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Using a reverse auction to promote household level stormwater control

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ABSTRACT

Phase II of the US Environmental Protection Agency's (USEPA) National Pollution Discharge Elimination System (NPDES) stormwater regulations requires communities smaller than 100 000 residents to meet new criteria for stormwater runoff reduction. In many cases these smaller communities have no established stormwater utility, and are investigating alternatives for complying with these new, sometimes expensive requirements. We note that it might be cost effective for some communities to encourage homeowners to control stormwater runoff at the parcel level instead of, or in conjunction with more traditional large, infrastructural best management practices (BMP). We go onto argue that in the absence of a strict regulatory cap, an auction is a cost-effective tool for implementing controls on stormwater runoff quantity at the parcel level. In this paper, we test the effectiveness of a procurement auction as the coordinating mechanism for encouraging installation of parcel-scale rain gardens and rain barrels within a small suburban watershed in the Midwest. The auction, which was conducted in spring 2007 and 2008, resulted in installation of 81 gardens and 165 barrels on 107 of the 350 eligible properties. Average cost per liter of runoff detention in both years was $0.36 for gardens and $0.59 for barrels. Interestingly, approximately 55% of the bids were for $0, suggesting that an educational campaign may result in substantial runoff mitigation if utilities paid for the installation of stormwater management practices. However, we found that an auction promoted more participation than education alone and at a cheaper per-unit control cost than a flat stormwater control payment plan. Overall, this study demonstrates that relatively minimal financial incentives can result in homeowners' willingness-to-accept stormwater management practices on their property, thus opening an important avenue for retrofitting watersheds that are largely in private ownership.

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1. Introduction

Historically, stormwater runoff has been treated as a water quantity problem, and was most often dealt with through large-scale flood prevention and treatment projects (i.e., combined or separate stormwater sewer systems) (USEPA, 2007). More recently, attention has focused on the impacts of stormwater runoff on the environment and public health. Since the enactment of the Clean Water Act (CWA) in 1972, the National Pollutant Discharge Elimination System (NPDES) program has required all point source dischargers of water pollutants to maintain, protect, and restore the water quality of streams, lakes, and rivers. However, stormwater runoff was exempt from the NPDES, because it was considered to be nonpoint source in nature, entering waters in a diffuse manner across the surface of various structures and land. This perspective changed in 1999, when Phase II of the NPDES stormwater program was signed into law. This regulation builds upon the existing Phase I program, developed in 1990, by requiring communities with less than 100 000 residents, also known as small municipal separate storm sewer systems (MS4s), to hold NPDES permits. While stormwater runoff typically enters the municipal stormwater system from nonpoint sources, it exits the system and enters streams and rivers through easily discernable outfalls.

Under Phase II, operators of regulated small municipal separate storm sewer systems (MS4s) must obtain an NPDES permit, which requires them to develop a storm management program that addresses: (i) public education and outreach; (ii) public participation and involvement; (iii) illicit discharge detection and elimination; (iv) control of construction site runoff; (v) control of post-construction runoff; and, (vi) promotion of pollution prevention and good housekeeping (USEPA, 2005). Many of these smaller communities presently have no established stormwater utility, and are investigating alternatives for complying with these new, sometimes expensive requirements. The NPDES program does not give specific quantity limits to communities; rather municipalities have options and flexibility in how they develop their own stormwater management plan. This provides an opportunity for municipalities to develop a cost-effective stormwater management plan; one which meets all the requirements of the permitting process at the lowest overall cost. However, a lack of familiarity and understanding regarding the availability and benefits of the myriad stormwater best management practices, as well as a lack of experience in creating policies to achieve their adoption, can result in municipalities relying on more conventional and possibly more costly approaches.

Ideally, a cost-effective stormwater runoff management system would incorporate an economic incentive mechanism that encourages the discovery and adoption of the lowest cost management practices. This paper describes such an approach, and details the results of a pilot program that was run in Cincinnati, OH. First, we briefly discuss issues involved in managing stormwater runoff in an urban watershed including differences between large-scale infrastructural solutions to stormwater runoff pollution problems and small scale dispersed stormwater management practices (Section 2). We then describe the Shepherd Creek pilot study area, our choices of stormwater management practices (rain gardens and rain barrels), the basis for the use of a reverse auction, and the incorporation of an environmental weighting index in the auction process (Section 3). In the auction we sent mailings to homeowners in the subwatershed and asked them to name their price to participate in the program. We then placed the rain gardens and rainbarrels throughout the neighborhood, taking into consideration bid amounts and environmental factors. Based on auction results, we compare the cost of stormwater detention under three incentive scenarios: auction, flat payment, and an educational campaign. We conclude with a discussion of the potential application of market-based incentives as a tool for restoring environmental quality to suburban watersheds through the reduction of stormwater runoff quantity.

