ABSTRACT

WALLER, JUHANN Resilient Infrastructure: An Integrated Design Approach for the Equitable Distribution of Stormwater Capital Improvements Projects for Pluvial Flood Mitigation.

Six decades of research has shown infrastructure under-investment in socio-economically depressed places disproportionately impact and subject socially vulnerable populations to environmental hazards (NASM, 2019; EPA, 2016; Bullard & White, 2009; Bullard et al., 2008; Heck, 2021; ASCE, 2021). Environmental Justice literature focusing on environmental hazards, especially pluvial flooding, is beginning to underscore policy and governance failures in the targeted allocation of infrastructure investment and community capacity-building resources (Campanella, 2006; Bullard & White, 2009; O'Hare & White, 2017; EPA, 2016; NASM, 2019). With the continued deterioration and under-investment in stormwater infrastructure in the United States, localized (non-disaster declared) pluvial flooding events are frequently occurring. This creates a significant disruption to the socio-economic fabric of communities and impairs the community's ability to absorb the initial shock (cope), retain functionality (adapt), and minimize recovery time and cost (recover) (NASEM, 2019; Bullard & White, 2009; USGCRP, 2018; Yamagata & Sharifi, 2018; Birkmann et al., 2013).

Environmental justice (EJ) as well as hazards and resilience literature has identified capacity limitations of underserved and communities of color to cope, adapt and recover from pluvial flooding events attributed to climate change. EJ advocates have long recognized the disproportional impact of climate change on underserved and communities of color. To increase the resilience of this population, EJ advocates have long emphasized the principles of unequal exposure, the importance of community voice, and capacity building. Fundamental changes are needed to improve the technocratic system that identifies, prioritizes, and determines the distribution of urban drainage infrastructure. This study describes the development and application of a novel EJ-based algorithm (UDRiS) using the City of Greensboro, North Carolina as a demonstration site for the identification and ranking of Stormwater Capital Improvement Projects (CIP).

The novel EJ-based algorithm UDRiS is utilized to perform a comparative analysis to determine if the current project screening methods (Scorecard and Anecdotal evidence) used by stormwater departments for identifying and ranking stormwater capital `improvement projects are inherently subjective, technocratic, and biased. It is presumed the inherent prejudice in the existing methodologies, results in the inequitable distribution of resources for mitigating the impacts of pluvial flooding on the most vulnerable populations and places. The findings of this study show the spatial distribution of pluvial flooding events is disproportionately higher for census tracts with lower incomes, higher poverty rates, and/or significant populations of color within the City of Greensboro, North Carolina. The study also determined the identified urban drainage capital improvement projects identified for project-specific appropriations within the City of Greensboro Fiscal Year 2022-2023 CIP is not cognizant of the socioeconomic conditions of the project′s census tract. This results in the most vulnerable populations and places with the greatest need getting overlooked for urban drainage infrastructure investment.

Key Words: urban drainage; resilience; environmental justice; capital improvements planning, infrastructure investment

Resilient Infrastructure: An Integrated Design Approach for the Equitable Distribution of Stormwater Capital Improvements Projects for Pluvial Flood Mitigation.

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DEDICATION

I dedicate this manuscript to my family, Farrokh Mirzai-fard, Sherry Bittle, Dr. Judy Perkins, Dr. Sameer Hammoush, and others that planted the seed of a doctoral degree and watched it grow and blossom into reality. This is also dedicated to my students at North Carolina Agricultural and Technical State University who showed interest in my work and provided motivation and encouragement throughout this journey. ***AGGIES Do and AGGIES are never done, keep striving for excellence!***

Lastly, I dedicate this manuscript to all the underserved and communities of color whose voices are oftentimes not heard. I hope this work provides you with the recognition, voice, and change you desire and deserve for your communities.

BIOGRAPHY

Juhann Waller is a native of the Commonwealth of Virginia and is currently a resident of Greensboro, North Carolina. He received his Master's (2006) and Bachelor of Science (2005) Degrees in Civil Engineering from North Carolina Agricultural and Technical State University in Greensboro, North Carolina. Urban Planning and Residential Development was the concentration of his Master of Science Degree which guided his passion for infrastructure and community resilience. He is also a registered Licensed Professional Engineer and practices in the States of North Carolina, South Carolina, and Virginia.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

-Chapter 1-

1.0 Introduction

With the increased prevalence of non-disaster declared pluvial flooding and the availability of funding contained in the Bipartisan Infrastructure Law for urban drainage systems, many counties, cities, and towns are evaluating the adequacy of their aging urban drainage infrastructure (American Society of Civil Engineers, 2021; DeAngelis et al., 2019). Under the provisions of the National Pollutant Discharge Elimination System (NPDES) program, permittees of urban drainage systems also known as municipal separate storm sewer systems (MS4) in federal regulations are required to implement stormwater management programs. These programs are obligated to address the six minimum statutory requirements for limiting the total maximum daily load (TMDL) and total suspended solids (TSS) contained within stormwater that discharges into the waters of the United States (Environmental Protection Agency, (EPA), 2016; PG Environmental, 2017; Ross & Associates Environmental Consulting, Ltd., 2012). These six minimum statutory requirements for each stormwater management program are: 1) Public education and outreach, 2) public participation and involvement, 3) illicit discharge detection and elimination of construction site runoff control, 4) post-construction runoff control, 5) pollution prevention and 6) good housekeeping.

In January 2019, the Water Infrastructure and Improvements Act amended the CWA to include the 2012 Integrated Municipal Stormwater and Wastewater Plan Framework. This framework placed additional emphasis on the linkage between capital improvement programs or planning (CIP) and the public participation statutory requirement (Water Infrastructure Act, 2018). Although voluntary, this framework was designed to synchronize community goals and CIP activities to assist municipalities in prioritizing their capital investment needs to achieve their long-term CWA objectives. The 2012 Integrated Municipal Stormwater and Wastewater Plan also recognize the increased pressure local governmental units (LGUs) are faced with balancing competing interests caused by changing climatic patterns, population growth, aging infrastructure, and limited financial resources (Ross & Associates Environmental Consulting, Ltd., 2012).

In general, CIP is a multi-phase process that focuses on the planning, financing, and construction of prioritized capital investments using the planning-programming-budgeting theory. This theory is used to optimize the allocation of a limited amount of resources for maintaining or improving the quality of life of citizens (DeAngelis et al., 2019; Grigg, 2012). Capital improvement programs are a multi-departmental and transdisciplinary process that requires input from multiple stakeholders and governance boards. The stakeholders and governance boards are responsible for the identification, prioritization, and approval of resources for the identified capital expenditures. CIP in the context of urban drainage systems has grown in the last twenty years because of more stringent regulatory requirements, increased urbanization, and more prevalent pluvial flooding and drainage complaints (National Academies of Sciences, Engineering, and Medicine (NASEM), 2019).

1.1 Climate Impact Framing

With the expected increase in heavy rain events and its relationship with increased urbanization and greenhouse gases associated with human activities. Its predicted urban drainage systems will become frequently overburdened and cannot convey stormwater runoff that results in the accumulation of water on the ground surface is defined as pluvial flooding (Association of State Flood Plain Management, (ASFPM), 2019; Butler, 2018; National Academies of Sciences, Engineering, and Medicine (NASEM), 2019; Zhou, 2014). According to the Intergovernmental Panel on Climate Change (IPCC), climate change will continue to present added risks and stressors to all populations, interconnected systems, and infrastructures that are already compromised by pre-existing conditions and under-investment. Various climate studies and models have predicted a 20-80% increase in climatic events of heavy rain depending on the geographical location and the prediction model utilized (Butler, 2018; IPCC, 2021; Zhou, 2014).

Climate change is simply not a sequence of events with known impacts on populations and geographical locations but creates a dimension of uncertainty and risks that challenges our perception of the interaction between the environment, urbanscapes, and society (Friend & Moench, 2013). Most communities are aware of the inherent flood risks associated with developing in or adjacent to Special Flood Hazard Areas (SFHA) as delineated by the Federal Emergency Management Agency (FEMA). These areas are primarily defined along riverine features and coastal areas to indicate the probability of floodwater inundation that triggers governmental-sanctioned loss mitigation and prevention measures at the community and household scales. However, little attention has been given to the plausibility of pluvial floodwater inundation of non-SFHAs.

These non-SFHAs are defined as areas outside of the FEMA-delineated SFHA boundary which primarily consists of the areas where we live, work, and play. This distinction is critically important because the hazards and Environmental Justice (EJ) literature has noted, non-disaster-declared pluvial flooding occurs predominately in non-SFHAs. The past belief of low to no flood risk in non-SFHAs has resulted in little communication and emphasis on flood prevention measures. This lack of communication and emphasis has resulted in flood insurance coverage being less prevalent in non-SFHAs which has increased the risk for all populations due to an increase in high rainfall events attributed to climate change (Association of State Flood Plain Management, (ASFPM), 2019; National Academies of Sciences, Engineering, and Medicine (NASEM), 2019).

Most of the urban drainage infrastructure in the United States has been noted as being overwhelmed and has surpassed its useful life due to deferred maintenance, poor land use policies, and infrastructure planning practices (American Society of Civil Engineers, 2021). This has resulted in the degradation of stream water quality and increased pluvial flooding risk to all populations. The more prevalent, non-disaster declared pluvial flooding events make all populations more vulnerable due to the non-availability of Federal and State governmental resources for the recovery efforts. This leaves the impacted population including the underserved and communities of color, to heavily rely on local governmental or self-produced resources for the recovery efforts (Association of State Flood Plain Management, (ASFPM), 2019; Blessing, Sebastian, & Brody, 2017; Boone, 2013; O'Hare & White, 2018).

1.2 Stormwater Governance

Stormwater governance is hierarchically structured in the United States (US) with most regulations created at the Federal and State governmental levels with enforcement provided by LGUs (Finewood et. al., Michael H, 2019; Government Accountability Office, 2017; Smith, Sabbag, & Rohmer, 2018). Over the last 20 years, US Disaster policy has begun to evolve from reactionary to a more sustainable proactive system of hazard mitigation. Even with the changing attitudes at the Federal Level regarding resilience and hazard mitigation, inadequate resources and support are provided to LGUs for lower-level non-disaster declared pluvial flooding events. These events tend to occur outside of the SFHA and are not of a magnitude that triggers Federal or State Disaster Declarations due to the resources and management capabilities of LGUs are not exceeded (Federal Emergency Management Agency, (FEMA), 2017a; National Academies of Sciences, Engineering, and Medicine (NASEM), 2019; Smith et al., 2018).

FEMA's premier disaster preparedness grant program, Building Resilient Infrastructure, and Communities (BRIC) provides financial assistance to LGUs and Tribal Governments for mitigation activities designed to strengthen the United States' efforts to bolster a culture of preparedness that incentivizes public green infrastructure projects (FEMA,2020b). While the intentions of the program are admirable, the requirement for having a federal disaster declaration under the Stanford Act within the past seven years is a major barrier to the utilization of this funding opportunity (FEMA, 2020a; FEMA, 2020b). In addition to the federal disaster declaration requirement, Smith and Vila, 2020, in a survey of State Hazard Mitigation Officers identified insufficient attention at the Federal and State level to the technical capacity of LGUs. This inattentiveness results in an additional barrier to smaller LGUs which are mostly rural communities from obtaining Federal and State funding due to their inability to provide resources for preparing " winning" proposals against resource-rich communities.

1.3 Existing CIP Decision-Making Process

An important link between stormwater governance and long-term planning is the stormwater capital improvements planning (CIP) process. This process plays a key role in assessing and determining a community's resilience to pluvial flooding and the distribution of pre-flood event resources (DeAngelis et al., 2019; Hendricks & Van Zandt, 2021). The CIP process assesses urban drainage infrastructure needs within the entire jurisdictional boundary of an LGU over a defined timeframe. At the end of the assessment phase, the identified urban drainage infrastructure needs are then benchmarked against the overall community goals and objectives as identified in long-range comprehensive plans that improve or sustain a community's quality of life (DeAngelis et al., 2019; Savage et al., 2012).

To create a comprehensive plan, most LGUs have adopted various methodologies for the identification and selection of projects for inclusion in the Capital Improvements Plan. Two of the most common screening practices among LGUs are the scorecard and anecdotal evidence methodologies. The balanced scorecard methodology is primarily used by LGU's budget office as a macro-scale project screening tool. This screening tool is used for describing and communicating how selected projects support an LGU's goals and mission (Kaplan, 2010; Sharma & Gadenne, 2011). At the departmental level, the scorecard and anecdotal evidence methods are commonly utilized for the identification and selection of projects for submission to the LGU's budget office to request project-specific appropriations through the LGU's Capital Improvements Plan (City of Durham, 2022; City of Greensboro, 2022).

The balanced scorecard method developed by Kaplan (2010) in the early 1990s, is a performance evaluation method that uses financial and non-financial performance measures. These performance measures are used for evaluating tangible and intangible assets that play a key role in achieving an LGU's core social and economic mission and objectives (Kaplan, 2010; Sharma & Gadenne, 2011). A major criticism of the balanced scorecard methodology is its failure to consider some of the most vulnerable stakeholders. In doing so, this limits the socio-economic benefit to a small subset of stakeholders with socio-political infrastructure and unmuted voices which is counter to the principles of EJ (Bullard & Wright, 2009; Campanella, 2006; Schlosberg, 2013; Sharma & Gadenne, 2011). "Socio-political infrastructure" as coined by Eakin et al., 2017 refers to the social and political norms, values, rules, alliances, and relationships that provide the underpinnings and institutional structure to the numerous decisions made by public and private political players, which define the roles actors play in forming and shaping the urbanscape.

Anecdotal evidence methodology is defined in this study as a project screening approach used to establish the priority of a project based on limited scientific data and personal observations. This project screening methodology is utilized by most Stormwater Departments to investigate pluvial flooding events or drainage concerns reported by citizens for inclusion in the capital improvements plan for project-specific appropriations (City of Durham, 2022; City of Greensboro, 2022). This project screening approach is insufficient because it is a non-comprehensive assessment of the urban drainage infrastructure which could result in projects being included in the CIP that do not increase the resilience of the population and places impacted by pluvial flooding. Fundamentally, this subjective screening practice coupled with the self-report system of drainage systems deficiencies perpetuates bias and disparities in the distribution of pre-pluvial flood resources by narrowly defining project locations.

For most LGUs, a small percentage of the overall CIP program budget is allocated for small-scale pluvial flooding and drainage concerns for publicly maintained urban drainage systems. This requires the LGU to internally identify and prioritize a non-comprehensive set of candidate pluvial flood mitigation projects. These projects in most cases are derived from citizen-reported flood/drainage concerns or data collected through very limited means which perpetuates a system of inequality, misrecognition, and exclusion. Prevailing literature suggests most hazard mitigation decision-making practices and governmental policies do not adequately acknowledge, provide inclusivity and provisions for underserved and communities of color who are less able to recover from pluvial flooding events (Bullard & Wright, 2009; Cutter et al., 2013; Flanagan et al., 2011; National Academies of Sciences, Engineering, and Medicine (NASEM), 2019).

1.4 EJ Framing

Environmental Justice (EJ) is broadly defined by the United States Environmental Protection Agency as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income concerning the development, implementation, and enforcement of environmental laws, regulations, and policies (United States Environmental Protection Agency, (EPA), 2016). The concept of EJ is associated with the unjust siting of a PCB landfill in a rural underserved community of color in Warren County, North Carolina (Bullard & Wright, 2009; Schlosberg, 2013). Since then, EJ has evolved over the years to include a broader definition for both “environment” and “justice” to align with society’s changing perspectives of injustices (Bullard & Wright, 2009; Colten, 2007; Jerolleman, 2019; Schlosberg, 2013). The current environmental and economic justice movement, formerly known simply as the environmental justice movement, now reverberates more to the interrelationship between vulnerability, disadvantages, and the environment (O'Hare & White, 2018; Schlosberg, 2013).

This broader definition of the "environment" is important because it encompasses all aspects of the environment from the urbanscapes "where we live, work and play" to natural and created landscapes (Bullard & Wright, 2009; Schlosberg, 2013). The expanded definition of "justice" is also critically important to the movement because it provides academia a basis for critical inquiry into the principles of equity, recognition, and participation which are key aspects of the movement (Bullard & Wright, 2009; Schlosberg, 2013; Walker & Burningham, 2011). These broader definitions of the key aspects of the EJ movement led Mohai et al. (2009), to outline three empirically linked interrelated causal factors that provide additional foundational support for EJ beyond the underlying response of racial inequalities. The identified interrelated causal factors identified were 1) the exploitation of the economic condition and situation of the vulnerable and their environment for the economic gains of others; 2) governmental and empowered players seeking the path of least resistance coupled with the notion that vulnerable populations make easier targets; 3) distinct forms of disenfranchisement are associated with underserved and communities of color with regards to pollution. Schlosberg (2013) concludes that if any or all these causal factors are present, a systemic culture of misrecognition, exclusion, and inequities will exist.

The integration of EJ principles into urban drainage infrastructure projects is still a novel concept (Cutter et al., 2013; Dunning & Durden, 2013). The notion of integrating EJ and resilience principles was thrust into the forefront beginning with the Presidential Policy Directive PPD-8 National Preparedness, followed by Executive Order 13653-Preparing the United States for the Impacts of Climate Change and now through Executive Order 13985-Advancing Racial Equity and Support for Underserved Communities Through the Federal Government. These Policy Directives and Executive Orders promote the equitable delivery of government benefits and equitable opportunities which extended itself to the environmental regulations and federal appropriations spent on infrastructure improvements. These Policy Directives and Executive Orders acknowledge institutionalized racism and classism that are interwoven into laws and public policies that have resulted in systemic inequities and infrastructure under-investment in underserved and communities of color. These policies of systemic inequities rooted in racism and classism are further amplified by climate change and will further destabilize socially vulnerable populations and socio-economically distressed places (Hendricks & Van Zandt, 2021).

1.5 Resilience Framing

Resilience is still a broad aspirational concept with positive connotations that are used to frame scientific, political, and social discourse around the ability of a system to rebound from external shocks, recover and adapt to new circumstances while preserving key components and relationships (Cutter et al., 2008; Linkov & Palma-Oliveira, 2017; Wardekker, 2018; Yamagata & Sharifi, 2018). The concept of resilience in academic literature can be traced back to the 1973 C.S. Holling article, Resilience, and Stability of Ecological Systems (Rodina, 2019). Since the publishing of this groundbreaking article, three major theories and epistemologies of resilience have emerged from the disciplines of engineering (engineering resilience), ecology (ecological resilience), and the social sciences (adaptive resilience also known as social-ecological resilience) (Linkov & Palma-Oliveira, 2017; Yamagata & Sharifi, 2018).

In urban drainage system applications, resilience is often viewed from the perspective of engineering resilience. This epistemology emphasizes creating systems that can withstand anticipated stressors by adding robustness and resistance to the physical system (Yamagata & Sharifi, 2018). When systems experience failure from anticipated stressors that exceed pre-established thresholds, engineering resilience will enable the system to rapidly recover to pre-disruption conditions. However, the robustness and resistance of the system have minimal effect on the system's ability to cope, adapt, and recover from unanticipated stressors. Looking at resilience through this lens results in a single equilibrium-focused approach that fails to capture the behavior of complex dynamic systems such as urbanscapes (Yamagata & Sharifi, 2018).

Climate Change has evoked uncertainty within urbanscapes which have led counties, cities, and towns to employ principles of adaptive resilience to better prepare for future conditions (Rockefeller Foundation 100 resilient cities.n.d.). Adaptive resilience is defined as the ability of a complex system to absorb unanticipated stressors with the capacity to explore new opportunities through evolutionary learning techniques to adapt to changing conditions across varying temporal and spatial scales (Birkmann et al., 2013; Kim & Lim, 2016; Wardekker, 2018; Yamagata & Sharifi, 2018). Since urban drainage systems have a useful life span of 50-plus years, a different epistemology of resilience is necessary to quantify the coping and adaptation capacity of urbanscapes to absorb and recover from unanticipated stressors associated with climate change (Kim & Lim, 2016; Wardekker, 2018; Yamagata & Sharifi, 2018). Integrating adaptive resilience principles into urban drainage design practices and decision-support models is a novel concept that diverges from the epistemology of engineering resilience (Oulahen et al., 2019).

1.6 Discussion

The work of (Bullard & Wright, 2009; Friend & Moench, 2013; Heck, 2021; Hendricks & Van Zandt, 2021; Krings & Schusler, 2020; McFarlane, 1999) highlights how governmental policies influence how people access and benefit from a range of resources. These studies suggest economic development and infrastructure inequalities are the byproducts of racial capitalism. Institutionalized racism and classism further perpetuate environmental injustices during the identification and ranking process for urban drainage system improvements. This becomes a biased technocratic quagmire that narrowly defines and minimizes the added benefits and the equitable distribution of those benefits, which are typically not realized by socio-economically vulnerable populations and places (Butler, 2018; Finewood et. al., Michael, 2019; United States Environmental Protection Agency, (EPA), 2014; United States Environmental Protection Agency, (EPA), 2016; Webber et al., 2019).

These studies begin to characterize and provide a long lineage of underlining inequalities built into our social constructs and urbanscapes which are inherently linked to urban drainage systems. From the very beginning, urban drainage systems embodied classism that still exists today that underserved and populations of color face pre and post-pluvial flooding events. Recognizing the inequities in the distribution of the CIP projects including stormwater CIP, the City of Durham and the City of Charlotte have adopted and implemented tools that provide distributive justice and a voice to vulnerable populations and places (AECOM, 2012; City of Durham, 2022; City of Durham Budget & Management Services, 2021). Each of the CIP programs within these two municipalities has similar objectives which are achieved through the implementation at two touch points within the CIP process.

The City of Durham's CIP racial equity scoring tool is implemented at the Stormwater Division and Budget & Management Services project screening levels to provide a deeper analysis of budget requests through an EJ lens (City of Durham Budget & Management Services, 2021). This racial equity tool integrates race-conscious considerations into policies, processes, procedures, and practices. These race-conscious factors require the meaningful consideration of racial data and encourages community engagement for the co-creation of solutions (City of Durham Budget & Management Services, 2021). The City of Charlotte's Flood Risk Assessment and Risk Reduction Plan is implemented at the departmental level to provide prioritization of flood-risk reduction mitigation projects for inclusion in the budget request for the overall CIP. The Flood Risk Assessment and Risk Reduction Plan is a parcel scale scorecard methodology used primarily to facilitate the identification, assessment, and prioritization of riverine flooding minimization projects (including buyouts) within the SFHA that minimizes the impact to people and property.

Most governmental policies and practices do not adequately acknowledge, provide inclusivity, or provisions for underserved and populations of color pre-, during, and post-pluvial flood events (Cutter et al., 2013; Cutter et al., 2008; Flanagan, et al., 2011; National Academies of Sciences, Engineering, and Medicine (NASEM), 2019). Restructuring and rethinking processes that embody and promote problematic practices connected to injustices may be subdued with the enactment of governmental policies that strive for the basic need for racial, social, economic, and political equality which transcends race and economic status (Eakin et al., 2017; Schlosberg, 2013; United States Environmental Protection Agency, (EPA), 2016). Understanding how stakeholders, underserved, and populations of color are affected and perceive hazards, vulnerability, and resilience can help with the most effective allocation of resources pre-, during, and post-pluvial flooding events (Birkmann et al., 2013; Campanella, 2006; Jerolleman, 2019).

Social vulnerabilities in the natural hazards and disaster management literature are characterized as the manifestation of social inequalities that are exemplified by qualitative and quantitative indicators that are representative of the population's capacity to adapt, cope and recover from the impacts of natural hazards (Chen et al., 2013; Cutter et al., 2013; Cutter et al., 2008; Filion et al., 2016; Flanagan et al., 2011). With no universally accepted way of formulating linkages between societal and ecological /environmental systems, each discipline has developed various approaches and epistemologies to the concept of vulnerability (Adger, 2006; Alwang et al., 2001; Cutter et al, 2003; Cutter et al., 2008; Fernandez et al, 2016; Flanagan et al, 2018; Fuchs, 2009; Singh, et al 2014; Tapsell et al., 2002). Even with these divergent views, there are several commonalities in the broader theoretical context that vulnerability 1) does not exist in isolation and is driven by societal actions or inactions; and 2) there is a relationship between adaptive capacity (response), shock/stressor (threat) and exposure (risk), however, the various disciplines have various opinions on the causal and functional relationship of these components (Adger, 2006; Alwang et al., 2001; Cutter et al., 2008; Flanagan et al., 2011).

Resilience-thinking principals provide the framework for the operationalization of resiliency strategies and policies that can change how communities prepare, cope, adapt, and recover from pluvial flooding events (Linkov & Palma-Oliveira, 2017; Meerow, Newell, & Stults, 2016; Wardekker, 2018; Yamagata & Sharifi, 2018). However, these strategies and policies must recognize and prioritize the needs of vulnerable populations and places by incorporating environmental justice principles into the decision-making process for the allocation of finite resources (Campanella, 2006; DeAngelis et al., 2019; Dunning & Durden, 2013; Malecha et al., 2019). Even with the best intentions, policies that are envisioned to be race and/or class-neutral can accelerate the ferocity of a disaster and have long-term impacts on the most socially vulnerable population and places if the policies are not race and class-conscious (Bullard et al., 2008; Bullard & Wright, 2009; Chakraborty et al., 2019).

