A Private Incentive-Based Stormwater Mitigation Program To Enhance Stormwater Management Control beyond Current Minimum Standards in Residential Subdivisions

Matthew C. Huber,[a]* David B. Willis,[b] Charles V. Privette III,[c] and John C. Hayes[d]

[a] *Graduate Teaching Assistant, The John E. Walker Department of Economics, Clemson University; Clemson, SC; mhuber@clemson.edu*
[b] *Associate Professor, School of Agricultural, Forestry, and Environmental Sciences, Clemson University; Clemson, SC*
[c] *Associate Professor, School of Agricultural, Forest, and Environmental Sciences, Clemson University; Clemson, SC*
[d] *Professor Emeritus, School* of Agricultural, Forestry, and Environmental Sciences, Clemson University; Clemson, SC
* *Corresponding author.*

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Abstract

Incentive-based stormwater management policies offer the prospect of reducing urban stormwater runoff while increasing developer profits. This paper describes an incentive-compatible developer-based stormwater mitigation program (DSMP) that would enable both outcomes. Under a DSMP, developers would be able to earn additional profits by building at higher residential densities in exchange for including low-impact development stormwater best management practices in the development's stormwater management infrastructure. One can modify the parameters of the DSMP to fit location conditions and multiple policy objectives.

Introduction

Population increases coupled with economic growth have fueled urbanization and residential development. In many watersheds, residential development has converted land from its natural condition and increased the percentage of land in impervious cover, with resulting decreases in stormwater infiltration rates. Expansions in impervious land cover generally increase stormwater runoff, the probability of flooding events, and the associated transport of nutrients and sediment loadings within watersheds. Significant costs are associated with mitigating stormwater runoff. For example, Vistacion et al. (2009) estimate that the cost of stormwater control programs in the Puget Sound region of Washington State will exceed $1 billion within the next decade. The magnitude of such costs, and the pressures on state and local government budgets nationwide, require new and innovative approaches to address stormwater management. For watersheds forecasted to experience rapid population growth in coming decades, the need for policy tools that cost-effectively manage stormwater runoff impacts is especially acute.

Various policy measures have been proposed to help local governments manage stormwater impacts associated with residential development. Two emerging tools are the adoption of high-density residential development and the use of low-impact development (LID) practices. Compared with medium- or low-density development, high-density development results in a greater number of residences per unit area by building up instead of out or by decreasing lot size. If well planned, high-density development can reduce the total area of land converted to impervious surface in a particular watershed because, by concentrating most of the development in one area, it reduces the need for infrastructure such as roads. LID, which can be of any density, is designed to minimize impacts by reducing impervious cover and by treating stormwater runoff on-site, while protecting open space and environmentally sensitive areas from development. Used in conjunction, these two development techniques have the potential to improve water quality by (1) diminishing the quantity of runoff and the amount of nutrient and sediment loads reaching water supplies by reducing the amount of impervious cover created by residential development and (2) mitigating the impact of stormwater runoff by concentrating more intensely developed land on a subarea of the parcel, allowing the conserved open space to be protected and/or used for stormwater management.

Unless financially compensated, residential developers are unlikely to use LID techniques to control stormwater runoff beyond existing minimum control levels because of the additional cost (Wossink and Hunt 2003; Thurston et al. 2003). This paper presents a voluntary developer-based stormwater mitigation program (DSMP) that would provide an incentive for the adoption of LID in residential developments by allowing developers to increase building densities in exchange for the implementation of LID best management practices (BMPs) to mitigate stormwater runoff. The developer pays a participation fee—based on the expected profits earned from the additional housing lots allowed under the DSMP—and must reduce stormwater runoff beyond the existing regulatory minimum control standard. The developer receives a rebate on the participation fee if he or she chooses to exceed the minimum stormwater control standard established for program participation. We demonstrate the operation of the DSMP with a representative subdivision and present the benefits and costs to the developer under alternative participation scenarios.

This paper is organized into five sections. The next section reviews the literature on incentive-based environmental policies, high-density development, and LID. The second section explains how a DSMP operates. The third section discusses the model and data. The fourth section presents the representative subdivision used in the analysis as well as the developer and water quality benefits for four scenarios. The final section summarizes our major findings.