2. Stormwater management

The effects of stormwater runoff on stream ecosystems are exacerbated by urbanization and the coincident increase in impervious surface in a watershed. This is problematic when the magnitude of impervious surface that is created through continued development and urban sprawl is taken into account. For example, a residence with a footprint of 186 m^2 will create 4743 L of additional runoff (based on 2.5 cm rainfall), and this figure does not include the additional runoff contributed by the roads, sidewalks, driveways, etc. that are typically associated with suburban development. This proliferation of impervious surface increases the quantity and velocity stream water flows. During storm events peak flows are higher and faster, causing stream bank erosion and also washing away aquatic wildlife habitat (Konrad and Booth, 2005). Due to a concomitant elimination of infiltrative surface and reduced water table or groundwater recharge, during extended dry periods the base flow of streams can be lower or restricted to shorter periods, leading to another avenue for the degradation of stream habitat (Konrad and Booth, 2005). Finally, as stormwater runoff travels to the local waterbody, it dissolves, collects and transports pollutants that are built up upon impervious surface that it passes over. Therefore, runoff is often constituted with a wide variety of chemicals, eroded soil material, minerals, and heavy metals, some of which present health hazards at low concentrations (e.g., pesticides, petroleum products). Sediment, nutrients, bacteria, and excess organic material (e.g., grass clippings and leaves) can additionally harm creeks, rivers and lakes when they reach sufficient levels (Paul and Meyer, 2001; Walsh et al., 2005).

Communities have struggled with developing effective and affordable methods for dealing with stormwater runoff. As development increases, stormwater sewer systems can easily be stressed beyond capacity. In older communities with combined sanitary and stormwater sewer systems, overflows can result in high property damages and public concern over health impacts (USEPA, 2005). A centralized approach to deal with the increased stormwater runoff focuses on augmenting the capacity of the stormwater sewer system. Retrofitting stormwater pipes and construction of underground holding tanks can reduce the problems associated with larger-scale flooding, as well as increased stream flow velocity and higher peak flows (Heaney et al., 2002). However, these centralized approaches are often expensive. In addition, by not treating the system as an interconnected water resource, these centralized approaches cannot, for example, deal with the problem of reduced base flows associated with the loss of natural recharge systems.

A decentralized approach focuses on the distributed implementation of stormwater management practices (SWMPs) across the landscape to detain and/or retain runoff at its point of creation. This approach employs source control to eliminate or reduce runoff before it reaches the centralized stormwater sewer system or any body of water. It directly counteracts the effect of increased impervious surface across the landscape. Examples of SWMPs include detention ponds, grassy swales, rain gardens, and rain barrels. Decentralized systems hold the potential for managing all of the negative impacts of stormwater runoff at a lower overall cost when compared to retrofitting centralized systems (Thurston et al., 2003). Many communities have had success in requiring SWMPs on new development projects, however, due to property rights issues, dealing with existing properties has proven more difficult in a regulatory setting (Parikh et al., 2005). A practical program that can address problems associated with existing levels of stormwater runoff will use economic incentives to encourage the voluntary adoption of SWMPs on most parcels of land.

To achieve the goal of cost-effectiveness in managing stormwater runoff, the policy instrument must encourage residential homeowners to participate in the program at their minimum required level of compensation to install the SWMP. The quantity of runoff detained or retained by a SWMP on any particular parcel will be determined by many site-specific factors, such as slope, soil type, distance to the stream. Therefore, the policy instrument must also have a mechanism for estimating the effectiveness of the SWMP on each parcel of land, in order to maximize those that provide the best detention or retention per dollar spent. For these reasons we chose to conduct a reverse auction, with bids being weighted by environmental factors, to see if incentive to participate by adopting SWMPs would be sufficiently high to improve ecological indicators.

A reverse, or as it is called in the economics literature, a procurement auction is one allocation mechanism a regulating entity has at its disposal to reward and coordinate participants in a program. Procurement auctions are used in land set-aside programs like the Conservation Reserve Program (CRP). Under the CRP the US Department of Agriculture (USDA) solicits citizens, in this case agricultural land holders, to place bids stating the amount they would need to be paid to participate in the program. To participate the landowner must convert crop land to non-crop uses such as vegetative cover or riparian buffer. The landowners' bids will be closely tied to what they have to give up in forgone crop production to install water quality improving practices. In our case we were asking homeowners to give up portions of their yards for stormwater runoff control. As in the USDA program, we use an environmental effectiveness index to give certain bids more weight based on geologic and hydrologic characteristics of each participating property. The auction mechanism and this index are explained more fully in Sections 3.3 and 3.4.

