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Contextual Considerations of Green Stormwater Infrastructure Siting

Green infrastructure increasingly is used to ameliorate water quality and quantity problems caused by runoff in cities. Studies show how the spatial distribution of these Green Stormwater Infrastructure (GSI) sites are unevenly distributed relative to socioeconomic and demographic groups. Often this is described as an indicator of perpetuated environment injustice, given the purported social and environmental benefits of GSI. To assess equity, researchers often examine either who gets what with respect to environmental 'goods' such as tree canopy and other green infrastructures, or investigate the procedures, decision making processes, and power structures pertaining to planning processes. This paper uses both spatial analyses to examine where GSI is located and who lives nearby in New Haven, CT, and illuminates the processes by which those locations were determined. An environmental injustice pattern was not observed: most GSI were located in low-income communities of color. However, the process that led to the siting had very little to do with who was living where. Instead, GSI siting decisions were determined by funding opportunities and their site selection criteria, flooding, combined sewer infrastructure, and avoiding infrastructure conflicts on a street segment. Future spatial analyses could consider the implicit or explicit baselines for equity in light of the processes and constraints that determine how and where GSI gets installed, and better incorporate the process of green infrastructure allocation in the chosen analytical metrics. By examining the process (ie the "how") and the outcomes (ie the "what went where") this study broadens the spatial analyses to include embedded knowledge from those who actually make the decisions that ultimately determine the location of GSI.

Keywords

Urban ecology, green infrastructure, environmental justice, New Haven, spatial analyses

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1 INTRODUCTION

The landmark United Church of Christ Commission for Racial Justice demonstrated social and economic disparities in the distribution of environmental hazards (Commission for Racial Justice, 1987). Spatial coincidence, a technique that demonstrates connection between the siting of a hazard and the socio-demographic characteristics of the surrounding area, a measure of the distribution of environmental risk, became a primary test for whether decisions about siting were deemed unequal (Chakraborty et al., 2011). In recent years, a growing body of literature has also emphasized how the presence of environmental amenities such as parks, playgrounds, or recreational spaces may contribute to broader framings or analyses of environmental injustice (Crompton, 2001; Giles-Corti et al., 2005; Rigolon et al., 2018). Moving to understand the distribution of amenities and services, in addition to hazards, emerged as a conceptual addition to the environmental injustice hypothesis. This addition accounts for both the procedures that govern environmental decision making and the presence of perceived environmental value within a demarcated area (Grove et al., 2018). By tracking the distribution of amenities, scholars suggested that patterns might reveal legacies of bureaucratic, procedural, and administrative decision making that privileged white property owners and economically empowered groups (Boone et al., 2009).

Attention to the distribution of environmental amenities simultaneously stimulated policies, programs, and projects that seek to improve access to and the quality of nature within cities, such as MillionTreesNYC (MillionTrees NYC, 2008) and Philadelphia's Greenworks plan (Greenworks Philadelphia, 2009). Many cities have turned to green infrastructure (GI) as one mechanism of improving environmental quality while also increasing the distribution of amenities (Dunn 2010). Green Infrastructure is often framed as a corrective technology that can fix or ameliorate existing environmental harms such as nutrient loading or recurrent sewer overflows (Millennium Ecosystem Assessment, 2005; Pataki et al., 2011). Additionally, GI may provide co-benefits such as aesthetic improvements, space for recreation, and positive health outcomes (Benedict and McMahon, 2001; Coutts and Hahn, 2015; Millennium Ecosystem Assessment, 2005; Tzoulas et al., 2007). This conceptual positioning of GI as not only a neighborhood amenity but also a municipality-wide technological fix raises complex questions for both planners and analysts. For instance, what is the spatial scale of benefit delivery when a rain garden is assumed to improve regional water quality and provide neighborhood aesthetic improvements? Or, what constitutes the most appropriate unit of analysis to match the scaled conceptual framing of GI as an environmental amenity?

Complicating matters are the broad forms that constitute the suite of GI, and the anticipated benefits. Some use the term to refer to a system of interconnected green spaces (Benedict and McMahon, 2001; Tzoulas et al., 2007), while others understand GI as additions to the built environment that contribute to the management of stormwater (BenDor et al., 2018; Grabowski, Z.J., McPhearson, T., Matlser, A.M., Groffman, P., Pickett) *Forthcoming*). This second definition, often evoked by engineers, planners, and the United States Environmental Protection Agency (EPA), defines GI as a "cost-effective, resilient approach to managing wet weather impacts that provide many community benefits" (United States Environmental Protection Agency (EPA), 2020). The second definition is often distinguished as green stormwater infrastructure (GSI) and refers to a suite of technologies and best management practices that can retain or detain stormwater runoff. While this paper focuses on green stormwater infrastructure, both definitions generally position GI as a positive amenity that can provide functional and community value. Note that depending on circumstances, GI (Lyytimäki and Sipilä, 2009) and even urban trees can produce ecosystem disservices (Roman et al., 2021). Further, because GI and GSI provide external value, it is often understood as an environmental fix to an existing hazard such as water pollution caused by urban runoff, flooding, or a lack of community green space (Finewood, 2016; Finewood et al., 2019).

Many municipalities across the US have installed GSI to solve or attempt to ameliorate water quality or quantity problems stemming from stormwater runoff in cites. Most often these installations consist of facility types like bioswales, enhanced tree pits, or rain gardens, which can range widely in size, function, and possible co-benefits. For instance, a rain barrel, although it provides a stormwater capture function, is not capable of being used for outdoor recreation. While GI are capable of providing co-benefits, the types of benefits vary across technological types and/or across different scales in different ways.

Further complicating the issue of what types of benefits GSI can provide in different locations, the functional efficacy and applicability of GSI is linked to a multitude of environmental and land use factors including, but not limited to, soil type (United States Environmental Protection Agency (EPA), 2011), landscape context (Pauleit et al., 2017), and legacy uses (Frickel and Elliott, 2008). For municipalities installing GSI to meet regulatory requirements, these environmental conditions often decide the eventual location of a facility. Moreover, utility conflicts and legacy infrastructure systems (Baltimore City Department of Public Works, 2017, 36), prevent installation in certain locations altogether. Multiple environmental and landscape factors are perceived by planners and engineers as fixed determinants of the location and provision of GI's benefits across the landscape.

Given the emerging body of literature in urban ecology, urban planning, and science and technology studies (STS) demonstrating how infrastructural and environmental features implicitly and explicitly produce segregationist effects, it is essential to understand GSI implementation within this larger history (Grove et al., 2018; Hoffman et al., 2020; Namin et al., 2020; Phillips de Lucas, 2020). Indeed, as GI and GSI continue to be supported by planners, engineers, and community organizations for their ability to deliver multiple ecosystem services, a need emerges to evaluate our existing methods for assessing environmental injustice following the provisioning of apparent amenities.