-Chapter 2-

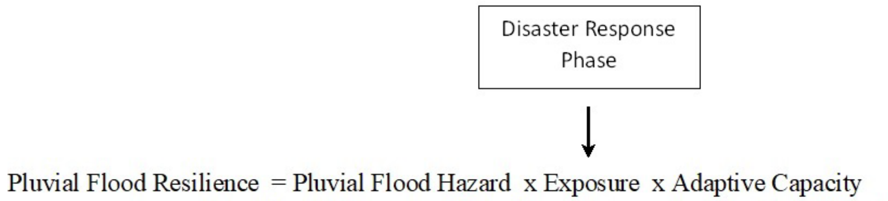
2.0 Urban Drainage Resilience Index System (UDRiS)

UDRiS is a transdisciplinary multi-criteria decision and analysis model that pairs stormwater hydraulic and hydrological analysis principles with EJ and resilience-thinking principles. UDRiS also seeks to recognize and move beyond the impact of past injustices through the continuous assessment and communication of risk. Just like other multi-criteria decision and analysis (MCDA) models, UDRiS allows for the straightforward conveyance of complex information for the engagement of stakeholders and policymakers to increase pluvial flood resilience. MCDA models in general facilitate the sharing and the communication of 1) knowledge, 2) awareness, and 3) the co-creation of solutions.

2.1 UDRiS Theoretical Framework

The theoretical concept of UDRiS is centered around the operationalization of pluvial flood resilience which depicts the interaction of the environment (natural and built) and society's ability to cope, adapt and recover from pluvial flood events. UDRiS is a transdisciplinary communication, analysis, and decision-support model that quantifies the pluvial flood resilience of urban drainage systems. This is achieved through the analysis of urban drainage systems from the perspective of adaptive resilience and EJ principles that are integrally linked to the Disaster Risk Management's disaster cycle. To operationalize and quantitatively measure the level of pluvial flood resilience of populations and places, three basic conditions must be present, 1) pluvial flood hazards (natural condition), 2) exposure (man-made condition), and 3) adaptive capacity (human condition) as shown in Equation-1: Conceptual Equation of Pluvial Flood Resilience.

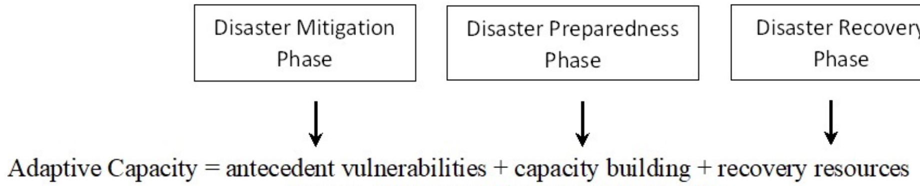
Equation 1: Conceptual Equation of Pluvial Flood Resilience



Pluvial Flood Resilience = Pluvial Flood Hazard x Exposure x Adaptive Capacity

Source: Adaptation of (Alexander, 2012), p.24 and (Flanagan, Barry E et al., 2011), p.1

Equation 2: Conceptual Equation of Adaptive Capacity



Adaptive Capacity = antecedent vulnerabilities + capacity building + recovery resources

Source: Adaptation of Yamagata & Sharifi, 2018

In Equation-1, pluvial flood hazard is suggestive of the occurrence probability of pluvial flooding events which are directly connected to land use policy, urban drainage infrastructure design practices, and heavy rain precipitation events. Events of heavy rains as defined by the United States Environmental Protection Agency (EPA) as precipitation events that substantially exceed what is statistically considered normal for a geographical location that tends to overwhelm the urban drainage infrastructure (EPA, 2016). Climate change research has noted some geographical locations are experiencing increased pluvial flood risk because actual rain events are more frequently aligning and, in some cases, exceeding the synthetic storms use for the design of urban drainage systems (Moore et al., 2016; Butler et al., 2018; NASEM, 2019; Konrad, 2003; Brody et al., 2013).

The exposure element in Equation-1 is suggestive of the temporal and spatial susceptibility of populations and places to unanticipated pluvial flooding events that result in substantial physical and/or economic impacts. These relationships and the natural variability associated with urbanscapes and precipitation events fundamentally expose all populations and places to pluvial flood risk. However, the level of pluvial flood risk populations and places experience can increase or decrease over time unbeknownst to the said population due to upstream urbanization, diminished infrastructure maintenance, and overall system life cycle, which is further influenced and degraded by the effects of climate change (Moore et al., 2016; NASEM, 2019; Konrad, 2003; Brody et al., 2013; Butler et al., 2018).

The adaptive capacity element in Equation-1 and Equation-2 is suggestive of the dynamic interaction between urban drainage infrastructure and society's ability to smoothly transition between long periods of stability and short periods of chaotic change without losing its integrity and functionality. This relationship between urbanscapes, society, and climate change is characterized as a complex dynamic social-ecological environmental system. This system changes at different spatial and temporal scales to achieve and maintain equilibrium. To operationalize this complex interaction, the integration of prevalent adaptive resilience principles are required. UDRiS embraces the overarching adaptive resilience principles of diversity, stability, equity, foresight capacity, resourcefulness, and adaptability. The incorporation of these principles is to 1) lessen potential damages, 2) create evolutionary learning opportunities, and 3) communicate pluvial flood risk (Kim & Lim, 2016; Linkov & Palma-Oliveira, 2017; Yamagata & Sharifi, 2018).

In equation-2, the antecedent vulnerabilities element is suggestive of the precursor socioeconomic characteristics of a population. This predisposition of susceptibility is inherent to all populations but underserved and communities of color are fundamentally more socio-economically vulnerable. This heightened vulnerability stems from years of governmental and societal-sanctioned exclusionary practices such as Jim Crow laws, redlining, urban renewal, segregated housing, exclusionary zoning & annexation practices, gentrification, and urban revitalization (Bullard et al., 2008; Bullard & Wright, 2009; Chakraborty et al., 2019; Hendricks & Van Zandt, 2021). These exclusionary practices tended to push underserved and communities of color to undesirable low-lying land or high-density urban areas with deficient urban drainage infrastructure provisions (American Society of Civil Engineers, 2021; Bullard & Wright, 2009; Heck, 2021; Hendricks & Van Zandt, 2021).

The capacity-building element in equation-2 provides a linkage to the role LGUs and community-based organizations play in providing educational, financial, and technical resources for mitigating the negative socioeconomic impacts of pluvial floods. In this element, the educational, financial, and technical resources are indicative of the actions taken to promote community voice recognition and authentic participatory engagement through a capacity-building framework. These capacity-building frameworks such as VCAPS (Vulnerability, Consequences, and Adaptation Planning Scenarios), the EPA's Collaborative Problems Solving Model, or Community Action Roadmap provide a systematic approach for authentic engagement and collaborative problem-solving (Waller, 2023). The implemented co-created solutions from the capacity-building framework should have tangible outcomes such as equal access to and awareness of flood insurance policies, flood risk awareness, wealth creation, financial literacy, and community economic development opportunities. (Rowel et al., 2012), suggests disseminating information in this manner increases the probability of the implementation of prevention measures, especially for underserved and populations of color that distrust governmental systems.

The recovery resources element in equation-2 represents the level of access to and spatial availability of provisions that allow impacted populations to recover at a reasonable temporal scale. The quality and rapidity of recovery have been identified in hazards and EJ literature as one of the measurements for a successful recovery process. A successful recovery process as described in the literature is one that at a minimum returns the impacted population to pre-pluvial flood levels of functionality both physically and economically at a reasonable temporal scale commensurate with the magnitude of pluvial flood damage. (Bullard & Wright, 2009; Campanella, 2006; Olshansky, 2005). At the neighborhood scale in terms of the boots-on-the-ground impact, there is no significant distinction between disaster-declared and non-disaster-declared pluvial flood events.

Generally, pluvial flood events tend to be very disruptive to the impacted population and usually result in the substantial expenditure of financial resources for recovery efforts. The main differentiation between disaster and non-disaster-declared pluvial flood events at the neighborhood scale is the timing and access to financial resources which heavily influences the quality and rapidity of recovery. With non-disaster-declared pluvial flooding occurring predominately outside of SFHAs where flood insurance is less prevalent, the impacted population has to solely rely on self-produced, familial, and community resources (non-governmental including LGUs) for the recovery efforts (McCarthy, 2011; Olshansky, 2005). This self-dependence usually results in an extended recovery period, which for underserved and communities of color goes beyond the immediate impact of the event. This has generational impacts with the loss of financial resources and opportunities that are never recovered which puts this population in an overall more vulnerable state (Bullard & Wright, 2009; Schlosberg, 2013; Twigg, 2015).

The concept of pluvial flood resilience is further operationalized into a culture of actionable practices by providing linkages to the Disaster Risk Management (DRM) disaster cycle. The DRM disaster cycle is an easy-to-understand four-phase linear operational model for disaster interventions for technical and nontechnical actors. It is a powerful communication tool that provides a linear sequence of interventions at the disaster mitigation, preparedness, response, and recovery phases. However, Twigg (2015) has noted the complexity and fluidity of disasters are not fully conveyed with the DRM disaster cycle model.

The mitigation phase of the disaster cycle is linked to the antecedent vulnerability's element in equation-2. This linkage is used to communicate the level of readiness afforded by activities taken by populations and places to counteract preexisting vulnerabilities. In equation-2, the preparedness phase of the disaster cycle is linked to the capacity-building element. This linkage is used to communicate the level of readiness provided by actions that create a continuous culture of self-improvement, prevention, and readiness due to the uncertainties created by climate change and the dynamic nature of urbanscapes. The response phase of the disaster cycle is linked to the exposure element within equation-1. This linkage is used to communicate the availability of resources during or immediately after pluvial flooding events to safeguard property and lives. The last and final phase of the disaster cycle, the recovery phase is linked to recovery resources in Equation 2. This linkage is used to communicate the available capacity populations have for recovery efforts.

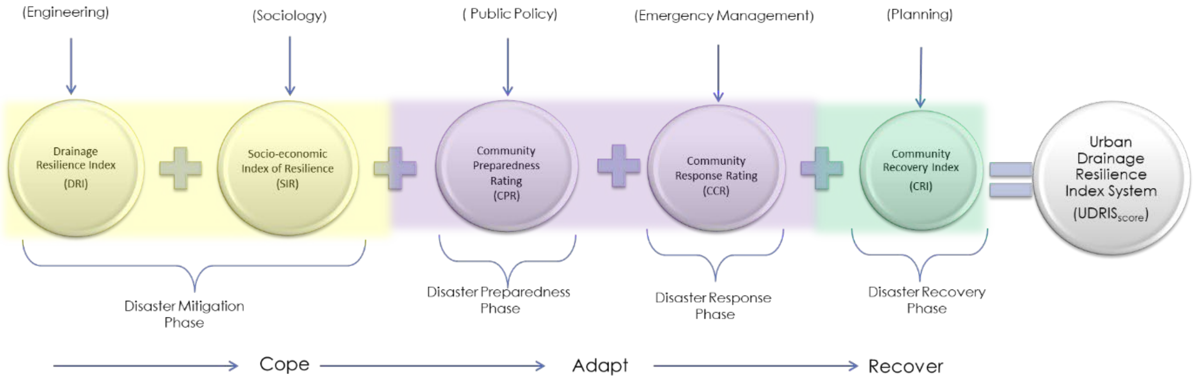
2.2 UDRiS Methodology +Dimensions Construct

UDRiS employs five dimensions as shown in **Figure 1: Bubble Diagram of UDRiS** to comprehensively assess and create a culture of actionable practices as the literature suggests (Fernandez et al., 2016; Hamidi et al., 2020; Karmaoui, 2020). To further emphasize a culture of actionable practices and resiliency principles, the dimensions of UDRiS are linked to the easy-to-understand DRM disaster cycle as a means for communicating disaster preparedness to stakeholders and policymakers within the United States (Waller, 2023). Within each dimension, quantifiable proxy indicators were identified through a Google Scholar search for relevant literature that contained keywords of models, indicators, and indices within the scientific fields of engineering, public policy, emergency management, and planning. Additional keyword searches that included disaster recovery, flood vulnerabilities, social vulnerabilities, community preparedness, and community disaster recovery were performed.

The literature has revealed a core set of proxy indicators that has been replicated in various studies and models that transcend spatial and temporal scales (Cutter et al., 2013; Cutter, et al., 2010; Dunning & Durden, 2013; Flanagan et al, 2018; Tapsell et al., 2002). In addition to the repeated use of a core set of proxy indicators, each study developed a listing of proxy indicators that best correlated to the study purpose and conveyed the author's view of the concept of resilience and/or vulnerabilities. The literature also revealed the unit of analysis of most studies was at the city and county spatial scale. Since UDRiS is a multi-scalar and dimensional model, it required the incorporation of existing proxy indicators or the development of new ones that's available at the component, neighborhood, and city scales.

The core set of proxy indicators that transcends spatial and temporal scales such as age, poverty, and ethnicity was integrated into UDRiS in an effort to stay within the developing framework of proxy indicators. The ability to integrate proxy indicators from previous studies was determined by two factors. The first factor was the availability of data from open sources at the component, neighborhood, or city scale depending on which dimension the proxy indicator resides. The second condition was the ability of the proxy indicator to represent and clearly communicate the relationship of resilience between society, the environment, and pluvial flooding. If these two conditions were not met, the existing proxy or new proxy indicator was disregarded.

Figure 1: Bubble Diagram of UDRiS



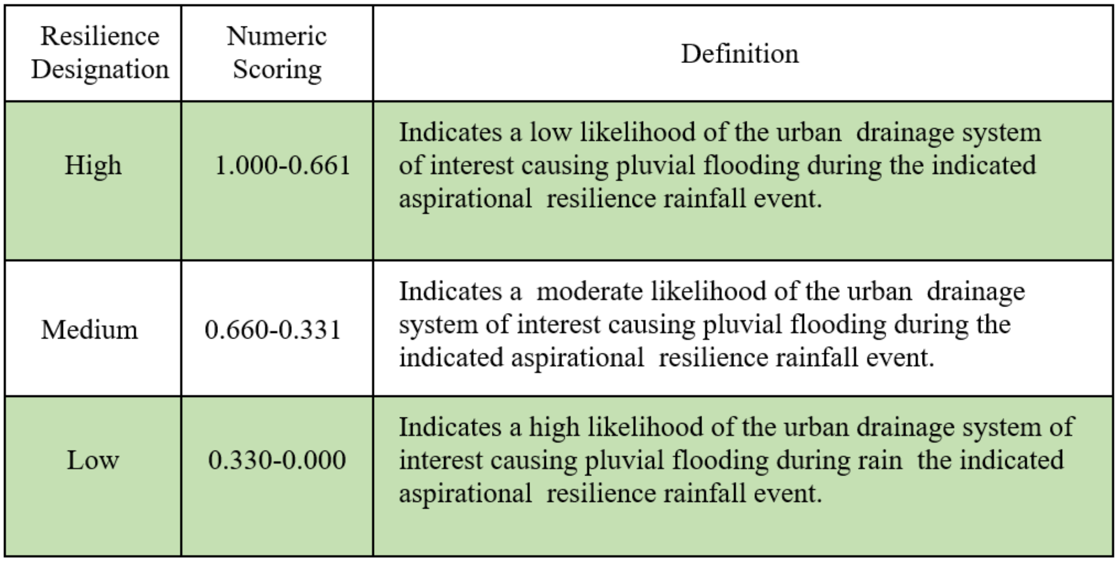
Source: Author

The first dimension, Drainage Resilience Index System (DRI) shown in **Figure 1: Bubble Diagram of UDRiS** provides a component level measurement of an urban drainage system's ability to cause pluvial flooding during the aspirational resiliency rainfall event. The aspirational resiliency rainfall event is defined as the rainfall event that affords a pre-determined level of pluvial flood readiness an LGU aspires to achieve. The goal of the aspirational resiliency rainfall event concept is to reduce the financial impacts and increase the rapidity of recovery efforts of impacted populations without unilaterally instituting more stringent urban drainage infrastructure design requirements. This supports the notion that populations and places have varying degrees of capacity for coping, adapting, and recovering from disasters (Waller, 2023).

The dimensional factors contained within this dimension are a compilation of indicators that are reflective of the culpability of an urban drainage system to cause pluvial flooding at the aspirational resilience rainfall event. The use of proxy indicators for this dimension is not required due to the response/capacity of an urban drainage system is directly quantifiable. The indicators within this dimensional factor are based on a combination of computational outputs from hydraulic and hydrological analysis and condition assessment criteria of urban drainage systems. To communicate the level of culpability and flood risks, the DRI dimension uses an easy-to-understand three-tiered scoring system as shown in **Figure 2: Drainage Resilience Index** Rating Metrics**.**

To promote a culture of preparedness, the resilience designation and numeric scoring systems are designed to provide a transparent measurement that can be utilized to evaluate existing urban drainage systems and the effects of urban drainage improvement upgrades. This numeric score for this dimension is the sum of indicators to provide insight into the culpability of urban drainage systems to cause pluvial flood events which are linked to the resilience designation. The numeric scoring system is mainly a risk communication method used by technical users to communicate the performance and condition assessment of an urban drainage system. The resilience designation is the primary risk communication method to non-technical stakeholders to convey the likelihood of an urban drainage system to cause pluvial flooding.

Figure 2: Drainage Resilience Index Rating Metrics



Resilience Designation	Numeric Scoring	Definition
High	1.000-0.661	Indicates a low likelihood of the urban drainage system of interest causing pluvial flooding during the indicated aspirational resilience rainfall event.
Medium	0.660-0.331	Indicates a moderate likelihood of the urban drainage system of interest causing pluvial flooding during the indicated aspirational resilience rainfall event.
Low	0.330-0.000	Indicates a high likelihood of the urban drainage system of interest causing pluvial flooding during rain the indicated aspirational resilience rainfall event.

The second dimension, the Socio-economic Index of Resilience (SIR) shown in **Figure 1: Bubble Diagram of UDRiS** provides a comparative measure of the socioeconomic predisposition of populations at the census tract level to shocks in the socio-economic system without the added burden of a pluvial flooding event. EJ and hazards literature has empirically linked the capacity for populations to provide hazard minimization (pre-disaster condition) and recovery (post-disaster condition) to the antecedent socio-economic capacity (Oliver-Smith et al., 2012; Oulahen et al., 2019; Tierney, 2006). Underserved and communities of color are fundamentally more socioeconomically susceptible to the socio-economic shocks and the impacts of pluvial flooding as a result of systematic governmental and non-governmental sanctioned injustices (Bullard & Wright, 2009; Chakraborty et al., 2019; Hendricks & Van Zandt, 2021; Hendricks, 2017). The Socio-economic Index of Resilience dimension within UDRiS is designed to identify populations in need of capacity-building resources that will holistically increase the resilience of the population to withstand shocks in the socio-economic system.

The dimensional factors within the SIR dimension are comprised of neighborhood scale proxy indicators that are suggestive of the social-economic susceptibility of populations due to systemic systems of bias and injustices that inherently reduces their resiliency capacity (Campanella, 2006; Oliver-Smith et al., 2012; Tierney, 2006). To identify populations in need of capacity-building resources, SIR uses an easy-to-understand three-tiered scoring system as shown in **Figure** 3: Socio-economic Index of Resilience Metrics**.** This scoring system is the sum of proxy indicators as shown in **Figure 26:UDRiS Dimensions + Proxy Indicators**. The selected indicators within UDRiS as suggested by the literature provide insight into the antecedent socio-economic conditions at the census tract level for targeted capacity-building and community economic development resources. Community economic development is the holistic improvement of a neighborhood or in this case, a census tract through the starting of new businesses and employment opportunities to improve the economic conditions for the constituents of that area (McFarlane, 1999).

Figure 3: Socio-economic Index of Resilience Metrics

Resilience Designation	Numeric Scoring	Definition
High	1.000-0.661	Indicates a significant amount of coping and adaption capacity due to the limited presents of pre-existing socio-economic barriers and stressors before the introduction of non-disaster declared pluvial flooding events.
Medium	0.660-0.331	Indicates an average coping and adaption capacity due to the pre-existing socio-economic stressors before the introduction of non-disaster declared pluvial flooding events.
Low	0-0.330	Indicates limited coping and adaptation capacity due to pre-existing socio-economic stressors before the introduction of non-disaster-declared pluvial flooding events.

The third dimension, the Community Preparedness Rating (CPR) as shown in **Figure 1: Bubble Diagram of UDRiS** provides a measure of community social bonds and the influence of adopted governmental policies for fostering a culture of pluvial flood preparedness. The first set of dimensional factors is comprised of proxy indicators derived from categories within the FEMA National Flood Insurance Program Community Rating System. Under the Community Rating System (CRS), communities are provided discounted flood insurance premiums for their work in developing a comprehensive flood hazard management program that provides protections above the Federal minimum requirements (Atreya, 2016; Federal Emergency Management Agency, (FEMA), 2017b).

The second aspect of the CPR dimension reflects the influence risk communication and social networks has on bolstering a culture of disaster prevention and preparedness as noted in the literature (Haer et al., 2016; Lundgren & McMakin, 2018; Santos, 1990). The dimensional factors within this dimension are suggestive of the community-level pathways for disseminating disaster prevention information from trusted sources. The scoring metric for CPR is an easy-to-understand three-tiered scoring system as shown in **Figure 4: Community Preparedness Rating Metric**. This scoring metric provides insight into the community level of preparedness afforded by pluvial flood policies and the connectedness of the social bonds at the city scale.

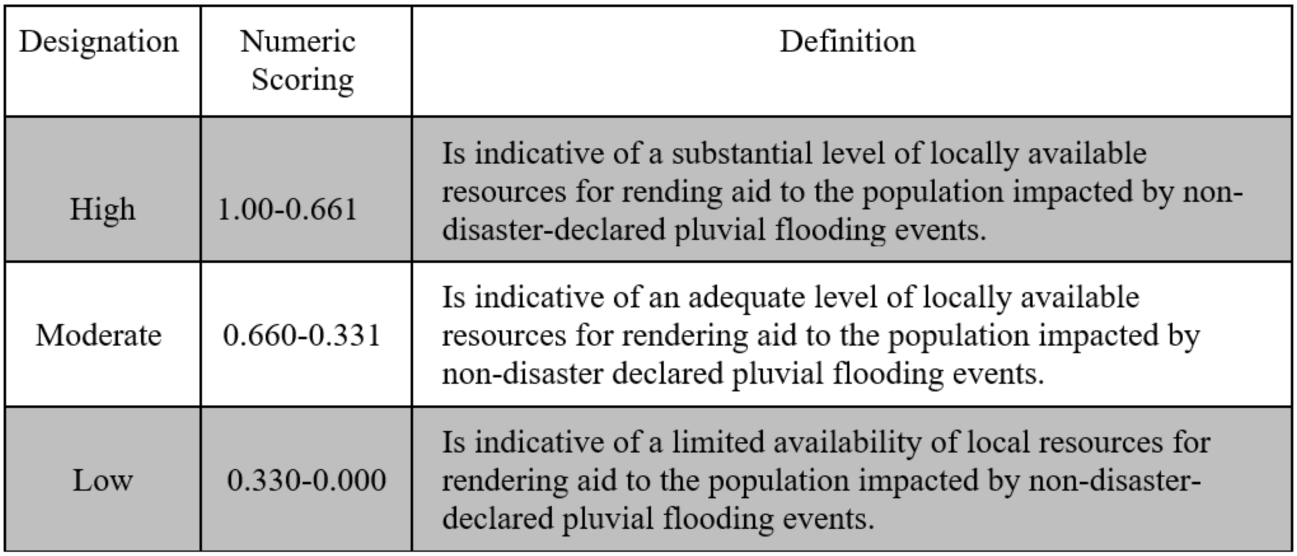
Figure 4: Community Preparedness Rating Metric

Designation	Number Scoring	Definition
High	1.000-0.661	Indicates a significant number of community level risk communication pathways and policies that creates a culture of prevention and preparedness for non-disaster-declared pluvial flooding events.
Moderate	0.660-0.331	Indicates a moderate number of community level risk communication pathways and policies that creates a culture of prevention and preparedness for non-disaster-declared pluvial flooding events.
Low	0.330-0	Indicates a limited number of community level risk communication pathways and policies that creates a culture of prevention and preparedness for non-disaster-declared pluvial flooding events.

Dimension four, Community Response Rating (CRR) as shown in **Figure 1: Bubble Diagram of UDRiS** is indicative of a community's ability to respond during and immediately after non-disaster declared pluvial flooding events. This is characterized within UDRiS as the sum of weighted city scale dimensional factors as shown in **Figure 26:UDRiS Dimensions + Proxy Indicators**. Within this dimension, there are two aspects, the first noting the LGU's ability to render aid during and immediately after a pluvial flooding event. This is acknowledged with proxy indicators that are representative of the geographic distribution of resources, personnel, equipment, and training provided to LGU's Fire Rescue Department.

The second aspect of the CRR dimension is the ability of a community to self-organize to render aid. The hazard and EJ literature have identified a strong correlation between social bonds and the ability of a community to organize and provide aid at the neighborhood scale (Bullard & Wright, 2009; Campanella, 2006; Forrest et al., 2020). To acknowledge the correlation identified in the literature, UDRiS uses the number of community-faith-based organizations as a surrogate for measuring the social bonds and the interconnection within a community. This distinction is critically important because the rendering and timing of both governmental and non-governmental aid during and immediately after a pluvial flooding event substantially impacts the quality and rapidity of the recovery efforts (Olshansky, 2005). The community response rating (CRR) is communicated through a three-tiered sliding scale as shown in **Figure 5:Community Response Rating Metrics**. This numeric and classification system is used to describe, identify, and communicate the anticipated level of community response capacity.

Figure 5:Community Response Rating Metrics



Designation	Numeric Scoring	Definition
High	1.00-0.661	Is indicative of a substantial level of locally available resources for rending aid to the population impacted by non-disaster-declared pluvial flooding events.
Moderate	0.660-0.331	Is indicative of an adequate level of locally available resources for rendering aid to the population impacted by non-disaster declared pluvial flooding events.
Low	0.330-0.000	Is indicative of a limited availability of local resources for rendering aid to the population impacted by non-disaster-declared pluvial flooding events.

