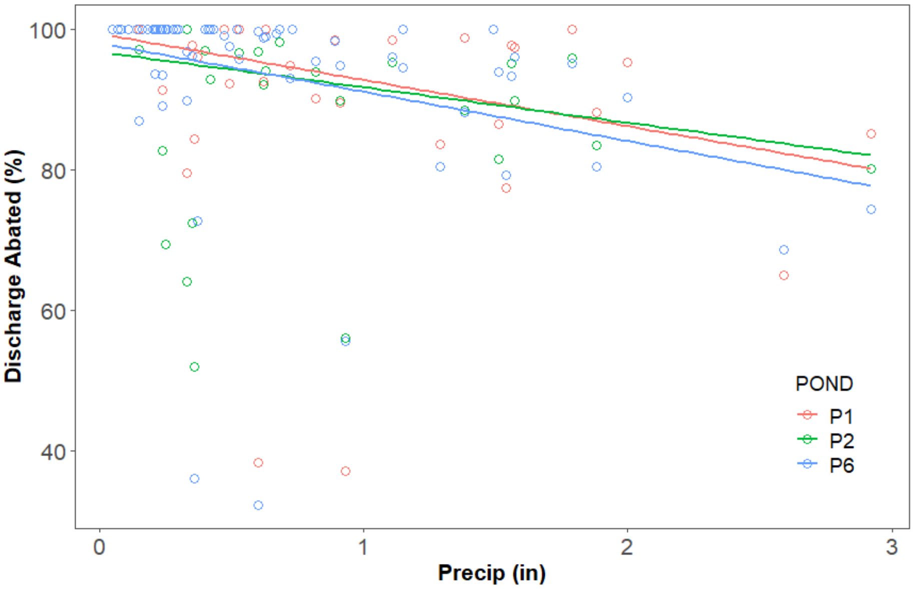

Figure A.9: Log-Linear Scatter Plots and Linear Regressions of Discharge Abatement (%) versus Precipitation Amount (in) for each storm event across each treatment train. Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

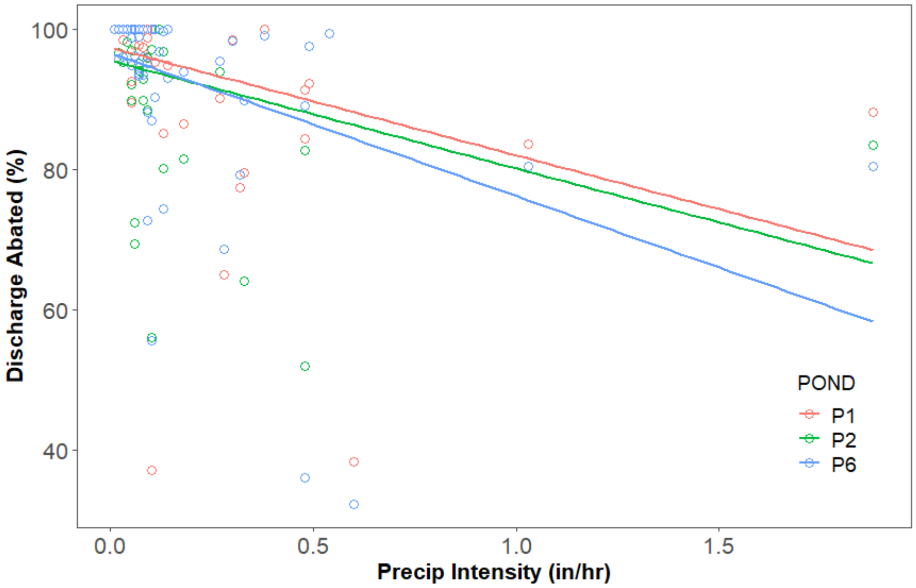

Figure A.10: Log-Linear Scatter Plots and Linear Regressions of Discharge Abatement (%) versus Precipitation Amount (in/hr) for each storm event across each treatment train. Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

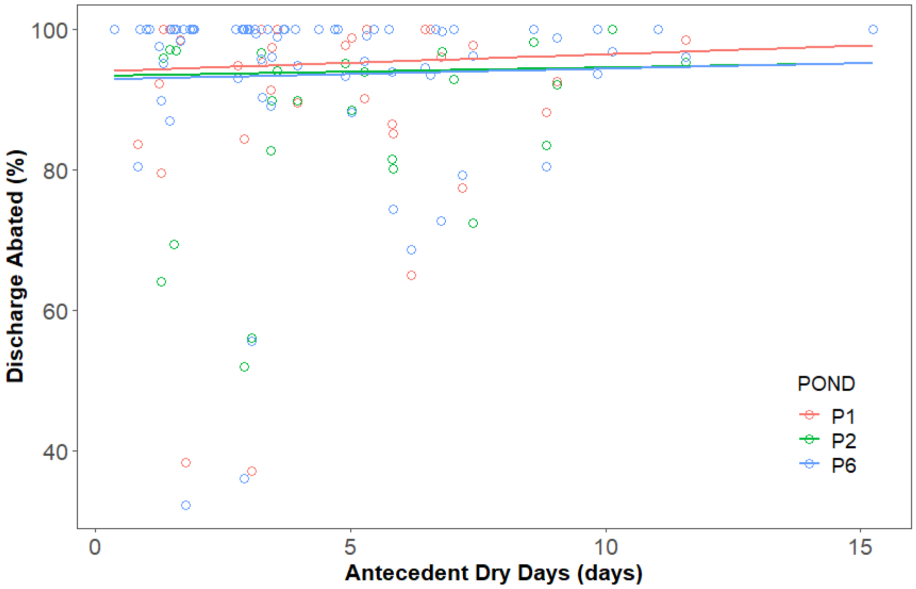

Figure A.11: Log-Linear Scatter Plots and Linear Regressions of Discharge Abatement (%) versus Antecedent Dry Days for each storm event across each treatment train. Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