Put another way, if GI and GSI are framed as practices that enhance the quality of environments, a need emerges to evaluate how we assess whether the presence of an amenity serves as an appropriate metric to assess environmental justice. Researchers often examine either who gets what with respect to environmental 'bads' like pollution and hazards (Chakraborty et al., 2011) or 'goods' such as tree canopy and other green infrastructures (Crompton, 2001; Giles-Corti et al., 2005; Rigolon et al., 2018), or investigate the procedures, decision making processes, and power structures pertaining to planning processes (Mohai and Saha, 2006; Pellow, 2007; Pulido, 2000). It is unclear whether existing spatial methods for assessing environmental inequality patterns, such as measuring the distribution of GSI installations within a given spatial area, represent the most appropriate unit of analysis when applied to green infrastructure.

This article asserts that to assess GSI's role in environmental justice, the siting process must be examined in conjunction with and inform the spatial analytical approach. This paper therefore uses both spatial analyses to examine where green stormwater infrastructure (204 bioswales) in New Haven, CT were installed from 2013 to 2019, who lives nearby, and illuminates the processes by which those locations were determined. By examining the outcomes (ie the "what went where") and the process (ie the "how"), this study broadens the spatial analyses to include embedded knowledge from those who actually make the decisions that ultimately determine the location of GSI. Integrating the planning and siting process improves the assessment of environmental justice and the interpretations, by informing and refining the spatial analyses to better assess the relationship between green infrastructure and inequality. Further, this assessment of environmental justice destabilizes the presumption of the presence of GSI as an inherent a 'good' within spatial analysis. Instead, by describing the linkages between pattern and process we gain a more comprehensive sense of how technologies come to embody particular meanings, authority, and power within environments (Winner, 1980).

2 Justice, Inequity, and Green Stormwater Infrastructure

2.1 Metrics of Environmental (In)Justice

The 1987 report by the United Church of Christ Commission for Racial Justice (Commission for Racial Justice, 1987) importantly documented environmental distributional injustice, and simultaneously advanced a method for measuring the demographic characteristics of communities located near these industries. The main approach would later become common place. The report presented the results from two cross-sectional studies. The first examined whether "variables of race and socioeconomic status played a significant role in the location of commercial hazardous waste treatment, storage, and disposal facilities" (9). The second study drew from population, location, and comparative data to describe the presence of toxic waste in "racial and ethnic communities" (12). In their study, community as a conceptual unit, was captured by 5-digit zip code area, while racial and ethnic categories used in analysis drew from Census data. These two variables, a spatially bracketed community paired with demographic population data, ushered in many studies concerned with tracing existing environmental disparities. This research often followed a basic formula: a fixed harm (e.g., industries producing toxic waste) was analyzed within a community (e.g., Zip Code) and population (e.g., racial, ethnic, and economic categories) context (Downey, 2005; Holifield, 2001; Holifield et al., 2017).

The report from the Commission for Racial Justice paved the way for many Environmental Justice (EJ) focused inquiries. This field of research contends with two distinct methodological questions – what units of analysis researchers should deploy, and what definitions ought to be deployed as a standard of proof for the existence of environmental inequality? In regard to units of analysis, debates persist to this day about how to quantify metrics and indices that demonstrate that environmentally unjust outcomes are present. These debates can take the form of what counts as a community (Taquino et al., 2002), which demographic populations are most impacted (Anderton et al., 1994), or the conditions or intentionality of siting decisions (Hurley, 1997; Mohai and Saha, 2015). Importantly, the definitions of environmental inequality that a researcher draws from influences not only the units of analysis selected for a study, but also the conclusions that can be drawn from the analysis, to begin with. Definitionally, Liam Downey has argued that "quantitative environmental inequality research has been too narrowly focused on one set of environmental inequality outcomes" (Downey, 2005, 2). As Downey discusses, this narrowness is often evidenced by researchers and practitioners who deploy different definitions of environmental inequality based on their professional orientation. Disciplinary definitions of environmental inequality may privilege one set of measurements or desired outcomes over another. For instance, Downey identifies discriminatory intent inequality (i.e. whether a disamenity was installed intentionally in a minoritized region) and disparate exposure inequality (whether the exposure to toxics disproportionately impacts a particular demographic group) as commonly utilized definitions within EJ literature that produce different analyses and findings.

Both abovementioned definitions create a relationship between the presence of a hazard and the production of disparate environmental risk – either through the intentional siting of a facility in an impoverished community or by greater exposure to a hazard than other surrounding populations. Like the Commission for Racial Justice report, these definitions are concerned with the spatial relationship between a fixed harm within a community and population context. Conversely, neither definition is positioned to consider how environmental amenities may mitigate risk or signal additional inequities within a community. Simply, the definitions utilized to study environmental inequality do not easily adapt for the selection of units of analysis that can spatially contextualize or determine environmental hazards and/or assets.

Additionally, recent scholarship has demonstrated that environmental inequality is not solely caused by the presence of toxic waste, hazardous industries, or illegal dumping. Inequality may also emerge in the distribution and accessibility of environmental benefits such as parks, street trees, or outdoor recreation spaces (Landry and Chakraborty, 2009; Rigolon et al., 2018). Legacy infrastructures such as highways or historical land uses like industrial sites and/or landfills may accumulate hazards over time that produce risk at uneven spatial and temporal scales (Frickel, 2008; Frickel and Elliott, 2008). Further, while all of the above-mentioned sources have a clear spatial correlate, the procedures and historical patterns that contributed to environmental decision making are far more opaque and less amenable to distributional analysis (Bocking, 2004; Light, 2009). We point to these multiple and intersecting concerns not to raise doubt about existing analyses, but rather to highlight the continued importance of carefully selecting the units of analysis that support specific definitions of environmental inequality. The process and reasoning for unit selection are of even greater importance as definitions are adapted to consider how perceived environmental amenities, such as green infrastructure, may influence assessments of environmental inequality, or increasingly, inequity.

2.2 Green Stormwater Infrastructure and Environmental Injustice

Green stormwater infrastructure recently emerged as an environmental solution for cities facing challenges associated with aging infrastructure systems, impervious surfaces, dwindling budgets, and increased calls from residents for improving the quality and quantity of public green spaces (Ahern, 2007; Mell, 2009; Roe and Mell, 2013). Installing green infrastructure promises an array of possible benefits. Supporters of this technology describe possible economic (Schilling and Logan 2008, Jaffe 2010), hydrologic (Liu et al. 2017, Rai et al 2019), habitat (Filazzola et al. 2019, Knapp et al. 2019), and social benefits (Center for Neighborhood Technology, Buijis et al 2016) associated with installing GI. In municipal agencies GI is often positioned as desirable for its smaller size, lower costs, and ease of siting compared to grey infrastructures within dense urban areas. Prioritizing these values within the technical choices of stormwater management options, as we will discuss in section 3, often emerges against the backdrop of strained municipal budgets, regulatory mandates, and high costs of separating grey sewer systems. GI installation may cost less upfront than sewer separation or end of pipe filtration upgrades, and that is the case in New Haven.