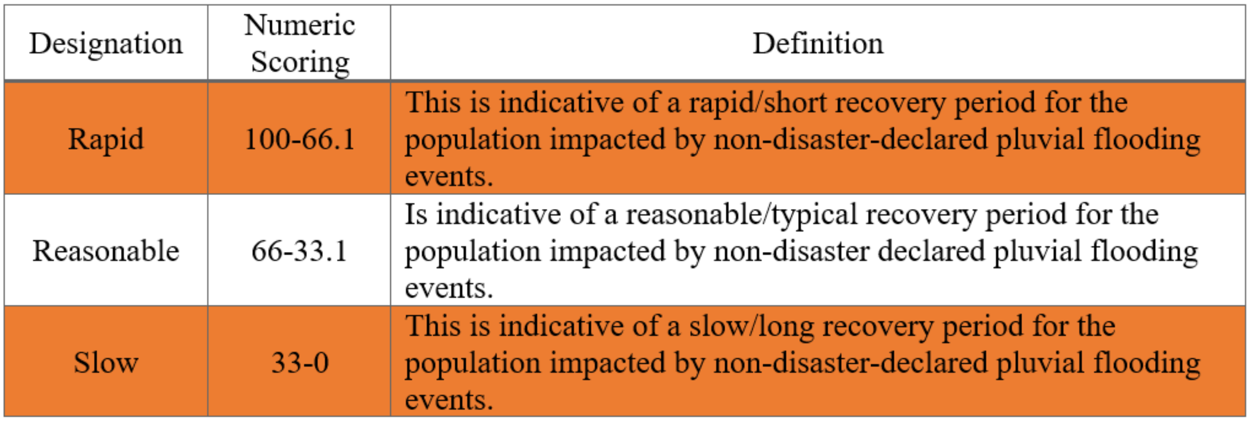
The fifth and final dimension of UDRiS, the Community Recovery Index (CRI) is the weighted sum of census tract level proxy indicators as shown in **Figure 26:UDRiS Dimensions + Proxy Indicators**. The selected proxy indicators represent the available capacity impacted populations have for recovery efforts preceding a pluvial flooding event. This set of indicators is employed to provide insight into the anticipated duration of the recovery efforts. This is achieved by providing a comparative assessment of the available socio-economic capacity of the population with the anticipated pluvial flood depth to damage relationship.

This insight is powerful because it identifies spatial locations and populations where additional resources are needed to increase the rapidity of the recovery efforts. Within UDRiS this can be achieved in one of two ways based on the anticipated pluvial flood depth to damage relationship. The first technique is to provide urban drainage infrastructure improvements by the integration of green infrastructure to provide peak-flow attenuation or the replacement of deficient grey infrastructure. This technique provides a reduction to the flood depth to damage relationship at the pluvial flooding location which increases the resilience and rapidity of the recovery efforts at that location.

The second technique is to provide locally earmarked disaster funds in instances where the benefit-to-cost ratio of the project location is less than 1. The benefit is calculated within UDRiS using the anticipated number of pluvial flooding events multiplied by the anticipated flood damage cost over the useful life of the urban drainage system. The cost aspect of the benefit-to-cost ratio in UDRiS is currently derived from the anticipated construction cost to replace grey urban drainage infrastructure with a larger size, however, this input could be easily modified for the input of green infrastructure construction and maintenance cost. In addition to the benefit-to-cost ratio, the locally earmarked disaster funds can be utilized to provide a comparative analysis for providing aid to vulnerable populations and places instead of providing immediate infrastructure upgrades.

Using it in this manner provides a voice to the voiceless in an effort to increase the resilience and rapidity of the recovery efforts for vulnerable populations and places when infrastructure replacement appropriations are not imminent. The community recovery rating is communicated through a three-tiered sliding scale as shown in **Figure 6: Community Recovery** Index Metrics. This rubric communicates the anticipated recovery rate of the impacted population from pluvial flooding based on the flood depth to damage and the socioeconomic characteristics that would impact these populations and places from recovering from pluvial flood events.

Figure 6: Community Recovery Index Metrics



Designation	Numeric Scoring	Definition
Rapid	100-66.1	This is indicative of a rapid/short recovery period for the population impacted by non-disaster-declared pluvial flooding events.
Reasonable	66-33.1	Is indicative of a reasonable/typical recovery period for the population impacted by non-disaster declared pluvial flooding events.
Slow	33-0	This is indicative of a slow/long recovery period for the population impacted by non-disaster-declared pluvial flooding events.

The weighted sum of the five dimensions discussed previously makes up the $\text{UDRiS}_{\text{score}}$ which indicates the pluvial flood resilience of the infrastructural system. This scoring system is comprised of a numerical and alphanumeric grading scale based on the depth-to-damage ratio of flood waters to structures and the available recovery capacity of the impacted population. The $\text{UDRiS}_{\text{score}}$ translates into a five-band (A, B, C, D, F) academic alphanumerical letter grading scale with a color-coding scheme as shown in **Figure 7: UDRiS Scoring Rubric.** This grading and color-coding scheme is then applied to each segment of piping to communicate the resilience of the infrastructural system and the population that would be impacted if pluvial flooding was to occur.

Figure 7: $\text{UDRiS}_{\text{Score}}$ Rubric

Letter Grade Designation	Numeric Scoring	Definition
A	100-90	This designation is indicative of a high level of resiliency. There is a low risk of the urban drainage system causing pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event.
B	89-80	This designation is indicative of a moderately-high level of resiliency. There is a low risk of the urban drainage system causing pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event.
C	79-70	This designation is indicative of a moderately-low level of resiliency. There is a moderate risk of the urban drainage system causing pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event.
D	69-60	This designation is indicative of a low level of resiliency. There is a substantial risk of the urban drainage system causing pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event.
F	59-0	This designation is indicative of a very low level of resiliency. There is a high risk of the urban drainage system causing pluvial flooding that significantly damages structures or property during the aspirational resiliency rainfall event.

2.3 Data Normalization

The raw data sets collected for the proxy indicators in their native form are expressed at various scales and units of measurement. To transform the raw data into a common mathematical vernacular, UDRiS uses the z-score methodology for data normalization (Asadzadeh et al., 2017; Karmaoui, 2020). The z-score scaling methodology which statistically describes the data relationship to a normal distribution curve is the second most common normalization method for the development of comparative indices (Bakkensen et al., 2017; Cutter et al., 2013; Cutter et al., 2014; Peacock, 2010). In this method, as shown in **Equation 2: Z-Score Normalization**, the indicator of interest, x_i, is subtracted from the sample mean value μ and divided by the range is the sample standard deviation σ of the indicator of interest, which results in the normalized value ($v_i{}'$) of the indicator of interest.

Equation 2: Z-Score Normalization

$$v_i{}' = \frac{x_i - \mu}{\sigma}$$

The z-score output values (v_i') represent the number of standard deviations the native value is from the mean and provides additional explanatory power to the proxy indicators within UDRiS. This allows the critical examination of how the proxy indicators at the census tract level compare to the mean city scale value. In general, this method is sensitive to the sample size and value ranges of the data by which the sample mean, and sample standard deviation are calculated (Films Media Group, 2010a; Films Media Group, 2010b). The sensitivity of sample size is limited with UDRiS due to the data compiled and used are from all the census tracts within the entire municipal jurisdictional boundary.

2.4 Weights

The literature of Hamidi et al., 2020 and Moghadas et al, 2019 identified several methodologies for establishing weights to proxy indicators which are classified into two principal categories, equal weight and unequal weight. UDRiS uses both simple or equal weighting methods in the computation of dimensional factors that are mathematically summed to generate UDRiS's dimensions. The literature suggests the use of equal weighting to minimize the introduction of subjectivity and bias as was done for many previous models (Cutter et al., 2013;

Peacock, 2010; Tapsell et al., 2002). In addition to reducing subjectivity and bias, the use of simple weighting aids in the transferability of the model due to the varying perspectives of resilience.

In the equal weighting method, each of the proxy indicators has an equal influence in the computation of the dimension index or rating as shown in **Equation 3: Dimensional Factors Equal Weighting.**

Equation 3: Dimensional Factors Equal Weighting

$$\mathrm{D}f_i = \frac{PI_1 + PI_2 + PI_3 \ldots PI_n}{n}$$

In **Equation 3: Dimensional Factors Equal Weighting**, $\mathrm{D}f_i$ is the generalized nomenclature that represents dimensional factors within each UDRiS Dimension; *PI* is the generalized nomenclature for the proxy indicators within each dimension factor. *n* is the number of proxy indicators.

Equation 4: UDRiS Dimensions Equal Weighting

$$\mathrm{D}_i = \frac{Df_1 + Df_2 + Df_3 \ldots Df_n}{n}$$

In **Equation 4: UDRiS Dimensions Equal Weighting,** D_i is the generalized nomenclature that represents (DRI, SIR, CPR, CRR, and CRI); D*f* is the generalized nomenclature for the dimensional factors within each UDRiS dimension; *n*, is the number of dimensional factors.

UDRiS also utilizes unequal weighting in the final computation of the $\text{UDRiS}_{\text{Score}}$ which is the mathematical sum of the five weighted UDRiS dimensions. Since UDRiS is multi-dimensional with various units of analysis, the unequal weighting scheme is applied to provide more weight to the dimensions that are primarily at the neighborhood scale as the default condition. However, the unequal weighting scheme can also be used to reflect how a community views resilience with the assignment of weights to the various dimensions. However, caution should be used to not heavily weight the city-level dimensions (Community Preparedness Rating [CPR] & Community Recovery Rating [CRR]) which would change the unit of analysis of the model.

Equation 5: UDRiS $_{\text{Score}}$ Unequal Weighting

$$UDRIS_{SCORE} = (w_1 * DRI) + (w_2 * SIR) + (w_3 * CPR) + (w_4 * CRR) + (W_5 * CRI)$$

In **Equation 5: UDRiS $_{\text{Score}}$ Unequal** Weighting, w$_i$ is the generalized nomenclature that represents the weight assigned to each of UDRiS's dimensions; DRI, SIR, CPR, CRR, and CRI are the dimensions within UDRiS; UDRiS $_{\text{score}}$ represents the numeric and letter grade output. With the unequal weight scheme, the total sum of the weights must equal 1 and the assigned individual weights must be greater than zero to not exclude any of the dimensions.

To calculate the composite UDRiS $_{\text{score}}$ for an identified project, the weighted mathematical sum of the UDRiS $_{\text{score}}$ for the individual drainage system segments. The segments are weighted based on the linear footage of piping within each segment.

Equation 6: Composite UDRiS $_{\text{score}}$

$$Composite\ UDRIS_{SCORE} = \left(p_{seg\ 1} * UDRIS_{score\ (seg\ 1)}\right) \ldots . + \left(p_{seg\ n} * UDRIS_{score\ (seg\ n)}\right)$$

In **Equation 6: Composite UDRiS $_{\text{score}}$**, p is the generalized nomenclature that represents the length of pipe between drainage structures; UDRiS $_{\text{score (seg n)}}$ represents the numeric and letter grade output for the section of pipe between drainage structures.

2.5 Directionality

The proxy indicators assembled to generate the UDRiS dimensional factors are assigned negative or positive directionality based on the prevailing literature (Cutter et al., 2013; Moghadas et al., 2019). The literature suggests the directionality of the proxy indicators should correlate to their ability to either increase or decrease resilience. UDRiS dimensional factors uses a systematic approach for associating positive directionality with indicators that increase resilience and negative directionality with indicators that decrease resilience.

3.0 UDRiS beta version Testing & Validation

UDRiS was beta tested in April of 2022 during the performance of a Flood Study for a 1.59-acre multi-family residential property in Greensboro, North Carolina. This property had previously experienced several cases of documented pluvial flooding on August 24, 2019, that resulted in significant property damage that impacted the residence. In addition to the 2019 pluvial flooding event, a heavy precipitation event occurred on March 31, 2022, that produced 1.36 inches of rain within a 24-hour period. This resulted in pluvial flooding at the testing site that was documented by the study author. The findings of the flood study and the results of UDRiS concluded pluvial flooding was caused by deficient urban drainage infrastructure.

3.1 Precipitation Characterization of Confirming Observations

On August 24, 2019, Greensboro, North Carolina experienced a heavy rain-extended duration/high-intensity event that produced 1.22 inches of rain over a 24-hour period. Within this 24-hour period, there were six consecutive 15-minute periods of heavy rainfall (0.11, 0.15, 0.12, 0.12, 0.12, and 0.09 inches) according to the Greensboro Piedmont International Airport rain gauge data. This resulted in documented pluvial and riverine flooding at various locations around the city. In the days preceding the August 24th heavy rain event, Greensboro, North Carolina experienced a total of 1.12 inches of rain from August 19 thru August 23, 2019. The elevated water levels in riverine systems were further exasperated by the 1.22 inches of rain received on August 24, 2019.

On March 31, 2022, Greensboro, North Carolina experienced a heavy rain-extended duration/high-intensity rainfall event that produced 1.36 inches of rain over a 24-hour period. According to the South Buffalo Creek at US 220 Rain Gage Data this rain event had four consecutive 15-minute periods of heavy downpours (0.08, 0.16, 0.44, and 0.41 inches) that resulted in pluvial flooding documented by the authors at the test site. This visual observation along with the August 2019 event confirmed the output of UDRiS and the findings of the traditional flood study.

3.2 Beta Test Data Collection

The data utilized for the beta test was assimilated from multiple open data sources. The beta test utilized data from the United State Census Bureau, NOAA's Hydro-meteorological Design Studies Center, USGS National Water Dashboard, and NOAA's National Center for Environmental Information for the various proxy indicators. The socio-economic data was compiled from the 2010 US Census Bureau's Factfinder and Quickfacts databases for each census tract within the municipal boundaries of the City of Greensboro, North Carolina. Precipitation data was assimilated from NOAA climatology data and the National Water Dashboard for 24-hour and 15-minute rainfall data. The rainfall data range analyzed for the beta testing was from February 5, 2019, to April 10, 2022. The spatial location and elevations of the on-site urban drainage infrastructure were collected using traditional land surveying methods for the test of the UDRiS $_{\text{beta version}}$.

3.3 Beta Test Methodology

The private on-site stormwater conveyance infrastructure was assessed utilizing standard hydrologic and hydraulic methodologies to establish the peak elevation-frequency relationships for pluvial floods for the aspirational rainfall event. Due to various ideologies and definitions of resilience, the beta test utilized the 1% Annual Chance Rain event as the aspirational resilience rainfall event to coincide with the Federal Emergency Management Agency (FEMA) regulated 1% Annual Chance of Flooding floodplain. The socio-economic data for each census tract within the entire jurisdictional boundary of the City of Greensboro was utilized for the beta test and normalized using the z-score methodology as described in 2.3 Data Normalization section of this paper.

The beta test utilized the weighting scheme and values built into UDRiS, however, the dimensional factors for Community Preparedness rating (CPR) and Community Response rating (CRR) were still under development during testing. Since these dimensions were still under development when the Beta test was performed, a default value of 1 was assigned to each of the dimensions. It is presumed these dimensions would have little impact on the results since they are city-scale dimensions that are applied uniformly to all urban drainage systems within the municipal boundaries of the City of Greensboro, North Carolina.

The testing of UDRiS consisted of two scenarios that utilized different assessment thresholds for the UDRiS $_{\text{score}}$ for each segment of urban drainage infrastructure. The first scenario utilized the lowest finished floor elevation of the structure (building) adjacent to the urban drainage infrastructure as the indicating benchmark in the calculations of the UDRiS $_{\text{score}}$. The second scenario utilized the elevation of the ground adjacent to the urban drainage structure as the benchmark in the calculation of the UDRiS $_{\text{score}}$. The results from each of the UDRiS scenarios were assessed against the following, 1) results of the traditional flood study; 2) the March 2022 pluvial flood event observed by the author; and 3) the information obtained from the owner regarding the 2019 pluvial flooding event. It is critically important to note, the second scenario was developed as a follow-up to the findings from scenario 1 and the additional information obtained from the property owner. The UDRiS $_{\text{score}}$ was calculated for each segment of urban drainage infrastructure in each scenario for the ranking and identification of deficient infrastructure.

3.4 UDRiS $_{\text{beta version}}$ Testing Results- Scenario 1

UDRiS $_{\text{beta version}}$ scenario 1 analysis was performed using the elevation of the adjacent structure (building) and the 1% Annual Chance Rain Event as the aspirational resiliency benchmark. The results of this scenario indicated a composite UDRiS $_{\text{score}}$ of 81.8, Level B for the site's private urban drainage network. This scoring is reflective of the urban drainage infrastructure having a high degree of capacity available to cope, adapt and recover from heavy rain events (both extended duration and high intensity) that produce ensuing pluvial flooding. However, the Drainage Resilience Index (DRI) dimension of UDRiS identified capacity deficiencies of flumes 1 & 2 as shown in **Figure 8: Scenario 1 Using UDRiS** $_{\text{Beta Version}}$.

Figure 8: Scenario 1 Using UDRiS $_{\text{Beta Version}}$

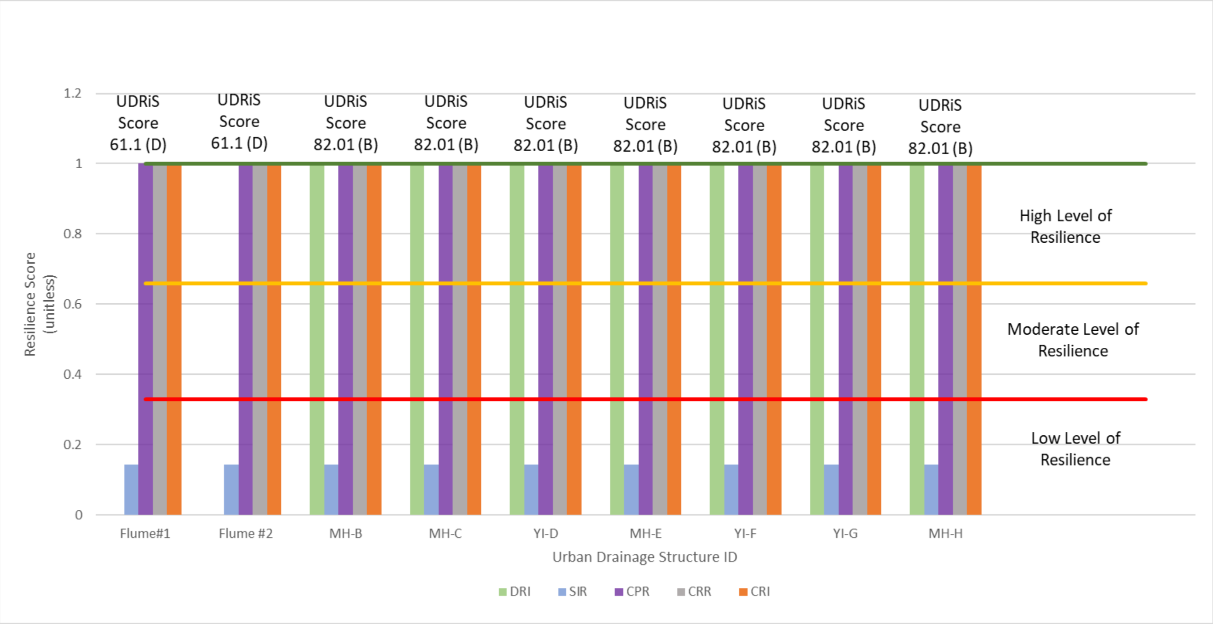
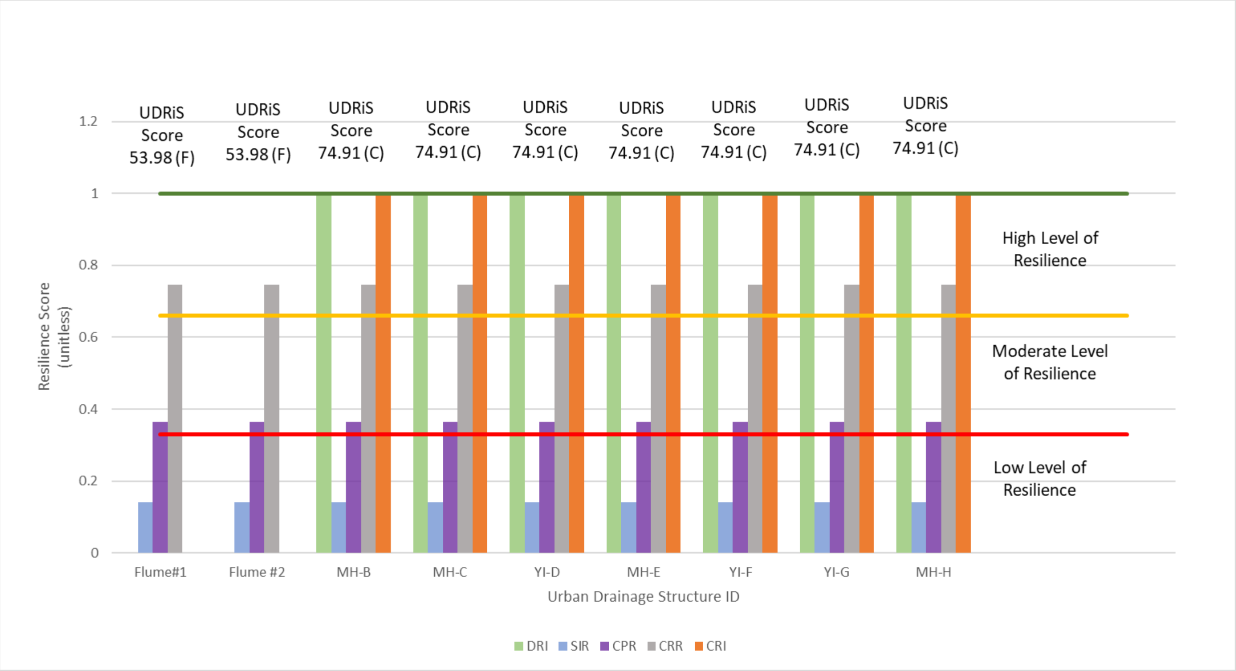


Figure 8: Scenario 1 Using UDRiS Beta Version provides a comparative analysis of the UDRiS dimensions and the UDRiS$_{\text{score}}$ results for the private urban drainage system. As noted in this figure, a drainage resilience index (DRI) dimension resilience score of 0.0 was calculated for flumes 1&2 due to the capacity deficiencies discovered during this scenario. However, the calculated UDRiS$_{\text{score}}$ for the flumes that incorporates the influence of the five UDRiS dimensions was 61.01. This indicates a low level of resilience for these segments of urban drainage infrastructure due to the capacity deficiencies, but the pluvial flooding is not of a magnitude that would subject structures and their contents to floodwaters as noted with the high resilience level of the community resilience index (CRI).

In this scenario, the community resilience index (CRI) score of 1 indicates the population has a high level of resilience and can rapidly recover from pluvial flood events. This is only due to the flood waters not reaching a height that would endanger and cause structural (building) property damage. This finding resulted in additional critical inquiry into the capabilities of UDRiS which was explored with the performance of scenario 2 that will be discussed later in this paper. Both scenarios utilized the UDRiS $_{\text{beta version}}$ algorithm with the community preparedness rating (CPR) and the community response rating (CRR) dimensions that were still under development and not calculated by that algorithm during the testing of UDRiS $_{\text{beta version}}$.

The socio-economic index of resilience (SIR) dimension for the test site as calculated by UDRiS was 0.143. The SIR provides insight into the antecedent socio-economic factors of the population that resides within the test site census tract and the capacity available for the recovery efforts. The SIR score of 0.43 indicates a low level of resiliency and identifies this population (census tract level) as a candidate location for the deployment of capacity-building resources. In both scenarios, the SIR dimension score was unchanged due to its linkage to the spatial location of urban drainage infrastructure.

Figure 9: Scenario 1 Results Using UDRiS $_{\text{Version 2}}$



As shown in **Figure 9: Scenario 1 Results $_{\textbf{Using UDRiS Version 2}}$**, the DRI, SIR, and CRI dimensional scores remained the same between the UDRis $_{\text{beta version}}$ and the UDRiS $_{\text{version 2}}$. The only modifications made to the algorithm between the two versions were the incorporation of the completed community preparedness (CPR) and community response (CRR) rating dimensions. The CPR and CRR are city-scale proxy indicators that are applied equally to all census tracts within the jurisdictional boundary. The City of Greensboro's CPR and CRR as calculated by UDRiS was 0.365 and 0.747 respectively.

The calculated value of 0.365 for the CPR indicates a moderate number of community-level risk communication pathways and policies that create a culture of prevention and preparedness. The CRR value of 0.747 indicates an average level of response capabilities during and after a pluvial flood event. Adjusting the initial assumption that utilized the maximum value of 1 for these dimensions resulted in a reduction of the resilience score for each of the infrastructure segments and the overall site composite UDRiS $_{\text{score}}$ for the test site.

The resilience score for flumes 1 & 2 decreased by 13% with the incorporation of the calculated CPR and CRR. This resulted in an overall lower alpha-numeric designation with the letter grade designation downgraded from D to F. The remaining infrastructure segments had a 9% reduction in the numeric designation, however, the letter grade designation remained at level B. The composite site UDRiS $_{\text{score}}$ was also affected by the incorporation of the CPR and CRR which caused a 10% reduction in the numerical designation and the downgrading of the site letter grade from a B to a C. During the recalculation of the UDRiS $_{\text{score,}}$ it was noticed the results for flumes 1 &2 were a better representation of deficiencies and more intuitively communicated the level of urgency for performing corrective actions.

