Assessment of Stormwater BMP Cost Effectiveness

A new model for decision makers

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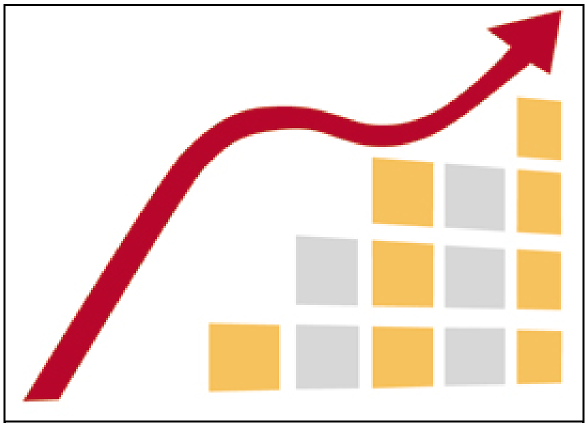

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Communities and agencies responsible for stormwater management—i.e., municipal separate storm sewer (MS4) permit holders—continually face new challenges in the form of more stringent onsite control regulations to protect receiving waters. All these requirements have to be met with limited funding. At the roots of both of these challenges lie stormwater surface runoff best management practices (BMPs), which not only are designed to protect receiving waters from the impacts of urbanization, but also come with significant costs to install and maintain into perpetuity.

To improve stormwater planning and management, communities, decision makers, and regulators need concise and objective information to select stormwater surface runoff BMPs that will be effective and economically sustainable in meeting their goals. To help in reaching these decisions, they need information that compares different BMPs and how they reduce pollutant loads and surface runoff volumes and what the long-term economics are of keeping the BMPs in operation. In many cases, municipalities accept stormwater management facilities or products based on promotional literature or the beliefs of the public or the staff who may have not had access to information that objectively compares BMP performance and whole-life costs.

Unfortunately, little information is available that does allow them to objectively compare how facilities or types of BMPs measure up in being “effective” or what the long-term financial implications are in selecting them. Few tools exist that incorporate parts of this information. For example, the USEPA’s SUSTAIN model (Shoemaker et al. 2009) incorporates sophisticated algorithms for evaluating BMP effectiveness, but its default cost functions are limited only to construction costs, and its use requires a relatively high level of technical expertise. The Water Environment Research Federation’s (WERF’s) Performance and Whole Life Costs of BMPs and SUDS (sustainable urban drainage systems) spreadsheet tools (Lampe et al. 2005) can be used to estimate the whole-life costs of a single BMP at a time; however, they lack BMP effectiveness algorithms.

To assist with these types of decisions, a spreadsheet-based computer model titled “BMP-Rational Estimation of Approximate Likely Costs of Stormwater Treatment” (BMP-REALCOST) (Olson et al. 2010) was developed at the Colorado State University under the sponsorship of the Urban Drainage and Flood Control District, Colorado (UDFCD), and the Urban Watersheds Research Institute Inc. The model is relatively open source and easy to use and permits the user to assess and adjust various program parameters as needed. The economic analysis accounts for inflation, cost of money, and the regional and temporal variations of construction and maintenance costs using the *Engineering News Record* Construction Cost Index (ENR CCI). Additional details on BMP-REALCOST development are provided by Olson et al. (2010).

This article illustrates how BMP-REALCOST can help to compare various types of BMPs a municipality or a state may consider for use by evaluating 10 different BMP scenarios applied to a 1-square-mile urban watershed with mixed land uses in Denver, CO, using a 50-year planning horizon.

Physical Setting for the Example of the Model’s Application
Description of Land Uses in the Example Urban Watershed. The BMP- REALCOST model was used to test a series of BMP application scenarios using the BMP sizing and design standards recommended by UDFCD for use in the Denver, CO, region. The intent was to illustrate how this model can be applied to assess the runoff and pollutant load reductions and the whole-life costs of each BMP type. Each run examined the use of a single BMP type applied uniformly throughout a 1-square-mile watershed. The results illustrate for planners, decision makers, and regulators what their choices of the BMP types used in a community mean in terms of long-term economics, maintenance and rehabilitation costs, administrative costs, and effectiveness in controlling stormwater runoff and its pollutants.

