Modeling the hydrologic and economic efficacy of stormwater utility credit programs for US single family residences
Ruben Kertesz, Olivia Odom Green and William D. Shuster

ABSTRACT
As regulatory pressure to reduce the environmental impact of urban stormwater intensifies, US municipalities increasingly seek a dedicated source of funding for stormwater programs, such as a stormwater utility. In rare instances, single family residences are eligible for utility discounts for installing green infrastructure. This study examined the hydrologic and economic efficacy of four such programs at the parcel scale: Cleveland (OH), Portland (OR), Fort Myers (FL), and Lynchburg (VA). Simulations were performed to model the reduction in stormwater runoff by implementing bioretention on a typical residential property according to extant administrative rules. The EPA National Stormwater Calculator was used to perform pre- vs post-retrofit comparisons and to demonstrate its ease of use for possible use by other cities in utility planning. Although surface slope, soil type and infiltration rate, impervious area, and bioretention parameters were different across cities, our results suggest that modeled runoff volume was most sensitive to percent of total impervious area that drained to the bioretention cell, with soil type the next most important factor. Findings also indicate a persistent gap between the percentage of annual runoff reduced and the percentage of fee reduced.

Key words | citizen stormwater management, economic incentive, EPA National Stormwater Calculator, green infrastructure, stormwater utility

INTRODUCTION
Federal regulatory pressure to reduce the environmental impact of urban stormwater increasingly spurs municipalities to establish dedicated funding mechanisms for stormwater management programs, such as a public stormwater utility (i.e., fee) (Van der Tak et al. 2012). Utilities are fee-based and were first established in the 1970s to fund flood control programs in the Pacific Northwest. Many more stormwater utilities were established in the 1990s as larger municipal separated storm sewage systems (MS4) were made subject to regulation under Phase I National Pollutant Discharge Elimination System (NPDES) stormwater permits. Recent growth in utility implementation was spurred by Phase II NPDES stormwater permits, which mandate that smaller- and moderate-sized MS4s reduce stormwater pollution to the maximum extent practicable. Complying with NPDES permits and upgrading and retrofitting aging capital infrastructure for flood control carry heavy price tags, and stormwater utilities are the most popular method of funding such activities.

Stormwater utilities appeal to some ratepayers and administrators because, as non-ad valorem fees (i.e., fees not based on property value), they are perceived as more fair and equitable than funding stormwater systems from tax revenue. Generally, the fee is based on a property’s contribution to the problem – amount of impervious surface, a proxy for the volume of runoff discharged from property – which can be objectively determined. Also, the fee applies to all properties, including tax-exempt properties such as nonprofits and faith-based organizations. Recent amendments to the Federal Clean Water Act also make federal properties subject to stormwater utilities, fees, and taxes (33 U.S.C. § 1323, Senate Bill 3481, January 2011), which is particularly important in areas with high concentrations of federal property (e.g., Washington, DC 20%, Portsmouth, VA 16%) (Van der Tak et al. 2012).
Although stormwater fees are equitable, they are not without controversy, and several state supreme courts have ruled on their constitutionality with varying results (e.g., Bolt v. Lansing, where the Michigan Supreme Court overturned the fee; Homewood Village v. Athens-Clarke County, where the Georgia Supreme Court upheld the fee). One measure to curb public opposition to the new fee is to offer discounts or credits for onsite stormwater management (Doll et al. 1998). Such an approach complements and incents the growing trend in stormwater management toward widely-dispersed decentralized installation of stormwater control measures (SCM) to reduce excess stormwater flow in the combined sewer or MS4 infrastructure (i.e., green infrastructure). Green infrastructure integrates an overall land management concept with principles of low-impact development, and at the residential level can take the form of rain gardens, bioretention, rain barrels, and pervious pavement, among other practices to sever the hydraulic connection between impervious surfaces and inlets to grey infrastructure. This method works best at the source of the problem, commonly private properties to which stormwater managers have no access or authority. To incent source control on private property, municipalities are beginning to offer stormwater utility discounts to residential ratepayers that install and maintain certain SCMs onsite.