3.5 UDRiS $_{\text{Beta Version}}$ Testing Results-Scenario 2

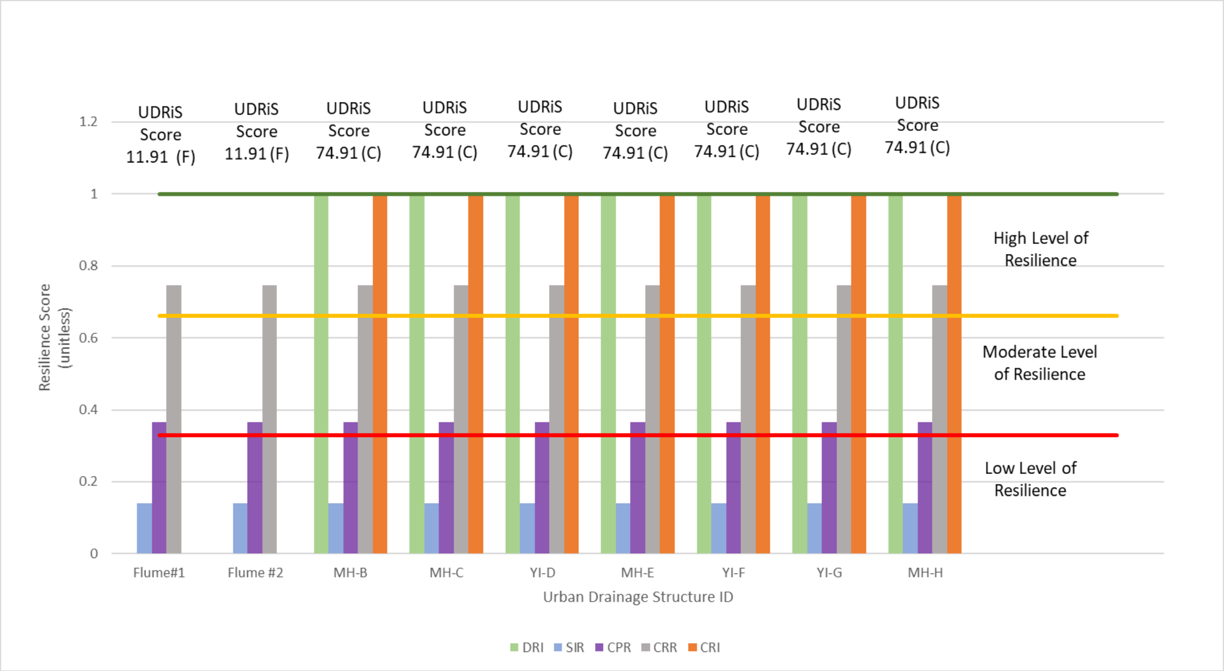
As stated previously, scenario 2 was developed as a follow-up to the scenario 1 results that reveal that pluvial flooding was not of a magnitude that impacted structures. However, scenario 1 revealed capacity deficiencies with flumes 1 & 2 which were cause for additional study to determine the effects of changing the benchmark elevation on the UDRiS $_{\text{score}}$. Additionally, the study was also warranted due to new information provided by the owner regarding damage to vehicles caused by flood waters. In scenario 2, the elevation of the ground adjacent to each urban drainage structure and the 1% Annual Chance of Rain event was utilized as the aspirational resiliency benchmark.

Figure 10: Scenario 2 Results Using UDRiS beta version

The results of the UDRiS beta version for Scenario 2 indicated a slightly lower composite site UDRiS score of 81.3, Level B for the site's private urban drainage infrastructure than in Scenario 1. The resulting composite site UDRiS score is still reflective of the urban drainage infrastructure and the impacted populations having a high degree of capacity available to cope, adapt and recover from the rain events that cause pluvial flooding. As identified with this analysis, pluvial flooding events again occurred at isolated locations within a parking area due to capacity deficiencies of flumes 1 & 2. However, the results of scenario 2 call attention to the floodwater inundation of vehicles within the parking lot. The impact of the floodwaters on this population is reflected in the lower UDRiS beta version dimensional resilience scores for flumes 1&2 as shown in **Figure 10: Scenario 2 Results Using UDRiS beta version.**

In **Figure 11:Scenario 2 Results Using UDRiS Version 2**, the DRI, SIR, and CRI dimensional scores remained the same between the UDRiS beta version and UDRiS version 2. The only significant modification made to the computational aspect of the algorithm between the two versions for this scenario was the incorporation of the completed community preparedness (CPR) and community response (CRR) rating dimensions. As with scenario 1, the calculated value of 0.365 and 0.747 for the CPR and CRR respectively, was integrated into the calculation of the UDRiS score. This resulted in a reduction of the resilience score for each of the infrastructure segments and the overall site composite UDRiS score for the test site.

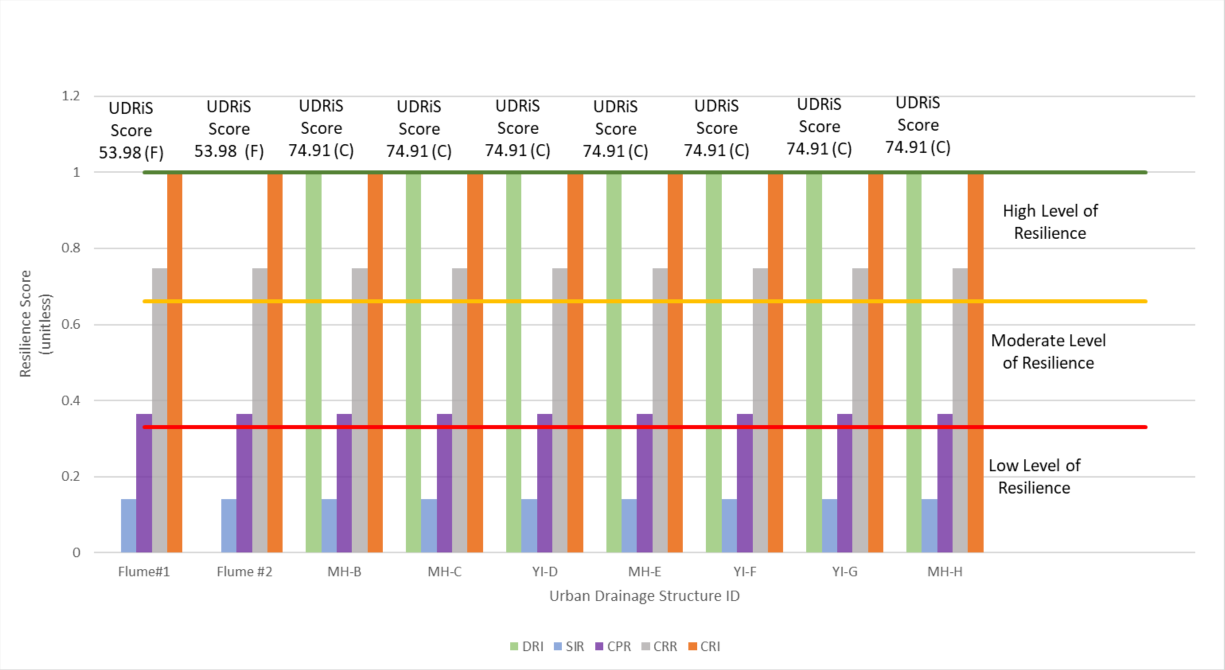
Figure 11:Scenario 2 Results Using UDRiS $_{\text{Version 2}}$



When comparing the output of UDRiS $_{\text{version 2}}$ for scenario 1 and scenario 2, the DRI resiliency score for both flumes 1 & 2 was reduced by 78% when the resilience benchmark is taken at the ground level adjacent to the urban drainage system. This reduction is caused by the floodwater impact on personal property (vehicles) within the parking lot. The recalculated CRI resiliency score was reduced to a value of 0.0. This indicates the impacted population would have a slow recovery period without an external intervention with scenario 2.

UDRiS $_{\text{beta version}}$ and UDRiS $_{\text{version 2}}$ estimated approximately thirty-four thousand dollars ($34,000.00) of flood damage associated with the flooding caused by flumes 1 &2 within the parking lot. The remaining on-site urban drainage structures in this scenario were not impacted by changes to the resilience benchmark elevation. This is due to the water elevation remaining within the drainage system during the aspirational rainfall event. The estimated damage cost component of UDRiS was verified with the August 2019 pluvial flood event. This event resulted in a goodwill payout of approximately $27,000.00 (in 2022 dollars) for 12 vehicles that were damaged by flood waters as noted by the property owner. **Figure 12:Scenario 2 Results Using UDRiS $_{\text{Version 2}}$ with Financial** Assistance demonstrates how the UDRiS$_{\text{score}}$ increases when financial assistance is provided to the impacted population to increase the rapidity of the recovery efforts.

Figure 12:Scenario 2 Results Using UDRiS Version 2 with Financial Assistance



3.6 UDRiS beta version Modifications

UDRiS beta version performed as anticipated and during the testing process which did not reveal any major defects within the algorithm. The only required major modifications to the mathematical computations of the algorithm was the completion of the CPR and CRR Dimensions. Most of the modifications made to UDRiS after the beta testing were improvements to the graphical user interface (GUI) and the incorporation of additional informational output for the analysis of the results. **Figure 13: UDRiS Updates based on Beta Testing Results** identify the modifications made to UDRiS including the completion of the CPR and CRR dimensions.

Figure 13: UDRiS Updates based on Beta Testing Results

- Completed the development of the CPR and CRR dimensions.
- Added weighting to composite site UDRiS $_{\text{score}}$
- Incorporated infrastructure replacement cost.
- Created user inputs for Flood Damage Assistance Funds on the graphical user interface (GUI)
- Incorporated additional settings for drainage maintenance on the user inputs on the GUI.

The most notable improvement to UDRiS was the incorporation of the Flood Damage Assistance Funds user input. This function was designed to reflect the influence external financial assistance would have on the CRI score. The incorporation of this function identifies the anticipated amount of financial assistance the impacted population would require for increasing the speed and recovery capacity from a singular pluvial flooding event. The application of this function is demonstrated in **Figure 12:Scenario 2 Results Using UDRiS $_{\text{Version 2}}$ with Financial Assistance**.

In addition to its utilization for determining the impact of external financial assistance on the CRI score. This function is also used when the benefit-to-cost ratio of the proposed improvements is less than 1. This indicates the replacement cost of the urban drainage system is substantially greater than the magnitude of flood damage at the aspirational rainfall event. This allows the algorithm's user to set-aside recovery assistance funds to aid the impacted population with the recovery efforts. This payment-in-lieu system incorporates a fiscal responsibility aspect into the algorithm for nuisance pluvial conditions that results in limited non-frequent property damage due to the limited availability of project funding. This can also become a means to allow for deficient infrastructure to remain in place until its useful life span is reached while providing some protection to the impacted population should a pluvial flood event occur prior to the LGU having the financial capacity to replace the infrastructure.

3.7 UDRiS $_{\text{Beta Version}}$ Testing Discussion

Generally, both the UDRiS $_{\text{beta version}}$ and UDRiS $_{\text{version 2}}$ scores align with the results of the traditional flood study, the owner's eye-witness accounts of the pluvial flood event on August 24, 2019, and the author's accounting of the March 31, 2022, pluvial flooding event. The incorporation of the CPR and CRR dimensions impacted the UDRiS $_{\text{score}}$ as shown in **Figure 11:Scenario 2 Results Using UDRiS $_{\text{Version 2}}$,**. In **Figure 11:Scenario 2 Results Using UDRiS $_{\text{Version 2}}$** the DRI, SIR, and CRI dimensional scores remained the same between the UDRiS $_{\text{beta version}}$ and UDRiS $_{\text{version 2.}}$ The only significant modification made to the computational aspect of the algorithm between the two versions for this scenario was the incorporation of the completed community preparedness (CPR) and community response (CRR) rating dimensions. As with scenario 1, the calculated value of 0.365 and 0.747 for the CPR and CRR respectively, was integrated into the calculation of the UDRiS $_{\text{score}}$.

This resulted in a reduction of the resilience score for each of the infrastructure segments and the overall site composite UDRiS $_{\text{score}}$ for the test site**.** In Figure 11:Scenario 2 Results Using UDRiS $_{\text{Version 2}}$ the drastic change in the UDRiS$_{\text{score}}$ that resulted from the actual calculation of the CPR and CRR was unexpected due to the lesser weight assigned to these dimensions. However, the recalculation of the numerical UDRiS$_{\text{score}}$ resulted in more concise reporting of pluvial flood risk that better correlates to the observed field conditions.

-Chapter 3-

4.0 Research Objectives + Outcomes

The purpose of this study is to determine how the implementation of a novel EJ-based algorithm UDRiS reduces the inherent bias and subjectivity in the existing CIP project screening methodology at the departmental level. This study hypothesizes the current project screening methods used for identifying and ranking stormwater capital improvement projects are inherently subjective, technocratic, and biased. This results in the inequitable distribution of resources to vulnerable populations and places for mitigating the effects of pluvial flooding.

Figure 14:Comparison of the Existing CIP Screening Methods vs. UDRiS highlights the shortcomings from an EJ perspective of the existing screening methodologies currently utilized by practitioners for the identification and ranking of stormwater capital improvement projects. The scorecard method in this figure is noted as being less transparent in communicating to the public how the scoring was derived during the CIP screening process. This is partially due to the scorecard user having to assign points to projects using overarching themes that are linked to an LGU′s missions and goals. These themes sometimes do not translate well for the identification and ranking of urban drainage projects at the departmental level.

This has led many Stormwater Departments utilizing the anecdotal evidence methodology as a project screening approach to select projects for submission to the LGU′s Budget Office for project-specific CIP appropriation requests (City of Durham, 2022; City of Greensboro, 2022). Even with this secondary approach, this method still lacks the clarity needed to communicate to the public how the scoring was derived during the screening process. Both project screening methodologies do not adequately acknowledge the needs of vulnerable populations and places using defensible socio-economic data. These methodologies are less supportive of the equitable distribution of CIP resources and appropriations.

The proposed EJ-based methodology UDRiS provides more clarity and defensibility to the screening of urban drainage projects at the departmental level for submission to the LGU′s Budget Office for project-specific CIP appropriation requests (Waller, 2023). This approach provides the public with a clear and easy-to-understand ranking process that is described in detail in Chapter 2 of this paper. With the incorporation of EJ and resilience-thinking principles, this methodology promotes the equitable distribution of CIP appropriations to the most vulnerable populations and places.

Figure 14:Comparison of the Existing CIP Screening Methods vs. UDRiS

Evaluation Element	Scorecard (Existing Methodology)	Antidotal Evidence (Existing Methodology)	UDRIS (Proposed Methodology)
Transparency	-Increased subjectivity and bias due to the technocratic and compliant-driven system used to identify and prioritize projects.	-Increased subjectivity and bias due to the technocratic and compliant-driven reporting system.	-Reduces subjectivity and bias with continuous empirical data and information.
	- The ranking process is conducted in "closed session" amongst governmental departments.	-The ranking process is conducted in a "closed session" amongst technical experts or singularly performed by an individual.	-The ranking process information is available to stakeholders and the public.
	-Defensible information is available to stakeholders and the public concerning the derivation of the ranking results.	-Limited defensible information is available to stakeholders and the public concerning the derivation of the ranking results.	-Defensible information is available to stakeholders and the public concerning the derivation of the ranking results.
	-Limited pluvial flood risk information is available to stakeholders and the public. (Static)	-Limited pluvial flood risk information is available to stakeholders and the public. (Static)	-Pluvial flood risk information is readily available to stakeholders and the public. (dynamic)
Outcome	Less Transparent	Less Transparent	More Transparent
Equitability	-Projects identified and prioritization based on complaint-based system and technical data.	-Process can be influenced by external political pressure.	- Project identification and prioritization based on technical data, environmental justice, and resiliency principles relative to adaptation, coping, and recovery capacities of vulnerable populations.
	-Process politically influenced and is limited to locations that align with the goals and objectives of municipality.	-Process is influenced by social political infrastructure with stakeholders having the loudest voice receiving the most attention and a higher priority.	- Process allows for the evaluation of urban drainage infrastructure at locations where pluvial flooding concerns have not been reported without a substantial expenditure of resources.
	-Limited recognition of vulnerable populations and places.	-limited recognition of vulnerable populations and places.	- Provides recognition of vulnerable populations and places.
Outcome	Less Equitable	Less Equitable	More Equitable

Source: Author

Due to the lack of a consensus among academics, practitioners have employed an assortment of metrics and tools to convey, assess and manage resilience strategies (Balsells et al., 2013; Wardekker, 2018; Yamagata & Sharifi, 2018). The following gaps in the literature were identified because of varying theoretical perspectives and epistemologies with the implementation of EJ and resilience-thinking principles into practice.

GAP-1. A more effective translation of knowledge from theory to practice (Melillo et al., 2014).

GAP-2. Current stormwater infrastructure decision-making practices do not recognize how vulnerable populations are less able to cope and adapt to climate change (Hendricks & Van Zandt, 2021; National Academies of Sciences, Engineering, and Medicine (NASEM), 2019; O'Hare & White, 2018).

GAP-3. Current stormwater infrastructure decision-making tools are not well-informed, fair, and equitable in the distribution of hazard risks nor provide an effective means to communicate those risks (Campanella, 2006; Hendricks & Van Zandt, 2021; Melillo et al., 2014; University of Maryland, Center for Disaster Resilience, and Texas A&M University, Galveston Campus, Center for Texas Beaches and Shores, 2018).

In summary, a great deal of research has been conducted on the topics of environmental justice and resilience from various theoretical perspectives, branches of science, and epistemologies (Birkmann et al., 2013; Kim & Lim, 2016; O'Hare & White, 2018). However, the development and implementation of a CIP screening methodology have not been identified that provides the unbiased and transparent identification and ranking of capital improvement projects. The proposed novel CIP screening methodology (UDRiS) provides additional transparency and defensibility to the identification and ranking developed by infrastructure designers and program managers. In addition to its use as a project identification and ranking mechanism, the output of UDRiS, the $\text{UDRiS}_{\text{Score}}$ is also a means of communicating pluvial flood risk to stakeholders and the public.

4.1 UDRiS Integration into the Stormwater CIP Process

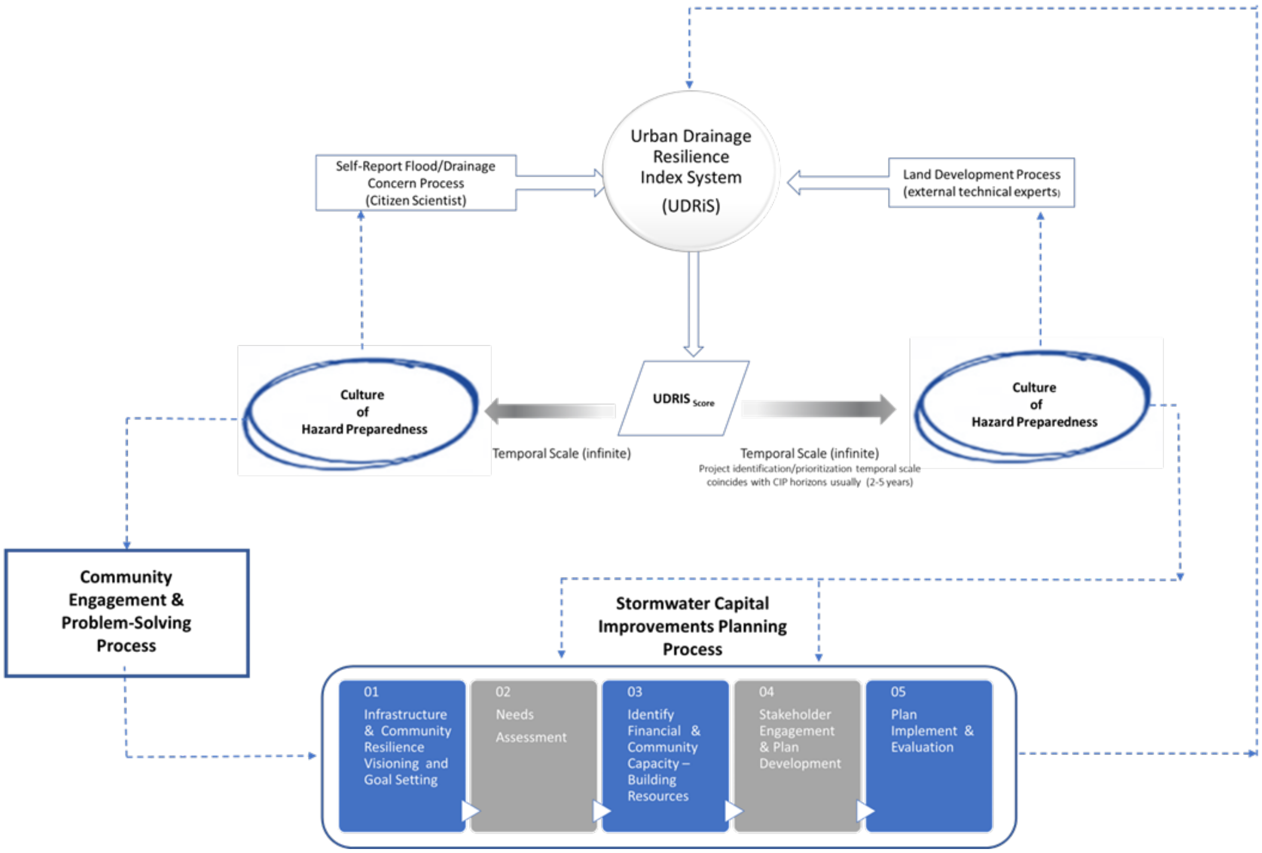
The distribution of pre-pluvial flood resources through the stormwater CIP process plays a key role in determining the degree of community flood resilience (DeAngelis et al., 2019; Hendricks & Van Zandt, 2021).

As shown in **Figure 15: UDRiS Integration into CIP Decision-Making Process,** the needs assessment phase of stormwater CIP is where projects to repair, rehabilitate, or replace urban drainage systems are identified to maintain an adequate level of service. In most cases, this assessment is non-comprehensive and is compiled from pluvial flooding events or drainage concerns reported by citizens with socio-political infrastructure. This self-report system fundamentally perpetuates bias and disparities in the distribution of pre-pluvial flood resources by narrowly defining project locations (DeAngelis et al., 2019; Grigg, 2012; United States Environmental Protection Agency, (EPA), 2016).

The application of UDRiS in the context of stormwater CIP is primarily an analysis and communication tool to increase transparency in the identification and distribution of stormwater resources. When UDRiS is incorporated into the needs assessment phase of the CIP process, it provides a quantitative assessment of the culpability of urban drainage systems to cause pluvial flooding. The continuous conveyance of risk communication information through the embedded feedback loops creates a culture of hazard preparedness. To evaluate the resilience of the urban drainage infrastructure and the coping, adaptation, and recovery capacity of the impacted population is accomplished through the calculation of a numerical score for each urban drainage system within an LGU. This numerical scoring system as shown in **Figure 7: UDRiSScore Rubric** is used to develop a comprehensive unbiased prioritization listing of deficient urban drainage infrastructure. The deficient infrastructure that falls below the LGU's established aspirational resiliency goal should be assimilated into capital improvement projects.

In this scenario, the composite letter designation output of UDRiS provides insight into the vulnerability of urban drainage infrastructure causing pluvial flooding within a defined spatial boundary such as the census tract. The spatial boundaries with lower letter designations such as F, D, and sometimes C, are candidate locations that need additional resources for increasing the coping, adaptation, and recovery capacity of the population. In addition to using the letter designation output from UDRiS, the Socio-economic Index of resilience and the Community Recovery Index within a defined spatial boundary can provide further justification for the allocation of capacity building and community economic development resources.

Figure 15: UDRiS Integration into CIP Decision-Making Process



Source: Author

4.2 Research Methodology

To determine how the implementation of a novel EJ-based algorithm UDRiS reduces the inherent bias and subjectivity contained within the existing CIP project screening methodology, a systematic review of the City of Greensboro, North Carolina Capital Improvements Program was performed. A review of the Capital Improvements Programs from Fiscal Year 2004-2023 was performed to get an understanding of the City of Greensboro CIP process from a historical perspective and to capture any evolutions to the process over time. This in-depth review also assessed the types of projects submitted for appropriations by the City of Greensboro's Water Resources Department. During the review of historical data, it was revealed candidate projects for demonstrating the application of UDRiS would come from the Stormwater Drainage and Management categories within the City of Greensboro CIP program. Overall, the CIP program and the project categories have mostly remained the same.

The City of Greensboro Capital Improvements Program Fiscal Year 2023-2032 contained 19 projects that will receive earmarked appropriations under the City of Greensboro's Water Resources Stormwater Management and Stormwater Drainage Programs. Of the 19 projects that will receive earmarked appropriations, 6 projects were identified as candidate demonstration locations for this study as shown in **Table 1: The City of Greensboro CIP Candidate Projects.** The candidate project locations were identified through the systematic screening for the keywords of "undersized pipe" and "flooding" in their project description. Once the candidate demonstration locations were compiled, an information request was submitted to the City of Greensboro's Water Resources Department. The requested information included additional background information on the candidate demonstration project locations and any associated flood/drainage studies. The common characteristics of the identified candidate demonstration locations is capacity deterioration due to the age of the urban drainage system coupled with documented incidents of pluvial flooding.

In addition to reviewing the Fiscal year 2023-2032 Capital Improvements Program a series of follow-up questions and a virtual roundtable discussion with several personnel from the City of Greensboro's Water Resources Department was conducted. This was performed to obtain an understanding of the City of Greensboro CIP project screening and ranking methodology, flood reporting protocols, and their ideology and definitions of resilience. The identified candidate locations were individually ranked by the City of Greensboro's Water Resources Department personnel during the roundtable discussion due to a previously developed project ranking was not available. A listing of the City of Greensboro ranking is found in **Table 1: The City of Greensboro CIP Candidate Projects**.

Table 1: The City of Greensboro CIP Candidate Projects.