3. Shepherd Creek pilot auction

3.1. Study area

We investigated the cost-effectiveness of an auction approach to stormwater management in a watershed that exhibited the problems associated with excess stormwater runoff and was appropriately sized to discern any measurable effects of the implementation of several SWMP. The Shepherd Creek watershed in Cincinnati is a subwatershed of the Mill Creek, which in turn drains into the Ohio River. The study area was chosen for its geo-physical characteristics as well as its similarity to other developed areas, thus providing more opportunity for application of project results in other communities, nationally and internationally, with similar impervious surface-driven stormwater runoff problems. The Shepherd Creek watershed spans an area of 1.8 km^2, and its boundaries contain a suburban neighborhood typical of the Midwestern United States, with approximately 400 single family homes. One-third of the watershed is city park land (Fig. 1). The watershed's streams are affected by urbanization impacts; sites downstream of headwater development exhibit a ''flashy'' response to storms and considerable bank erosion. The streams have generally poor water quality with very low diversity of macroinvertebrates and periphyton, as typical of urban streams. This is likely a consequence of correspondingly poor water quality evidenced by high conductivity attributed to road salting, and all tributaries exhibit elevated nutrients, and fecal coliform bacteria and *Escherichia coli* concentrations that exceed US EPA limits, with little seasonal variation in the magnitude of these exceedances (Thurston et al., 2008).

3.2. Stormwater management practices

Because a majority of the total impervious area (TIA) in Shepherd Creek was on private property in the form of buildings and driveways (Roy and Shuster, 2009), we selected dispersed residential stormwater control in the form of rain gardens and rain barrels. A rain garden is a horticultural landscaped area that infiltrates and evapotranspires what would have been uncontrolled stormwater runoff, and at a rate higher than the surrounding landscape. A rain barrel is simply a holding tank that is commonly placed under one or more of the downspouts of the roof's gutters, where it collects rainwater. These relatively low-cost SWMPs are engineered to impart higher detention capacity to a residential lot, where space is often at a premium. For this project, we constructed uniform-area rain gardens by excavating an area approximately 16 m^2 to a maximum depth of approximately 0.66 m. The native soils were retained and amended with organic matter in the form of compost and peat moss. We planted a community of hydrophilic, generalist plant species such as Lobelia and Sedge that are adapted to the local climate and soils. More detailed specifications about the rain gardens we employed can be found in Dyke et al. (2008). Where landscape slope was sufficient (80% of sites), an underdrain was installed to provide some free-drainage of soil water, and to prevent extended ponding from serial storm events. Rain barrels were equipped with a spigot attached to a hose inches above the

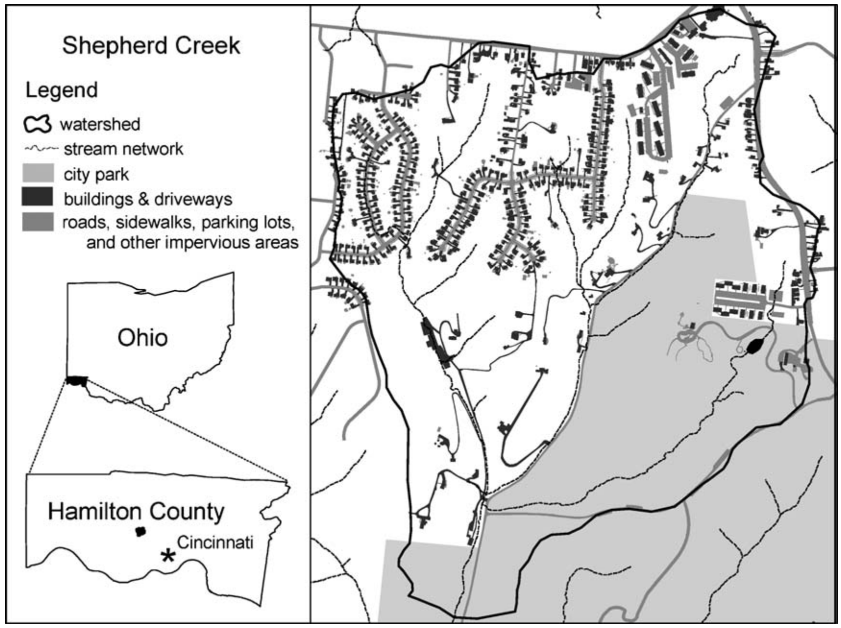

Fig. 1 – The Shepherd Creek watershed.

bottom that allows the homeowner to use the captured rainwater for watering lawns or gardens. The rain barrels had a capacity of either 208 or 284 L (depending on availability) and each barrel came complete with a screened lid to keep mosquitoes out (Thurston et al., 2008).

3.3. *Choice of a reverse auction*

In a procurement or reverse auction there is one buyer and many sellers. These auctions are commonly found in agricultural management policies wherein an agency identifies a group of agricultural property owners who can affect some ecological change or management practice on their land for a cost (see for example Greenhalgh et al., 2007; CSIRO, 2005). The procurement auction can be uniform price (all bidders paid the same) or discriminative price (each bidder is paid his or her bid amount). For this project, we used a sealed bid, first price, discriminative price auction, where bids were further tempered by the environmental weighting index, and are accepted up to the cumulative reservation price as determined by the funding agency (i.e., USEPA). Because there is competition among sellers, it theoretically should induce an optimal bidding strategy that reflects the actual opportunity cost of management practice adoption. The theoretical underpinnings of auctions have been well defined in the economics and game theory literature and are treated rigorously elsewhere (e.g., Vickrey, 1961; Riley and Samuelson, 1981; Milgrom, 1989). Although there are theoretical arguments favoring a second price auction (one in which the winning bidder is paid the second highest bid) over a first price auction, we felt ease of explanation to auction participants took precedence over this slight improvement in auction efficiency.