A smaller body of literature utilizes spatial analysis to understand the landscape and sociodemographic contexts of where GSI is placed (Baker et al., 2019; Chan and Hopkins, 2017; McPhillips and Matsler, 2018). The variety of GSI types examined, the assorted spatial units of analyses, different analytical techniques, diverse set of covariates considered, and wide-ranging climatic conditions complicates identifying a clear distributional pattern. Distributional studies are often framed as contributing to assessments of, or conversations pertaining to, the spatial equity of environmental features. Spatial equity is often described as the evaluation of “the benefits and burdens associated with the distribution of environmental and social amenities” (Landry and Chakraborty, 2009, 2652). What the literature has done consistently, however, is count GSI installations within areas that also have sociodemographic data associated with them in an attempt to understand distributional equity.

While equality and equity are sometimes used interchangeably in the literature, we maintain that it is essential to keep the two terms, and subsequently, methods of analysis definitionally separated in environmental injustice inquiries. As Christopher Boone, et al, write “Equity or fairness of distribution, which incorporates, needs, choices, and merits, is more difficult to measure and evaluate than equality of distribution” (2009). By this reasoning, spatial analysis concerned with equity must be performed within a local context where needs, choices, and merits are both documented and incorporated into the analysis. Equality, by contrast, refers to an even distribution of benefits and burdens. We argue, and as our case discussion demonstrates, that understanding historical patterns of development, deliberative processes, and project motivation are essential components to assessing whether spatial or distributional equity is an outcome of a GI project. These qualitative, and often historical, data identify and describe the processes that inform the eventual spatial pattern. Without describing these trends, spatial analysis of distribution may risk reifying inequities – environmental and otherwise.

2.3 Research Questions

The remainder of this paper uses planning narratives, archival data, and project documents to identify the needs, merits, and choices evoked during the planning and siting process of green stormwater infrastructure in New Haven from 2013-2019. In the concluding discussion, we discuss at greater length how attending to these narratives enhances analyses of spatial equity. To test whether the siting of green stormwater infrastructure is equitable we ask the following questions:

1. Process: What processes informed where GSI was located in New Haven? How were local needs addressed in this process? What were the motivations for installing GSI? How were siting decisions made?
2. Pattern: Where are the green infrastructure installations and which socioeconomic and demographic groups live near those installations?

3 METHOD

3.1 Study Area

New Haven, Connecticut, is a city with a population of just over 130,000 (United States Census Bureau) located in southern New England, north of the Long Island sound (41°18'29.0"N, 72°55'38.3"W). The municipality is ~19 mi^2 and has a temperate climate. From 1981 to 2010 the average annual January and July temperatures were 30.0 °F and 74.0 °F, respectively. The average annual precipitation is approximately 47 inches (NOAA, 2020).

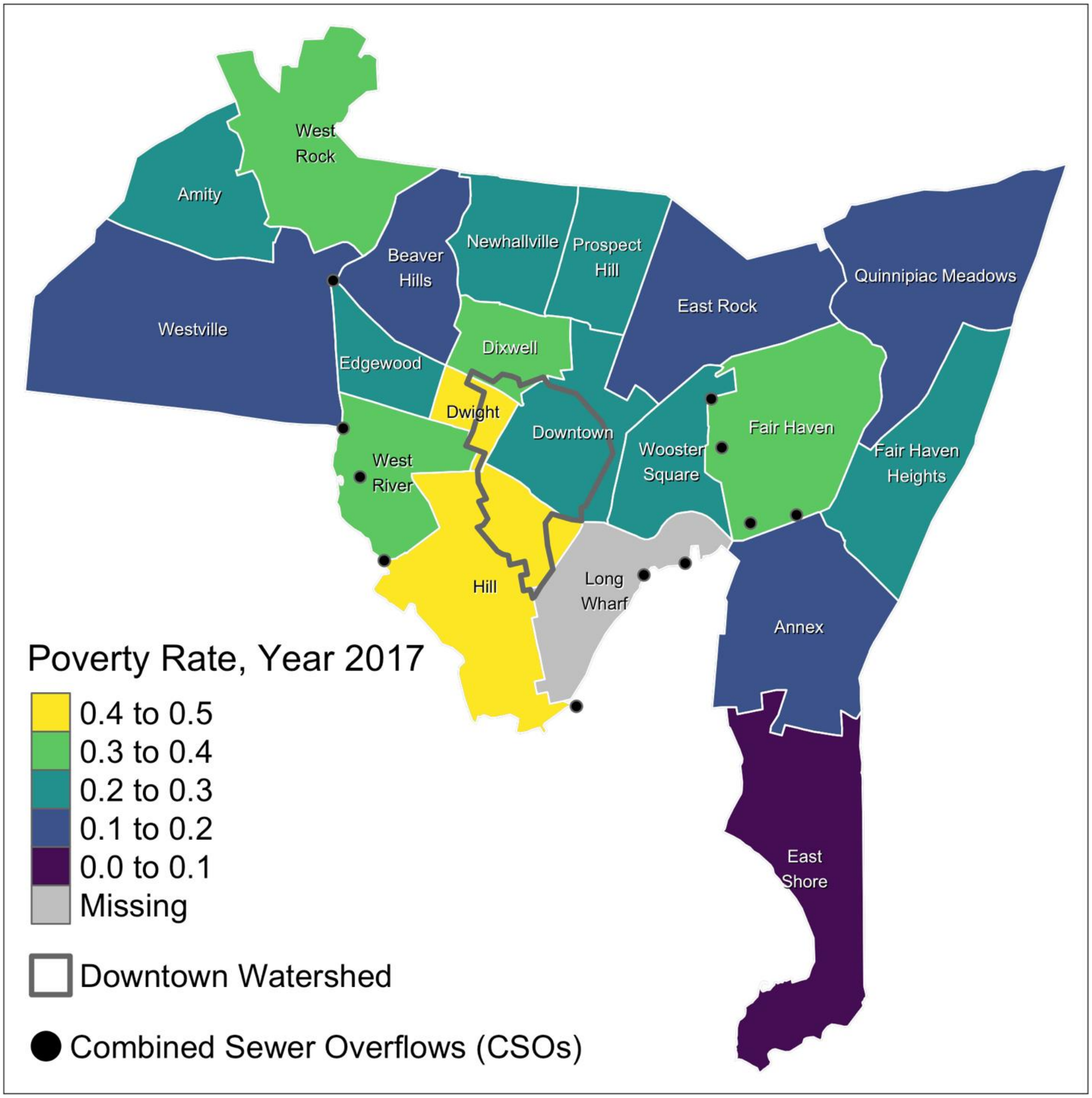

Figure 1. New Haven's Neighborhood boundaries by poverty, CSOs, and the Downtown Watershed. The Downtown watershed experiences flooding.

