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Understanding Combined Sewer Overflow (CSO) and Green Infrastructure Interaction in New Jersey : An Economic Analysis

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UNDERSTANDING COMBINED SEWER OVERFLOW (CSO) AND GREEN INFRASTRUCTURE INTERACTION IN NEW JERSEY: AN ECONOMIC ANALYSIS

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UNDERSTANDING COMBINED SEWER OVERFLOW (CSO) AND GREEN INFRASTRUCTURE INTERACTION IN NEW JERSEY: AN ECONOMIC ANALYSIS

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ABSTRACT

New Jersey, as a coastal area, has historically struggled with a variety of problems stemming from stormwater runoff, which have only grown more prevalent and harmful as urbanization and climate change have taken their toll. One such issue that has emerged in recent years is the prevalence of combined sewer overflows (CSOs). These sewer systems are common in urban areas in the United States and abroad, and increased urbanization has them not only obsolete but a persistent danger, as their discharges can contaminate waterways and affect human health. While municipalities across the United States are beginning to move towards mitigating or replacing CSO systems, many areas still struggle to do so due to cost. Further, few studies have been done to understand the full cost of CSOs, as externalities such as effects on society or housing markets are largely understudied. As such, this study proposes a number of interlinked economic valuations to understand the costs of CSOs and the benefits of their solutions. To understand costs, we utilize a hedonic analysis using observable real estate data to understand the economic impact of CSOs on the housing market. As CSOs are heavily regulated by the EPA, there is significant value in also understanding the benefit of possible solutions to the problems that CSOs represent. To this end, we analyze green infrastructure, which has been used extensively around the United States and abroad to cheaply and effectively limit CSO discharges. We use a choice-experiment survey to delineate willingness to pay in target cities, and to understand preferences of residents in terms of green infrastructure capabilities and payment vectors for funding such projects. Finally, we use an ArcGIS linked framework to analyze the potential benefit of green infrastructure in terms of runoff reductions, and understand what land use types are ideal for installation. The combination of these economic analyses should give a more complete picture of the full cost of these fixtures than has existed in the literature to date, and can be useful to researchers and decision makers alike.

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CONTENTS

CHAPTER 1. INTRODUCTION

1 New Jersey, Stormwater Management, and Combined Sewer Overflows (CSOs)

New Jersey, as a coastal state, has often dealt with problems stemming from flooding and the stormwater runoff issues that stem from it. Historically, the state's industrial past has caused numerous issues in how humans and urban environments affect their surroundings, particularly in terms of pollution and contamination in the biosphere and hydrosphere. Today, with growing concerns over climate change and its effects on storms and sea level rise, New Jersey faces considerable risk in how issues of pollution and contamination will interact with evolving challenges. One issue of particular concern in such an environment is the effect of combined sewer overflows (CSOs) on the surrounding environment. CSO infrastructure is fairly common in many of New Jersey's urban areas, and represents considerable risk for human and environmental health. During storm events, CSOs can often fail and discharge combined runoff and sewer waste bound for water treatment plants into nearby waterways, causing significant environmental contamination, often in waterways that are already polluted. This discharge carries with it serious health risks, as it spreads contaminants such as human sewage, garden waste, chemicals, oils, and residential pollution; these pollutants can affect humans either via ingestion or recreational contact, and can cause negative phenomena such as eutrophication in affected water bodies. While this effect has been well documented in large storms such as Superstorm Sandy, where large amounts of contaminants made their way into water bodies, CSOs fail on a regular basis during typical storm events for a variety of reasons, largely exacerbated by rising populations and increasing impermeable surface in urban areas. Therefore, this is a regularly occurring problem that thus far has few effective solutions.

The response to these problems has been somewhat sluggish, and the rising sea levels and increasing storm frequency/intensity as a result of climate change stands to complicate the issues. In order to address the problem, the EPA has created guidelines that require CSO operators to have short and long term control strategies to deal with the discharges, and require cities with CSO permits to develop long term mitigation strategies. Cost, as with any project in a municipality, is a major determinant of action, and thus many cities have hesitated in pursuing management solutions as a result of the often prohibitive costs of upgrading or otherwise mitigating this infrastructure. However, though grey infrastructure has traditionally been used as the primary stormwater mitigation tool, there is a rising desire for the use of green infrastructure as part of the overall mitigation strategy. Green infrastructure has become more common in the past decade, and can be useful in mitigating CSOs in urban areas because they can help slow stormwater runoff during a storm by increasing infiltration, which therefore leads to less water to overwhelm a CSO and trigger a discharge event. Furthermore, green infrastructure has considerable value economically, as it can have a host of other benefits including biofiltration and improving aesthetics. Critically, it can be a relatively inexpensive option, as it can be installed in a variety of areas, and doesn't necessitate removing or upgrading the current sewer system.

2 CSO History, Function, and Issues

CSOs are becoming an increasingly glaring environmental and human health issue as research strives to better determine the damage done by this infrastructure. Combined sewers represent an aging design introduced in the 1800s that was meant to better accommodate urban areas with rapidly expanding populations. These systems had some precedent for success in European cites, and generally were chosen by growing cities over separated sewers because they were cheaper, easier to maintain, and considered better suited in dealing with agricultural runoff. (Burrian et al., 1999). CSO discharges were designed in line with the common strategy for wastewater disposal at the time, which called for treating the water with dilution into water systems when a treatment plant was unavailable (Burrian et al., 1999). In the late 1800s, concern grew over the effect of wastewater in the environment as it related to diseases in humans, and studies have since identified the negative effect of CSO discharges on water systems. Modeling and studies have become increasingly complex and accurate since the implementation of these systems, and have been effective in pointing out their flaws, particularly in the lens of modern problems and trends (Burrian et al., 1999; Schroeder et al., 2011; Sandoval et al., 2013).

Combined sewer systems are characterized by a design of sewer infrastructure that uses a common pipe in order to transport sewer water, such as sewage and other residential waste, along with runoff and other waste water, to its destination at a water treatment plant. Under normal circumstances, runoff waste water will travel from the street level down into this combined pipe, keeping this water separate until treatment. This combined design, however, can fail during rain events with high runoff; too much water entering the pipes may overwhelm the system, and the wastewater will then be discharged. Urban areas, which are characterized by a high percentage of impervious surface, contribute to this problem, and rainfall events that are not particularly significant may still cause CSOs to be overwhelmed. Changing water dynamics and other uncertainties caused by global climate change have given these issue more urgency, as increased discharge from CSOs brought on by rising water levels or increased storm frequency or strength could make contamination more common (Jagai et al., 2015; Keupers and Williams, 2013; Li et al., 2019). Further, these events exacerbate existing problems with increasing flooding, including threats to public infrastructure, urban networks, and resident health and property, especially for vulnerable populations (Venkataramanan et al., 2020).

3 CSO Effects on Human and Environmental Health

CSOs create significant problems for both human and environmental health, the effects of which have been well documented in the literature. CSOs, when they discharge, can put significant amounts of environmental, chemical, and anthropogenic wastes and hazards into waterways; the EPA estimates that over 23 billion gallons of untreated sewage may be discharged into North Jersey waters due to CSO failures annually (EPA, 2012). What makes the issue of CSOs particularly difficult and problematic is its frequency, and how easily these systems can be overwhelmed; some urban areas of New Jersey can face discharge events due to the system being overwhelmed with as little as one inch of rainfall (Battelle, 2005; Donovan et al., 2006). These mild events, though not to the scale that larger storms such as Irene or Sandy, can still trigger stormwater discharge that is sufficient to cause significant waterway contamination or toxicity, especially near the discharge site (Casadio et al., 2010; Sandoval et al., 2013).

While the discharge of numerous pollutants into waterways as a result of CSOs is obviously problematic, several studies have noted the danger they pose to both human and environmental health. During a discharge event, untreated sewage is the contaminant that is the biggest cause of concern for human populations, as it includes microbial pathogens, viruses, and protozoa, which are all linked to illness in humans at certain concentrations. Microbial pathogens, for example, are the second leading cause of water body impairment in the United States, and are known to cause gastrointestinal, respiratory, skin, eye, ear, nose, and throat diseases due to exposure (Donovan et al., 2006). Jagai et al. (2015) used hospital visits to examine the effects of CSO discharge on local populations; the study found that in the 10 days following a discharge event, there was a 13% increase in emergency room admittances for gastrointestinal illness in urban Massachusetts. Microbial pathogens, which are the second leading cause of numerous health impairments, including gastrointestinal ones, are present in abundance in CSO discharges, and thus the study concluded that hospital admittance rose as a result of discharge into drinking water (Donovan et al., 2006; Jagai et al., 2015). This phenomenon is not uncommon, as high concentrations of fecal coliforms and other dangerous microbes as a result of CSO discharge have been tied to waterborne disease outbreaks in the United States and abroad, such as in Milwaukee, Cincinnati, New York, and Tokyo (Donovan et al., 2006; Brokamp et al., 2017; Jagai et al., 2015; Shibata et al., 2014). However, though drinking water contamination presents the most serious risks to human health, CSO contamination can also be dangerous to contact that does not involve ingestion; the EPA estimates that between 1.8 and 3.5 million people become ill due to recreational contact with water contaminated by sewer outfalls (Veronesi et al., 2014).

CSOs also contribute to pollution through the collected storm runoff being discharged into the stream, as it may contain chemicals, fertilizers, and other pollutants that can cause environmental damage; nitrogen and phosphorous can be responsible for outbreaks of eutrophication in waterways in which their concentrations get too high, and the increasing occurrence of pharmaceuticals and other personal care products in residential and commercial waste can cause environmental damage, particularly to the resident aquatic life (Veronesi et al., 2014). The extent of damage caused by CSO discharges is largely dependent on intensity, duration, and depth of wastewater, but even mild rainfall can cause dangerous levels of contamination and toxicity near the discharge site (Casadio et al., 2010; Sandoval et al, 2013).

4 Efforts to Mitigate CSO Impacts

In response to the environmental concerns and in an attempt to protect the health of the public, the US Environmental Protection Agency has made efforts to regulate the usage of CSO systems. The Clean Water Act includes provisions to mitigate CSO issues; under the Act, municipalities must have a permit for CSO discharges, must meet 9 technological control minimums, and must develop a long term plan to mitigate or eliminate CSO discharges, preferably with the input of stakeholders and affected populations (USEPA, 2011; USEPA, 2013). Though progress in some areas has been slow, the enforcement of this legislation has had some success in encouraging municipalities to pursue solutions to CSO infrastructure. Perth Amboy, New Jersey had failed to meet the requirements of the legislation and, in addition to the fine they faced, have spent $5.4 million towards projects to improve sewer infrastructure (USEPA, 2012). Oswego, New York is a success story stemming from this Act, as improvements that have been planned and implemented are estimated to eliminate 30 CSO discharge events annually and prevent over 10 million gallons of overflow from reaching local waterways (USEPA, 2013).

Provisions in the Clean Water Act are forcing municipalities across the United States to improve CSO infrastructure, so naturally cost is a key concern. While costs associated with upgrading infrastructure are the primary factor to determine the feasibility of a project, benefit-cost analyses may not fully represent the cost of damages brought on by CSOs. Due to constrained budgets, limited resources, and difficulties due to institutional structures already in place, rapid adjustment to these and other climate change exacerbated issues is difficult (Bowen and Lynch, 2017).

5 Green Infrastructure as a Control Mechanism

Green infrastructure refers to source control measures that reduce stormwater flow by promoting infiltration, evapotranspiration, and the capture and reuse of rainwater (de Sousa et al., 2012). Green infrastructure has grown in popularity in part due to its utility; green infrastructure takes a number of different forms, including green roofs, rain gardens, biofiltration basins, and permeable pavement, all of which act in varying capacity to reduce the overall amount of impervious surface area in an urban setting (USEPA, 2013). Reducing impermeable area in this way can reduce stormwater runoff and delay lag time, which can reduce flooding and the negative effects caused by it (Li et al., 2019). Green infrastructure variety allows it to be used in a number of settings, including in areas that traditional grey infrastructure generally has difficulty utilizing effectively, such as rooftops (USEPA, 2013; Li et al., 2019). Though the increased infiltration of stormwater is one of the primary draws of this infrastructure, it also has a host of other benefits, both for sustainability and more generally; studies have found that different kinds of green infrastructure can remove pollutants from water, enhance carbon sequestration, reduce urban heat island effect, improve air quality, increase drought resilience, control temperature, and improve aesthetics and real estate value, among other benefits (Abhijith et al., 2017; Cohen et al., 2012; De Sousa et al., 2014; Li et al., 2019; Venkataramanan et al., 2019; Venkataramanan et al., 2020; Zhang and Chui, 2018). Though grey infrastructure can present a more effective solution in terms of flooding risk, the use of green infrastructure can avoid some of its shortcomings, including increasing non-point source pollution, water quality deterioration, groundwater shortage, and changes in air temperature, humidity, and evapotranspiration (Zhang and Chui, 2018).

Cities around the United States and abroad have begun to make green infrastructure a part of their plans for CSO issues, among others, including New York, Kansas City, and Chicago (De Sousa et al., 2014; Cohen et al., 2012); Philadelphia has taken an innovative lead in the push against CSOs, relying heavily on green infrastructure installations around the municipality to incrementally reduce discharges while providing significant benefit to its economy (Econsult, 2016; Philadelphia Water Department, 2017). Studies carried out in many of these areas and others have found that green infrastructure is a cost effective solution, especially in comparison to traditionally used grey infrastructure (USEPA, 2007; USEPA, 2013; Auckland Regional Council, 2009; Li et al., 2019; Nordan et al., 2018); a study by Cohen et al. (2012) used the study area in Turkey Creek, Kansas to model and compare the prices of green infrastructure as compared to grey infrastructure alternatives. The study found that applying rain gardens to augment some grey infrastructure improvements rather than use grey infrastructure exclusively could save between $22 and $35 million for this CSO drainage area, and significantly reduce the amount of storm runoff to force CSO discharge. Thus, as both a cost saving and effective measure against CSOs and increasing storm runoff in general, green infrastructure has become a staple in many areas worldwide. However, despite these quantified benefits, the adoption of green infrastructure has been relatively slow (Bowen and Lynch, 2017).

6 Study Area

New Jersey is home to a significant number of CSO sites, particularly in the industrialized and urbanized areas in the northern part of the state. The Newark Bay and the

Lower Passaic region of New Jersey are noted for the considerable pollution and contamination of water bodies, largely as a result of historical and continuing industrialization, manufacturing, and urbanization. Several water bodies, including the Passaic River, flow through this area, which is densely populated and industrialized. Nearly 40 CSO outlets discharge into the Newark Bay/Kill van Kull area, and another 22 discharge into other waterways in this region. This area has several of the factors that put it at risk for high frequency and volume of CSO discharge events, notably a large percentage of impervious surface. As such, this area experiences increased overland flow volume and frequency during rain events, resulting in flooding, and therefore CSO discharges. In the wake of Hurricane Sandy, in which large amounts of discharge contamination was released into local waterways, the state administration is taking steps to improve the resilience of this area and others in New Jersey that are at risk during future extreme weather events (NJDEP, 2016).

Newark, Elizabeth, and Paterson are all cities within this area that have some of the highest numbers of outfalls in the state, with 17, 28, and 24 outfalls, respectively. All three cities are among the highest population centers in New Jersey for both population and population density, which exacerbates the health issues that CSOs present. These cities also continue to grow, and considering that CSO discharges are strongly affected by stormwater runoff due to impervious urban surfaces, these cities serve well as examples for areas vulnerable to worsening consequences of using CSOs. It is also worth noting that these cities all suffered damages during Hurricane Sandy in 2011, and were subject to considerable contamination stemming from CSO discharge events throughout the storm. Further, these areas have high rates of poverty, low college graduation rates, and high minority populations, which can make these areas of note for environmental justice concerns. The 2010 census data for these areas is summarized in Table 1 below:

Table 1: Census and EPA Population and Demographic Statistics for Study Areas

	Newark	Elizabeth	Paterson
Population	280,463	128,153	145,800
Number of CSO Outfalls	17	28	24
Poverty Rate	28%	18.4%	28.1%
Demographics	White alone 26.1% Black or African American alone 49.7% American Indian and Alaska Native alone 0.5% Asian alone 2.1% Hawaiian or Other Pacific Islander alone 0% Some other race alone 19.1% Two or more races 2.4%	White alone 45% Black or African American alone 18.6% American Indian and Alaska Native alone 0.5% Asian alone 2.0% Hawaiian or Other Pacific Islander alone 0% Some other race alone 30.2% Two or more races 3.7%	White alone 29.3% Black or African American alone 26.5% American Indian and Alaska Native alone 0.1% Asian alone 3.8% Hawaiian or Other Pacific Islander alone 0% Some other race alone 35.6% Two or more races 4.7%
College Education	Associate's Degree 5.5% Bachelor's Degree 10.4% Graduate or professional degree 4.4%	Associate's Degree 4.5% Bachelor's Degree 9.3% Graduate or professional degree 3.9%	Associate's Degree 3.4% Bachelor's Degree 8.4% Graduate or professional degree 2.4%
Median Household Income	$35,181	$46,975	$39,282

2018 American Community Survey 5-Year Estimates via data.census.gov

7 Research Objectives

While municipalities across the United States are beginning to move towards mitigating or replacing CSO systems, many areas still struggle to do so due to cost. Further, few studies have been done to understand the full cost of CSOs, as externalities such as effects on society or housing markets are largely understudied. As such, this study proposes a number of interlinked economic valuations to understand the costs of CSOs and the benefits of their solutions. The combination of these economic analyses should give a more complete picture of the full cost of these fixtures than has existed in the literature to date, and can be useful to researchers and decision makers alike. The proposed components are as follows:

1. A hedonic analysis using observable real estate data to understand the economic impact of CSOs on the housing market. The hedonic study will use relevant data to estimate the costs of CSOs on population, which may reveal significant social costs.
2. A choice-experiment survey to delineate willingness to pay in target cities, and to understand preferences of residents in terms of green infrastructure capabilities and payment vectors for funding such projects. Though green infrastructure is a popular tool to mitigate CSO discharges and other stormwater flow issues, municipalities can often struggle to find effective funding vectors or understand public needs; projects that mitigate the effects of CSOs can incur significant capital and require public support, but even when projects succeed, they may not be equitable or meet residents' needs. As such, the choice experiment survey will reveal resident preferences for green infrastructure, which can both provide novel economic analyses and timely data for cities looking to create green infrastructure programs.

3. Spatial analysis through ArcGIS will estimate the impact of various green infrastructure installation scenarios in the target cities, and optimization analysis will be used to suggest ideal scenarios for individual cities. This stormwater runoff framework will demonstrate potentially avoided runoff in across different storm intensity, permeability, and land type permutations and estimate the costs of the optimal scenarios, all while using precise ArcGIS analysis to target impermeable areas.

This project will provide relevant economic analyses on these prevalent human and environmental health problems. Though CSOs are a considerable issue in many urban areas, including many in New Jersey, we are currently unaware of any studies that look to understand the costs and benefits of CSOs in this way. This work provides novel primary data for a problem that is both persistent and worsening in many areas in New Jersey, the United States, and beyond. While economic studies have been done for CSOs and green infrastructure broadly, there are currently few uniform solutions to problems caused by CSO discharges. Broader and deeper economic analyses will provide more intricate data that municipalities can use to plan more effective and efficient strategies for eliminating CSO discharges and utilizing green infrastructure. This can be useful for the cities in question, as the decision makers here will be able to assess economic tradeoffs and the needs of their populace directly. However, this study may also be useful in a wider context; areas with similar attributes or demographics may be able to use this data to make comparable programs and solutions, or can use similar techniques to build economic analyses of their own.