Literature Review

High density residential development and low-impact development both present opportunities to improve water quality. Richards (2006) summarizes the primary benefits that can be achieved by well-designed high-density residential developments. Benefits consist of decreasing runoff levels per new residential unit, reducing the amount of impervious cover, and targeting development to avoid environmentally sensitive areas. In their overview of the literature on impervious surfaces and water quality, Brabec et al. (2002) demonstrate that no single environmental measure fully quantifies the impact of a change in impervious cover on a watershed. They emphasize that the most important aspect of impervious cover is the identification of the threshold point at which water quality impacts become a concern. Goonetilleke et al. (2005), in an examination of the water quality impacts of various residential development practices, found that the best option, in terms of protecting water quality, is high-density development that disturbs less land by concentrating most of the development within a smaller subarea of the site. Thus, land use planning can play an important role in improving or maintaining water quality. Dietz (2007) states that LID seeks to maintain the predevelopment hydrology of a site after development. This is done through site planning that conserves natural areas and reduces impervious cover as well as by incorporating stormwater BMPs that are distributed throughout the site. Focusing on bioretention cells, grassed swales, pervious pavement, and green roofs, Dietz found that the environmental benefits of these practices include increasing infiltration and reducing the export of pollutants.

Several studies have analyzed the efficiency or cost-effectiveness of conventional and LID stormwater BMPs. In a ten-year study, Hood et al. (2006) found that LID configurations outperform conventional BMPs on measures of runoff and peak discharge. Weiss et al. (2007) analyzed cost-effectiveness in terms of total suspended sediments and total phosphorous trapping for six stormwater BMPs, including three LID BMPs (bioretention cells, constructed wetlands, and infiltration trenches). They found that constructed wetlands are the most cost-effective BMP if land cost is ignored, but in crowded urban environments with high land costs, less land-intensive BMPs may be more cost-effective. These studies indicate that (1) few general conclusions are apparent regarding which LID BMPs are the most efficient at trapping nutrients and sediment and (2) the appropriate selection of LID BMPs is highly site dependent.

Previous studies have analyzed how incentive based policies to control stormwater runoff can produce greater runoff control at lower cost. In an overview of the merits of incentive-based environmental policies, Randall and Taylor (2000) emphasize that incentive-based policies provide more flexibility than command-and-control policies and have lower compliance costs. Parikh et al. (2005) provide a hydrologic, economic, and legal framework for examining market-based incentive instruments to reduce stormwater runoff. They note that voluntary offset programs can provide incentives for landowners to reduce runoff with LID BMPs. Thurston et al. (2003) examined stormwater runoff control using tradable allowances based on impervious surface area. They demonstrate how the potential to earn revenue from selling excess allowances provides property owners with an incentive to build LID BMPs with greater detention capacity than the minimum regulatory requirement. Thurston (2006) analyzed the economics of using a mandatory stormwater fee versus a voluntary option to construct a BMP in exchange for a rebate on construction costs for each parcel in a watershed. He found that the rebate provides the homeowner with an economic incentive to build a BMP if the cost of the BMP minus the rebate is less than the stormwater control fee that would be assessed.

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Voluntary Developer-Based Stormwater Mitigation Program

The basic premise behind the DSMP concept is to align the incentives of stormwater control authorities with those of residential developers to reduce stormwater runoff below the current regulatory standard through a voluntary program that increases developer profit and improves regional water quality. Under the conventional regulatory approach, cost-efficient developers have an incentive to meet the regulatory standard at minimum cost. A DSMP would be designed to provide the developer with an additional private economic incentive to exceed the minimum standard. The regional water management agency would incur no additional cost, other than the cost of ensuring that program participants comply with program regulations. Moreover, a well-designed DSMP would generate funds sufficient to cover any additional administrative cost.

We chose Greenville, South Carolina, to illustrate how a DSMP would work. Greenville currently stipulates area-specific density limits for new single-family housing developments. The DSMP would allow developers to build at higher gross densities than currently allowed, providing that the developer reduced stormwater runoff below the existing regulatory standard by incorporating LID BMPs. In addition to reducing runoff, the developer would pay a participation fee to the DSMP based on a percentage of estimated net profit earned from the additional lot sales permitted at the higher-density development. A profit-motivated developer would have an incentive to voluntarily participate if the estimated benefits of participation (the value of the additional lots less the development cost) exceeded the sum of the additional LID BMP cost plus the participation fee.

