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**Costs and Benefits of Capturing Urban Runoff with Competitive Bidding for  
Decentralized BMPs**

W. Bowman Cutter<sup>1</sup>, Kenneth A. Baerenklau<sup>2</sup>, Autumn DeWoody<sup>3</sup>, Ritu Sharma<sup>4</sup>,  
and Joong Gwang Lee<sup>5</sup>.

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<sup>1</sup> Department of Environmental Sciences, University of California, Riverside, CA, USA  
<sup>2</sup> Department of Environmental Sciences, University of California, Riverside, CA, USA  
<sup>3</sup> Department of Environmental Sciences, University of California, Riverside, CA, USA  
<sup>4</sup> Department of Environmental Sciences, University of California, Riverside, CA, USA  
<sup>5</sup> Tetra Tech, Inc. Boulder, CO, USA.

1 Urban stormwater runoff is both a source of pollution and a potentially valuable resource.  
2 Centralized facilities traditionally have been used to manage runoff. Decentralized Best  
3 Management Practice (BMP) options may be able to avoid the costs of purchasing expensive  
4 urban land needed for centralized facilities. We investigate the cost-effectiveness of  
5 implementing BMPs in a Los Angeles area watershed with two voluntary incentive mechanisms:  
6 competitive bidding and a fixed subsidy. The subsidy mechanism has lower BMP placement  
7 costs but generates relatively large excess profits for landowners. The bidding mechanism has  
8 higher BMP placement costs, but generates smaller excess profits and tends to be more cost-  
9 effective for the regulator particularly at higher runoff capture levels. We also compare the costs  
10 of bidding and centralized alternatives and find that the bidding alternative is significantly less  
11 costly than a centralized alternative for a range of stormwater capture goals. Finally, we examine  
12 the value of infiltrated stormwater and find that it is up to 38% of total BMP costs

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**1. Introduction**

Urban stormwater runoff is both a significant pollution problem as well as a potential resource. The pollution problem results from the “urban sludge” (heavy metals, petroleum residue, salts, solid waste, etc.) that is carried off impermeable surfaces by storm events and washed into receiving water bodies where it damages ecological and recreational resources (Arnold and Gibbons 1996). If these pollutants can be effectively removed from stormwater then runoff also represents a potentially beneficial resource. Without urban development more of this runoff would naturally infiltrate and replenish groundwater stocks, but instead it is treated as a waste and disposed of accordingly (Ferguson 1994). Groundwater supplies in urban regions thus remain lower than they might be otherwise, which seems especially inefficient in arid regions such as the U.S. desert southwest. In light of recent predictions of increased likelihood of long-term drought in such areas (IPCC 2007, Seager et al. 2007), it is imperative to investigate cost-effective ways to capture, clean, and infiltrate more of this potential resource.

The dominant paradigm in stormwater management has been to avoid flooding by quickly conveying runoff to a receiving water body (Ferguson 1998). For this purpose, conveyance structures that centralize runoff are essential. Local stormwater agencies have continued to emphasize centralized solutions even as the emphasis on water quality in receiving waters has grown. These centralized facilities (such as detention pond, infiltration pits and trenches, artificial wetland, etc.) have the advantage of economies of scale where large capacities are cheap on a per-unit capacity basis. However, in order to use that capacity, such facilities must drain a large area. In dense urban areas it is often difficult to achieve this goal without impinging on private land, purchasing contiguous land parcels, or significantly redesigning redevelopment to accommodate centralized facilities.

1           Recent work has focused on the use of decentralized parcel-level best management  
2 practices (BMPs) for managing runoff or improving runoff quality across a larger area of a  
3 landscape. Arabi et al. (2006) uses a genetic algorithm approach to find the most cost-effective  
4 approach to implementing BMPs to control pollutants in agricultural runoff. Similar papers that  
5 use an optimization approach to find the best placement of parcel-level BMPs include Bekele  
6 and Nicklow (2005), Muleta and Nicklow (2005) and Srivastava et al. (2002) among others.  
7 Perez et al. (2005) examines optimal placement of infiltration BMPs in a watershed to control  
8 peak runoff.

9           Although decentralized BMPs cannot provide the same scale economies as centralized  
10 facilities, they do not require large contiguous land areas. Furthermore they can be placed on  
11 parcels with relatively low marginal land use value thus effectively reducing the total installation  
12 cost. This is particularly beneficial in dense urban areas where land values can be in the millions  
13 of dollars per acre. It is therefore an empirical question whether centralized or decentralized  
14 runoff control is more cost-effective.

15           In order to exploit their potential cost advantage, decentralized BMPs must be targeted at  
16 parcels with relatively lower costs of converting land to BMP area. If a regulatory agency  
17 oversees relatively few parcels, has good information about costs, and has the authority to order  
18 BMP installations, then it may be relatively straightforward for the agency to impose the least-  
19 cost placement of BMPs. However, with many parcels, limited information, and/or limited  
20 authority, the agency may not be able to implement this approach in practice. Instead the agency  
21 can employ relatively simple economic incentive policies to encourage BMP installations by  
22 private landowners.

1           At least two types of incentives have been examined previously: a fee/rebate system  
2 (Thurston 2006) and a tradable allowance system (Thurston et al. 2003; Thurston 2006). Both of  
3 these approaches involve both mandatory and voluntary components: the fee/rebate system  
4 includes a mandatory stormwater fee and a voluntary rebate; the tradable allowance system  
5 involves a mandatory “cap” on total runoff and voluntary trading of runoff allowances. In  
6 addition, both applications involve assignment of BMP types to parcels based on soil types,  
7 rather than allowing endogenous selection of BMP types by landowners. Purely voluntary  
8 competitive bidding also has been proposed in the recent literature (e.g., Roy et al. 2006), but to  
9 our knowledge its cost-effectiveness has not yet been evaluated.

10           Our research extends this work in several ways. First, the incentives we examine are  
11 purely voluntary and thus apply to regulatory agencies with limited authority to compel  
12 landowners to modify their properties to achieve runoff capture goals. In this scenario regulatory  
13 alternatives are limited and economic incentives must provide the entire motivation for  
14 landowner participation in the regulatory program. We believe this is more relevant for existing  
15 developments than new developments where BMP requirements can be more easily built into the  
16 permitting process. The stormwater fee rebates used by several cities (Doll and Lindsey 1999)  
17 are similar to the decentralized, incentive-based systems we propose in that they give financial  
18 incentives for on-site stormwater management. These incentives are structured as discounts on  
19 stormwater runoff charges and are based on retention or detention capacity. However, these  
20 rebates have incentive structures that do not appear to be designed to minimize stormwater  
21 capture costs.

22           Second, in keeping with the voluntary nature of our mechanisms, we allow each  
23 landowner to endogenously select the BMP type and capacity for each parcel, rather than

1 assigning BMP types to parcels based on soil types or other characteristics. Third, we  
2 incorporate a hedonic analysis of land costs for our heterogeneous study area which shows  
3 substantial variability in land costs across parcels. Fourth, we explicitly model the economies of  
4 scale inherent in decentralized BMPs which previous studies typically have overlooked in favor  
5 of a constant marginal cost schedule.

6 We use this framework to estimate costs for two approaches to stormwater runoff  
7 reduction in our Southern California study area: a fixed subsidy paid per unit of runoff captured  
8 by decentralized BMPs, and a competitive bidding process designed to reduce total agency costs  
9 (i.e., budgetary costs for the regulatory agency) below those of the subsidy mechanism. We also  
10 estimate the cost for an equivalent amount of centralized treatment. Our baseline results show  
11 that competitive bidding is more cost-effective than either centralized treatment or a fixed  
12 subsidy for a range of stormwater capture goals. A sensitivity analysis further demonstrates this  
13 result is robust to various combinations of plausible parameter values. Finally we estimate the  
14 value of infiltrated water and find that it represents a significant fraction of total BMP costs.

