WHERE MONEY GROWS ON TREES: JOB CREATION AND ECONOMIC IMPACT OF GREEN INFRASTRUCTURE FOR STORMWATER MANAGEMENT IN WASHINGTON, D.C.

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Abstract

Environmental management and restoration are commonly valued according to the benefits they provide to a community, such as through increased food production or recreation values. However, cost-benefit analyses of environmental regulation often fail to incorporate economic impact–or jobs created and value added to the economy–of environmental management for climate change adaptation. Projected increases in precipitation intensity may require governments to devise new policies to manage urban stormwater. Green infrastructure (GI) can be an effective tool for stormwater management. In this paper, I conduct an analysis of the economic impact generated by the construction of green infrastructure in Washington, D.C. from 2015 to 2020. I collect data from contractors in the District to determine annual investment in GI during the study period and use these results in an input-output modeling software (IMPLAN v.6) to estimate economic impact. This analysis found that GI construction in D.C. from 2015 to 2020 directly supports 1,744 jobs, $404,627,207 in economic output, and $265,776,575 in value added to the D.C. metro area economy. This analysis is intended to provide a more comprehensive accounting for the economic feasibility of green infrastructure for urban stormwater management.

Keywords: Green infrastructure; economic impact analysis; stormwater management; stormwater crediting; flood mitigation; input-output modeling

Introduction

As the natural hazard with the greatest economic and social impact in the United States, flooding poses extensive costs to urban settings (NAS, 2019). Between 1960 and 2016, the United States experienced $107.8 billion in property damage due to freshwater flooding (NAS, 2019), Even beyond coastal regions, urban flooding has become more frequent and less easily managed (Ashley et al., 2005; NAS, 2009), damaging homes and businesses, disrupting transportation networks, threatening human health (Hajat et al., 2005; Houghton & Castillo-Salgado, 2017) and transporting untreated urban pollutants into receiving water bodies.

Traditionally, cities have relied on 'gray' infrastructure, or networks of hardened pipes and drains that do not follow principles that mimic natural hydrologic cycles. Gray infrastructure transports stormwater runoff to drainage outlets that may be discharged in local water bodies downstream (Lucas et al., 2012). As a result, rainwater becomes a flooding and pollution nuisance, rather than a viable source of freshwater, as the flow of stormwater contributes to flooding and transports pollutants to receiving water bodies (Dhakal & Chevalier, 2017).

As cities grow in both population and geographic extent, they may consider building additional gray infrastructure to manage stormwater from increased impervious surfaces. However, these projects are capital-intensive and may be burdensome to municipal taxpayers, in addition to contributing to increased environmental hazards from flooding and downstream pollution. Moreover, substantial damage can still occur due to outdated, undersized, or badly maintained gray infrastructure (T. K. BenDor et al., 2018a).

In light of these problems, cities are increasingly turning towards nature-based 'green' stormwater infrastructure (GI; Young, 2011). The U.S. Clean Water Act (Section 502(27), 33 U.S.C. 1362(27)) defines "green infrastructure" as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters." GI utilizes natural ecological drainage cycles to increase infiltration on development sites and reduce the load of surface runoff from stormwater and the contaminants it carries (Dhakal et al., 2017).

Numerous studies show that green infrastructure can cost less than gray infrastructure in both construction and lifecycle expenses (e.g., Baerenklau et al., 2008, Foster et al., 2011, Shaver, 2009; US EPA, 2015; Zhang et al., 2017; US EPA, 2007; Browder et al., 2019). However, many local-level policymakers remain skeptical of GI due to concerns about financial uncertainties and performance risks of these projects. First, the cost profile of green infrastructure can be difficult to discern (T. K. BenDor et al., 2018b). One of the primary barriers to implementing green infrastructure is the uncertainty surrounding performance and cost-effectiveness, making discrete funds for green infrastructure difficult to dedicate.

As a result of a largely decentralized approach to implementing green infrastructure, uncertainties remain in applying cost-benefit analyses to GI (Ashley et al., 2018). Many studies attempt to quantify green infrastructure according to its economic *benefits*, such as its increase in surrounding property values or production of ecosystem services (Vandermeulen et al., 2011; Kousky et al., 2013; Naumann et al., 2011; Liu et al., 2016; Steffen et al., 2013; Blackhurst et al., 2010; Kalman et al., 2000). However, few studies model the economic *impacts* of green infrastructure, which include jobs created and revenue added to the regional economy. Impact analyses include quantitative projections on how industries and businesses produce effects throughout the regional economy, beyond the value of a final sale of a product, for example (Steinback, 1999). By accounting for GI's economic *impacts*, cost-benefit analyses can more fully consider the implications of GI construction and tradeoffs between gray and green infrastructure.

However, few studies have explicitly considered the economic impact of GI. With most cost-benefit analyses not accounting for GI's economic impacts, evaluations of GI feasibility by municipalities, infrastructure analysts, and developers fail to incorporate a full accounting of the benefits and impacts of green infrastructure. One study utilizes similar methods to estimate the economic impact and jobs created from green infrastructure maintenance in northeast Ohio (Piazza & Clouse, 2013). However, no study quantifies the economic impact of green infrastructure as created by the nation's first-of-its-kind stormwater retention credit trading program, in addition to the District's robust stormwater regulatory scheme.

Similar questions have been raised regarding the economic impacts of environmental restoration, more broadly, and ecological restoration is a significant source of demand for GI (Hou et al., 2021; McEwen et al., 2013). An analysis by BenDor et al., (2015) indicated that the organizations that frequently perform ecological restoration form an industry that employs approximately 126,000 workers nationwide and generates approximately $9.5 billion in economic output annually. In addition, the authors found that 95,000 jobs and $15 billion are produced in indirect business-to-business and household spending. This type of analysis demonstrates the importance including economic impacts of cost-benefit and ecosystem services models, which do not traditionally include economic impact analyses.

In this paper, I evaluate the economic and employment impacts of the industry composed of firms that construct GI, as developed out of DC's municipal stormwater regulatory mechanisms. I address two primary questions: How does GI construction affect employment and economic output throughout the regional economy? How do GI policy changes alter the extent of these economic impacts?