We used the site score (SC) to determine the existing regulatory runoff level and the reduction in the runoff level under improved control. The site score is a complex function of eight factors that impact runoff—such as impervious cover, soil factors, infiltration factors, sediment factors, and particulate runoff factors—in combination with control practices (Hayes et al. 2010). To determine the amount and severity of runoff from a development for a given set of control practices, one scores each individual factor on a scale from zero to ten and weights it based on its relative importance. Table 1 provides a brief explanation for each factor and weight used to construct the site score for a given subdivision. The constructed site score for a subdivision ranges from a low of 0 to a high of 100. A site score of 0 implies that all runoff eventually leaves the subdivision and adversely impacts regional water quality; a site score of 100 implies that almost all runoff and particulates are trapped within the subdivision and do not significantly impact regional water quality.

We calibrated the site score index for Greenville, South Carolina. After model calibration, we determined that a site score of 40 is consistent with the current minimum regulatory standard. Subsequently, we introduced alternative combinations of LID BMPs into the stormwater management design for the subdivision. We estimated the effect of the BMPs on the site score using Integrated Design, Evaluation and Assessment of Loadings (IDEAL), a computer model that predicts runoff and pollutant loadings prior to routing the runoff and pollutants through BMPs and then estimates trapping after the runoff is routed through the BMPs (Barfield et al. 2006; Woolpert, Inc. 2007). By incorporating soil type, slope, impervious area, and expected rainfall, IDEAL simulates stormwater-driven runoff and pollutant levels for a variety of watershed configurations and BMP scenarios. This iterative simulation procedure provides the means to find appropriate combinations of LID BMPs and traditional BMPs, as well as their required scale, to meet a specific site score. After finding the optimal combination of BMPs and their associated scale of implementation to achieve a specific site score, one merges the data with a collected BMP cost data set to estimate the cost of increasing the site score from the regulatory minimum compliance score of 40 to the higher site score representing greater control.

Table 1. Factor weights for computing the site score

Factor	Weight	Basis	Explanation
Runoff Factor	1.5	Natural land cover	Function of surface area
Soil Factor	1	Impermeable area	Reflects soil texture, permeability and impervious surfaces

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Detention Factor	1.5	Impervious area connected to drainage	Based on runoff speed; varies with amount of impervious area connected to drainage
Infiltration Factor	1	Area draining through BMPs	Dependent on percentage of area draining through BMPs
Sediment Factor	1.5	IDEAL sediment TE	Evaluates whether site is stabilized; critical because sediment clogs BMPs
Nitrogen Factor	1	IDEAL nitrogen TE	Reflects measures that reduce nitrogen runoff
Phosphorous Factor	1	IDEAL phosphorous TE	Reflects measures that reduce phosphorous runoff
Bacteria Factor	0.5	IDEAL bacteria TE	Reflects measures that reduce bacteria runoff
Maintenance Factor	1	Who performs maintenance and frequency	Considers whether BMPs require maintenance and who performs it

Note: Trapping efficiency (TE) is the percentage of effluent kept on the site. Each factor is scored on a scale of zero to ten. The factor scores are weighted and summed into a total site score between 0 and 100.

The DSMP also provides developers with an economic incentive to achieve an even higher SC (control level) than is required to participate in the program. This additional incentive comes in the form of a percentage rebate on the participation fee for each point above the target site score (TSC), the minimum site score required for DSMP eligibility, that the developer designed control plan achieves. A profit-motivated developer will voluntarily control runoff at a level higher than that required for DSMP eligibility if the projected cost of the additional control is less than the estimated rebate value.