In Chapter 2, we apply a hedonic model to the study areas to understand the effects of CSOs on local real estate prices. This method combined Garden State Multiple Listing Service (GSMLS) real estate data with ArcGIS MOD-IV data to accurately represent household, neighborhood, and environmental attributes over 2336 residences in the study area. We then carried out a hedonic regression for these households to estimate amenity and disamenity values of attributes in the study area, and measure implicit price. This study serves to estimate the true cost of continued CSO use in the study areas by accounting for changes in market value that may not necessarily be accounted for in cost benefit analyses. This may be useful for land managers and decision makers as they plan how best to move with CSO control and mitigation.

In Chapter 3, we use a discrete choice experiment model to understand resident preferences and willingness to pay (WTP) for green infrastructure. We administered surveys through the online sampling firm Qualtrics in the study area, gathering opinions on what attributes of green infrastructure residents preferred, including distance to their residence, cost, secondary attributes, and runoff mitigation capabilities. We analyzed the sample to see how strongly options were preferred and avoided, and also performed a WTP analysis to estimate an implicit price for each attribute. This study serves to better understand the preferences of the public in regards to green infrastructure, which are critical in facilitating higher levels of adoption in urban populations. This information could be useful in guiding policy planners towards implementing green infrastructure programs that are in line with what residents would like to utilize.

In Chapter 4, we utilize a GIS-informed stormwater runoff model to predict the effectiveness of green infrastructure installation over multiple scenarios. GIS modeling was used to give an accurate representation of land cover areas, and recognizes impermeable area such as roofs, roads, and sidewalks. This data was then used to inform a model to calculate runoff using the NRCS Curve Number method under various storm intensity, curve number, and green infrastructure conversion scenarios. We then used an optimization analysis to estimate the most cost effective scenarios for each city. This study can be useful for cities to get a rapid assessment of potential green infrastructure runoff reductions, and can provide a range of values to account for variability within green infrastructure types.

In Chapter 5, we discuss the overall conclusions from these studies. We evaluate the findings of the economic analyses, as well as suggest how these findings may affect the overall understanding of CSO and green infrastructure related economics.

CHAPTER 2. A HEDONIC ANALYSIS OF COMBINED SEWER OVERFLOWS (CSOS) IN NORTHERN NEW JERSEY

ABSTRACT: Significant water pollution caused by flooding due to heavy precipitation and extreme weather events has become a considerable problem, and changing weather patterns and sea level rise attributable to global climate change stand to further exacerbate the issue. During heavy precipitation events, combined stormwater and untreated sewage may be diverted to adjacent water bodies via combined sewer overflows (CSOs), resulting in contamination and water pollution that can be harmful to human and environmental health. Though water quality effects of CSO discharges have been studied, the socio-economic aspects of this infrastructure has not received much scientific attention. This study provides an analysis of the socio-economic impacts from the continued use of CSOs in the communities of Elizabeth, Newark, and Paterson in northern New Jersey through a hedonic analysis of disamenity value for residential properties near CSOs. We use GSMLS real estate data and county MOD-IV data in a GIS overlay to map residences and household, neighborhood, and environmental attributes in these urban New Jersey areas. We the use the data from GIS analysis in logistic regressions to analyze the significance of a number of these attributes, including proximity to the nearest CSO, and estimate the economic effect that each factor has on a residence's sale price. This information is critical for revealing the socio-economic consequences of continued CSO operation, and can be used to inform CSO management strategies, including the use of green infrastructure, to understand economic impacts and intuit public perceptions of various strategies.

1. INTRODUCTION

Historically, New Jersey has struggled with different environmental issues stemming from its rapid and widespread urbanization. One such problem that has become more prevalent with increased population density is the frequency of discharges from combined sewer overflow (CSO) systems. Discharges from these systems are a significant concern for human and environmental health during rainfall events due to the pollutants they release into local waterways. In the wake of Hurricane Sandy and similar storms in the past, New Jersey has become increasingly aware of the damage that large storms have the potential to cause, and have begun to seek out ways to reduce damage and become more resilient.

CSOs, particularly during heavy rainfall events, can release discharges containing significant levels of pollutants, notably human sewage, garden waste, chemicals, oils, and residential pollution into nearby waterways; the EPA estimates that over 23 billion gallons of untreated sewage may be discharged into North Jersey waters due to CSO failures annually (USEPA, 2012). Urban areas, which are characterized by a high percentage of impervious surface, are particularly vulnerable to these events because water cannot infiltrate easily, and rainfall events that are not particularly significant may still cause CSOs to be overwhelmed; some urban areas of New Jersey can be overwhelmed with as little as one inch of rainfall (Battelle, 2005; Donovan et al., 2006). These discharges therefore lead to untreated waste entering waterways, creating a notable health risk for both the environment and humans in the form of microbial and environmental contamination; the EPA estimates that between 1.8 and 3.5 million people annually become ill due to recreational contact with water contaminated by sewer outfalls (Veronesi et al., 2014). Though disastrous storm events are the biggest concern for contamination, even mild amounts of rainfall can be the cause of significant contributions to local waterway contamination (Casadio et al., 2010).

Because provisions in the Clean Water Act are forcing municipalities across the United States to improve CSO infrastructure, cost is a key concern. The EPA has created guidelines that require operators to have short and long term control strategies for these outfalls, though some municipalities have struggled to reach those targets (NJDEP). One of the key controls is a permit that allows for discharges, but permits issued since 2015 in New Jersey come with the requirement that the cities in control of the permit must develop long term plans to control and mitigate discharges from CSOs (NJDEP). Due to the high cost of replacing such infrastructure, attention to different economic models for reaching these goals is of the utmost importance (USEPA, 2007; Auckland Regional Council, 2009).

While installation and maintenance costs of different grey CSO solutions are fairly well documented, less attention has been paid to the socio-economic aspects of stormwater reduction options and the green infrastructure that can potentially mitigate it. Those residing within close proximity to CSOs stand to feel the effects of CSO-created pollution most strongly, making community acceptance of CSO solutions of utmost importance. As such, this study attempts to examine these issues using a hedonic modeling approach. The hedonic analysis aims to delineate the effect that proximity to a CSO outfall has on a property value, which in turn can help to inspect the effect on CSOs on the housing market overall and how those most affected by CSOs due to their proximity are affected economically. This technique aims to provide a more complete picture of the costs and benefits of CSO infrastructure by taking into account the costs that individuals perceive or must deal with as a result, and the effect that it has on the economy of the area. This study seeks to fill a gap in the research by using this hedonic method to evaluate the disamenity value of CSO discharge outfalls. As CSOs remain prominent in the American Northeast and elsewhere in the United States, this study could provide telling data to assist management officials in this area with financial decisions in the face of a growing effort by the USEPA and NJ Department of Environmental Protection to mitigate CSO risks.

2. LITERATURE REVIEW

2.1 Human and Environmental Health Impacts

While it is clear that CSOs are a cause of concern due to discharge of raw sewage and other contaminants in nearby waterways, extensive modeling and study has made their relationship with the environment clearer (NJDEP, 2019; Soriano and Rubio, 2019; Salerno et al., 2018; Fu et. al, 2019). During a discharge event, untreated sewage is the contaminant that is the primary cause of concern for human populations, as it includes microbial pathogens, viruses, and protozoa, which are all linked to illness in humans at certain concentrations. Microbial pathogens, for example, are the second leading cause of water body impairment in the United States, and are known to cause gastrointestinal, respiratory, skin, eye, ear, nose, and throat diseases due to exposure (Donovan et al., 2006). A study by Jagai et al. (2015), linked extreme weather effects to a 13% increase in gastrointestinal diseases in the 10 days following a discharge event. Donovan et al. (2007) found that in the Lower Passaic River in New Jersey, bacterial levels increased almost tenfold in the two days following a CSO discharge, well above the allowed limits by the EPA. Higher concentrations of fecal coliforms and other dangerous microbes as a result of CSO discharge have been tied to numerous waterborne disease outbreaks in the United States and abroad, such as in Milwaukee, New York, and Tokyo (Donovan et al., 2006; Jagai et al., 2015; Shibata et al., 2014).

Changing water dynamics and other uncertainties caused by global climate change have given this issue more urgency, as increased discharge from CSOs brought on by rising water levels or increased storm frequency or strength could make this contamination more common

(Jagai et al., 2015; Keupers and Williams, 2013). CSOs also contribute to pollution through the collected storm runoff being discharged into surface water, as it may contain chemicals, fertilizers, and other pollutants that can cause environmental damage; nitrogen and phosphorous can be responsible for outbreaks of eutrophication in waterways in which their concentrations get too high, and the increasing occurrence of pharmaceuticals and other personal care products in residential and commercial waste can cause environmental damage, particularly to the resident aquatic life (Veronesi et al., 2014). The extent of damage caused by CSO discharges is largely dependent on intensity, duration, and depth of runoff, but even mild rainfall can cause dangerous levels of contamination and toxicity near the discharge site (Casadio et al., 2010; Sandoval et al., 2013).

2.2 Hedonic Studies in Sustainability and Urban Planning Disciplines

Despite the prevalence of CSOs in many urban areas in the United States and beyond, there are few available studies that use hedonic valuation to estimate the effects of nearby CSO infrastructure, and none that we are aware of that were carried out in New Jersey. However, hedonic valuation has been used with a variety of different subjects in environmental, sustainability, and urban planning fields. Poor et al. (2006) employed the hedonic model to assess the effect of ambient water quality on sales prices, and demonstrated that increases in dissolved inorganic nitrogen and total suspended solids were linked to lower sales prices. Netusil et al. (2014) used hedonic valuation to estimate the effect of green street (a type of green infrastructure) facilities on residential prices, and found that residential sales prices were estimated to increase as distance from the facility grew, though the magnitude was small. Sander and Haight (2012) used hedonic pricing to elicit values for ecosystem services in Minnesota. They concluded that residents generally valued ecosystem services, as total view area, access to outdoor recreation areas, tree cover, and some land cover types positively affected residential sales prices, while views of impervious surfaces negatively affected price. To complicate this, Yamagata et al. (2016) found that while green spaces and ocean views could increase sales prices, the effect was not linear, as “very nice” views had a positive premium and “slightly nice” ones did not. Eshet et al. (2007) estimated the effects of local waste transfer stations, which have some similar characteristics to those of CSOs, using the hedonic method. They found that the transfer stations had a significant disamenity effect on local residential sales prices. Nepal et al. (2020) analyzed the effects of municipal waste management using the hedonic method, and found a high price premium on cleaner neighborhoods, with a negative effect from open drains. Mei, Y. et al. (2018) used hedonic regression to analyze the effect of wetlands, and reported that proximity affected price in an inverted U shape. Nicholls (2019) created an extensive review of the hedonic method in regards to increasing risks due to climate change, and noted trends in pest, invasive species, and fire risks.

3. METHODOLOGY

3.1 The Hedonic Model

Accounting for the direct and indirect implications of CSOs is feasible using the hedonic pricing method (Rosen, 1974). Hedonic analysis is a well-established econometric method that assumes that the price of goods or services are comprised of a various attributes that can be discretely valued despite having only one total price (Nicholls, 2019). Using this case as an example, the hedonic method can compare homes with similar observable attributes and evaluate the influence of positive (waterfront view, beach access) and negative (near a landfill or polluted area) attributes on price (Ashford and Caldart, 2008; Freeman, 2014). For houses, attributes are generally grouped into household characteristics (e.g., number of bedrooms and bathrooms, lot size), neighborhood characteristics (e.g., crime rate, access to various services), environmental characteristics (e.g., proximity to green spaces or waterways), among others (Nicholls, 2019). This method uses a regression model to measure the marginal implicit price of each attribute, which represents the estimated price an individual would be willing to pay for it (Ashford and Caldart, 2008). In the regression model, price is considered the dependent variable, and the characteristics are used as independent variables to arrive at implicit prices for each (Rosen, 1974; Nicholls, 2019).

Recently, Geographic Information Systems (GIS) technology has been adopted for hedonic projects to provide more accurate analyses (Tietenberg and Lewis, 2012); GIS allows for precise mapping for hedonic studies, allowing users to calculate distances accurately between a number of different spatial variables to inform regression analyses. By using this method, we may demonstrate a monetary loss in the housing market for homes near CSO outfalls in Newark, Elizabeth and Paterson due to health, environmental, and aesthetic concerns. In estimating the potential effects of discharge sites on local real estate, another cost associated with CSOs can be defined, perhaps offering further incentive to upgrade this infrastructure and remove the negative effects it has on housing in the area.

To estimate the hedonic pricing model, we utilized a regression analysis to demonstrate the relationship between housing price and household, neighborhood, and environmental variables. This study used a typical hedonic equation of housing price as elaborated as the following equation:

$$P_i = \beta_1 H_i + \beta_2 N_i + \beta_3 E_i + \varepsilon_i$$

where P_i is the price of property $_I$, H_i is a matrix of household characteristics of a property (such as flood zone and shape area), N_i is a matrix of neighborhood characteristics (such as distance to transit and distance to hospitals), E_i is a matrix of environmental characteristics (such as distance to parks and distance to CSOs). The ε_i's are the error terms and the β's estimate the coefficients associated with each of the independent variables included in the model.

It should be noted, however, that while hedonic pricing methods can be used to estimate the value associated with different amenities and disamenities, it generally cannot account for the full value of the characteristic (Ashford and Caldart, 2008). Additionally, hedonic pricing usually best demonstrates the value of amenities that are highly localized, such as open space, as their effects are more likely to be monetized as opposed to more widespread effects, such as air quality, which will also affect other homes in the area (Sander and Polasky, 2009). As such, hedonic pricing can be trusted to create a partial, not total, estimate of the value of the environmental amenities (Ashford and Caldart, 2008; Freeman, 2014; Sander and Polasky, 2009).

3.2 Data

Data used in this study came from a variety of sources. Home prices and their structural characteristics were obtained from the real estate database, Garden State Multiple Listing Service (GSMLS), in order to use the most up to date and accurate information. For the purposes of this study, real estate data provided a consistent and singular set of data, and did not have many of the pitfalls of data obtained from tax records (data gaps, differing characteristic data, and large outliers in the data). We used properties sold in the study areas over 5 years (2013-2017) to provide a reasonable sample size and subsequently capture observations under a relatively stable market, as reaching further back in time may have biased the data due to the 2008 market crash and housing crisis. In doing so, we sacrificed a larger dataset with tax records for more accurate, up to date information on a smaller sample size; publicly available data via MOD-IV or tax records were largely incomplete in terms of house characteristics, and therefore were not practical for an analysis such as this. In order to ensure that the prices were comparable in terms of inflation, we standardized the data using Federal Reserve Economic Data: All-Transactions House Price Index (Not Seasonally Adjusted) from the Federal Reserve Bank of St. Louis for Essex, Passaic, and Union counties (FRED, 2018a; FRED, 2018b; FRED, 2018c). We applied the appropriate multiplier for each year and county to standardize the sale prices to 2018 $USD.

House characteristics derived from the GSMLS database were merged with MOD-IV data layers for the target cities, which were downloaded from the New Jersey Office of Information Technology Office of GIS website (NJOGIS, 2016a; NJOGIS, 2016b). Additional data layers, including locations for rivers, parks, CSOs, and flood zones, were taken from other online GIS databases, including the NJDEP Bureau of GIS database and FEMA databases. This data contained parcels in GIS for every residential property in the studied cities. However, our analysis excluded rental properties, as their price may not accurately convey the monetary value of the property and the data we had available for them from the GSMLS database was incomplete. Distances for the variables that require them were measured via GIS using the "Generate Near Table" tool, which measures raw distance ("as the bird flies") as opposed to driving distance. We decided on using raw distance rather than driving distance due to the nature of CSO contamination, particularly in terms of its ability to be aerosolized and create local hazards regardless of driving distances.

With considerations for the availability of data and after analyzing common trends in existing studies in the literature (Asami, 2001; Czembrowski and Kronenberg, 2016; Eshet, 2007; Lowicki and Piotrowska, 2015; Panduro and Veie, 2013; Sander and Haight, 2012; Sander and Polasky, 2009; Schläpfer et al., 2015; Yamagata et al., 2016), the factors in Table 2.1 were chosen to be calculated for the final analysis. We decided on a number of structural, neighborhood, and environmental factors that were likely to have some effect on the pricing of a home.

Table 2.1: Independent Variables for Hedonic Analysis

Variable Name	**Variable Class**	**Definition**	**Hypothesized Relationship to Sale Price**
Shape Area	Household	Calculation of the area of the residential parcel in square meters.	Positive
Flood Zone	Household	Dummy variable indicating whether residence is (1) or is not (0) in the 100-year FEMA flood zone.	Negative
Rooms	Household	Number of rooms in the house	Positive
Bedrooms	Household	Number of bedrooms in the house	Positive
Bathrooms	Household	Number of bathrooms in the house	Positive
Garage	Household	Indicates the size of the garage in terms of car occupancy (0 for no garage)	Positive
Basement	Household	Dummy variable indicating basement (1) or none (0)	Positive
Distance to CSO	Environmental	Distance to closest combined sewer overflow in meters	Positive
Distance to Park	Environmental	Distance to closest park in meters	Negative
Distance to Water	Environmental	Distance to nearest waterway in meters	Negative
Distance to Transit	Neighborhood	Distance to closest train station in meters	Negative
Distance to Hospital	Neighborhood	Distance to the nearest hospital in meters	Negative
Distance to Police	Neighborhood	Distance to nearest police station in meters	Positive

Household factors in the hedonic analysis are inherent in the property itself, and include items such as shape area and various rooms. We hypothesize that more rooms of any kind (including the basement) will increase home values, as will garages, especially in urban areas such as these where street parking is often limited. Rooms, bedrooms, and bathrooms are all important variables in hedonic analyses, and using real estate data gave us a complete picture of these data points for the properties in question. Whether or not the residence lies within a FEMA flood zone was the final household variable tested, as homes along the water may be less attractive within these zones due to the possibility of damage from future storms. While other studies in the literature address age of the residence, we did not use this variable; due to a lack of consistent or verifiable data in both the real estate dataset and the municipal dataset, adding this variable to the analysis would have eliminated a considerable number of observations.

Variables capturing the neighborhood characteristics included distance to transit centers, distance to police stations, and distance to hospitals. The map points for all of these factors were plotted using municipal MOD-IV data from NJPTA. Police stations are commonly used in hedonic studies, especially in urban areas. Though they can feasibly provide some semblance of safety to nearby residences, more often they have associated disamenity values due to the noise pollution of constant sirens and the 24/7 nature of police activities. Transit centers are of high importance in these areas due to the commonplace practice of commuting into nearby New York for employment. Finally, hospitals can be a useful consideration for house prices, as while providing a service, can also be a source of nuisance for residents due to the sirens of the ambulances coming in and out. Notably, we do not address school districts in this analysis; because urban areas often have several school districts, simply mapping the nearest schools would have been insufficient to accurately note the effect of school district on pricing. Further, though lack of data is unfortunate, there is considerable precedent in the literature for excluding this factor (Yamagata et al., 2016; Schlapfer et al., 2015; Panduro and Veie, 2013; Votsis, 2017).

The environmental factors were the final subset of data in this analysis, and included factors that are not necessarily a part of residences themselves, but focus on the distance to different environmental amenities or disamenities and how they affect home prices. Parks have several benefits to residents, including adding greenery to an otherwise urban area and providing a place for social and recreational activity. Residents may also value parks not only for recreation and aesthetics for their ability to mitigate flooding issues via infiltration. Proximity to waterbody is often also a very sought after amenity in a residence. In Newark and Elizabeth specifically, some waterways provide a view of New York City, which may also enhance its value. Distance to the nearest CSO discharge point is of course the key factor in the study, and measures the raw distance between a CSO and a residence. CSOs are, as explained in the literature review, dangerous from human and environmental health perspectives, and thus it was expected that close proximity to CSOs could negatively impact the sale price of a residence.