I address these questions by evaluating Washington, D.C.'s (USA; "DC" or "the District") regulatory and incentive programs for stormwater management (DDOE, 2020). The District administers the only robust set of stormwater regulations in the US that allow developers to comply with city stormwater requirements either by 1) providing stormwater retention on-site or 2) leveraging a novel (first of its kind in the United States) market to purchase off-site retention generated by private, voluntary GI investments

In order to measure the economic impact generated by these policies and resulting GI construction activity, I implement an input-output economic impact model using the IMPLAN modeling platform (V. 6 (IMPLAN, 2021c), as informed by data collected from city staff and interviews with contractors who construct green infrastructure in the District. I found that, between 2015 and 2020, construction of the five major GI practices in the District generated a yearly direct average of 291 jobs, $37,366,658 in labor income, $44,296,096 in value added, and $67,437,868 in regional economic output. Including the indirect and induced impact, these values are greater. Incorporating these estimates into stormwater policy discussions and decision-making processes may significantly alter cost-benefit analyses and policy discussions.

Study Area

D.C.'s regulatory environment for stormwater management

In 2003, the District of Columbia's sanitary sewage overflows had reached a volume and frequency that violated standards in the Clean Water Act (O. US EPA, 2015). The U.S. Department of Justice, the EPA, the United States, and a coalition of citizen groups reached a settlement on the Clean Water Act litigation against the agency responsible, DC Water, leading to the creation of a program to decrease discharges of untreated sewage into the Anacostia and Potomac Rivers and Rock Creek (O. US EPA, 2015). In 2005, the District adopted the 20-year, $2.6 billion long term plan, the Clean Rivers Project (District of Columbia Water and Sewer Authority, 2015). However, in 2015, the District paused proceedings on a significant, gray stormwater infrastructure project (the largest District infrastructure project since the creation of their metro system in 1967; WMATA, 2019). The EPA agreed to modify the consent decree to allow DC to incorporate $100 million of green infrastructure investments in a cost-savings effort to reduce capital costs and deliver stormwater management benefits (USEPA, 2021).

In the District, stormwater is managed differently across geographic areas, constituting two primary sewer sheds. Much of the internal region of the District is dominated by the Combined Sewer System (CSS) sewer shed, while outer regions are primarily managed by the Municipal Separate Storm Sewer System (MS4). The CSS collects rainwater, household sewage, and industrial wastewater in the same pipes. This water is treated, but high volumes can overwhelm the system and result in untreated discharge (R. 01 US EPA, 2021). The municipal separate storm sewer system (MS4), which collects runoff from approximately two thirds of the District, discharges stormwater directly into water bodies without treatment. The District has argued that green infrastructure is most beneficial in the MS4 (DDOE, 2021). In Figure 1, the gray regions within the District perimeter represent the MS4 sewer shed. Areas within the city perimeter not included in the MS4 sewer shed are managed by the CSS.

To manage these systems, the District has developed one of the most robust stormwater policy schemes in the country. Because of this, it serves as an exemplary case study from which to examine the effects of environmental policy on green infrastructure investment and economic impact (Yin, 2009). The District leverages a series of policies to both enforce required stormwater retention and encourage voluntary green infrastructure construction. In 2013, the District adopted a retention-based standard to mitigate runoff from development (DDOE, 2020). This policy stipulates that major land-disturbing activities must retain the volume of stormwater from a 1.2-inch storm event (which can generate 525 million gallons of runoff within the municipality (DDOE, 2020). Substantial improvement activities must retain the volume from a 0.8-inch storm event.

Within these retention requirements, land developers may opt to purchase a certain amount of the stormwater retention volume at an offsite location, creating a market-like structure of trading stormwater credits. This program – the stormwater retention credit (SRC) trading program – was established in 2013 as the first of its kind in the U.S. Sites within the MS4 sewer shed must retain a minimum of 50% of Stormwater Runoff Volume (SWRv) onsite, and the rest may be purchase offsite. Sites in the CSS sewer shed have no minimum onsite retention requirement (DDOE, 2020). The District estimates that a green infrastructure retrofit of the entire region would cost over $7 billion (DDOE, 2021). Instead, regulations and the SRC trading environment produce GI without a centralized retrofitting process by incentivizing voluntary GI construction. An overview of these policies is provided in Table 1.

Table 1: Stormwater Management Policies in Washington, D.C. (DOEE 2020)

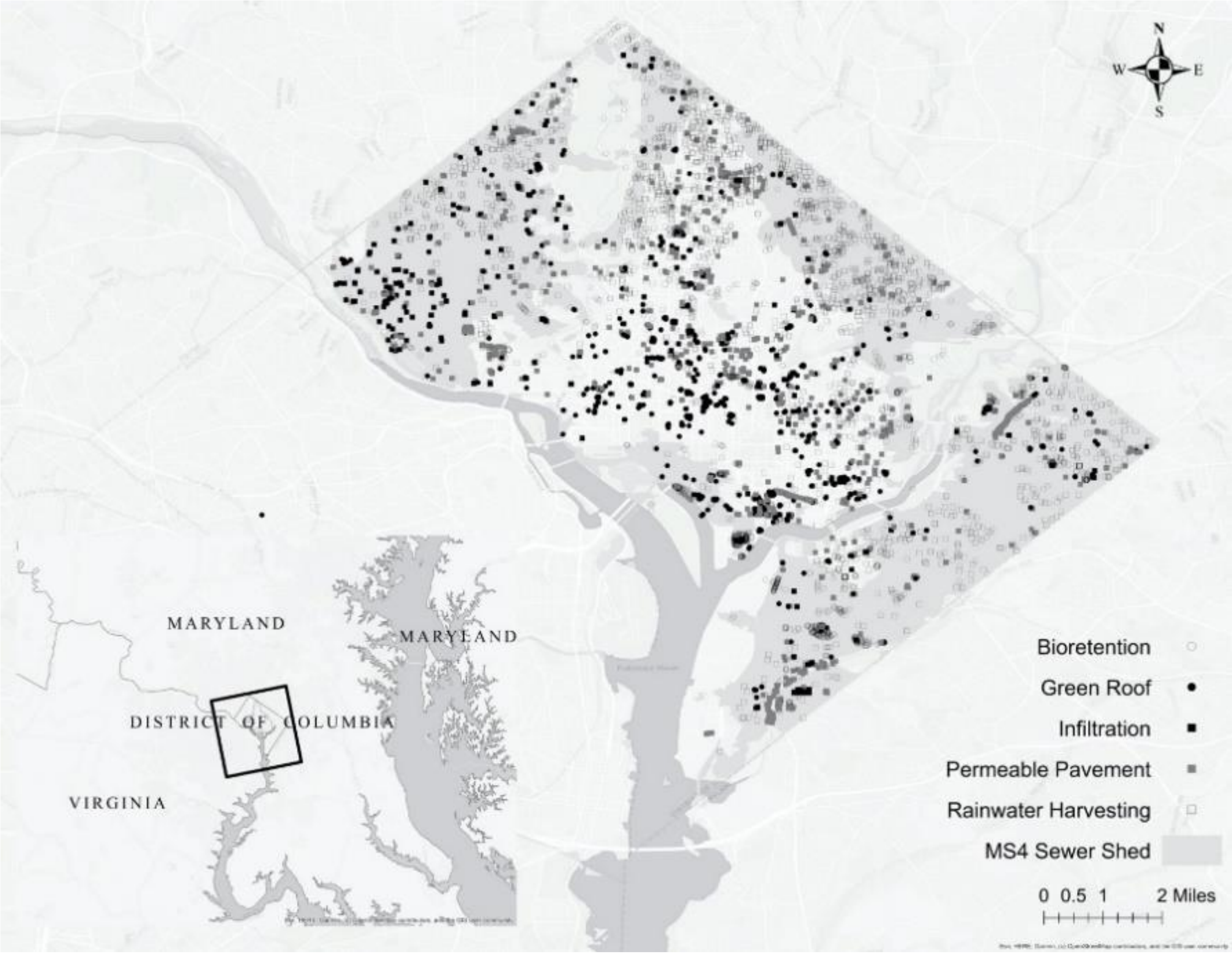
Policy	Description
Stormwater management regulations	In 2013, the District adopted a retention-based standard applied to private development, stipulates that major land-disturbing activities retain volume from 1.2-inch storm event, and substantial improvement activities must retain the volume from a 0.8-inch storm event. MS4 Sites must retain a minimum of 50% of the Stormwater Runoff Volume (SWRv) on-site. CSS sites have no minimum on-