## 15 **2. Methodology**

16 Our approach posits a constrained cost-minimization problem for the regulator: minimize  
17 the present value of land, construction, and maintenance costs while achieving a desired level of  
18 runoff capture. For the two decentralized mechanisms, we assume landowners act as profit-  
19 maximizers when faced with regulatory incentives. We limit our attention to two infiltration  
20 BMP options: infiltration pits and porous pavement. Infiltration BMPs are likely the best  
21 approach when trying to meet a broad array of water quality, supply, and ecological goals  
22 (Ferguson 1994). We also have good local cost data for these devices. We do not consider  
23 infiltration basins because evidence from Santa Monica City's stormwater program indicates that

1 landowners rarely choose to install this option (DeWoody, 2007). We do not consider swales  
2 because Heaney et al. (2002) states that swales are not usually suitable for commercial/industrial  
3 and heavily urban areas similar to our study site. Future research should examine other BMPs;  
4 however, it is important to note that more BMP choices could only lower the costs or increase  
5 the effectiveness of the incentive-based approach.

6 This study considers the commercial, industrial, retail, and multi-family use parcels in the  
7 Sun Valley watershed near Los Angeles, California (918 parcels with sufficient information, see  
8 figure one for a map of the area). The entire watershed is 4.4 square miles situated on alluvial  
9 rock and gravel soils. Industrial and commercial uses make up 59 percent of the watershed,  
10 residential 35%, and open space 5% of the entire watershed (County of Los Angeles 2004). The  
11 watershed is approximately 63.3 percent impervious. This very heterogeneous watershed is  
12 representative of problematic runoff-generating urban landscapes. We exclude single-family  
13 houses from the parcels we consider because we believe that they are relatively poor candidates  
14 for financial incentives in mixed-use areas because it would be relatively difficult to monitor  
15 single-family houses to ensure BMP maintenance (due to the number of parcels that might be  
16 enrolled) and because economies of scale would be relatively limited on these smaller parcels.  
17 We first simulate runoff and capture for a wide array of parcel characteristics and BMP types and  
18 sizes for the Sun Valley precipitation record. Using these results, we construct reduced-form  
19 relationships between parcel characteristics, BMP capacity, and runoff capture for each  
20 infiltration rate. We use the reduced form equations to model the fixed subsidy mechanism and  
21 determine the optimal location and sizing of infiltration capacity across the watershed. We then  
22 construct the competitive bidding mechanisms intending to approximate the optimal mix of BMP  
23 types and capacities.

1 **2.1. Runoff and BMP Modeling**

2 We model runoff and BMP capture at the parcel level using the spreadsheet-based  
3 STORM (SS STORM) runoff and BMP modeling approach. SS STORM is a mass-balance  
4 based area-normalized stormwater flow routing and water quality simulation model (Lee et al.  
5 2005). This model originated from STORM (Storage, Treatment, Overflow, Runoff Model)  
6 which has been used to find the best mix of stormwater storage and release control strategies  
7 over an extended period (Hydrologic Engineering Center 1977). This model can work with  
8 parcel level data on parking, roof, and permeable area. Standard local roll parcel data does not  
9 contain this information. In order to estimate these areas we obtained real estate sales data with  
10 the building footprint or roof area and the number of parking spaces on the property and matched  
11 the real estate parcels sales data to the local roll data for 550 parcels in and around Sun Valley.  
12 We used a regression approach to estimate the relationship between plot characteristics and  
13 pervious, rooftop, and parking area. We use these estimates of parking, roof, and impermeable  
14 area for runoff and land cost estimates in the optimization modeling. The procedure is presented  
15 in appendix A (see <http://www.envisci.ucr.edu/faculty/baerenklau.html>) Table 1 lists the estimates for  
16 the 918 non-single-family parcels in the Sun Valley area.

17 We customize SS STORM to the Sun Valley area by incorporating a five year hourly rain  
18 file from the nearby La Tuna Canyon rain station. In addition, we assume a number of other  
19 parameter values summarized in Table 2. In order to make the optimization modeling tractable,  
20 we use regression analysis to find reduced form specifications that match the simulation models.  
21 However, before reporting our results we take the BMP capacities generated by the optimization  
22 process and simulate runoff capture with SS STORM. Therefore all runoff capture results  
23 presented in the paper are derived from SS STORM simulations.



1 Centralized BMP runoff capture is modeled by using SS STORM to find the capacities  
2 necessary to capture a given proportion of runoff from the 231 hectare area (see Table 3 for the  
3 parameters). We assume the same roof, grass, and pavement proportions, infiltration rates, and  
4 precipitation data as in the decentralized runs. The modeling is approximate and does not  
5 consider conveyance travel times; therefore cost comparisons for an actual application should  
6 implement a more detailed flow-routing model.

## 7 **2.2. Land, Construction, and Maintenance Costs**

8 When landowners dedicate a portion of their parcel to a BMP, they likely forgo other  
9 potentially more valuable uses of that land. Losing the opportunity to otherwise employ that  
10 land area has a cost, but it is likely less than the cost of buying land because the owner does not  
11 lose all uses of the land. We assume that it would be prohibitively expensive to tear down  
12 buildings to replace them with BMPs. That leaves parking and permeable areas as area that  
13 could be used for BMPs. We assume the owner values area devoted to infiltration pits as  
14 permeable area and the area devoted to porous pavement as parking. Because parking is more  
15 valuable than permeable area in our sample, land costs are incurred only when infiltration pits  
16 displace existing parking area.

17 We use a three step process to estimate this land use cost that is explained in detail in  
18 DeWoody (2007). First, we estimate a hedonic regression equation that relates property values  
19 to variables including parking and permeable area. For this step we use real estate data covering  
20 the sales of non-single-family residential parcels from 1996-2005 over most of Los Angeles  
21 county. Next, we use this regression equation to estimate property values for each eligible Sun  
22 Valley parcel. Then we simulate the net cost of replacing parking area with permeable area by  
23 decreasing the parking area and increasing the permeable area by equal amounts and using the

1 regression equation to predict a new property value. The difference in estimated property values  
2 between the original property and the modified property divided by the change in area is our  
3 estimate of the opportunity cost of converting parking area to infiltration pit area. Table 4 shows  
4 the summary statistics for the estimated opportunity costs of parking in the study area by land  
5 use. The unit land values are high enough so that only a few properties at the highest capture  
6 percentages incur land costs by converting parking area to infiltration pits. At these land prices,  
7 parking area is essentially fixed so in the interest of conserving space the hedonic regressions are  
8 not included in this paper.

9 Centralized BMPs also occupy land which, whether it is land that is explicitly purchased  
10 for the BMP or existing public land, will likely have an opportunity cost similar to the market  
11 value of land. For these land costs we use data on 1,398 land sales in the area from 2003-2005  
12 from the COSTAR real estate database. Table 5 shows the median price per square meter for  
13 vacant land zoned for retail, commercial, or residential uses and for different areas of Los  
14 Angeles County. For the comparisons in this paper we use the \$696/m<sup>2</sup> value that is the mean  
15 for the San Fernando Valley area where Sun Valley is located. Comparison of Table 4 and Table  
16 5 shows the estimated average parking use values for the parcels in Sun Valley are significantly  
17 less expensive than vacant land in the same geographic area.