Since this is an applied research effort, a major factor we considered in choosing the discriminative, first price auction was simplicity of presentation to the homeowners. Likewise, since we assumed people would not be familiar with the cost of installing rain gardens and rainbarrels, and because there were legal and analytical barriers to allow people to participate by installing their own individualized SWMPs, our bid solicitation was explicitly stated to be for that amount above and beyond installation and material costs of pre-specified SWMPs. We installed uniform size rain gardens and identical rainbarrels so we could control the price and effectiveness of these SWMPs, and we made the strong assumption that homeowners armed with the knowledge that the "specified" SWMPs would cost $x, their bid would be $x + the opportunity cost of having the SWMP on their property. Allowing the homeowner to select the size and asking bid for a rain garden which he/she would install and pay for is a possible next-step in complexity that might work. A more complicated bid format could ask homeowners to bid on a per-unit detention amount. That is, a bid could be "30 cents per cubic foot with a 100 square foot rain garden." We maintain that the complexity and cost of analyzing and ranking such bids would be too great.

From a policy perspective any auction mechanism has great promise. Among the advantages of the auction over other means of allocating public funds for conservation programs are "efficiency, objectivity, transparency and flexibility" (CSIRO, 2005). They are efficient because they allocate the resource to those who are willing to pay the most and therefore are situated to make the best use of them; objective because the price is not determined capriciously by a government official, rather it is market determined; transparent because the rules for bidding and winning are known; and flexible in that the mechanism can be altered to allow for various contingencies, such as changing annual budgets. While this type of incentive mechanism has been applied in agricultural settings, it is a novel approach to urban stormwater management, and the extent to which private homeowners will participate in such a program has not been tested.

To ensure the auction emphasizes not only low-cost (by virtue of the incentive of competition), but also potential environmental ''bang for the buck'', we incorporated an environmental weighting scheme. This allowed for objective comparison of landowner bids based on the potential environmental benefits. Variables were scored for each property, with high numbers indicating a preferred condition. Environmental weightings were developed separately for rain gardens and rain barrels since the factors influencing the potential environmental benefit differed. Optimizing the costs and benefits among different SWMPs would be more appropriate with actual cost and environmental (non-market) benefit data, the estimation of which is outside the scope of this paper.

The scoring process was designed to be a simple, informative, and repeatable technique for quantifying the potential environmental value of placing SWMPs on a property. Thus, we selected information that was easily obtained using available GIS (e.g., impervious cover and soil type), rather than information that required site-specific surveys (e.g., surface runoff routing and site-specific soil infiltration). Because the goal was to compare properties, we excluded variables that may impact the potential environmental benefit but were the same within the study area (e.g., annual rainfall). We also excluded partially redundant variables (e.g., total and directly connected impervious area) to avoid overemphasizing one environmental aspect such as land cover and simplify the scoring process. Finally, we did not include the location and homeowner maintenance of the SWMP in the scores because they were unknown at the time of the bid evaluation; however, we acknowledge that these could be critical in terms of actual environmental benefits. The rationale and scoring for each variable included in the environmental index is detailed below.

3.4. *The Environmental Benefits Index*

The environmental index value assigned to proposed rain gardens was based on the amount of stormwater runoff potentially infiltrated and the proximity of property to a stream channel. Potential infiltration of runoff was determined using: (1) percent total impervious area (TIA) on the parcel, (2) soil drainage characteristics and (3) distance from a stream channel. Environmental value for SWMP installation will be maximized where: there is high % TIA on the parcel, soils have comparatively low capacity for drainage, and the property is in close proximity to stream channels.

TIA is the area of land that is covered by rooftops, driveways, sidewalks, pools, or other surfaces that do not allow for water to infiltrate into the ground. Parcel-level TIA was available as GIS layers of rooftops, driveways, and sidewalks which were digitized from 2001 ortho-rectified aerial photography. The dominant soil types are Switzerland silt loam, which has moderate drainage characteristics; and Eden silty clay loam, which has relatively poor drainage characteristics. Parcels where the dominant soils have poorer drainage characteristics were given preference for receiving a rain garden because these properties are likely to generate a greater amount of surface runoff, and would likely benefit the most from having a rain garden. A detailed soil survey map created by the Natural Resource Conservation Service was used to determine the dominant soil series for a given parcel (Shuster et al., 2007).