3.3 Data Compilation and Analysis

After compiling the data, we used ArcGIS Mapping software to map the residential parcels. We had a total sample of 2957 parcels altogether, with 1005 in Elizabeth, 1020 in Newark, and 930 in Paterson. We then used municipal shape files to add layers for the majority of the neighborhood variables, including police stations, hospitals, waterways, CSOs, parks, and transit stations. Using FEMA data, we also added a layer to include their flood zones, and designated residences within or outside of the layer. Using the "Generate Near Table" tool in

ArcGIS, the three residential data sets were compared to the closest object on the map in its respective category, generating a number of map layers and tables.

Upon completion of the mapping steps, the tables were joined and exported into an Excel table, where they were again compiled into a single table for analysis. We used JMP analytical software to examine and clean the data. To do this, we excluded blank observations, including ones that appeared to be in error. Specifically, observations whose number of rooms or bathrooms were zero were excluded from the analysis. In order to ensure validity of the data, we also eliminated any residences that appeared multiple times with identical information. We chose to take the natural logarithm of the sale price (adjusted for inflation), which is commonly used to reduce skewness and improve the interpretation of the coefficients (Nicholls, 2019; Nepal, 2020; Poor et al., 2007). We then used a Cook's D test to remove observations that were having a significantly disproportionate influence on the model, removing any observations that were greater than $4/n$ and any that could not calculate influence due to missing values. Using these guidelines for data quality management, we eliminated 621 observations from the total dataset, leaving a final dataset of 2336 (Newark: 1012, Elizabeth: 455, Paterson: 869) observations for analysis. Finally, we used ordinary least squares (OLS) regression to estimate the hedonic price model.

4. RESULTS AND DISCUSSION

After running the regression analysis using the log of Adjusted Sale Price as the dependent variable, we arrived at the final hedonic model, as demonstrated in section 3.1. The results of this analysis are shown below, in Table 2.2. The model had a R^2 value of .30 and a P value of <.0001, with a total of 2336 observations.

Table 2.2: Results of Hedonic Regression with Adjusted Sale Price as Dependent Variable

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	59914.81	16718.96	3.58	0.0003*
Rooms	14252.85	1784.07	7.99	<0.0001*
Bedrooms	873.37	2470.47	0.35	0.7237
Bathrooms	33517.53	4002.46	8.37	<0.0001*
Garage	21146.67	2929.14	7.22	<0.0001*
Basement [No]	3066.28	5009.50	0.61	0.5405
Flood Zone [0]	-37059.97	10431.61	-3.55	0.0004*
Distance to water (M)	-24.15	5.77	-4.18	<0.0001*
Distance to police station (M)	10.26	5.70	1.80	0.0720
Distance to park (M)	-1.12	0.29	-3.85	0.0001*
Distance to public transit (M)	-8.99	4.14	-2.18	0.0297*
Distance to hospital (M)	8.17	3.62	2.26	0.0242*
Shape Area	14.61	1.38	10.61	<0.0001*
Distance to CSO (M)	-5.94	2.12	-2.80	0.0052*

Several variables proved to be significant, both with the hypothesized sign of coefficient and against it. The variables basement, bedrooms, and distance to police were found to not be statistically significant in the final regression. The presence of a basement was hypothesized to have a positive effect on price since these areas are highly urban where space is limited, though our study area, it appears to be less important. Similarly, the number of bedrooms was insignificant. Distance to police stations was also not significant, which may suggest either that proximity to police stations is not prioritized in cities where the distance may have only a minor effect on response time, or that distance to these stations is not an appropriate measure of safety for a homeowner.

Household variables, exempting the aforementioned ones, performed relatively as expected. Both number of rooms and number of bathrooms proved significant and represented a considerable boon for home prices, which is in line with findings in the literature (Nepal et al., 2020; Mei, Y., et al., 2018). The presence of a garage, too, added value to the home, likely as a result of the difficulty of urban street parking and thus the value of a guaranteed place to park. This finding was shared by Poor et al. (2007) in Maryland. Shape area performed as predicted, as larger houses with larger tracts of land tend to be more valued, especially in urban areas where space is at a premium. While the terminology used is slightly different, larger plot sizes and acreages are generally found to improve on sale price (Eshet et al., 2007; Sander and Haight, 2012; Mei, Y., et al., 2018). The testing for flood zone, however, did not perform as expected, as homes that were not in the flood zone were significantly less valued than those within the flood zone. This can likely be explained by flood zone areas, as a rule, being closer to the waterfront, which is generally a desirable area to live. We expand on this further later in this section.

Of the neighborhood values, distance to transit and distance to hospital were both significant, though to the 95^{th} percentile as opposed to the 99^{th} that many of the other factors were. As expected, distance to transit stations had a significant negative coefficient, which marks it as having an amenity value. Prices rise as proximity increases to the transit stations; this matches expectations, as these areas, like many in northern New Jersey, house many commuters to New York or New Jersey cities, making transit valuable. Our regression results were opposed by the literature for distance to transit hubs, which had a positive value to represent a disamenity value in the literature (Sander and Polasky, 2009; Yamagata et al., 2016; Czembrowshi and

Kronenberg, 2016). While we hypothesized that a proximity to hospitals would represent an amenity, the opposite has proven to be true in the analysis. While a proximity to an emergency facility could be useful in certain situations, it is likely that the far more common situation of noise pollution from sirens instead turns this proximity into a nuisance, which could explain the results of the regression. The positive coefficient associated with distance to hospitals was shared by Nepal et al (2020).

The environmental variables, distance to water and distance to parks, were both significant and behaved as hypothesized. Parks, representing green spaces of relative rarity in urban areas, carried a small but significant amenity value. Waterways, however, represented perhaps one of the largest amenity values in the study at a change of nearly $25 per meter away from the waterway. As hypothesized, the desirability of living near waterway for the views it affords proved to increase the price of a home, despite complications such as a stigma of polluted waterways, especially in the Newark and Elizabeth areas. Though the study areas varied widely in the cited literature, including the United States and abroad, many studies used distance to water as a factor. Whereas in this study, any nearby water source was used for the distance, a variety of terms and subdivisions were used for factors concerning water, including “lakes,” “oceans,” “streams,” and “ponds.” When these factors are considered all as a similar “water” factor, our study concurs with others in the literature that the signs of the coefficient of these water factors are negative, and therefore have an amenity value that adds to the price of a residence (Sander and Polasky, 2009; Sander and Haight, 2012; Yamagata et al., 2016; Schlapfer et al., 2015). Similar conclusions can also be drawn from distance to parks, which also proved to have a negative coefficient and therefore amenity value, confirming findings of other studies in the literature (Sander and Polasky, 2009; Sander and Haight, 2012; Yamagata et al., 2016; Schlapfer et al., 2015; Czembrowski and Kronenberg, 2016).

Distance from CSOs was the final significant variable among those that were chosen for the analysis, and had a negative value of -$5.94. As such, the analysis suggests that CSOs are a desirable factor. While this seems paradoxical in light of the dangers of CSOs, there may several factors at play that influence this result. First and foremost, while distance to waterways and distance to CSOs are discrete factors that did not have significant correlations in testing, the simple fact remains that CSO discharge sites, as a rule, are located at waterways. Since proximity to water was found to be significantly desirable in this analysis, we hypothesize that this amenity value may override the negative effects presented by CSOs. In addition to this, it may be that the public is unaware of the dangers of CSOs; excepting days when significant signs of CSO discharge are obvious (such as strong odors), it may be that residents near discharge sites are unaware that these sites contain pollutants or are harmful to their health in any way. As CSOs have not had significant study in terms of hedonic analysis in the literature, there are no true benchmarks to compare to. However, it can be noted that Eshet et al. (2007) found that waste transfer stations had a disamenity effect on sales prices, and Nepal et al (2020) found a high premium on cleaner neighborhoods, which may provide some insight given the wastewater transfer role that CSOs serve.

The hedonic method, despite its versatility, entails certain challenges and the results should be interpreted accordingly. Since housing price is a critical part of the analyses, the scope of environmental benefits that can be measured using hedonic analyses are limited to attributes that are related to housing prices. Differences in environmental attributes are also considered to directly affect property value; though market signals may account for this, if individuals do not recognize the link between an environmental attribute and its effect on property, property value may not fully reflect differences in the environmental attribute. By directly linking differences in environmental attributes to property value, the method also inherently assumes individuals recognize the direct relationship between the environmental attribute of interest and property value. While this assumption may hold for some individuals and for some types of environmental attributes, it applications for lesser known environmental attributes (such as CSOs) and across all individuals could be improbable. The role of exogenous factors, including interest rates, is also not always included in the analyses. Lastly, the approach assumes that individuals have opportunities to select combinations of features they prefer given their income. If their options are limited, determining the value of environmental attributes accurately could be challenging.

5. CONCLUSIONS AND FUTURE STUDY

The hedonic analysis using the data that we have collected suggests that the effects of combined sewer infrastructure do not have economic consequences in the housing markets studied. In Elizabeth, Newark, and Paterson, proximity to CSO discharges were found to have an amenity effect on the prices of homes near them, and it can therefore be surmised that residents in this area do not value living farther away from CSO discharge points, and therefore will not pay a premium to avoid them. However, due to the nature of the study, it is unclear whether or not this points to a populace that is uneducated on the possible dangers of CSO discharges or if residential prices are simply reflecting more common trends tied to the desirability of residences near waterways. While the hedonic regression failed to find a disamenity effect tied to CSOs, this in itself can provide insight into possible action by policy makers and city planners. The apparent amenity value of CSOs is paradoxical given the harmful nature of these areas, and it can therefore be inferred that residents are not thoroughly aware of the dangers that these discharges represent. Efforts should be made to educate the populace on these potentially harmful areas, both to inoculate residents against the dangers of these areas and to perhaps reveal more coherent links between CSOs and the economy.

While this study provides important and relevant socio-economic information for cost-benefit analyses for the study areas and areas similar to them, the results are by no means comprehensive or indicative of all cities of their type. Future research could expand on this theme by including more factors in the hedonic model and analyzing other geographic areas to provide a more robust base of research for cities looking to phase out their CSO infrastructures. Ideally, this study and future ones may be used to craft education and outreach tools to inform and protect the public.

CHAPTER 3. PUBLIC PREFERENCES FOR GREEN INFRASTRUCTURE IMPROVEMENTS IN NORTHERN NEW JERSEY: A DISCRETE CHOICE EXPERIMENT APPROACH

ABSTRACT: Significant water pollution caused by flooding due to heavy precipitation and extreme weather events has become a considerable problem, especially in urbanized areas such as in Northern New Jersey. These cities experience heavy downpour-related contamination and water pollution when stormwater and untreated sewage are diverted through combined sewer overflow (CSO) drainage systems to adjacent water bodies. Though CSOs are a largely outdated infrastructure component, they can still be found in municipalities throughout the United States. Green infrastructure (GI) has proven a successful intervention method for mitigating these unintended environmental consequences. However, while the effects of CSOs and the ability of green infrastructure to reduce them are well documented, there has been considerably less study addressing public preferences and willingness to pay for GI-based solutions. As such, this study seeks to understand these facets of GI management in urbanized areas of New Jersey, focusing on Newark, Paterson, and Elizabeth townships. A discrete choice experiment method was used to analyze the willingness of residents to pay for additional CSO infrastructure through the installation of green infrastructure options such as bioretention gardens, rain barrels, and green roofs. Furthermore, study identified attributes such as secondary benefits, proximity, and water retention that respondents found the most utility in when choosing green infrastructure stormwater management interventions. We found that several attributes, including improved air quality ($58.60), increased water supply ($49.71), and closer proximity ($110.01-$125.97) had the highest utility and similarly were associated with a higher willingness to pay than other tested

attributes. These findings are important in assessing the overall attitude towards these fixtures, and may be critical in crafting local policy and development, especially to address environmental equity.

1. INTRODUCTION

As a result of dense urbanization over decades, northern New Jersey towns and cities are exposed to significant risk from high precipitation and flooding events. These hydrologic events can have significant adverse effects for both human and environmental health (Soriano and Rubio, 2019). Combined sewer overflow (CSO) infrastructure is one of the most critical water quality issues facing coastal and river communities; limited control of CSOs is one of the foremost problems leading to surface water impairment in urban environments (Soriano and Rubio, 2019; Fu et al., 2019). CSOs are common in the Northeastern United States, and are considered public health risks as a result of discharge containing domestic, commercial, industrial, and stormwater pollution, especially when exacerbated by the growth of impermeable surfaces that characterize urbanization (Chen et al., 2019; Fu et al., 2019). This infrastructure largely represents an aging fixture for stormwater management in older urban areas across the United States, and has come under increased scrutiny in recent years for its potentially harmful effects on the environment and human health (NJDEP, 2019).

The socio-economic aspects of stormwater management options (especially aging solutions such as CSOs) are not well understood and rarely reported in the literature, or integrated with more common physical and technological solutions. A better understanding of the socio-economic features of stormwater problems is needed to develop successful design and public policy solutions (Jayasooriya and Ng, 2014). In the wake of large storms such as

Hurricane Sandy, there has been heightened perception of the problems presented by continued use of CSO infrastructure, and efforts by the New Jersey Department of Environmental Protection (NJDEP) and the United States Environmental Protection Agency (USEPA) to mitigate CSO discharges are improving (NJDEP, 2019). While several technical solutions for CSO mitigation exist, including improved grey infrastructure and different green infrastructure solutions, there is limited understanding of the public perception and comprehension of the economic and environmental tradeoffs of these solutions, particularly regarding green infrastructure (Jayasorriya and Ng, 2014; Tsihrintzis and Hamid, 1997). As such, this study proposes to bridge this research gap by studying the socio-economic aspects of stormwater management and assessing public perceptions to ultimately improve management decision making for public officials.

While the costs and benefits of grey infrastructure have a broad base of understanding and standardized methods of valuation, green infrastructure options are less understood (Bowen and Lynch, 2017). Green infrastructure can necessitate considerable public investment in terms of both private property and capital, which creates a need for better understanding (Bowen and Lynch, 2017; Nordman et al., 2018). Public willingness to pay analyses for different green infrastructure options may be able to help identify the best approach to improve public participation in investing, managing, and overall taking a more active role in stormwater management strategies. This may be able to not only help allocate resources more effectively, but also add resources in the form of social capital. The results of this study will be of interest to government agencies, city planners, and environmental managers, may help to fill in gaps in the current research, and also create a more complete picture of the socio-economic structure behind management decisions.

2. LITERATURE REVIEW

2.1. Green Infrastructure as a Mitigation Option

Green infrastructure refers to source control measures that reduce stormwater flow by promoting infiltration, evapotranspiration, and the capture and reuse of rainwater (de Sousa et al., 2012). Green infrastructure can be in different forms, including green roofs, rain gardens, biofiltration basins, and permeable pavement, all of which act in varying capacity to reduce the overall amount of impervious surface area (USEPA, 2013). Reducing impermeable area can reduce stormwater runoff and delay infiltration, which can reduce flooding and the negative effects caused by it (Li et al., 2019). Green infrastructure's adaptability facilitates its use in a number of settings, including in areas that traditional grey infrastructure options generally has difficulty utilizing effectively, such as rooftops (USEPA, 2013; Li et al., 2019). Though the increased infiltration of stormwater is one of the primary draws of green infrastructure options, these also have a host of other benefits, both for sustainability and more generally. Studies have found that different kinds of green infrastructure can remove pollutants from water, enhance carbon sequestration, reduce the urban heat island effect, improve air quality, increase drought resilience, control temperature, and improve aesthetics and real estate value, among other benefits (Abhijith et al., 2017; Cohen et al., 2012; De Sousa et al., 2014; Li et al., 2019; Venkataramanan et al., 2019; Venkataramanan et al., 2020; Zhang and Chui, 2018). Though grey infrastructure can potentially present a more effective solution in terms of flooding risk, the use of green infrastructure can avoid some of its shortcomings, including increasing non-point source pollution, water quality deterioration, groundwater shortage, and changes in air temperature, humidity, and evapotranspiration (Zhang and Chui, 2018).

Cities around the United States and abroad have begun to make green infrastructure a part of their plans for stormwater management, including Philadelphia, New York, Kansas City, and Chicago (De Sousa et al., 2014; Cohen et al., 2012). Philadelphia, for example, relies heavily on green infrastructure installations around the municipality to incrementally reduce discharges while providing significant benefit to its economy (Econsult, 2016; Philadelphia Water Department, 2017). Studies suggest that green infrastructure can work as a cost-effective solution, especially in comparison to traditionally used grey infrastructure (USEPA, 2007; USEPA, 2013; Auckland Regional Council, 2009; Li et al., 2019; Nordan et al., 2018). Cohen et al. (2012) used the study area in Turkey Creek, Kansas to model and compare the prices of green infrastructure as compared to grey infrastructure alternatives. They found that applying rain gardens to augment some grey infrastructure improvements rather than use grey infrastructure exclusively could save between $22 and $35 million for this CSO drainage area, and significantly reduce the amount of storm runoff to force CSO discharge. Thus, as both a cost-saving and effective measure against CSOs and increasing storm runoff in general, green infrastructure has become a staple in many areas worldwide. However, despite these quantified benefits, the widespread adoption of green infrastructure has been relatively slow (Bowen and Lynch, 2017).

2.2 Public Perception Regarding Green Infrastructure

While green infrastructure is growing in popularity and has been used effectively, it remains a relatively new solution compared to traditional grey infrastructure, and therefore research gaps exist in areas such as pricing and public perception. Thus, the body of literature on areas such as social perception (specifically with discrete choice experiment) is not yet comprehensive, though there have been some studies that have explored this facet of green infrastructure. Veronsei et al. (2014) utilized a discrete choice experiment on a local population in Switzerland to understand their willingness to pay to reduce the negative effects of CSOs, and what factors affected their willingness. They found that most of the selected sample was willing to pay higher taxes to reduce this risk, largely to protect water bodies and prevent environmental and human health risks. Meng and Hsu (2019) explored the use of green infrastructure in public municipalities with public officials as respondents. They found that public agencies are willing to pay more for smart green infrastructure with lower maintenance and operating costs over time, and that agencies that had utilized green infrastructure previously were more likely to do so again with smart infrastructure. Shr et al. (2019) used choice experiment approach to understand how visual aids affected respondent perception of green infrastructure, and found more favorable results from surveys that included images. Halkos and Matsiori (2012) used contingent valuation to understand willingness to pay and desired attributes for coastal zone quality improvements, and concluded that previous environmental behavior was critical in predicting willingness to pay.

This study applied a discrete choice experiment methodology to green infrastructure in the general public to reveal new insights on perceptions and willingness to pay. This built on existing literature by using discrete choice experiment and willingness to pay to understand public preferences for green infrastructure. Such a study will not only be able to inform city planning and management for green infrastructure projects, but may be able to suggest effective ways to move forward with stormwater management (particularly in mitigating CSOs) with more public support. To our knowledge, no such study has been carried out in New Jersey, which may be a critical area due to the confluence of urban and coastal climate change challenges it faces.

3. METHODOLOGY

3.1 Discrete Choice Experiment

A discrete choice experiment (DCE) approach can help understand consumer preferences for products or services that do not have a traditional market. This technique presents respondents with a number of different alternatives with varying attribute levels in order to understand which choices are favored over the others. An analysis of the resulting choices can then be used to allow for an estimation of the overall value of each attribute, and can identify both significance of attributes and how individuals are willing to trade attributes (Meng and Hs u, 2019; Mangham et al., 2008). This method can also estimate the willingness to pay (WTP) for unit changes in the various attributes, which can be useful in management and planning scenarios (Mangham et al., 2008).

DCEs are grounded in random utility theory, which posits that the utility an individual derives from a good is dependent on the characteristics of a good and its unobserved components (McFadden, 1976). When stating their preference in their choice, it is assumed that respondents choose the alternative that yields the highest individual benefit (or utility), which in turn results from the combination of various attributes and attribute levels (Lancaster, 1966; Mangham et al., 2008).