Determining Developer Net Benefit

Given the uncertainty regarding the type of single-family residence likely to be built on any subdivision lot and the final selling price of the house—together with the reality that developers will want to know the costs and benefits of DSMP participation before they enroll—we used the expected lot price, rather than house price, to estimate developer profit from building at a higher density under the DSMP. Developer profit from participation in the DSMP, before considering the additional LID BMP cost and any participation fee rebate, is specified in equation 1:

$$\pi \quad = [\{\%\pi_B \times L_B \times P_B\} - \{L_{NB} \times (P_{NB} - P_B)\}] \times (1 - c)\,, \qquad (1)$$

where π is the program profit (net value of additional lots) before possible program rebate and additional BMP costs; $\%\pi_B$ is the percentage profit on bonus lot sales, $P_B - Cost_B / P_B$, where $0 \leq \%\pi_B \leq 1$; $Cost_B$ is the additional infrastructure cost per bonus lot; L_B is the number of bonus lots (additional lots with DSMP participation); P_B is the lot price at bonus density; L_{NB} is the number of original subdivision lots with DSMP participation; P_{NB} is the original lot price; and c is the fraction of density profits paid to the DSMP as participation fee, $0 \leq c \leq 1$.

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The first bracketed term on the right side of equation 1 is developer profits from the bonus lot sales. The second bracketed term captures the potential lost profit to the developer on the original price of subdivision lots, if lot price decreases as density increases. If lot price does not vary with lot size, the bonus lots will sell for the same price as the original lots and the second bracketed term in equation 1 will equal zero. After any lost profit on the original lots is subtracted from the profit on the bonus lots, the density profit is multiplied by the third term, one minus the fraction of density profit paid to the DSMP as the participation fee, to calculate program profit before considering the additional BMP costs and possible rebate based on the participation fee.

The lost profit on the original number of lots in equation 1 is not multiplied by a percentage profit term on lot sales similar to the bonus term because the infrastructure cost incurred in preparing the original lots does not change at the higher density. Thus, the lost profit on the original lots is simply the potential decrease in lot price multiplied by the number of original lots. We conservatively assume that the percentage profit on the bonus lots is equal to the percentage profit on the original lots ($\%\pi_B = \%\pi_{NB}$). However, the percentage profit on the bonus lots is likely to be greater because the primary infrastructure costs (engineering and site design, permits and impact fees, clearing and grading, sewer and water infrastructure, and roads) to construct the subdivision have already been incurred.

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If the developer chooses to exceed the TSC through more intensive LID BMP use, he or she receives a partial rebate on the original participation fee. The partial rebate provides the developer with an additional economic incentive to voluntarily exceed the TSC and incur the additional associated BMP costs when it is profitable to do so. The rebate value is calculated by equation 2:

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$$A = \{(L_B \times P_B \times \%\pi_B) - (L_{NB} \times (P_{NB} - P_B))\} \times c \times \{a \times (SC - TSC)\}\,, \tag{2}$$

Where *A* is the rebate on the participation fee; *a* is the percentage rebate on the participation fee for every point by which *SC* exceeds *TSC*, $0 \le a \le 1$; and $SC \ge TSC$. When the *SC* equals the *TSC*, the rebate is zero.

Combining equations 1 and 2 produces equation 3, program profit before considering additional BMP costs (π^*):

$$\pi^* = \pi + A\,. \tag{3}$$

Subtracting the additional LID BMP costs (C_{BMP}) from π^* provides net program profit (Net π^*), equation 4:

$$Net\pi^* = \pi^* - C_{BMP}\,. \tag{4}$$

If equation 4 is positive, then a profit-seeking developer has an economic incentive to participate in the DSMP, subject to the conditions imposed for participation in the program.

Benefit and Cost Data

This study used housing lot size and sale price data, collected from the Greenville County, South Carolina, Geographic Information System Division, for residential housing lot sales in the county from 2004 to 2009. We used the S&P Case Shiller Home Price Index for Charlotte, North Carolina, to adjust all sale prices to 2012 dollars. The analysis includes only lot sizes between 0.07 and 0.42 acre[i] because those lots were the smallest feasible for single-family residential lots and were the most common range of lot sizes for new single-family housing developments in Greenville County. Because of increasing land prices and environmental concerns, the trend in Greenville County has been toward smaller lots. Figure 1

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shows the distribution of new housing lots by size, ranging from 0.07 to 1 acre during the 2004 to 2009 time period for Greenville County. To be consistent with the criteria used in this study, the reported sample is restricted to lot sale prices ranging from $12,000 to $250,000. Of the 599 lots in the sample, the average size is 0.38 acre, and 437 (73%) are less than 0.5 acre.