The proximity of a parcel to a stream channel is inversely proportional to the land mass available to act as a buffer for upstream developed land. The closer the parcel is to the stream channel, the fewer opportunities there are for infiltration of runoff, and therefore there is an increased potential for runoff contributing to peak flows in the stream channel. Thus, properties that are closer to the stream were expected to benefit the most from a rain garden acting to intercept and infiltrate surface runoff. The stream network determined from digital elevation maps was used to calculate the distance between the centroid of the parcel and the stream channel following the flow path. The Environmental Benefits Index (EBI) for placing rain gardens on each parcel was based on individual scores for TIA, soils, and proximity to stream channel (Table 1) and combined according to the following equation (Thurston et al., 2008):

$$\mathrm{EBI} = (2 \times \mathrm{TIA\ score}) + \mathrm{soils\ score} + \mathrm{proximity\ score} \tag{1}$$

The EBI for the rainbarrels was based on the potential amount of water that would otherwise be lost to direct connection or conveyance to storm sewers. We determined that the ecological impact would be highest where more barrels were requested per house and where the roof gutter downspouts were wholly or in-part connected to storm sewers. Rooftop connectivity was calculated using a combination of local storm sewer pipe information, a rooftop data layer digitized from 2001 ortho-rectified aerial photography, and site-specific surveys of roof gutter downspouts (ca. 50% of properties; Roy and Shuster, 2009). Rooftop connectivity was scored according to criteria in Table 2.

Table 1 – Rain garden EBI score descriptions.

Score	TIA	Soils	Proximity
4	>30% parcel area as TIA	Dominant soil type has low infiltration capacity (UELC)	Centroid of parcel <50 m from stream channel
3	15–30% parcel area as TIA	Dominant soil type has med-low infiltration capacity (Eden)	Centroid of parcel 50–100 m from stream channel
2	5–15% parcel area as TIA	Dominant soil type has med-high infiltration capacity (USLC)	Centroid of parcel 100–150 m from stream channel
1	<5% parcel area as TIA	Dominant soil type has high infiltration capacity (Switzerland)	Centroid of parcel >150 m stream channel

Table 2 – Rain barrel EBI score descriptions.

Score	Variable description: rooftop connectivity
4	75–100% connectivity of rooftops to storm sewers
3	50–75% connectivity of rooftops to storm sewers
2	25–50% connectivity of rooftops to storm sewers
1	0–25% connectivity of rooftops to storm sewers

The EBI for a rain barrel was calculated:

$$\text{EBI} = \text{barrels} \times \text{rooftop connectivity score} \quad (2)$$

3.5. *The Shepherd Creek auction process*

The auction was conducted once in March 2007 and again in March 2008. Homeowners were first contacted and briefed on auction details through mailings. An introductory letter and informational brochure were mailed to each eligible household in the treatment portion of the watershed (~350 residents). The letter described the project, summarized some benefits of rain gardens and rain barrels, and notified residents that they would be receiving a second mailing with an opportunity to participate. The informational brochure included color photos of rain gardens and rain barrels and text that described both the research project and the environmental benefits of rain gardens and rain barrels. The brochure also referred interested residents to a demonstration rain garden and rain barrel installed in their neighborhood park, and a project website (www.mtairyraincatchers.org) for more information. Approximately one and a half weeks after the initial mailing, door hanger notices were distributed to each house to remind them of the upcoming auction. Two weeks after the first mailing, each resident was sent an auction package by mail containing a follow-up letter explaining the bid process, a map that depicted their property, a reverse auction bid form, and $5 as a token financial incentive, as is recommended in the survey literature to increase response rates (e.g., Dillman, 2000). All residents were eligible to place separate bids for one rain garden and/or up to four rain barrels. The residents were asked to complete the bid form, draw their preferred rain garden location on the property map, and return the bid form and map in an included addressed stamped envelope (Thurston et al., 2008). The auction was repeated in spring 2008 with the same sequence of mailings, excluding the door hanger and extension mailing. Because we did not want to exclude willing residents from the second round of the auction, we allowed participation in either, or both years. Residents were allowed to bid on SWMPs to reach a total of one garden and four barrels in both years combined. We clarified this in the second year literature.

Upon receiving the bids we analyzed them, applying the EBI and bid amount ranking process and, within a month informed the winners that they would be eligible to receive their SWMP(s). Those whose bids were not accepted were also notified appropriately and thanked for their willingness to participate. During an initial visit, we provided, through a contractor, a ''homeowner agreement'' which, though not legally binding, provided strong encouragement for the homeowner to perform regular maintenance, such as weeding the rain gardens and emptying rainbarrels at the onset of freezing temperatures, and to allow contractors periodic access to the SWMPs for a period of 3 years (the length of post-installation monitoring deemed necessary for our research program). If a municipal stormwater utility was to incorporate our methods into their stormwater control polices, a longer term agreement, replete with language defining rights and responsibilities under certain contingencies, such as sale of the property, could be designed. This would ensure long-term operation and maintenance and reduce uncertainty about effectiveness.