Although utilities operate in many cities in the United States, the hydrologic effectiveness of stormwater credit programs remains unknown. This is especially the case where credits are applied at the parcel scale. This work intends to add to the growing body of work on incentives to engage private citizens in managing their own impervious footprints. Our focus on single family residences (SFRs) is in line with the movement toward decentralized ‘citizen stormwater management’ (Green et al. 2012). There are no previous publications documenting programs available for SFRs; however, there are a number of benefits for municipalities that focus on SFRs. Programs that provide credits for participating homeowners foster a culture of citizen stormwater management where homeowners can become ambassadors of green infrastructure awareness, influence their neighbors, and encourage adoption through the exchange of social capital (Parikh et al. 2005; Thurston et al. 2010; Green et al. 2012).

Because residential stormwater fees are generally low (US$50–100 per year), financial incentives, such as utility credits, may be insufficient price signals to motivate mass decentralization of stormwater management on private property (Doll et al. 1998). However, social contagion (Hunter & Brown 2012), coupled with economic incentives (Green et al. 2012), may prove sufficient to motivate the installation of attractive and highly visible SCMs. Providing credit opportunities may also curb opposition to new fees and may make the fees less vulnerable to attack on constitutional grounds in some states (see Homewood Village v. Athens-Clarke County). There is also no other mechanism to encourage adoption on private SFRs, whereas commercial, multi-family, and industrial properties often receive stormwater credits for onsite control, often simply for following current legal requirements to control stormwater.

There are few credit programs available for SFRs in the United States. Four programs that offer credit to residences are located in Portland, OR; Cleveland, OH; Fort Myers, FL; and Lynchburg, VA. Each program is unique and differs on the basis of credit structures, outreach materials, design parameters, and rules for monitoring and maintenance.

One of the most common SCMs available to SFRs is a rain garden or bioretention cell. They offer aesthetic appeal and ecosystem services beyond stormwater quantity abatement (e.g., pollinator habitat). Bioretention design and performance can vary widely due to differences in rainfall pattern, soil, and topography among the different climate zones in the United States, and within a given municipal sewershed (i.e., area draining to a specific sewer). A physical model that takes such physical properties into account can serve to evaluate the effectiveness of rain gardens on SFR properties. Numerous models simulate hydrologic control by infiltration, such as SWAT, HSPF, EPA-SWMM, BASINS, and others. However, these prove tedious to prepare and operate, requiring extensive knowledge of model operation, and are not readily accessible to the average SFR owner.

A recently released application, the EPA National Stormwater Calculator is based upon EPA-SWMM hydrologic algorithms. It allows users of various skill levels to perform pre- vs post-SCM performance comparisons and obtain meaningful results. While the Stormwater Calculator software may even allow homeowners to perform their own assessments of stormwater control for various SCM practices (US Environmental Protection Agency 2013), the focus of this investigation is on comparing and contrasting existing credit programs. We are seeking to answer the question, ‘How do projected reductions in stormwater discharges from a standard home lot compare between cities offering green infrastructure credit programs, and what relation is there to runoff reduction and the value of the credit being offered?’
METHODS

We employed a multifactor analysis to simulate the capture of roof runoff in rain gardens. An economic evaluation was then performed to compare the projected annual reduction in stormwater runoff to the eligible percent discount of each simulation. Social factors, such as the accessibility of bioretention (as rain garden) or credit program resources, were also considered.

Rain garden design was based upon the available guidebook and/or administrative rules for each municipality’s credit program. When parameters were not specified by the programs, reasonable characteristics for the program area were applied. The simulations explored high and low intensities of impervious area, varied capture ratios, soil types, ponding depths, and property slopes. The capture ratio is defined as the size of the control relative to impervious area it treats. Ponding depth is defined as the surface storage available. Soil type is represented by Natural Resources Conservation Services (NRCS) hydrologic soil group.

Table 1 shows the parameters for the selected programs. Note that Lynchburg (VA) includes a prescribed media depth in addition to ponding; this is defined as ‘soil media thickness’ in the Calculator. The Stormwater Calculator is designed for US customary units. Parameters will be presented in US customary units with parenthetical values in SI.