18 Detailed descriptions of our construction and maintenance cost calculations are provided  
19 in DeWoody (2007). Here we summarize the cost functions used for our baseline results.  
20 (appendix B at <http://www.envisci.ucr.edu/faculty/baerenklau.html> describes the cost ranges used for  
21 our sensitivity analysis.) Construction costs for infiltration pits are estimated using the  
22 following equation which was chosen based on goodness of fit with available data:

23 
$$cost = \gamma_1 (capacity)^{\gamma_2} \exp[\gamma_3 + \gamma_4 (\gamma_5 + \ln[capacity])^2] + \gamma_6 + \gamma_7 \ln(\gamma_8 + e^{\gamma_9 capacity}) \quad (1)$$

1 Where: capacity ( $m^3$ ) = area ( $m^2$ )  $\times$  depth (m)  $\times$  void fraction;  $\gamma_1=1665.46$ ;  $\gamma_2=1.33$ ;  $\gamma_3=1.55$ ;  
2  $\gamma_4=-0.049$ ;  $\gamma_5=5.58$ ;  $\gamma_6=-5622.60$ ;  $\gamma_7=1464.29$ ;  $\gamma_8=47.67$ ; and  $\gamma_9=0.074$ . The second two  
3 terms keep marginal costs in a narrow range for relatively large capacities where DeWoody  
4 (2007) has little data. For maintenance costs we use estimates from the Southeastern Wisconsin  
5 Regional Planning Commission (SWRPC 1991) updated to 2005 dollars using the Engineering  
6 News Record Los Angeles construction cost index. From this we derive a maintenance cost for  
7 infiltration pits of \$ 1.89E-04 / $m^3$  of void capacity/year. We also add 1.13% of capital costs per  
8 year to reflect periodic rehabilitation costs (EPA 1999).

9 The construction cost for porous pavement (specifically, porous concrete) has been  
10 estimated between \$48.44 / $m^2$  for large installations with porous soils and \$96.88 /  $m^2$  for small  
11 installations with poor soils where existing asphalt must first be removed (Youngs, California  
12 Cement Council, verbal communication, 2006). We use an estimate of \$86.11 / $m^2$  in our  
13 baseline simulations that is appropriate for small installations with well-drained soils. We derive  
14 porous pavement maintenance cost estimates from SWRPC (1991) updated to 2005 dollars using  
15 the Los Angeles Engineering News Record construction cost index. This gives an annual  
16 maintenance cost for the Los Angeles area of \$0.0753 / $m^2$  of porous pavement.

17 For construction and maintenance cost data on centralized alternatives we use  
18 information contained in RWQCB-LA (2005), Caltrans (2001), USEPA (1999), and FHA  
19 (2003). We restrict our attention to two designs proposed by local regulators (RWQCB-LA  
20 2005): infiltration trenches and infiltrations basins. We concentrate on these two designs because  
21 they are the key infiltration technologies identified as possible centralized devices by Los  
22 Angeles area water quality regulators (RWQCB-LA 2005). Since economies of scale are a  
23 critical part of the comparison between centralized facilities and decentralized BMPs it would

1 not be useful to examine centralized facilities for which this information is not available. The  
2 cost for infiltration trenches is based on FHA (2003), inflated to 2005 dollars using Engineering  
3 News Record (ENR) cost indices:

$$4 \qquad \qquad \qquad \text{cost} = 1661.7 \text{ capacity}^{0.63} \qquad \qquad \qquad (2)$$

5 where *capacity* is measured in cubic meters. EPA (1999) estimates the annual maintenance cost  
6 are between 5-10% of the construction cost; we use 7.5% as our baseline value. We add an  
7 additional 1.13 % of capital costs per year for rehabilitation costs based on periodic rehabilitation  
8 (EPA 1999) for a total maintenance and rehabilitation cost of 8.63% of capital costs per year.

9         FHA (2003) also estimates the construction cost of infiltration basins. These may be  
10 more cost-effective alternatives than infiltration trenches or sand filters for larger drainages  
11 (FHA 2003). After adjusting the costs to 2005 dollars, construction costs are:

$$12 \qquad \qquad \qquad \text{cost} = 205.16 \text{ capacity}^{0.69} \qquad \qquad \qquad (3)$$

13 where *capacity* is measured in cubic meters. FHA does not estimate maintenance costs for this  
14 BMP, so we use an annual value of 5% of construction costs which is at the lower end of the  
15 range of the other centralized alternatives. We add an additional 1.72 % of capital costs per year  
16 for rehabilitation costs based on periodic rehabilitation (FHA 2003) for a total maintenance and  
17 rehabilitation cost of 6.72% of capital costs per year.

### 18 **2.3. Enforcement and Monitoring Costs**

19         For the comparison between centralized and decentralized systems it is not the level of  
20 enforcement and monitoring costs that matter, but the difference between decentralized and  
21 centralized costs. The enforcement, monitoring, and other transaction costs for an incentive-  
22 based system are difficult to determine. The limited evidence that exists suggests that these costs  
23 are high for residential properties. Only one of the cities in Doll and Lindsey's (1999) list of

1 cities that implement incentives for BMP adoption allows residential owners to be eligible for the  
2 credits. This data lends further support to our decision to not include residences among the  
3 property types eligible for incentives.

4 It seems likely that the transaction costs for monitoring many small BMPs will be larger  
5 than for a few larger BMPs. However, centralized infrastructure, especially when placed in  
6 multiple-use open space such as parks, also needs regular monitoring and upkeep agreements.  
7 Though these costs may be lower than the enforcement and monitoring costs of a decentralized  
8 approach, they will still be significant. The cost difference in enforcement and monitoring is an  
9 open question for future research.

#### 10 **2.4. Optimal Placement and Sizing of Decentralized BMPs**

11 We define “optimal” decentralized BMP implementation as the combination of BMP  
12 types, sizes, and locations that minimizes the present value of land, construction, and  
13 maintenance costs (which we call the “BMP placement cost”) for all parcels while achieving the  
14 desired level of runoff capture. This ideal cost-minimizing solution may not be attainable in  
15 practice, but it provides a useful best-case scenario against which practical second-best solutions  
16 may be compared.

17 Any decentralized solution potentially involves many parcels. An important aspect of  
18 our specific problem is that parcels can be treated independently from one another. Runoff from  
19 any parcel enters directly into streets, gutters, and other conveyances where it flows to an  
20 eventual outfall (the Los Angeles River) without flowing back across any other parcels where it  
21 might be captured by other BMPs. This means there is no parcel-to-parcel runoff and therefore  
22 runoff capture on any parcel does not affect capture on any other parcels (Merrill, personal  
23 communication, 10/16/2007). This is a common situation in urban and suburban areas,

1 especially with non-single family parcels and where parcel-to-parcel runoff is prohibited by law,  
2 which differentiates urban from rural and agricultural areas where parcel-to-parcel runoff is more  
3 common and thus parcels cannot be treated independently (Arabi et al. 2006). Furthermore,  
4 shallow groundwater mounding and lateral flow also is not an issue due to a very low  
5 groundwater table. Therefore infiltration at any parcel is not affected by infiltration at any other  
6 parcel.

7 Parcel independence also allows us to solve a simpler set of “dual” unconstrained profit-  
8 maximization problems instead of the more complicated “primal” constrained cost-minimization  
9 problem mentioned earlier (Silberberg 1990). The solution to the primal would require solving a  
10 high-dimensional problem with 3672 variables: a binary variable for each BMP type and a  
11 continuous variable for each BMP size at each of 918 parcels. This solution would generate  
12 optimal BMP locations and sizes. It also would allow us to calculate the marginal cost of capture  
13 (\$/unit) at each parcel. A necessary condition for the cost-minimizing solution is that the  
14 marginal cost of capture is equal across all parcels with BMPs. We can use this condition to  
15 instead solve a set of “dual” problems in which we find the lowest common payment (subsidy)  
16 per unit of capture that induces independent profit-maximizing landowners to build enough BMP  
17 capacity to achieve the desired amount of runoff capture. Each of these 918 independent  
18 problems involves only 4 variables (2 binary and 2 continuous variables per parcel) and thus is  
19 much easier to solve than the primal problem. A simple grid search finds the optimal payment.