	site retention if any SRC is used (below) to meet the requirement. Major land disturbing activities are activities or parts of plans that disturb 5,000 square feet or greater of land and either or both: (a) any of the pre-project land cover is natural; and/or (b) 2,500 square feet or more of the post-project land cover is impervious (DDOE, 2020).
Stormwater Retention Credit (SRC) trading program	This program stipulates that voluntary GI installations can generate and sell SRCs. One SRC is equivalent to one gallon of stormwater retention over one year.

Best management practices for urban stormwater

The District has specified a collection of best management practices (or BMPs) for addressing urban stormwater. These practices are cataloged by the District. In addition, in order to fulfill the requirements for generating stormwater retention credits, SRC-generators use best management practice guidelines to generate credits. For the purpose of this study, five best management practices were identified for study based on the District's recommendations for practices that could provide a reliable cost profile. Among the top seven most common practices, five were selected: bioretention, green roofs, permeable pavements, infiltration, and rainwater harvesting. Bayscaping and trees were excluded from the study due to unreliable cost information. Tree planting is the second most common practice in the District, following rainwater harvesting, and bayscaping is the fourth most common practice, behind bioretention and before green roofs, permeable pavements, and infiltration, respectively. Figure 1 shows the five green infrastructure practices constructed in the District between 2015 and 2020, totaling 8,399 practices

Figure 1: MS4 and CSO Sewer Sheds and five major GI Sites throughout the District of Columbia, from 2015 to 2020 (n=8,399 total sites). Combined Sewer shed exists in all areas outside of MS4 sewer shed.



Methods and Data Sources

Understanding the infrastructure landscape for GI in D.C.

In order to determine the economic impact of green infrastructure in the District, I developed a survey that assesses the cost structure for the construction of five GI practices. Using publicly available data on all installed GI practices in the District (DCGIS, 2021), I calculated total investment in each of the study practices over the study period (2015-2020). This spending served as the input for the IMPLAN economic impact software.

These data may not reflect the entirety of green infrastructure practices adopted within the District, as they are categorized according to BMP Group, which is subject to inconsistencies according to recording and logging practices. I used DOEE's GI site dataset to understand general trends in the District's green infrastructure, such as spatial distribution and retention capacity changes across sewer sheds.

Table 2*:* Number of Newly Installed GI Practices in the District, 2015 - 2020

Green Infrastructure Practice	**Number of Installed Projects (2015 – 2020)**
Rainwater Harvesting	2,714
Bioretention	2,452
Green Roof	1,634
Permeable Pavement	1,242
Infiltration	357
All other sites	5259
Total	13,658

Survey of GI construction firms

To determine average costs of constructing these practices, I constructed an original survey to administer to GI construction firms in the District MSA (reviewed by UNC-Chapel Hill Institutional Review Board; #20-3205) to determine construction costs of green roofs, permeable surfaces, bioretention infiltration, and rainwater harvesting sites. Contact information for firms was provided by the DOEE according to their records of D.C. low-impact developers. In total, the entire list of 70 firms were contacted. Ultimately, 17 low-impact development firms were interviewed using a structured method for a total response rate of 24.29%. Results were entered into a Qualtrics survey. Interview questions ranged from the size and annual revenue of each firm to the average construction cost and retention volume of building each GI practice the firm engaged with. Data from the responses of these firms were compiled to determine average costs of construction for the five study practices. Based on the original survey responses for the five study practices, average costs were determined for each practice. Costs and retention volume (in volume; cubic feet) were collected from respondents.

Regional commerce and spending patterns vary by industry and location, so data for economic impact analyses through IMPLAN are specific to the study geography and involved industries. The NAICS codes for each interviewed business was determined in order to understand the primary industries impacted by investing in green infrastructure. NAICS codes are used as an industry classification scheme based off of a standardized economic system (NAICS Association, 2017). The most commonly occurring NAICS code among survey respondents was converted to a code used by IMPLAN (457 – architectural, engineering, or related services). IMPLAN utilizes this code to determine economic impacts based on typical spending patterns between industries in the selected region. IMPLAN models economic impact by year, so all investment acts as an input on a yearly basis.

Investment in green infrastructure

Using the District's open source platform to access information on the historical construction of GI in the District, all of the projects in the five practices from 2015 to 2020 were aggregated. From this data, I was able to determine the number of projects and total retention volume created for each practice for each of the six years in the study period. By multiplying the average cost per unit volume of each practice by the amount of retention generated each year, I determined the investment in the five GI practices from 2015 to 2020. All investment values were converted to represent 2020 USD.