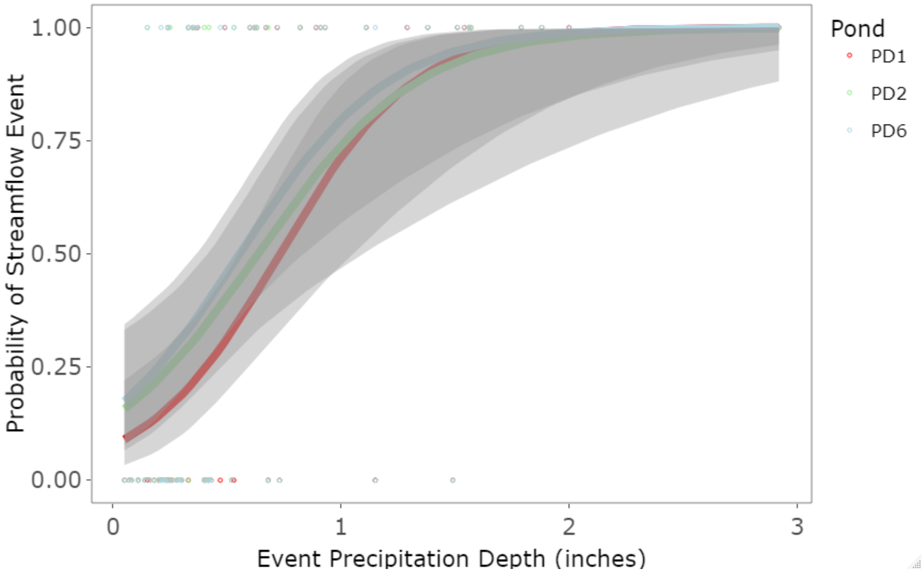

Figure A.12: Logistic regression on the probability of discharge (streamflow event) versus Precipitation Amount (in). Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

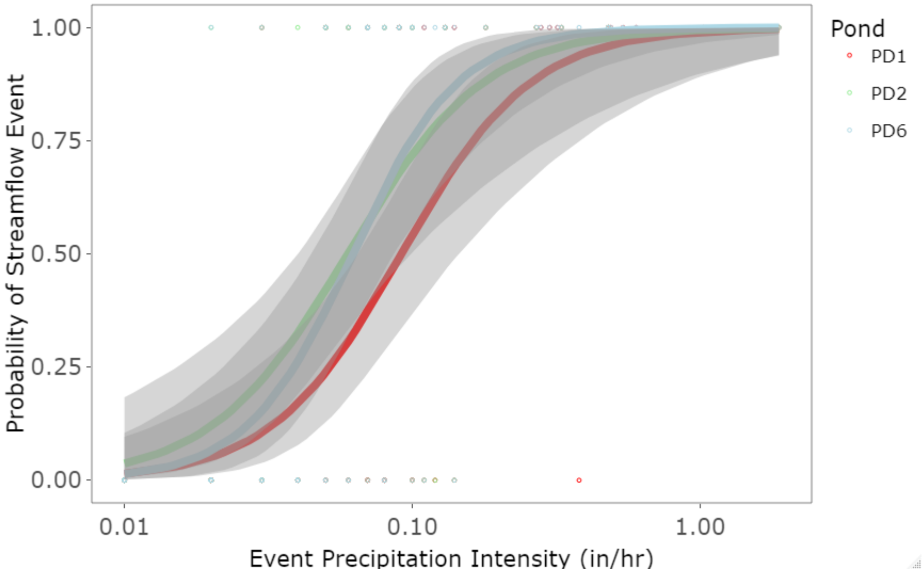

Figure A.13: Logistic regression on the probability of discharge (streamflow event) versus Precipitation Intensity (in/hr). Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

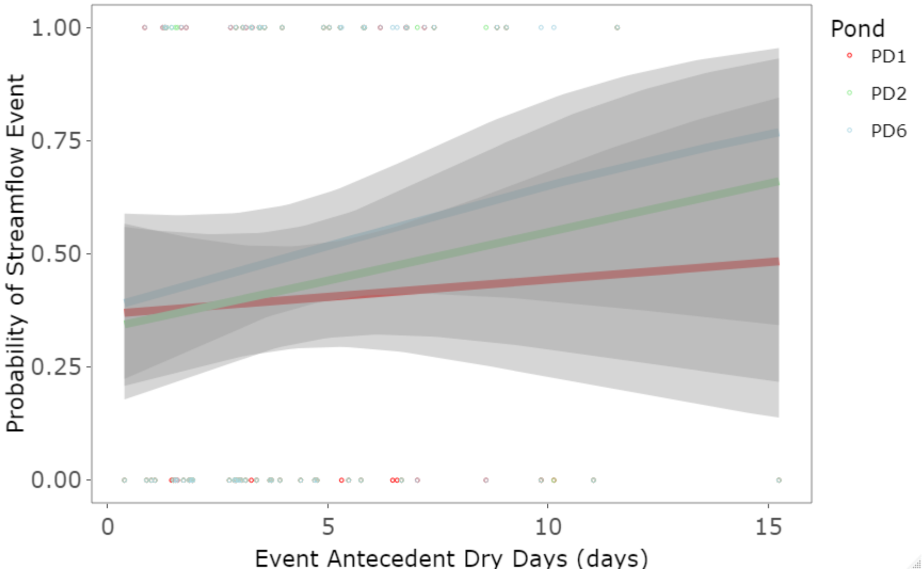

Figure A.14: Logistic regression on the probability of discharge (streamflow event) versus Antecedent Dry Days. Pond 1 is shown in red; Pond 2 is shown in green; and Pond 6 is shown in blue.

Table A.1: Results from the multiple linear regression process for each treatment train across all storm events for normalized discharge versus precipitation dynamic variables (precipitation amount (in), precipitation intensity (in/hr), and antecedent dry days (days)). Regression variable slopes, adjusted R2 value, and F statistic is reported for each regression. ** conveys variable statistically significant at p <0.01 and * conveys variable significant at p <0.05.

