Parcel Scale Green Infrastructure Siting and Cost Effectiveness Analysis
A Pilot Study for Pittsburgh, PA

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Executive Summary

Over the last several decades, green infrastructure has become increasingly utilized for compliance with local, state, and federal wet weather standards. However, identifying cost-effective combinations of green and gray infrastructure has been challenging due to differing definitions of costs and benefits, extreme and often unknown variability in project performance, incomplete information describing potential projects, and a poor reflection of green infrastructure in hydrologic and hydraulic models.

In an effort to overcome these challenges, this study aims to identify all installations of rain gardens, downspout disconnects, pervious pavement, and green roofs feasible through inexpensive retrofits (those requiring no additional regrading) in Pittsburgh, PA and estimate their cost and wet weather performance. By focusing on inexpensive retrofits for an entire service area, this study captures variability in the wet weather performance of green infrastructure projects, which can then be used to estimate their potential to meet wet weather goals.

This study identified unique installations of approximately 28,000 rain gardens (18 million square feet), 18,000 downspout disconnects (from 12 million square feet of roofing), 3,600 green roofs (73 million square feet), and 64,000 conversions of impervious surfaces to pervious pavement (96 million square feet). These installations would cost $3.3B ($2.5 - $4.4B) on a 30-year net present value basis and reduce overflows by 2.4% (1.7% - 3.4%) assuming year 2003 precipitation.

Results demonstrate high variability in cost effectiveness, from roughly $0.05 to more than $100 per gallon of overflow reduced. Cost effective parcels demonstrate site layouts, land use, and topography that direct runoff to a potential green infrastructure amenity utilized to near maximum retention capacity. On average, downspout disconnects are estimated to be the most cost effective ($0.20 - $ 0.45 per gallon). Rain gardens ($1.8 - $3.7 per gallon) and pervious pavement ($0.97 - $4.3 per gallon) are similarly cost effective. Green roofs are the least cost effective ($76 - $130 per gallon).

Assuming a cost competitive basis of $0.35 per gallon of overflow reduced, only 18% of the feasible retrofits are cost effective, including 360 rain gardens (range of 12 - 3,000), 2,900 downspout disconnects (range of 410 - 4,600), and up to 70 installations of pervious pavement. No green roofs were found to be cost competitive. The cost effective installations reduce overflows by 0.15% (0.01% - 0.8%).

These results indicate that there are few cost effective, parcel-scale retrofits in Pittsburgh. Should these solutions be part of an overall wet weather plan, their cost performance is highly sensitive to the selected technology and installation location. Given the few cost effective installations identified in this report, results suggest random green infrastructure project selection in Pittsburgh would most likely increase the cost of wet weather compliance. A cost minimizing strategy would select green infrastructure projects only when offsetting more expensive gray infrastructure projects.

Hydraulic models of the collection system are needed to identify potential offsets of gray infrastructure from upstream green infrastructure. These models are generally considered protected information by municipalities, which may challenge consensus building. For planning purposes, it may be feasible to decouple hydraulic modeling from identifying cost effective green infrastructure amenities if municipalities could approximate the green infrastructure hydrologic performance "equivalent" to any gray infrastructure projects. If municipalities could publish such "equivalence" alongside recommended gray strategies, it would allow them to preserve protected information while also providing much needed benchmarks to green infrastructure stakeholders.

Similarly, consistent measures of cost effectiveness would aid in consensus building. Measures of cost effectiveness are specific to the desired level of wet weather performance (e.g., no overflows) given a precipitation record (e.g., year 2003 precipitation), cash flow basis (e.g., 30-year net present value), and technical modeling assumptions, none of which are currently consistently applied. The technologies, strategies, and projects deemed cost effective for eliminating overflows for a 5-year event are different than those for halving overflows for a 25-year event. The community would benefit from consistent definitions of cost effectiveness so that ongoing efforts can be more fairly compared.

Results also challenge strategies that do not spatially resolve modeled green infrastructure technologies. Green infrastructure is typically understood using applied models configured at the sewershed scale. Sewershed models are agnostic with respect to the location(s) appropriate for green infrastructure and, in turn, assume land use and topographical patterns within a sewershed are adequate to fully utilize green infrastructure. Results from this project suggest that such an assumption is unrealistic for Pittsburgh, which means reconfiguring a sewershed to fully utilize widespread deployments of green infrastructure will likely require re-grading and/or rerouting to a degree not typically reflected in models of green infrastructure at the sewershed scale.

In an effort to enhance community awareness, build consensus, and support other related endeavors, project results are published openly on a project website that includes an interactive map of the estimated feasible installations, tabular data of project results, and links to this report and model assumptions.

1. Background and Motivation

The Pittsburgh region is served by a combined sewer, which collects, conveys, and partially treats both stormwater and wastewater in the same infrastructure system. During periods of heavy rainfall, stormwater can exceed the capacity of combined sewers, which causes overflow into nearby rivers and streams. While these combined sewer overflows (CSOs) mitigate upstream flooding, they release untreated wastewater into receiving water bodies.