Investment in the SRC trading system

The SRC system is a unique policy scheme to incentivize voluntary construction of GI on properties in the District. However, unlike most environmental markets, in which transaction prices stay private, the District catalogs the history of SRC sales, representing the revenue that SRC sellers can generate by building excess voluntary GI to sell as offsets. SRC investment data represents the revenue earned by SRC sellers, while the GI investment data from the previous section represents the revenue earned by contractors and GI developers. Because the profit margin of SRCs sold is unknown, the value of SRCs sold cannot be directly compared to investment in GI. Sales between buyers and sellers of SRCs are negotiated privately, so profit margins may vary within the credit trading system. However, the District does impose a price ceiling on ‘high impact’ SRCs, or those generated in the MS4 sewer shed that have greater impacts on decreasing the contamination of receiving water bodies from surface water runoff (DOEE, 2021).

A variety of firms and organizations, such as real estate developers or community organizations generate voluntary GI for listing in the SRC program. Because of this, SRC generators do not necessarily construct the GI itself. In the first part of this analysis, the revenue received by contracting firms acted as the industry output for use in the IMPLAN model. For the SRC industry, however, the value of SRCs sold can be modeled as a commodity output. IMPLAN defines commodity as “a product or service” which “may be produced by one or multiple industries of institutions” and “represents the total value of production of that product or service, regardless of the industry or institution that produced it” (IMPLAN, 2021a). Because

SRCs are generated voluntarily by a range of firms and organizations and only the final sale price of the SRC is available, analysis based on commodity output is more appropriate than industry output. The value of SRCs sold per year served as the input to the IMPLAN model for the impacts of investment in architectural, engineering, and related services commodity market in D.C. This commodity market corresponds to the classification of total GI investment as an architectural, engineering, and related services industry.

IMPLAN modeling

IMPLAN, a commonly used input-output modeling framework, draws on business and spending flows in a study area, based on information from the Bureau of Economic Analysis (BEA), Census of Employment and Wages (CEW), County Business Patterns (CBP), and National Income and Products Accounts (NIPA; IMPLAN, 2021b) to estimate the direct, indirect, and induced economic impact of an activity.

In this project, IMPLAN (Impact Analysis for Planning) models the supply chain effects of building GI, including the jobs created and regional value of the materials and services purchased from other sectors of the economy (indirect impact) and the economic impact of workers who are employed both directly and indirectly though both construction and other sectors that sell inputs to contracting firms (Parajuli et al., 2018). In addition, the induced impact captures the value of spending of household labor income.

While this project examines GI built only within the District perimeter, companies engaged in GI construction are located throughout the DC MSA. All of these actors spend earnings on a variety of goods and services outside of the workplace. Thus, other sectors are stimulated by the demand in the green infrastructure economy, and households that benefit from these indirect sectors also spend earnings on goods and services both in and outside the regional economy (induced impact). IMPLAN is intended to model these ripple effects of spending in a regional economy. As a result, while the sites are localized in the District, the jobs created and economic impact modeled are distributed throughout the MSA. However, any purchases made outside the region are excluded from the model. These figures, in essence, represent an estimate of the impact that would not have happened *but-for* the regulated activity and stormwater retention credit generation in the District.

Results

Green infrastructure in the District: projects and retention over time

All GI best management practices are logged in an open data platform on the District government's website. Data from this site were obtained in order to understand the extent and practices of GI constructed in the District. Of the five GI practices included in the scope of this project, installation increased from 2015 to 2020. For three GI practices (permeable pavements, bioretention, and green roofs), new installations per year have also increased during the study period. For rainwater harvesting and infiltration, new installations per year have decreased during the study period (Figure 2).

Figure 2: New GI Practices Installed by Year, 2015 – 2020.