Treatment Train	**Intercept**	**Precip.**	**Precip. Int.**	**ADD**	**Adj. R2 value**	**F-statistic**
Pond 1	-165.25	519.10**	246.15	-1.50	0.3744	14.76
Pond 2	-100.32	468.56**	281.77	-3.41	0.5368	22.25
Pond 6	-219.54	629.03**	365.98*	-0.10	0.5464	28.71

Appendix B: Rainfall and Storm Discharge Data from Monitoring Study

Table B.1: Precipitation data from all seventy storm events sampled throughout the monitoring period.

Storm Date	Total Precip. (in)	Precip. Time (hrs)	Precip. Intensity (in/hr)	Antecedent Dry Days (days)
12520	1.51	8.25	0.18	5.8
20520	1.11	36.50	0.03	11.6
21020	0.53	22.50	0.02	3.3
31320	0.33	2.75	0.12	10.1
31820	0.63	8.75	0.07	3.6
41420	0.25	4.50	0.06	1.5
42420	0.68	18.25	0.04	8.6
42620	0.40	8.75	0.05	1.6
43020	1.57	18.75	0.08	3.5
60420	2.92	23.00	0.13	5.8
61020	1.38	15.00	0.09	5.0
61920	0.49	1.00	0.49	1.3
62220	0.72	5.25	0.14	2.8

62520	0.60	1.00	0.60	1.8
70120	0.47	1.25	0.38	5.3
71020	0.67	1.25	0.54	3.1
71220	0.89	3.00	0.30	1.7
72220	0.21	3.00	0.07	9.8
80420	2.00	19.00	0.11	3.3
81220	0.24	3.00	0.08	6.6
82920	1.56	21.50	0.07	4.9
90320	1.29	1.25	1.03	0.8
101120	1.15	16.50	0.07	6.5
52821	0.91	18.00	0.05	4.0
60321	0.82	3.00	0.27	5.3
61121	0.42	5.25	0.08	7.0
61421	0.33	1.00	0.33	1.3
62121	0.60	4.75	0.13	6.8
70121	0.62	11.75	0.05	9.1
71721	0.35	5.50	0.06	7.4
80121	0.24	0.50	0.48	3.4
81021	1.88	1.00	1.88	8.8
81321	0.36	0.75	0.48	2.9
81621	0.93	9.25	0.10	3.1
81821	0.15	1.50	0.10	1.4
90121	1.79	19.50	0.09	1.3
90921	1.54	4.75	0.32	7.2

91621	0.37	4.25	0.09	6.8
92321	2.59	9.25	0.28	6.2
30220	0.2	0.08	4.75	4.75
30620	0.07	0.01	3.68	3.68
32320	0.14	0.02	3.91	3.91
41820	0.05	0.01	3.13	3.13
50320	0.29	0.1	2.89	2.89
50620	0.4	0.02	1.85	1.85
50820	0.3	0.03	1.89	1.89
70720	0.23	0.02	3.03	3.03
72220	0.21	0.02	9.84	9.84
72320	0.3	0.03	1.07	1.07
73120	0.68	0.06	4.7	4.70
81220	0.24	0.02	5.75	5.75
81320	0.14	0.01	0.38	0.38
81420	0.11	0.01	1.55	1.55
81520	1.15	0.11	0.88	0.88
81920	0.29	0.03	2.92	2.92
82320	0.23	0.02	4.38	4.38
91020	0.52	0.05	6.67	6.67
92520	0.26	0.02	15.24	15.24
92920	0.41	0.04	3.72	3.72
100220	0.08	0.01	1.93	1.93
105020	0.11	0.01	2.88	2.88

102920	1.49	0.14	3.38	3.38
110120	0.22	0.02	2.76	2.76
61321	0.28	0.03	1.72	1.72
70921	0.43	0.04	0.99	0.99
72821	0.42	0.04	11.03	11.03
82021	0.73	0.07	1.49	1.49
82521	0.18	0.02	5.47	5.47
82821	0.2	0.02	2.98	2.98
83020	0.16	0.01	1.92	1.92

Table B.2: Discharge and Normalized Discharge from all seventy storm events sampled throughout the monitoring period.

Storm Date	**Discharge Pond 1 (cfs)**	**Normal Discharge Pond 1 (cf/ac)**	**Discharge Pond 2 (cfs)**	**Normal Discharge Pond 2 (cf/ac)**	**Discharge Pond 6 (cfs)**	**Normal Discharge Pond 6 (cf/ac)**
12520	6662.16	740.24	9918.15	1012.06	5666.63	337.30
20520	544.72	60.52	1846.79	188.45	2652.96	157.91
21020	0.00	0.00	638.01	65.10	1390.26	82.75
31320	0.00	0.00	0.00	0.00	635.30	37.82
31820	6.08	0.68	1318.55	134.55	444.68	26.47
41420	0.00	0.00	2723.40	277.90	0.00	0.00
42420	0.00	0.00	439.15	44.81	0.00	0.00

42620	0.00	0.00	431.50	44.03	0.00	0.00
43020	1312.43	145.83	5677.12	579.30	3734.16	222.27
60420	14212.97	1579.22	20695.80	2111.82	45545.27	2711.03
61020	584.14	64.90	5660.33	577.59	9914.55	590.15
61920	1231.69	136.85	Displaced Weir	Displaced Weir	735.17	43.76
62220	1204.71	133.86	Displaced Weir	Displaced Weir	3061.84	182.25
62520	12083.78	1342.64	Displaced Weir	Displaced Weir	24800.01	1476.19
70120	0.00	0.00	Displaced Weir	Displaced Weir	255.78	15.22
71020	133.60	14.84	Displaced Weir	Displaced Weir	271.65	16.17
71220	448.79	49.87	Displaced Weir	Displaced Weir	885.91	52.73
72220	0.00	0.00	Displaced Weir	Displaced Weir	826.08	49.17
80420	3087.39	343.04	Displaced Weir	Displaced Weir	11933.81	710.35
81220	0.00	0.00	Displaced Weir	Displaced Weir	958.57	57.06
82920	1187.43	131.94	2719.95	277.55	6438.15	383.22