In order to compare programs, some property characteristics were held equal between all simulations (Table 2). This does not account for architectural differences and average lot sizes between cities. The rainfall/evaporation data station was chosen for each municipality (from those available within the EPA National Stormwater Calculator) based upon the longest period of record within the municipality.

The Northeast Ohio Regional Sewer District (NEORSD) (i.e., the greater Cleveland, OH region) offers a flat fee reduction of 25% through the Individual Residential Property Credit (Northeast Ohio Regional Sewer District 2012a). All SFRs are eligible as long as they treat the minimum 25% of their roof. The average fee is $5.05 per month for SFRs with an impervious footprint of 2,000–4,000 ft² (186–372 m²). Although the program is relatively young, the outreach materials are thorough and include interactive fee maps and educational programming. Note that, as of September 2013, NEORSD suspended their stormwater utility due to pending litigation. This analysis was conducted using the programmatic parameters in place prior to program suspension. While no longer available to the public, all program materials are on file with the authors.

Cleveland, OH, uses a comprehensive design manual – Raingarden Manual for Homeowners – where rain garden depth is a function of slope, and rain garden area is a function of soil type, distance from the house, and the previously calculated depth (Northeast Ohio Public Involvement Public Education Committee 2007). Because SFRs must treat 25% of roof area to receive credit, we designed a simulation at 25, 50, and 100% of roof area treated; 50% was included because it was thought that treating half of the roof was more practical than 100%, particularly for roofs split between front and back yards, etc. Slopes were selected based upon the categories available in the rain garden credit manual. The model requires soil type specified as A through D. The ‘sandy,’ ‘silty,’ and ‘clayey’ denominations in the manual were equated to A, C, and D soils, respectively. Infiltration

Table 1 | Parameters applied to rain garden simulations in four cities

<table>
<thead>
<tr>
<th>Utility</th>
<th>Slope (%)</th>
<th>Ponding depth* (inches) [mm]</th>
<th>Soil typea</th>
<th>Conductivity* (inches hr⁻¹) [mm hr⁻¹]</th>
<th>% Roof treated</th>
<th>Capture ratio (%)</th>
<th>Impervious area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland</td>
<td>5, 10</td>
<td>6 [152], 12 [305]</td>
<td>A, C</td>
<td>2.00 [50.80], 0.25 [6.35]</td>
<td>60, 66.6, 100</td>
<td>9</td>
<td>33, 66</td>
</tr>
<tr>
<td>Cleveland (NEORSD)</td>
<td>2, 6, 10</td>
<td>f(slope)c</td>
<td>Sand-A, Silt-C, Silt-D</td>
<td>1.40 [35.56], 0.57 [14.48], 0.06 [1.52]</td>
<td>25, 50, 100</td>
<td>8–43</td>
<td>33, 66</td>
</tr>
<tr>
<td>Fort Myers</td>
<td>2, 5</td>
<td>6 [152], 12 [305]</td>
<td>A, B</td>
<td>5.00 [127.00], 1.50 [38.10]</td>
<td>10, 50, 100</td>
<td>20</td>
<td>33, 66</td>
</tr>
<tr>
<td>Lynchburg</td>
<td>2, 5</td>
<td>6 [152]</td>
<td>A, B</td>
<td>1.50 [38.10], 1.00 [25.40]</td>
<td>50, 100 +</td>
<td>5, 33</td>
<td>33, 66</td>
</tr>
</tbody>
</table>

*Rain garden media depth is prescribed, 18–36 inches (457–914 mm).

*Conductivity related to soil type by USDA NRCS National Engineering Handbook: Part 630 Hydrology (USDA NRCS 2009). Note that in Portland, OR, 2 inches hr⁻¹ minimum uptake in bioretention is required for full credit; Lynchburg, VA, 1 inch hr⁻¹ minimum without requiring underdrain. Fort Myers, FL, shows higher required infiltration rate due to proximity of water table to the ground surface.