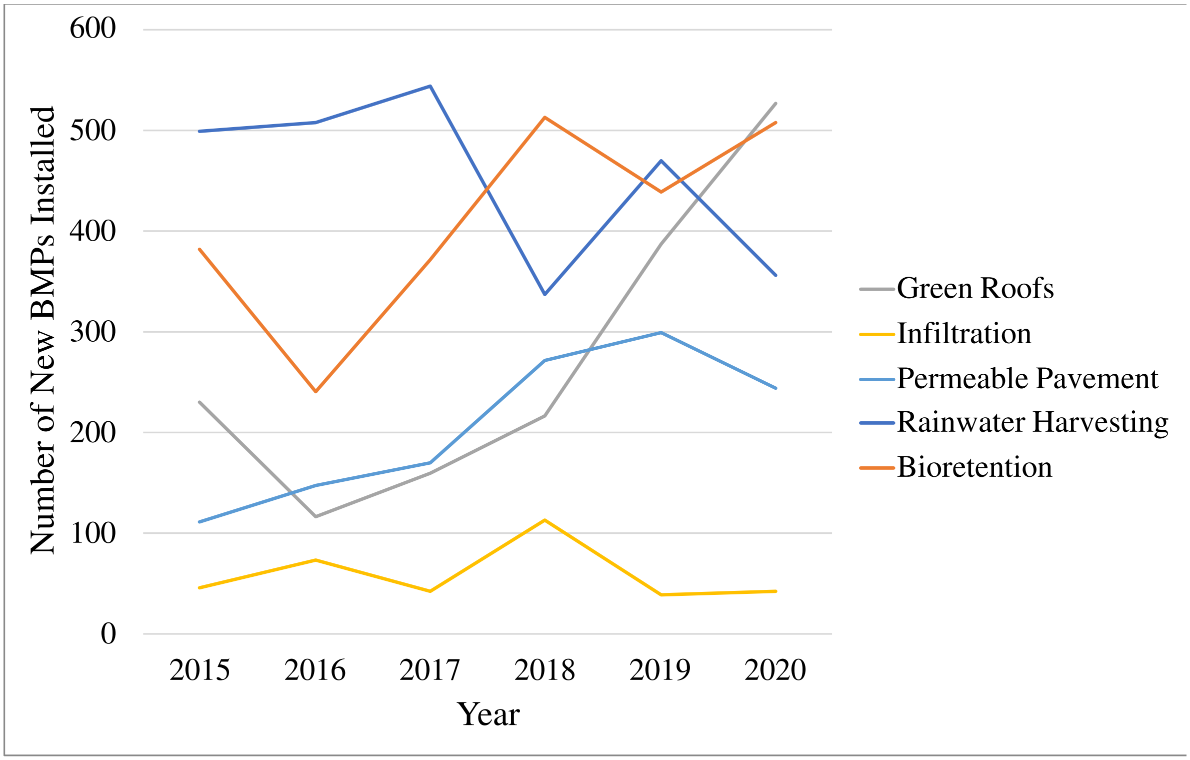
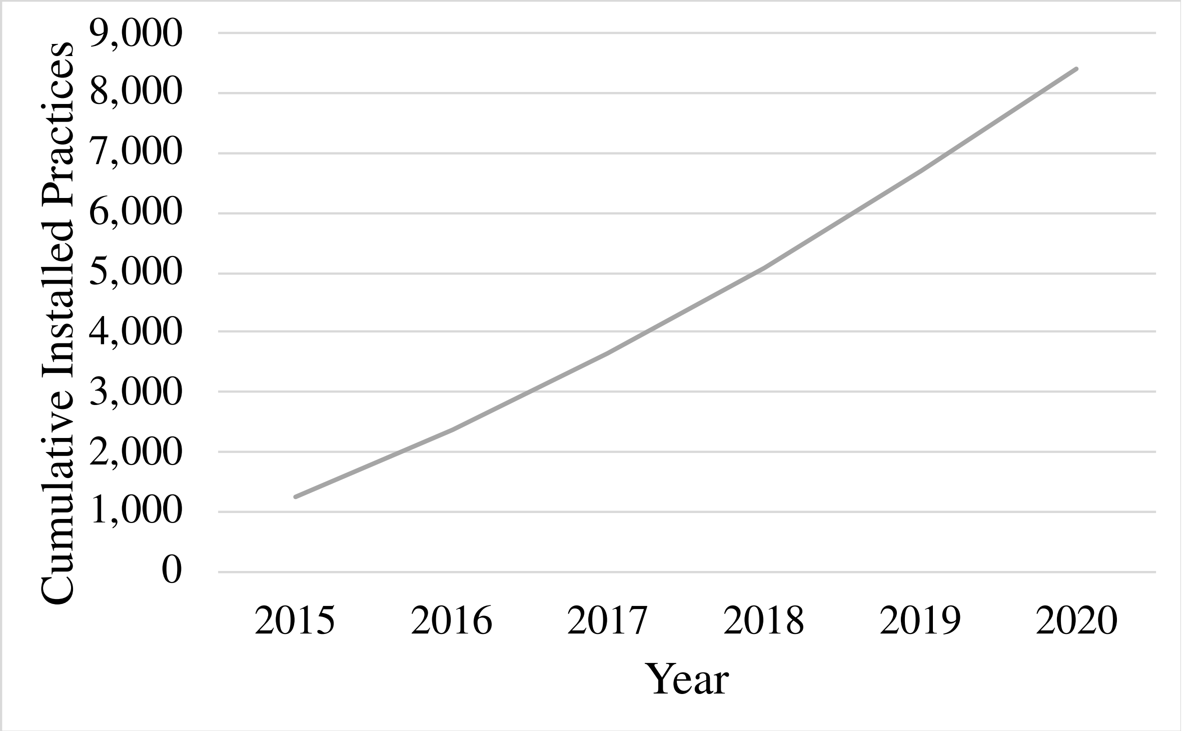
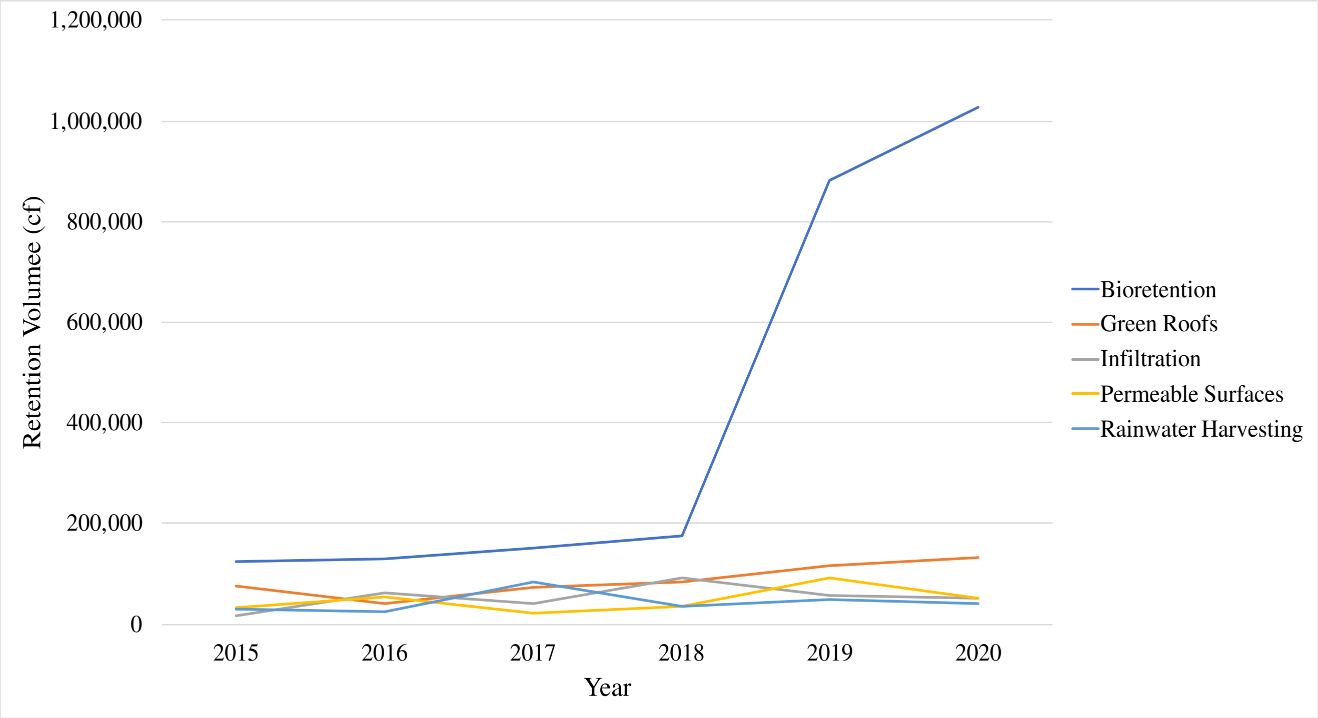


Figure 3: Cumulative Installed GI Study Practices, 2015 – 2020



Retention volume across the District also increased during the study period. From 2019 to 2020, the amount of new added retention volume decreased from the following year, perhaps due to the effects of the COVID-pandemic, but cumulative retention still increased. As shown in Figure 4, installation of bioretention projects adds a significant amount of retention to the total volume retained in the District. Bioretention projects make up the majority of volume retained by the five best management practices in the scope of this study (Figure 4). Bioretention is among the practices with the highest numbers of installed practices, but it is the retention volume of bioretention practices that far exceeds the capacity of other practices. Thus, bioretention represents the practice with the highest retention per practice.