20 A potential problem with the dual approach is related to the shape of the marginal cost of  
21 capture function. As discussed previously, we find that the marginal cost of capture at the parcel  
22 level often decreases for small BMP sizes (low levels of capture) due to economies of scale, but  
23 eventually increases for larger BMP sizes (high levels of capture) due to the relative infrequency

1 of large storms. Thus the marginal cost of capture is U-shaped (Figure two). If the marginal cost  
2 of capture were strictly increasing (and if certain other mathematical conditions are satisfied,  
3 including continuous differentiability of the cost function and convexity of the feasible solution  
4 set), offering landowners a fixed subsidy per unit of capture could achieve the optimal BMP  
5 placement and sizing as described in the dual problem above. But when marginal cost is U-  
6 shaped, a subsidy may not achieve the optimal result. This is because the subsidy induces each  
7 landowner with a U-shaped marginal cost curve to build either no capacity or a relatively large  
8 capacity (associated with the upward sloping part of the marginal cost curve). But it may be  
9 optimal for a landowner to build a relatively small capacity (associated with the downward  
10 sloping part of the curve) that also has the appropriate marginal cost. However, the optimal  
11 solution to our primal problem necessarily involves at most only one landowner building a  
12 capacity associated with the downward sloping part of his/her marginal cost curve; otherwise  
13 total cost can be reduced by increasing capture at one parcel and decreasing it at the other.  
14 Because we have hundreds of landowners, if one builds a sub-optimal capacity this will not have  
15 a significant effect on either the total BMP placement cost or the total runoff capture. Therefore  
16 we can be assured that a fixed subsidy per unit of runoff capture will result in BMP locations and  
17 capacities that are arbitrarily close to the optimal solution to our constrained cost-minimization  
18 problem.

## 19 **2.5. Policy Options: Subsidy and Bidding Mechanisms**

20 A practical problem with offering a fixed per-unit subsidy to encourage voluntary BMP  
21 installation is that landowners who choose to install BMPs do so because it is profitable. That is,  
22 their subsidy revenue exceeds their BMP placement cost, and therefore the agency cost (the  
23 present value of all the payments made to landowners) exceeds the BMP placement cost,

1 possibly by a significant amount. One way to reduce the agency cost, relative to the subsidy  
2 case, is to utilize a competitive bidding process. Competitive bidding can reduce the total  
3 agency cost by creating an incentive for bidders to lower their offer prices, thereby effectively  
4 giving up some of the excess profit (defined here as the economic rent received from ownership  
5 of private information) they would earn in the subsidy case. The incentive is inherent in the  
6 competition among landowners who do not know how other landowners will bid: a higher price  
7 reduces the chance that a bid will be accepted, in which case the landowner earns no excess  
8 profit; whereas a lower price increases the chance that it will be accepted, in which case the  
9 landowner earns a positive excess profit. Thus each landowner tends to offer a lower price in  
10 hopes of earning at least some excess profit. The upshot is that if landowners can be induced to  
11 offer (bid) to install BMP capacities that are similar to those they would install in the subsidy  
12 case, a well-designed bidding process should reduce the total agency cost below that for the  
13 subsidy case.

14 In light of the preceding, we investigate the cost-effectiveness of both subsidy and  
15 bidding instruments for inducing voluntary installations of decentralized BMPs that achieve  
16 various annual aggregate runoff capture targets for the Sun Valley watershed. For the subsidy  
17 mechanism, our goal is to find the smallest annual per-unit payment that achieves the desired  
18 level of (estimated annual long-run average) runoff capture. Runoff capture is determined by the  
19 BMP capacity installed by each landowner, as determined by SS STORM. The capacity installed  
20 by each landowner is given by the solution to a parcel-level optimization problem whereby the  
21 landowner selects the BMP types and capacities that generate the most excess profit given the  
22 subsidy level being offered.



1           The subsidy mechanism compensates each participating landowner with an annual  
2 payment throughout the useful life of the BMP in exchange for incurring land and construction  
3 costs initially and maintenance costs periodically (other opportunity costs of participating in the  
4 program, such as acquiring information, submitting an application, and maintaining records, are  
5 not explicitly modeled here). Thus each landowner faces a problem no different from that of  
6 investing in a financial instrument that will pay a fixed annual dividend in the future. Each  
7 landowner also faces a strong incentive to remain in the program for the entire duration because  
8 early exit (i.e., removing the BMP or failing to perform required maintenance) from this payment  
9 schedule reduces the effective rate of return below the minimum acceptable rate. Therefore we  
10 assume each landowner acts to maximize the net present value of participating in the BMP  
11 subsidy scheme as though it were a financial instrument. In our baseline scenario we specify a  
12 time horizon of 30 years and a discount rate of 8% for the present value calculation. We select  
13 30 years because it is a common time horizon for long-term investments (e.g., treasury bills,  
14 fixed mortgages). We select an 8% discount rate to reflect the opportunity cost of “investing” in  
15 the BMP rather than in other available low-risk investments such as government bonds.  
16 Therefore, if there is no combination of BMP types and capacities that can generate at least an  
17 8% before-tax rate of return over a 30 year time period, we assume the landowner will choose  
18 not to participate in the subsidy program and will instead invest elsewhere. Later we conduct a  
19 sensitivity analysis of the discount rate

20           Mathematically, each landowner’s optimization problem under the subsidy mechanism is  
21 expressed as:

$$22 \quad \max_{\{I,P\}} \left[ \sum_{t=1}^{30} \left( \frac{s \cdot PCPT(I+P) \cdot R - m_I I - m_P P}{(1+r)^t} \right) - C_I(I) - C_P(P) - L(I) \right] \quad (4)$$

1 Where:  $I$  is the installed capacity of infiltration pits and  $P$  is the installed capacity of porous  
2 pavement;  $t$  is time measured in years;  $r$  is the annual discount rate;  $s$  is the per-unit subsidy;  
3  $PCPT$  is percent capture averaged over the five-year hydrological record;  $R$  is estimated annual  
4 runoff;  $m_I$  and  $m_P$  are maintenance costs per unit of capacity for each type of BMP;  $C_I$  and  $C_P$  are  
5 construction costs for each type of BMP (each a function of BMP capacity); and  $L$  is land cost  
6 for infiltration pits. We also impose upper and lower constraints on BMP capacity, both to  
7 prevent total BMP area from intruding into the building footprint (or exceeding the total paved  
8 area, for porous pavement) and to preclude construction of very small BMPs (no less than 50  
9 square feet for infiltration pits and 100 square feet for porous pavement, but sometimes larger for  
10 very large parcels).

11 After converting this expression and the associated functions and constraints into a form  
12 that is amenable to numerical optimization, we end up with a mixed-integer non-linear  
13 programming problem that can be solved to obtain each landowner's optimal response to any  
14 given subsidy. We solve this problem using the GAMS programming language and the BARON  
15 commercial solver package to find the globally optimal solution for each landowner. It is then  
16 straightforward to add the subsidy payments and calculate the present value of agency costs and  
17 to determine the total capture. Since all costs reported in the paper are from the agency's point of  
18 view, a discount rate of 5% was used to calculate present values because this is in the middle of  
19 the range of values used by public agencies (Kohyama 2006). This is consistent with the  
20 decision to evaluate all costs from the public agency point of view. From a social point of view  
21 all profits that accrue to landowners are transfers and would not be counted as costs.