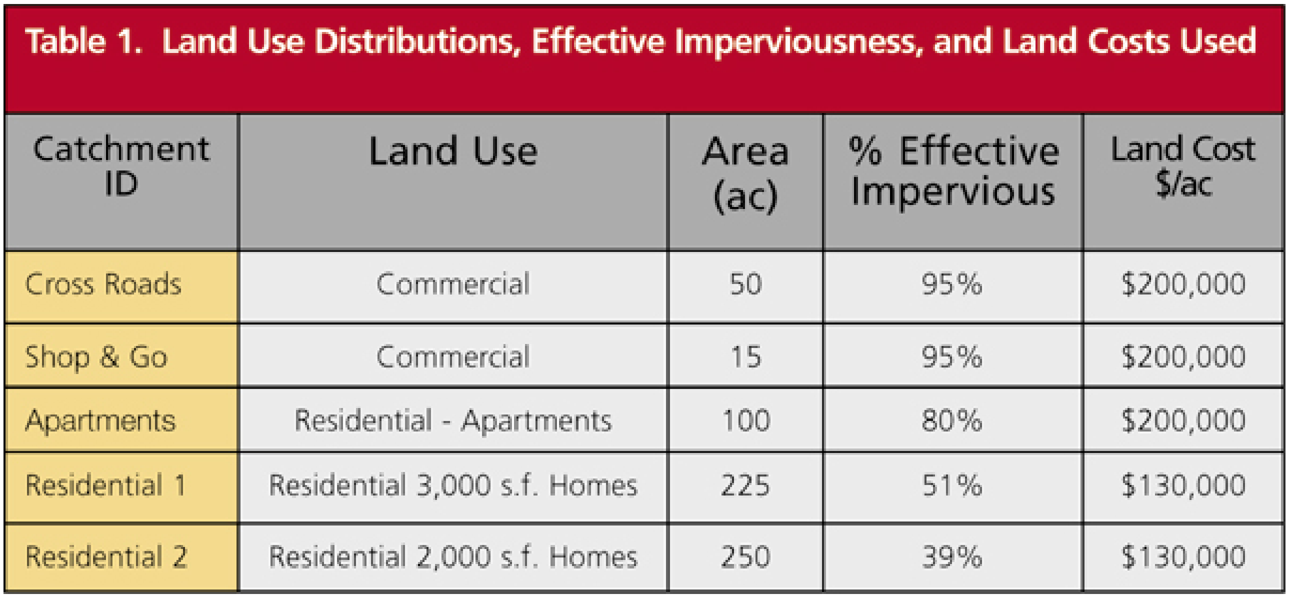

Table 1. Land Use Distributions, Effective Imperviousness, and Land Costs Used

Catchment ID	Land Use	Area (ac)	% Effective Impervious	Land Cost $/ac
Cross Roads	Commercial	50	95%	$200,000
Shop & Go	Commercial	15	95%	$200,000
Apartments	Residential - Apartments	100	80%	$200,000
Residential 1	Residential 3,000 s.f. Homes	225	51%	$130,000
Residential 2	Residential 2,000 s.f. Homes	250	39%	$130,000

The example 1-square-mile urban watershed contained commercial, multi-family residential, and two different densities of single-family residential land uses as shown in Table 1, along with their assumed effective imperviousness. No other source controls were provided.

Table 1 also lists the assumed per-acre cost of land for each of the land uses in this watershed. The values used in this example are based on discussions with a commercial real estate broker in the Denver area. According to the broker, the land costs used in this example represent “reasonable” but somewhat-on-the-low-side median land values in the Denver area. BMP-REALCOST accounts for the value of land that needs to be set aside for each type of BMPs unless the BMP occupies the same land area that has another primary use of the land surface, such as pavement within a development. The pavement, whether conventional or permeable, is a part of the development and does not require separate areas to be set aside for the BMP.