90320	6889.36	765.48	Displaced Weir	Displaced Weir	15406.94	917.08
101120	0.00	0.00	Displaced Weir	Displaced Weir	3813.58	227.00
52821	3098.14	344.24	3317.00	338.47	2878.61	171.35
60321	2636.48	292.94	1790.91	182.75	2288.79	136.24
61121	0.00	0.00	1061.96	108.36	0.00	0.00
61421	2202.40	244.71	4218.79	430.49	2057.11	122.45
62121	630.48	70.05	677.07	69.09	95.48	5.68
70121	1496.40	166.27	1730.49	176.58	477.72	28.44
71721	264.62	29.40	3446.18	351.65	808.79	48.14
80121	679.74	75.53	1482.00	151.22	1605.53	95.57
81021	7278.00	808.67	11069.05	1129.50	22470.69	1337.54
81321	1840.25	204.47	6147.17	627.26	14053.83	836.54
81621	19135.11	2126.12	14564.60	1486.18	25208.17	1500.49
81821	0.00	0.00	155.46	15.86	1191.29	70.91
90121	42.75	4.75	2588.12	264.09	5253.05	312.68
90921	11363.76	1262.64	Displaced Weir	Displaced Weir	19575.00	1165.18
91621	479.09	53.23	Displaced Weir	Displaced Weir	6172.80	367.43
92321	29592.53	3288.06	Displaced Weir	Displaced Weir	49685.70	2957.48
30220	0.00	0.00	0	0	0.00	0.00

30620	0.00	0.00	0	0	0.00	0.00
32320	0.00	0.00	0	0	0.00	0.00
41820	0.00	0.00	0	0	0.00	0.00
50320	0.00	0.00	0	0	0.00	0.00
50620	0.00	0.00	0	0	0.00	0.00
50820	0.00	0.00	0	0	0.00	0.00
70720	0.00	0.00	0	0	0.00	0.00
72220	0.00	0.00	0	0	0.00	0.00
72320	0.00	0.00	0	0	0.00	0.00
73120	0.00	0.00	0	0	0.00	0.00
81220	0.00	0.00	0	0	0.00	0.00
81320	0.00	0.00	0	0	0.00	0.00
81420	0.00	0.00	0	0	0.00	0.00
81520	0.00	0.00	0	0	0.00	0.00
81920	0.00	0.00	0	0	0.00	0.00
82320	0.00	0.00	0	0	0.00	0.00
91020	0.00	0.00	0	0	0.00	0.00
92520	0.00	0.00	0	0	0.00	0.00
92920	0.00	0.00	0	0	0.00	0.00
100220	0.00	0.00	0	0	0.00	0.00
105020	0.00	0.00	0	0	0.00	0.00
102920	0.00	0.00	0	0	0.00	0.00
110120	0.00	0.00	0	0	0.00	0.00
61321	0.00	0.00	0	0	0.00	0.00

70921	0.00	0.00	0	0	0.00	0.00
72821	0.00	0.00	0	0	0.00	0.00
82021	0.00	0.00	0	0	0.00	0.00
82521	0.00	0.00	0	0	0.00	0.00
82821	0.00	0.00	0	0	0.00	0.00
83020	0.00	0.00	0	0	0.00	0.00

Table B.3: Duration of Discharge, Lag Time, and Percent of Discharge Abated from all seventy storm events sampled throughout the monitoring period.

Storm Date	**Duration Pond 1 (hr)**	**Lag Time Pond 1 (hr)**	**Duration Pond 2 (hr)**	**Lag Time Pond 2 (hr)**	**Duration Pond 6 (hr)**	**Lag Time Pond 6 (hr)**	**% Abated Pond 1**	**% Abated Pond 2**	**% Abated Pond 6**
12520	6.73	0.65	10.40	3.4	22.98	1.63	86.50	81.54	93.85
20520	1.42	16.05	24.67	17.36	31.25	16.53	98.50	95.32	96.08
21020			10.50	7.11	16.67	6.28	100.00	96.62	95.70
31320					5.33	0.50	100.00	100.00	96.84
31820	1.17	2.82	5.75	3.92	15.00	2.08	99.97	94.12	98.84
41420			13.58	3.15			100.00	69.38	100.00
42420			5.25	5.78			100.00	98.18	100.00
42620			1.92	4.11			100.00	96.97	100.00
43020	2.75	-2.79	19.00	5.53	17.08	1.76	97.44	89.84	96.10
60420	4.00	9.50	20.92	10.56	16.00	9.39	85.10	80.08	74.42
61020	1.67	-0.75	7.50	0.72	6.00	0.97	98.70	88.47	88.22

61920	0.58	0.25	Displaced Weir	Displaced Weir	1.50	0.39	92.31	Displaced Weir	97.54
62220	0.67	0.12	Displaced Weir	Displaced Weir	4.00	0.34	94.88	Displaced Weir	93.03
62520	2.83	-0.11	Displaced Weir	Displaced Weir	15.17	-0.14	38.35	Displaced Weir	32.22
70120			Displaced Weir	Displaced Weir	0.83	0.24	100.00	Displaced Weir	99.11
71020	0.67	-0.15	Displaced Weir	Displaced Weir	0.92	-0.18	99.39	Displaced Weir	99.34
71220	0.75	-0.78	Displaced Weir	Displaced Weir	1.17	-0.72	98.46	Displaced Weir	98.37
72220			Displaced Weir	Displaced Weir	1.00	-1.22	100.00	Displaced Weir	93.55
80420	2.75	7.06	Displaced Weir	Displaced Weir	6.67	8.70	95.27	Displaced Weir	90.22