22 The bidding mechanism is largely based on the same functions and parameter values  
23 presented above for the subsidy mechanism. However, compared to the subsidy approach, the

1 bidding mechanism provides landowners with an additional degree of freedom: not only can they  
2 specify the attributes of the BMPs, but they also can specify the payments they would require.  
3 Therefore, without additional structure, there is no longer a well-defined solution to the  
4 landowner's optimization problem. Furthermore, bidding potentially involves strategic behavior  
5 by landowners who are competing to have their bids accepted into the program, but who also  
6 want to earn excess profit. Despite the incentive to submit lower bids, some landowners may  
7 strategically bid above their true BMP placement costs in hopes of earning excess profit.  
8 Because the extent of such "bid shading" would be driven by the subjective beliefs and risk  
9 preferences of landowners, it is not obvious how landowners will respond to a bidding program  
10 and thus how cost-effective a bidding program will be without some additional assumptions  
11 about bidding behavior

12         There is a very large economics literature on mechanism design and auction theory.  
13 Latacz-Lohmann and Schilizzi (2005) provide an excellent survey focused on conservation  
14 auctions. The authors emphasize that auction theory offers little guidance for conservation  
15 auction design due to structural differences between conservation auctions and standard auctions  
16 that have been examined in the literature. They also state that empirical studies have produced  
17 mixed results, thus highlighting the importance of practical implementation issues in auction  
18 design. Space limitations prevent a more complete discussion of the rationale for our chosen  
19 bidding mechanism, but we note that its characteristics largely reflect the authors' conclusions.  
20 Future work will examine conservation auction theory in more detail.

21         In our baseline scenario we examine the best possible case where landowners do not  
22 attempt to "shade" their bids (however later we relax this assumption and incorporate bid  
23 shading in the sensitivity analysis of the discount rate). In other words, we assume competitive

1 bidding drives down the rate of return from the BMP program to that of the best alternative  
2 investment (8%), thus generating no excess profit for bidders. (An 8% rate of return is high for  
3 safe investments, so it could also be regarded as combining a lower rate of return requirement  
4 with some bid shading.) This allows us to specify that any bid must satisfy a zero excess profit  
5 condition when the net present value is calculated at an 8% rate of return; however, it does not  
6 tell us which of many bids that satisfy this condition will be chosen by each bidder.

7         Therefore we must specify what constitutes a “good bid” before we can model how bids  
8 are generated. If all bidders were submitting bids for a uniform amount of runoff capture, then a  
9 good metric would be the bid price: the lower, the better. However, in this case landowners will  
10 submit bids for different BMPs based on the characteristics of their land. Therefore we need to  
11 specify a metric for ranking bids that involves different BMP capacities and bid prices. To do  
12 this, we define an “index function” that converts a bid of the form [infiltration pit capacity,  
13 porous pavement capacity, annual payment] into a numerical value with higher values  
14 corresponding to “better” bids. We then assume that each landowner submits the bid that  
15 maximizes this index function for his/her parcel subject to the zero excess profit condition, and  
16 that the regulator ranks all bids by the index values and accepts bids in rank order until the  
17 capture target is satisfied.

18         For any desired level of runoff capture, the ideal index function would induce landowners  
19 to submit bids with the same BMP capacities as would be induced by a subsidy that achieves the  
20 same level of capture *and* give up all excess profits that would be earned from the subsidy  
21 mechanism (i.e., bid their true BMP placement cost). This would allow placement of optimal  
22 BMP capacities at each parcel at the lowest possible cost. However, designing and  
23 implementing such an ideal index function generally is not possible when the agency has

1 incomplete information. Intuitively, for our case, this is because landowners must be  
 2 compensated for revealing their private information about land costs. Therefore we implement a  
 3 simpler index function that encourages landowners to bid relatively large capacities (which the  
 4 results for our subsidy mechanism reveal to be desirable) and relatively low prices.

5 Each landowner’s optimization problem under the bidding mechanism is expressed as:

$$\begin{aligned}
 & \max_{\{I,P,S\}} \left[ \frac{(PCPT(I+P) \cdot R)^\alpha}{S} \right] \\
 & s.t. \sum_{t=1}^{30} \left( \frac{S - m_I I - m_P P}{(1+r)^t} \right) - C_I(I) - C_P(P) - L(I) \geq 0
 \end{aligned} \tag{5}$$

7 The term in square brackets is the index function: the numerator is the total capture (with terms  
 8 defined in Equation (4)) raised to the power  $\alpha$ ; the denominator is the bid price (a total annual  
 9 payment rather than per-unit of capture as in the subsidy case). The second line is the zero  
 10 excess profit condition which acts as a constraint. Setting-up the associated Lagrangian and  
 11 deriving the first order conditions for a solution shows that  $\alpha$  can be selected by the agency to  
 12 “tune” the index function for different capture goals: a larger value tends to elicit bids for larger  
 13 BMP capacities and thus better approximates the outcome of a relatively large per-unit subsidy.  
 14 However because this index function is not ideal, it does not exactly replicate the optimal BMP  
 15 locations and capacities produced by the subsidy mechanism; but it does provide an incentive for  
 16 landowners to reduce their bid prices. Therefore, as modeled here, the agency faces a trade-off:  
 17 departing from the optimal placement and sizing of BMPs tends to increase BMP placement  
 18 costs and thus increases total agency costs, but competition among bidders tends to reduce  
 19 excess profits and thus reduces total agency costs. The relative cost-effectiveness of the  
 20 decentralized incentives is thus an empirical question.

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**3. Results**

We analyze the cost and performance of both mechanisms for our baseline estimates described above and for a range of plausible parameter values described in the sensitivity analysis below. In nearly all cases, the bidding mechanism achieves the desired capture level at considerably less cost than the fixed subsidy. We also compare centralized and incentive-based alternatives and find that a bidding alternative is almost always less expensive than the centralized solution. Finally, we examine the value of runoff infiltration and find that it is a significant proportion of BMP costs.

**3.1. Baseline Estimates**

Table 6 shows the relative performance of the incentive instruments for different proportions of total runoff capture (Column 1) assuming baseline parameter values. Column 2 shows the minimum BMP placement cost. Column 3 shows the agency cost of achieving the capture proportion with a fixed subsidy. The subsidy is at least 35% more expensive than the lowest achievable cost. The difference between Columns 2 and 3 represents excess profit earned by participating landowners. The difference shown is excess profit from the regulator’s perspective (discounted at 5%) rather than from the landowner’s perspective (discounted at 8%). Landowners thus perceive the excess profit to be smaller. Columns 4 through 6 give the agency cost of achieving the given level of capture with the different bid indices (i.e.,  $\alpha = 1.0, 1.2,$  and  $1.4,$  from left to right). The bidding mechanisms have lower costs for the same capture proportion at every level of capture and tend to be substantially more cost-effective at higher levels of capture: bid two is only 71% of the subsidy cost at 45% capture. This is because, in order to achieve a higher capture level, a subsidy provides a higher per-unit payment for all

1 participants whereas a bidding approach raises the payment level only for the marginal  
2 participant. Thus the bidding approach approximates the aggregate cost curve better than the  
3 subsidy approach, particularly at high capture levels. Among the bidding mechanisms, bid two  
4 has the lowest average cost across the three capture percentages and thus is arguably the most  
5 preferred if one had to select a single mechanism for a range of capture values; therefore we use  
6 it below in our baseline comparison with a centralized approach.

7         The key issue in deciding when centralized or decentralized alternatives perform better is  
8 whether the land cost savings of a decentralized approach outweigh the capacity cost savings due  
9 to the economies of scale of centralized facilities. Table 7 shows that the land cost savings of an  
10 incentive-based system outweigh the economies of scale advantages of a centralized system. Bid  
11 two is significantly less expensive than either a centralized infiltration trench or infiltration basin  
12 for capture levels between 10 and 45 percent of total runoff for the baseline parameter values.  
13 The cost advantage is greatest at lower capture levels where bid two is less than half the cost of  
14 an infiltration trench (the most cost-effective centralized approach). At higher capture levels the  
15 cost difference narrows, but even at 45% capture the bid two cost is only 61% of the costs of the  
16 infiltration trench. Of course it is unlikely that a centralized facility could drain 231 ha in the  
17 Los Angeles area as is assumed in this analysis. For instance, the metals TMDL assumed that  
18 BMPs would be sized to drain an average of only 2.02 ha each (RWQCB-LA 2005). This  
19 implies that the cost advantage of a decentralized system would generally be greater than this  
20 comparison implies.