Improvements to "gray" infrastructure - pipes, pumps, storage, and treatment facilities - can increase the capacity of the collection system to accommodate more severe wet weather events. Conversely, "green" infrastructure includes features that reduce the stormwater entering the collection system by temporarily retaining or diverting stormwater. Types of green infrastructure vary from completely natural systems, such as converting a parking lot to a park, to single purpose engineered systems, such as pervious paving.

A comprehensive green infrastructure strategy starts with identifying broad areas appropriate for green infrastructure using hydrologic and hydraulic models then applying a mix of additional criteria to target specific installations. This procedure is demonstrated schematically in Figure 1.

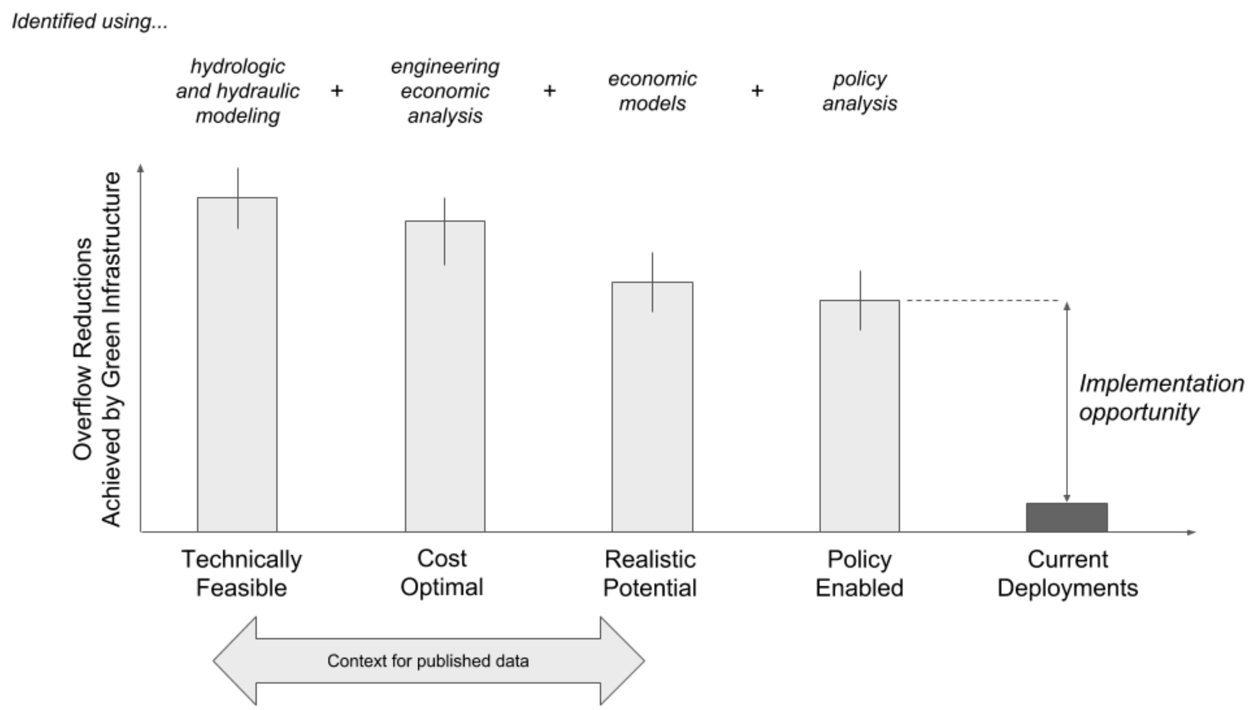


Figure 1: The tiers of green infrastructure estimates, shown on the x-axis, derived through different types of analyses, shown across the top of the figure.

Technically feasible installations of green infrastructure include all possible structural and non-structural installations utilized at their maximum load ratio. The technically feasible installations are identified through hydrologic and hydraulic models performed at the sewershed scale.

Cost optimal installations are technically feasible projects that, taken together, minimize the net cost of a wet weather plan. These projects are identified by applying engineering economic analysis to potential projects. The cost optimal set of installations recognizes dependencies between gray and green infrastructure. Figure 2 show a hypothetical solution space where a combination of green and gray solutions achieve the same wet weather performance but at different costs. The far left represents an all gray solution, and the far right represents a solution that is mostly green (an all green solution is not likely realistic). The hypothetical chart orders gray infrastructure projects from most to least cost effective and green infrastructure projects from most to least cost effective. Moving from left to right, the chart offsets the most cost ineffective gray infrastructure projects with the most cost effective green infrastructure projects, resulting in a reduction in total costs (gray + green). After total costs reach a minimum, gray infrastructure projects become more cost effective than green infrastructure projects, and the total cost efficiencies of a gray plus green strategy decrease. At some point, the cost inefficiencies of a combined strategy exceed that of an all gray solution.

This hypothetical exercise makes it clear that there are two components to the cost effectiveness of green infrastructure: its runoff performance independent of downstream gray infrastructure and its ability to offset gray infrastructure. If gray and green strategies are not combined so that green solutions offset more expensive gray solutions, total cost inefficiencies could occur.