4. Analysis

4.1. *Assessment of auction bids*

The first round of the auction produced 73 bid responses with 46 of these requesting both rain barrels and rain gardens. Another 16 requested only rain barrels and 11 requested only rain gardens. Average bids were $58 for a rain garden and $32 per rain barrel. A majority of bidders (60% for gardens and 60% for barrels) responded with zero bids, meaning that the resident did not request any subsidy payment. Assuming those homeowners who participated in the first round (2007) were those who were more willing to participate, we would expect the bids from round two (2008) to be higher, and they are. In 2008, we received 49 bids, 38 bids for gardens and 46 bids for a total of 74 barrels. Bids ranged from $25 to $1000 with an average bid of $90 for a rain garden and $44 per barrel. Fifty-two percent of the bids for gardens were zero bids while 47% of bids for barrels were zero bids.

Logit regression analysis was used to assess the influence on bid price Bid price was assessed using either: all bids, zero bids only, positive bids only, and bid price as a binary variable (zero or positive). Next, analysis was conducted on bids from each auction year, and then combined. Our parcel-level (independent) data included proximity to stream, soil type, EBI, year house was built, house size in square footage, number of bedrooms and bathrooms rooms in the house, acreage of the lot, and appraised value of the parcel and home. Results showed few statistically significant relationships between these variables and the bid price offered by parcel owners. Parcel data was unable to identify any correlation with the decision of whether to place a zero price bid or a positive price bid. The only statistically significant relationship was a positive correlation (Pearson's $r = 0.452$; p value = 0.023) between bid price and the total appraised value of the parcel (lot and home combined) for landowners who placed a positive bid in both auctions (considered separately and combined). This shows that landowners with higher appraised parcel values were more likely to place higher rain garden bids.

While we find little statistically significant relationship, we felt it was important to include these results as they point to research gaps for future work. To improve the robustness of these statistical relations, future research calls for the application of the auction mechanism to a larger watershed wherein we can split the sample to allow for comparison. We also intend to conduct a post-implementation survey to explicitly account for some of the variables we have estimated or not have access to, such as income. With a larger dataset we feel we will be more justified applying other complex statistical techniques, such as Tobit estimation and bootstrapping.

4.2. Assessment of auction cost-effectiveness

To assess the cost-effectiveness of the auction we evaluated SWMPs actually installed and their expected runoff retention capacity. Since our budget was not exhausted we accepted most bids and only dropped the ranked-bid outliers: one garden and two barrel bids in 2007, and two gardens and three barrels in 2008. In the first round of the auction there were 56 acceptable bids for rain gardens, but only 50 were installed. Six gardens were not installed for various reasons such as the homeowner changed his/her mind, placement in the yard was unacceptable, or the homeowner moved. Bid amounts ranged from \$0 to \$500 in each year of the auction. The result of the two rounds of auctions was the installation of 81 gardens and 165 barrels on 107 of the 350 eligible properties. Total stormwater detention in the watershed effected by these SWMPs for a 2-year storm event is 391 460 L. Average cost per liter of runoff detention is \$0.36 for gardens and \$0.59 for barrels. All costs and detention volumes assume a design storm of 3.12 cm.

Using the auction data, and with a few admittedly strong assumptions, we compared the cost-effectiveness of the auction as an incentive for SWMP placement with an educational campaign and a flat rate payment.

For the auction, we calculate cost per liter of detention for rain gardens as follows:

$$\frac{\bar{C}N + B}{N\bar{D}} \tag{3}$$

where $\bar{C}$ is the average cost of installation, in our case \$1500, N is the number of gardens installed, B is the total bid amount paid and $\bar{D}$ is the average detention in liters of the gardens—in our case 4276 L. Stormwater detained with this constraint was 213 800 L and the average cost was \$1556 per homeowner (including average cost of installation and bid price). Thus, we calculate an average cost of \$0.36 per liter of stormwater runoff detained via rain gardens over all participating properties in the study area.

We assume there are people in the subwatershed who would have participated in an education-only campaign, one that included only the mailings and information we provided homeowners, but not the economic incentive. Of course, there would be significant differences in an education program wherein homeowners were responsible for installation costs, but we did not have a split sample area to test for this in a robust fashion. We do feel, though, that we can glean some information from our sample with some assumptions. We assumed those who bid \$0 did so not for competitive reasons, but were those who would have participated following an education campaign that did not include economic incentives above and beyond the installation and maintenance. This is, of course, arguable, but our logic is that a 0 bid is not a competitive bid. A legitimate competitive bid would be low, but non-zero. We calculated cost per-unit detention as:

$$\frac{N_0\bar{C}}{N_0\bar{D}} \tag{4}$$

where N_0 is the number of gardens installed at \$0 bids, our proxy for education-only participants. Based on zero-bid SWMPs over all participating properties in the study area, stormwater detained was 128 280 L at an average cost of \$0.35 per liter of stormwater runoff. Finally, we calculated cost per-unit of detention as if we had offered a flat rate payment for accepting rain gardens. Had we not used an auction to determine the different willingness-to-accept amounts of different homeowners, and simply offered the highest accepted bid price (\$250) to all participating homeowners, 213 800 L would be detain at a cost of \$0.41 per liter.