Value is a function of the slope.
The capture ratio required in the manual is 30.5 mm. Simulations were not performed for soils (<20 inches hr⁻¹ or <51 mm hr⁻¹) because underdrains are required for such soils by the City of Portland, OR, and the Calculator does not include such functionality. As such, the 0.25 inches hr⁻¹ (6.4 mm hr⁻¹) simulation maintained the infiltration rate in the rain garden as 2 inches hr⁻¹, while the rest of the pervious area was 0.25 inches hr⁻¹, simulating a soil amendment. Soil types A and C were used for the 2 and 0.25 inches hr⁻¹ infiltration rates, respectively.

The City of Portland, OR, issues credits through the Clean River Rewards program, which offers utility discounts for SFRs on a sliding scale. Portland’s program is unique in that it separates stormwater fees by onsite (35%) and offsite (65%) portions, and discounts are only available for the onsite portion of the fee. The justification behind limiting the credit to the on-site portion of the fee is that even if a property owner manages 100% of stormwater onsite, that property owner still benefits from stormwater management practices in the greater community (e.g., infrastructure upgrades that prevent flooding, basement backups). Further, if all property owners managed 100% of stormwater onsite, the municipality would still need program funds for stormwater management on public property, such as roads. The average SFR stormwater fee is $22.37 per month, which includes both onsite and offsite portions. To receive a 100% discount of the onsite fee, all roof drainage must be retained onsite. A partial credit of 67% is available to SFRs that detain or partially retain roof discharge.

The parameters for Portland, OR, simulations were determined by following the How to Manage Stormwater: Rain Gardens manual, which thoroughly defines rain garden parameters (City of Portland Environmental Services 2009). The capture ratio required in the manual is >9%. A property must have less than a 10% slope to qualify for credit. In fact, certain neighborhoods are ineligible due to high slope. The minimum required rain garden depth is 6–12 inches (152–305 mm). Simulations were not performed for low infiltration soils (<2 inches hr⁻¹ or <51 mm hr⁻¹) because underdrains are required for such soils by the City of Portland, OR, and the Calculator does not include such functionality. As such, the 0.25 inches hr⁻¹ (6.4 mm hr⁻¹) simulation maintained the infiltration rate in the rain garden as 2 inches hr⁻¹, while the rest of the pervious area was 0.25 inches hr⁻¹, simulating a soil amendment. Soil types A and C were used for the 2 and 0.25 inches hr⁻¹ infiltration rates, respectively.

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Table 1 lists the roof area treated as ‘100 + %’ to denote treatment of 90% of TIA (which is greater than the total roof area). The stormwater credit manual suggests a capture ratio of 33% but Table 9.2 of Lynchburg’s design guidelines requires a minimum ratio of 5% of a roof area draining to a rain garden. Simulations were run with both capture ratios. The minimum allowable infiltration without installing an underdrain is 1 inch hr⁻¹. The selected rates (1.5 and 1 inch hr⁻¹, corresponding to A and B soils) were determined using the NRCS criteria for assessment of hydrologic soil groups when any water-impermeable layer exists at a depth between 20 and 40 inches (508 and 1,016 mm).

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RESULTS AND DISCUSSION

Hydrologic analysis by site

Figure 1 illustrates the outcomes of the various simulations for each municipality. General observations for Cleveland are that there is no discernible difference between slopes of 2% and 6%, within a treatment (25, 50, 100% contributing roof area). Nor is there a large difference between A and C soils. This suggests that the NEORSD guideline correction factor effectively controls for differences in slope and soil group. However, when simulating treatment of 100% of the rooftop, D soils are not as well mitigated as for the 25% and 50% simulations. There is an apparent doubling of reduction between treating 25% of the roof (results in approximately 15% reduction in runoff) and treating 50% of the roof (results in approximately 30% reduction in runoff).