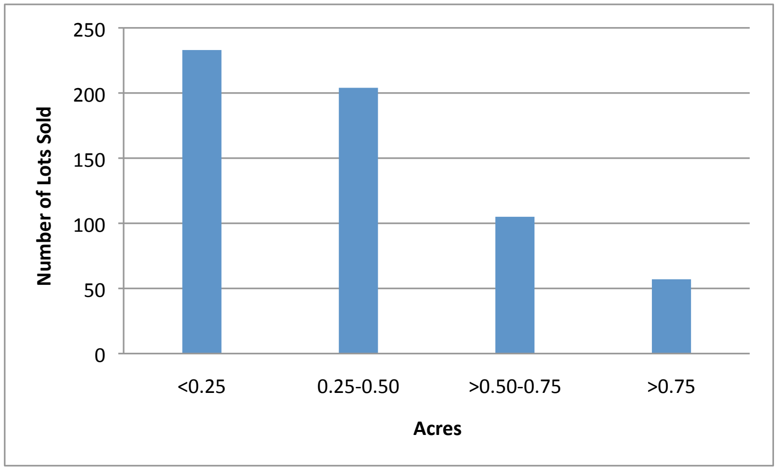

Figure 1. Housing lots sold in Greenville County, South Carolina, 2004–2009.

Based on conversations with eight Greenville area residential developers, we estimated that 15% of the average home price is attributable to lot value. Using this information and the current asking prices for new homes in Greenville, we determined that lot sale prices range between $12,000 and $180,000 for the lot sizes used in this study. With these restrictions on lot size and lot sale price, 277 lots fit the criteria and the average lot size in the data set was 0.24 acre. We constructed a centered moving average to determine average housing lot prices for lots between 0.09 and 0.40 acre.

Regressing lot price against lot size, we estimated that the average price for a 0.09-acre lot in Greenville is $38,540 and that every 0.01-acre increase in lot size increases the lot price by $340. We used equation 5 to determine residential lot sale price with and without the density bonus. The sale price of bonus lots, P_B, is calculated as:

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$$P_B = \$38{,}540 + \$34{,}000 \times (LS - 0.09)\ , \tag{5}$$

where LS is lot size. Both coefficients are significant at 5%. The estimated lot price equation is consistent with information provided by residential developers that lot prices do not vary much with lot size because developers add amenities to increase the value of smaller lots, such as placing the lots closer to parks or green space, to compensate the buyer for the smaller lot size. According to discussions with eight residential developers in the Greenville area, developers earn an average profit of 25% on each lot developed.

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We determined the construction requirements and specifications for both conventional and LID stormwater BMPs using construction plans from the Greenville County Land Development Division, 2003, the North Carolina Division of Water Quality, 2007, and the Maryland Department of the Environment, 2000. Since the modeling tool was developed for Greenville County, South Carolina, we used Greenville County specifications whenever possible.

Table 2. BMP standardized unit size and associated unit cost

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BMP practice	Standardized size	Cost

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Bioretention Cell	46.45 m^2 (500 ft^2)	\$3,524
Natural Filtration	0.4046 ha (1 acre)	\$0
Infiltration Trench	9.29 m^2 (100 ft^2)	\$627
Buffer Strip	9.29 m^2 (100 ft^2)	\$7
Enhanced Bioswale	9.29 m^2 (100 ft^2)	\$315
Dry Pond	0.1012 ha (0.25 acre)	\$14,203
Wet Pond	0.1012 ha (0.25 acre)	\$18,315
Wetland	92.90 m^2 (1,000 ft^2)	\$9,148
Porous Pavement	9.29 m^2 (100 ft^2)	\$915
Sand Filter	9.29 m^2 (100 ft^2)	\$3,942
Green Roof	9.29 m^2 (100 ft^2)	\$1,956

Rain Barrel	208.175 L (55 gallons)	$225

Note: ft, feet.

The analysis used a standard depth for each BMP: bioretention cell, 1.829 m; bioswale, 0.457 m; infiltration trench, 1.68 m; dry pond, 1.22 m; wet pond, 1.52 m; wetland, 0.92 m at the deepest point; and sand filter, 2.13 m. We estimated construction costs from a combination of sources, using the cost of recently constructed BMPs in the Greenville region, component costs from regional sources, and appropriate national average costs of completed BMPs and components when regional cost data were unavailable. Tetra Tech Incorporated, an environmental consulting firm, provided the national BMP cost data under a US Environmental Protection Agency contract. We converted all costs to 2012 dollars using the Producer Price Index for Intermediate Materials. We used a nonlinear equation to adjust the standardized BMP unit cost to reflect economies of scale in construction costs for BMPs implemented at a scale greater than the standardized unit size (Huber et al. 2010).