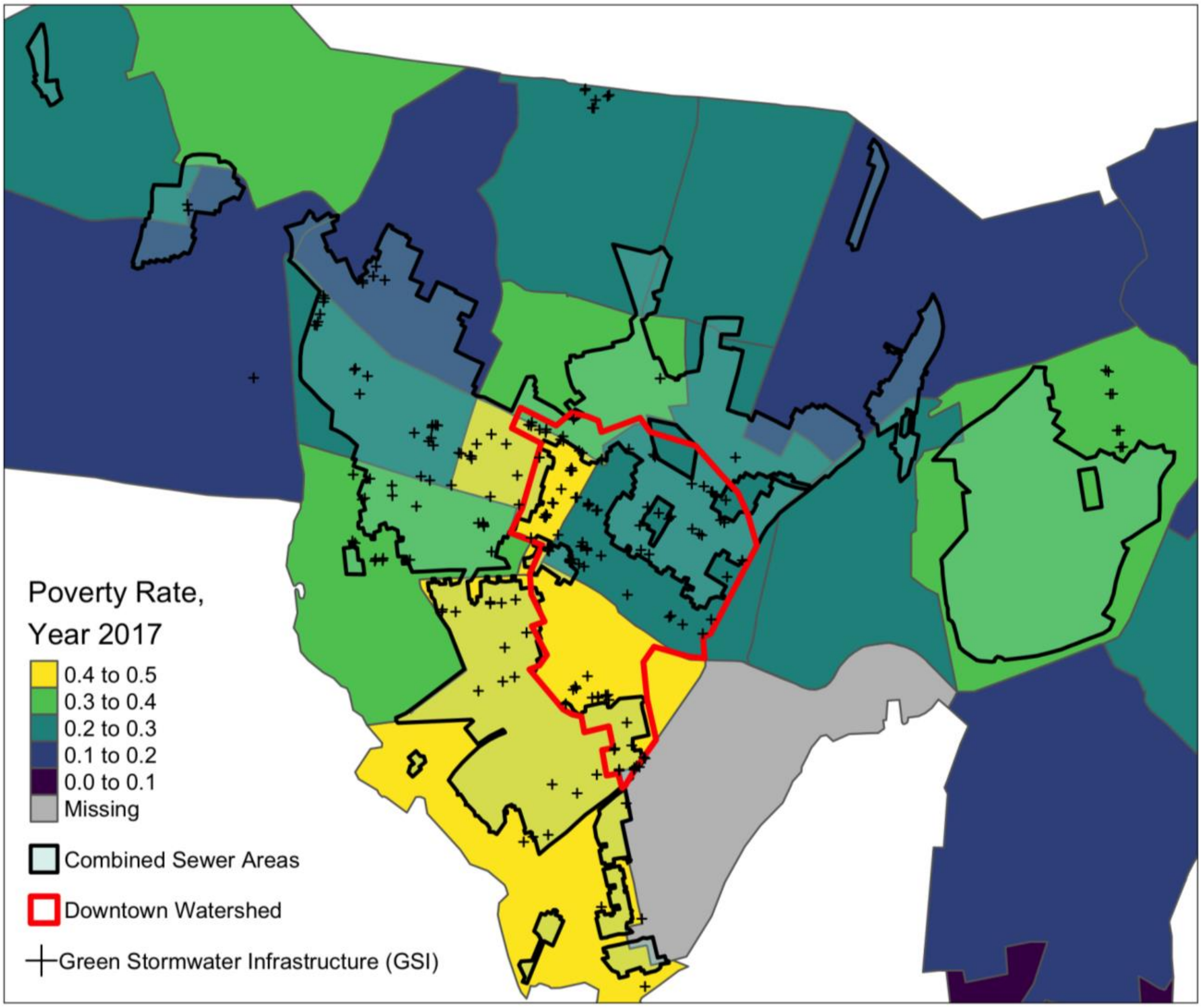

Figure 2. Poverty is concentrated in the center of the study area, which is spatially coincident with the Downtown watershed, green stormwater infrastructure is predominantly sited within watersheds, which tend to have higher poverty rates. Long Wharf (shown in gray) is a predominantly industrial area and without residential land.

3.2 Data

3.2.1 Green Infrastructure Locations

The City of New Haven's Engineering Department uses GIS as a data management tool for its Green Stormwater Infrastructure installations. The GSI geodatabase was created using three different methods. For the smaller projects (less than 10 GSI), points were created using ArcMap/ArcGIS Pro desktop version. For the Downtown bioswales project, the City had to site up to 200 bioswales within an approximately 600-acre area. In order to capture as much runoff as possible, the City sought to install GSI as close to the existing catch basins as possible. Therefore, a catch basin layer was used to create a Collector app so field data could be collected and managed using GIS. The goal of the Collector app was to document the space available for GSI in the public right of way by creating candidate point locations. Impediments within 50 feet upstream of existing catch basins were documented along with the distance between these impediments and the existing catch basins. Additionally, the width of the sidewalk was also captured. All data were stored within the catch basin data point in GIS. When space was available and GSI was constructed in one of these locations, the Status field was changed to reflect “Constructed”. Finally, a consultant was used to create the final 70 GSI locations in a separate geodatabase. These 70 GSI locations reflect a project led by GNHWPCA to build bioswales in combined sewersheds draining to the West River. Because of New Haven’s relatively small geographic and population size (relative to other often-studied areas), and the few GSI actors on the scene, we can be reasonably confident that the entire universe of street-side bioswales are accounted for in this paper.

3.2.2 Neighborhoods and Census Geographies

Neighborhood boundaries and demographic data came from DataHaven https://www.ctdatahaven.org/communities. DataHaven is a non-profit organization based in New Haven that developed neighborhood boundaries with The City in 2012, in order to support the Comprehensive Plan Data Book. Most of the neighborhood boundaries align with 2010 Census tract boundaries, but there are a few instances where Census tracts or block groups are split, to better match locally-relevant understandings of neighborhoods. DataHaven created neighborhood estimates by allocating Census data to corresponding neighborhoods using the share of population or households that fell within each geographic area. The very small number of people and households living within the boundaries of the city’s Long Wharf neighborhood, which is predominantly a commercial and industrial area, were automatically assigned to the directly adjacent neighborhood called the Hill.

Census block group geographic boundaries, socioeconomic, and demographic data for the US Census Bureau’s 2015-2019 5-year American Community Survey were accessed via the tidycensus R package using the `get_acs` function (Walker, 2020). Variables included race, homeownership, vacancy, and educational attainment, to be consistent with other similar EJ research. Data and code for replication can be found in Locke 2021.

3.3 History and Process

Authors gathered relevant city, sewer, and storm water plans from New Haven dating back to 1979. These planning documents are placed within their broader context within the historical studies of the technological evolution and design choices pertaining to urban sewerage and water management. For more recent discussion of process, we spoke with engineers, planners, and non-profit organizations involved in the implementation of green infrastructure.