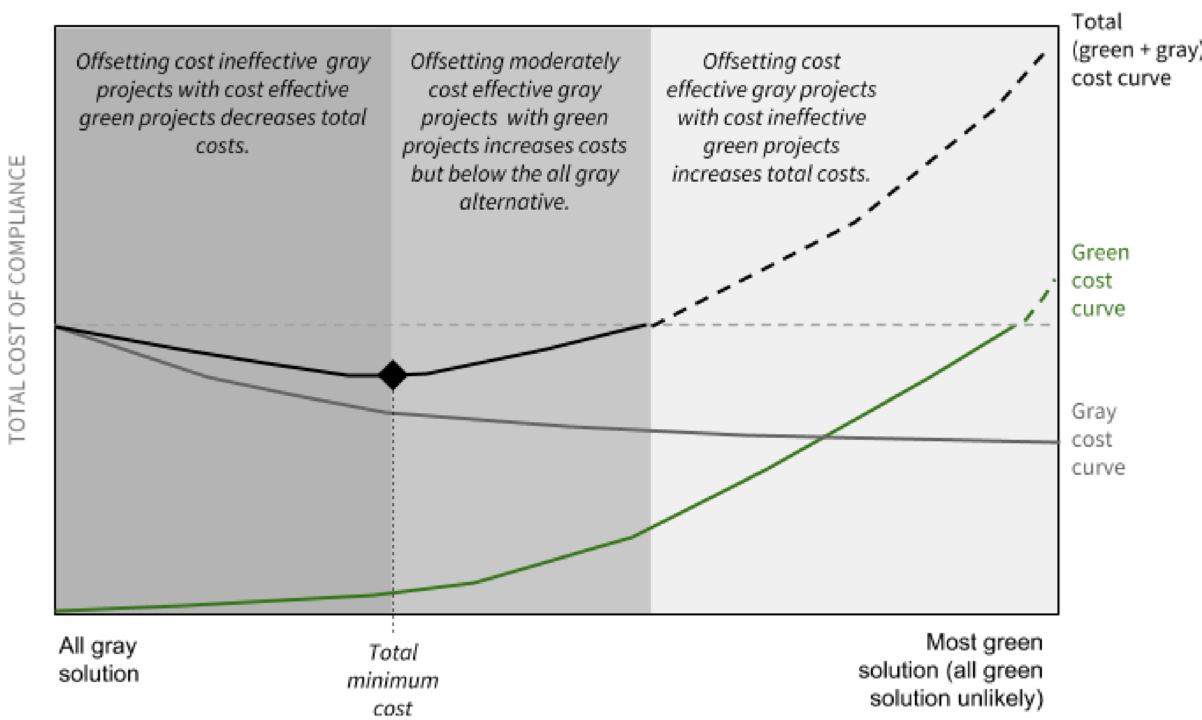


Figure 2: Hypothetical total cost curves for different combinations of green and gray infrastructure solutions that meet the same wet weather performance but at different costs. Hypothetical gray solutions are ordered from least to most cost effective. Hypothetical green solutions are ordered from most to least cost effective. Moving from left to right, gray projects are offset by green projects.

Not all cost optimal installations are realistic. The ***realistic potential*** of green infrastructure considers stormwater management in balance with other land uses to recognize the preferences of private property owners. For example, property owners value uses of outdoor open space that may be precluded with a rain garden, and such valuations may exceed any real or non-monetary benefit property owners derive from improved stormwater protection.

Policy enabled green infrastructure projects are those resulting from a policy. Ideally, policies support cost effective projects that otherwise face implementation barriers, such as providing a rebate to property owners for providing stormwater protection on their property. Other examples might include projects spurred by a stormwater fee on impervious cover, decommissioning of distressed property, or requiring stormwater controls for new development. Thus, it is important to understand not only the engineering economic cost performance of private property retrofits but also how people value potential changes to private property that improve wet weather performance.

This project is limited to identifying all possible locations of green infrastructure suitable for managing runoff from a typical parcel through inexpensive retrofits, i.e., locations that require little to no regrading or other accessory stormwater diversions. As such, it includes some technically feasible retrofits (where the existing site layout utilizes green infrastructure to its maximum capacity), some cost effective retrofits, and some realistic retrofits (where property owners would permit installation of green infrastructure). This set of installations is referred to as the “retrofit potential” throughout this report.

2. Objectives, Limitations, and Intended Uses

This study aims to identify all installations of rain gardens, downspout disconnects, pervious pavement, and green roofs feasible through inexpensive retrofits (those requiring no additional regrading) in Pittsburgh, PA and estimate their cost and wet weather performance.

Given limitations in the data and methods, the results here are considered adequate for decisions related to wet weather planning and are not sufficient for site specific design or analyses. Projects results are published online for applications beyond the insights discussed herein. Example future applications of the resulting data could be to identify vacant or public property with a high inflow reduction potential, contrast the published parcel level green infrastructure installations with higher level sewershed estimates, elicit variation in cost effectiveness driven by variation in site characteristics, identify variation in wet weather performance by property type or demographic for subsequent policy analyses, and/or identify locations where parcel aggregation towards a particular installation is sensible.