81220			Displaced Weir	Displaced Weir	1.17	-1.14	100.00	Displaced Weir	93.45
82920	1.42	10.64	4.00	10.83	4.00	-9.67	97.67	95.10	93.23
90320	2.67	0.35	Displaced Weir	Displaced Weir	7.08	0.46	83.65	Displaced Weir	80.42
101120			Displaced Weir	Displaced Weir	3.00	5.83	100.00	Displaced Weir	94.56
52821	11.08	2.24	4.67	3.88	17.17	-6.70	89.58	89.75	94.81
60321	4.00	1.07	4.17	2.38	8.50	1.84	90.16	93.86	95.42
61121	0.00		3.50	0.14			100.00	92.89	100.00
61421	1.42	-0.35	6.67	1.43	9.00	0.19	79.57	64.06	89.78
62121	0.83	2.19	2.33	3.39	1.17	2.73	96.78	96.83	99.74
70121	1.08	-1.73	5.08	-1.61	11.17	-1.36	92.61	92.15	98.74
71721	2.67	-1.35	8.00	3.18	8.92	-1.15	97.69	72.32	96.21
80121	0.92	-0.09	9.08	0.03	2.75	0.93	91.33	82.64	89.03
81021	2.42	-0.18	17.25	3.61	11.00	0.68	88.15	83.45	80.40
81321	1.83	0.28	5.25	2.57	7.25	1.22	84.35	52.00	35.99

81621	5.33	2.03	13.00	1.99	12.25	1.97	37.02	55.98	55.55
81821	0.00		1.00	0.86	1.58	0.43	100.00	97.09	86.98
90121	0.75	7.16	5.67	7.53	5.50	6.60	99.93	95.94	95.19
90921	5.17	-1.72	Displaced Weir	Displaced Weir	15.08	1.81	77.41	Displaced Weir	79.16
91621	0.58	0.87	Displaced Weir	Displaced Weir	5.25	1.31	96.04	Displaced Weir	72.64
92321	7.92	0.45	Displaced Weir	Displaced Weir	37.58	3.22	65.03	Displaced Weir	68.54

Appendix C: Code System and Code Book for Coding Analysis of Semi-Structured Interviews

Table C.1: Code Table and Coding System for Semi-Structured Interviews

Code Name	**# of Statements**
1. Discipline of Stormwater Management	276
2. Biopolitics of Stormwater Management	261
3. Responsibility to Manage Stormwater	135
4. Opportunities for Stormwater Management	154
5. Personal Management of Stormwater	52
6. Definition of Stormwater	13
7. Motivation to Manage Stormwater	55
8. Stormwater Management Practices	156
9. Obstacles to Stormwater Management	312

1. Discipline of Stormwater Management

Discipline is the mode of governmentality through which governments seek to produce behaviors and practices by individuals typically through influencing the ways in which individuals relate to and view the world, typically to correspond with governance goals and objectives.

2. Biopolitics of Stormwater Management

Biopolitics typically utilizes "statistical approaches and quantitative metrics, to make visible the broader patterns beneath the surface of the everyday world". Under biopolitics, governments attempt to reduce natural and social phenomena into a single assemblage that can be quantified, predicted, and modeled or more simply – "reduce the signal from the noise”. Through biopolitics, governments do not try to regulate individual behavior but render them quantifiable allowing for the manipulation and operation of the system itself as a single entity.

3. Responsibility to Manage Stormwater

Who is responsible for managing stormwater? What factors influence this responsibility? Especially interested in understanding the difference is responses between stakeholder groups and how each respondent justifies their responsibility allocation. What does the perceived responsibility of stormwater management describe, in terms, of the hydrosocial relationship among residents, government, and stormwater management?

4. Opportunities for Stormwater Management

What opportunities do the respondents discuss for stormwater management? What is the future of stormwater management? Is there a difference between the opportunities highlighted by stakeholder groups? What do the opportunities discussed describe about their views on stormwater, stormwater management, and the future?

5. Personal Management of Stormwater

How does each respondent personally manage stormwater on their property? Which BMPs do they talk about and use? Do stakeholder groups talk about and manage stormwater differently on their personal property? The way in which respondents manage stormwater on their own property can illuminate their personal relationship with stormwater and stormwater management.

6. Definition of Stormwater

What is stormwater? A nuisance, pollutant, resource? How do respondents talk about stormwater, as something that needs to be managed, or as an under-utilized resource? Are there differences between how Stakeholder groups talk about stormwater? Words, phrases to describe stormwater can illuminate perceptions and underlying causes of these perceptions about stormwater and stormwater management.

7. Motivation to Manage Stormwater

What is the motivation described by each respondent to manage stormwater? Are these motivations different between stakeholder groups? What is the motivation to manage stormwater at the residential (individual) level? Examples: manage household flooding, improve neighborhood/community wellness and health, improve waterways, meet permitting regulations, be ethical environmental citizens. The motivation to partake in stormwater management as a resident and the motivation of stakeholder to push for residential/individual involvement can illuminate how each perceives stormwater and stormwater management.

8. Stormwater Management Practices

What are the stormwater management practices being utilized or discussed by each respondent? Are they strictly for stormwater management or provide auxiliary benefits? Is there a difference in stormwater management practices and techniques being discussed among stakeholder groups? What does the practices that each respondent discusses tell us about their relationship with stormwater and stormwater management? The practices being cited by each respondent and each group can tell us how they view their responsibility and place within stormwater management.

9. Obstacles to Stormwater Management

What are the impediments, obstacles, and barriers to residential stormwater management? Are these perceived obstacles similar or different between stakeholder groups? What does the perceived obstacles to residential stormwater management tell us about their relationship and view of stormwater and stormwater management? Examples: insufficient funding for implementation and maintenance, lack of knowledge and expertise, not enough ongoing support for maintenance, insufficient physical room for implementation of BMPs, lack of desire or willpower.