In general, a respondent *q*'s utility from choosing alternative *j* in choice situation *t* in a utility function with random parameters can be defined as

$$Ujtq = Vjtq + \varepsilon jtq = \beta' qkXjtqk + \varepsilon jtq$$

Where respondent *q* (*q*=1,….*Q*) obtains utility U from choosing alternative *j* (Option A, B or C) in each of the choice sets t (*t*=1,....6). The utility has a non-random component (*V*) and a stochastic term *(ε)*. The non-random component is assumed to be a function of the vector *k* of choice specific attributes: X_{jtqk}, with corresponding parameters β_{qk} which may vary randomly with a mean β_k and standard deviation δ_k. The utility function of the model with the error term ε_{jtq} that includes the alternative specific constant representing a dummy for respondent choosing the status quo, can be expressed as a linear function of an attribute vector (*X1, X2, X3, X4*) = (secondary benefit, proximity, reduced flooding, payment).

$$Vjq = ASCq + ß1X1qj + ß2X2,qj + ß3X3,qj + \beta 4X4,qj$$

The probability that an individual q will choose alternative i over any other alternative j belonging to some choice set t of:

$$Probiq = Prob\,(V\,iq + \varepsilon iq > Vjq + \varepsilon jq) \qquad \forall\, j \in t$$

Which equals

$$= Prob\,\{(Vin - Vjn) > (Ejn - Ein)\}$$

To empirically estimate the observable parameters of the utility function (3), this study assumed that the stochastic components are independently and identically distributed (IID) with a Gumbell or Weibull distribution. This leads to the use of multinomial/conditional logit (MNL) which assumes that unobserved factors affecting the choice of alternatives are strictly independent of each other (Independence of Irrelevant Alternatives, IIA) (Bergman et al., 2006). Hence determines the probabilities of choosing *i* over *j* options.

$$Probin = exp\,(\mu Viq)/\Sigma jexp(\mu Vjq) \qquad \forall\, j \in t$$

The willingness to pay (WTP) is the amount a consumer will accept to keep a utility unchanged for a change in attribute (Heng et al., 2020). Hence, the marginal WTP between any attributes and a cost attribute is obtainable.

$$WTP = (\beta a/\beta cost)$$

3.2 Attributes and Optimal Choice Profiles

We considered choice experiment literature, green infrastructure literature, and previously run studies in the area to determine attributes and their corresponding levels (Veronsei et al., 2014; Meng and Hsu, 2019; Shr et al., 2019; Halkos and Matsiori, 2012; USEPA, 2007). In our analyses, we decided on a total of four attributes, as described in Table 3.1 below. Since green infrastructure has varied benefits depending on its form, secondary benefits (secondary to its flood mitigation uses) are critical to their utility. To this end, we included some of the more common and more easily recognized benefits of green infrastructure, including increased water supply, noise reduction, habitat creation, improved air quality, and reduced energy use. Not in my backyard (NIMBY) has become a common problem with grey infrastructure, wherein residents desire the benefits from the fixture, but do not want it in close proximity to them. To delineate this impact, we included several levels of proximity, including on the property, within a city block, or within the watershed. Though green infrastructure may not be subject to the same NIMBYism considering its generally more natural forms, this is a critical measurement for perception, and may have significant influence in how municipalities may address proliferation in the future. In our study, more general values for flood mitigation amounts (high and low), could be more effective given that past studies have shown that the general populace may be unfamiliar with flooding dynamics and prevention methods (Shandas, 2015; Barnhill and Smardon, 2012). Finally, payment levels were developed from pre-test surveys studies in the area, as respondents reacted favorably to them and we received a higher percentage of completed responses as a result. We conducted a pilot survey as pre-test and included an open-ended response for willingness to pay. Respondents were asked to give a realistic amount that they would be willing to pay for green infrastructure improvements. These pre-test values were used to determine four equidistant bid amounts for the final survey.

Table 3.1: Choice set attributes and levels

	Description	**Levels**
Secondary Benefits	The main benefit that the green infrastructure option offers besides its water retention/flood mitigation functions	• Increased water supply • Noise reduction • Habitat creation • Improved air quality • Reduced energy use
Proximity	How close the green infrastructure would be to a respondent's residence	• On personal property • Within a block • Within the watershed
Reduced Flooding	The effect of the green infrastructure on local flooding in general terms	• Low • High
Payment	How much the respondent would be willing to pay for the green infrastructure package in question as a one-time payment	• $25 • $50 • $75 • $100

The associated attribute levels resulted in 120 possible profiles (5*3*2*4). We applied a D-efficient combination accounting for orthogonality, level balance, and minimum overlap using the software R. The resulting fractional factorial design of 60 choice set profiles were randomly paired to create 30 choice set cards. These presented two distinct green infrastructure projects along with a status quo option for no green infrastructure intervention. Using this design, each respondent was given five choice tasks. A sample choice card is included in Figure 3.1 below.

SAMPLE CHOICE CARD

Attribute	Option A	Option B	Option C
Secondary benefit	Habitat Creation	Improved Air Quality	
Proximity	Personal property	Within a block	No Green Infrastructure
Reduced Flooding	Low	High	
Payments	$50	$100	
Your choice (tick only one)	✖	☐	☐
Please rate how certain you are of your choice on a scale of 1 to 5 where 1 is "Not Certain" and 5 is "Very Certain".			
1 ☐ **2** ☐	**3** ☐	**4** ✖	**5** ☐

Figure 3.1: Sample Choice Card for Choice Experiment Segment

3.3 Survey Design, Distribution, and Analysis

The survey was developed using an extensive literature review, and was pre-tested in summer 2016 (n=123) to improve comprehensiveness and understandability in Elizabeth, NJ. The pre-test survey introduced the topic of green infrastructure with a brief explanation of green infrastructure and its potential benefits, including a brief infographic describing some common green infrastructure types (permeable pavement, rain cisterns, etc.). Questions in the survey asked for a variety of information from the respondents, including perceptions of stormwater dynamics, the behavior and dangers of stormwater in their area, and how they had personally been affected by flooding or other stormwater event in the past.

The improved survey used questions from the earlier pretest version, and was expanded to include the discrete choice experiment question. This improved version excluded any questions from the earlier version that did not adequately contribute to green infrastructure understanding, or that appeared to have comprehension issues. The improved survey was again pre-tested via Qualtrics random sampling, which was refined to arrive at the final survey. The survey began with Likert scale questions to understand their perceptions on green infrastructure, current grey infrastructure, flooding in their area, and their health and safety. Respondents were then presented with choice experiment sets, wherein they were asked to choose between three options to showcase their preferences for various green infrastructure attributes. Finally, respondents were asked questions regarding their socio-demographic background information.

Surveys were distributed online via Qualtrics, a third-party polling company, between March and May 2020; surveys were delivered via an email link and respondents were compensated with a small undisclosed reward. In order to ensure a non-biased, representative sample of the cities targeted for the study, surveys were distributed only to residents living in those zip codes. The targeted respondents needed only to be residents of the targeted study areas, and were not chosen for any specific expertise. Surveys were in English, and were not translated to other languages. In total, we received 471 complete responses, including 226 in Newark, 110 in Elizabeth, and 135 in Paterson. These responses were imported into the analytics software STATA 15 E for analysis.

4. RESULTS AND DISCUSSION

4.1 Demographic Results and Goodness of Fit

Our survey received 471 total responses throughout the three cities in the study area. Before moving on to the choice experiment analysis, we used a Pearson χ^2 test to understand if our sample was a reasonable representation of the areas in question and New Jersey as a whole. Most of our socio-demographic characteristics had equal means at the 1% level, indicating a goodness of fit. However, our survey sample was slightly more educated and wealthy compared to the population average. At a 1% significance level, the evidence for rejection of the null hypotheses of the equality of means was found for annual household income only. This information is detailed in Table 3.2 below.

Table 3.2: Socio-demographic Characteristics of Survey Respondents for Elizabeth, Newark and Paterson and Total Response vs US Census for the Elizabeth, Newark, Paterson and New Jersey

	Elizabeth		Newark		Paterson		Total NJ	
	Sample	Population	Sample	Population	Sample	Population	Sample	Population
Sample size	107	129,216	224	282,011	140	145,233	471	8,882,190
Gender (% female)	38.32%	49.8%	45.94%	51.2%	54.28%	51.4%	46.7%	51.1%
Age (median)	35.5	34.5	35.5	34.4	35.5	33.5	35.5	39.9
Household size	3.08	2.39	3.22	2.67	2.89	3.25	3.09	2.69
Annual household income (median)	87,499.5	48,407	62,499.5	35,199	42,499.5	41,360	62,499.5	82,545
Housing (% Ownership)	53.27%	24.2%	52.23%	22.3%	45%	26.1%	50.32%	63.9%
High school completion rate	92.52%	73.4%	95.98%	75.3%	95.14%	74.8%	94.59%	89.8%

In italics the sample mean and the population mean are not equal at the 1% level according to the Pearson χ^2 test. Interpretation of the goodness of fit means that the sample and population at 1% are a good fit (for those demographics without italics).

4.2 Choice Experiment Analysis

Following the procedure for choice experiment evaluation, we ran a conditional logit regression (MNL) in STATA. In order to avoid a saturated model, we considered the attribute levels with the lowest utility to be the baseline that was dropped and considered the reference case; this in line with the choice experiment criteria we utilized. The baseline attribute for secondary benefits was noise reduction, for proximity we considered within a watershed, and for reduced flooding the baseline level was low. Further, we applied interaction factors such gender, education and income on the attributes levels within a watershed and personal property to further delineate factors that may influence respondents' preferences. Because these areas are notable for lower levels of education and income, we felt that interactions with these attributes could make for interesting interaction. Gender, though not particularly notable in the demographic sense, is nevertheless an important attribute that we wanted to explore, as it has implications for targeted outreach as GI initiatives move forward. These results can be found in Table 3.3 below.

Table 3.3: Conditional logistic regression (MNL) of choice experiment

Attribute levels and interactions	**Conditional Logit**		
	Estimate	**P>|z|**	**Robust Std Error**
Secondary benefit			
Improved air quality	.254	0.005 ***	.090
Increased water supply	.208	0.016 **	.085
Habitat creation	.0415	0.661	.094
Reduced energy use	.0544	0.539	.088
Proximity			
Personal property	.348	0.007 ***	.128
Within a block	.217	0.074 *	.121
Reduced flooding			
High	.366	0.000 ***	.046
Cost	-.004	0.000 ***	.0009
ASC	-.794	0.000 ***	.168
Interactions			
Within watershed * gender	-.399	0.000 ***	.109
Personal property * gender	-.389	0.000 ***	.105
Personal property * education	-.204	0.078 *	.116
Within watershed * income	3.74e-06	0.000 ***	9.25e-07
Wald chi^2 (13)		547.13	
Prob> Chi^2		0.000	
Log pseudolikelihood		-2657.8879	
No of Observations		1006	

*Note: ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively.*

471 responses with several choice experiment sets in each resulted in 1006 total observations. The R^2 value of .1053 indicates a goodness of fit for the model, and suggests that the model provides good parameter estimates. The regression reveals that a number of the choices in the choice sets were significant, including air quality, green infrastructure on personal property, high water retention, cost, and increased water supply and green infrastructure within a block, albeit at higher levels of significance (.95 and .90, respectively). Further, interactions between proximity (within the watershed and on personal property) and gender and proximity (within watershed) and income were also significant, with the interaction between proximity (on personal property) and education significant at the .90% interval.

Our regression reveals that a number of these attributes provide utility to respondents. Improved air quality and increased water supply were the most important secondary benefit attributes, with improved air quality having the highest coefficient among them. We hypothesized that the attributes that respondents would use most frequently would have the most utility, and the results appears to support this. Improving air quality may have high utility because of the rising importance of clean air, especially in urban areas (Derkzen et al., 2017). Further, past studies have found that air purification generally enjoys higher preference and willingness to pay (Derkzen et al., 2017; Lera-Lopez et al., 2012). Increased water supply may appeal to homeowners that may see easy applications for retained water in irrigation for their property, as respondents in past studies have placed higher values on green infrastructure that can provide water (Miller and Monalto, 2019). Habitat creation and reduced energy use had considerably lower coefficients when compared to improved air quality and improved water supply. This may be because these attributes do not provide a high level of personal benefit, as ecosystem services that provide more direct benefits to health and well-being tend to be rated more highly (Derkzen et al., 2017). Further, it could also be a symptom of low levels of familiarity or understanding of green infrastructure, which have been observed in the literature (Barnhill and Smardon, 2012; Shandas, 2015).

Proximity was a major component of the choice experiment and proved significant. Respondents significantly found utility in green infrastructure that was within a city block or on their personal property; personal property had one of the highest coefficients in the model (.348), and was considerably higher than within a block, which was also relatively high. This is a somewhat surprising result, as NIMBYism is a fairly common phenomena in the United States. Further, while literature connecting this phenomenon to green infrastructure explicitly is scarce, studies like the one done by Katy and Jari (2016) in Finland found that residents preferred stormwater ponds be sited away from their residences. Given that the least preferred option was within the watershed, and that the most preferred one was on personal property, our results suggest that this NIMBY trend is fading, or simply may not be as strong in this area of the United States. This may be due to changing perceptions, but may also be a result of green infrastructure being much smaller and less intrusive than the clean energy generators that NIMBYism is often associated with. Personal property green infrastructure had the most utility to respondents; this may reflect homeowners who perceive this as the best way to maximize their benefit while also giving them greater leverage and control over form, function, and maintenance.

Unsurprisingly, respondents found high utility in green infrastructure that has a high level of water retention rather than a low level. This is in line with our hypothesis, as we expected respondents that were interested in green infrastructure to want to maximize the utility of their expressed purpose in terms of flood mitigation. While we did not quantify this attribute, the general nature of the analysis suggests that homeowners, when faced with a choice, will prefer the option that gives better flood protection and reduce water flow around their home, which is in line with previous findings (Derkzen et al., 2017). Similarly, cost was found to be significant, and negative, which follows general trends for choice experiment models. As a result, this is fairly commonplace, as respondents can be expected to want to pay the lowest amount possible to maximize their utility.

We generated interactions with the intention of investigating how various attributes interacted with demographic attributes in hopes of revealing some insights as to what factors influence respondent's decisions. Specifically, we interacted variables on gender, income, and education, as we wanted to explore how they could influence CSO and green infrastructure policy in New Jersey. Interactions with gender and proximity were significant, namely with proximity within the watershed and on personal property. Our regression found that respondents that identified as female attributed less utility to both of these levels of proximity. This may suggest that females have a higher preference for green infrastructure on their property as opposed to their male counterparts, which may reveal outreach opportunities and needs for future policy. Respondents with higher levels of education tended to attribute less utility to green infrastructure on personal property. This may potentially be a result of better education on water dynamics and green infrastructure utility; while other respondents may want the assurances of seeing and maintaining green infrastructure personally, respondents with more education may be content to reap the benefits of infrastructure that they don't interact with. Finally, we found that respondents with higher incomes found higher utility for green infrastructure within their watershed. This may be due to a preference to use personal property and the surrounding neighborhood for other uses. These interactions may provide insight during policy creation, as they may be able to target various groups to increase acceptance.

4.3 Willingness to Pay

We used a marginal willingness to pay analysis and analyzed the interactions between cost and various attributes on the choice experiment set, to understand which attributes were considered the most valuable in monetary terms. The results can be found below in Table 3.4.

Table 3.4: Marginal willingness to pay estimates (95% confidence intervals)

Attribute	MNL		
	WTP ($USD)	Lower limit	Upper limit
Secondary benefit			
Improved air quality	58.60	4.483	112.716
Increased water supply	49.71	-1.465	100.884
Reduced energy use	13.68	-28.421	55.787
Habitat creation	10.28	-34.601	55.168
Proximity			
Personal property	125.97	42.125	209.806
Within a block	110.01	32.462	187.552
Water retention			
High	84.90	37.777	132.027

The results show a fairly wide distribution of effects. In terms of secondary benefits of the green infrastructure itself, respondents were willing to pay more for increased water supply and improved air quality. Improved air quality had the highest willingness to pay, with respondents willing to pay an additional $8.89 over increased water supply, and over four times more than they would pay for reduced energy use or habitat creation. This confirms our findings from the earlier parameter estimate analysis in Table 3, wherein we found that respondents found significant utility in these attributes; they are willing to pay a premium to receive the benefits. Furthermore, this reflects findings in earlier studies, in which air quality and water supply had high utility, and thus enjoyed a higher willingness to pay (Derkzen et al., 2017; Lera-Lopez et al., 2012).

Though these secondary benefits were valuable, respondents were willing to pay higher premiums for placement than for any of the benefits. Respondents were willing to pay about $16 more for green infrastructure closer to home as compared to within the block, mirroring our findings in the earlier analysis. However, this constitutes a $67.37 increase from the highest secondary benefit and a $41.07 increase from the water retention attribute, making it the most valuable attribute by a considerable margin. This may be in an effort to realize more of the benefits, or to have more control in the implementation and maintenance. Respondents were also willing to pay more for retaining high amounts of water and mitigating floods than for any of the secondary benefits, which may suggest that respondents are more concerned with damages from flooding than with any of the problems that the secondary benefits could potentially help mitigate. This conforms to our expectations, as these areas are prone to flooding, and thus residents should be interested in reducing their frequency through mitigation. These findings suggest that green infrastructure that focuses on increasing water supply and improving air quality closer to residences may be ideal in term of garnering social capital.

4.4 Policy Implications

Taken together, these findings can provide some insight into potential policies. Given the utility of an increased water supply and improved air quality, decision makers may want to prioritize green infrastructure that can more effectively provide them, such as rain barrels and bioretention gardens, respectively. Further, the preference for green infrastructure closer to respondents' properties may suggest an opportunity for outreach through offering grants or discounts on the installation of green infrastructure on personal property or on a neighborhood basis. As there was considerable utility and willingness to pay attached to high levels of runoff mitigation, it will also be important to ensure that green infrastructure is chosen and sited in such a way to maximize that benefit. Finally, our interactions may reveal useful clues as to how to target outreach by gender, education, and income depending on the desired green infrastructure installation.

5. CONCLUSIONS AND FUTURE STUDY

Green infrastructure is an increasingly popular environmental management tool in mitigating the increasing effects of climate change, and has shown increased popularity throughout the United States and abroad. Though it has been proven effective, there remain many questions on the public preferences of its various forms, and how municipalities might best implement their use of green infrastructure with public favor. To this end, this study used discrete choice experiment surveys to gauge the perceptions and willingness to pay of New Jersey residents of three major urban cities (Newark, Elizabeth, and Paterson). Surveys were distributed by Qualtrics online in the spring of 2020, eliciting 471 total responses. The data was analyzed in STATA 15 E using conditional logit regression and marginal willingness to pay analyses. The survey results suggests considerable utility for many secondary attributes (air quality, habitat creation, water supply, noise reduction, etc.), with improved air quality and increased water supply as the most preferred benefits. We also found that respondents found more utility in green infrastructure fixtures either on their own property or within a block of them, perhaps due to greater perceived benefits or better control over the form and function of the green infrastructure in use. Overall, the utility from green infrastructure fulfilling its main purpose, namely increasing water infiltration, was significant and high, showing that respondents, while interested in the other benefits to be gained from infrastructure, are significantly invested in preventing flooding using these tools. Our willingness to pay analysis, suggests a direct correlation between utility and willingness to pay, and thus attributes that were preferred in the choice experiment had higher willingness to pay. This information can be valuable to policy makers and municipal governments for designing green infrastructure and other flood mitigation policies in New Jersey by informing some of the qualities that residents' value more highly when choosing green infrastructure. Ideally, this study may help inform policy by identifying opportunities to garner public support, add social capital, and allocate resources for more effective deployment of green infrastructure. This study helps explain trends across populations, and thus can inform environmental policy in similar urbanized areas.