We developed a standard size and a cost estimate for each of 13 BMPs (Table 2). The analysis included two conventional constructed stormwater BMPs—dry ponds and wet ponds. We treated unbuildable areas of a subdivision that provide natural filtration as a conventional BMP; no construction cost is associated with natural filtration areas. We included ten LID stormwater BMPs: bioretention cells, buffer strips, bioswales, infiltration trenches, porous pavement, rain barrels, green roofs, wetlands, and sand filters. The estimates shown in Table 2 are consistent with those derived from the cost equations in Wossink and Hunt (2003). We used an equation based on the standardized unit cost for each standard-size BMP to scale the cost for BMPs implemented at a scale greater than the standardized unit size (Huber et al. 2010).

Example Development

This analysis demonstrates the relationships among the site score, the number of bonus lots and lot price, BMP costs, and developer profit under the DSMP for two alternative DSMP control scenarios relative to the baseline minimum regulatory control scenario. The first DSMP scenario determines the economic net benefit of DSMP participation when a minimum TSC of 70 is required for participation. The second scenario investigates the potential economic benefit the DSMP provides to a developer implementing a stormwater control plan that achieves a higher site score of 80 for the representative subdivision in Greenville, South Carolina. The analysis examines both site score scenarios with and without allowing lot prices to change in response to building density.

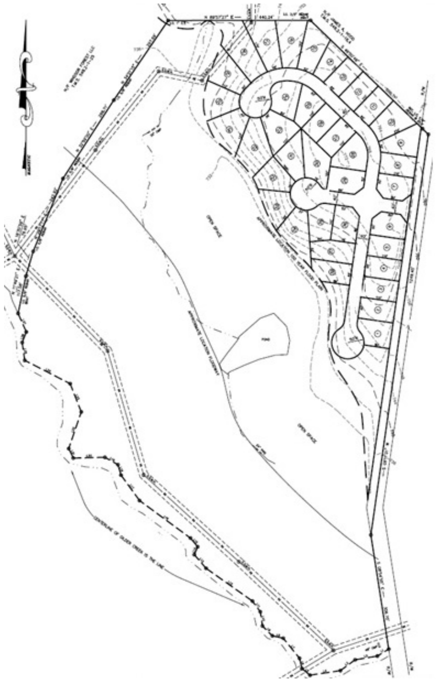

Figure 2, Barker Village

We selected Barker Village, a residential development in Greenville, South Carolina, to illustrate the private economic benefit and control benefits of the proposed DSMP. As shown in Figure 2, Barker Village is a 39-acre subdivision, consisting of 11 buildable acres. Under current density requirements, no more than 38 lots can be built on the 11 acres. The remaining 28 acres consist of an unbuildable floodplain that serves as a natural filtration area. Without access to the DSMP (the baseline scenario), Barker Village is planned as a 38-lot subdivision with an average lot size of 0.29 acre; the development achieves the current minimum regulatory control standard site score of 40 using conventional BMP practices.

Based on IDEAL water quality simulations, we selected a TSC of 70 as the minimum site score required to participate in the DSMP. A site score of 70 provides considerably more stormwater control than the minimum regulatory score. The primary benefits of achieving the higher site score are reductions in annual runoff volume; peak flow; and sediment, nitrogen, phosphorous, and total bacterial colonies loadings (Huber et al. 2013). However, achieving the higher site score is not costless to the developer, as reported in Table 3. The additional BMP cost of increasing the site score from 40 to 70, while maintaining the number of lots at 38, is an additional $10,860, as reported under the scenario labeled SN 1 in Table 3. The potential benefit of the DSMP, which may offset the additional developer-incurred BMP cost to achieve the TSC, is reported in Table 3. The two DSMP scenarios that achieve a site score of 70 are labeled SN 2A (fixed lot price) and SN 3A (changing lot price).

Table 3. BMP scale, cost, effective participation fee, and developer profit by management scenario with and without lot price change for alternative site scores.