Appendix D: Q-Methodology Concourse Statements, Survey Questions, and Figures

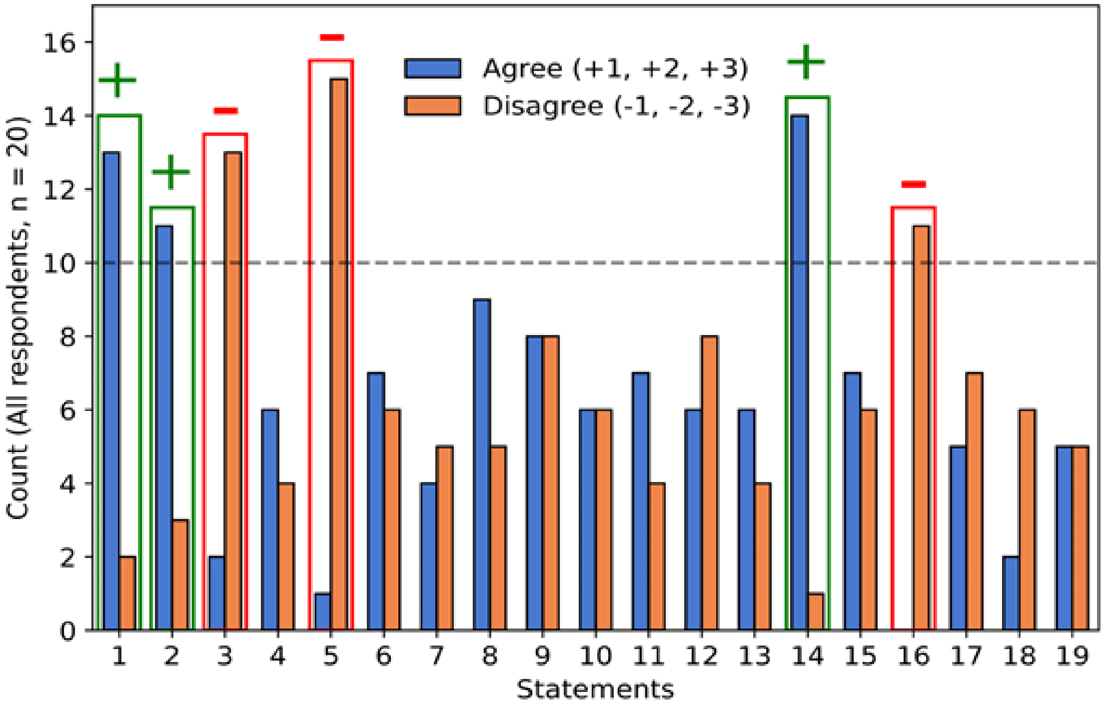

Figure D.1: Total count for each concourse statement of agree (+1, +2, +3) and disagree (-1, -2, -3) for all respondents. Dashed gray line represents half of the respondent pool. Statements agreed upon are outlined in green and statements disagreed upon across respondents are outlined in red – these statements were highlighted if greater than half of the respondents ranked the statement similarly.

Table D.1: Concourse statements paraphrased and created from content analysis of forty-two semi-structured interviews with stormwater professionals and residents in Watts Branch watershed and Watershed 263. These are the statements utilized for the Q-sort survey.

1.	Stormwater is an important resource in urban environments.
2.	Stormwater is a hazard to public and environmental health.
3.	Stormwater is most effectively managed through large-scale centralized projects that capture and treat stormwater.
4.	Stormwater is most effectively managed through small-scale, decentralized green infrastructure.
5.	The government should be solely responsible to manage stormwater.
6.	All property owners should be responsible for the stormwater emanating from their property.
7.	Local landowners lack the knowledge to effectively participate in stormwater management planning.
8.	All stormwater planning and management decisions should be made with direct and continuous input from local landowners.
9.	Stormwater fees are necessary to ensure that cities and local governments have the funding required to effectively manage stormwater.
10.	Stormwater fees have a negative connotation due to the inequity in who pays, how much each landowner pays, and how the revenues from the fees are utilized.
11.	The stormwater fees and rebate systems promote the implementation of stormwater management practices on private land.
12.	A stormwater fee and rebate systems are inherently unjust and inequitable due to the inability for lower income landowners from either paying the fee or implementing practices to receive rebates.
13.	The future of stormwater management must be driven by technological innovations and scientific research.
14.	The future of stormwater management must contain a mixture of both centralized and decentralized infrastructure.
15.	The future of stormwater management must be decentralized and use small-scale infrastructural practices.
16.	The best way to improve stormwater management is through updating existing large-scale, centralized infrastructure.
17.	The best way to improve stormwater management is through the adoption of small-scale, decentralized practices.
18.	The best way to improve stormwater management is through increased regulation and market-based approaches.
19.	The best way to improve stormwater management is through education and outreach.

Table D.2: Initial and Follow-up survey questions asked of each respondent through the online QMethod software. The initial survey questions were mandatory, while the follow-up questions were optional.

<table>
<tr><th colspan="3">Initial Survey Questions</th></tr>
<tr><th colspan="2">Question</th><th>Answer Type</th></tr>
<tr><td colspan="2">Which watershed do you
more closely identify with?</td><td>Watershed 236 or
Watts Branch watershed</td></tr>
<tr><td colspan="2">Do you live in Watershed 263 or
Watts Branch Watershed?</td><td>Yes or No</td></tr>
<tr><td colspan="2">Do you work within Watershed 263 or
Watts Branch Watershed?</td><td>Yes or No</td></tr>
<tr><td colspan="2">Stormwater is part of your daily life?
(0=no, 10=everyday)</td><td>Slider from 0-10</td></tr>
<tr><th colspan="3">Follow-up Survey Questions</th></tr>
<tr><th>1.</th><td colspan="2">How difficult was the Q-sort survey?</td></tr>
<tr><th>2.</th><td colspan="2">What statement did you least agree with (-3) and why?</td></tr>
<tr><th>3.</th><td colspan="2">Which statement did you most agree with (+3) and why?</td></tr>
<tr><th>4.</th><td colspan="2">If you could change where you placed one statement,
where would you place it and why?</td></tr>
<tr><th>5.</th><td colspan="2">Any other general comments you have about how you sorted
the statements?</td></tr>
</table>