Our study did suffer from some limitations. A key limitation lay in the fact that knowledge of complex issues such as water dynamics and green engineering is generally uncommon, and thus it can be difficult to evaluate the effectiveness of green infrastructure. COVID-19 and the ensuing pandemic limited our survey to an online format, as in person surveys were nearly impossible and mail surveys may have been viewed skeptically given unknowns about how the virus spread. However, due to lockdowns and other restrictions, it is possible that the pandemic led to a higher response rate for an online survey. Future study could utilize a mixed method approach, which could richen the dataset and reduce biases that come from only using an online survey. As this study was largely concerned with understanding perceptions with the intention of identifying areas for policy, future study could also use surveys to assess various green infrastructure programs and policies to predict public response. Further, our analysis focused on a relatively small subset of urban areas by focusing on New Jersey. To date, there are relatively few large green infrastructure initiatives in the state. Thus, it could be interesting to use future work to compare attitudes in areas such as these with ones that have seen large scale mobilization of green infrastructure initiatives, such as Philadelphia.

Chapter 4. The Effect of Green infrastructure on Runoff in Northern New Jersey: A Novel GIS Approach

ABSTRACT: As a coastal state, New Jersey faces increasing threats from storm events and the resultant flooding caused by climate change. Many urban areas in the state find these formidable challenges exacerbated by considerable cover by impermeable surfaces, which can increase stormwater runoff and pressure combined sewer overflows (CSOs). CSOs represent aging infrastructure that can be overwhelmed during even minor storm events, and the resulting discharges can create hazards for local human and environmental health. Many municipalities are turning to green infrastructure (GI) to supplement existing grey infrastructure, as it can mitigate runoff effectively, be sited with relative versatility, provide secondary benefits, and be installed and maintained at a lower cost than other options. While other studies have sought to site this infrastructure effectively in terms of maximizing benefit, few of these studies have done so in the context of reducing CSO discharges while considering multiple GI options. This study proposes filling this gap by using a scenario-based GIS framework to understand potential GI uptake and installation options, and how that can affect stormwater flows and CSO discharges. We applied this analysis to two coastal urban centers in New Jersey (Elizabeth and Newark) to understand the potential for porous pavement, rain cisterns, and green roofs in the study area.

1. INTRODUCTION

New Jersey, as largely urbanized coastal state, has become increasingly vulnerable to hydrological risks, which can pose dangers to human and environmental health (Soriano and Rubio, 2019). Among the most pressing challenges that urban areas in the United States face currently are combined sewer overflows (CSOs), which are common throughout the urban areas of the northeastern United States and other areas around the world. CSOs are among the foremost contributors to low water quality in urban environments, largely as a result of high percentages of impermeable surfaces that reduce infiltration and amplify storm runoff (Soriano and Rubio, 2019; Fu et al., 2019). During storm events, runoff can potentially overwhelm CSOs, leading to discharges that release domestic, commercial, industrial, and stormwater pollution into local water bodies (Chen et al., 2019; Fu et al., 2019). While large storm events contribute to this issue, many urban areas can suffer CSO discharges with relatively little rainfall due to high percentages of impervious surfaces that are common in that environment (NJDEP, 2019; Salerno et al., 2018); some urban areas of New Jersey can face discharge events with as little as one inch of rainfall (Battelle, 2005; Donovan et al., 2006). Uncertainties brought on by global climate change, such as increased storm intensity or frequency, has lent further urgency to the health risks brought on by CSOs, as contamination could become increasingly common (Jagai et al., 2015; Li et al., 2019).

The dangers of CSO discharge have not been overlooked, as USEPA mandates under the Clean Water Act have made mitigating or eliminating CSO discharge part of a federal mandate (Fu et al., 2019). However, many areas around the United States have continued to struggle with the implementation of these measures, as they may be costly or difficult to carry out; constrained budgets, limited resources, and difficulties due to institutional structures already in place, has made rapid adjustment climate change exacerbated issues difficult (Bowen and Lynch, 2017). Thus, it has increasingly become important to identify new solutions that are less costly and more versatile, and to analyze how best to implement such measures effectively.

Green infrastructure (GI) is one such solution, and is recommended for use to mitigate CSO discharges as a Best Management Practice (BMP) (Fu et al., 2019). Green infrastructure can take a number of forms, including rain cisterns/barrels, green roofs, rain gardens, biofiltration basins, and permeable pavement, which promote some combination of evapotranspiration, infiltration, and detention to reduce stormwater flow (de Sousa et al., 2012; Fu et al., 2019; USEPA, 2013). GI serves to reduce the overall area of impervious surface, which is critical in urban areas, where it can reduce runoff and delay infiltration to ultimately reduce flooding and its consequences (Li et al., 2019). While in many urban centers grey infrastructure is still used widely, GI offers flexible and environmentally friendly designs, and can provide a number of secondary benefits, including pollutants removal, carbon sequestration, urban heat island effect reduction, air quality improvement, drought resilience, temperature control, and aesthetic and real estate value improvements (Abhijith et al., 2017; Cohen et al., 2012; De Sousa et al., 2014; Fu et al., 2019; Li et al., 2019; Venkataramanan et al., 2019; Venkataramanan et al., 2020; Zhang and Chui, 2018).

Though green infrastructure siting simulation models in the literature are useful, many of them lack the planning capabilities for an entire watershed or sewershed, and can often require significant data inputs that make accurate modeling difficult. Further, many studies utilize scenarios that are specific to proposed policy, without exploring other options that may provide a wider vision of GI implementation and acceptability. To address these shortcomings, we used an ArcGIS linked GI modeling platform to rapidly assess the capacity for GI installation in the region. This platform used publicly available GIS data map the land use across our study area, then model GI installation through transformations to understand the capacity for runoff reductions in the area. Detailed maps on impervious surfaces within our study area allowed us to pinpoint potential area for GI installation within existing land use types to broadly model reduction potential. As cost and public acceptability are critical, this platform took into account three major GI fixtures (rain cisterns, green roofs, and permeable pavement) at different levels of penetration to demonstrate their effectiveness, and repeats this across private and public land uses types. We utilized optimization modeling in the final stage to identify ideal scenarios in terms of cost, reductions, and efficiency for the various land use types. In this study, we applied this model to two cities in New Jersey that are at risk of CSO discharge.

2. LITERATURE REVIEW

2.1 Green Infrastructure Modeling

Due to the increasing popularity of GI as a CSO mitigation tool, there have been several studies that have simulated various GI interventions. Fu et al. (2019) developed a Stormwater Planning Support System aimed at reducing CSO discharges on the watershed scale, which was able to highlight the costs and efficacy of different GI scenarios and better account for public preferences. Garcia-Cuerva et al. (2018) used the Storm Water Management Model (SWMM) to simulate GI scenarios across private and public lands in North Carolina, prioritizing placement in underprivileged communities. Li et al. (2019) simulated GI placement and effectiveness with the Long-Term Hydrologic Impact Assessment-Low Impact Development 2.1 model (L-THIA-LID 2.1) to identify the most cost efficient scenarios for runoff reduction and nitrogen and phosphorus loads. Raei at al. (2019) combined a SWMM neural network, fuzzy and optimization techniques, and a decision-making support model to produce optimal GI scenarios in terms of reducing runoff and contamination while also taking into account cost and public acceptability.

3. METHODS

3.1 Stormwater Runoff Calculations using NRCS Curve Number Method

For stormwater runoff calculations, we used curve number (CN) method from Technical Release 55 (TR-55) the National Soil Conservation Service (NRCS, 1986). This method is based on land cover, and is commonly used to estimate runoff from rainfall volume (Fu et al., 2019; Nidhi et al., 2016). The curve number method is appropriate for runoff simulations at the parcel scale, and can estimate the effects of various land cover and use changes in a GI management and implementation scenario (Fu et al., 2019). This equation can be written as:

$$Q = (P - Ia)2/(P - Ia) + S$$

where Q is the depth of runoff in inches, P is rainfall depth in inches, I_a is an initial abstraction of losses before runoff begins (equal to 0.2S), and S is the potential maximum retention after runoff begins (equal to 1000/CN-10). CN is the curve number according to the NSCS, which is based on soil groups and land use. This equation can be simplified as:

$$Q = (P - 0.2S)2/(P + 0.8S)$$

The curve number method generally becomes more accurate in cases where hydrological soil groups can be easily defined. While this can be the case in some areas of cities, many soil surveys in urban areas are incomplete due to a variety of factors, often because impervious surfaces make obtaining samples difficult. To account for this, this analysis uses a range of values for the various land cover types. Our "Low" estimate uses the curve number for soil group A, which tends to allow the most infiltration, while our "High" estimate uses the curve number for soil group D, which tends to have the least. This method allows for some variability in our analysis to account for scenarios that may be considered best or worst case for these soil types.

Some of the GI tested in our scenarios also have low and high curve number estimates based on various literature, which is described in their respective sections.

Though a more advanced hydrology modeling tool would have perhaps given us more accurate data, many of such methods require sewer and flow data, which is not readily available to the public. Thus, the curve number method allowed us to take the average permeability of soils in our study area and understand infiltration and runoff with relative accuracy. We used data by county for 1, 2, 5, and 10 year storms to understand runoff. We neglected to test this for larger storms as CSOs are problematic due to more frequent discharges with relatively smaller storms, and because green infrastructure at many scales may be insignificant in mitigating runoff in larger storms.

To account for lost accuracy that can result from the use of the curve number method instead of a more intricate modeling tool, we leveraged our GIS integration for a more complex analysis of the land cover. Instead of calculating the raw acreage for each of our land use types and using the corresponding curve number to arrive at total storm runoff, we further differentiated impervious surfaces within each land use type. GIS analysis allowed us to identify rooftops, roads, and "other" area (sidewalks, parking lots, and similarly impervious surfaces) within each land use type. We assigned each of these land uses their appropriate curve number, and calculated the runoff for these areas after subtracting them from their parent land use type. Thus, the overall calculation for the baseline stormwater runoff can be written as:

$Total\ Runoff = ResidentialQ + CommercialQ + OpenQ + IndustrialQ + RoadQ + ResidentialRoofQ + ResidentialOtherQ + ResidentialRoadQ + CommercialRoofQ + CommercialOtherQ + CommercialRoadQ + OpenRoofQ +$

$OpenOtherQ + OpenRoadQ + IndustrialRoofQ + IndustrialOtherQ + IndustrialRoadQ$

where each non-Q term is the calculated area of its respective land use type.

Curve numbers are meant to account for the mix of impervious and pervious surfaces within each given land type. However, due to the nature of our scenarios, wherein we are theoretically replacing large percentages of exclusively impervious surface, using the base curve number method as is generally done would have resulted in misleading results, such as increases in runoff with green infrastructure calculation. It is important to account for how the permeability of the parent land use types changes when the calculated areas from the impervious sub-types are removed. To do this, calculated modified curve numbers using the following equation:

$$\mathrm{CN_p} = \frac{\frac{1000}{\mathrm{CN_o}} - (\mathrm{CN_{Im}} * \mathrm{P_{Im}}\}}{1 - \mathrm{P_{Im}}}$$

Where CN_O is the original curve number of the land use, CN_{IM} is the curve number of the impermeable area, P_{IM} is the potential maximum retention of the impermeable area, and CN_P is the adjusted curve number. This equation allowed the computation of the assumed curve numbers for the permeable areas based on the remaining portion of the ground that was not covered by impermeable surfaces (CN=98) and is based on the fact that any curve number is implicitly the combination of the curve numbers of its composite parts.

While commercial districts and industrial areas both had only one category in the curve number chart, our open areas, residential areas, and roads had to make some assumptions. Residential areas can have drastically different curve numbers depending on the average lot size.

The average lot size for residential parcels in Elizabeth in our study was 0.078 acres, while Newark's parcel size was 0.097 acres. Thus, we used the "1/8 acre or less" cover type for these areas, as they fall well within the boundary. The cover types for roads included several types such as dirt and gravel, but given the urban environment, we assumed that the majority of these roads were fully paved, which provided a higher curve number. Open spaces were defined in the curve number chart by the amount of grass cover in the area. Because the average open space in our data had consistently high coverage by impervious or semi-pervious surfaces such as parking lots and walkways, we assumed that the average open space would call under the "Poor condition" cover (<50% grass cover).

3.2 GIS Integration

In order to get an accurate estimate of runoff in the target cities, we integrated ArcGIS for spatial analysis. We used definitions in the Parcels and MOD-IV data to identify most parcels with their most appropriate land use type. Open area parks, sports fields, and similar structures were considered "Open" area, commercial buildings and larger community service buildings constituted "Commercial" areas, and industrial and residential area belonged to the grouping of the respective name. Then, we used the Impervious Surfaces (2015) of New Jersey dataset to fill in roads, sidewalks, outbuildings, and other similar structures that were not included in parcel data. Finally, we used the New Jersey 2015 Land Use Land Cover dataset to fill in the remaining gaps in our study area map. For urban areas, this database separates areas into four categories: Open, Commercial, Residential, and Industrial. While this dataset is useful in identifying these parcels by zoning information, it includes 13 categories, which had to be grouped according to the curve number data to match our planned categories. The groupings are displayed in Table 4.1 below.

Table 4.2: Curve Number Dataset Classifications

MODIV Property Tax Dataset Zone	Curve Number Calculation Group
Vacant	Open
Farm	Open
Railroads	Open
Cemetery/Graveyard	Open
Public Space*	Open, Commercial
Commercial	Commercial
Apartments	Commercial
Public School	Commercial
Church and Charitable Property	Commercial
Residential	Residential
Industrial	Industrial
Private Property Telephone	Industrial
Refinery	Industrial

**Separated using 2015 LULC dataset*

Open areas for this dataset are characterized by low amounts of impermeable surface and therefore better infiltration, and generally have few buildings or parking lots. Open area was defined as Vacant, Farm, Railroads, Cemetery/Graveyard, and some Public Space zones. Vacant, Farm, and Cemetery/Graveyard areas comprise a relatively low amount of space in urban areas, and meet criteria for Open area with little impermeable surface. Railroads, while featuring more impermeable surface due to railway infrastructure, are largely gravel-based and therefore largely permeable. Public Space as a zoning category included both public buildings (such as government buildings) and public spaces (such as parks). As these are very divergent uses, we utilized the 2015 LULC dataset to split this category into its respective uses. Parcels that were categorized as Recreational Land were classified as Open area. All other LULC classifications for Public Space was relegated to commercial use, as explained in its respective section.

Residential areas are characterized by private residences with smaller properties, parcel sizes, and relatively low amounts of impermeable surface. Importantly, residential buildings also tend to have slanted roofs, which are ideal for using rain cisterns to reduce runoff. This group included parcels in the MODIV data that were classified as Residential in addition to churches with slanted roofs.

Commercial areas are characterized as places of business, which generally have larger buildings, larger parking lots, and higher amounts of impermeable surfaces. For the purposes of green infrastructure calculation, buildings in this category also tend to have flat roofs instead of slanted ones, which make them strong candidates for green roof installation. This grouping included Commercial, Apartment, Public School, Church and Charitable Property, and some Public Space zones. Commercial, Public School, and Church and Charitable Property zones all met the definitions of this grouping due to building size, flat roofs, and impermeable surfaces. Apartments, while places of residence, were grouped into this category rather than in Residential because the parcels that they represent have more common attributes with Commercial parcels than Residential ones in terms of stormwater runoff patterns. As noted in the Open section, Public Space included both open areas such as parks and public buildings, such as government buildings. We used 2015 LULC data to identify Recreational Land in this category to be grouped with Open area. The remaining LULCs, such as dominant areas of Commercial/Services and Urban LULC classification.

Industrial areas are characterized by large buildings, large amounts of impermeable surface, and large parking lots. Like commercial buildings, they also generally have flat roofs, which make them ideal for green roofs. This grouping included Industrial, Private Property Telephone, and Refinery zones. Industrial and Refinery zones fit well into this category, as they fit all of the identifying criteria. Private Property Telephone zones are comprised of phone service hubs, which more accurately fit the definition of Industrial than Commercial given the amount of impermeable surface.

Roads were the final major land use category in our study, and did not need further definition through land use types. This category includes all paved roads in the study area in addition to a relatively low amount of buildings and other impermeable surface (such as sidewalks or parking lots) that are not accounted for by other areas in the study. As these areas have an identical curve number to that of roads, our analysis grouped them together for simplicity.

The resulting maps had few gaps, and were categorized using the most specific data available first. The areas for each grouping were then summed and exported for each municipality.

3.3 Scenario Design

We developed a baseline scenario and a number of alternative scenarios, as described in Figure 2 below. Following Fu et al. (2019), our scenarios moved from the most inexpensive GI in private parcels and added in more expensive GI options in public parcels in subsequent scenarios. To account for various implementation scenarios, we roughly followed a scenario design by Garcia-Cuerva et al. (2018) in which differing percentages of penetration were used; for each infrastructure option, we ran permutations in which 10, 25, 50, and 75 percent of parcels would adopt the GI in question. This aims to account for differing adoption rates depending on areas and local attitudes, and may provide low and high estimates for the effectiveness of the scenarios on stormwater runoff. Further, combining these scenarios in various combinations can be used to mimic different preferences and priorities in management systems for better customization. As noted in Section 2.2, each scenario was tested under 1, 2, 5, and 10 year storm runoff permutations. To account for variability in CNs for both GI and the land uses in our study, each of the aforementioned scenarios was recreated under conditions of high and low estimates for GI and/or CN. Thus, each scenario (with one exception, explained in the appropriate section) was run under 4 permutations: Low Land CN/Low GI CN (LCN LGI), High Land CN/Low GI CN (HCN LGI), Low Land CN/High GI CN (LCN HGI), and High Land CN/High GI CN (HCN HGI). As the baseline did not have any additional GI, there were only High and Low CN estimates.

Table 4.2: Scenario Variables

Scenario	Land Use Type	GI Used
1	Residential	Rain barrels
2	Commercial	Green Roof
3	Open	Green Roof
4	Industrial	Green Roof
5	Residential	Permeable Pavement
6	Commercial	Permeable Pavement
7	Open	Permeable Pavement
8	Industrial	Permeable Pavement

The baseline scenario uses a combined GIS dataset for Elizabeth and Newark, and does not include any new GI development (NJOGIS, 2021a; NJOGIS, 2021b; NJOGIS, 2021c). This study area was divided into CN land use types as described in section 2.2, and ultimately included 2215.72 and 1482.56 acres of residential area, 1438.86 and 621.86 acres of industrial area, 5760 and 2020.01 acres of commercial area, 2954.78 and 2573.96 acres of open area, and 2417.87 and 1007.51 acres of road area, for Newark and Elizabeth respectively.

Scenario 1 assumes the increased use of rain barrels across the cities in the study area. Following Fu et al. (2019), we calculated the impact of these scenarios using rain barrels with 0.79m^3 (200 US gallons) capacity in our higher estimate, but also used smaller .29m^3 (70 US gallons) capacity in our lower estimate; this is to account for the fact that 200 gallon cisterns may not be viable for smaller parcel sizes, or that residents may prefer a cheaper or smaller option. However, because our results showed low stormwater reductions across all permutations in this scenario, we did not include .29m^3 barrels in the final results. This scenario installs rain barrels at random among residential parcels, which total 28221 and 15140 overall in Newark and Elizabeth, respectively. These are installed at rates ranging from 10% (2822 parcels in Newark, 1514 in Elizabeth) to 75% (21166 parcels in Newark, 405 parcels in Elizabeth). To ensure that we did not exceed the total runoff possible for rain barrels, we calculated the runoff from an average sized roof and reduced it by the capacity of the rain barrel system, which assumes 100% catch efficiency.