3. Data Sources, Data Manipulation, and Limitations

Three data sources were used to characterize land cover. The data set *Urban Tree Canopy* [Allegheny County 2010] roughly delineates land into building, roadways, trees, open space, water, and other surface impervious cover (such as driveways, sidewalks, and parking lots). The *Allegheny County Wooded Areas* [Allegheny County 2011] provides additional information about denser stands of trees. The data set *Building Footprints* [City of Pittsburgh 2008] reflects building footprints as of 2008. These data were harmonized by prioritizing the building footprints' spatial information and reallocating any buildings misestimated by the urban tree canopy layer using nearest neighbor algorithms.

The resulting land cover data were assigned to five types: buildings, open space, trees, surface impervious cover, and roadways in the public right-of-way. Land cover data were then intersected with parcel delineations [Allegheny County 2016] and a 10-foot building buffer. To ensure adequate inspection of green infrastructure, polygons adjacent to the public right-of-way were identified by proximity to the street curb [City of Pittsburgh 2009]. The resulting database divides land cover for the City of Pittsburgh into 3.2 million polygons with a mean area of 520 square feet defined parcel boundaries, land cover, proximity to buildings, and proximity to the right of way. The mean elevation and slope was then assigned to each polygon for hydrologic modeling.

Allegheny County's original parcel identifier (field name "PIN") was modified (modified field "PINnew") to better reflect the land cover associated with condominiums. Currently, Allegheny County codes common space for all condominiums with the value of "COMMON" for PIN. All common areas were given a modified, unique identifier by concatenating the County's map and block identifier with the word "COMMON." For example, the common area for a condominium on map 0001, block G00, would be labeled, "0001G00COMMON."

Additionally, condominiums with more than one floor were often represented by stacked polygons with unique identifiers for each unit. In these situations, identifiers for the building cover of condominiums were arbitrarily selected to ensure the aerial footprint of land cover is properly represented.

Any changes to buildings since 2008, land cover since 2010, and street curbs since 2009 are not properly reflected in the results. In addition, the various land cover information, while the best available at the start of this study, is spatially approximate. For example, many buildings are indicated as crossing property lines and extending into the public right-of-way. The land use data are taken on an "as is" basis.

4. Green Infrastructure Sizing and Siting Criteria

The green infrastructure sizing and siting criteria are summarized in Table 1.

Ineligible parcels for the installation of rain gardens, downspout disconnects, pervious pavement, and green roofs were assumed to be public parks, cemeteries, railroad right-of-ways, and parcels where impervious surfaces represents less than 5% of the total parcel area (15,200 out of 121,600 parcels).

Roof types labeled as either "rolled" or "rubber" in Allegheny County's property tax database [Allegheny County 2016] were assumed to be flat roofs, and the remaining roofs with completed records were assumed to be sloped. However, most roof descriptions in Allegheny County's property tax database are missing. Thus the roof type (flat or sloped) was assumed based upon the property use as described in the Supplemental Information.

R code was developed to apply the sizing and siting criteria, roof type assumptions, and property eligibility criteria to each parcel in the City of Pittsburgh, resulting in the selection of land portions representing potential locations for the indicated green infrastructure technologies.

Where both downspout disconnects (without downstream retention) and rain garden were feasible, the more cost effective of the two was selected. Similarly, where rain garden sizes and performance differed based upon receiving runoff from a building or impervious cover at grade, the more cost effective installation was selected.

5. Hydrologic Modeling and Overflow Estimation

For each parcel, baseline and reduced runoff were estimated using the Environmental Protection Agency's Stormwater Management Model (SWMM). Runoff reductions were estimated by simulating discrete green infrastructure interventions for each parcel. Thus the runoff reductions from combinations of interventions are not additive. By simulating each parcel separately, overland flow across parcels is not modeled. The assumptions regarding land cover for each parcel are presented in Section 3 and are included in the Supplemental Information. The remaining hydrologic modeling parameters and the simulated precipitation are also summarized in the Supplemental Information.

Table 1: Green infrastructure sizing and siting criteria applied to each eligible parcel. Downspout disconnects assume no downstream retention.

	Green infrastructure type			
Criteria	Rain Garden	Pervious Pavement	Green Roof	Downspout Disconnect
Affected land cover	Open space	Impervious cover not in right-of-way	Buildings	Buildings
Size criteria	At least 20 square feet of contiguous open space		At least 200 square feet	
Slope criteria	Existing grade less than 15%			
Building buffer	At least 10 feet from building	At least 10 feet from building		
Curb proximity	Adjacent to curb	Adjacent to curb		At least 10 feet from all curb boundaries
Elevation	Below impervious cover	Below building		Conforming, contiguous open area below building skirt
Load ratio	1:5			1:1
Limitation	1 per parcel on largest conforming area	1 per parcel on largest conforming area	Flat roofs greater than 10,000 square feet only as per assumptions summarized herein	The maximum of either half or all of the building footprint given the assumed load ratio

Only hydrologic modeling was completed as part of this study, as the hydraulic models of the collection system are considered protected information. Even if the hydraulic models were available, the scale of inflow reductions from parcel scale installations is small enough such that their reduction in overflows would be masked by rounding introduced during a full hydrologic and hydraulic simulation. Thus, to estimate overflow reductions from each installation, reductions in overflows per reductions in inflow published by PWSA were applied to each installation [PWSA 2016]. Summarized in Table 2, PWSA produced these ratios only for the so called "priority sewersheds," which demonstrate relatively more potential to reduce overflows.