3.4 Statistical Analyses

Analyses were carried out separately with the Neighborhood and block group boundaries. New Haven’s neighborhoods (n = 20) are larger than its Census block groups (n = 106). Neighborhoods are better understood by residents and planners, but their numbers are fewer, and the polygons are larger and potentially more heterogenous than block groups. Block groups are poorly understood by residents, but there are more of them allowing for greater statistical flexibility, and more internally homogenous. Given the pros and cons of each set of geographic boundaries, analyses were conducted separately for both and compared. For both sets of boundaries, the number of green stormwater infrastructure installations were counted in their containing polygons using the st_join function in the sf package (Pebesma, 2018). Next odds ratios of the green infrastructure installations relative to the population were calculated. To do so, the total green infrastructure per capita was calculated as the sum of all green infrastructure installation sites divided by the sum of the population. This represents an overall GI per capita installation rate. Next, for each polygon, in either Neighborhoods or block groups, an expected rate was calculated as that polygon's population times the overall rate. Then the actual GI installation counts per polygon were divided by the expected rate to arrive at odds ratio per polygon. An odds ratio of 2 means that the number of GI installations is twice the expected study-area wide rate, while an odds ratio of 0.5 means that there are half as many GI installations in that area as expected, given its population and the study-area wide expectation. Again, the expectation is based on the overall rate, so the baseline reference is a totally equal distribution of GI relative to the population in a specified geographic area. The pois.exact function in the epitools package (Aragon, 2020) was used to estimate 95% confidence intervals around the odds ratios. All analyses were carried out with R version 3.6.0 (2019-04-26).

The odds ratios for neighborhoods are provided along key social and demographic data for qualitative comparison. With twenty neighborhoods, and one of those without people due to predominantly industrial land uses (Long Wharf), bivariate statistical relationships are likely spurious due to small sample sizes. Moreover, typically the motivation for statistical inference arises from having samples and seeking to generalize to a larger set of cases. Here all of the relevant data are in hand. Among the more numerous block groups, correlations with socioeconomic and demographic data were conducted to show how GI installation varies relative to socioeconomic and demographic characteristics.

4 RESULTS

4.1 History and Process

Like many older municipalities, New Haven was originally developed with only one sewer to convey both sewage and stormwater to the harbor and surrounding waterbodies. This type of sewer, called a combined sewer, was frequently chosen in the American urban context beginning in the 1860's. The choice to build combined sewer systems emerged from several factors including a lack of precedence for separated systems, hesitancy to experiment, and cost concerns (Tarr, 1996). Further, as Joel Tarr describes, the cost-benefit analysis conducted by engineers argued that building a separated system to support sewerage recycling for agricultural purposes would not produce enough value. He writes, "they (engineers) believed that sewage could be safely deposited in the nearby waterways, a belief based on the theory that running water purifies itself" (Tarr, 1996, 137). The choice to initially prioritize cost minimization led to future water quality issues requiring additional, even costlier fixes (Tarr, 1996).

As the population of New Haven began to grow in the 1920's, so did pollution within the receiving waterbodies. Sewage treatment works were constructed at the present site of the East Shore Water Pollution Abatement Facility. In order to ensure that the treatment plant was not overwhelmed during large rain events, various combined sewer overflow (CSO) regulators were installed by the City to provide wet weather relief by discharging excess sewage and stormwater into waterbodies when the treatment plant is at capacity during rain events. Areas of the City developed after the construction of the abatement facility were built with separated sewer systems, with one pipe to convey sewage to the treatment plant and another to convey storm water directly to surrounding waterbodies.

As the development and construction continued in New Haven, surfaces once permeable were replaced with pavement and concrete. In turn, the growing area of impervious surfaces increased the volume and frequency of combined sewer overflow events, reducing the quality of waterbodies throughout the City (Tarr, 1996). In 1979, Cardinal Engineering Associates, hired by the city of New Haven, developed a sewer facility plan recommending sewer separation to reduce combined sewage overflows and associated pollution. The creation of this long-term plan coincided with broader social and political shifts including federal regulations such as the Clean Water Act. The 1979 report emphasizes both state and federal water quality and effluent limitations as motivations for pursing separation (City of New Haven 1979). The total cost proposed for this plan put the proposed budget at $21,768,000 in 1979 dollars. Adjusted for inflation, this amounts to just under $80 million in today's money. Of the 24 proposed sewer separation projects outlined in the 1979 report, only a third have been completed as of 2021. The costs of these eight projects were significant. The most recent figure listed by Cardinal Engineering puts the total cost at over 40 million dollars (2013 dollars) (Cardinal Engineering).

2005 marked a major governance shift in the management of New Havens sewer system with the formation of The Greater New Haven Water Pollution Control Authority (GNHWPCA). This regional authority approved by legislators in New Haven, East Haven, Hamden, and Woodbridge was formed to manage over "500 miles of sewer mains and 30 pump stations" (Greater New Haven WPCA, 2021). While the agency continues to pursue sewer separation project, installing green infrastructure has also emerged as a strategy to address CSO overflow events. Green infrastructure projects are supported by the authority for their cost effectiveness compared to grey (separation) projects (Sgroi et al., 2015).

At present, the City of New Haven has 13 combined sewer outfalls (CSOs, Figure 1) and about 250 storm sewer outfalls. A sewershed is the area of land that drains to a particular storm or combined sewer outfall(s). The City's largest sewershed, the Downtown sewershed, encompasses approximately 800 acres, and covers most of Downtown, part of the Hill neighborhood, and most of the Long Wharf neighborhood. Downtown and the Hill are some of the oldest neighborhoods in New Haven and contain the original combined sewer system. Only parts of these neighborhoods have been separated. Additionally, the Downtown sewershed suffers from chronic flooding during high intensity rainfall events. A 600-acre portion of the sewershed (Figure 1), drains towards the railyard, which has two pipes (twin 4'x6' box culvert and a 66" circular pipe) underneath to convey flow to the Harbor, about half of the capacity needed to drain this area. This bottleneck, along with high water levels in the Harbor, further limits the capacity of the sewer system and contributes to flooding. In addition, Long Wharf was created of fill material and is extremely low-lying at some locations. When the water level in the Harbor is high from the ocean tides and there is rainfall, there is not enough head to push water through the outfalls without the water level exceeding ground levels. Due to the high cost of separating sewers, recurrent flooding issues, and land characteristics, this watershed was identified by the City of New Haven as an appropriate area to site GSI interventions.

Below we discuss how various stakeholders determined the location of eventual green infrastructure projects. By providing this preceding context the governance, economic, and

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environmental factors shaping location determination of green infrastructure can be seen as a continuation of sewer system construction and retrofit. This suggests that understanding the spatial distribution of GSI alone may fail to consider how broader drivers of infrastructural uptake led to development in some parts of the city rather than others. Here, we argue that the process of determining the location of GI began in 1979 with the prioritization of sewer separation projects, rather than in 2013 when New Haven's first bioswale was installed. This context also complicates questions of equity and justice– particularly when considering procedural or transgenerational concerns. The Downtown and Hill neighborhoods have been excluded from sewer separation projects that occurred elsewhere in the watershed. This complicates the neat binary promised with the presence/absence models assessing the spatial distribution of green infrastructure. Can green infrastructure be understood as an asset if its presence signals an absence of other infrastructural investments?