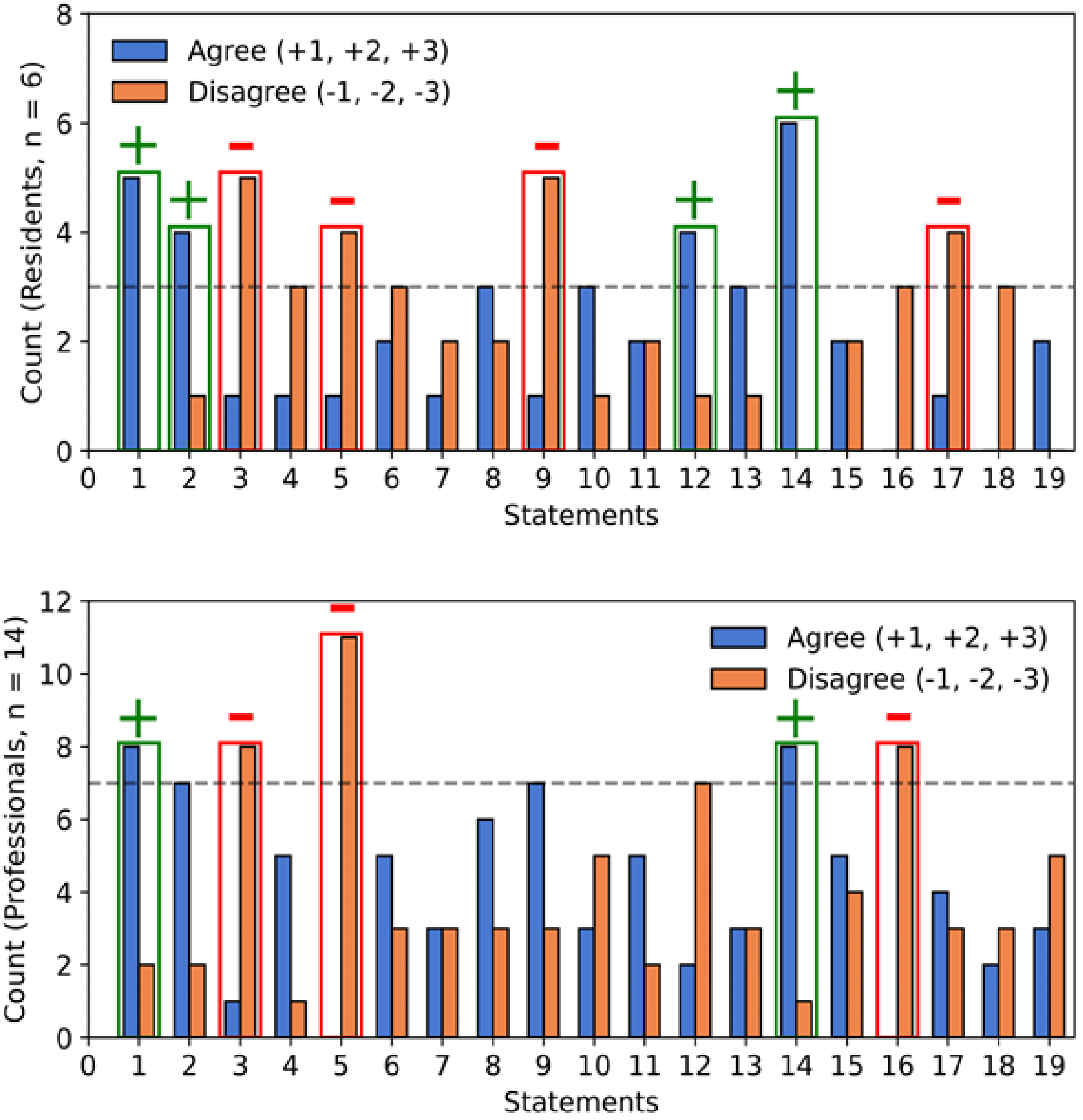

Figure D.2: Total count for each concourse statement of agree (+1, +2, +3) and disagree (-1, -2, -3) for stormwater professionals and residents. Dashed gray line represents half of the respondent pool for that group. Statements agreed upon are outlined in green and statements disagreed upon across respondents are outlined in red – these statements were highlighted if greater than half of the respondents ranked the statement similarly.

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Research Interests

I am a highly interdisciplinary scholar focused on water research. My current research focuses on the ecological, social, and political aspects of urban stormwater management. My previous research was focused on assessing the performance of soil amendments in bioretention media, specifically for the attenuation of metals. Broadly, I am particularly interested in investigating the political ecology of environmental management and governance and the resulting impacts on ecological and public health across a variety of settings.

Education

University of Maryland, College Park, MD 2018–2022 (expected)

- Ph.D. in Environmental Science and Technology, GPA: **3.975/4** – via 38 credits.
- Advisors: Associate Professor Mitchell Pavao-Zuckerman and Professor Michael Paolisso
- Dissertation: Hydrosocial Relations and Hydrocitizenship within the Shift towards Decentralizing Stormwater Management.

Towson University, Towson, MD 2015–2018

- M.S. in Environmental Science, GPA: **3.851/4** – via 41 credits.
- Advisors: Professor David Ownby and Professor Ryan Casey
- Thesis: Performance of Commercially Available Soil Amendments for Enhanced Copper Attenuation in Bioretention Media.

Washington College, Chestertown, MD 2011–2015

- B.S in Chemistry and B.A in Environmental Studies, GPA: **3.601/4** – via 144 credits.
- Thesis: Determining Trace Metal Concentrations in Estuarine Sediments of the Chester River using Aluminum as a Reference Element.

Research Experience

University of Maryland, College Park, MD 2018 - present

- Graduate Research Assistant
    - Planned, proposed, and coordinated a monitoring program to analyze discharge within stormwater best management practice treatment trains in Clarksburg, MD.
    - Reviewed and synthesized interdisciplinary conceptual approaches to urban water management including stormwater management.
    - Utilizing interdisciplinary approach to investigate hydrosocial drivers of siting stormwater management practices and the ecological and social outcomes.
    - Interview coding analysis and production of Q-sort survey to investigate the relationships of stormwater across residents and stakeholders in urban watersheds in Maryland/D.C.