CIP Tracking #	Candidate Project	Composite City Ranking (Anecdotal Evidence)
745	Warren/Wright Street Drainage Issue	1
773	Avondale/Edgewater Flooding (401 W. Avondale) Flood Hazard Minimization	2
744	Prescott Street Flooding	3
752	Shady Lawn Storm Outfall Upgrade & Madison Ave. Evaluation	4
741	Windshield Glass Outfall	5
742	Chapman Street Storm Outfall Improvements	6

Source: City of Greensboro Capital Improvements Program FY 2023-2032

The City of Greensboro Stormwater Department did not have a listing of project locations that were under consideration and not selected for inclusion in the Fiscal Year 2023-2032 CIP. It was determined from the roundtable discussion; the City of Greensboro's Water Resources Department was in the early stages of exploring and defining the vernacular of resilient stormwater infrastructure to combat the effects of climate change. Since the City did not have resiliency goals or an aspirational resilience rainfall event, the 1% Annual Chance Rainfall event was utilized as the aspirational resilience rainfall event. This was done to coincide with the Federal Emergency Management Agency (FEMA) regulated 1% Annual Chance of Flooding floodplain. The socio-economic data for each census tract within the entire jurisdictional boundary of the City of Greensboro was utilized and normalized using the z-score methodology as described in the **2.3 Data Normalization** section of this paper.

A spatial visualization of the candidate City of Greensboro CIP projects and the documented pluvial flooding events noted in the National Oceanic and Atmospheric Agency (NOAA) National Centers for Environmental Information Storm Events Database was performed. This review of the spatial distribution was performed to determine if a disparity exists between the spatial distribution of pluvial flooding events and the City of Greensboro CIP locations. The search criteria for the (NOAA) National Centers for Environmental Information

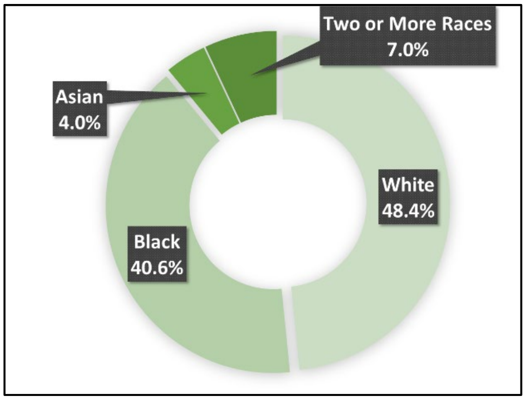
Storm Events database were limited to flood and flash flood events within Guilford County for the years 2000 to 2022. The search identified 110 records of flooding within Guilford County with 86 flood events occurring within the municipal limits of the City of Greensboro.

The recorded flooding events within the municipal limits of the City of Greensboro were further culled to only include the pluvial flooding typology which resulted in the identification of 31 locations. The riverine flooding typology was eliminated from the dataset by identifying and removing the locations that contained key phrases such as “flooding of nearby creek”, ”flooding along creek”, “flood waters from creek” and “creek overflowed its banks” in the event and episode narrative fields provided in the database. In addition to the analysis of the spatial distribution of the flooding events, a comparative ranking analysis of the City of Greensboro CIP project ranking and the ranking afforded by the numerical $\text{UDRiS}_{\text{score}}$ was performed.

4.3 Demonstration City Background

The demonstration City used for this research was the City of Greensboro, North Carolina which is the 3rd largest city in North Carolina with a population of 269,666 residents as noted in the 2010 (United State Census Bureau, 2022). In addition, to its population density and tax base, the City of Greensboro has a well-established Capital Improvements Program (CIP) that dates to at least the early 2000s. The longevity of their CIP and robust Stormwater Management Programs with a GIS-based inventory of their urban drainage infrastructural assets makes this City an ideal candidate for this research.

Figure 16: City of Greensboro 2010 Demographics



Source: 2010 US Census

4.3.1 Warren/Wright Street Drainage Issue Project Location Background + Anecdotal Evidence Assessment

The Warren/Wright Street Drainage Issue project is located in southwestern Greensboro in census tract 106.02. This project first appeared in the City of Greensboro CIP for Fiscal Year 2023-2032 for project-specific appropriations. Per the drainage study performed by Tera Tech, this location has been experiencing significant flooding in recent years which has caused the City of Greensboro to study this location. The City of Greensboro ranked this project site using anecdotal evidence as the top priority during the roundtable discussion amongst the six projects under consideration. The City of Greensboro Stormwater Department noted the following reasons for the determined ranking in order of importance: 1) the frequent project status reporting to the City Council/City Manager's Office; and 2) the temporal span by which pluvial flooding has been occurring. The appropriations for this project are scheduled to occur in Fiscal Year 2023-2032 for the design and Fiscal Year 2024-2025 for the construction of the improvements.

4.3.2 Chapman Street Storm Outfall Improvements Project Background + Anecdotal Evidence Assessment

The Chapman Street Storm Outfall Improvements Project is located in southwestern Greensboro in census tract 106.02. This project first appeared in the City of Greensboro CIP for Fiscal Year 2023-2032. The City of Greensboro Stormwater Department performed an internal review of this drainage concern and determined the piping system was slightly undersized which resulted in occasional pluvial flooding. Using anecdotal evidence, the City of Greensboro Stormwater Department ranked this project as the sixth priority during the roundtable discussion amongst the six projects under consideration. This ranking was established partly due to the City of Greensboro Stormwater Department has not received any further drainage complaints. Based on this, the Stormwater Department formed the opinion that the magnitude and frequency of the pluvial flooding events appear to be minor and would be monitored. Even with its status noted as observational, the project was significant enough for inclusion in the Fiscal Year 2023-2032 CIP with appropriations scheduled for Fiscal Year 2026-2032 for the design and Fiscal year 2027-2032 for the construction of the improvements.

4.3.3 Shady Lawn Storm Outfall Upgrades & Madison Ave. Project Background + Anecdotal Evidence Assessment

The Shady Lawn Storm Outfall Upgrades & Madison Ave. project is located in northern Greensboro in census tract 125.08. This project first appeared in the City of Greensboro CIP for Fiscal Year 2023-2032 for project-specific appropriations. Per the drainage study performed by Arcadis G&M of North Carolina, Inc., excessive flooding occurs at 2606 Shady Lawn Drive which was determined to be caused by undersized urban drainage infrastructure. The City of Greensboro Stormwater Department ranked this project using anecdotal evidence as the fourth priority during the roundtable discussion amongst the six projects under consideration. This project ranking was established partly due to the following reasons: 1) the socio-political infrastructure of the drainage complainant; 2) the frequent project status reporting to the complainant; and 3) the ability of the infrastructure to cause property damage is less than the other projects under consideration. The project appropriations are scheduled for Fiscal Year 2023-2024 for the design and Fiscal year 2024-2025 for the construction of the improvements.

4.3.4 Avondale/Edgewater Flood Hazard Minimization Project Background +Anecdotal Evidence Assessment

The Avondale/Edgewater Flood Hazard Minimization project is located in northwestern Greensboro in census tract 125.05. This project first appeared in the City of Greensboro CIP for Fiscal Year 2023-2032 for project-specific appropriations. Per the drainage study performed by Atkins North America, Inc., yard flooding on residential property is occurring at 401 West Avondale Drive which was determined to be caused by undersized urban drainage infrastructure. The results of the study noted upgrades to the piping system and/or the installation of stormwater attenuation measures may not be practical due to space and cost constraints. To mitigate the spatial concerns noted in the report, the City of Greensboro purchased 401 West Avondale Drive in December 2019 for the design and construction of stormwater attenuation measures.

The City of Greensboro Stormwater Department ranked this project using anecdotal evidence as the second priority during the roundtable discussion among the six projects under consideration. This project ranking was established partly due to the following reasons: 1) the interest and socio-political infrastructure of the neighborhood; and 2) the length of time that has elapsed since the property was purchased. The project appropriations are scheduled for Fiscal

Year 2023-2024 for the design and Fiscal year 2024-2025 for the construction of the improvements.

4.3.5 Windshield Glass Outfall Project Background + Anecdotal Evidence Assessment

The Windshield Glass Outfall project is in the commercial business zoning district just northwest of Downtown Greensboro in census tract 107.01. This project location first appeared in the City of Greensboro CIP for Fiscal Year 2023-2032 for project-specific appropriations. The City of Greensboro Stormwater Department performed an internal review of this project location during the evaluation of an economic development project proposal. During this evaluation, it was determined the piping system was slightly undersized and had to be relocated to accommodate the proposed future development.

The City of Greensboro Stormwater Department ranked this project using anecdotal evidence as the fifth priority during the roundtable discussion amongst the six projects under consideration. This project ranking was established due to the timing of a future economic development project in the area which would necessitate the relocation of the urban drainage infrastructure. The project appropriations are scheduled for Fiscal Year 2024-2025 for the design and Fiscal Years 2025-2026 & 2026-2027 for the construction of the improvements.

4.3.6 Prescott Street Project Location Background + Anecdotal Evidence Assessment

The Prescott Street project is in the commercial business zoning district just northwest of Downtown Greensboro in census tract 107.01. This project location first appeared in the City of Greensboro CIP for Fiscal Year 2023-2032 for project-specific appropriations. Per the drainage Analysis Report performed by McAdams, structural flooding of the commercial building at 412 Prescott Street was determined to be caused by undersized urban drainage infrastructure. The City of Greensboro Stormwater Department ranked this project using anecdotal evidence as the third priority during the roundtable discussion amongst the six projects under consideration. This project ranking was established partly due to the following reasons: 1) the frequency of flooding and occasional water damage to the structure; and 2) the socio-political infrastructure of the business. The project appropriations are scheduled for Fiscal Year 2022-2023 for the design and Fiscal year 2025-2026 for the construction of the improvements.

4.4 Unit of analysis

The unit of analysis for this study was the census tract which is used to describe community resilience and the socio-economic characteristics of populations impacted by pluvial flood events. The US Census Bureau describes census tracts as relatively permanent statistical subdivisions that are maintained over a long period of time for statistical comparison purposes between census data collection cycles. Census tracts typically have a population size between 1,200 and 8,000 people with an optimum size of 4,000 people (United States Census Bureau, 2022). This distinction and small population size make this the ideal unit of analysis for performing component-level analysis on infrastructural assets and socio-economic impacts on populations.

The unit of analysis for the infrastructural assets is the individual components (piping network) for the hydraulic and hydrological portions of UDRiS. Since pluvial flooding is unpredictable, this granular assessment scale allows for the individual analysis of urban drainage infrastructure system components and the anticipated impact on populations when the system becomes overwhelmed. The unit of analysis for climatic data was performed on both the 15-minute and 24-hour increments for identifying the two topologies of heavy precipitation.

4.5 Data Source + Availability

The data utilized for this study was assimilated from open-source data and information made available by the City of Greensboro. Data for the proxy indicators within UDRiS as shown in **Figure 26:UDRiS Dimensions + Proxy Indicators in Appendix D** were obtained from the City of Greensboro CIP, NOAA's Hydro-meteorological Design Studies Center, and NOAA's National Center for Environmental Information. The socio-economic-related data for the proxy indicators was compiled from the 2010 US Census Bureau's Factfinder and Quickfacts databases for each census tract within the municipal boundaries of the City of Greensboro.

Precipitation data for this study was assimilated from NOAA climatology and the National Water Dashboard for 24-hour and 15-minute rainfall data. The rainfall data range analyzed for the study was from February 5, 2019, to April 10, 2022. The spatial location and elevations of the urban drainage infrastructure at the candidate project locations were assembled from a combination of the City of Greensboro Stormwater GIS application and the provided drainage studies. The information collected from the City of Greensboro Stormwater GIS application was from the piping and storm structure mapping layers. The information used from these layers was the invert out elevations of the pipes, pipe length, and infrastructure installation date if available. In a few cases, the invert out elevations of the pipes were not available in the GIS application, which resulted in the use of the invert out pipe elevations contained in the flood studies.

It is important to note that the City of Greensboro did not provide or have available information for all the proxy indicators identified in **Figure 26:UDRiS Dimensions + Proxy Indicators** and some of the inputs for the algorithm**.** The input information that was not provided or available from the City of Greensboro was related to the properties of the urban drainage infrastructure such as age. When infrastructure age information was not available in the City of Greensboro Stormwater GIS application or the drainage studies, online property records search for recorded plats in the Guilford County Register of Deeds was performed. This search was performed to determine the age of the neighborhood which provided insight into the approximate age of the infrastructure. In addition to using the date on the recorded plat, the material type and size were also used to gauge the age of the infrastructure.

The proxy indicator information that was unavailable during the performance of this study was data tied to the FEMA's Community Rating System (CRS) and the Drainage System Maintenance proxy indicators. FEMA's CRS-related data was not available due to the city not pursuing the CRS credits identified as proxy indicators within UDRiS. In addition to the city historically not pursuing those credits, they were in the beginning stages of reassessing their overall CRS credit pursuit efforts and strategy. Their CRS credit re-evaluation results could make this information available for future UDRiS analysis.

The other area that information was not provided was related to the tracking of their stormsewer related preventative maintenance efforts such as debris removal and pipe flushing. The availability of the above discussed proxy indicators is not detrimental to the UDRiS analysis and output. As a decision support model, UDRiS has the ability through the respective UDRiS dimensions to assist the City in determining from a resilience purview if they should devote resources for pursuing and obtaining these credits or the performance of preventative maintenance efforts.

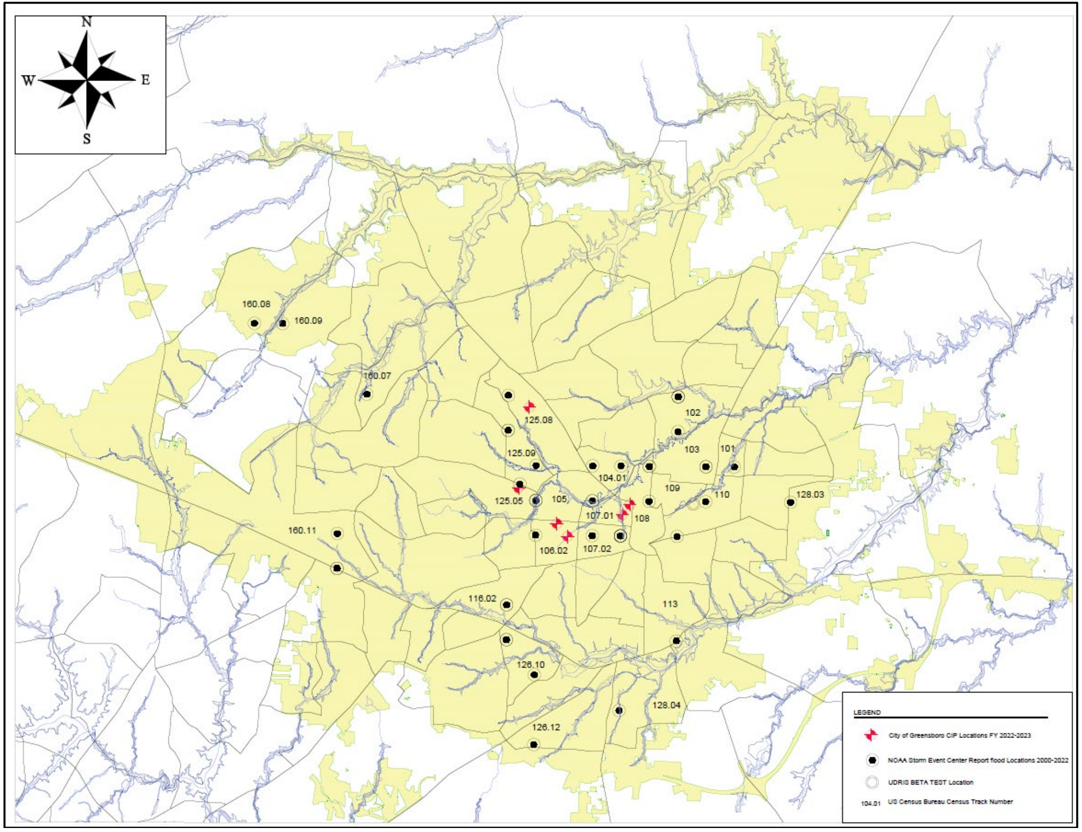
-Chapter 4-

5.0 Spatial Analysis

The spatial analysis of environmental hazards has been the foundational support for EJ discourse for describing where and what populations are unfairly impacted by natural and man-made hazards (Bullard et al., 2008). Various EJ and Hazards studies have identified a strong correlation between the recovery capacity of populations from flooding events to race, poverty, and income (Bullard & Wright, 2009; Chakraborty et al., 2014; O'Hare & White, 2018). The conclusion of these studies has demonstrated that underserved and communities of color are disproportionately exposed to environmental hazards. To provide systematic scientific inquiry into the study question, an analysis of the pluvial flooding and CIP locations within the City of Greensboro, North Carolina was performed. This analysis is required for determining if socioeconomically vulnerable populations and places are unequally exposed to pluvial floods and their ability to seek CIP appropriations for mitigating pluvial flood risk.

In **Figure 17: The City of Greensboro CIP and NOAA Reported Flood** Incidents Spatial Analysis is the spatial visualization of reported mappable flood occurrences within the City of Greensboro. This data was compiled from the City of Greensboro Capital Improvements Program Fiscal Year 2023-2032 and reported incidents of pluvial flooding from the National Oceanic and Atmospheric Agency (NOAA) National Centers for Environmental Information Storm Events Database for years 2000-2022. Reported mappable locations are defined as locations that was reported to the City of Greensboro or NOAA that had site-specific identification markers such as coordinates, a street intersection, or an address where the pluvial flooding event occurred.

Figure 17: The City of Greensboro CIP and NOAA Reported Flood Incidents Spatial Analysis



Source: Author

5.1 EJ and Race + Poverty

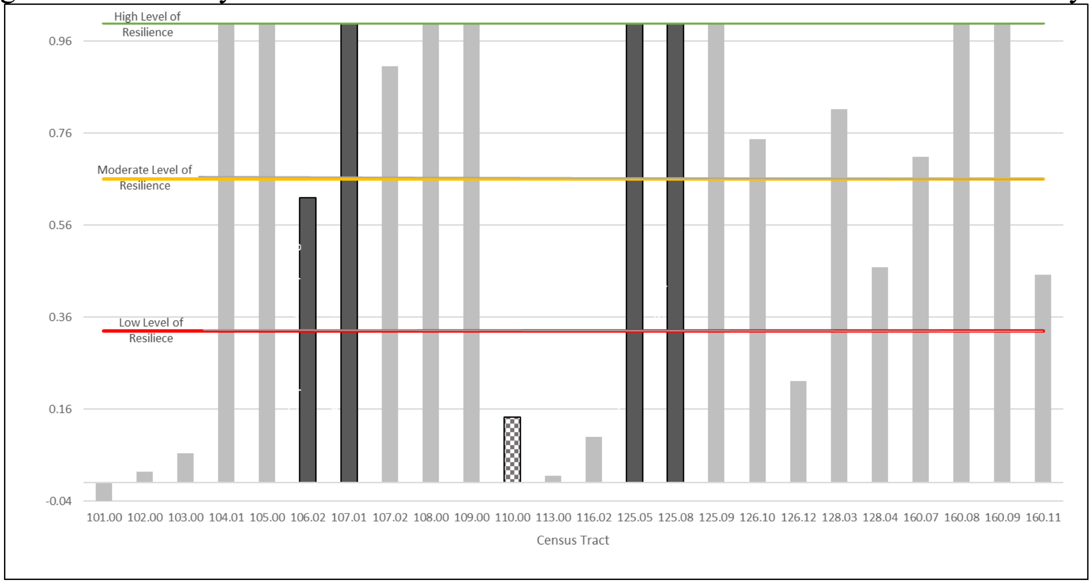
This study defines Environmental Justice (EJ) in accordance with the US Environmental Protection Agencies' definition as noted in section 1.4 EJ Framing of this paper. Disproportionality is defined as a census tract having at least one standard deviation more or less than the mean value for the metric of interest within the municipal boundaries of the City of Greensboro. The spatial distribution of pluvial flooding locations within the City of Greensboro through the EJ lens of race, approximately 29% of the 24 census tracts with documented pluvial flooding events have a disproportionately higher population of color. In census tracts where there are no reported occurrences of pluvial flooding, approximately 15% of the remaining 129 census tracts have a disproportionately higher population of color. This shows a slightly unequal distribution of pluvial flood hazard exposure to populations of color within the City of Greensboro.

Another metric used by various studies for determining unequal exposure to environmental hazards is poverty and income (Chakraborty et al., 2019; Walker & Burningham, 2011). The spatial analysis of the distribution of pluvial flooding locations within the City of Greensboro has revealed a wide disparity in poverty and income in the locations that had flooding events and the locations that did not have events of pluvial flooding. Of the 24 census tracts with documented pluvial flooding events, 25% of the census tracts have a disproportionately higher percentage of the population living in poverty. Conversely, 8% of the 24 census tracts had a disproportionately lower percentage of the population living in poverty.

In addition to the disproportionate population living in poverty, 21% of the census tracts with documented pluvial flooding events had disproportionately lower median household incomes. Whereas approximately 8% of the locations with documented pluvial flooding events have disproportionately higher median household incomes and a disproportionately lower percentage of the population living in poverty. In terms of the City of Greensboro CIP locations, two locations (Chapman and Warren/Wright) have incomes slightly lower than the mean income within the City of Greensboro and disproportionately higher percentages of the census tract population living in poverty. On the other side of the spectrum, the Shady Lawn project location has incomes disproportionately higher than the mean income within the City of Greensboro and a disproportionately lower percentage of the census tract population living in poverty.

To determine if populations of color have an equal opportunity to CIP appropriations, a spatial analysis was performed on the candidate UDRiS demonstration locations contained within the City of Greensboro CIP for Fiscal Year 2023-2032. The results of that analysis revealed the census tracts that contained the Windshield Glass, Prescott, and Shady Lawn project locations had lower populations of color. However, the Shady Lawn location was the only project site that reached the threshold for classification as having a disproportionally lower population of color. The Avondale project census tract contained the City of Greensboro's average percentage of populations of color. The remaining two project locations (Chapman and Warren/Wright) which are in the same census tract had a slightly higher percentage of populations of color but did not reach the threshold for classification as disproportional. The findings of this analysis show that populations of color based on the identified City of Greensboro CIP projects used in the demonstration of UDRiS, do not provide an equal opportunity for CIP appropriations that increase the resilience of underserved and populations of color from pluvial flooding events.

Figure 18: The City of Greensboro UDRiS Socioeconomic Index of Resilience Analysis



To demonstrate the EJ aspect of UDRiS, the census tracts with reported flooding, the SIR dimension within UDRiS was calculated as shown in **Figure 18: The City of Greensboro UDRiS Socioeconomic Index of Resilience** Analysis. This figure provides a comparative analysis of the antecedent resilience capacity of the documented pluvial flood locations within the City of Greensboro from the years 2000 to 2022 as calculated by UDRiS. This analysis shows approximately 37% of reported pluvial flooding event locations have lower antecedent resiliency capacity than the project locations identified for the demonstration of UDRiS. This suggests the demonstration locations within the City of Greensboro Capital Improvements Program for Fiscal years 2023-2032 are not necessarily the areas where the implementation of such projects would increase the resilience of the most vulnerable populations and places.

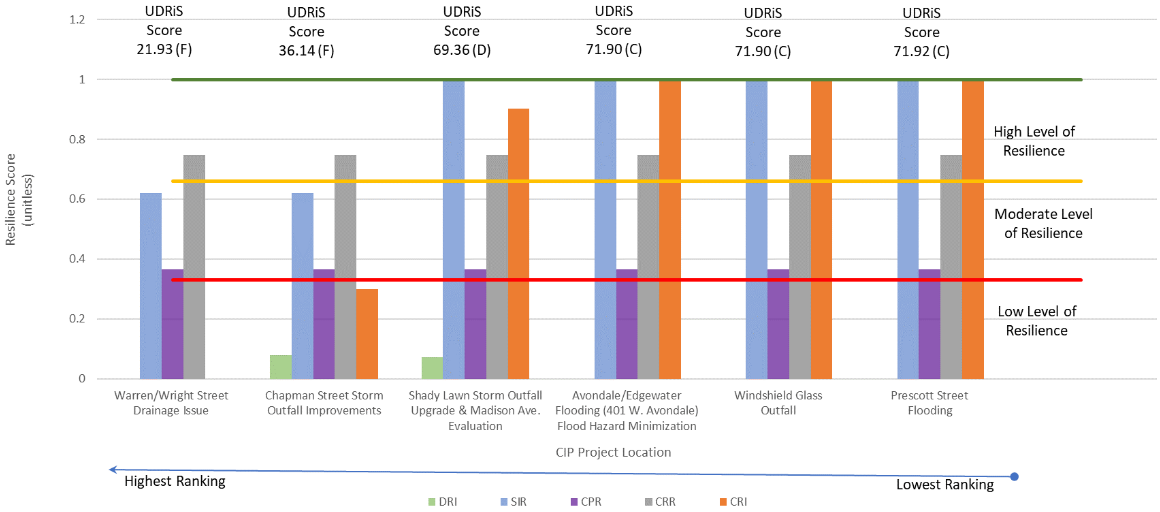
The historical review of the City of Greensboro CIP did not reveal set-aside appropriations for identified pluvial flooding locations in the NOAA database. Therefore, it is reasonably presumed that urban drainage infrastructure improvements have not been implemented to resolve the pluvial flooding events at these locations. This diagram also provides insight into the census tracts where the appropriation for capital improvement projects would provide the greatest benefit for reducing the flood risk of the identified population. This aligns with the conclusion of the spatial analysis that the selected CIPs for replacing undersized urban drainage piping networks from an EJ perspective are benefiting segments of the population that have a moderate or high capacity for recovery. Increasing the overall pluvial flood resilience of the most vulnerable populations and places not only benefits the localized community but also the greater Greensboro community.

5.2 City of Greensboro CIP UDRiS Assessment

The implementation of UDRiS into the CIP process at the departmental level is a way to give a voice to the voiceless and provide recognition to socioeconomically vulnerable populations and places. Based on the roundtable discussion with the City of Greensboro Stormwater Department, they currently do not have internal protocols at the departmental level for the identification or ranking of projects other than the reporting of drainage concerns by citizens with socio-political infrastructure. The City of Greensboro's current protocols addresses drainage concerns in the order they are received. In some cases, projects can receive a higher prioritization based on the magnitude of flood damage, political influence from elected officials, and/or the influence of the complainant. The influence from the complainant comes in the form of continual reporting and/or follow-up on previously submitted drainage concerns. The frequency of these follow-ups can occur on a weekly or monthly basis which becomes an inconvenience to staff and detracts them from their other duties.