Results from Portland, OR, exhibit a sharp difference in performance between A and C soils for all simulations. There is no great effect of slope on results while depth has a greater effect on C soil simulations than on A soil simulations, suggesting that type A soils are largely unaffected by property slope. In Portland, OR, treating 50% of the roof area results in 25–33% reduction in runoff, depending on the on-site conditions, similar to Cleveland, OH. However, the SFRs are required to treat at least two-thirds of their property, resulting in approximately 33 to 45% reduction in runoff.

Results from Fort Myers, FL, show that treating only 10% of a rooftop results in 6–7% reduction in runoff, but sending at least 50% of rooftop runoff into the rain garden results in approximately 30% reduction in runoff. There is a minor difference between depths, slopes, and soils for simulations of ≤50% contributing rooftop area. The infiltration rate is a slightly conservative estimate due to the

Figure 1   | Annual reduction in runoff due to installation of rain garden from four different programs under varied conditions. (a) Cleveland, OH; (b) Portland, OR; (c) Fort Myers, FL; (d) Lynchburg, VA. The term “% Contributing” represents the percent of the rooftop that is contributing to the rain garden. Note that “depth” is a measure of ponding depth except for Lynchburg, VA, where ponding depth is constant. For Lynchburg, “depth” is a measure of the media depth (which varies). “Capture ratio” is the size of the control relative to treated impervious area.
potential for the water table to remain close to ground surface. The differences in runoff reduction are more pronounced for the 100% simulation, particularly between simulations of different ponding depth.

Lynchburg, VA, results are very different from the other locations; at a capture ratio of 33%, rain garden depth, property slope, and soil type have no impact on results. Treating 50% of the roof area runoff results in 27–29% reduction in runoff, subject to the TIA of the property. If the rain garden is sized as only 5% of the roof area (capture ratio), then the soil type does have an impact on results but, interestingly, there is almost no difference between the 33% and 66% TIA simulation results.

Figure 1 shows that there is a nominal difference in runoff reduction between 33% and 66% TIA, particularly for the smallest contributing areas and lowest capture ratio simulations. The greatest difference is observed at high percentage contributing areas. As the percentage of TIA is increased on a property, runoff is not increased linearly. This is likely because the impervious area is only increased by 326 ft² (out of 1,720 ft²) when % TIA is doubled. The major cause for the change in % TIA is the 2,390 ft² reduction in lawn area (70% reduction). Likely, the lawn is producing little runoff in either simulation scenario. In general, differences in rain garden depth do not present a difference in performance for any site except for where 100% of roof area contributes runoff volume. Changing slopes have some effect in Cleveland, OH, and Fort Myers, FL, but the effect is minor compared to the effect of contributing area treated, which is illustrated as a distinct step function for the Cleveland, OH, Fort Myers, FL, and Lynchburg, VA, simulations. All of the municipalities show similar reduction of runoff when capturing runoff from 50% of the roof area.

Comparisons between sites

Direct comparisons between sites are shown in Figure 2. Overall, while there is little difference between A and B soils in both Fort Myers, FL, and Lynchburg, VA, and A and C soils in Cleveland, OH, there is a strong difference between A and C soils in Portland, OR, where fees are highest. Fort Myers, FL, shows little difference between soil groups because of the high sand content in native soils. As for Cleveland, OH, the similar results between A and C soils may be due to the NEORSD guidance design accommodations for lower infiltration soils. On SFRs with 66% impervious area and where 50% of the roof area is drained to the rain garden (Figure 2(b)), performance is similar between both soil type and municipality. Even a very low capture ratio (5%), treating 50% of the roof area results in >25% reduction in site runoff in the Lynchburg simulation (Figures 2(b) and 2(c)).

Similarly, simulation results of A soils in Portland, OR, show >30% reductions in site runoff at a capture ratio of only 9%. High-infiltration soils and well-constructed rain gardens may not necessitate a large capture ratio. This is important in the context of both the price signal and the potential for successful adoption of management options that are directed at ratepayers in the cities where rates are highest. The price signal affects ratepayers’ perceptions of cost and benefit and needs to be set so as to attract demand for these stormwater management services. Doing so benefits ratepayers, the stormwater/wastewater authority, and the natural environment.