	Current	**No DSMP**	**DSMP w/price fixed**		**DSMP w/price change**	
BMP practice	baseline	SN 1	SN 2A	SN 2B	SN 3A	SN 3B
Bioretention Cell (m^2)	0	167.23	267.56	445.93	267.56	445.93
Natural Filtration (ha)	11.61	11.61	11.61	11.61	11.61	11.61
Infiltration Trench (m^2)	0	92.90	148.64	222.97	148.64	222.97
Dry Pond (ha)	0.08	0.04	0.06	0.06	0.06	0.06

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Bioretention Cell	$0	$11,312	$17,472	$28,298	$17,472	$28,298
Natural Filtration	$0	$0	$0	$0	$0	$0
Infiltration Trench	$0	$5,228	$8,234	$12,240	$8,234	$12,240
Dry Pond	$11,363	$5,681	$8,522	$8,522	$8,522	$8,522
Total BMP Cost	$11,363	$22,223	$34,228	$49,060	$34,228	$49,060
Site Score	40	70	70	80	70	80
Additional BMP Cost	NA	$10,860	$22,865	$37,697	$22,865	$37,697
Number of Lots	38	38	64	64	64	64
Lot Price	$45,340	$45,340	$45,340	$45,340	$41,260	$41,260
Participation Fee	NA	NA	$147,355	$147,355	$56,575	$56,575
Participation Fee Rebate	NA	NA	$0	$29,471	$0	$11,315

Effective Participation Fee	NA	NA	$147,355	$117,884	$56,575	$45,260
Program Profit before Paying Effective Participation Fee and Additional BMP Cost	NA	NA	$294,710	$294,710	$113,150	$113,150
Net Program Profit	NA	–$10,860	$124,490	$139,129	$33,710	$30,193

Note: All cost, benefit, and profit measures are relative to the baseline scenarios

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2A and 3A simulate developer net profits under the assumption that the developer achieves the required TSC of 70 at least cost. We used IDEAL, in combination with budgeting procedures, to determine the BMP combination that would achieve the required site score at least cost. The DSMP allows the developer to construct an additional 26 bonus lots within the subdivision at an average lot size of 0.17 acre for the now 64-lot subdivision. The difference between scenarios 2A and 3A is that scenario 3A adjusts the lot price downward to reflect the likely reduction in lot price at higher building density. This analysis assumes that the developer pays 50% of all density-related lot profit to the DSMP as the participation fee. Scenarios 2B and 3B are nearly identical to scenarios 2A and 3A, respectively, except that scenarios 2B and 3B provide the developer with an incentive to earn additional profit by controlling stormwater runoff at a higher SC value of 80, instead of the TSC of 70, when the economic incentive is sufficiently large.

The upper portion of Table 3 reports the optimally selected BMP size configurations and associated costs for each scenario. The baseline scenario uses traditional stormwater BMPs, consisting of a combination of 11.61 ha of natural filtration area and two dry ponds that total 0.08 ha, to attain the minimum regulatory site score of 40. Scenario 1 achieves the TSC of 70, the minimum score required to participate in the DSMP, but the subdivision is constrained to the original 38-lot development. The higher site score is achieved by reducing the baseline dry pond area by half and replacing the reduced dry pond area with one 9.29-m^2 bioretention cell on each of 18 lots, and a 4.65-m^2 infiltration trench on each of the remaining 20 lots. This results in a total of 167.23 m^2 of bioretention cells and 92.90 m^2 of infiltration trenches within the development. The additional cost to achieve the site score of 70 is $10,860—a cost the developer would not incur unless properly incentivized.

Scenario 2A achieves the minimum TSC of 70 but factors in the additional value of 26 bonus lots, provided by the DSMP as an incentive, and the additional control measures needed at the higher density relative to scenario 1. At the higher density, 64 lots are permitted. The site score is achieved by using three-fourths of the baseline dry pond area and adding an 8.36-m^2 bioretention cell on each of 32 lots and a 4.65-m^2 infiltration trench on each of the remaining 32 lots, for a total of 267.56 m^2 of bioretention cells and 148.64 m^2 of infiltration trenches within the development. As reported in the bottom half of Table 3, at the higher density, BMP control costs increase by $12,005 relative to scenario 1, and by $22,865 relative to the low-density baseline scenario.