We repeated the calculations for the second round (2008) and then for a pooled first and second round bids. The second round results were similar; the auction resulted in 31 gardens

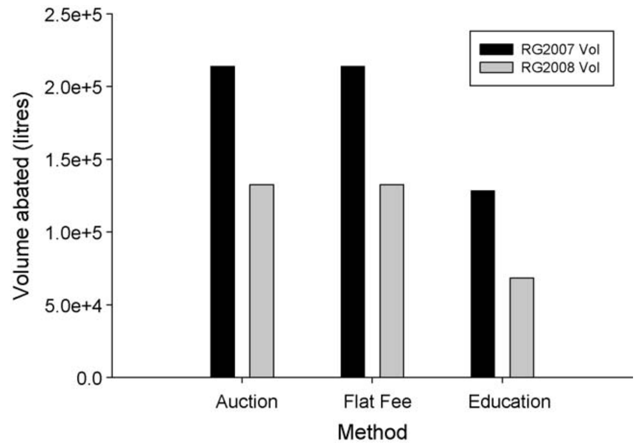

Fig. 2 – Rain garden volume detained by year in liters.

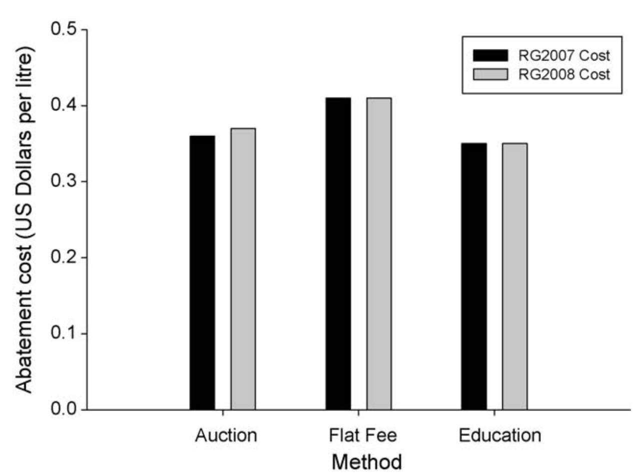

Fig. 3 – Rain garden cost per liter detained by year.

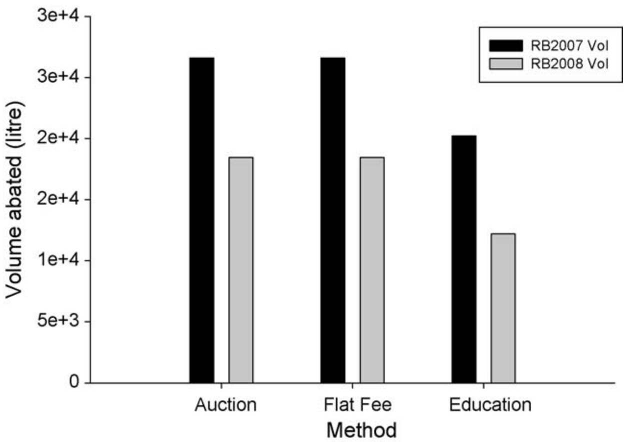

Fig. 4 – Rain barrel volume detained by year in liters.

installed at a cost for stormwater detention of $0.37 per liter. Assuming the zero bids are those who would have responded to an education campaign without economic incentives (with the same caveats as above), the cost per liter detained was the same at $0.35. The highest accepted bid was once again $250 for a rain garden, so a fee-based campaign that paid that amount to residents who allowed the installation of a rain garden resulted in the same average cost of detention at $0.41 per liter (Figs. 2 and 3). Combined, the 2007 and 2008 auctions resulted in 346 400 L, 196 700 L, and 346 400 L total stormwater detention under the auction, education and fee scenario, respectively. The resultant costs per liter of stormwater detained were $0.36 for the auction, $0.35 for the educational campaign, and $0.41 for the flat rate payment.

We repeated the same calculations for the rain barrels installed in the two rounds of auctions. In 2007, 100 barrels, with an average capacity of 284 L were installed at a cost of $130 per barrel, a total bid payout of $2532, and a total detention volume of 26 600 L (Fig. 4). In 2008, we installed 65 barrels that each detained 284 L of runoff at a total bid payout of $2152, for a total detention volume of 18 460 L. Cost per liter of stormwater detained in barrels was $0.58 in 2007 and $0.59 in 2008 (Fig. 5).