Table 2: Estimates of overflows reduced per inflow reduced for high priority sewersheds identified by the Pittsburgh Water and Sewer Authority [PWSA 2016].

Sewershed Name	Volume Overflows Reduced per Volume Inflow Reduced	Sewershed Name	Volume Overflows Reduced per Volume Inflow Reduced
A-22	0.77	M-16	0.8
A-41/ 121H001-OF	0.43	M-19	0.85
A-42	0.59	M-19A	0.67
A-42/ 177K001-OF	0.59	M-19B	0.66
A-48	0.47	M-21	0.62
A-58/ OF009E001	0.67	M-29	0.85
A-60	0.91	O-27	0.55
A-61	0.58	O-39	0.48
A-65	0.6	O-41	0.7
M-15	0.94		

6. Cost Effectiveness Analysis

For each discrete installation, cost effectiveness was estimated as the 30-year net present value per gallons of inflow (or overflow) reduced as shown in Equations 1a and 1b. A discount rate of 6 % was assumed.

$$CE_{Inflow,\,p,\,i} = NPV_{p,i} \,/\, (\text{Runoff Reduced}_{p,i}) \qquad \text{Eq. 1a}$$

$$CE_{Overlow,\,p,\,i} = NPV_{p,i} \,/\, (\text{Runoff Reduced}_{p,i}) \times (\text{Runoff Reduced} \,/\, \text{Overflow Reduced})_{p,\,i} \qquad \text{Eq. 1b}$$

Where

$CE_{p,i}$ = cost effectiveness for parcel, p, and installation, i

$NPV_{p,i}$ = net present value for parcel, p, and installation, i

The assumed unit costs are summarized in Table 3. Methods for estimating the area of each installation are summarized in Sections 3 and 4. Methods for estimating reductions in runoff and overflows are summarized in Section 5.

Uncertainty and variation in cost effectiveness was modeled by first pairing all potential combinations of low, base case, and high inputs for costs (see Table 3) with low, base case, and high scenarios for runoff generation (see the tab "LID Modeling Summary" in the Supplemental Information). Assuming that ranges in costs are independent from ranges in runoff (e.g., an installation may cost more but produce relatively low runoff), this pairing produced 9 scenarios: scenarios 1-3 pair high costs with low, base-case, and high runoff assumptions; scenarios 4-6 pair base-case costs with low, base-case, and high runoff assumptions; and scenarios 7-9 pair high costs with low, base-case, and high runoff assumptions. From these 9 scenarios, three uncertainty scenarios are reported: the median, minimum (assumption favor cost effectiveness), and maximum (assumptions favor cost ineffectiveness).

Table 3: Assumed construction, operations, and maintenance costs.

Technology	Installed Cost ($ per sq ft. drainage area)			Operations and maintenance costs			References
	Base Case	Low	High	Base Case	Low	High	
Pervious Pavement	10	9	12	0.07	0.05	0.09	3RWW 2016; City of Lancaster 2011
Green Roof	22	16	29	0.5	0.3	0.8	Roseen et al. 2011; GSA 2011; EPA 2007; 3RWW 2016; City of Lancaster 2011
Rain Garden	6	4	10	0.09	0.07	0.11	3RWW 2016; EPA 2007
Downspout Disconnect	0.20	0.30	0.50	0	0	0	3RWW 2016; EPA 2007
Area Weighted Avg	13.00	10.10	16.90	0.22	0.14	0.33	

7. Flow of information and analysis

Figure 3 summarizes the overall flow of information and data processing. Where feasible within project resource constraints, methods were made extensible to new information should future analysis be needed.

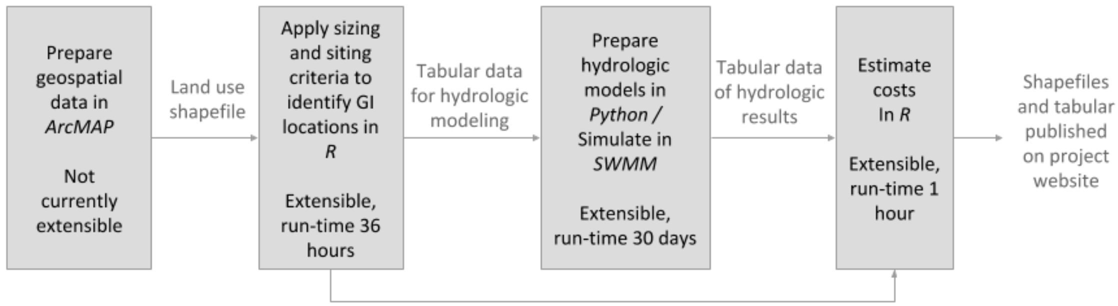


Figure 3: Chart describing the flow of information used to identify potential locations of green infrastructure and estimate their hydrologic and cost performance.