Economic Parameters. The planning horizon (i.e., economic life) of all BMPs was assumed to be 50 years. These are permanent public works facilities that will need to continue to function indefinitely as designed and installed under the terms of MS4 stormwater discharge permits. An inflation rate of 4.6% was applied to all future maintenance and rehabilitation costs. This inflation rate was based on the average published rates over the last 50 years in United States. The discount rate for invested funds was assumed to be 5.0%, a rate that is little higher than the inflation rate and one that appears reasonable when looking at the municipal bond rates over the last 10 to 20 years. In addition, the current ENR CCI index of 6570 was applied to adjust the costs for the year 2009 and the Denver region. All default cost parameters in BMP-REALCOST were input using ENR CCI = 8141, but some default costs were overwritten by the authors to reflect subtle differences in capital costs between BMPs that require underdrains and ones that do not. Administrative costs, namely the cost for the MS4 permit holder to "ensure" that the BMPs continue to function as intended, was assumed to be 12% of the annual maintenance costs plus the cost of inspections by the MS4 discharge permit holder.

The construction costs used in this model were developed be Muller Engineering Company Inc. for UDFCD (Muller Engineering 2009). The model also adds 40% to these costs to account for contingencies and for the costs of planning, engineering, inspection, and MS4 permit oversight during construction. Whether this factor is too large or small can be debated, but the relative comparisons would not change because the same factor is used for all BMPs. The whole-life cycle cost modeling includes the cost of maintenance, rehabilitation, and administration of the permit over the selected economic life of the installation. For comparison purposes, the totals are reduced to a net present cost (NPC) after accounting for inflation and discount rates discussed earlier.

Basis for Sizing and Design of the BMPs Investigated. All the BMPs were sized using the UDFCD's recommended protocols: namely, the complete capture and treatment of the 80th percentile runoff event for storage BMPs and conveyance of the 2-year design storm for conveyance BMPs (UDFCD 2004). In Denver, the mean annual precipitation is 15.8 inches, the 2-year 1-hour depth is 0.95 inch, and the mean storm depth is 0.43 inch (Driscoll et al. 1989).

When applying the findings reported here to other locations, local meteorology needs to be considered. Denver is located in a semi-arid region and, because of the lesser precipitation totals than found in more water-rich eastern and midwestern areas of the United States, may have smaller BMP sizes than other areas. However, the model can be easily modified to address regional sizing and design standards.