Urban Environmental Biogeochemistry Lab, Towson, MD 2015–2018

- Graduate Research Assistant
    - Conducted laboratory column experiments to determine performance of various soil amendment additions to bioretention media for copper attenuation.
    - Conducted field study to determine performance of bioretention planter boxes to minimize copper exports from copper roof runoff.
    - Utilized Biotic Ligand Model (BLM) to determine potential copper toxicity of pre and post-treatment runoff from copper roof.
    - Analyzed water sample for various water quality parameters including: trace metals (ICP-MS), dissolved ions (IC), total organic carbon (TOC/TN), alkalinity, and pH.

Washington College 2013–2015

- Undergraduate Research Technician
    - Preformed trace metal analysis of soil samples using ICP-MS.
    - Utilized gravimetric methods to prepare trace metal standards for ICP-MS.
    - Preformed microwave-aided digestions on estuarine sediments for ICP-MS analysis.

Publications

1. *State Factors Control Progressive Stages of Freshwater Salinization Syndrome*
   S Kaushal, P Mayer, G Likens, J Reimer, C Maas, M Rippy, S Grant, I Hart, R Utz, R Shatkay, B Wessel, C Maiett, M Pace, S Duan, W Boger, A Yaculak, J Galella, K Wood, C Morel, W Nguyen, S Querubin , R Sukert, A Lowien, A Wellman-Houde, A Roussel, A Houston, A Cacopardo, C Ho, H Wendlandt, J Widmer, J Slagle, J Bader, J Chong, J Wollney, J Kim, L Shepherd, **M Wilfong**, M Houlihan, N Sedghi , R Butcher, S Chaudhary, and W Becker
   Limnology and Oceanography Letters - March 2022
2. *Performance of Commercially Available Soil Amendments for Enhanced Copper Attenuation in Bioretention Media*
   M Wilfong, DR Ownby, RE Casey - Journal of Environmental Management - June. 2021
3. *Rethinking Stormwater: Analysis using the Hydrosocial Cycle*
   M Wilfong, M Pavao-Zuckerman - Water - April. 2020

In Review

1. *Shifting Paradigms in Stormwater Management: Hydrosocial Relations and Stormwater Hydrocitizenship*
   M Wilfong, M Paolisso, D Patra, M Pavao-Zuckerman, P Leisnham
   Journal of Environmental Policy and Planning
2. *Diffusing Responsibility, Decentralizing Infrastructure: Hydrosocial Relationships within the Shifting Stormwater Management Paradigm*
   M Wilfong, D Patra, M Pavao-Zuckerman, P Leisnham
   Journal of Environmental Planning and Management

Presentations

1. *The "Hydrocitizen" and Why Anthropology is Key to Water Quality*
   M Wilfong - Invited Speaker - York River and Small Coast Basins Round Table
   Gloucester Point, VA - May 2022
2. *Diffusing Responsibility, Decentralizing Infrastructure: Hydrosocial Relationships within the Shifting Stormwater Management Paradigm*
   M Wilfong, M Paolisso, D Patra, M Pavao-Zuckerman, P Leisnham - SfAA Annual Meeting - Salt Lake City, Utah - Mar. 2022
3. *Rethinking Stormwater: Analysis using the Hydrosocial Cycle*
   M Wilfong, M Pavao-Zuckerman - SfAA Annual Meeting - Virtual - Mar. 2021
4. *Improving Water Quality in Beargrass Creek: A Designed Experiment through Community Green Infrastructure Adoption and Citizen Science*
   G Russell, **M Wilfong**, F Shoushtarian, M Wong, JHP Rathnaweera - ESA Annual Meeting - Virtual - August 2020
5. Invited Speaker - From Undergraduate to PhD: How to Bridge the Gap - Washington College - Chestertown, MD - Nov. 2019
6. *Performance of Commercially Available Soil Amendments for Enhanced Copper Attenuation in Bioretention Media*
   M Wilfong, DR Ownby, RE Casey - SETAC 37th North America - Orlando, Fl - Nov. 2017

Teaching Experience

University of Maryland

- ENST 360 - Ecosystems Ecology — Fall 2021
  - Led discussions utilizing variety of methods to promote active engagement and supplemental and reinforced learning of lecture materials.
- ENST 104 - Introduction to Environmental Health — Fall 2020
  - Led fully remote discussions focused on real-world applications of complex public and environmental health research and problem-solving.

Towson University

- CHE 121 - Chemistry I Lab - as **Adjunct Professor** — Spring 2018
  - Led and instructed students in basic chemistry lab focused on applying lecture-based theory in laboratory practice.

- CHE 221 - Chemistry II Lab - as **Adjunct Professor** Spring 2018
  - Led and instructed students in basic chemistry lab focused on applying lecture-based theory in laboratory practice.
- ENV 104 - Introduction to Environmental Chemistry Lab Fall 2015, 2016, and 2017
  - Led and instructed students focused on applying environmental chemistry to real-world examples through laboratory experimentation.

GRANTS

- Maryland Sea Grant Extension- Graduate Research Support Grants - 2019-2020
  Assessing the Ecohydrological Performance of Stormwater Green Infrastructure Treatment Trains at the Subwatershed Scale in Montgomery County, MD.
  M Pavao-Zuckerman (PI, advisor) and **M Wilfong** (Co-PI) - **$ 9,996**

AWARDS AND FELLOWSHIPS

- Graduate Summer Research Fellow - UMD Graduate School - June 2020
- Earth Stewardship Initiative Fellow - Ecological Society of America - Aug. 2019
- Student Travel Grant - Society of Toxicology and Environmental Chemistry - Oct. 2017

REFERENCES

- **Associate Professor Mitchell Pavao-Zuckerman**
  - Ph.D Advisor at University of Maryland, College Park
  - mpzucker@umd.edu
  - 301-405-1178
  - 1426 Animal Science Building, 8127 Regents Drive, College Park, Maryland 20742
- **Professor Michael Paolisso**
  - Ph.D Advisor at University of Maryland, College Park
  - mpaoliss@umd.edu
  - 301-405-1433
  - 0131 Woods Hall, College Park, Maryland 20742
- **Professor David Ownby**
  - M.Sc Advisor at **Towson University**
  - downby@towson.edu
  - 410-704-2946
  - 8000 York Road, Towson, MD 21252