Social and economic results and discussion

Accessibility of the programs, as defined by an average SFR homeowner’s ability to participate given just the materials provided by the program, vary widely. Portland, OR, has one of the oldest stormwater management programs in the country, and the thorough materials available to SFRs make the program highly accessible (i.e., an average homeowner would be capable of installing a rain garden on their own using the outreach materials provided by the program). Portland’s outreach materials include a thorough, user-friendly manual, community workshops, and several complimentary incentive programs. Although relatively young, Cleveland’s program is also highly accessible with a thorough manual, interactive maps, and community workshops.

Lynchburg’s (VA) program offers a relatively straightforward and user-friendly manual but no training workshops for residents. Further, the contradictory guidance on capture ratios (5% and 33%, depending on information source) limits the accessibility of the program to average homeowners. Although credits are available to Fort Myers, FL, SFRs, it appears that the focus is predominantly on commercial properties. Fort Myers requires the approval of a licensed engineer for a rain garden to comply with the credit program, thus significantly increasing the cost of installation and approval. Further, Fort Myers offers zero outreach materials or manuals for rain garden design or construction.

Economic findings indicate a persistent gap between the percentage of annual runoff reduced and the percentage of fee reduced (Figure 2), with most cases resulting in either...
a windfall to the residents (i.e., percentage discount > percentage runoff reduction) or to the stormwater agency (i.e., percentage of lost revenue < percentage runoff reduction).

As illustrated in Figure 2, Cleveland’s (OH) flat discount of 25% results in a windfall to NEORSD when an SFR treats 50% or 100% of roof area (Figures 2(a) and (b)) but a windfall to the SFR when only 25% of roof area is treated (the bare minimum to be eligible for the discount) (Figure 2(c)). Lynchburg, VA, results in a windfall to the agency when the SFR does the bare minimum required to receive credit.
(Figures 2(b) and 2(c), treating 50% of roof area, results in 20% discount) and when the SFR does the maximum treatment of 100% TIA, resulting in a credit of 40% (Figure 2(a)).

Portland’s (OR) onsite/offsite fee structure initially hides the windfall to the agency, in that it would first appear that the 100% discount greatly benefits the homeowner. However, when the discount is adjusted to reflect that only the onsite portion of the fee (35%) is eligible for the discount, a windfall results to the agency in both circumstances where the SFR does the bare minimum (Figure 2(c), treating two-thirds of roof area) or maximum (Figure 2(a), treating 100% roof area). When an SFR treats less than two-thirds of roof area in Portland, OR, they are not eligible for any credit (Figure 2(b)). In most circumstances, Fort Myers’ (FL) flat 10% discount benefits the agency considering that a homeowner is unlikely to undergo the effort of installing a rain garden at a minimum treatment roof area of 10% (Figure 2(c)).

However, windfalls must be put in context, especially considering the cost of annual residential fees, the cost of installing bioinfiltration features, and the inaccessibility of SFR property to stormwater managers. Where a windfall may exist to the residential ratepayer, it is likely an insufficient price signal to motivate mass decentralization of stormwater management on private property. Even the largest average credit (Portland, OR) at $7.81 per month (average fee $22.37 with 100% discount of onsite portion) would be unlikely to cover the cost of installing a garden, thus leading to an economically inefficient result and thus not a windfall to the homeowner.

Likewise, the relatively negligible loss in stormwater fee revenue to the agency may be the least expensive (and perhaps only) method of source control on SFR property. Although some programs may overcompensate residential ratepayers for SCMs with regard to the volume of stormwater abated by residential SCMs, this may still be a cost-effective approach for municipal stormwater management when compared to the cost of capital infrastructure, whether green or grey. For example, NEORSD estimates of the cost per gallon of combined sewer overflow (CSO) reduction using green approaches are $2.10–2.83 per gallon ($0.55–0.75 per litre) (Northeast Ohio Regional Sewer District 2012b) and $1.51 per gallon ($0.40 per litre) using green and grey approaches (Northeast Ohio Regional Sewer District 2012c). In contrast, our simulated Cleveland, OH, SFR reduced annual runoff by a range of 6,819–8,072 gallons year$^{-1}$ (25,813–30,555 litres per year) at a cost (in terms of lost revenue to NEORSD) of $15.12 per year (average SFR utility fee of $5.05 per month minus credit of 25%), which roughly equates to $0.002 per gallon ($0.0005 per litre) per year. (These estimates are total cost of infrastructure, not annual. These results may be atypical due to the temporal structure of NEORSD’s consent decree which requires SCM benefits to be calculated post-implementation of grey infrastructure upgrades, resulting in benefit ratios of 1:8, where other municipalities use ratios closer to 1:2–3 as the ratio of volume detained by SCM to volume removed from CSO.)