21         The land costs savings are the major factor in making an incentive based approach more  
22 cost-effective. Table 7 shows that construction and maintenance costs are much higher for bid  
23 two than the infiltration trench, as we expect given the greater economies of scale for the

1 centralized alternatives. However, the land cost savings more than make up the difference. This  
2 implies that some sort of incentive-based mechanism is crucial for deploying parcel-level,  
3 decentralized BMPs. A traditional command-and-control regulatory approach might force  
4 landowners to displace high-value land uses, which would eliminate the cost advantage of  
5 decentralized BMPs.

6 Net costs of infiltration approaches are further reduced if one considers the value of the  
7 infiltrated water. Our analysis considers a range of water values: 1) a low value of  $\$0.40/\text{m}^3$  from  
8 The Los Angeles Department of Water and Power; 2) a mid-range value of  $\$0.65/\text{m}^3$  reflecting  
9 historical water supply risks from Cutter (2007); and 3) a high value of  $\$0.81/\text{m}^3$  reflecting future  
10 drought risks due to climate change (Seager et al. 2007). For bid two, we then calculate the  
11 present value of infiltrated water for a range of capture proportions using the average yearly  
12 infiltration modeled over the 2001-2006 precipitation record. At low capture levels and with the  
13 highest water values infiltration benefits are 38.5% of costs (see Table 8). This percentage  
14 declines with the capture percentage due to the increasing marginal cost of capture.

### 15 **3.2 Sensitivity Analysis**

16 We construct plausible ranges for important parameters to test the robustness of our  
17 finding that bidding is more cost-effective than a subsidy or a centralized facility. We use a  
18 quantile regression approach to Equation (1) to predict the 25<sup>th</sup> and 75<sup>th</sup> percentile of  
19 construction costs for infiltration pits. We also establish a likely range of costs for porous  
20 pavement in our study area:  $\$70/\text{m}^2$  to  $\$96.88/\text{m}^2$ . For centralized alternatives we find that our  
21 baseline estimates in Equations (2) and (3) are low compared to available Los Angeles data, so  
22 we use multiples of these estimates to establish mid-range and high cost estimates that better  
23 reflect the Los Angeles data (note that this means our baseline cost comparison in Table 7 favors



1 centralized treatment). We also determine a range of values for the required landowner rate of  
2 return (5% and 11%), with the higher value incorporating our best estimate of the amount of bid  
3 shading we could expect from landowners who would normally demand an 8% return. And we  
4 consider a range of BMP infiltration rates: 25.4 mm/hr and 215.9 mm/hr. A more detailed  
5 explanation and justification for each of these ranges is given in appendix B (see  
6 <http://www.envisci.ucr.edu/faculty/baerenklau.html>.)

7 For each of three capture levels, we calculate agency costs for the subsidy and bidding  
8 mechanisms given each of the 16 possible combinations of decentralized BMP costs, required  
9 rate of return, and infiltration rate. Table 9 reports the cost difference between the subsidy and  
10 bidding approaches for the various combinations of BMP costs and infiltration rates and for each  
11 capture level. At 10% capture subsidies are sometimes superior to a given bid index (denoted by  
12 negative table entries) but never superior to all bid indices. At the higher capture levels bidding  
13 is nearly always more cost-effective except for one case. A subsidy is never more cost effective  
14 than bid two. This is consistent with the findings reported in Table 6 and demonstrates the  
15 robustness of our base case results.

16 We use the same simulations for a sensitivity analysis of the centralized and  
17 decentralized cost comparison (reported for the base case in Table 7). These results are  
18 summarized in Table 10, again for the 16 possible combinations of decentralized BMP costs,  
19 required rate of return, and infiltration rate. Each cell contains the difference between the  
20 infiltration trench cost and the mean of the three bid costs (i.e.,  $\alpha = 1.0, 1.2, \text{ and } 1.4$ ) for the  
21 desired level of runoff capture. Negative numbers indicate that the infiltration trench is less  
22 expensive. This situation occurs in only 6 of 144 cases, and only when decentralized costs are  
23 set at high levels. In all other cases, bidding on average has lower costs, often by substantial

1 amounts. The sensitivity analysis suggests that an incentive-based approach will be significantly  
2 cheaper than centralized facilities in nearly all situations.

### 3 **4. Conclusion**

4 This research shows that a decentralized incentive-based strategy that effectively targets  
5 BMPs at areas with low land use value is likely to be a cost-effective approach for reducing  
6 urban runoff. Whether an incentive-based strategy is more cost-effective than a centralized  
7 approach ultimately depends on whether the land cost advantage of incentive-based BMPs  
8 outweighs the economies of scale advantage of a centralized facility. We find that this trade-off  
9 favors decentralized incentive-based BMPs in all but very few cases, and only when  
10 decentralized costs are at the high end of the range we consider. Construction and maintenance  
11 costs are lower for the centralized alternative due to economies of scale, but land costs are much  
12 greater so the incentive-based approach is overall more cost-effective for our study area.  
13 Notably, realizing the land cost advantage of decentralized BMPs requires a mechanism for  
14 placing BMPs on areas with low land-use value, something which a command-and-control  
15 regulatory approach is unlikely to do.

16 This paper does not attempt to estimate a key benefit of incentive-based approaches –by  
17 rewarding the outcome rather than the technology incentive-based systems are expected to  
18 encourage technological advances. In a system such as we propose, where the incentive payment  
19 is based on the modeled performance of the BMP, there would need to be a process to certify and  
20 model new types of BMPs. A third party organization with academic, regulatory, and  
21 stormwater consulting firm representatives could perform this function. Also, our methodology  
22 does not fully capture the information benefits of a bidding system. In particular we do not

1 directly model the landowner's opportunity cost of time and the greater the heterogeneity in this  
2 cost the more cost-effective bidding is likely to be relative to a subsidy.

3 We also compare bidding and subsidy approaches to implementing a decentralized,  
4 incentive-based system. A subsidy system implements the optimal BMP placement, but allows  
5 for excess profits by landowners. A bid system eliminates the excess profits at the cost of non-  
6 optimal BMP placement. We find that a well-designed bid index (e.g., bid two) is always more  
7 cost-effective than subsidies, and that the cost advantage grows with the capture percentage. This  
8 occurs because the bidding approach achieves greater capture by increasing payment to the  
9 marginal participant while the subsidy approach raises the capture level by increasing the  
10 payment to all participants. The analysis suggests that bidding is a better approach when the  
11 policy aim is to capture a significant portion of runoff.

12 There are costs of centralized and incentive-based systems that are not included in this  
13 analysis. Monitoring and enforcement costs may be higher with a decentralized alternative but  
14 we cannot estimate the cost differential. The cost curves for centralized infrastructure assume  
15 that the local government could purchase large undeveloped parcels in a location that could drain  
16 a large area without the need for additional conveyance infrastructure. It is unlikely that all of  
17 these conditions could be fulfilled in many areas in Los Angeles or any other heavily urbanized  
18 area. A survey of possible infiltration locations and characteristics in Los Angeles could give  
19 more realistic estimates of drainage areas and conveyance costs but such work is beyond the  
20 scope of this article.

21 Incentive-based BMPs will not provide a solution to many runoff problems. They are  
22 likely not cost-effective for single-family houses due to very limited economies of scale and the  
23 expense of monitoring and enforcement across the large number of parcels this would entail.