Scenarios 2, 3, and 4 assume the increased installation of green roofs across various parcels. Commercial, open, and industrial areas are targeted primarily in this scenario, as the majority of residential parcels in this area have sloped roofs, making them largely incompatible with green roofs. This scenario used the CN equation to change the permeability of the roof areas of these land use types, which combined with fairly rich data from the Impervious Surfaces (2015) of New Jersey dataset (NJOGIS, 2021b), can give a fairly accurate estimate of GI potential on rooftops. Though the NRCS does not have a built-in CN for green roofs, we used estimations for CN by the Maryland Department of the Environment ranging from 77 to 94 (Maryland Department of the Environment, 2018). A CN of 77, representing deeper retention media of 2.4 inches was used for our low estimate, while a CN of 94 was used for the high estimate. These scenarios were divided by land use type, since each type has a diverse range of issues and benefits that come with GI adoption and installation, and we felt that the ability to combine scenarios in various ways could prove useful for the overall utility of the model. Scenario 2 represents commercial roofs, Scenario 3 represents roofs on open areas (including fieldhouses, bathrooms, and other enclosed areas), and Scenario 4 represents industrial areas. Our analysis maintained the same rates as in Scenario 1 to estimate adoption over the total area; because of the variability of size and coverage of roof areas, estimating the impact of green roofs of a specific size would have been unfeasible given the size of the study area and the variance in size per parcel. As such, a percentage of the total roof area in each scenario is converted from its higher initial curve number to the green roof curve number. Scenario 2 covered a total of 1321.71 and 452.56 acres of rooftops in Newark and Elizabeth respectively, ranging from 10% adoption (Newark 132.17 acres, Elizabeth 45.26 acres) to 75% adoption (Newark 991.28 acres, Elizabeth 339.42 acres). Scenario 3 covered a total of 126.39 and 123.19 acres of rooftops in Newark and Elizabeth respectively, ranging from 10% adoption (Newark 12.64 acres, Elizabeth 12.32 acres) to 75% adoption (Newark 94.79 acres, Elizabeth 92.39 acres). Scenario 4 covered a total of 513.46 and 226.55 acres of rooftops in Newark and Elizabeth respectively, ranging from 10% adoption (Newark 51.35 acres, Elizabeth 22.65 acres) to 75% adoption (Newark 385.10 acres, Elizabeth 169.91 acres).

Scenarios 5, 6, 7, and 8 cover the installation of porous pavement across various land use types. To estimate the increase in runoff that this would provide, we used the CN equation to transform area classified as "other" in the Impervious Surfaces (2015) of New Jersey dataset to permeable pavement (NJOGIS, 2021b). Like green roofs, permeable pavement does not have an assigned CN in the NRCS database, but estimates ranging from 60-72 have been used by past studies (Fu et al., 2019; Ballestero and Roseen, 2011); we used 60 for our low estimate and 72 for our high estimate. Land identified as "other" constitutes driveways, paved lots, sidewalks, and similar infrastructure, which are generally ideal candidates for porous pavement replacement (Fu et al., 2019). These scenarios used the same range of adoption preferences as the other scenarios. Scenario 5 represented residential area, Scenario 6 represented commercial area, Scenario 7 represented open land, and Scenario 8 represented industrial area. Scenario 5 covered a total of 690.65 and 511.48 acres in Newark and Elizabeth respectively, ranging from 10% adoption (Newark 69.7 acres, Elizabeth 51.15 acres) to 75% adoption (Newark 517.99 acres, Elizabeth 383.61 acres). Scenario 6 covered a total of 3071.88 and 967.13 acres in Newark and Elizabeth respectively, ranging from 10% adoption (Newark 307.19 acres, Elizabeth 96.71 acres) to 75% adoption (Newark 2303.91 acres, Elizabeth 725.35 acres). Scenario 7 covered a total of 1089.57 and 1736.38 acres in Newark and Elizabeth respectively, ranging from 10% adoption (Newark 108.96 acres, Elizabeth 173.64 acres) to 75% adoption (Newark 817.18 acres, Elizabeth 1302.28 acres). Scenario 8 covered a total of 790.13 and 315.77 acres in Newark and Elizabeth respectively, ranging from 10% adoption (Newark 79.01 acres, Elizabeth 31.58 acres) to 75% adoption (Newark 592.60 acres, Elizabeth 236.83 acres).

3.4 Optimization Analysis

Because cost is a factor in green infrastructure analyses, we adopted a simple optimization analysis to model the costs of using various green infrastructure types. Because this analysis is based on the assumption that there are both high and low cost areas for installation evenly distributed in both cities, we used a linear curve to model the relationship between runoff reduction benefits and costs. To do this, we used MATLAB to model scenario combinations that could be used at various price points to reduce stormwater runoff. The assumptions for the costs of the green infrastructure used in this study can be found in Table 4.3 below. Additionally, the cost of purchasing and installing a rain barrel was assumed to be $150 (Macro et al., 2019). These costs were assigned on a linear scale to the scenarios, with cheaper installations on lower adoption rates (as they are using ideal land), and more expensive costs for higher adoption rates (as "low hanging fruit" sites are already developed).

Table 4.3: Annual cost per unit of runoff volume for suitable GI

GI Type	**Total initial cost ($/m^2)**
Green Roofs [a]	69-165
Porous Pavement [b]	31.36-153.36

[a] *Mei et al. (2018), Peck and Kuhn (2003)*
[b] *Mei et al. (2018), Xie et al. (2018)*

4. RESULTS AND DISCUSSION
4.1 Scenario Comparison

The simulations of green infrastructure installation in the 8 scenarios were calculated in a spreadsheet, which can be found in the appendix. As expected, in all scenarios, the amount of total runoff in the study area decreased as the total conversion area increased. This effect is also seen, albeit with less dramatic effects, in the high CN scenarios. For clarity and in with respect to perspective we report the results of each scenario in terms of percentage of runoff avoided.

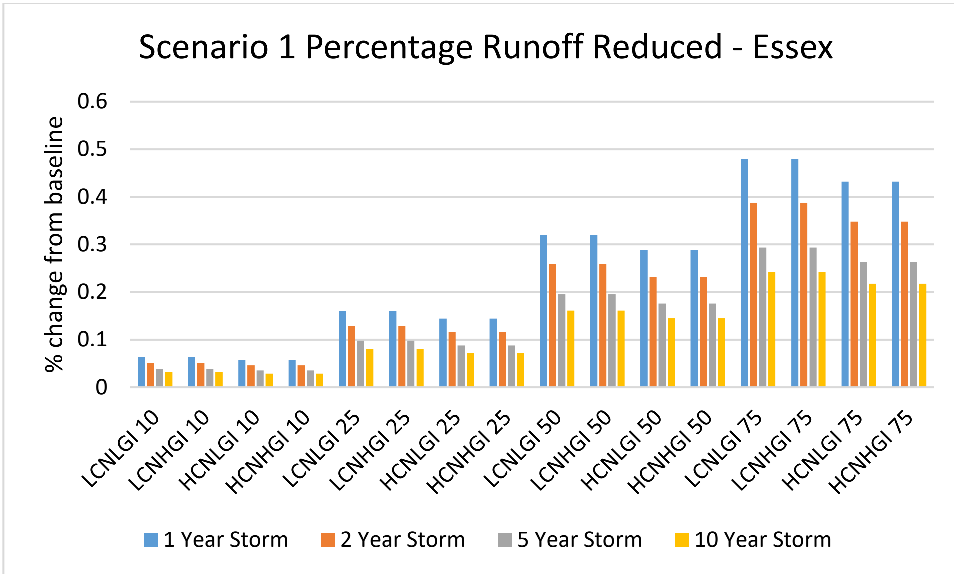

Figure 4.1: Scenario 1 Results for Newark

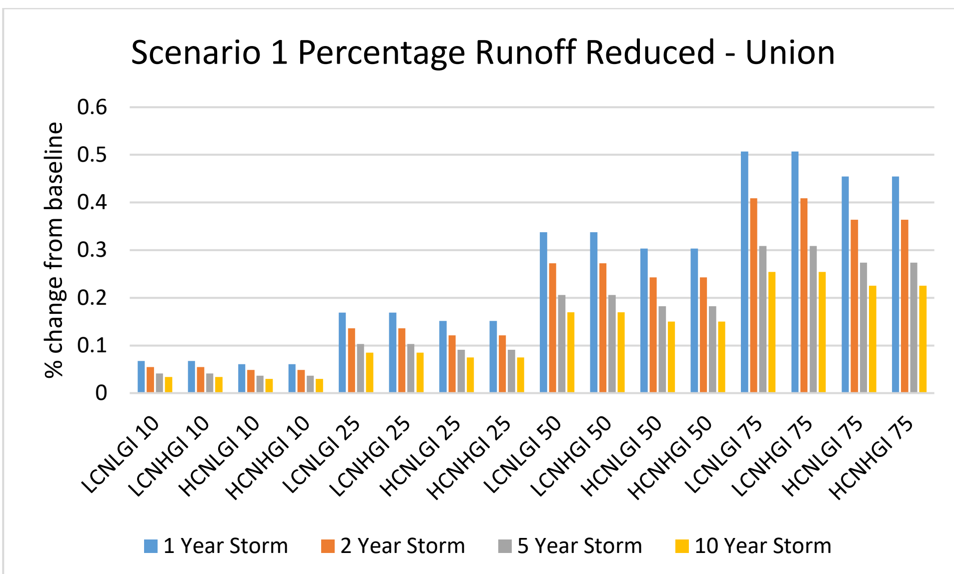

Figure 4.2: Scenario 1 Results for Elizabeth

Scenario 1, which modeled rain cisterns, had the lowest total runoff reductions of all tested scenarios. This was likely because unlike the green infrastructure in other scenarios, which function on infiltration, rain cisterns operate on the capture of stormwater, and hence have a limit of what can be controlled in a single storm. Even in the lightest scenarios (1 Year storm), rain barrels reached their maximum capacity, and therefore had a negligible effect on the overall runoff reduction. In Newark, total reduction ranged from .02% in the HCN 10 year storm permutation to a maximum of .48% in the LCN 1 year storm permutation. Elizabeth saw similar trends, with reductions ranging from .03% in the HCN 10 year storm permutation to .51% in the LCN 1 year storm scenario. Because rain barrels in these scenarios reached their maximum capacity, as storms grew larger, their effect did not change, and thus this form of GI became less effective with storms of increasing intensity. As such, given our framework and assumptions, rain barrels appear to be the least effective of the GI options tested in terms of total runoff reductions. This agrees with the lower end of findings by Garcia-Cuerva et al. (2018), who found that rain barrels reduced total runoff between 0.0% and 4.5% across their scenarios, which included adoption rates higher than the ones used in this study. However, Fu et al. (2019) found a much higher reduction of 14.17% in overall runoff volume, though some of this can be attributed to a high (97.25%) adoption rate in their scenarios.

Scenarios 2, 3, and 4 were run to understand the possible effects of green roofs in the study area, and replaced impervious roof area in commercial, open, and industrial areas, respectively. As expected, permutations with higher adoption rates performed better in terms of total runoff avoided, though due to CN calculations, there was no increase or decrease in efficiency. All permutations in both study areas showed downward trends in reduction percentages as storms grew, suggesting that overall effectiveness decreases in larger storms. However, this may also signal that green roofs may be more effective in smaller storms that we did not test for, suggesting higher reductions in more common storms.

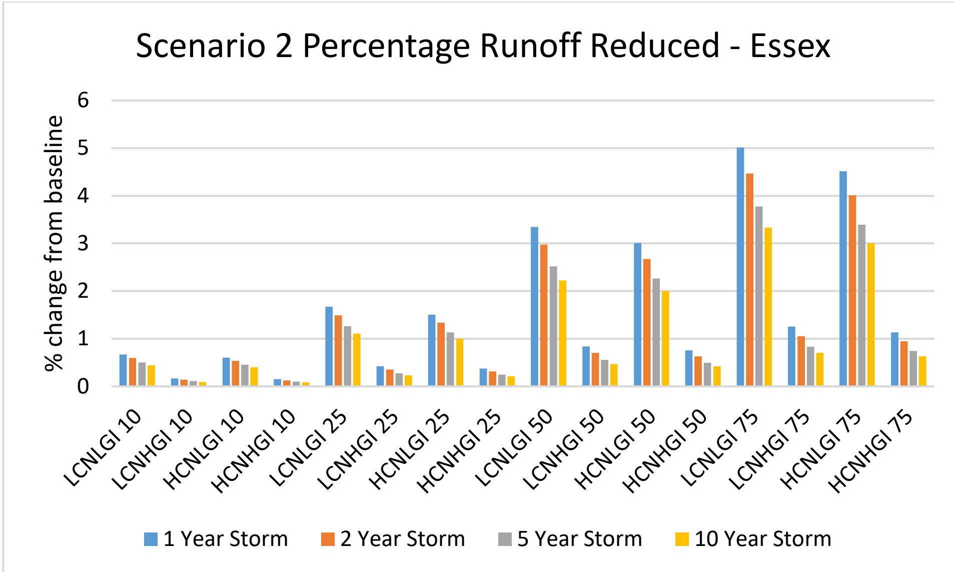

Figure 4.3: Scenario 2 Results for Newark

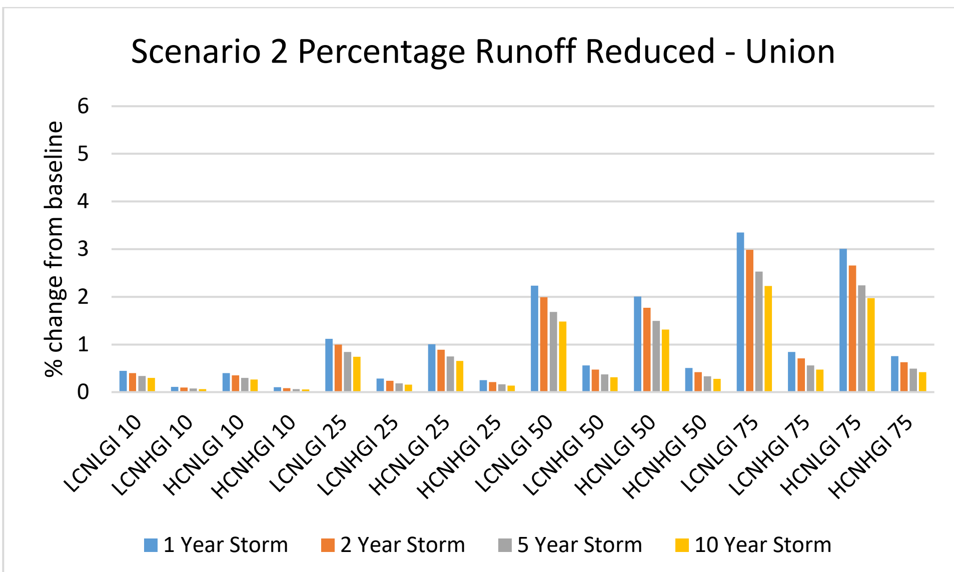

Figure 4.4: Scenario 2 Results for Elizabeth

Scenario 2 was the first scenario to model green roofs, and had a considerably stronger effect than rain barrels on runoff reductions. Stormwater reductions in Newark ranged from .08% in the HCN HGI 10 year permutation to 5.02% in the LCN LGI 1 year permutation, while reductions in Elizabeth ranged from .06% to 3.35% in the same respective permutations.

Replacing impermeable surface on commercial roofs proved to be the most effective option for reducing runoff among the green roof scenarios. While this is partially because of the high percentage of commercial area in the study areas (particularly in Newark), the conversion of highly impermeable areas to green roof appear to have a significant effect on runoff reduction.

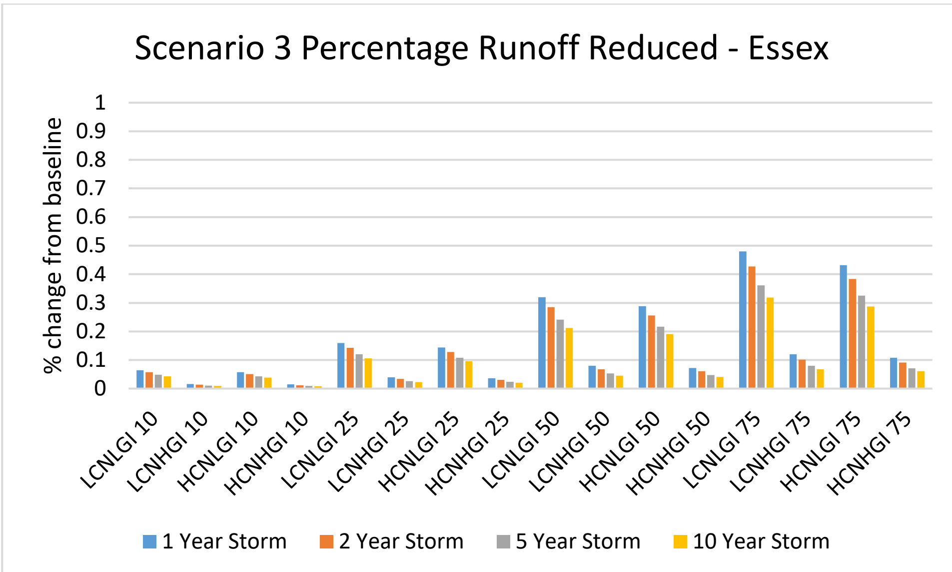

Figure 4.5: Scenario 3 Results for Newark

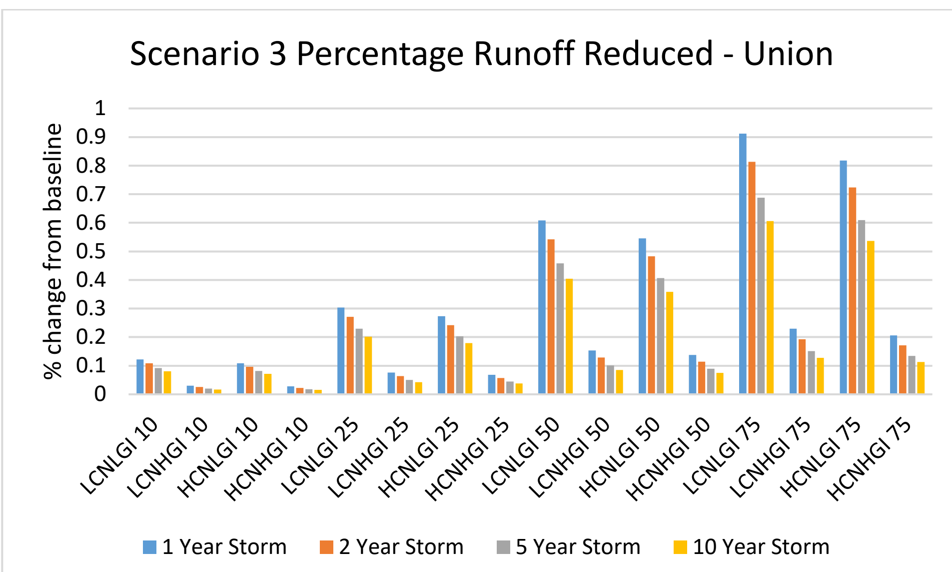

Figure 4.6: Scenario 3 Results for Elizabeth

Scenario 3 modeled green roofs in open areas, and had a much weaker effect. Reductions in Scenario 3 ranged from .01% in the HCN HGI 10 year permutation to .47% in the LCN LGI 1 year permutation in Newark, and ranged from a similarly low .02% in the HCN HGI 10 year permutation to .91% in the LCN LGI 1 year permutation in Elizabeth. Regardless of permutation, green roofs on open land had the lowest runoff reduction percentages among the green roof scenarios, and had effectiveness only slightly higher than rain barrels, which was the lowest among all scenarios. This suggests that commercial and industrial area are much more effective targets for green roofs for runoff reduction. This is likely due to the relative permeability of open areas generally, as the low CN in these areas doesn't benefit from the reduction of impermeable surface in as dramatic fashion as areas with higher impermeable percentages do.