8. Results

Retrofit Feasible Installations

Table 4 summarizes the feasible retrofits. This study identified unique installations of approximately 28,000 rain gardens (18 million square feet), 18,000 downspout disconnects (from 12 million square feet of roof space), 3,600 green roofs (on 73 million square feet of roof space), and 64,000 conversions of impervious surfaces to pervious pavement (96 million square feet). In sum, we estimate these 110,000 installations would cost roughly $3.3B ($2.5 - $4.4B) on a 30-year net present value basis and reduce 960 million gallons (740 - 1,200 million gallons) of inflow into the sewer system for an inflow reduction of 5.5% (4%-7%,) assuming year 2003 precipitation.

As indicated in Table 4b, about 38% of the feasible retrofits by area (28% by count) are located in PWSA's priority sewersheds. Table 4b indicates that the feasible retrofits in the priority sewersheds would cost $810M ($630M - $1.1B) and could reduce overflows by approximately 2.4% (1.7% - 3.4%), assuming a 2003 overflow volume of 9.5 billion gallons (Fischbach et al. 2017).

Table 4 indicates significant variation in the cost effectiveness of green infrastructure, which can be sourced to variation in site conditions. Figure 4 demonstrates two sites where a rain garden is feasible but its cost effectiveness varies as a result of different site conditions. Some parcels, such as that shown in Figure 4b, direct a relatively high degree of runoff towards a potential green infrastructure technology. In these cases, a high degree of runoff can be managed by green infrastructure. Figure 4a shows the other extreme, where existing pervious surfaces can already accommodate a fair degree of upstream runoff, reducing the effectiveness of a rain garden.

Figures 5a and 5b show the estimated marginal cost inflow and overflow reduction curves, respectively, for all feasible retrofits of rain gardens, pervious pavement, green roofs, and downspout disconnects. The marginal cost curves are the derivative of the green total cost curve shown in Figure 2. For each feasible green infrastructure installation, the inflow mitigation supply curve plots the rank-ordered cost effectiveness (y-axis) against the cumulative inflow or overflow reduced. In other words, cost effectiveness decreases moving from left to right.

Table 4: Estimated green infrastructure projects feasible through retrofits, their expected costs, and their estimated effect on inflows and overflows. Ranges reflect uncertainty scenarios described in Section 6.

a. All feasible retrofits in City of Pittsburgh, reported on inflow basis.

Technology	Million sq. ft	Count	Mean size in sq. ft	Inflow reduced in million gallons	Net present value in millions	Cost effectiveness in $ per gallon inflow reduced
Disconnect	12	18,000	660	37 (12-72)	3.5 (2.3-5.8)	0.18 (0.13-0.28)
Perm. Pave.	96	64,000	1,500	770 (660-890)	1,100 (930-1,300)	1.7 (1.3-2.5)
Rain garden	18	28,000	640	110 (62-170)	130 (92-210)	1.7 (0.74-2.9)
Green roof	73	3,600	20,000	40 (9.4-69)	2,100 (1,500-2,900)	70 (60-93)
All	200	110,000	23,000	960 (740-1,200)	3,300 (2,500-4,400)	73 (63-98)

b. All feasible retrofits in priority sewersheds, reported on overflow basis.

Technology	Million sq. ft	Count	Mean size in sq. ft	Overflows reduced in million gallons	Net present value in millions	Cost effectiveness in $ per gallon overflow reduced
Disconnect	3	4,600	640	6.1 (2.1-12)	0.89 (0.59-1.5)	0.28 (0.2-0.45)
Perm. Pave.	7.3	11,000	650	36 (20-52)	54 (37-86)	2.2 (0.97-4.3)
Rain garden	32	25,000	1,300	180 (150-210)	350 (310-420)	2.5 (1.8-3.7)
Green roof	14	1,300	11,000	6.1 (1.6-10)	410 (280-570)	94 (76-130)
All	56	42,000	13,000	230 (170-290)	810 (630-1,100)	99 (79-140)