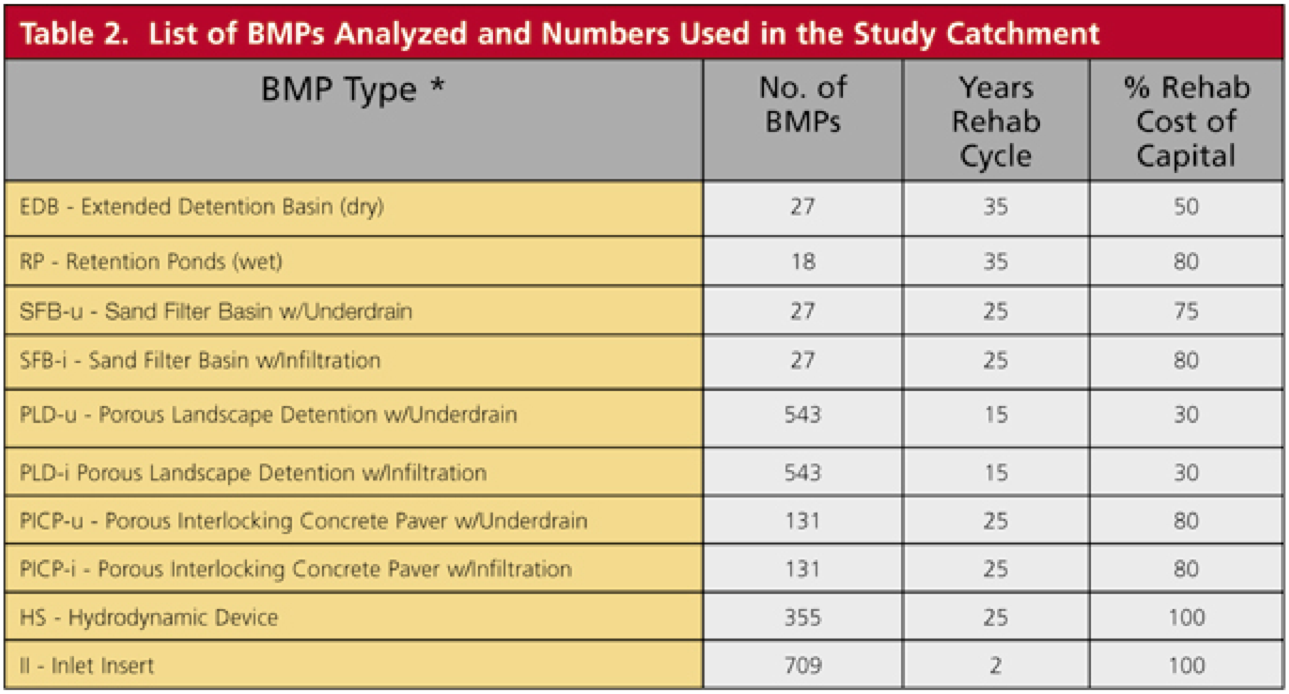

Table 2. List of BMPs Analyzed and Numbers Used in the Study Catchment

BMP Type *	No. of BMPs	Years Rehab Cycle	% Rehab Cost of Capital
EDB - Extended Detention Basin (dry)	27	35	50
RP - Retention Ponds (wet)	18	35	80
SFB-u - Sand Filter Basin w/Underdrain	27	25	75
SFB-i - Sand Filter Basin w/Infiltration	27	25	80
PLD-u - Porous Landscape Detention w/Underdrain	543	15	30
PLD-i Porous Landscape Detention w/Infiltration	543	15	30
PICP-u - Porous Interlocking Concrete Paver w/Underdrain	131	25	80
PICP-i - Porous Interlocking Concrete Paver w/Infiltration	131	25	80
HS - Hydrodynamic Device	355	25	100
II - Inlet Insert	709	2	100

*** BMP types available in the model that were not analyzed in this paper include concrete grid pavers, constructed wetlands, full-spectrum detection, media filter vault, porous concrete pavement, porous gravel pavement, reinforced grass pavement, sand filter vault, sediment-oil separator, and underground vault with capture volume.**

The local design standards for porous interlocking concrete pavers (PICP) with underdrains in the Denver region are likely to have higher unit costs than what is recommended by the industry. The local design guidance recommends a sand layer between the gravel base and the underdrains. These modifications are recommended by UDFCD with the thought that the sand filter layer will provide additional reductions in pollutants, including bacteria, over the standard industry design and appear also to provide significant reductions in runoff volumes. At the same time, the local design standards for rain gardens, labeled locally and in this paper as porous landscape detention (PLD), may result in significantly lower costs than those experienced in eastern United States because the local hydrology addresses less rainfall and the design cross section is smaller.