As stated in **4.1 UDRiS** Integration **into the Stormwater CIP** Process, the application of UDRiS in the context of stormwater CIP is primarily an analysis and communication tool. This tool increases the transparency in the identification and distribution of project-specific appropriations for urban drainage improvements. In this demonstration, the capabilities of UDRiS as an analysis tool are highlighted with the implementation of UDRiS into the internal departmental protocols for requesting project-specific appropriations within the overall City of Greensboro Capital Improvements Plan. The application of UDRiS in this scenario increases defensibility, transparency, and equity to the screening of projects to remedy capacity deficiencies in urban drainage infrastructure caused by upstream urbanization and climate change. In addition to capacity deficiencies, UDRiS also provides strong inferences to EJ principles with the incorporation of metrics that identify and bring to the foreground the most vulnerable populations and places.

Figure 19:UDRiS$_{version2}$ Ranking Results for The City of Greensboro CIP FY 22-23 Stormwater Piping Projects



Source: Author

5.2.1 Warren/Wright Street Drainage Issue UDRiS Assessment

The UDRiS analysis of the Warren/Wright project location consisted of a desktop review of approximately 118 linear feet of piping for calculating a UDRiS$_{score}$. The numerical UDRiS$_{score}$ for this project location was 21.93 with a letter grade designation of (F). This designation is indicative of the urban drainage system and the population impacted by pluvial flooding having a lower level of resilience. As discussed in the earlier section **2.2 UDRiS Methodology +Dimensions** Construct, the UDRiS$_{score}$ is composed of several dimensions.

The first dimension Drainage Resilience Index (DRI) for the Warren/Wright project location has a low level of resilience due to the system nearing the end of its useful life and the pipe is currently undersized which causes pluvial flooding events. The second dimension, the Socioeconomic Index of Resilience (SIR) indicates the population within the Wright/Warren project census tract has a moderate level of antecedent resilience capacity. This moderate level of capacity suggests the census tract has a reasonable level of accessibility to resources to increase their overall coping, and adaption capability. The third-, and fourth-dimension community preparedness and community response ratings represent the policies and city-wide resources available to prepare and provide response resources to the community at large.

The fifth and final UDRiS Dimension, Community Resilience Index (CRI) is suggestive of a low level of resilience that results in a slow recovery period. This low level of resilience is partially due to the magnitude of estimated flood damage as calculated by UDRiS. The other factor that impacted the CRI is the disproportionately higher levels of poverty within the census tract which impacts the rapidity of the recovery efforts. In summary, the results of this project site align with the independently performed City of Greensboro drainage study.

5.2.2 Chapman Street Storm Outfall Improvements Project Location UDRiS Assessment

The Chapman Street Storm Outfall Improvements project location consisted of a desktop review of approximately 242 linear feet of urban drainage piping for calculating a UDRiS $_{\text{score}}$. The UDRiS analysis revealed a numerical UDRiS $_{\text{score}}$ for this project location was 36.14 with a letter grade designation of (F). This designation is indicative of the urban drainage system and the population impacted by pluvial flooding having a lower level of resilience. The first dimension Drainage Resilience Index (DRI) for the Chapman Street Storm Outfall Improvements project has a low level of resilience. This is due to the system has exceeded its useful life and the pipe is currently slightly undersized which causes pluvial flooding events.

The second dimension, the Socioeconomic Index of Resilience (SIR) indicates the population within Chapman Street Storm Outfall Improvements project census tract has a moderate level of antecedent resilience capacity. This moderate level of capacity suggests the census tract has a reasonable level of accessibility to resources to increase their overall coping, and adaptation capability. The third-, and fourth-dimension, community preparedness, and community response ratings represent the policies and city-wide resources available to prepare for and provide response resources to the community at large.

The fifth and final UDRiS Dimension, Community Resilience Index (CRI) is suggestive of a low level of resilience that results in a slow recovery period. For this project location, the low level of resilience is partially due to the UDRiS calculated estimated flood damage. The other factor that impacted the CRI is the disproportionately higher levels of poverty within the census tract which impacts the rapidity of the recovery efforts. Even though this project and the Warren/Wright project are within the same census tract, the CRI scores are considerably different. This difference is caused by the estimated magnitude of flood damage cost and the ability of the population to rapidly cope, adapt and recover.

5.2.3 Shady Lawn Storm Outfall Upgrades & Madison Ave. Project Location UDRiS Assessment

The Shady Lawn Storm Outfall Upgrades & Madison Avenue project location consisted of a desktop review of approximately 410 linear feet of urban drainage piping for calculating a UDRiS $_{\text{score}}$. The UDRiS analysis revealed a numerical UDRiS $_{\text{score}}$ for project location was 69.36 with a letter grade designation of (D). This designation is indicative of the urban drainage system and the population impacted by pluvial flooding having a lower level of resilience. The first dimension, Drainage Resilience Index (DRI) for the Shady Lawn Storm Outfall Upgrades & Madison Avenue project location has a low level of resilience. This is due to the system having exceeded its useful life and the pipe being currently undersized.

The second dimension, the Socioeconomic Index of Resilience (SIR) indicates the population within Shady Lawn Storm Outfall Upgrades & Madison Avenue project census tract has a high level of antecedent resilience capacity. This high level of capacity suggests the census tract has a more than adequate level of access to resources to increase their overall coping and adaptation capability. The third-, and fourth-dimension, community preparedness, and community response ratings represent the policies and city-wide resources available to prepare for and provide response resources to the community at large.

The fifth and final UDRiS Dimension, Community Resilience Index (CRI) is suggestive of a high level of resilience that results in a rapid recovery period. The high level of resilience for this project location is partially due to the UDRiS calculated estimated flood damage. The other factor that impacted the CRI for this project location is the lower levels of poverty. These two factors (estimated flood damage and poverty) substantially impact the rapidity of the recovery efforts.

5.2.4 Avondale/Edgewater Flood Hazard Minimization Project Location UDRiS Assessment

The Avondale/Edgewater Flood Hazard Minimization project location consisted of a desktop review of approximately 250 linear feet of urban drainage piping for calculating a UDRiS $_{score}$. The UDRiS analysis revealed a numerical UDRiS $_{score}$ for project location was 71.90 with a letter grade designation of (C). This designation is indicative of the urban drainage system and the population impacted by pluvial flooding having a moderate level of resilience. The first dimension, Drainage Resilience Index (DRI) for the Avondale/Edgewater Flood Hazard Minimization project location has a low level of resilience due to the system being slightly undersized and being unable to adequately convey upstream stormwater run-off.

The second dimension, the Socioeconomic Index of Resilience (SIR) indicates the population within Avondale/Edgewater Flood Hazard Minimization project's census tract has a high level of antecedent resilience capacity. This high level of capacity suggests the census tract has a more than adequate level of access to resources to increase their overall coping, and adaptation capabilities. The third-, and fourth-dimension, community preparedness, and community response ratings represent the policies and city-wide resources available to prepare for and provide response resources to the community at large.

The fifth and final UDRiS Dimension, Community Resilience Index (CRI) is suggestive of a high level of resilience that results in a rapid recovery period. The high level of resilience for this project location is partially due to the UDRiS calculated estimated flood damage. The other factors that impacted the CRI for this project location are the disproportionately lower levels of poverty and the disproportionately higher incomes. When compared to the other census tracts within the City of Greensboro, the incomes of this census tract are two standard deviations higher than the median income. These two factors (poverty and income) substantially impact the rapidity of the recovery efforts.

5.2.5 Windshield Glass Outfall Project Location UDRiS Assessment

The Windshield Glass project location consisted of a desktop review of approximately 340 linear feet of urban drainage piping for calculating a UDRiS $_{\text{score}}$. The UDRiS analysis revealed a numerical UDRiS $_{\text{score}}$ for this project location was 71.90 with a letter grade designation of (C). This designation is indicative of the urban drainage system and the population impacted by pluvial flooding having a moderate level of resilience. The first dimension, Drainage Resilience Index (DRI) for the Windshield Glass Outfall project location has a low level of resilience. This is due to the system being slightly undersized and unable to adequately convey upstream stormwater run-off.

The second dimension, the Socioeconomic Index of Resilience (SIR) indicates the population within the Windshield Glass Outfall project's census tract has a high level of antecedent resilience capacity. This high level of capacity suggests the census tract has a more than adequate level of access to resources to increase their overall coping, and adaptation capabilities. The third-, and fourth-dimension, community preparedness, and community response ratings represent the policies and city-wide resources available to prepare for and provide response resources to the community at large.

The fifth and final UDRiS Dimension, Community Resilience Index (CRI) is suggestive of a high level of resilience that results in a rapid recovery period. The high level of resilience for this project location is partially due to the UDRiS calculated estimated flood damage. The other factors that impacted the CRI for this project location are the slightly lower levels of poverty and the slightly higher incomes within the census tract. These two factors (poverty and income) substantially impact the rapidity of the recovery efforts.

5.2.6 Prescott Street Project Location UDRiS Assessment

The Prescott Street project location consisted of a desktop review of approximately 314 linear feet of urban drainage piping for calculating a UDRiS $_{\text{score}}$. The UDRiS analysis revealed a numerical UDRiS $_{\text{score}}$ for project location was 71.92 with a letter grade designation of (C). This designation is indicative of the urban drainage system and the population impacted by pluvial flooding having a moderate level of resilience. The first dimension, Drainage Resilience

Index (DRI) for the Prescott Street project location has a low level of resilience due to the system being slightly undersized and being unable to adequately convey upstream stormwater run-off.

The second dimension, the Socioeconomic Index of Resilience (SIR) indicates the population within the Prescott Street project's census tract has a high level of antecedent resilience capacity. This high level of capacity suggests the census tract has a more than adequate level of access to resources to increase their overall coping, and adaptation capabilities. The third-, and fourth-dimension, community preparedness, and community response ratings represent the policies and city-wide resources available to prepare for and provide response resources to the community at large.

The fifth and final UDRiS Dimension, Community Resilience Index (CRI) is suggestive of a high level of resilience that results in a rapid recovery period. The high level of resilience for this project location is partially due to the UDRiS calculated estimated flood damage. The other factors that impacted the CRI for this project location are the slightly lower levels of poverty and the slightly higher incomes within the census tract. These two factors (poverty and income) substantially impact the rapidity of the recovery efforts.

5.2.7 The City of Greensboro UDRiS Assessment Summary + Discussion

All of the City of Greensboro identified CIP projects had hydraulic capacity deficiencies as shown with the calculated DRI dimension resilience score within UDRiS. This corresponds with the hydraulic and hydrological findings of the drainage studies performed by the City of Greensboro which provides additional credibility to UDRis. UDRiS provides another layer of screening not currently afforded by typical drainages studies by the incorporation of the EJ and condition assessment aspects. The incorporation of these aspects provides further explanatory power and justification of project appropriations beyond the results of the hydraulic analysis which only highlights capacity deficiencies. The existing scorecard and anecdotal evidence methodologies leave practitioners and government officials having to mechanically rank projects which currently lack an EJ and resilience-thinking consideration.

The surprising aspect of the UDRiS analysis of each of the project locations was the race, poverty, and income findings among the project locations. The spatial analysis, SIR, and CRI UDRiS dimensions confirmed the hypothesis of the non-equitable distribution of pluvial flood resources to vulnerable populations and places to increase their resilience to pluvial flooding events. Instead, the resources are unintentionally being diverted to segments of the Greensboro community with socio-political infrastructure and an awareness of stormwater regulations to petition improvements within their neighborhoods. This perpetuates a system of inequity in the distribution of infrastructure resources for vulnerable populations and communities of color. This significantly impacts private investment and community economic development opportunities within these areas (De Barbieri, 2019; McFarlane, 1999).

In summary, the analysis portion of UDRiS provided promising results for screening projects in the wake of changing climatic conditions that are putting pressure on all urban drainage infrastructure. The UDRiS assessment of the CIP project locations demonstrated how the incorporation of an EJ screening metric for the identification of project locations for the allocation of pluvial flood mitigation resources. Using EJ as one of the screening metrics in conjunction with the hydraulic and hydrological data that is currently used to validate drainage concerns provides another layer of defensibility and transparency to the project selection process. In the context of this study, the use of UDRiS will increase the resilience of the greater Greensboro community by providing resources to populations and places that have less capacity to rapidly cope, adapt and recover from pluvial flooding events.

5.3 The City of Greensboro CIP Ranking vs. UDRiS Ranking Analysis + Discussion

The ranking calculated by UDRiS was based on the results of the Composite UDRiS score for each of the project locations. This ranking takes into consideration current stormwater policies and socioeconomic influences that affect the ability of a population to recover from a pluvial flooding event. In addition to this aspect, the algorithm incorporates hydraulic and hydrological factors that are typically considered during the performance of a drainage study. In general, the UDRiS results aligned with the independent drainage studies the City of Greensboro performed for supporting the request for project-specific appropriations during the CIP process.

However, the ranking varied slightly between the two methodologies as shown in **Table 2: Comparative Analysis of CIP Project Ranking Using Two Different Methodologies.**

Table 2: Comparative Analysis of CIP Project Ranking Using Two Different Methodologies

CIP Tracking #	Candidate Project	Composite City Ranking (Anecdotal Evidence) Design	Composite City Ranking (Anecdotal Evidence) Construction	UDRiS Ranking	Appropriation Schedule				
					FY 22-23	FY 23-24	FY 24-25	FY 25-26	FY 26+
745	Warren/Wright Street Drainage Issue	1	1	1	Des.	Const.			
773	Avondale/Edgewater Flooding (401 W. Avondale) Flood Hazard Minimization	2	3	4	Des.		Const.		
744	Prescott Street Flooding	3	5	6	Des.			Const.	
752	Shady Lawn Storm Outfall Upgrade & Madison Ave. Evaluation	4	2	3	Des.	Const.			
741	Windshield Glass Outfall	5	4	5		Des.	Const.	Const.	
742	Chapman Street Storm Outfall Improvements	6	6	2				Des.	Const.

Source: Author and City of Greensboro Capital Improvements Program FY 2023-2032

Of the projects scheduled to receive design appropriations in FY 2022-2023, the ranking determined by the calculated UDRiS $_{\text{score}}$ correlated with 3 out of 4 project locations identified by the City of Greensboro's Water Resources Department using the Anecdotal Evidence methodology. The outlier project Prescott Street is ranked as a third priority project for design by the City of Greensboro, however, the ranking using the UDRiS $_{\text{score}}$ determined this project should be a sixth priority. This is noteworthy because, from a construction standpoint, the Prescott Street project is ranked fifth for construction appropriations.

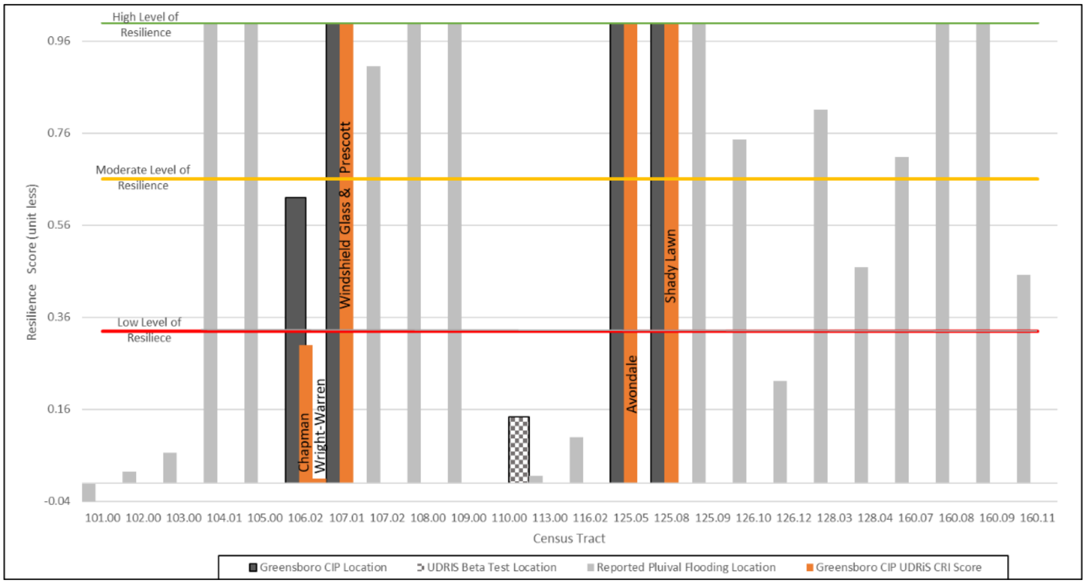
Knowing this, one would question the substantial gap between the allocation of design and construction appropriations which results in conflicting rankings for this project. In all three scenarios, the Warren/Wright Street Drainage Issues was identified as a top priority location. UDRiS identified this project location through the calculation of the Composite UDRiS $_{\text{score}}$ as the lowest score site amongst the other locations as noted in section **5.2.1 Warren/Wright Street Drainage Issue UDRiS Assessment.** The anecdotal evidence used by the City of Greensboro to rank this project as a top priority appears to have been done with little consideration of other factors. Ironically, the anecdotal evidence methodology appeared to not account for the socio-economic characteristics of the project location which was not communicated as a factor in the ranking of the project during the roundtable discussion.

One interesting thing to note, the 2 projects located within business zoning districts had the lowest ranking of the analyzed CIP projects with UDRiS $_{\text{version2}}$. This ranking could be induced by the current limitation of UDRiS $_{\text{version2}}$ which does not consider increased flood damage costs associated with commercial/business entities. The UDRiS ranking of the Prescott drainage improvements project as 6th may be biased. This presumption of bias is due to the CRI dimension proxy indicators, which are not currently designed to reflect the recovery capacity of commercial/business entities.

Even though the results of the CRI dimension are presumed to be biased for commercial/business entities, however, it does provide insight into the capacity of the population within the census tract to recover which includes the residents who could also be employees of the business. The high CRI also indicates the magnitude of flood damage does not exceed the recovery capacity of the commercial/business entity. Anecdotally, it can be assumed that business entities would have more resources available for the recovery efforts than a single-family residential property owners. Using this logic, the calculated value for the CRI for the Prescott Street project indicates the population within this census tract has the capacity for a rapid recovery.

Based on the information gleaned from the City of Greensboro’s Water Resources Department at the roundtable discussion, it appears the property owner had a rapid recovery from the flooding event which corresponds to the calculated CRI Score. The City of Greensboro ranked the Prescott Street project higher due to the document flood damage that occurred within the business and the social-political infrastructure afforded by the business. The external factor of social-political infrastructure is not considered with UDRiS to hold true to the basic EJ principle requiring the equal application of environmental regulations, policies, and laws to all people.

Figure 20: The City of Greensboro CIP FY 22-23 Comparison of UDRiS Socioeconomic Index of Resilience and Community Recovery Index



Source: Author

Figure 20: The City of Greensboro CIP FY 22-23 Comparison of UDRiS Socioeconomic Index of Resilience and Community Recovery Index, provides a comparison of the SIR and CRI for the census tracts with documented flooding events. The census tracts that have a SIR resilience score that indicates a low level of resilience are likely in need of capacity-building resources. The deployment of capacity-building resources will increase the overall resilience capacity of the population. In this figure, the census tract that contains the Prescott Street flooding project has a high SIR score which is indicative of a substantial amount of antecedent resilience capacity before the introduction of a pluvial flooding event. The availability of antecedent socioeconomic capacity contributes to the high CRI score which takes into consideration wealth as one of the proxy indicators.

In summary, implementing UDRiS as a methodology for identifying and ranking pluvial flooding locations provides additional defensibility and transparency to a project's priority ranking for requesting CIP appropriations for urban drainage infrastructure upgrades. With undersized and aging infrastructure being more prevalent, LGUs will be forced to develop methodologies that provide an equal opportunity for all populations and places to petition for CIP appropriations. This is especially true, for the most vulnerable populations and places that are less able to cope, adapt, and recover from pluvial flooding events. Acknowledging the socio-economic characteristics of the project's census tract provides recognition to populations and places that are more sensitive to the impacts of pluvial flooding and are often overlooked.

5.4 UDRiS Benefits, Limitations + Expandability

UDRiS is an algorithm that provides a quantifiable approach for identifying and ranking of urban drainage improvement projects to mitigate the effects of pluvial flooding through the lens of EJ. Implementing UDRiS affords more defensibility, transparency, and equitability to the project screening process which has numerous benefits for LGUs and the communities they serve. **Figure 21: UDRiS Societal Benefits** provides a brief synopsis of some of the benefits of implementing UDRiS. While there are many benefits for implementing UDRiS there are several key assumptions and limitations with the current version of the algorithm UDRiS $_{\text{Version 2}}$ that was utilized for this study.

Figure 22: UDRiS Limitations provides a listing of some of the known limitations of UDRiS $_{\text{version 2}}$, however as with any algorithm additional limitations will be discovered as the algorithm is further implemented and field tested.

Figure 21: UDRiS Societal Benefits

a. Provides social political infrastructure to segments of the population (typically underserved and communities of color) that anecdotally tend to underreport pluvial flooding drainage concerns.

b. Provides a defensible methodology for analyzing, identifying and ranking pluvial flooding drainage concerns for inclusion in a capital improvements program.

c. UDRiS communicates pluvial flood risk in an easy-to-understand format for technical and non-technical stakeholders.

d. Empowers communities to establish resilience goals relative to urban drainage infrastructure.

e. Empowers communities to holistically assess their urban drainage infrastructure through the lens of resilience and environmental justice.

Figure 22: UDRiS Limitations

a. Is not intended to provide an absolute measure of community capital and capacity.

b. Is not intended to provide a measure of a community's trust/faith in institutions.

c. Does not quantify the inherent resilience of populations that emerges when faced with adversity

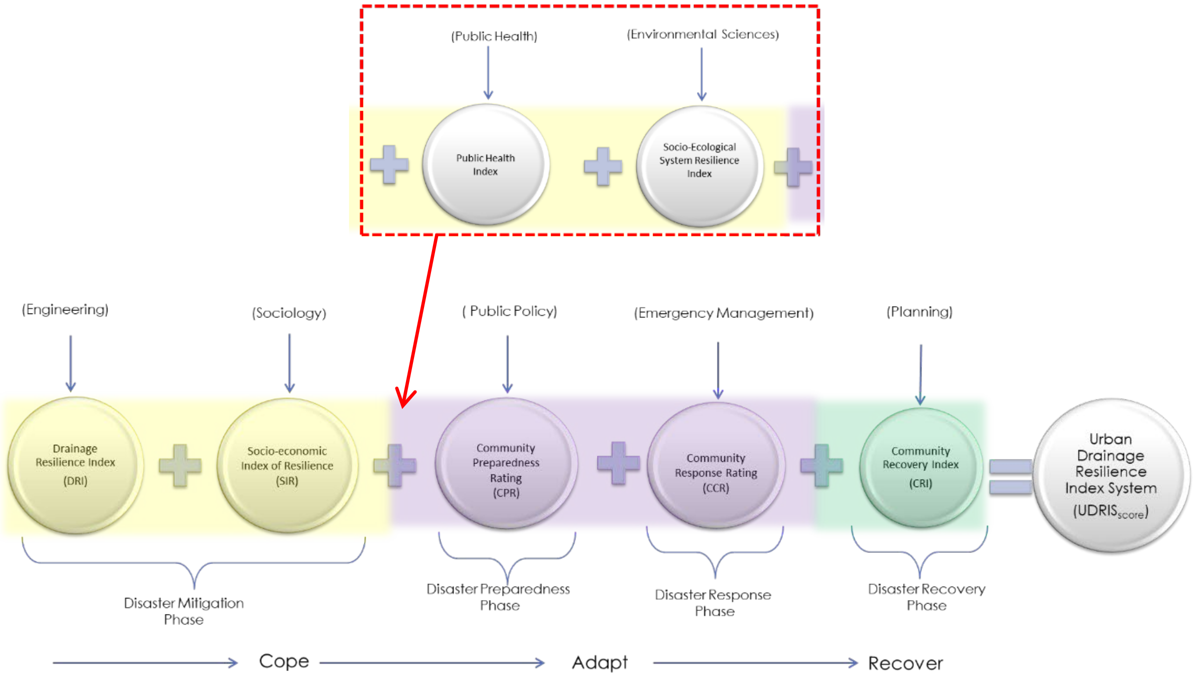
d. The estimated flood damage repair cost is an estimate to provide a rough order of magnitude for a single-story residential property without a basement.

e. The characterization and extent of the flood hazards contained within UDRiS are based upon free flow conditions and do not include impacts from impediments, clogging, or blockages within the stormwater conveyance infrastructure.

f. The estimated flood damage repair cost is an approximation based on the average housing value within the census tract. These values are provided to provide an order of magnitude for the anticipated flood damage repair cost and should not be construed as an estimate of the actual damage repair.

The design of UDRiS allows for the expansion of dimensions to improve the algorithms representation of EJ and resilience-thinking principles as shown in **Figure 23: UDRiS Expandability.** The algorithm is designed to evolve as more theoretical and applied research is performed in the areas of EJ, climate change, and resilient-thinking principles that are linked to pluvial flooding outcomes. This flexibility allows for the integration of new research outcomes while remaining steadfast to the overall theoretical concept and linkages as described in **2.1 UDRiS Theoretical Framework** of this paper. To stay true to the theoretical framework, the algorithm must include at a minimum the DRI, SRI, CPR, CRR, and CRI dimensions which provide the foundational support for UDRiS. In addition to the expandability of UDRiS's dimensions, the algorithm allows for the inclusion of additional proxy indicators or the exclusion of existing proxy indicators identified in **Figure 26:UDRiS Dimensions + Proxy Indicators** as the body of knowledge grows with new research findings.