The City of New Haven's first installed green stormwater infrastructure, a bioswale, out of necessity. Utility conflicts prevented a planned catch basin installation during a sewer separation project in 2013 and there was a relatively small street section (roughly 15 parking spaces worth of space) that had nowhere to drain when it rained. The City Engineer suggested a bioswale and The Urban Resources Initiative (URI) installed the practice to infiltrate runoff from this area. URI is a financially independent non-profit partner with Yale University with a long history of coupling community development with various forms of greening and research-practice linkages (Murphy-Dunning, 2009; Scanlan et al., 2021). URI also runs New Haven's request-driven street tree planting program. Following this initial project, two National Fish & Wildlife Foundation grants were secured by URI and the Yale School of Environment, in partnership with the City of New Haven and others, to research performance and experiment with bioswale design and construction methods. Preliminary data suggest that the soils are sufficiently able to infiltrate stormwater when needed, and that the monitored bioswales are largely effective (Benoit *personal communication*).

Most of the City's bioswales (~190) were constructed using grant funding. Two grants were used to construct a majority of the bioswales—a Clean Water Fund (CWF) grant and a Community Development Block Grant- Disaster Recovery (CDBG-DR) grant. Each grant's objectives stipulated where bioswales could be placed. For example, the CWF grant specified that bioswales needed to be built in combined sewer watersheds draining to the West River. There are 3 CSO outfalls that drain to the West River (Figure 1). Potential bioswale sites were located in all subwatersheds that drain into the West River. Then sites were prioritized starting in the subwatershed of the CSO with the most overflow events, using monitoring data collected by GNHWPCA. Overall, 70 bioswales were constructed in these West River CSO sewershed areas in 2018 and 2019.

The CDBG-DR project was designed to mitigate flooding in the Hill-Downtown sewershed, a 600 acre sewershed that includes most of Downtown and a portion of the Hill neighborhood. Planning began in 2014 and was completed in 2017. As the City's most impervious sewershed with the oldest sewer infrastructure, this area suffers from insufficient capacity in the sewer system and therefore flooding during high intensity rain events. As of 2020, over 150 bioswales have already been constructed in this sewershed (Figure 2) with an additional 75 to be constructed in 2021. Despite the need for restoration and impervious surface removal within this sewershed, finding locations suitable for bioswales is a persistent challenge.

Infrastructure conflicts such as parking meters, fire hydrants, trees, and above- and below-ground utilities preclude otherwise viable bioswale locations in the area of need.

4.2 Statistical Analyses

4.2.1 Neighborhood

The three neighborhoods with the *highest* poverty rates (the Hill, Dwight, and West River) had statistically significantly more GI than a baseline case of equal distribution by population (Figure 3, Table 1). Edgewood, Downtown, and West River have roughly three times more installations relative to the population, which is more different than chance alone can explain. Dwight had 6.36 times more GI installations than expected. The odds ratios in the Beaver Hills, Newhallville, and Dixwell neighborhoods are indistinguishable from chance. Seven neighborhoods have no Green Stormwater Infrastructure at all. These seven neighborhoods without GSI are all located in the perimeter of the city, which was developed later and were constructed as separately sewered. These neighborhoods have younger infrastructure, newer homes, and are more likely to be owner occupied. Generally, high-poverty, high-impervious surface neighborhoods received more GSI than lower-poverty, low-impervious surface neighborhoods

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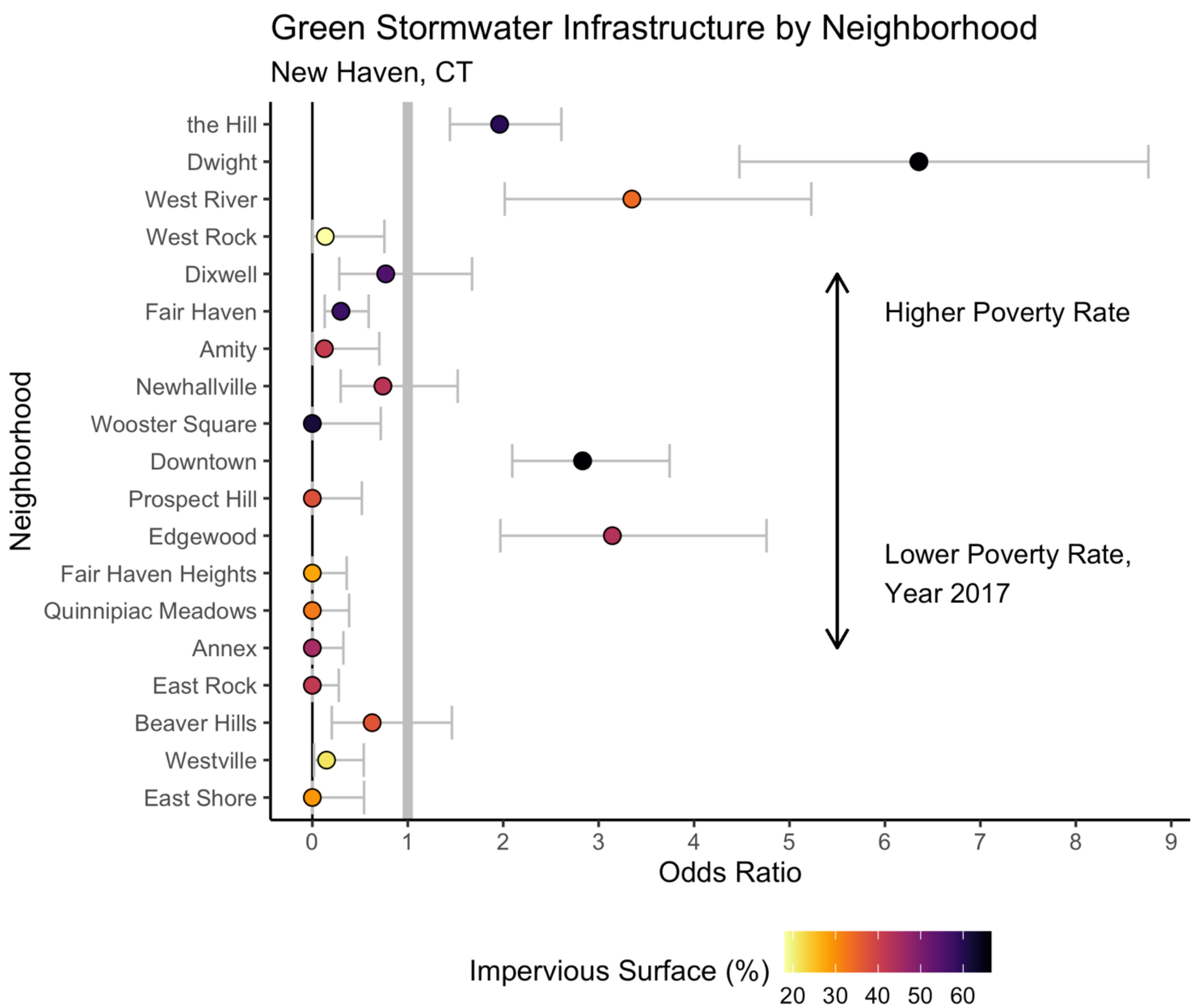

Figure 3. Odds ratios for Green Stormwater Infrastructure (GSI) installations by Neighborhood and percent impervious surface cover. Neighborhoods are arrayed by highest poverty (top) to lowest (bottom), horizontal grey lines indicate 95% confidence intervals. The vertical line at 1 indicates even distribution by population.