Scenario 2B illustrates the potential net profit a developer might earn by installing a set of BMPs that achieve a site score of 80, surpassing the score required for DSMP participation by 10 points. In this situation, three-quarters of the baseline dry pond area is retained, a 13.94-m^2 bioretention cell is incorporated onto each of 32 housing lots, and a 6.97-m^2 infiltration trench is added on each of the remaining 32 lots. In total, 445.93 m^2 of bioretention cells and 222.97 m^2 of infiltration trenches are used in scenario 2B to achieve the site score of 80. Despite the additional BMP cost incurred, DSMP net profit increases from $124,490 to $139,129 at the higher site score because the $29,471 rebate on the participation fee is nearly twice the cost of the additional BMPs. For illustration purposes, we assume that for every point by which the site score exceeds the minimum required target score of 70, the developer receives a 2% rebate on the participation fee. We found other, more expensive, BMP combinations that achieved each reported site score, but do not report these because of space limitations. Under the condition of constant lot price, the developer would maximize profit by enrolling in the DSMP and installing cost-effective LID BMPs to obtain the higher site score of 80 rather than achieve the minimum participation score of 70.

Scenarios 3A and 3B are identical to scenarios 2A and 2B, respectively, except lot price is not constant in scenarios 3A and 3B. Instead, we estimated lot price as a function of size using equation 5. In scenario 3A, the developer must still achieve the required site score of 70 to participate in the DSMP and be eligible for the 26-lot density bonus. Using equation 5, and the knowledge that average lot size is 0.29 acre when 38 lots are built on 11 acres, we determined that the average lot price is $45,340. When the maximum 64 lots are constructed within the subdivision under the DSMP, average lot size decreases to 0.17 acre. After we apply equation 5 to the smaller average lot size, the lot price decreases to $41,260 for all subdivision lots. As reported in Table 3, relative to scenario 2A, the decrease in lot price reduces DSMP participation net profit from $124,490 in scenario 2A to $33,710 in scenario 3A.

When lot price decreases with lot size, as shown in scenario 3B, the additional costs exceed the participation fee rebate when the developer of this specific subdivision achieves a SC of 80 relative to the TSC of 70 required to participate in the DSMP. As reported in Table 3, when lot price decreases with lot size, developer profit is $33,710 at the minimum TSC and decreases to $30,193 at the higher site score. At the lower lot price, the economic incentive is not sufficient for the developer to incorporate the additional LID BMPs into the subdivision's stormwater runoff control plan (beyond the minimum level required for DSMP participation). This occurs because, at the lower lot price, the participation fee is reduced; thus, the rebate on the participation fee is less for each site score point above the required minimum site score. In summary, initial lot value, the degree of lot price responsiveness to lot size, LID BMP control effectiveness, LID BMP cost, and rebate value all significantly impact developer profit and DSMP participation incentives.

Conclusion

Incentive-based policies hold promise for reducing stormwater runoff in urban areas and improving regional water quality by aligning the incentives of regulators with those of residential developers. The proposed DSMP privately finances stormwater control by incentivizing developers to build at a higher density in exchange for adopting LID stormwater BMPs. The proposed DSMP allows stormwater management authorities to exceed the stormwater runoff goals mandated by existing regulations, while enabling developers to earn higher profits. Regional water quality improves as a result of reductions in runoff and improvements in nutrient trapping efficiency.

The DSMP model parameters can be adjusted to fit local economic conditions and adapted to promote multiple water quality objectives and/or site-specific local water quality objectives. For example, if nitrogen or phosphorous loadings are a significant local water quality concern, one can modify the site score formula to place greater emphasis on controlling nitrogen or phosphorus runoff, thereby encouraging the adoption of LID BMPs that retain these loadings. If developers require greater financial incentives to participate in the program because lot price decreases at higher density or because of higher LID BMP construction costs, one can lower the participation fee or increase the rebate to promote LID BMP adoption. Moreover, the agency administrating the DSMP could use the revenue from participation fees to retrofit existing subdivisions that have substandard stormwater management systems with LID BMPs, further improving regional water quality.

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[i] We use acres instead of hectares because housing lot sizes are typically provided in acres for purposes of county level land use planning