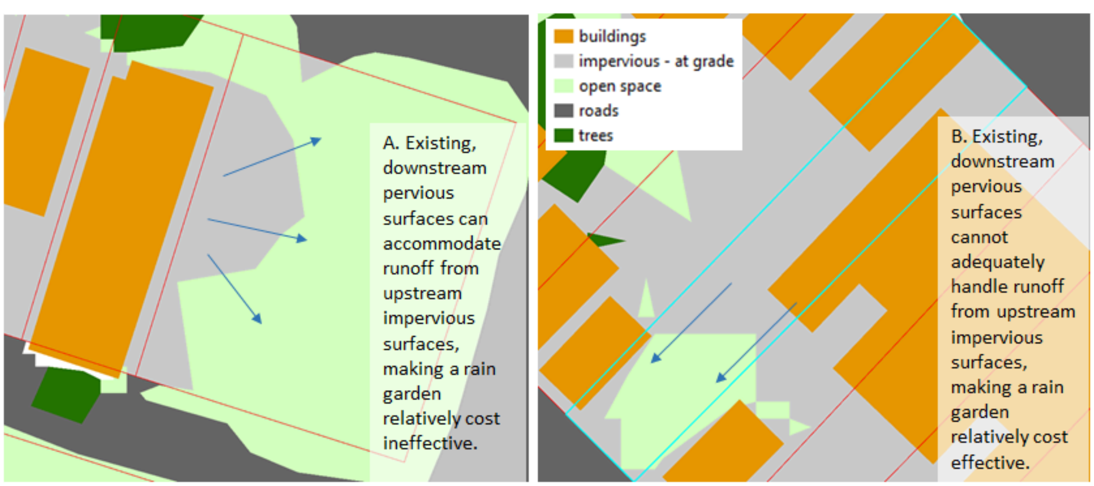
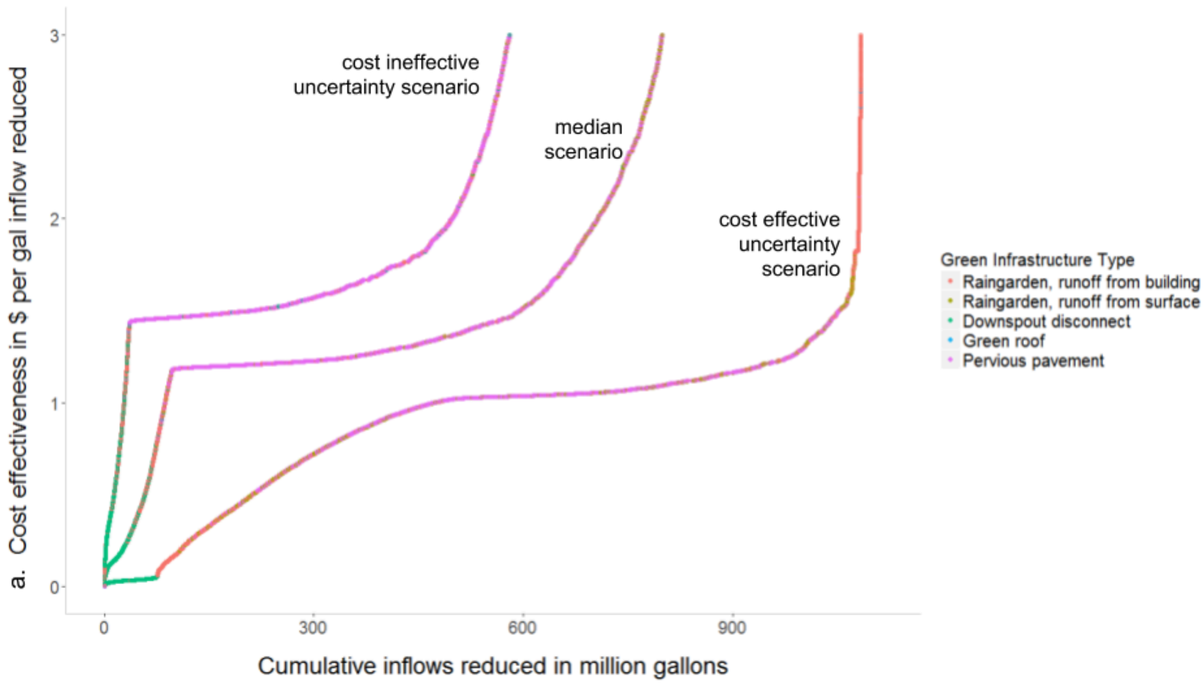


Figure 4. Examples of variation in site conditions that affect the cost effectiveness of a rain garden.