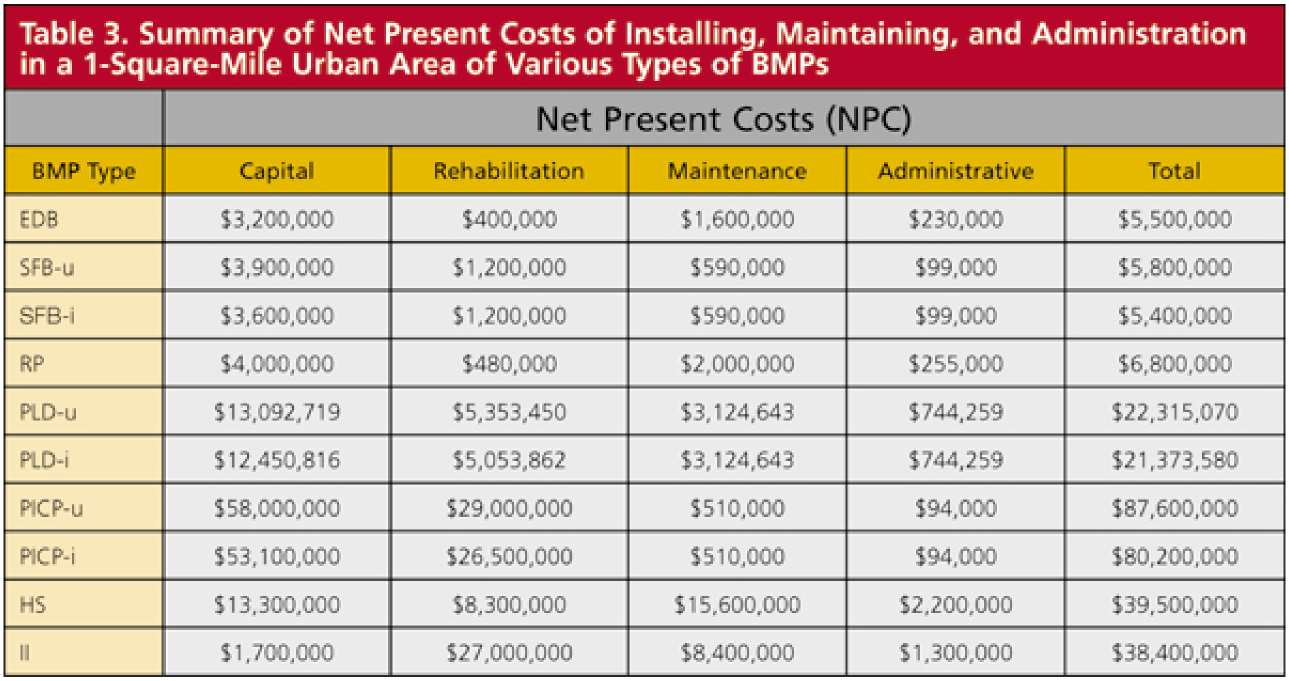

Table 3. Summary of Net Present Costs of Installing, Maintaining, and Administration in a 1-Square-Mile Urban Area of Various Types of BMPs

	Net Present Costs (NPC)				
BMP Type	Capital	Rehabilitation	Maintenance	Administrative	Total
EDB	$3,200,000	$400,000	$1,600,000	$230,000	$5,500,000
SFB-u	$3,900,000	$1,200,000	$590,000	$99,000	$5,800,000
SFB-i	$3,600,000	$1,200,000	$590,000	$99,000	$5,400,000
RP	$4,000,000	$480,000	$2,000,000	$255,000	$6,800,000
PLD-u	$13,092,719	$5,353,450	$3,124,643	$744,259	$22,315,070
PLD-i	$12,450,816	$5,053,862	$3,124,643	$744,259	$21,373,580
PICP-u	$58,000,000	$29,000,000	$510,000	$94,000	$87,600,000
PICP-i	$53,100,000	$26,500,000	$510,000	$94,000	$80,200,000
HS	$13,300,000	$8,300,000	$15,600,000	$2,200,000	$39,500,000
II	$1,700,000	$27,000,000	$8,400,000	$1,300,000	$38,400,000

BMP Types Investigated. Table 2 lists the numbers of each BMP type used in this example. The authors believe that the BMP density for site controls used in this example was somewhat on the light side, resulting in fewer installations and lower costs than may be practiced if they were applied on a lot-by-lot basis, but should be adequate to ensure coverage and interception of surface runoff. In other words, the authors did not want to over-densify the numbers of lot-based BMPs so as not to appear to favor community-based ones. Also listed in Table 2 are the years between rehabilitations, namely the assumed periods needed to rebuild or completely recondition each facility. This table also contains the percentages of the original capital cost used as the cost of rehabilitation for each BMP.