The results presented herein suggest that NEORSD is overcompensating residential ratepayers (i.e., % lost revenue > runoff reduced). However, the calculations above suggest that it is less expensive for NEORSD to provide credits than to invest in large-scale capital infrastructure for commensurate stormwater management benefits. Additional benefits to the stormwater/wastewater authority may accrue through the generation of goodwill (e.g., curbing opposition/litigation to new fees) and the exchange of social capital from the spread of the Citizen Stormwater Management model (Green et al. 2012).

While the hydrologic impact of one SFR on a large municipal system is negligible, SCM installations on SFRs in the aggregate could have significant benefits to the overall system. For example, Shuster & Rhea (2013) found that 85 rain gardens and 174 rain barrels dispersed over a suburban neighborhood in Cincinnati, OH, resulted in a small but statistically significant decrease in the amount of stormwater volume routed to the separate storm sewer system. This suggests that credit programs have the capacity to function as an effective stormwater management tool, incenting SFRs to install SCMs on individual properties. Single property installation has been shown to increase the likelihood of neighboring SFRs to install an SCM via accrued social capital such as neighbor-to-neighbor interactions (Green et al. 2012).

Although there is a persistent gap between the % discount and % annual runoff reduced, it is important to note that utility program developers may have no intention of equating those figures. We do not interpret this incongruence as a failure, as we recognize the difficulty of administering a program that matches credits to actual runoff reduction, figures that are highly site-specific. Again, it is important to view this as an approach that builds ratepayer participation in stormwater management, much like gas/electric utilities that actively promote energy conservation. However, should a municipality wish to have those figures closer in alignment, the methods outlined in this paper and the EPA National Stormwater Calculator may prove useful tools to optimize credit structures.

Likewise, for municipalities considering establishing a credit program but limited in the resources available to develop
thorough eligibility requirements, such in as Portland, OR, or Cleveland, OH, the EPA National Stormwater Calculator may be a valuable tool for pre- and post-installation evaluation. For example, an SFR owner could simply run their proposed SCM through the Calculator and submit the results to the agency, who may offer conditional approval to receive some proportion of credit based on the projected reduction in annual runoff, subject to post-construction site inspection. This approach would reduce the upfront cost of establishing thorough administrative guidelines and could foster creative solutions as property owners experiment simulating various SCM configurations in the Calculator. Notably, the software does not prevent zealous homeowners from placing too many SCMs too close to each other or to their house. Caution should be taken when integrating such a tool as the Calculator.

**CONCLUSION**

Credit programs have the potential to be an effective tool to incent stormwater management by homeowners. This study examined the hydrologic and economic efficacy of four such programs at the parcel scale in Cleveland (OH), Portland (OR), Fort Myers (FL), and Lynchburg (VA). The EPA National Stormwater Calculator was used to perform pre- vs. post-retrofit hydrologic simulations. Although surface slope, soil type and infiltration rate, impervious area, and bioretention parameters (e.g., ponding depth) were different across cities, our results suggest that modeled runoff volume was most sensitive to percent of TIA that drained to the bioretention cell, with soil type the next most important factor. Findings also indicate a persistent gap between the percentage of annual runoff reduced and the percentage of fee reduced, although programs were not necessarily designed to equate the two. Minimum treatment requirements in Lynchburg (VA) and Portland (OR) are shown to provide a higher reduction in runoff than constituted in the discount.

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