Figure 23: UDRiS Expandability



5.5 Future Research Questions

Complex decisions concerning risks posed by pluvial flooding cannot be made independently but requires public involvement and the continuous input of complex technical information (Haer et al., 2016; Rowel et al., 2012; Santos, 1990). This paper outlines a novel approach using UDRiS, an (MCDA) model to rethink and reimagine existing practices to create a more transparent and equitable decision-making process for the identification and allocation of CIP appropriations. This study developed a novel approach UDRiS to reduce the inherent partiality and subjectivity contained within the existing CIP project screening methodologies for pluvial flooding mitigation projects. Below is a list of future studies that would further validate and demonstrate the capabilities of UDRiS.

- A study that has both pluvial flooding and non-flooding locations to further validate the screening and project ranking through the UDRiS $_{score}$.
- A comparative study to determine the change in the UDRiS $_{score}$ before and after the implementation of a flood mitigation project.

- A qualitative study that provides additional validation of UDRiS's Community Recovery Index (CRI).

- A longitudinal study to provide further validation of the application of the UDRiS to neighborhoods that experience rain events of similar magnitude and intensity.

- A study to determine if the implementation of UDRiS improves the quality of Hazardous Mitigation Plans? If so to what extent does it improve the quality of such plans?

- A study to determine the linkages/associations between the Comprehensive Planning, Hazardous Mitigation Planning, and Capital Improvements Planning Processes?

APPENDICES

Appendix A

Glossary

Anecdotal evidence- is an approach that establishes a project priority based on personal observation and limited scientific data.

Climate Change- a global phenomenon by which rising global temperatures primarily driven by human activities have increased the concentration of greenhouse gases in the atmosphere that influences the hydrologic cycle which results in changing weather patterns (Mellio et al., 2014; Zhou, 2014; Butler et al., 2018).

Community Economic Development- the process that promotes the holistic improvement of socio-economically distressed places that focuses to entice the start of new businesses or the relocation of existing businesses to improve the economic conditions and the quality of life for a socially vulnerable population that resides within the socio-economically depressed area (McFarlane, 1999).

Community Preparedness Rating (CPR) -is a measure of community social bonds and the influence of adopted governmental policies for fostering a culture of pluvial flood preparedness.

Community Recovery Index (CRI) -is indicative of the available capacity an impacted population has for the recovery efforts preceding a pluvial flooding event.

Community Response Rating (CRR) -is indicative of a community's ability to respond during and immediately after non-disaster-declared pluvial flooding events.

Drainage Resilience Index (DRI)- is a component-level measurement of an urban drainage system's ability to cause pluvial flooding during the aspirational resiliency rainfall event.

Design Hyetograph- a synthetic rain event that has a low statistical probability occurrence with predetermined characteristics not comprised of actual rain events (McCuen, 1998; Brody et al., 2013; Butler et al., 2018).

Exposure- the spatial (where we work, play and live) and the temporal representation of the threat to cause harm and/or losses (Cho & Chang, 2017).

Green Urban Drainage Systems-natural or engineered systems (e.i. bioretention cells/swale, wetlands, permeable pavement, infiltration swales/systems, etc.) used to replica the natural hydraulic and hydrological process to more effectively manage the impacts (quality and quantity) of urban stormwater to receiving water bodies (EPA, 2013, Butler at el, 2018; Webber et al., 2020).

Grey Urban Drainage Systems -engineered systems that primary objective is to divert surface water (stormwater runoff) as quickly as possible way from the urbanscapes to the nearest downstream waterbody via a piping or conveyance system to provide sanitation and/or to prevent flooding (Bulter, 2018; Burian & Edwards, 2002; Jegatheesan et al., 2019).

Hazard- describes the potential occurrence of natural or man-made events that may have physical, societal, economic, and/or environmental impacts in a given area during a defined time period (Cho & Chang, 2017).

Pluvial Flooding Event – is the general term that represents various degrees of pluvial flooding.

Pluvial Flood Risk*-is* the likelihood of impacts or losses from pluvial flooding that links the negative consequences created by pluvial flooding at the confluence of hazards, vulnerability, and resources. resources (adapted from Cho & Chang, 2017; Proag, 2014).

Resources - describes the level of access to and the mobilization of assets both pre- and post-hazard that decreases or minimizes the impact of losses (Cho & Chang, 2017).

Resilience (noun)**-** is the ability to anticipate, prepare for, cope with, adapt to, and recover swiftly from changing conditions caused by natural and man-made disturbances (Linkov & Palma-Oliveira, 2017; Sharifi &Yamagata, 2018; Kim & Li, 2016; Birkmann et al., 2013).

Resilience (verb)**-** are the actions (sensing, anticipating, adapting, and learning) to anticipate, prepare for, cope with, adapt to, and recover swiftly from changing conditions caused by natural and man-made disturbances (Linkov & Palma-Oliveira, 2017).

Resilient Urban Drainage Systems-is the implementation of actions that improve the system's ability to "bounce back" from adverse events and reduces the post-flood event timeframe and the number of resources necessary to return the impacted drainage system and population back to a normal state of operation (adapted from Linkov & Palma-Oliveira, 2017).

Scorecard Method- is a performance evaluation method that uses financial and non-financial performance measures for evaluating tangible and intangible assets that play a key role in achieving a local governmental unit's core social and economic mission and objectives (Kaplan, 2010; Sharma & Gadenne, 2011).

Susceptibility- the predisposition of physical and socioeconomic characteristics that increase the likelihood of experiencing impacts and/or losses (Cho & Chang, 2017).

Socially Vulnerable Populations- is the segment of a population that is historically disenfranchised, lacks or has limited socio-political infrastructure, and exhibits causal characteristics in the areas of social, economic, cultural, and demographics which are suggestive of the negative differential impacts that limit their ability to respond to, cope with and recover from urban flooding events (Mohai et al., 2009; Schlosberg, 2013; Cutter et al., 2003).

Socio-economically Destressed Places- are communities in critical need of community economic development that has been largely ignored by governmental officials and planning policy with inadequate job creation opportunities, housing, infrastructure, and capacity-building resources (McFarlane, 1999; EPA, 2016; Finewood et al., 2018).

Socio-economic Index of Resilience (SIR)-is a comparative measure of the socioeconomic predisposition of populations at the census tract level to shocks in the socio-economic system without the added burden of a pluvial flooding event.

Socio-Political Infrastructure- refers to the social and political norms, values, rules, alliances, and relationships that provide the underpinnings and institutional structure to the numerous decisions made by public and private political players which define the roles actors play in forming and shaping the urbanscape (Eakin et al., 2017).

Stormwater Capital improvements planning (CIP) -is the visioning process for prioritizing the financial investment in upgrades, replacement, and maintenance of stormwater infrastructure that support a community's quality of life (Grigg, 3003).

Urbanscapes- dynamic artifacts of human design that embody ingenuity, creativity, and social stratification that are reflective of societal values and relationships (Friend & Moench, 2013).

Urban Drainage Resiliency Index System (UDRiS) – comprehensive multi-dimensional index and rating system that aims to capture the dynamic and evolutionary nature of vulnerability and the continuous implementation of interventions, tools, and methods necessary for increasing the resilience of socially vulnerable populations and socioeconomically depressed places from pluvial flooding events (Waller, 2023).

Appendix B

Figure 24: Beta Test Flume #1 Photo

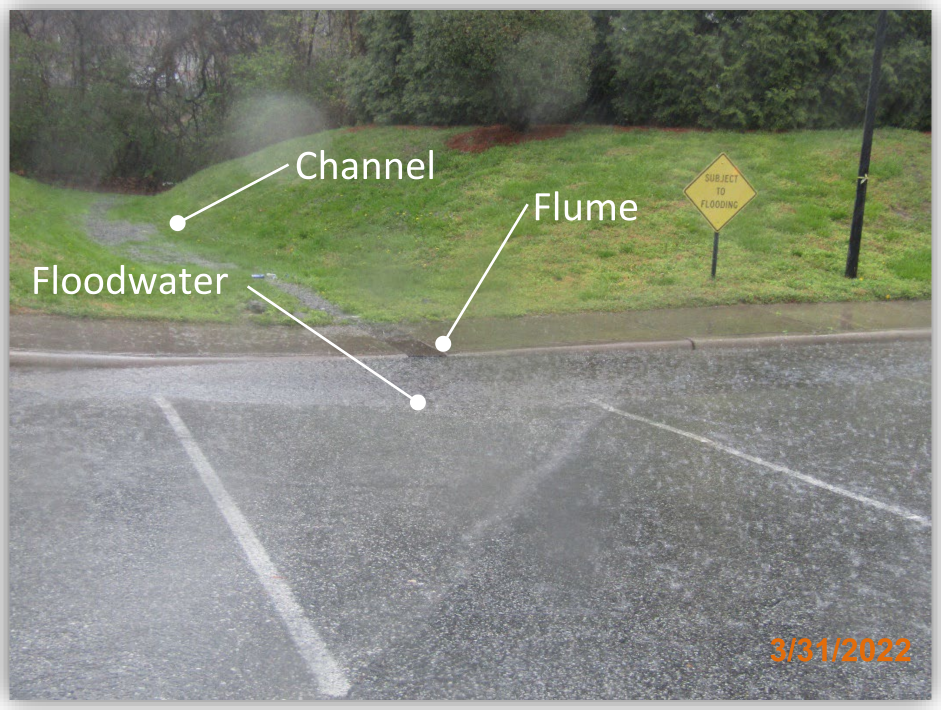
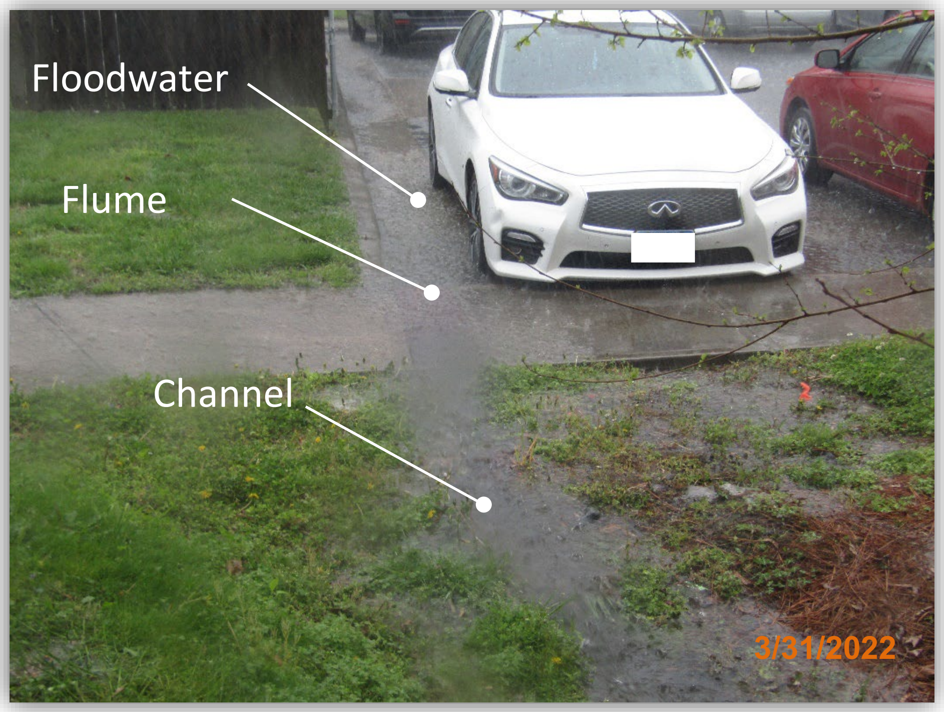
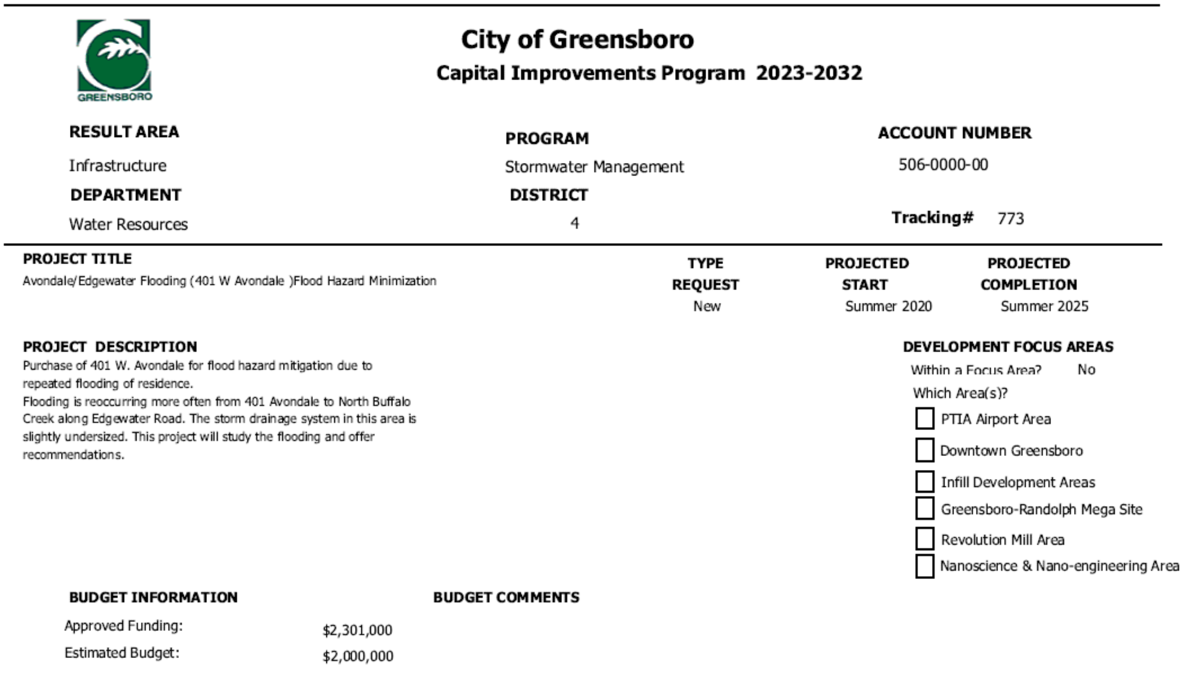


Figure 25: Beta Test Flume #2 Photo



Appendix C



City of Greensboro

Capital Improvements Program 2023-2032

RESULT AREA	**PROGRAM**	**ACCOUNT NUMBER**
Infrastructure	Stormwater Management	506-0000-00
DEPARTMENT	**DISTRICT**	
Water Resources	4	**Tracking#** 773

PROJECT TITLE	**TYPE REQUEST**	**PROJECTED START**	**PROJECTED COMPLETION**
Avondale/Edgewater Flooding (401 W Avondale)Flood Hazard Minimization	New	Summer 2020	Summer 2025

PROJECT DESCRIPTION

Purchase of 401 W. Avondale for flood hazard mitigation due to repeated flooding of residence.

Flooding is reoccurring more often from 401 Avondale to North Buffalo Creek along Edgewater Road. The storm drainage system in this area is slightly undersized. This project will study the flooding and offer recommendations.

DEVELOPMENT FOCUS AREAS

Within a Focus Area? No

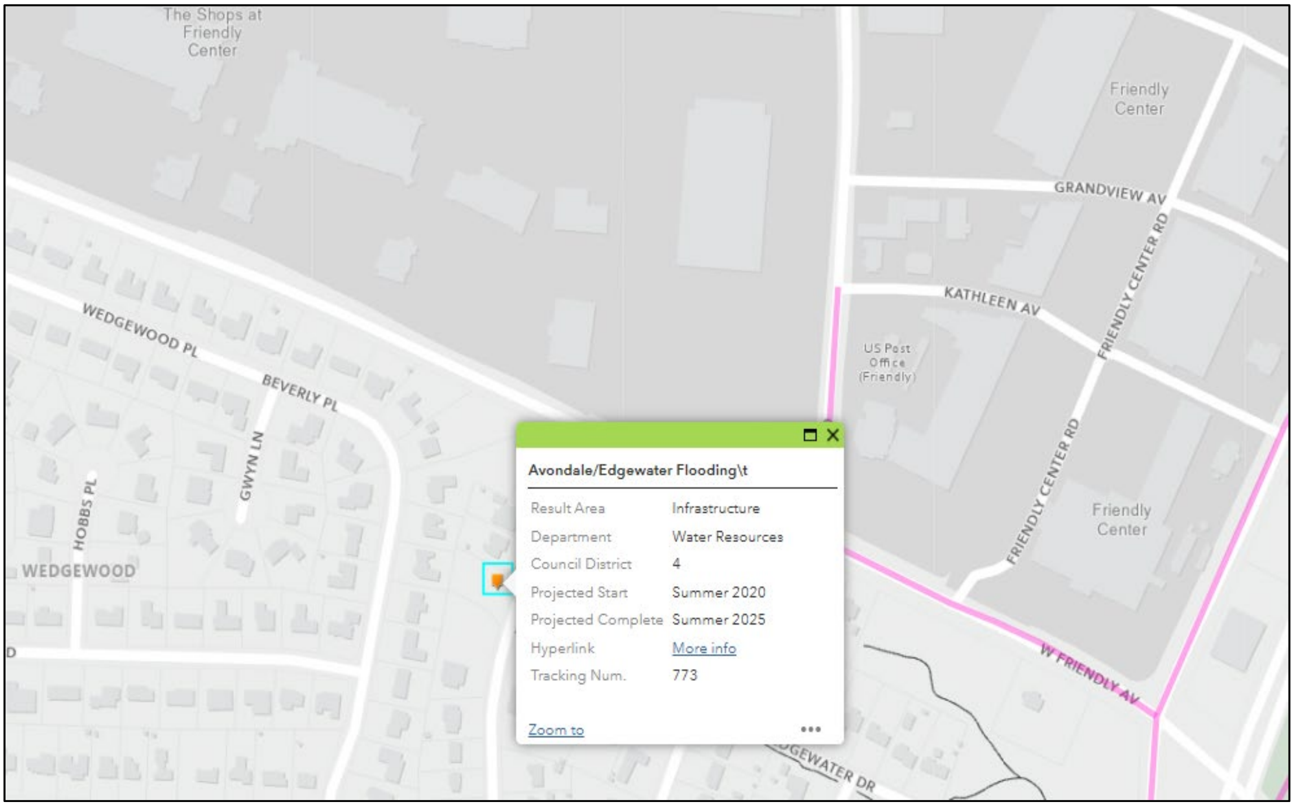
Which Area(s)?

- ☐ PTIA Airport Area
- ☐ Downtown Greensboro
- ☐ Infill Development Areas
- ☐ Greensboro-Randolph Mega Site
- ☐ Revolution Mill Area
- ☐ Nanoscience & Nano-engineering Area

BUDGET INFORMATION

Approved Funding:	$2,301,000
Estimated Budget:	$2,000,000

BUDGET COMMENTS



Avondale/Edgewater Flooding\t

Result Area	Infrastructure
Department	Water Resources
Council District	4
Projected Start	Summer 2020
Projected Complete	Summer 2025
Hyperlink	More info
Tracking Num.	773

Source: City of Greensboro CIP GIS Mapper & Capital Improvements Program FY 2023-2032

City of Greensboro

Capital Improvements Program 2023-2032

RESULT AREA	**PROGRAM**	**ACCOUNT NUMBER**
Infrastructure	Stormwater Management	506-0000-00
DEPARTMENT	**DISTRICT**	
Water Resources	3	**Tracking#** 744

PROJECT TITLE	**TYPE REQUEST**	**PROJECTED START**	**PROJECTED COMPLETION**
Prescott Street Flooding	New	Summer 2022	Summer 2026

PROJECT DESCRIPTION

This project expands on the study done by McAdams (Contract 2020-5042) which studied the stormwater system from downtown to the discharge point in N. Buffalo Creek. Upsizing, detention, relocation was studied.

DEVELOPMENT FOCUS AREAS

Within a Focus Area? No

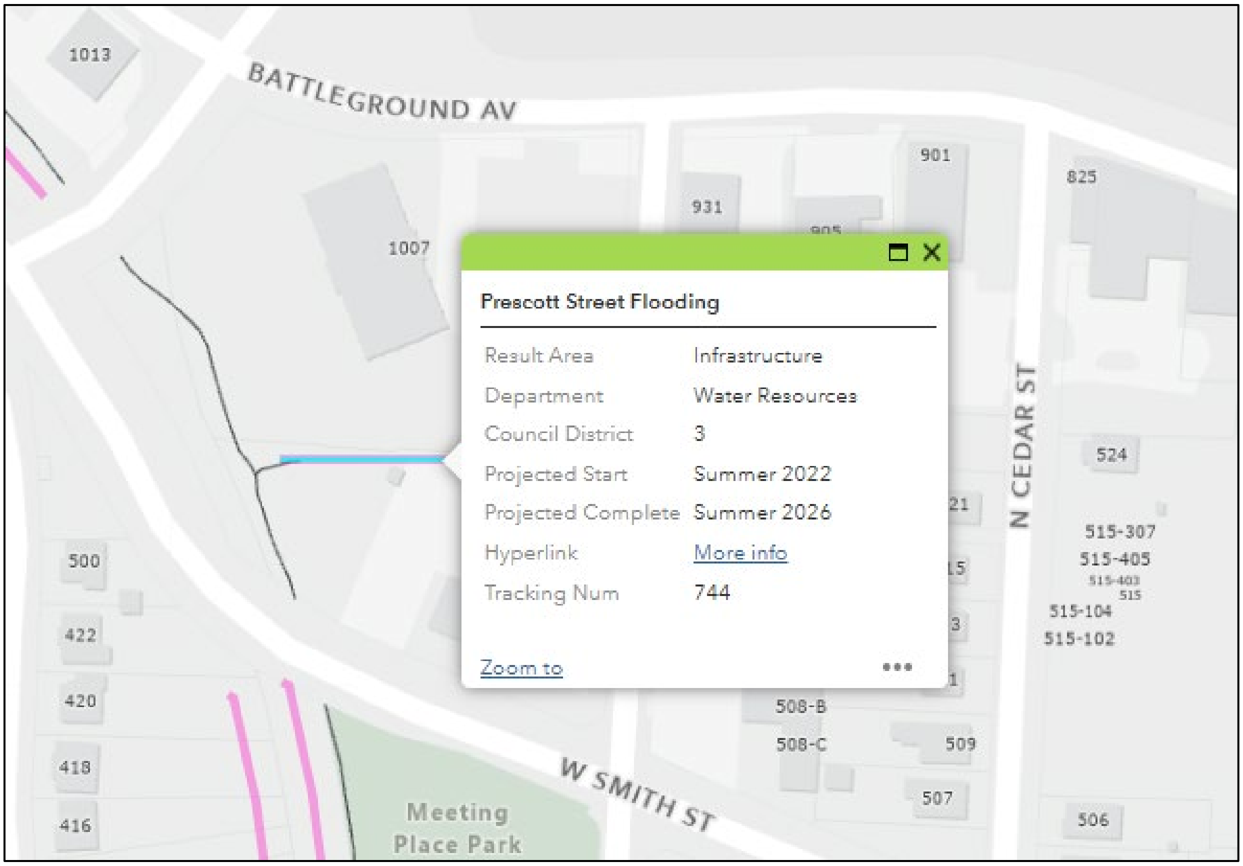
Which Area(s)?