1 Also, on-parcel BMPs do not capture precipitation which falls directly on streets. Because  
2 single-family parcels and transportation corridors occupy significant portions of total land area,  
3 an incentive-based approach would necessarily complement centralized facilities that would still  
4 manage runoff from a large area.

5         However, it does appear that incentive-based BMPs would be a cost-effective way to  
6 either reduce the size of centralized facilities or eliminate the need for them in heavily  
7 commercial, industrial, or retail areas. An evaluation of the optimal mix of centralized and  
8 incentive-based, decentralized approaches is an interesting topic that is beyond the scope of this  
9 paper but will be an avenue for future research.

10

1 **Notation**

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3  $\gamma_1, \dots, \gamma_9$  constants for infiltration pit cost equation.

4  $I$  installed capacity of infiltration pits,  $m^3$ .

5  $P$  installed capacity of porous pavement,  $m^3$ .

6  $t$  time period, yr.

7  $r$  annual discount rate.

8  $s$  subsidy per unit of expected annual runoff capture (fixed subsidy mechanism),  $\$/m^3$ .

9  $PCPT$  expected percentage of annual runoff capture.

10  $R$  expected annual runoff,  $m^3$ .

11  $m_I$  expected annual maintenance cost per unit of capacity for infiltration pits,  $\$/m^3$ .

12  $m_P$  expected annual maintenance cost per unit of capacity for porous pavement,  $\$/m^3$ .

13  $C_I$  construction cost for infiltration pits, \$.

14  $C_P$  construction cost for porous pavement, \$.

15  $L$  land cost for infiltration pits, \$.

16  $S$  annual BMP payment (bidding mechanism), \$.

17  $\alpha$  parameter selected by the agency to influence bid types.

18

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2

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5

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2 **Tables**3 **Table 1: Estimated Parcel Characteristics for Sun Valley Study Area (non-single-family parcels only).**  
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Land Use	Mean Area (square meters)				Proportion of Area			Obs.
	Parking	Roof	Other	Total	Parking	Roof	Other	
Duplex	136	165	283	584	0.23	0.28	0.49	51
Triplex	162	206	284	651	0.25	0.32	0.44	21
Quadplex	195	219	238	652	0.30	0.34	0.37	36
5plex	478	1,430	184	2,092	0.23	0.68	0.09	139
Commercial1	761	251	266	1,278	0.60	0.20	0.21	122
Commercial2	799	380	427	1,606	0.50	0.24	0.27	125
Industrial	888	846	2,038	3,773	0.24	0.22	0.54	424
Total	712	715	1,094	2,521	0.38	0.36	0.26	918

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6 **Table 2: Baseline Parameter Values for SS STORM.**  
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Parameter	Value	Units
Infiltration Rate	76.2 <sup>a</sup>	mm/hour
Infiltration Pit Depth	1.524	Meters
Infiltration Pit Void Proportion	0.4 <sup>b</sup>	-
Porous Pavement Depth	0.3048	Meters
Porous Pavement Void Proportion	0.22 <sup>c</sup>	-
Depression Storage-Roof	2.7	Mm
Depression Storage-Pavement	10	Mm
Depression Storage-permeable	13.5	Mm

<sup>a</sup> Based on sandy soil of the site<sup>b</sup> Ferguson (1994)<sup>c</sup> www.cncement.org gives a range of .15-.25.

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9 **Table 3: Baseline Centralized Facility Parameters for SS STORM.**  
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Parameter	Value	Units
Infiltration Rate	76.2 <sup>a</sup>	mm/hour
Infiltration Trench Depth	1.524	Meters
Infiltration Trench Void Proportion	0.4	-
Infiltration Basin Depth	0.762	Meters
Infiltration Basin Void Proportion	1	-
Depression Storage-Roof	2.7	mm
Depression Storage-Pavement	10	mm
Depression Storage-permeable	13.5	mm

<sup>a</sup> Based on sandy soil of the site

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**Table 4: Estimated Parking Land Use Costs for Sun Valley Parcels.**

Land Use	(\$/Square Meter)	
	Mean	Median
Duplex	\$0.65	\$0.00
Triplex	7.86	0.00
Quadplex	32.08	31.75
5plex	330.56	315.60
Commercial1	251.23	126.69
Commercial2	296.44	130.57
Industrial	272.00	244.77
Total	250.91	203.22

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**Table 5: Costs for Vacant Land in Los Angeles.**

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(\$/m<sup>2</sup>)

Geographic Area	Land Type*			Total
	Commercial	Industrial	Residential	
Southwest Los Angeles County				
(\$/Square Meter)	\$1,344	\$493	\$1,801	\$1,385
Observations	3,100	1,033	2,519	6,652
San Fernando West of Pasadena				
(\$/Square Meter)	717	348	747	696
Observations	721	226	1,270	2,217
San Gabriel Area				
(\$/Square Meter)	637	280	659	580
Observations	1,518	517	861	2,895
Total				
(\$/Square Meter)	1,058	413	1,301	1,057
Observations	5,339	1,776	4,650	11,765

\* Vacant land sales listed in the Costar sales database from 2003-2005, adjusted to 2005 dollars.

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**Table 6: Cost of Subsidy and Bid Incentives by Capture Proportion for Baseline Parameter Values.**

Capture Percentage	Regulator minimum cost (\$ Millions)	Public Cost (\$ Millions)*			
		Subsidy	Bid 1 ( $\alpha=1.0$ )	Bid 2 ( $\alpha=1.2$ )	Bid 3 ( $\alpha=1.4$ )
10%	0.99	1.34	1.17	1.27	1.27
25%	2.96	4.60	3.85	3.87	3.86
45%	6.61	12.47	9.15	8.82	8.87

\* The public costs are not upfront, but instead are annuitized over 30 years.

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**Table 7: Cost Comparison of Bidding Incentive and Centralized BMP Approach. (\$ Millions)**

BMP	% Capture	Construction	Maintenance	<i>Subtotal</i>	Land Cost	Opportunity Cost*	<b>Total Cost</b>
Infiltration Trench	10	0.178	0.236	<i>0.414</i>	1.911	0.000	2.325
	25	0.342	0.453	<i>0.795</i>	5.386	0.000	6.181
	45	0.546	0.724	<i>1.270</i>	11.336	0.000	12.606
Infiltration Basin	10	0.604	0.624	<i>1.228</i>	1.749	0.000	2.977
	25	1.252	1.293	<i>2.546</i>	5.028	0.000	7.574
	45	2.071	2.140	<i>4.211</i>	10.427	0.000	14.638
Bid 2	10	0.483	0.477	<i>0.959</i>	0.099	0.213	1.271
	25	1.881	1.220	<i>3.101</i>	0.099	0.670	3.870
	45	4.736	2.262	<i>6.999</i>	0.208	1.658	8.865

\* Opportunity cost represents payments to landowners in excess of construction, maintenance and land costs needed to achieve the required rate of return on investment (8%).