Table 1. Socioeconomic descriptive statistics and Green Stormwater Infrastructure installation rates, New Haven, CT 2013 – 2019.

Neighborhood	Impervious Surface (%)	Total Pop. (2017)	Latinx Pop. (%)	White Pop. (%)	African American Pop. (%)	Foreign Born Pop. (%)	Poverty Rate	GSI* (n)	GSI* per 1,000 residents	GSI* Odds Ratio	lower 95% CI	upper 95% CI
Amity	41	5,092	15.9	22.7	51.9	7.1	0.3	1	0.196	0.13	0	0.7
Annex	45	7,280	51.8	26.6	17.7	21.8	0.183	0	0	0	0	0.33
Beaver Hills	37	5,118	18.1	16.4	59.2	13.4	0.135	5	0.977	0.63	0.2	1.46
Dixwell	55	5,006	14.6	16.3	64.2	9.4	0.304	6	1.199	0.77	0.28	1.67
Downtown	67	11,102	12.3	55.3	10.5	22.6	0.249	49	4.414	2.83	2.09	3.74
Dwight	66	3,735	23.3	25.2	39.8	16	0.4	37	9.906	6.36	4.48	8.76
East Rock	42	8,544	11	63.7	9	29.2	0.157	0	0	0	0	0.28
East Shore	29	4,367	9.7	67.3	20.1	8	0.031	0	0	0	0	0.54
Edgewood	43	4,490	11.1	22.7	59.7	7.3	0.24	22	4.9	3.14	1.97	4.76
Fair Haven	58	17,141	66.3	14.9	17.4	17.9	0.301	8	0.467	0.3	0.13	0.59
Fair Haven Heights	28	6,580	47	29.4	21	10	0.218	0	0	0	0	0.36
the Hill	59	15,368	48.2	12.5	34.9	17.4	0.43	47	3.058	1.96	1.44	2.61
Long Wharf	73	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA
Newhallville	43	6,074	14.7	3	81.2	12.7	0.284	7	1.152	0.74	0.3	1.52
Prospect Hill	38	4,559	18.5	34.6	21.2	26.2	0.242	0	0	0	0	0.52
Quinnipiac Meadows	32	6,143	41.1	25.6	27.5	14.2	0.198	0	0	0	0	0.39
West River	34	3,641	27.2	13.4	53.7	13.8	0.368	19	5.218	3.35	2.02	5.23
West Rock	18	4,733	15	43.4	35.6	11.6	0.317	1	0.211	0.14	0	0.76
Westville	21	8,610	10.4	53.4	28.5	15.7	0.107	2	0.232	0.15	0.02	0.54
Wooster Square	62	3,302	22.3	48.5	22.3	13.7	0.264	0	0	0	0	0.72

4.2.2 Census Block Groups

Three measures of Green Infrastructure installations were used to associate GI installations with socioeconomic and demographic data: the number per block group, the per capita installation rate, and the aforementioned odds ratio. All GSI measures were negatively and significantly correlated with median household income (Table 2). There were no significant relationships among any of the GSI variables and race at the block group scale; neither the percent White nor the percent African American populations were correlated with GSI installation. The percentage of the housing units in a block group that are owner occupied were significantly and negatively associated with GSI, the opposite was true for vacant housing units. Educational attainment was also not associated with GSI.

Table 2. Correlations between Green Stormwater Infrastructure installation statistics and socioeconomic variables. Light gray values have high p-values and are not statistically significant.

	GSI[1] (n)	GSI[1] per capita	GSI[1] Odds Ratio
GSI[1] per capita	0.988***		
GSI[1] Odds Ratio	0.988***	1.000***	
Median Household Income ($)	-0.306**	-0.328**	-0.328**
White Population (%)	-0.128	-0.134	-0.134
African American (%)	0.168	0.183	0.183
Owner Occupied (%)	-0.353***	-0.349***	-0.349***
Vacant Housing (%)	0.239*	0.247*	0.247*
Educational Attainment[2]	-0.121	-0.135	-0.135

[1] GSI = Green Stormwater Infrastructure.
[2] Percentage of those 25 years or older with a high school diploma, equivalent or greater.
Computed correlation used spearman-method with listwise-deletion.
**** < 0.001, ** < 0.01, * < 0.05,*

5 DISCUSSION

Our findings further complicate questions associated with understanding the relationship between GSI and equity, and the use of distributional analysis of amenities as an index for equity within spatial analyses of environmental justice. In our case discussion highlighting the historical choices, constraints, and contemporary priorities shaping the of siting of GSI in New Haven, three distinct themes emerge that can inform not only the spatial analysis process but also the questions we ask of the findings. We identify these themes as grant funding; infrastructure conflicts; and prioritization of technical needs, merits, and choices in planning and siting activities. These themes complicate distributional analyses and demonstrate the necessity of understanding spatial data in context with procedural and process-oriented discussions.

In New Haven, grant funding is a determinant of specific projects. For instance, the Clean Water Fund grant only funded projects within CSO sewershed areas draining to the West River. The Community Development Block Grant also required the placement of funded projects within a specific sewershed. The geographically specific requirements of grant funding means that not all neighborhoods have the same likelihood of containing GSI. From an analytical perspective, this identified theme poses a methodological problem for the measuring the distribution of GSI: The baseline reference used here – for comparability to similar prior research - to understand whether distribution within New Haven's neighborhoods is equitably distributed set of GSI relative to the population in a specified geographic area.

The planning narrative reveals that this baseline is not congruent with the on-the-ground possibilities for GSI siting. There are geographic areas ineligible for GI installation by the funders. To frame this another way, the grant opportunity makes a totally equitable distribution amongst all city neighborhoods by population an impossibility. Therefore, utilizing a baseline that accounts for constraints such as funding priorities of infrastructural development might allow researchers to gain a hyperlocal understanding of regional distribution. Moreover, the concentration of GSI in the downtown sewershed points to the need to consider and incorporate other possible evaluative measures for assessing equity and inequity, such as the contextual information on the siting process from the practitioners planning, carrying out, and maintain the GSI.