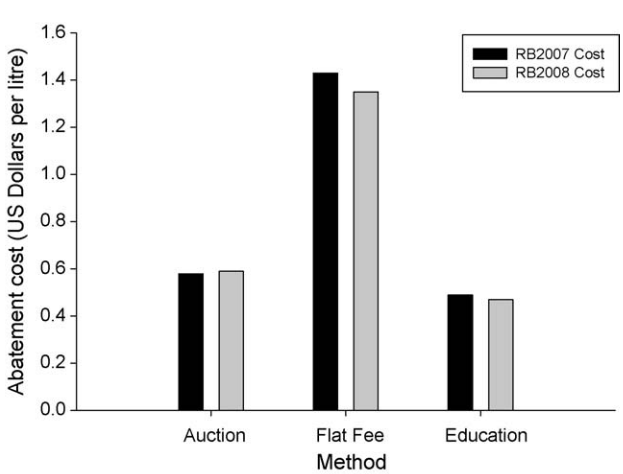

Fig. 5 – Rain barrel cost per liter detained by year.

The flat price was by far the least cost-effective way to incentivize a decentralized approach to control the stormwater runoff from this area (Figs. 3 and 5). Based on these data, an educational campaign is expected to be the cheapest method for encouraging homeowners to accept free rain gardens; however, to encourage additional acceptance beyond the initial 55% of homeowners, the auction proves to be cost effective.

While this study is more about incentive mechanisms available to municipal stormwater entities for installation of decentralized SWMP, we can attempt to put these per-liter detention values in perspective by comparing them to the per-liter cost of traditional, centralized stormwater best management practices. Using capital cost functions found in Sample et al. (2003) for detention basins, retention basins and deep tunnel wet weather controls:

$$C = 2.195 \times 10^4 V^{0.69} \quad (5)$$

$$C = 2.247 \times 10^4 V^{0.75} \quad (6)$$

$$C = 2.162 \times 10^6 V^{0.795} \quad (7)$$

where C is the cost, not including land acquisition, in 1999 $US, and V is the volume of storage in million liters. Using the same volume as the total amount detained in gardens and barrels, after both auction years, 391 460 L, and using Bureau of Labor Statistics consumer price index to adjust for inflation, we obtain the following per-liter results: $0.04, $0.04, $3.40. The deep tunnel costs are biased due to scale issues (a deep tunnel would never be built for such a small volume). A better approximation of the per-liter cost of the deep tunnel is to use current estimate of the cost of the proposed tunnel for the Cincinnati area ($8.0 billion) and use its capacity as volume. Calculating the cost thusly, we obtain the following result: $0.42 per liter. If we take $0.36 per liter as the best case scenario under the dispersed approach, and do not consider any other benefits, such as aesthetics, the break even cost of land acquisition for a detention basin or retention basin is approximately $125 300, a price that is reasonable for a suburban lot in some areas, and not in others. The cost-effectiveness of decentralized compared to centralized will depend critically on the availability of land in the area.

5. Conclusions

As impervious surface grows relative to natural landscapes the problems caused by stormwater runoff will increase, and municipal authorities will look for ways to deal with runoff problems that are both logistically feasible and ecologically effective. This study is a part of an ongoing effort to assess the implementation of a realistic market-based stormwater control program and the effect of the program on stormwater runoff related impacts in urban and urbanizing areas. Overall, this study demonstrates that relatively minimal financial incentives can result in homeowners' willingness-to-accept SWMPs on their property, thus opening and important avenue for retrofitting watersheds that are largely in private ownership. In areas where it is legal and politically feasible it may be preferred to require stormwater management practices be installed. However, in many cases where development has already occurred, voluntary retrofit opportunities are among very few options currently available to local governance or wastewater management authorities. The setting and our overall approach contributes to our impression that these results are generalizable, and thereby potentially applicable to stormwater management in other communities nationally and internationally. We have shown that the auction is an effective mechanism to encourage the adaption of retrofit stormwater runoff detention capacity. In particular, we find that a reverse auction mechanism is a more cost-effective way of identifying and securing the adoption of stormwater management practices on those residential parcels that will provide the greatest level of ecological benefit per program dollar spent. The high proportion of zero-dollar auction bids sent in by homeowners led us to believe that an educational campaign without the financial incentive may have encouraged numerous, but not as many, homeowners to participate. Further research is needed to explicitly address and account for the role of education in the recruitment of homeowners for stormwater control. For example, we would like to employ a paired watershed approach with a treatment that explicitly uses education without the auction, and one that uses the auction with minimal education. Also a split sample wherein one group receives education and installation, or subsidized installation, and a group that receives education without installation, would enhance our understanding of people's acceptance.

At the time of publication, we continue to monitor chemical, physical, and biological indicators within the Shepherd Creek watershed. The results of this long-term monitoring program will be published at a future date, and will shed light on whether the auction resulted in the adoption of enough stormwater management practices to result in measurable improvements in stream hydrology, water quality, and biotic integrity. As communities start to investigate the use of incentive mechanisms to encourage stormwater runoff control, comparison of the effectiveness of more traditional stormwater programs to a wholly voluntary programs such as the one outlined in this paper, allows policy makers to weigh the pros and cons of various approaches to management of excess stormwater runoff and choose the policy most appropriate for their constituency.

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