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**Table 8: Value of Infiltrating Runoff.**

		Water Value (\$/m <sup>3</sup> )					
		\$0.405		\$0.61		\$0.81	
% Capture	Infiltration (m <sup>3</sup> /Year)	Value (\$M)	Public Cost	Value (\$M)	Public Cost	Value (\$M)	Public Cost
10	39,326	\$0.245	19.2%	\$0.393	30.9%	\$0.490	38.5%
25	96,955	\$0.603	15.6%	\$0.969	25.0%	\$1.207	31.2%
45	174,096	\$1.083	12.3%	\$1.740	19.7%	\$2.168	24.6%

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**Table 9: Subsidy Less Bid Cost Across BMP Cost Ranges and Infiltration Rates. (\$ Millions)**

Bid Index	Infiltration Rate	% Capture	Decentralized Costs*							
			HHH	HHL	HLH	HLL	LHH	LHL	LLH	LLL
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	High	10%	0.103	0.102	0.103	0.103	0.124	0.040	0.111	0.111
		25%	0.756	0.328	0.631	0.727	0.325	0.114	0.378	0.394
		45%	-	-	2.388	2.060	-	-	1.320	1.082
	Low	10%	0.146	-0.154	0.094	0.094	-0.087	-0.221	0.069	0.076
		25%	0.745	0.452	0.647	0.670	0.384	-	0.421	0.423
		45%	-	-	1.941	1.923	-	-	1.496	-
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	High	10%	0.106	0.108	0.114	0.114	0.122	0.021	0.112	0.112
		25%	0.846	0.456	0.699	0.758	0.360	0.256	0.401	0.439
		45%	2.508	2.066	2.703	2.382	1.761	1.365	1.576	1.365
	Low	10%	0.218	0.304	0.068	0.068	0.001	0.056	0.042	0.053
		25%	1.515	1.714	0.727	0.736	1.154	0.783	0.508	0.510
		45%	7.308	4.449	3.460	3.315	3.938	2.357	2.528	2.631
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	High	10%	-0.004	-0.012	0.075	0.075	0.081	-0.013	0.103	0.019
		25%	0.864	0.169	0.543	0.725	0.316	0.113	0.384	0.439
		45%	2.391	1.985	2.728	2.429	1.710	1.389	1.628	1.392
	Low	10%	-0.040	-0.088	-0.003	-0.003	-0.098	-0.174	-0.190	-0.178
		25%	0.725	1.630	0.635	0.310	0.962	0.636	-0.131	0.325
		45%	7.025	4.634	3.141	3.663	3.942	2.031	2.525	2.832

\* The first letter refers to the discount rate (H=11%, L=5%). The second letter refers to the infiltration pit cost (H=75th percentile of costs, L=25th percentile). The third letter refers to the porous pavement costs (H=\$96.88 m<sup>2</sup>, L=\$70 m<sup>2</sup>). Under some conditions, bid one does not provide a strong enough incentive to achieve the higher levels of capture; these are denoted by empty cells.

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**Table 10: Cost Comparison of Bidding Incentive and Centralized BMP Approach. Mean of Infiltration Trench Less Bid Costs. (\$ Millions)**

Centralized Costs	Infiltration Rate	% Capture	Decentralized Costs*								
			HHH	HHL	HLH	HLL	LHH	LHL	LLH	LLL	
Low	High	10%	0.02	0.07	0.76	0.76	0.43	0.48	0.85	0.82	
		25%	-0.55	-0.16	1.51	1.53	0.79	1.13	1.91	1.94	
		45%	-1.49	-0.18	2.15	2.31	1.52	2.44	3.31	3.49	
	Low	10%	0.85	0.76	2.85	2.85	1.86	1.82	3.06	3.06	
		25%	1.41	1.55	7.48	7.36	4.76	5.04	8.17	8.32	
		45%	0.83	2.27	12.83	13.04	8.68	9.92	15.34	15.86	
	Mid	High	10%	0.28	0.33	1.02	1.02	0.70	0.75	1.11	1.09
			25%	-0.05	0.34	2.02	2.03	1.29	1.64	2.42	2.45
			45%	-0.69	0.62	2.95	3.11	2.32	3.24	4.11	4.29
Low		10%	1.46	1.37	3.46	3.46	2.47	2.43	3.67	3.67	
		25%	2.61	2.75	8.68	8.56	5.95	6.24	9.36	9.52	
		45%	2.73	4.17	14.73	14.94	10.58	11.81	17.24	17.76	
High	High	10%	1.27	1.32	2.01	2.01	1.69	1.74	2.10	2.08	
		25%	1.84	2.23	3.90	3.92	3.18	3.52	4.30	4.33	
		45%	2.32	3.63	5.96	6.12	5.34	6.25	7.12	7.30	
	Low	10%	3.75	3.66	5.75	5.75	4.76	4.72	5.96	5.96	
		25%	7.09	7.23	13.16	13.04	10.44	10.72	13.85	14.00	
		45%	9.84	11.28	21.83	22.04	17.68	18.92	24.34	24.86	

\* The first letter refers to the discount rate (H=11%, L=5%). The second letter refers to the infiltration pit cost (H=75th percentile of costs, L=25th percentile). The third letter refers to the porous pavement costs (H=\$96.88 m<sup>2</sup>, L=\$70 m<sup>2</sup>).

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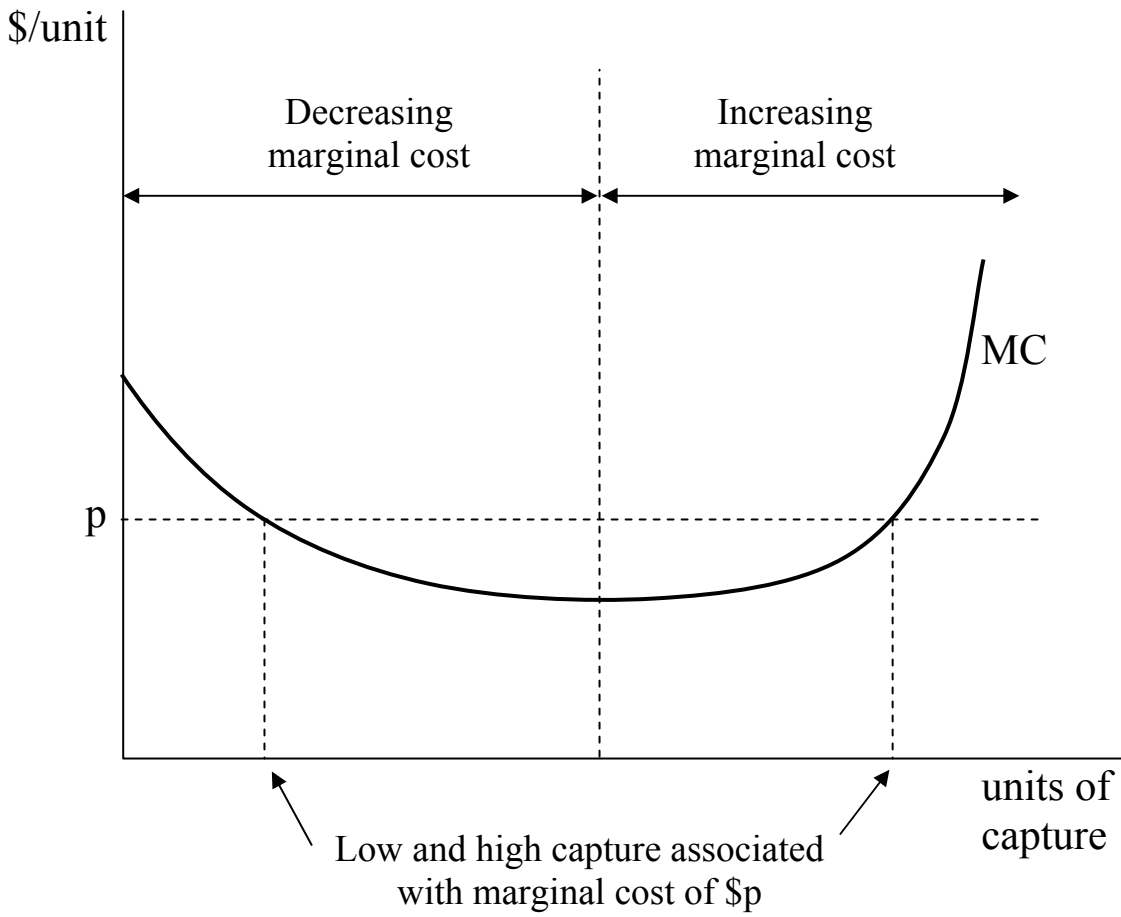
**Figures**

Figure 1: Map of Sun Valley Watershed:

See attached file.

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Figure 2: U-Shaped Marginal Cost.



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