Figure 4: Retention volume of installed BMPs from five study group categories in D.C., from 2015 to 2020.



Investment in GI practices

As described in the Methods section of this paper, the amount of retention generated per year across the five practices determined the investment in each GI practice. Investment was calculated based on the cost per unit volume as determined by original interviews with contractors, multiplied by the retention of each practice for each year in the study period. Investment in bioretention was the largest over the six-year period, due to the bioretention being the practice that retains the largest volume of water in the District (Table 4, Figure 4). Investment in green roofs was the next highest; it retains the second highest volume of water in the District, but the cost per unit volume of green roofs is also the highest amongst GI practices, as determined by interviews (Table 3). Rainwater harvesting had the third highest investment of the five practices, despite having the largest total number of installed practices in the District over the time period, indicating lower retention values associated with each practice installed.

Table 3: Unit Price of Constructing 5 GI Practices, from 2015 - 2020

Practice	$/Cubic Foot Retention
Green Roofs	$270.39
Rainwater Harvesting	$103.92
Permeable Pavement	$102.06
Bioretention	$70.24
Infiltration	$54.62

Table 4: Calculated direct investments (2020 USD) for five major categories of green infrastructure in Washington, DC (2015-2020).

GI Practice	2015	2016	2017	2018	2019	2020	**Total by Practice**
Bioretention	$9,595,589	$10,028,210	$11,305,698	$12,913,221	$63,212,540	$72,077,613	**$179,132,870**
Green Roof	$22,899,323	$12,286,777	$21,170,955	$23,916,502	$31,801,095	$36,082,682	**$148,157,334**
Infiltration	$931,099	$3,760,373	$2,367,784	$5,272,440	$3,111,954	$2,824,370	**$18,268,020**
Permeable Surfaces	$3,747,936	$5,974,665	$2,291,397	$3,879,969	$9,690,822	$5,277,330	**$30,862,119**
Rainwater Harvesting	$3,277,020	$2,642,798	$9,105,533	$3,836,338	$5,059,256	$4,285,918	**$28,206,862**
Annual Total	**$40,450,966**	**$34,692,823**	**$46,241,368**	**$49,818,469**	**$112,875,667**	**$120,547,912**	$404,627,205

Indirect and induced impacts

Based on the IMPLAN model derived from investment in GI over the study period, construction of the 5 GI practices in the District produced $696,168,634 in direct economic output and 3,374 job-years, or one job for one year. This activity also directly generates $343,312,974 in labor income and $450,075,471 in value added, according to the IMPLAN model. This estimate includes all of the final values of sales and revenues for firms that construct the green infrastructure. While the direct economic impact is the largest, investment in GI also produce indirect (through spending on business inputs, such as equipment and materials) and induced (through increased household spending) economic impacts. Investment generated 739 job-years and $135,727,751 in output through indirect impact and 1,075 job-years and $187,474,671 in induced economic impact. In all, total generated a direct impact of 1,744 job-years, $404,627,207 in economic output, $265,776,575 in value added to the economy, and $224,199,950 in labor income (Table 5). The average economic impact across the study period is presented in Table 5, with an average total yearly employment of 1,126 and output of $230,591,216.

Table 5: IMPLAN Results for Average Yearly Economic Impact of GI, 2015 – 2020

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	553	70,926,429	84,012,585	128,133,908
2 - Indirect	235	20,849,761	27,335,088	43,190,185
3 - Induced	339	21,014,889	37,540,644	59,267,123
Totals	1,126	112,791,079	148,888,317	230,591,216

Each economic impact indicator increased during the study period, decreasing slightly from 2015 to 2016 across all indicators (Table 6). From 2019 to 2020, employment, labor income, and value added per year decreased, but economic output still increased from 2019 to

2020 despite dips in the other three indicators (Table 5). This dip in 2020, like other patterns in investment and GI practice construction, likely represent the disruptive effects of the COVID-19 pandemic on development.

Table 6: IMPLAN modeling results five primary GI practices in Washington, DC (2020)

2015

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	171	$22,841,328	$27,477,639	$40,450,967
2 - Indirect	71	$6,090,762	$8,079,664	$12,314,392
3 - Induced	117	$6,871,090	$12,576,935	$19,346,602
Totals	359	$35,803,180	$48,134,238	$72,111,962

2016

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	146	$19,270,455	$22,982,740	$34,692,823
2 - Indirect	65	$5,500,723	$7,303,081	$11,266,183
3 - Induced	100	$5,901,377	$10,774,435	$16,612,786
Totals	310	$30,672,555	$41,060,256	$62,571,792

2017

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	194	$25,041,991	$29,989,625	$46,241,367
2 - Indirect	89	$7,654,420	$10,066,119	$15,644,925
3 - Induced	129	$7,612,757	$13,834,129	$21,467,711
Totals	413	$40,309,167	$53,889,872	$83,354,004

2018

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	205	$27,017,643	$32,621,326	$49,818,470
2 - Indirect	90	$8,094,424	$10,816,272	$16,526,511
3 - Induced	136	$8,313,259	$14,887,912	$23,217,689
Totals	431	$43,425,326	$58,325,510	$89,562,670

2019

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	536	$66,237,098	$75,820,734	$112,875,667
2 - Indirect	194	$16,800,929	$23,473,959	$36,788,129
3 - Induced	325	$19,871,153	$36,480,682	$57,316,536
Totals	1,056	$102,909,180	$135,775,375	$206,980,331

2020

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	492	$63,791,436	$76,884,513	$120,547,913
2 - Indirect	230	$21,453,405	$26,306,001	$43,187,610
3 - Induced	268	$17,910,578	$30,356,306	$49,513,347
Totals	990	$103,155,418	$133,546,820	$213,248,870

Total, 2015 - 2020

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	1,744	$224,199,950	$265,776,575	$404,627,207
2 - Indirect	739	$65,594,663	$86,045,097	$135,727,751
3 - Induced	1,075	$66,480,213	$118,910,398	$187,474,671
Totals	**3,558**	**$356,274,827**	**$470,732,070**	**$727,829,629**

Stormwater retention credit trading program: growing potential for economic impact

GI generated from the SRC represents only a small fraction of the GI built within the District, but GI built within the district has been growing steadily since the beginning of the study period. Though the number of SRCs being sold has increased, the sale price has remained relatively stable, increasing from 2015 to 2019 and decreasing in 2020 to below-2015 prices (Figure 5, Table 7). At the time of this study, only 14 entities in the District were selling stormwater retention credits, and data collected from these sellers was insufficient to build out the cost profile of the 5 GI practices in a way consistent with the interviews of low-impact contractors. Many sellers are not directly involved in GI construction and have less information on typical cost profiles.