- ☐ PTIA Airport Area
- ☐ Downtown Greensboro
- ☐ Infill Development Areas
- ☐ Greensboro-Randolph Mega Site
- ☐ Revolution Mill Area
- ☐ Nanoscience & Nano-engineering Area

BUDGET INFORMATION

Approved Funding:	$1,158,325
Estimated Budget:	$1,158,325

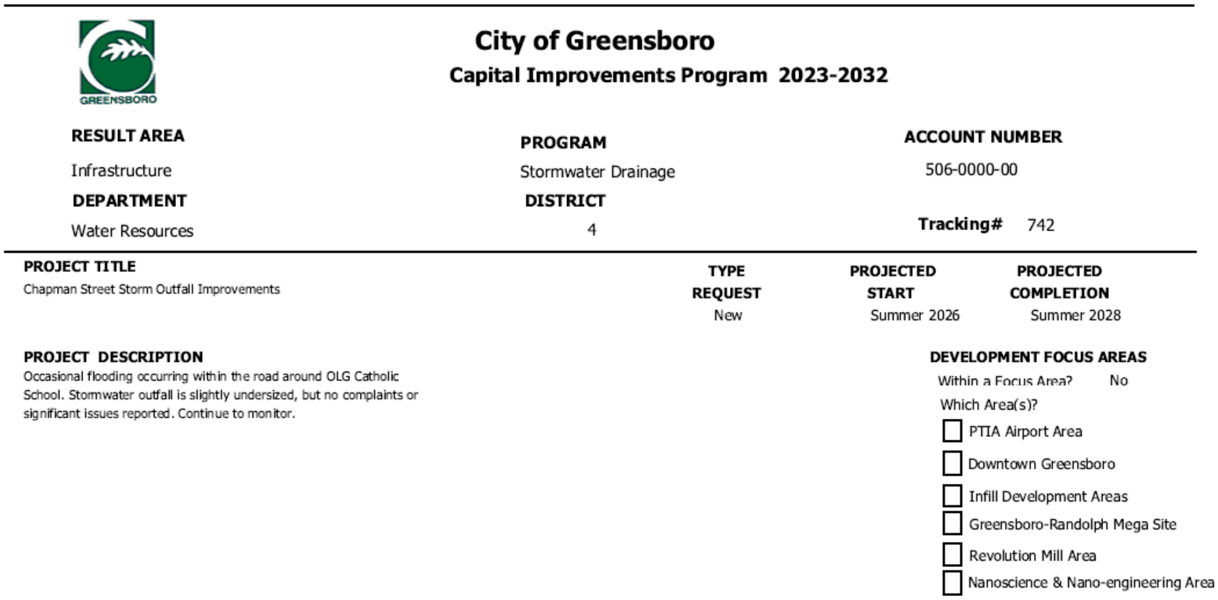
BUDGET COMMENTS



Prescott Street Flooding

Result Area	Infrastructure
Department	Water Resources
Council District	3
Projected Start	Summer 2022
Projected Complete	Summer 2026
Hyperlink	More info
Tracking Num	744

Source: City of Greensboro CIP GIS Mapper & Capital Improvements Program FY 2023-2032



City of Greensboro

Capital Improvements Program 2023-2032

RESULT AREA	**PROGRAM**	**ACCOUNT NUMBER**
Infrastructure	Stormwater Drainage	506-0000-00
DEPARTMENT	**DISTRICT**	
Water Resources	4	**Tracking#** 742

PROJECT TITLE	**TYPE REQUEST**	**PROJECTED START**	**PROJECTED COMPLETION**
Chapman Street Storm Outfall Improvements	New	Summer 2026	Summer 2028

PROJECT DESCRIPTION

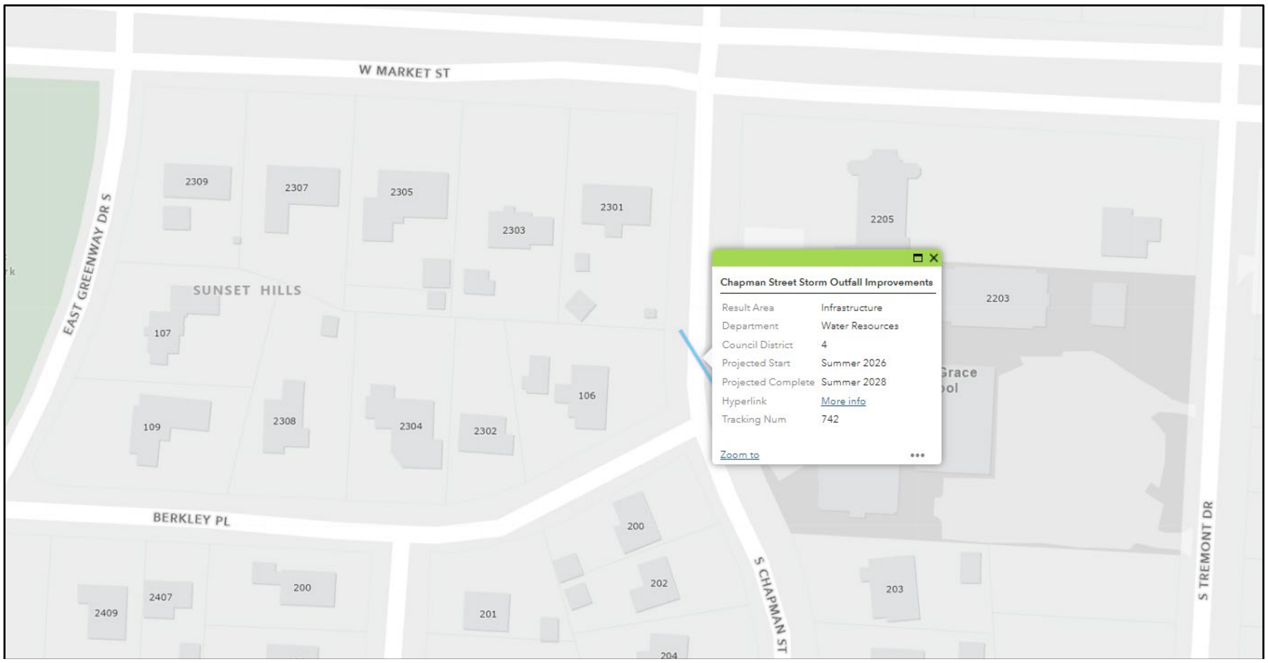
Occasional flooding occurring within the road around OLG Catholic School. Stomwater outfall is slightly undersized, but no complaints or significant issues reported. Continue to monitor.

DEVELOPMENT FOCUS AREAS

Within a Focus Area? No

Which Area(s)?

- ☐ PTIA Airport Area
- ☐ Downtown Greensboro
- ☐ Infill Development Areas
- ☐ Greensboro-Randolph Mega Site
- ☐ Revolution Mill Area
- ☐ Nanoscience & Nano-engineering Area



Chapman Street Storm Outfall Improvements

Result Area	Infrastructure
Department	Water Resources
Council District	4
Projected Start	Summer 2026
Projected Complete	Summer 2028
Hyperlink	More info
Tracking Num	742

Source: City of Greensboro CIP GIS Mapper & Capital Improvements Program FY 2023-2032

City of Greensboro
Capital Improvements Program 2023-2032

RESULT AREA	**PROGRAM**	**ACCOUNT NUMBER**
Infrastructure	Stormwater Drainage	506-0000-00
DEPARTMENT	**DISTRICT**	
Water Resources	NONE	**Tracking#** 741

PROJECT TITLE	**TYPE REQUEST**	**PROJECTED START**	**PROJECTED COMPLETION**
Windshield Glass Outfall	New	Summer 2024	Summer 2026

PROJECT DESCRIPTION

This upgrades the storm drainage system from Downtown. The existing storm is 54" There is a large development east of Windshield Glass that will require relocation of undersized pipe. This would discharge downstream of Wafco Mills

DEVELOPMENT FOCUS AREAS

Within a Focus Area? No

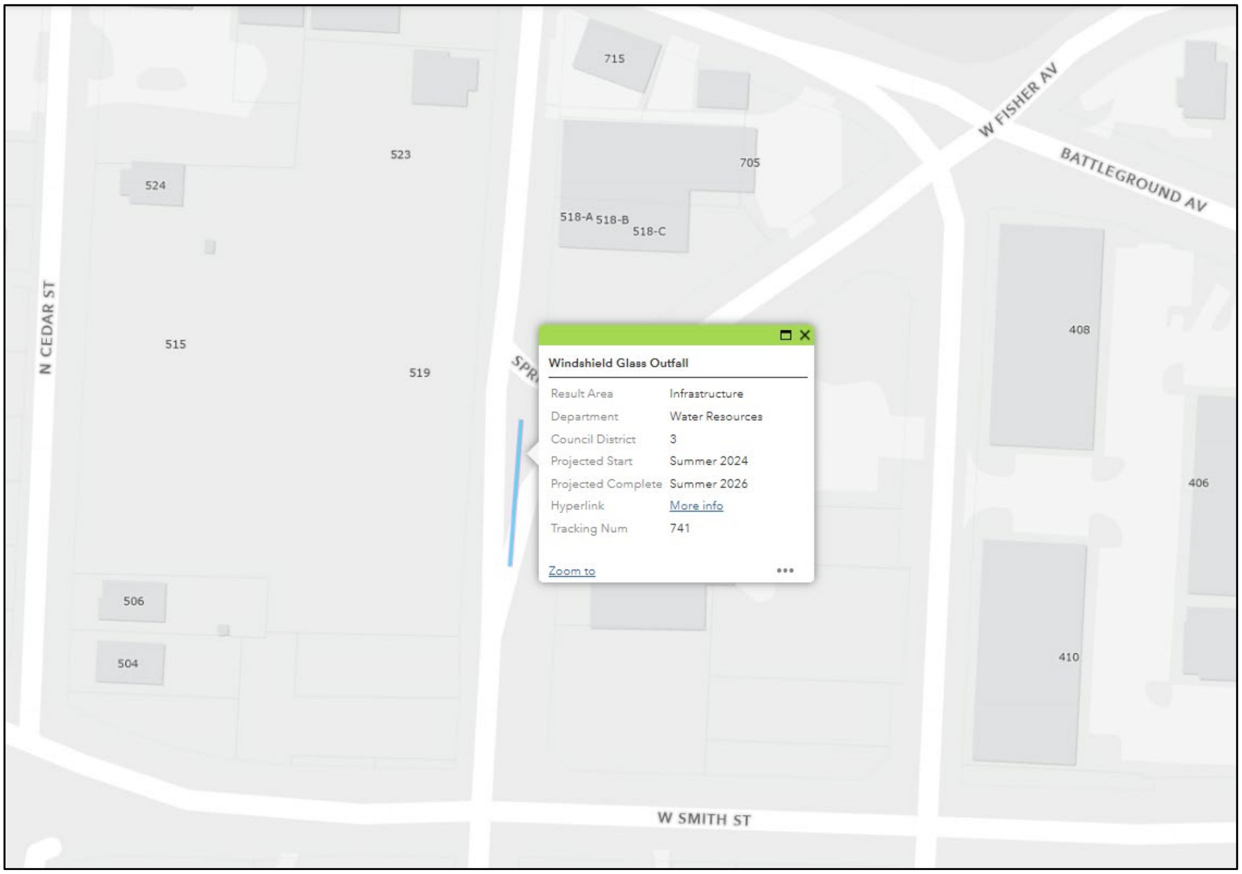
Which Area(s)?

☐ PTIA Airport Area
☐ Downtown Greensboro
☐ Infill Development Areas
☐ Greensboro-Randolph Mega Site
☐ Revolution Mill Area
☐ Nanoscience & Nano-engineering Area

BUDGET INFORMATION

Approved Funding:	$4,300,000
Estimated Budget:	$4,300,000

BUDGET COMMENTS



Windshield Glass Outfall

Result Area	Infrastructure
Department	Water Resources
Council District	3
Projected Start	Summer 2024
Projected Complete	Summer 2026
Hyperlink	More info
Tracking Num	741

Source: City of Greensboro CIP GIS Mapper & Capital Improvements Program FY 2023-2032

City of Greensboro
Capital Improvements Program 2023-2032

RESULT AREA	**PROGRAM**	**ACCOUNT NUMBER**
Infrastructure	Stormwater Management	506-0000-00
DEPARTMENT	**DISTRICT**	
Water Resources	4	**Tracking#** 745

PROJECT TITLE	TYPE REQUEST	PROJECTED START	PROJECTED COMPLETION
Warren/Wright Street Drainage Issue	New	Summer 2022	Summer 2025

PROJECT DESCRIPTION

This project expands on the study by Tetra Tech (contract 202-5045), Flooding is happening at this intersection. Design is based on the recommendations from Tetra Tech study

DEVELOPMENT FOCUS AREAS

Within a Focus Area? No

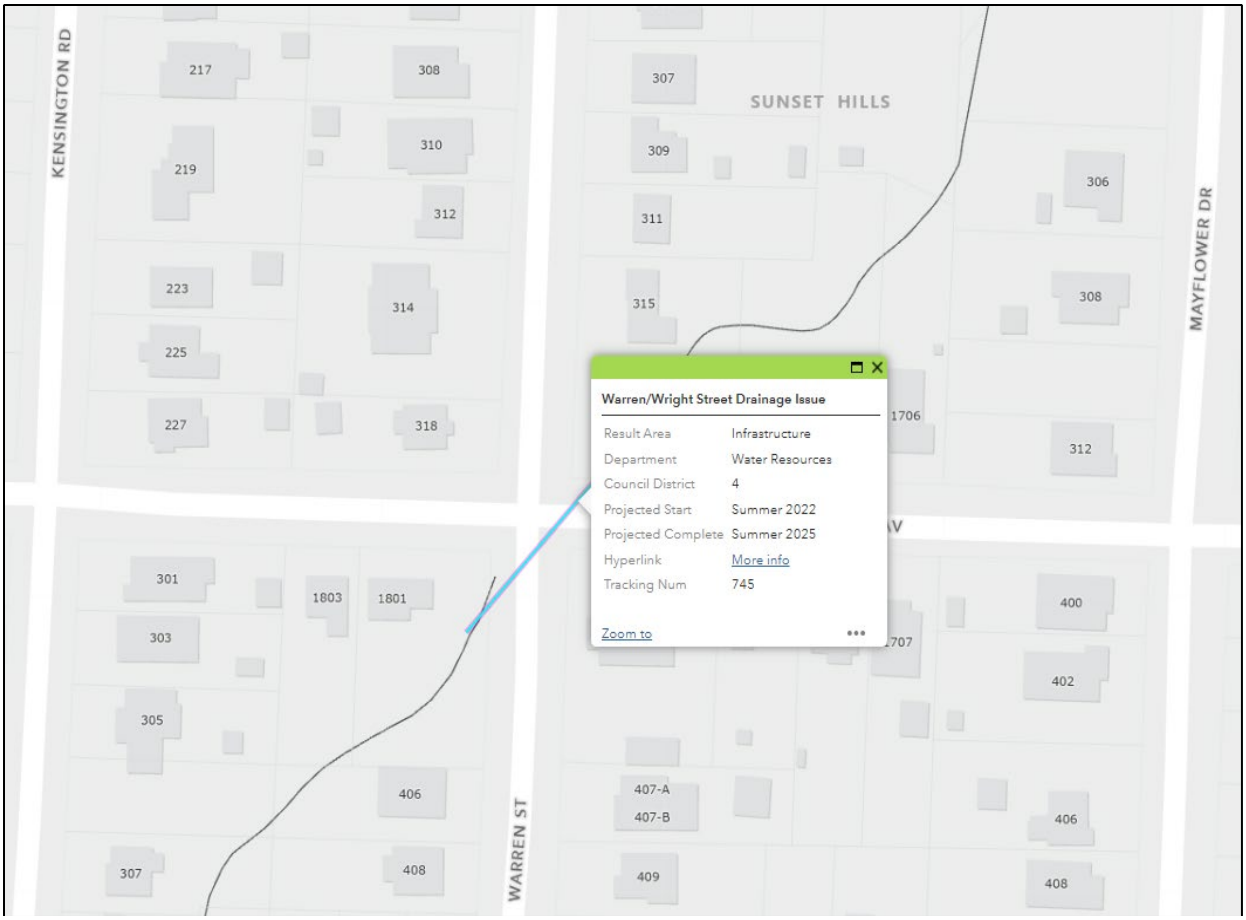
Which Area(s)?

☐ PTIA Airport Area
☐ Downtown Greensboro
☐ Infill Development Areas
☐ Greensboro-Randolph Mega Site
☐ Revolution Mill Area
☐ Nanoscience & Nano-engineering Area

BUDGET INFORMATION

Approved Funding:	$1,500,000
Estimated Budget:	$1,500,000

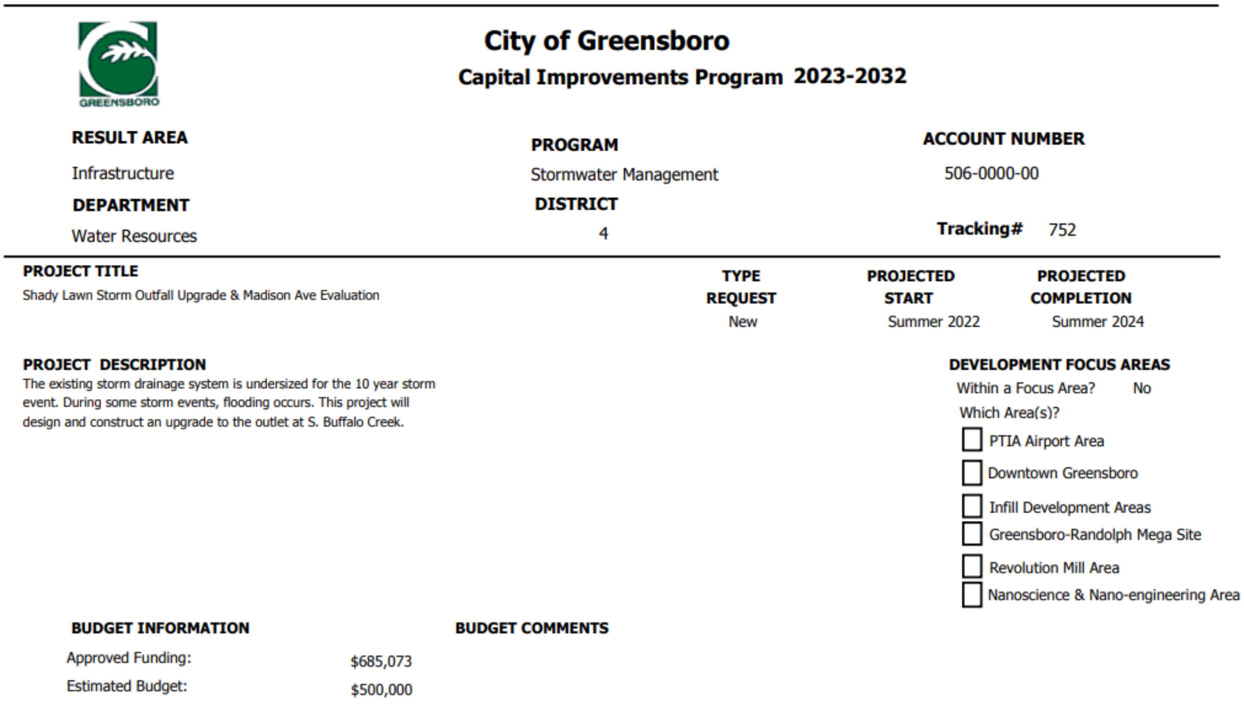
BUDGET COMMENTS



Warren/Wright Street Drainage Issue

Result Area	Infrastructure
Department	Water Resources
Council District	4
Projected Start	Summer 2022
Projected Complete	Summer 2025
Hyperlink	More info
Tracking Num	745

Source: City of Greensboro CIP GIS Mapper & Capital Improvements Program FY 2023-2032



City of Greensboro

Capital Improvements Program 2023-2032

RESULT AREA	**PROGRAM**	**ACCOUNT NUMBER**
Infrastructure	Stormwater Management	506-0000-00
DEPARTMENT	**DISTRICT**	
Water Resources	4	**Tracking#** 752

PROJECT TITLE	**TYPE REQUEST**	**PROJECTED START**	**PROJECTED COMPLETION**
Shady Lawn Storm Outfall Upgrade & Madison Ave Evaluation	New	Summer 2022	Summer 2024

PROJECT DESCRIPTION

The existing storm drainage system is undersized for the 10 year storm event. During some storm events, flooding occurs. This project will design and construct an upgrade to the outlet at S. Buffalo Creek.

DEVELOPMENT FOCUS AREAS

Within a Focus Area? No

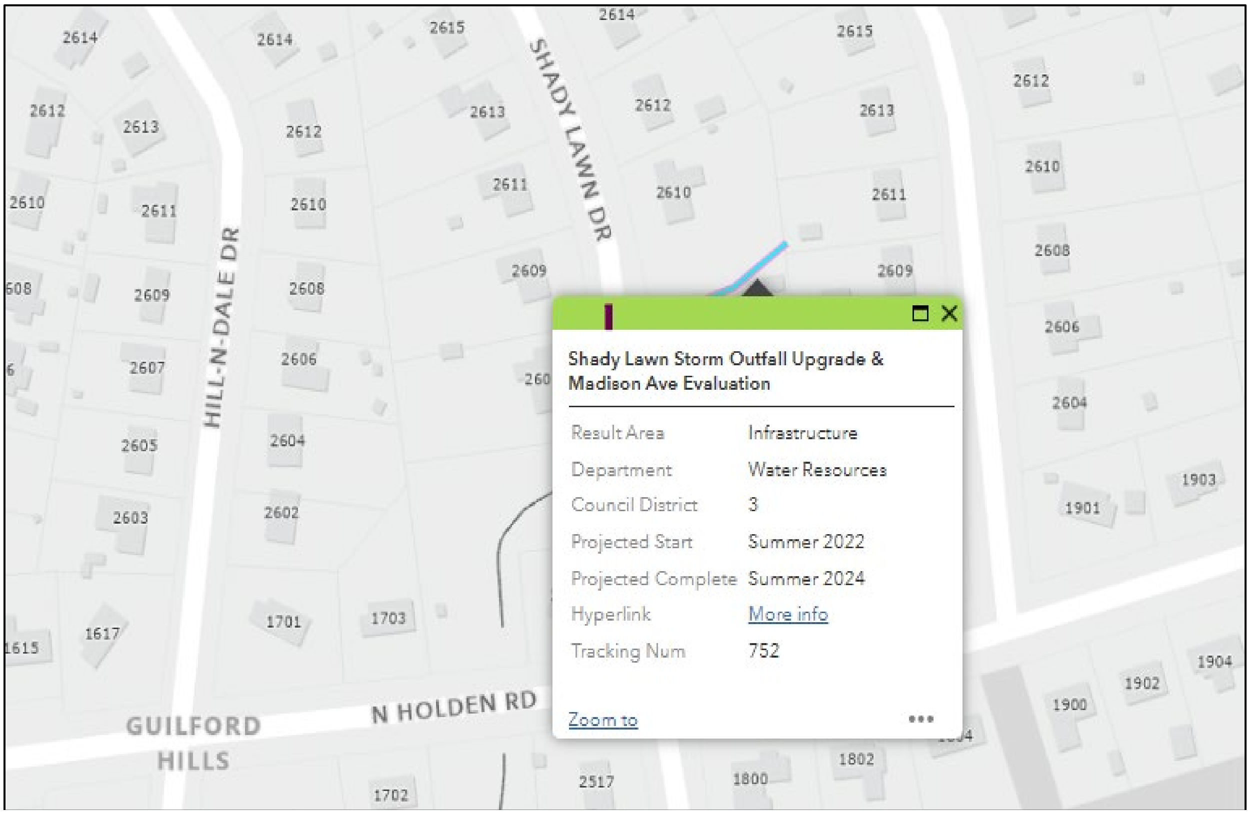
Which Area(s)?

☐ PTIA Airport Area
☐ Downtown Greensboro
☐ Infill Development Areas
☐ Greensboro-Randolph Mega Site
☐ Revolution Mill Area
☐ Nanoscience & Nano-engineering Area

BUDGET INFORMATION

Approved Funding:	$685,073
Estimated Budget:	$500,000

BUDGET COMMENTS



Shady Lawn Storm Outfall Upgrade & Madison Ave Evaluation

Result Area	Infrastructure
Department	Water Resources
Council District	3
Projected Start	Summer 2022
Projected Complete	Summer 2024
Hyperlink	More info
Tracking Num	752

Source: City of Greensboro CIP GIS Mapper & Capital Improvements Program FY 2023-203

Appendix D

Figure 26:UDRiS Dimensions + Proxy Indicators

bri

Dimension	Proxy Indicators	Description	Source
Urban Drainage System (DRI) Resilience Index	Pipe Condition Index	Represents the condition of the urban drainage system relative to system age.	Kannapiran et al., 2008
	Pipe Capacity Index	Represents the probability of the urban drainage system exceeding the design capacity relative to a communities' perception of resilience (aspirational rainfall event)	Waller, 2023
	Climate Change Score	Represents the frequency in which high-intensity rainfall events results in reported flooding events.	Waller, 2023; adapated from Karmaoui, 2020
	Flood Damage Potential Score	Represents the potential of the urban drainage system to create a flooding event that results in damage to structural and personal property.	Lee & Kim, 2017
	Drainage System Maintenance Score	Represents the local drainage maintenance practices such as pipe flushing and debris removal associated with urban drainage systems that are performed to a culture of hazard prevention and preparedness.	Waller, 2023
	Local Drainage Protection	Represents the local drainage protection policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.	Atreya & Kunreuther, 2016
	Stormwater Management Regulations	Represents the local stormwater management policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.	Atreya & Kunreuther, 2016
Index of Socio-economic Resilience (SIR)	**Proxy Indicators**	**Description**	**Source**
	Poverty and race	Represents the percentage of the population below the poverty line.	Barry et al, 2011; Cutter et al., 2013
	Age	Represents the percentage of the population over 65 years old.	Barry et al, 2011; Cutter et al., 2013
	Wealth	Represents the household wealth	Barry et al, 2011; Cutter et al., 2013; Fu & Wang, 2008
	Migration and renters	Represents the percentage of renter-occupied housing units and of foreign-born citizen	Cutter et al., 2013
	Gender	Represents the percentage of population that identify as female.	Cutter et al., 2013
	Ethnicity -Hispanic	Represents the percentage of the population that identify as non-white	Cutter et al., 2013
	Special needs	Represents the per capita number of community hospitals and residents in nursing homes	Cutter et al., 2013

Figure 25: UDRiS Dimension + Proxy Indicators (cont)

Dimension	**Proxy Indicators**	**Description**	**Source**
Community Preparedness Rating (CPR)	CIP-Flood Prevention Funds Allocated	Represents the flood prevention fund allocated through the Capital Improvements Planning Process	Waller, 2023
	Flood Protection Assistance	Represents the local flood protection assistance policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.	Waller, 2023; adapated from Horney et al., 2017
	Drainage System Maintenance Score	Represents the local drainage maintenance practices such as pipe flushing and debris removal associated with urban drainage systems that are performed to a culture of hazard prevention and preparedness.	Atreya & Kunreuther, 2016
	Local Drainage Protection	Represents the local drainage protection policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.	Waller, 2023
	Stormwater Management Regulation Score	Represents the local stormwater management policies and best practices that are recognized by FEMA's Community Rating System that creates a culture of hazard prevention and preparedness.	Atreya & Kunreuther, 2016
	Community-Faith Based Organizations Factor	Represents the number of community and faith base organizations.	adpation of Campanella, 2006; Cutter et al, 2010; Fu &Wang, 2008
Community Response Rating (CRR)	**Dimensional Factors**	**Description**	**Source**
	Public Safety Factor	Represents the capacity of first responders to respond during and immediately after pluvial flooding events.	Waller, 2023
	Community-Faith Based Organizations Factor	Represents the number of community and faith base organizations.	adpation of Campanella, 2006; Cutter et al, 2010; Fu &Wang, 2008
Community Recovery Index (CRI)	**Dimensional Factors**	**Description**	**Source**
	Flood Damage Recovery Factor	Represents the recovery capacity of a population based on the anticipated magnitude of flood damage.	Waller, 2023
	Socio-economic Recovery Factor	Represents the recovery capacity of a population post-pluvial flood event.	Waller, 2023
	Wealth	Represents the wealth of a population.	Fu & Wang, 2018
	Designated Flood/Disaster Recovery Funds (Local Level)	Represents the locally appropriated funds specifically designated for flood/disaster recovery.	Waller, 2023; adapated from Horney et al., 2017