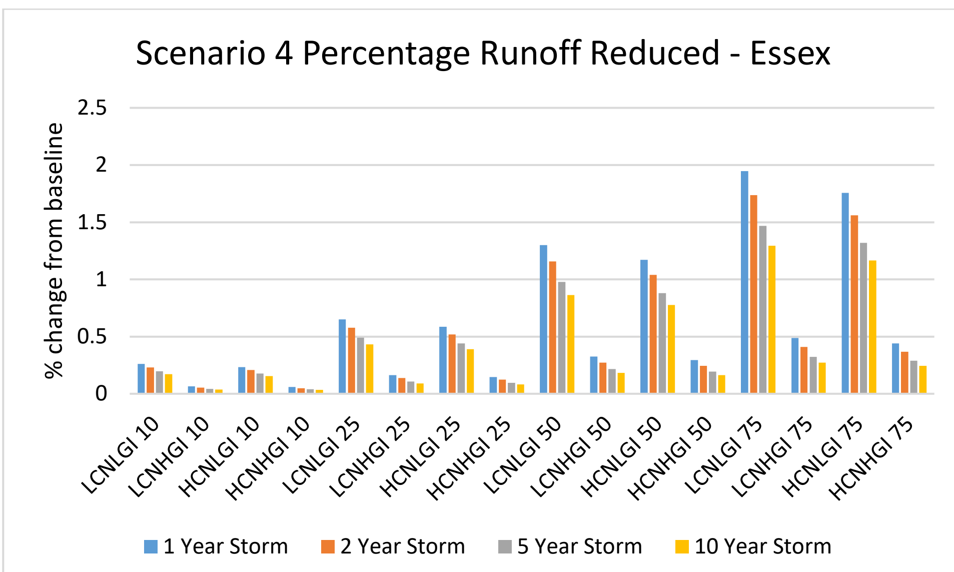

Figure 4.7: Scenario 4 Results for Newark

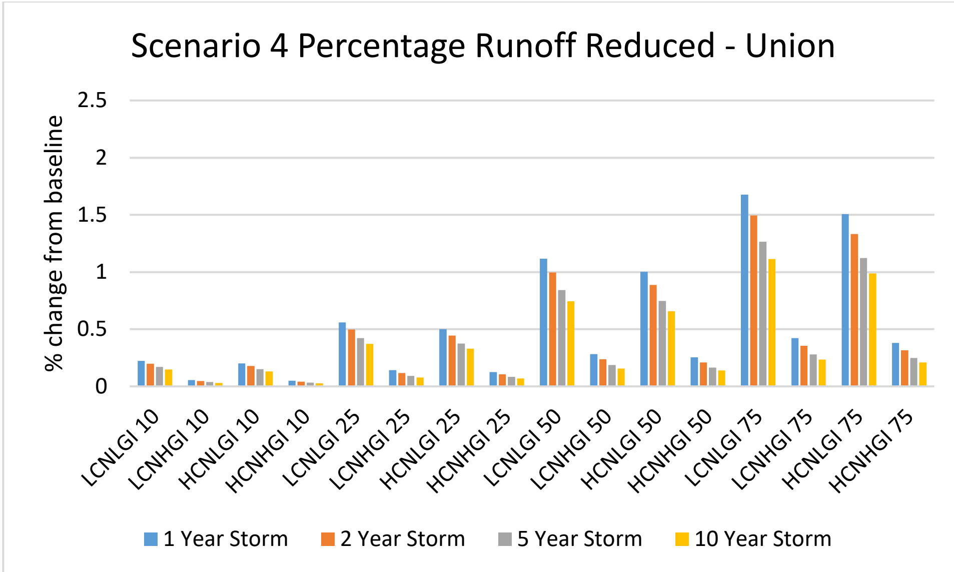

Figure 4.8: Scenario 4 Results for Elizabeth

Scenario 4 modeled green roofs on industrial areas, and had an effectiveness somewhat more pronounced than Scenario 3 and somewhat less than Scenario 2. Reductions in Scenario 4 ranged from .03% in the HCN HGI 10 year permutation to .43% in the LCN LGI 1 year scenario in Newark, and from .03% to 1.7% in Elizabeth in the same respective permutations. Low overall percentage reductions can be partially attributed to the relatively small area that is categorized as industrial; industrial area had the lowest coverage among the other sampled land covers (residential, commercial, and open) in both Newark and Elizabeth. However, significant concentrations of impermeable area on these lands make even small conversions relatively efficient in less intense storms. This effect is particularly pronounced in Elizabeth, where 226.55 acres of roof area, when converted, can reduce runoff by between .38% and 1.7% in the 75% adoption permutation.

Scenarios 5, 6, 7, and 8 all model the effect of replacing impermeable pavement classified as “other” with permeable pavement in residential, commercial, open, and industrial areas, respectively. Like the earlier scenarios, the effectiveness in terms of percentage of runoff reduced decreases with the intensity of storms, though the total reductions do increase overall. This may again suggest that permeable pavement could have larger reductions in smaller storms.

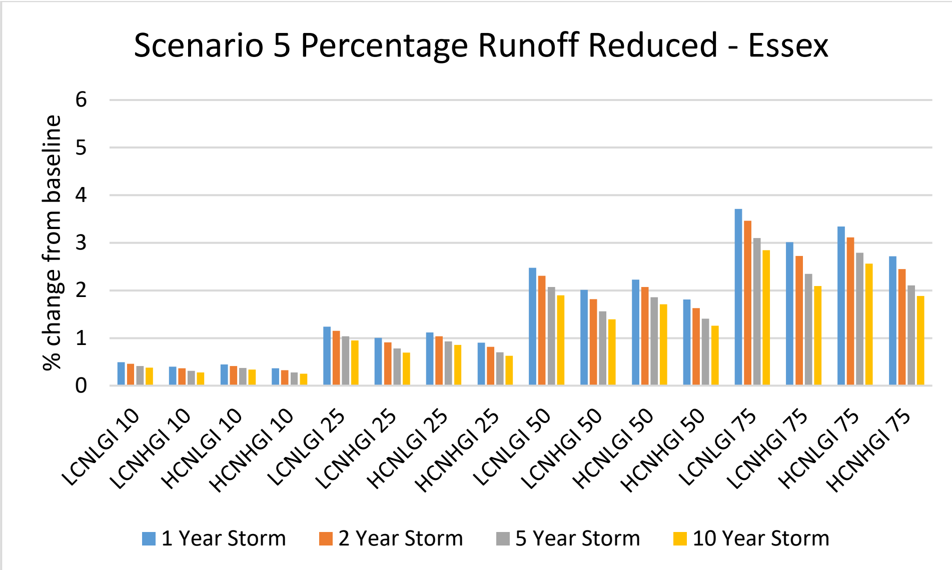

Figure 4.9: Scenario 5 Results for Newark

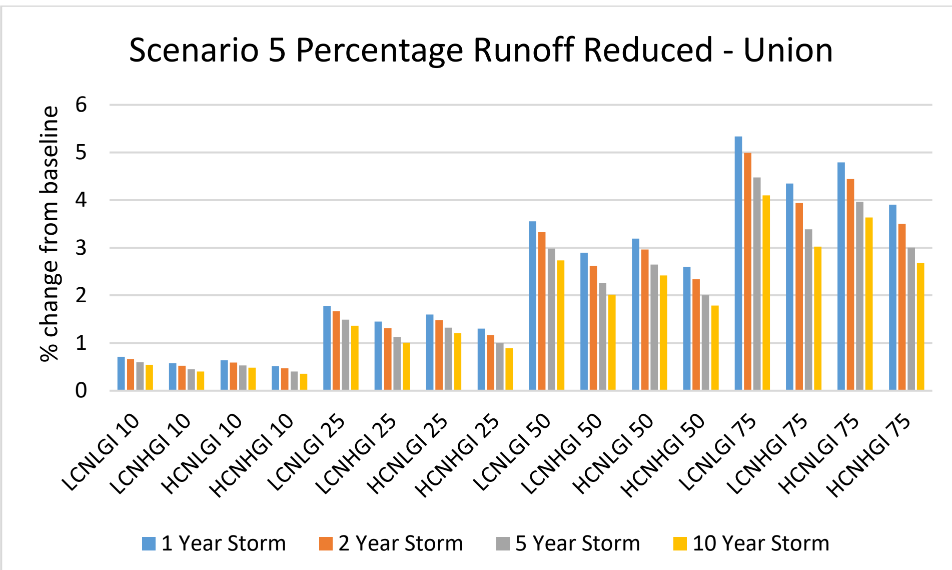

Figure 4.10: Scenario 5 Results for Elizabeth

Scenario 5 modeled permeable pavement on "other" residential areas. Reductions in Scenario 5 ranged from .25% in the HCH HGI permutation to 3.7% in the LCN LGI 1 year permutation in Newark, and .36% to 5.34% in Elizabeth under the same respective permutations. While modest, the reductions from these scenario rival or surpass many of those in the green roof scenarios. Further, as cities in various have found success in offering incentives or grants to build green infrastructure, residential areas may be more likely to reach higher rates of adoption. While permeable pavement may fall outside the normal range of what such incentives promote, the reductions, particularly in Elizabeth where the rates are higher, may make conversion to this GI type attractive. These findings were considerably lower than those from Fu et al. (2019), who estimated a 28.69% runoff reduction while using private parcels. A much higher adoption rate and different scenario bounds may partially account for this disparity.

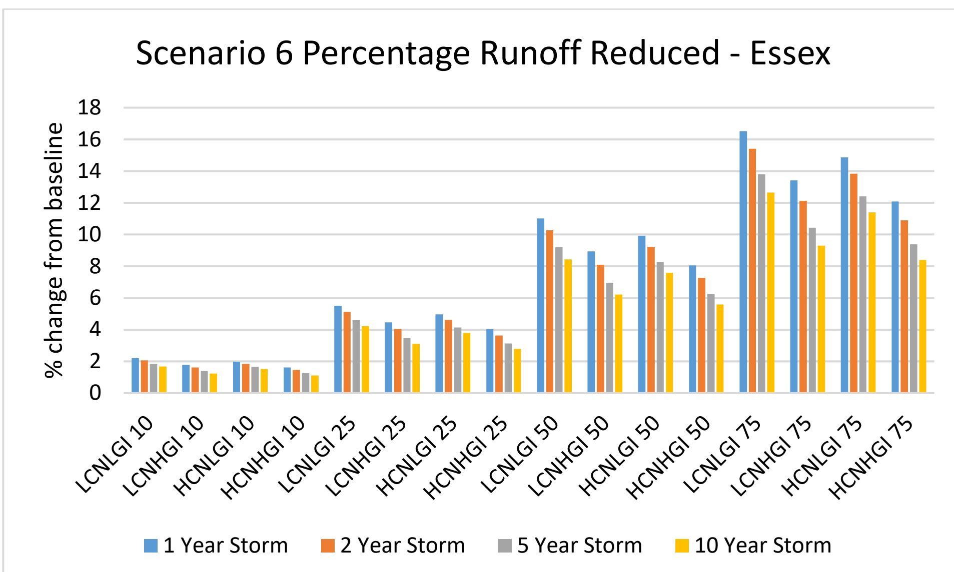

Figure 4.11: Scenario 6 Results for Newark

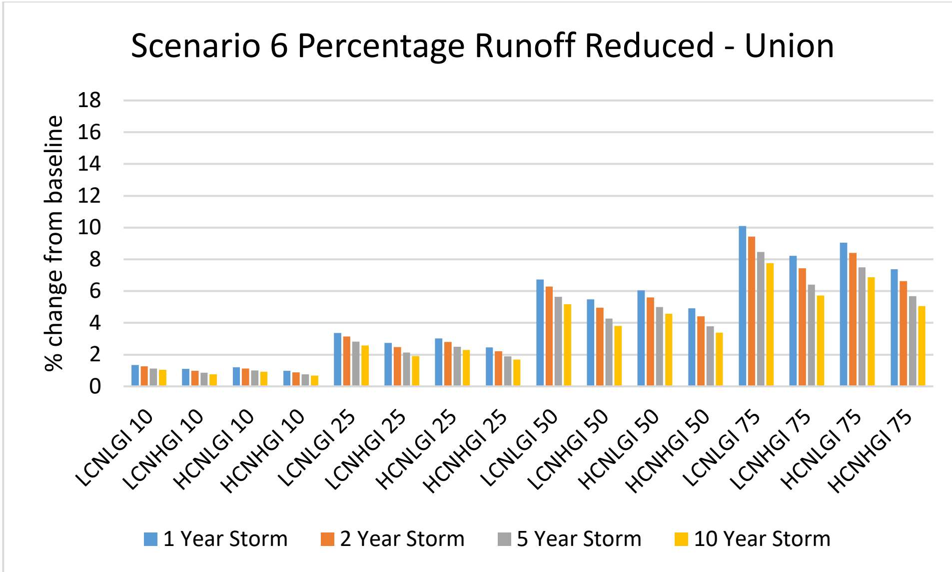

Figure 4.12: Scenario 6 Results for Elizabeth

Scenario 6 converted "other" area in commercial land types to permeable pavement, and had some of the best performance in terms of percentage in the entire model. Reductions in Scenario 6 ranged from 1.12% in the HCN HGI 10 year permutation to 16.5% in the LCN LGI permutation in Newark, and .68% to 10.09% in Elizabeth under the same respective permutations. This scenario represents the highest percentage of runoff reduction in Newark, and the second highest in Elizabeth, making it one of the most attractive options for conversion. While this is a difficult process owing to the amount of commercial land in both cities, large conversions of this impermeable pavement seem to have significant effect on total runoff, especially in less intense storm permutations.

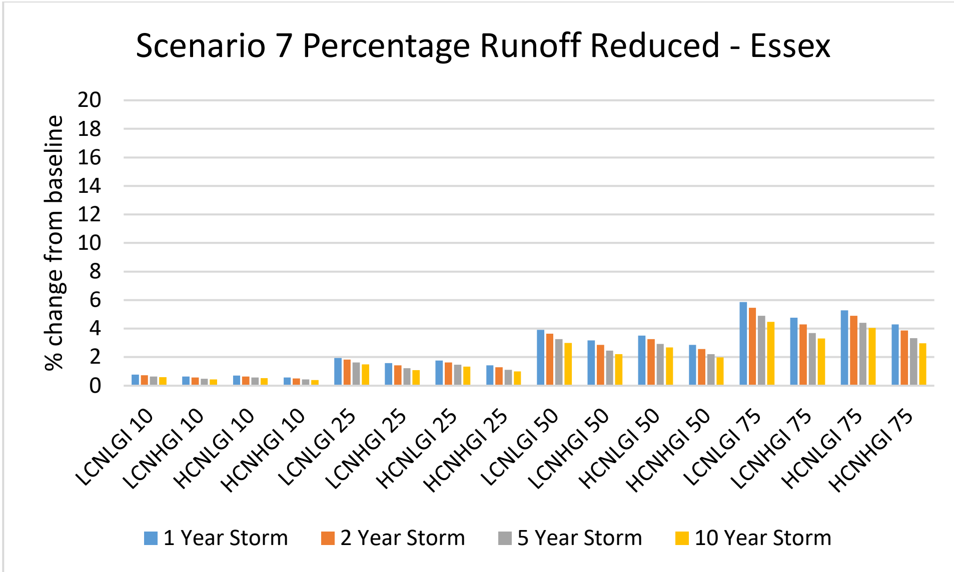

Figure 4.13: Scenario 7 Results for Newark

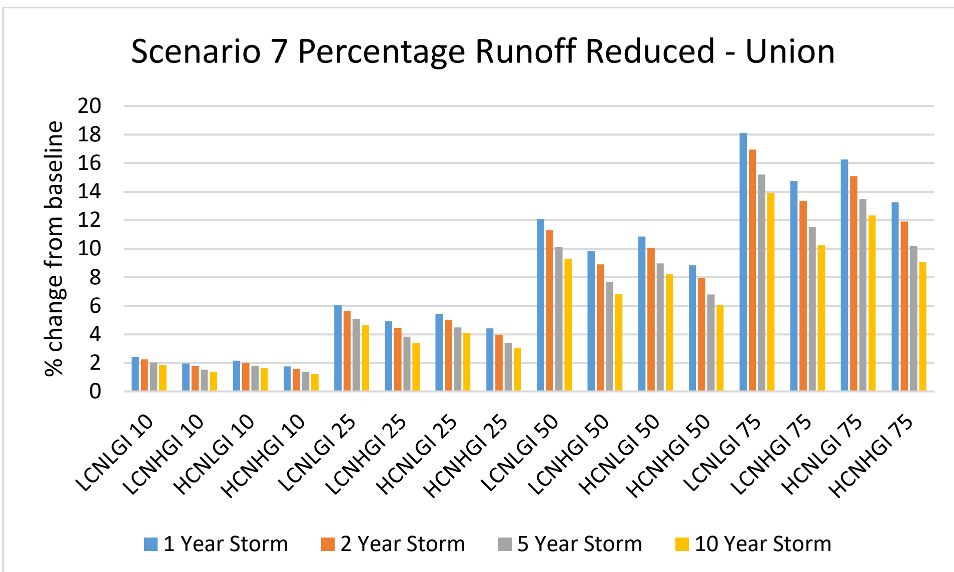

Figure 4.14: Scenario 7 Results for Elizabeth

Scenario 7 modeled the conversion of "other" area within open land to permeable pavement. While this scenario showed reasonable values in terms of runoff reduction percentage for Newark, it represented the most effective option for Elizabeth. Runoff reductions ranged from .4% in the HCN HGI 10 year permutation to 5.86% in the LCN LGI 1 year permutation for

Newark, and from 1.21% to 18.12% in Elizabeth under the same respective permutations. Though open area does constitute a higher area than any other in Elizabeth, the total gains from reducing impermeable pavement with permeable pavement (and assuming a low CN for the GI) results in the largest total reduction among scenarios for Elizabeth. As much of the area under this classification is public land owned by the government, these results suggest a strong option when pursuing GI installations. These findings differ from the 27.07% found by Fu et al. (2019), but some of this difference can be attributed to a higher adoption rate in their scenarios.

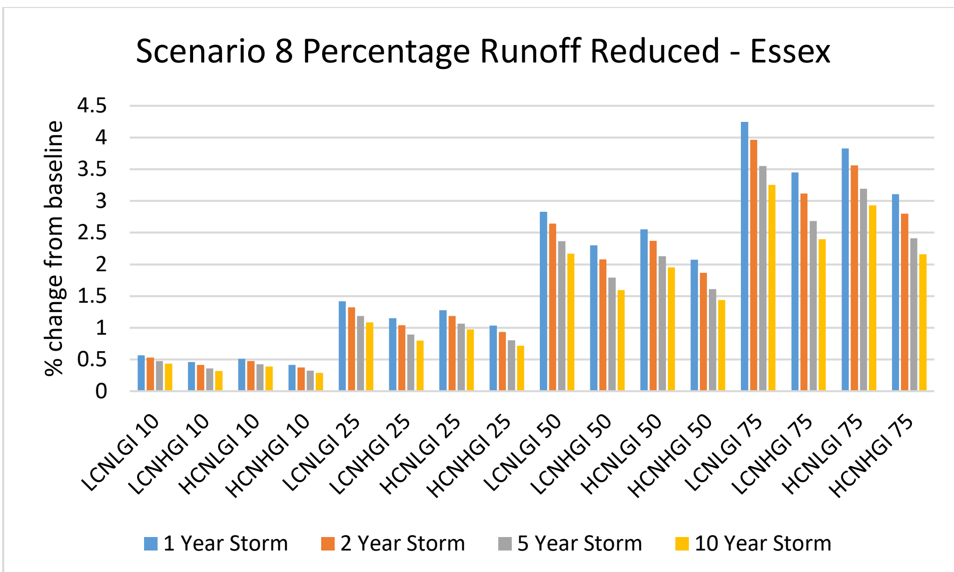

Figure 3: Scenario 8 Results for Newark

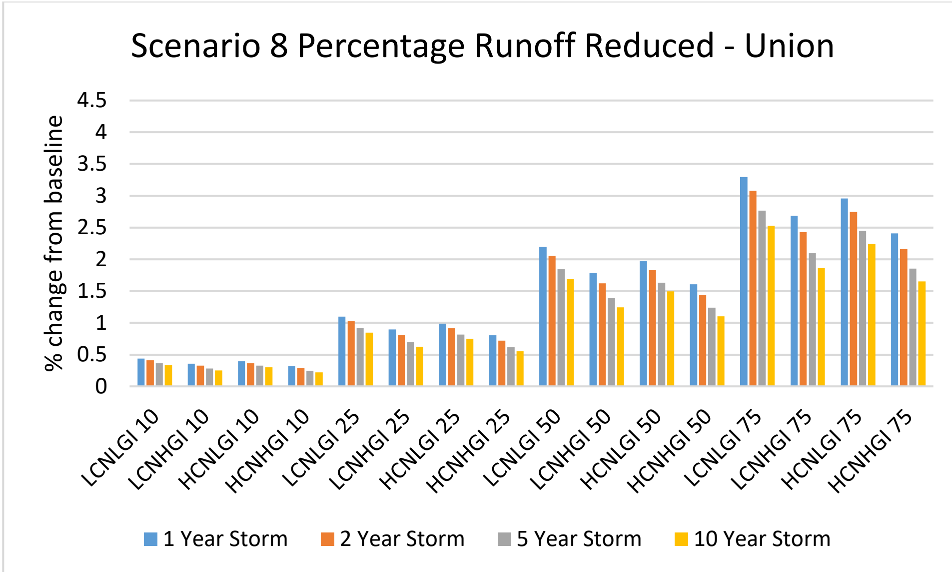

Figure 4.16: Scenario 8 Results for Elizabeth

Scenario 8 was the final scenario run, modeling the conversion of "other" areas of industrial land to permeable pavement. Runoff reductions ranged from .28% in the HCN HGI 10 year permutation to 4.25% in the LCN LGI 1 year permutation for Newark, and from .22% to 3.3% in Elizabeth under the same respective permutations. The results of this scenario were fairly middling, being neither the strongest nor weakest among the scenarios for both cities. However, given the difficulty of attaining high levels of adoption in industrial land, as well as complications that could arise depending on the use of the site, pursuit of this scenario may not be advisable due to the relatively low runoff reductions that result.