As shown in Table 7, the 77,727.81 cubic feet of retention credits sold in 2020 is less than a tenth of the retention generated by bioretention projects alone in 2020, for example. Still, it exemplifies a unique policy environment in which investment in GI is driven by voluntary investment. The SRC generated 17.30 job-years and $3,610,833 in total direct, indirect, and induced economic output during the study period (Table 8). The SRC also generated $1,763,284 in labor income and $2,314,259 in value added to the regional economy.

Table 7: SRCs Sold and Revenue Received by SRC Sellers in the District, 2015 – 2020

SRC Price Year	Number of SRC Sales	SRCs Sold (Gallons / Year)	Value of SRCs Sold, paid by buyer	Average SRC Sale Price	Cubic Feet Retained	Value Sold per Cubic Foot
2015	1	11,013	$20,925	$1.90	1,472.33	$14.21
2016	8	24,972	$46,284	$1.85	3,338.50	$13.86
2017	15	108,537	$218,913	$2.02	14,510.29	$15.09
2018	20	119,290	$247,212	$2.07	15,947.86	$15.50

2019	29	254,490	$472,837	$1.86	34,022.73	$13.90
2020	45	581,404	$954,163	$1.64	77,727.81	$12.28

Figure 5: Values of SRCs Sold (Paid by Buyer), 2015 - 2020

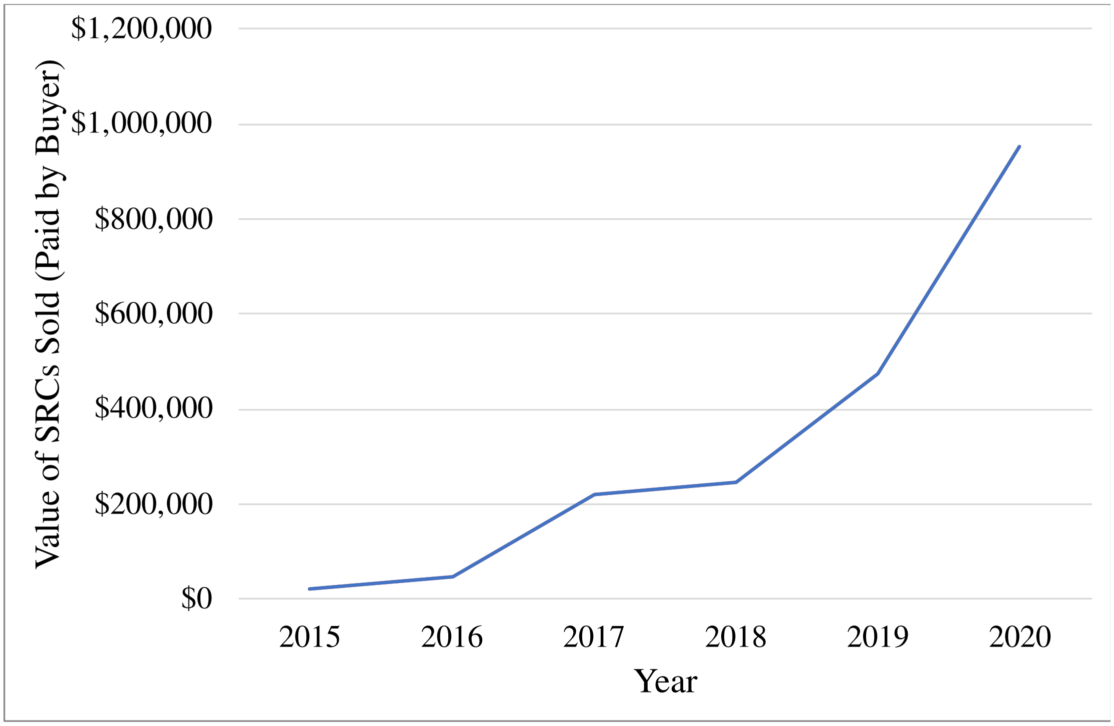


Table 8: IMPLAN Modeling Results for SRC Sales in Washington, DC (2015 - 2020)

2015				
Impact	Employment	Labor Income	Value Added	Output
1 - Direct	0.10	$13,258	$15,925	$23,456
2 - Indirect	0.04	$3,516	$4,663	$7,110
3 - Induced	0.07	$3,965	$7,259	$11,164
Totals	0.20	$20,739	$27,847	$41,730
2016				
Impact	Employment	Labor Income	Value Added	Output
1 - Direct	0.21	$28,596	$34,075	$51,412
2 - Indirect	0.09	$8,095	$10,746	$16,585
3 - Induced	0.14	$8,697	$15,881	$24,483
Totals	0.45	$45,389	$60,702	$92,480
2017				
Impact	Employment	Labor Income	Value Added	Output
1 - Direct	0.98	$128,314	$153,520	$236,504
2 - Indirect	0.45	$38,841	$51,075	$79,409
3 - Induced	0.65	$38,720	$70,367	$109,172
Totals	2.08	$205,875	$274,961	$425,085
2018				
Impact	Employment	Labor Income	Value Added	Output
1 - Direct	1.06	$142,459	$171,760	$262,054
2 - Indirect	0.46	$42,238	$56,427	$86,240
3 - Induced	0.70	$43,494	$77,895	$121,450
Totals	2.23	$228,191	$306,082	$469,743
2019				
Impact	Employment	Labor Income	Value Added	Output
1 - Direct	2.29	$287,762	$329,324	$490,085
2 - Indirect	0.82	$72,388	$101,107	$158,505
3 - Induced	1.38	$85,684	$157,320	$247,120
Totals	4.50	$445,835	$587,751	$895,710
2020				
Impact	Employment	Labor Income	Value Added	Output
1 - Direct	3.92	$506,345	$608,942	$953,182
2 - Indirect	1.82	$169,017	$207,480	$340,639
3 - Induced	2.12	$141,894	$240,495	$392,264
Totals	7.85	$817,256	$1,056,917	$1,686,085
Total, 2015 - 2020				
Impact	Employment	Labor Income	Value Added	Output
1 - Direct	8.56	$1,106,733	$1,313,545	$2,016,694
2 - Indirect	3.68	$334,096	$431,498	$688,487
3 - Induced	5.06	$322,454	$569,216	$905,653
Totals	**17.30**	**$1,763,284**	**$2,314,259**	**$3,610,833**