Further, legacy infrastructures, identified by engineers and planners as fixed determinants of final siting location, demand further attention within accounts of how the location of projects are determined. Incorporating an approach centered on understanding transgenerational equity can describe how past and future generations experienced or will experience the benefits and burdens of infrastructure provision. For instance, were previously constructed infrastructures built with either discriminatory intent or produced a disparate impact? Understanding the relationships between the perceived determinants of siting location and their historical impact remains in important part of a thorough equity analysis. Such analyses have the potential to uncover different matters of concern across longer-term histories of urban system building. What we see in New Haven is that some areas of the city received sewer modernization while others did not. The seven neighborhoods without any GSI were more recently developed and built as separately sewered (Figure 2), have lower poverty rates (Figure 3), and are more likely to be owner occupied (Table 1). At the neighborhood level GSI, GSI per capita, and GSI odds ratios are negatively associated with median household income and owner-occupied housing, and positively correlated with vacant housing. To understand if green infrastructure is equitable, it is also necessary to understand what investments have been made elsewhere.

Additionally, we learn in the case that the Downtown sewershed contains GSI because of the low-lying topography, high impervious surface cover, low sewer capacity, and pressures from sea level rise all combine and create frequent flooding. GSI was needed to reduce the flooding because it is not possible to construct enough storm sewer capacity within this area. While these existing systems are matters of material fact, the existence and absence of particular technological features and systems may point to prior patterns of uneven development. For instance, researchers may consider future analyses to understand the patterns of development that led some areas to receive separated sewer systems while others did not. Figure 2 demonstrates that separated sewers often correspond to areas with lower rates of poverty. While it is known that separated systems were built post-1920 in new development areas of the city, it remains unknown what demographic groups benefited from this shift in technological choice either immediately or in the time since. Additionally, it is worth considering whether the provisioning of separated sewer systems is coincident with historically segregationist practices such as redlining, highway building, or zoning.

If GSI is primarily concentrated in areas that were excluded from grey infrastructure construction or retrofit, it is necessary to examine whether GSI, as a technological choice, can have just or equitable outcomes. Our case study found that institutional motivations for project siting in New Haven have little to do with sociodemographic characteristics of the area. This finding demonstrates that technical needs, merits, and choices weighed heavily in the decision-making processes involved in location determination. When technical priorities dominate the decision-making process, distributional equity of siting locations might be a possible outcome. Yet, a technologically equitable (the installations are distributed within the areas of greatest need) system might also discount other forms of inequity. Examining the question of how 'need' is defined makes this distinction clear. Indeed, if environmental justice is an intended or proposed outcome associated with the uptake of GSI, considering how needs are defined across social, ecological, cultural, and political domains offers one mechanism of encouraging broader systemic transformations. If the needs of a given region or neighborhood are consistently defined through technical means, the first step towards just systemic transformations is broadening how and in what context needs are defined.

It was noted in the introduction that often a recipe for environmental justice analyses of distributional equity includes a fixed harm (or benefit), a set of spatial boundaries, and socioeconomic and/or demographic data on the people living in those boundaries and nearby (or not) environmental harms or benefits. This paper has demonstrated that incorporating the process of locating and allocating GSI informs and refines spatial analyses, and aids in the interpretation of the results without the a prioi assumption of it serving an environmental good. But a separate issue with the basic formula pertains to the use of spatial, polygon boundaries. How reflective of the lived experience of residents are zip codes, Census block groups, or neighborhoods? Dividing geographic space into polygons such as administrative units or Census block groups, and then aggregating observations using the so-called "container approach" (Talen and Anselin, 1998) raises separate issues. Within block group heterogeneity, for example, is implicitly assumed with the consequences of under- or over-estimated access or exposure (Miyake et al., 2010). The results of any analyses that use polygons and the container method are further subject to the modifiable areal unit problem (or MAUP). It is never known how much of the analytical results are attributable to the size, shape, and configuration of the set of polygons used (Openshaw, 1981). This paper used two sets of polygons – neighborhoods and Census block groups – to guard against the tradeoffs inherent between fewer, larger, plausibly more heterogenous neighborhoods that are better known to residents and decision makers, and the more numerous, smaller Census block groups with greater internal homogeneity. The quantitative findings were mutually reinforcing across neighborhoods and block groups; greater confidence can be given to the patterns and relationships found.

6 CONCLUSION

The purpose of this paper was to understand the spatial distribution of GSI in New Haven, CT, from 2013 through 2019, how it relates to the adjacent communities, and the process of how the GSI was located. Spatial analyses revealed a pattern contrary to the distributional inequity one may have expected, given similar research in other areas (Baker et al., 2019; Chan and Hopkins, 2017; McPhillips and Matsler, 2018). On a per person basis, GSI was most often located in the neighborhoods with the highest poverty rates (Table 1). Moreover, GSI (number), GSI per capita, and GSI odds ratios were significantly and negatively associated with median household income and owner-occupied housing, and positively associated with vacant housing at the block group scale

(Table 2). However, the focus on distributional equity (what, where, who) does not meaningfully engage with the processes and mechanisms that explain how these Green Stormwater Infrastructure sites were chosen.

A closer look at how GSI was sited revealed few connections, if any, to the socioeconomic and demographic characteristics of the neighborhoods. Instead, the history of the physical infrastructure, topography, soils, present-day flooding, and need influenced the location and allocation. How needs are defined, and by whom, may be important in future research. The creation of technological systems in urban areas often corresponds to historical patterns of segregation or other forms of racial or economic exclusion (Grove et al., 2018; Hoffman et al., 2020; Locke et al., 2021; Namin et al., 2020). If GSI is primarily constructed to retrofit existing systems rather than build a new, it is of even greater importance to understand this development within context.

This article has demonstrated that the presence of a perceived environmental amenity in terms of population or geographic context cannot fully address the environmental equity hypothesis based upon the idea that environmental benefits and burdens associated with green stormwater infrastructure are distributed fairly in the study area based on local needs, choices, merits, and motivations. In the case of New Haven, one measure of distributional equity was achieved using a complete set of GSI installation data. Larger cities and/or cities with more GSI actors may not have access to a similar census of spatially-explicit GSI installation data. As a consequence the analytical results could be biased. Missing data of this type may not be at random; organizations with greater funding and investment in record keeping are more likely to have complete inventories than organizations that do not have staff and technical capacity for maintaining these kinds of spatial data.

Yet, the narrative case demonstrates how siting constraints and technical priorities shaped this outcome. An equitable outcome was achieved, but technological equity does not necessarily result in social equity. Environmental equity and justice as domains of study have consistently demonstrated the need for localized interventions specific to the social, technological, and landscape contexts of the study region (Allen, 2018). This paper has shown that the ‘how’ of projects matters just as much as the ‘where’. As planners, engineers, and municipal officials continue to consider how GSI can amend environmental harms within local communities, increased attention on past technical choices, funding constraints, and economic variables can create richer metrics to understand environmental equity within the localities most impacted by development.

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