Overall, the scenarios were at their most effective in the scenarios that assumed lower CN values for the GI options and for the land cover itself. However, of these two variables, a lower CN for the GI appeared to have a stronger effect on the overall results. While this may hinge somewhat upon how the runoff is calculated, it does have planning and management implications; for example, the CN of green roofs is largely dependent on the depth of the media and the materials used, and thus deeper installations should be pursued for better results. As noted earlier, GI performance was less effective in stronger storms and more effective in weaker ones.

Figures 17 and 18 below detail the comparisons between scenarios for both target cities. Scenario 6, in which commercial land was converted to permeable pavement, was the strongest performer in Newark, while Scenario 7, which converted open land to permeable pavement, was the strongest performer for Elizabeth. In both cities, these scenarios had considerably higher runoff reductions than any others, particularly in Newark. Permeable pavement was more effective overall than either green roofs or rain barrels in most scenarios. Green roofs were largely a less effective option, though there were significant reductions involved with Scenario 2, which built green roofs on commercial roofs. Rain barrels were the least effective of the tested options.

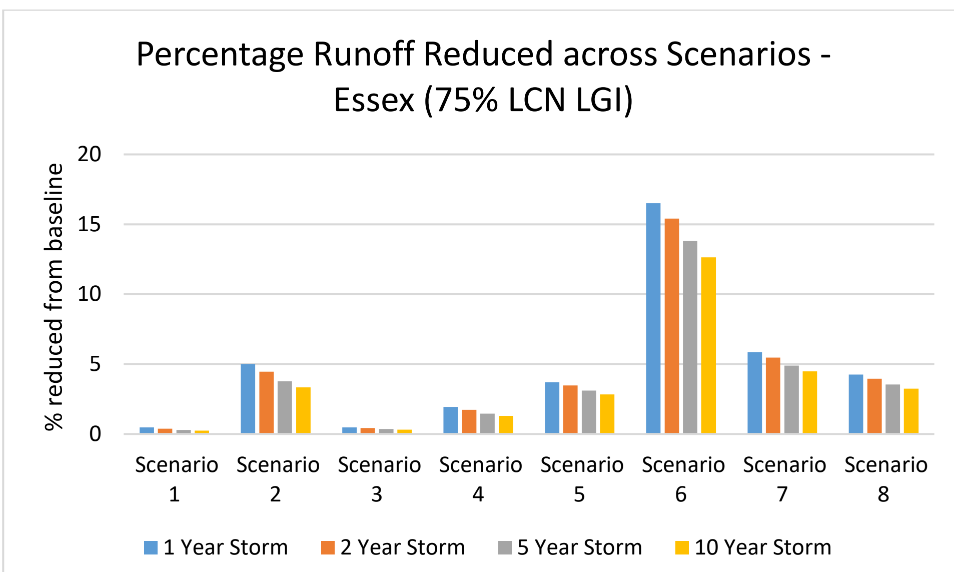

Figure 4.17: Comparisons of the Scenarios under the Highest Runoff Reduction Calculation in Newark (Low CN, Low GI CN)

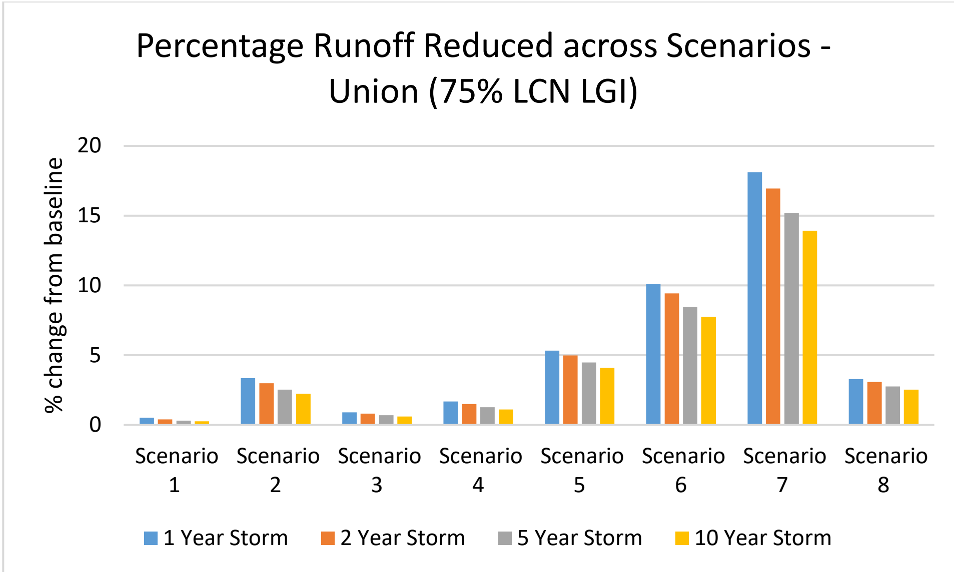

Figure 4.18: Comparisons of the Scenarios under the Highest Runoff Reduction Calculation in Elizabeth (Low CN, Low GI CN)

Thus, our analysis indicates that purely in respect to runoff reduction, conversion to permeable pavement, particularly in commercial and open areas, may bring the best result. These cities, therefore, should prioritize these options if attempting to maximize their runoff, and should aim to get as much conversion as possible. However, as many commercial areas may be privately owned, this may be difficult to do directly, and municipalities may instead have to rely on grants, discounts, and incentives to push opt-ins. Open area may present a simpler solution, as these lands are largely public and therefore owned by the city itself. While green roofs and rain barrels did not perform as well as permeable pavement in the analysis, it is important to note, albeit obvious, that both options do capture a considerable amount of runoff. These options can still be pursued to maximize runoff reductions, especially if they are more economically feasible; we attempt to address this with our optimization analysis.

4.2 Optimization Results

The results of the optimization for both cities can be found in Figures 4.19 and 4.20 below.

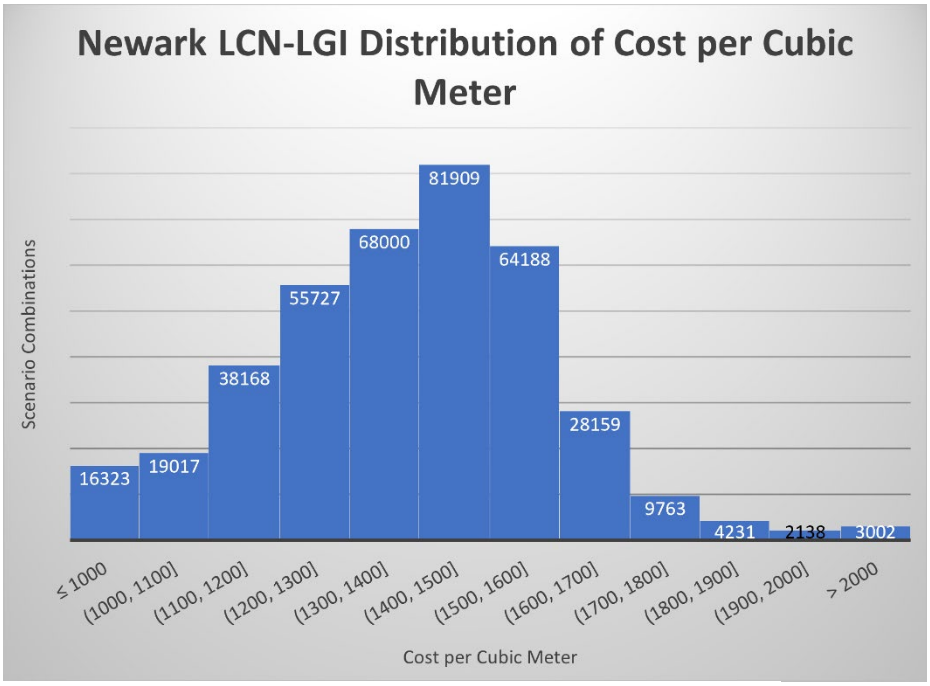

Figure 4.19: Distribution of Cost per Cubic Meter in Newark

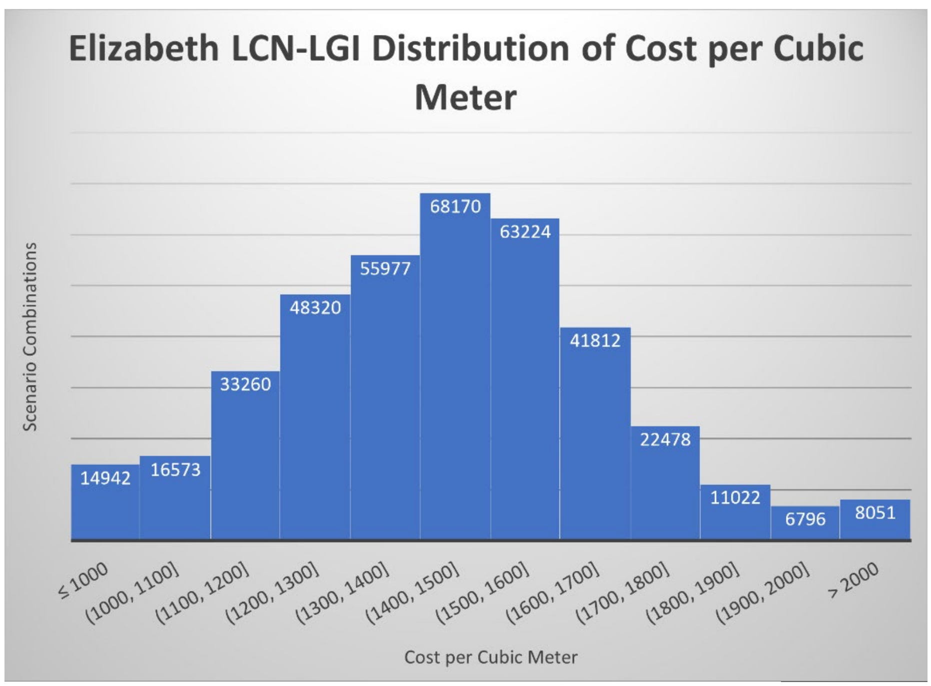

Figure 4.20: Distribution of Cost per Cubic Meter in Elizabeth

Both cities have similar overall trends in the optimization analysis. Both cities have the most scenario combinations in the $1400-$1500 per cubic meter averted range, suggesting that this may be a price point when considering large scale green infrastructure projects. On the lower end, there are 14,942 and 16,323 scenario combinations that can capture stormwater for lower than $1000 per cubic meter in Elizabeth and Newark respectively. These combinations are largely driven by extensive use of rain barrels, as our optimization shows that their cost effectiveness per cubic meter captured is exceptional. Permeable pavement and green roofs are both far less cost efficient, though permeable pavement is generally more cost efficient throughout the scenarios. While these price points may appear high for relatively small reductions, it should be noted that the majority of possible combinations achieve reductions at a lower cost than the mode, which suggests that early installations in ideal or suitable locations can be significantly more cost effective than later ones. Further, there are relatively few scenarios that necessitate spending $2000 or more per cubic meter of stormwater avoided.

5. CONCULSIONS AND FUTURE STUDY

We used an ArcGIS enhanced framework to model stormwater scenarios for the cities of Newark and Elizabeth, using rain barrels, green roofs, and permeable pavement as potential green infrastructure installations. We used GIS to calculate the total land area of different land use types, then converted them to these green infrastructure types using a range of curve number estimates and for 1, 2, 5 and 10 year storm intensities. We found that permeable pavement was the most effective option in terms of percentage runoff reduction in both cities, with commercial area conversions performing more strongly in Newark and open area conversions performing more strongly in Elizabeth. Further, all green infrastructure tested performed better in terms of percentages reduced in smaller storms, suggesting usefulness in common storms that may cause issues such as CSO discharges. An optimization analysis showed higher cost effectiveness in stronger storms, and suggested that rain barrels, while providing relatively low runoff reduction for its cost, is extremely efficient in reductions in terms of cost.

Our results suggest that green infrastructure can provide considerable reductions in runoff, and thus, policy should continue considering it as one of the primary options in urban spaces. While building policy, decision makers may consider the results of this framework to determine where there may be potential for reduction runoffs, and pair this with a more complex siting tool or ground surveys to determine the feasibility of installation and maintenance. Similarly, our optimization model suggests that urban areas may benefit significantly from "low hanging fruit" areas that are ideal for green infrastructure installation, and thus prioritizing the cheapest options as a minimum can be an efficient use of resources. This framework can also be applied to any watershed that has applicable databases available in ArcGIS to estimate green infrastructure impact over a given area.

Our study was limited in some respects. Our optimization analysis used a linear curve as opposed to a sigmoid curve largely due to a lack of information on the viability of different sites, which can be remedied with better data. While we attempted to group buildings by their class for the most accurate estimate, assumptions cannot fully account for variations within the groupings, and thus our estimates may over- or underestimate potential runoff reductions. Future study could expand upon this framework by testing more green infrastructure types to understand their relative effectiveness in various scenarios.

CHAPTER 5. SUMMARY AND CONCLUSIONS

5.1 Economic Impact and Perceptions of CSOs

As with any management decisions, cost and stakeholder perceptions are critical considerations. Because many municipalities are now moving to mitigate CSO discharges in response to growing concerns about the dangers they pose to both populations and environmental health, understanding these is critical. Though some costs associated with CSOs can be estimated by various means, social costs and its impact on markets has not been well understood. In Chapter 2, we explored this problem by applying a hedonic regression to urban areas of New Jersey to elicit values for CSOs and other attributes in the residential market.

Our hedonic regression identified a number of significant attributes that contributed to or worked against the overall value of a home. Critically, though we had predicted a disamenity value attached to CSOs due to their harmful effects and unpleasant attributes (such as foul odors during a discharge), we instead found the opposite. The amenity value that we found suggests that residents will not pay a premium to live further away from CSOs, but will instead actually pay more to live closer to one. While this may seem out of the resident's best interest, there may be a number of reasons for this. For example, though CSOs can cause illnesses in residents in the days following a discharge event, relatively low levels of education on CSOs or recognition of their effects may cause such events to go unrecognized. Further, CSO discharge sites, by nature, must be located on a body of water; as proximity to waterfronts or water generally are valued traits in a home, the amenity value that they provide may largely override any negative effect CSOs may have.

Our findings in later chapters suggest that residents are concerned about flooding, which is inexorably linked to CSO discharges, making it feasible that residents would also be concerned about discharge events. Thus, while this study did not reveal significant economic reasoning within the housing market to curtail CSO discharges as quickly as possible, it may reveal a need for educational outreach on the health hazards associated with them. Further, as this is the first study to our knowledge using the hedonic method to address CSOs, the values may nevertheless be useful to policy makers in urban areas with such infrastructure. It may also open the door to similar, more refined studies in the future.

5.2 The Role of Green Infrastructure in Curtailing Runoff

Green infrastructure has become one of the most widely used methods of curtailing CSO discharges due its adaptability, cost, and secondary benefits. However, as a relatively new tool, there are still many unknowns in terms of its best practices for use, particularly in terms of perceptions and public support. In Chapter 3, we attempted to better understand the perceived utility of green infrastructure by using a discrete choice experiment approach. We also used a willingness to pay analysis to better estimate what amount residents would be willing to pay for various attributes.

Our study found that a number of attributes were valuable to residents, including improved air quality, increased water supply, and closer proximity, among others. In terms of secondary benefits, our results suggest that attributes that provide direct utility (such as improved local air quality or more water to use in home upkeep applications) were more valued by our respondents. Surprisingly, while infrastructure is often subject to NIMBYism, our results found that residents preferred green infrastructure features closer to their home, perhaps to better be in a position to receive the benefits. Though other attributes were not as valued, they still elicited significant results, which reflects well on the overall attitudes on residents towards green infrastructure generally.

Our results from Chapter 4 reveal that residential areas can be a significant source of runoff reductions, and thus convincing home owners to install and maintain green infrastructures can be of critical importance in reducing the impact of storms and, in turn, CSO discharges. The results of this study will be helpful in suggesting what types of green infrastructure residents prefer to see, and may also provide insight into some of the ways that may be most effective in doing so. For example, as closer proximity is an attribute with a high willingness to pay and significant utility, programs that offer discounts or incentives to home owners to purchase and install green infrastructure on their property may be an effective way to reduce the overall impermeable area of the municipality. While our study only covered New Jersey, it may have implications for cities in similar situations in the United States and abroad.

Chapter 4 provides a framework to demonstrate the possible extent of these runoff reductions using a GIS-integrated NRCS curve number runoff model. The results for our scenarios showed that green infrastructure was more effective in smaller storms, which is ideal for more common storms that can still trigger CSO discharges. In terms of runoff reductions, permeable pavement performed the strongest, followed by green roofs and rain barrels. Both cities had different land uses that were the most productive, which could be a benefit or a hindrance depending on the difficulty of implementing green infrastructure installation in these areas. A cost optimization analysis, however, showed that some green infrastructure (particularly rain barrels) performed well in terms of efficiency, and were still viable options in reducing overall stormwater flow at a relatively low cost.

While significant runoff reductions can be achieved in some of the more aggressive scenarios, these are obviously difficult to attain; areas that are privately owned are not directly accessible by the municipalities, and thus crafting policy to increase participation will be critical. Further, other, more complex analyses can be paired with this method to efficiently site potential green infrastructure in these areas, so that the earliest installations can have the high impact suggested in our optimization model. Taken with our results from Chapter 3 and similar studies, municipalities can effectively build their stormwater management plans with a better grasp of their potential savings and with more stakeholder input.

5.3 The Way Forward

CSOs continue to represent a public and environmental health threat in urban areas in the United States and abroad, and there is no one-size-fits-all solution. However, given the complex economics that come with management decisions, the studies in here have attempted to better understand costs and benefits that have not often been studied in the literature. These studies can provide a framework to better plan for potential policies and management to curtail CSO discharges and position communities to benefit from green infrastructure.

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