Discussion

Limitations of data collection and IMPLAN modeling

While it is an aim of this paper to provide examples for incorporating economic impact analyses in decision-making for environmental policy, results of economic impact analyses may vary depending on the assumptions made by the analyst. Economic output values from IMPLAN are not intended to be predictive values; however, they do represent trends of industry linkages and regional economic patterns. While IMPLAN results are precise, they nonetheless represent estimates for economic impacts because of assumptions in building the industry. Because the green infrastructure industry is new and emergent, assumptions made in order to group these contractors and SRC sales into classical industries and commodities may alter the results. In addition, the scope of this project does not include a comparison to the jobs created and economic impact generated from constructing gray infrastructure in D.C.

Results also depend on the GI cost structure developed in this project. Interviewed firms varied largely in size and regional distribution. Some of the 17 firms surveyed worked only in the D.C. Metro Area; other firms conducted work across the United States. Some firms represented multi-office firms of over 1,500 employees, while other firms only had one full-time employee. As a result, the costs of projects varied widely throughout the firms, as some firms construct multi-acre landscape design, while other firms build small projects at a variety of locations. Firms were asked to provide information on the per-volume costs of building green infrastructure. However, while 17 firms were interviewed, not all firms conducted the five surveyed GI practices. As such, the model built from the survey of low-impact developers represent a range of potential cost values for green infrastructure, not a predictive cost model or estimate for building GI. These values depend on the size, location, and scope of the project. As such, in order for this type of study to be applied to other cities, the primary factor of interest will be the cost of constructive GI according to contractors and land value. These costs determine the investment in GI and resultant economic impact generated.

In addition, not all contractors were able to provide information about the retention capacity of projects in the same units. In cases where only a square footage area was known, a depth of 1.2 inches for water retention was applied, representing the requirement for according to the District's policies for major regulated activity. This assumption should be understood as a conservative estimate for retention volume, as it is the minimum required retention depth, and many practices retain more than the required volume of water from a 1.2-inch storm event.

Stormwater retention credit trading: site for future research

One of the points of interest of this project was to evaluate the effects of a market-like system for trading stormwater retention credits. Due to limitations of the sample size, it was not possible to collect sufficient data on the costs of constructing data for the SRC using the same methods as were possible for all GI development across the District. Using original interviews, I determined the exact industry and cost of building GI from each surveyed developer. With the SRC system, the IMPLAN model hinges on the assumption of SRCs being sold as a landscaping, engineering, and related service commodity. As the first trading program of its kind, this market product is novel and thus may not be accurately captured by commodities IMPLAN.

If the SRC follows its current trajectory, it will continue to lead to increased installation of GI in the District. Development of the SRC system may be an important area for further study. Insufficient data exists on how the cost structure – and therefore, economic impact – of GI built within the SRC system differs from GI built across the District as a whole. Incorporating new data on stormwater credit trading will provide a fuller account of the program as the first of its kind.

Social impacts and considerations

This economic impact analysis is intended to provide a tool for policymakers to more fully evaluate the impacts of green infrastructure. However, this necessitates the contextualization of GI amidst a broader policy environment for mitigation of problems like urban flooding. Evidence suggests marginalized and vulnerable communities are disproportionately exposed to environmental risks, yet they have the least access to environmental benefits (Bullard & Johnson, 2000). However, literature also suggests that vulnerable populations may be negatively impacted by adaptation strategies if these policies do not evaluate existing inequalities (Anguelovski et al., 2016). Therefore, vulnerable communities may have the highest potential for benefit from green infrastructure but may not benefit if GI is allocated in less vulnerable neighborhoods. It may be possible to incorporate green infrastructure and its benefits into a city without expediting processes like gentrification and disinvestment in other neighborhoods that may increase social inequities. The scope of this study does not include recommendations for equitable GI investment, but literature suggests that green infrastructure policy outcomes can be improved if GI policies are considered alongside efforts like affordable housing and property tax relief for low-income homeowners (Heckert & Rosan, 2018). In D.C., a 2019 study by Vogel found that race, ethnicity, and income did not have a strong relationship with green infrastructure at the census block level, but the proportion of renter-occupied housing units was a significant factor in association with green infrastructure (Vogel, 2019). Examining social variables such as these alongside GI investment will continue to be a crucial point of further study for equitable infrastructure solutions.

Conclusion

In this project, I conducted an economic impact of the construction of green infrastructure in D.C. from 2015 to 2020. In addition, I examined the nation's first stormwater retention credit trading program and its economic impact in the regional economy. For green infrastructure constructed across the District, the cost structure of five GI practices was determined through original interviews with contractors. These were used in order to determine total GI investment and resultant economic impact from 2015 to 2020. The yearly sales through the stormwater retention credit trading system from 2015 to 2020 were modeled as commodity outputs in D.C. to determine the economic impact of the SRC system.

As increasing research demonstrates that supplementing gray infrastructure with green infrastructure can provide environmental benefits at a lower cost than either infrastructure practice alone, more cities may develop regulatory schemes to increase the presence of green infrastructure. Incorporating economic impact analyses in these environmental policy decision-making processes may challenge dominant notions that environmental regulations are deadweight losses on regional economies and change traditional models for calculating ecosystem services of environmental management. In addition, impact analyses for environmental management can provide policymakers with relevant planning tools in light of recent federal plans for large-scale infrastructure investment. While these methods are made possible by IMPLAN's input-output modeling software and city-level data from the District, municipalities of all sizes may incorporate this framework in order to better account for the jobs created and economic impacts of environmental management.

Creating a more robust accounting of environmental policy will grow in importance as the District, other cities, and the nation increasingly adopt climate change mitigation strategies. As the federal government develops its infrastructure plan, incorporating green infrastructure into traditional infrastructure will not only provide a host of stormwater and wellbeing benefits, but it can provide jobs and value added to the regional economy at a scale on par with established industries, too.

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