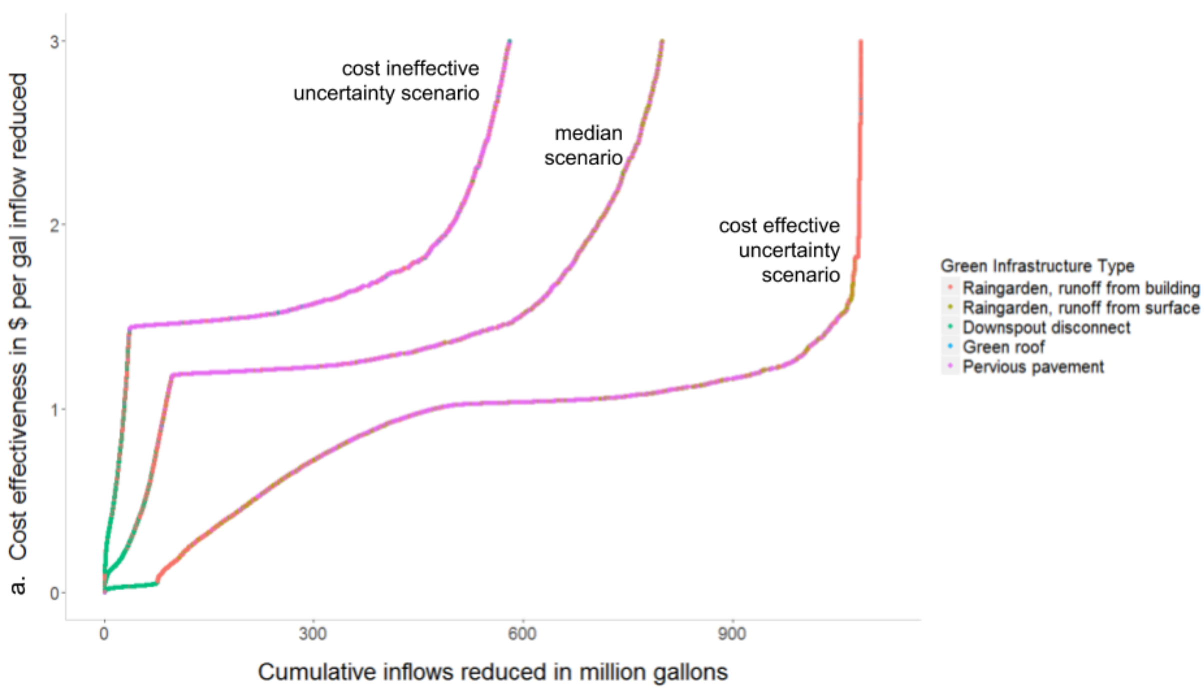


Figure 5 a. inflow and b. overflow reduction curves for feasible installations of green infrastructure identified by this report. Installations with an estimated cost of effectiveness greater than $3 per gallon are not shown for clarity.

<u>Cost Effective Installations</u>

Beyond identifying feasible installations, a primary objective of this study is to identify cost effective green infrastructure. Similar to Fischbach et al. (2017), we assume $0.35 per gallon of overflow reduced as the basis for cost competitive stormwater management in Pittsburgh, which is shown as a horizontal line on Figure 6b. Table 5 presents summary statistics of cost effective installations. Of the feasible retrofits, only 360 rain gardens (range of 12 - 3,000), 2,900 downspout disconnects (range of 410 - 4,600), and up to 70 installations of pervious pavement are considered cost competitive on the basis of $0.35 per gallon of combined sewer overflow reduced. On the basis of $0.35 per gallon of overflow reduced, no green roofs were found to be cost competitive. The cost effective installations reduce overflows by 0.15% (0.01% - 0.8%).

Under the uncertainty scenarios considered, downspout disconnects were most likely to be cost effective. All disconnects were estimated as cost effective under favorable assumptions, and 9% were cost effective under conservative assumptions. Under favorable assumptions, 1% of permeable pavement installations were estimated as cost effective. 1% to 12% of rain gardens were estimated as cost effective assuming conservative and favorable assumptions, respectively.

Table 5: Summary of feasible retrofits more cost effective than $0.35 per gallon of overflow reduced.

Technology	More cost effectiveness scenario		Base case cost effectiveness scenario		Less cost effectiveness scenario	
	Count (% of feasible retrofits)	Overflows reduced in million gallons	Count (% of feasible retrofits)	Overflows reduced in million gallons	Count (% of feasible retrofits)	Overflows reduced in million gallons
Disconnect	4,600 (100%)	17	2,900 (63%)	6.7	410 (9%)	0.73
Permeable pavement	69 (1%)	29	0	0	0	0
Rain garden	3,000 (12%)	29	360 (1%)	6.7	12 (1%)	0.71
Green roof	0	0	0	0	0	0
Totals	7,700 (18%)	75	3,300 (8%)	14	422 (1%)	1.4

9. Implications

These results indicate that there are few cost effective parcel-scale retrofits in Pittsburgh. Should these solutions be part of an overall wet weather plan, their cost performance is highly sensitive to the selected technology and installation location such that absent a robust cost-minimizing strategy, parcel-scale projects are likely to increase the cost of wet weather compliance. A cost minimizing strategy would select green infrastructure projects only when offsetting more expensive gray infrastructure projects.

Hydraulic models of the collection system are needed to identify potential offsets of gray infrastructure from upstream green infrastructure. These models are generally considered protected information by municipalities, which may challenge consensus building. For planning purposes, it may be feasible to decouple hydraulic modeling from identifying cost effective green infrastructure amenities if municipalities could approximate the green infrastructure hydrologic performance "equivalent" to any gray infrastructure projects. If municipalities could publish such "equivalence" alongside recommended gray strategies, it would allow them to preserve protected information while also providing much needed benchmarks to green infrastructure stakeholders.

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10. Published Data and Model Output

In an effort to enhance community awareness, build consensus, and support other related endeavors, project results are published openly on a project website that includes an interactive map of the estimated feasible installations, tabular data of project results, and links to this report and model assumptions. Metadata for the data published at CartoDB are included in the Supplemental Information.

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