Ten BMP types were analyzed. Some varied only by whether the captured runoff was permitted to infiltrate into the ground or the intercepted volume was to be discharge to the surface through underdrains. The ability to infiltrate into the ground is not available in all cases and is constrained by local geology, groundwater proximity to the surface, structural needs of structures in the proximity, potential for flooding basements, polluted groundwater plumes, and other factors. These constraints can make a significant difference in how effectively surface runoff reduction can be achieved.

Findings of the Whole-Life Effectiveness and Economics of Various BMPs
Relationships Between Whole-Life Costs and BMP Density. Table 3 shows a strong relationship between the density of BMPs within the watershed and their net present costs. Namely, the more BMPs per unit area used, the greater are the net present costs over the 50-year economic life of the facilities. This is understandable when one considers that the ongoing maintenance and rehabilitation costs are not proportional to BMP size. There are fixed cost to service and administer each facility regardless of size, which may include the cost of the land, mobilization,

setup, travel time, traffic control, inspections, and reporting. The BMP-REALCOST model attempts to account for all of these.

Of the 10 scenarios analyzed, the BMPs with the lowest NPCs were extended detention basins (EDB), retention ponds (RP), and sand filter basins (SFB) with and without underdrains. All these fall into a category of community-based or regionalized BMPs that can intercept and treat stormwater runoff from larger areas. The BMPs with the highest NPCs were PICP, which are discussed later. Hydrodynamic separators (HS) and inlet inserts (II) exhibited the highest maintenance and administrative costs, with PLDs (i.e., rain gardens and bioretention cells) exhibiting the second-highest maintenance and administrative costs.

Although one can argue that the PLDs will be maintained by the homeowner, the homeowners association, or the commercial property owner, the MS4 still has the administrative burden to ensure that needed maintenance and rehabilitation occurs. Experience so far within the Denver region has shown that it can be very difficult, and often not possible, to have private parties provide the needed maintenance despite the best efforts of MS4s. The MS4s have to take over those duties and front-end maintenance costs with the hope that they will be eventually recovered.

Apparent High Cost of Interlocking Concrete Pavers. The BMP with the highest apparent NPC examined in this study is PICP, with and without underdrains. However, the NPC results given by this model need to be adjusted by subtracting out the cost of the installation, maintenance, and rehabilitation of equivalent areas of non-permeable pavement (Figures 1 and 2). A net reduction in the NPC may be on the order of 50% to 100% when all the costs of ordinary pavement are accounted for, including the added cost of drainage infrastructure and the costs of maintenance and rehabilitation for the same economic life; however the current version of the model does no such accounting. The high NPC is driven by the cost of original installation and rehabilitation costs.

At the same time, PICPs appear to have the lowest maintenance and administrative costs of any BMP in this study. Maintenance and rehabilitation cost of all PICPs located on public rights of way are borne by the municipality or MS4, whereas the property owner has to assume these cost when the PCIP is located on private property. All administrative cost is the responsibility of the MS4.

Regardless of the higher initial cost, PICPs and other types of permeable pavements have a significant role in ultra-urban high-density applications. In urban areas, especially ultra-dense commercial zones, where cost of the land is high, use of permeable pavements can be an attractive alternative to BMPs that require setting aside land for their installation. Additional model runs using higher, site-specific land values (instead of the “average” values included with the model) for high-density areas could reveal at what land value permeable pavements become more economically feasible for a specific site; however, such evaluations were not studied for this application.

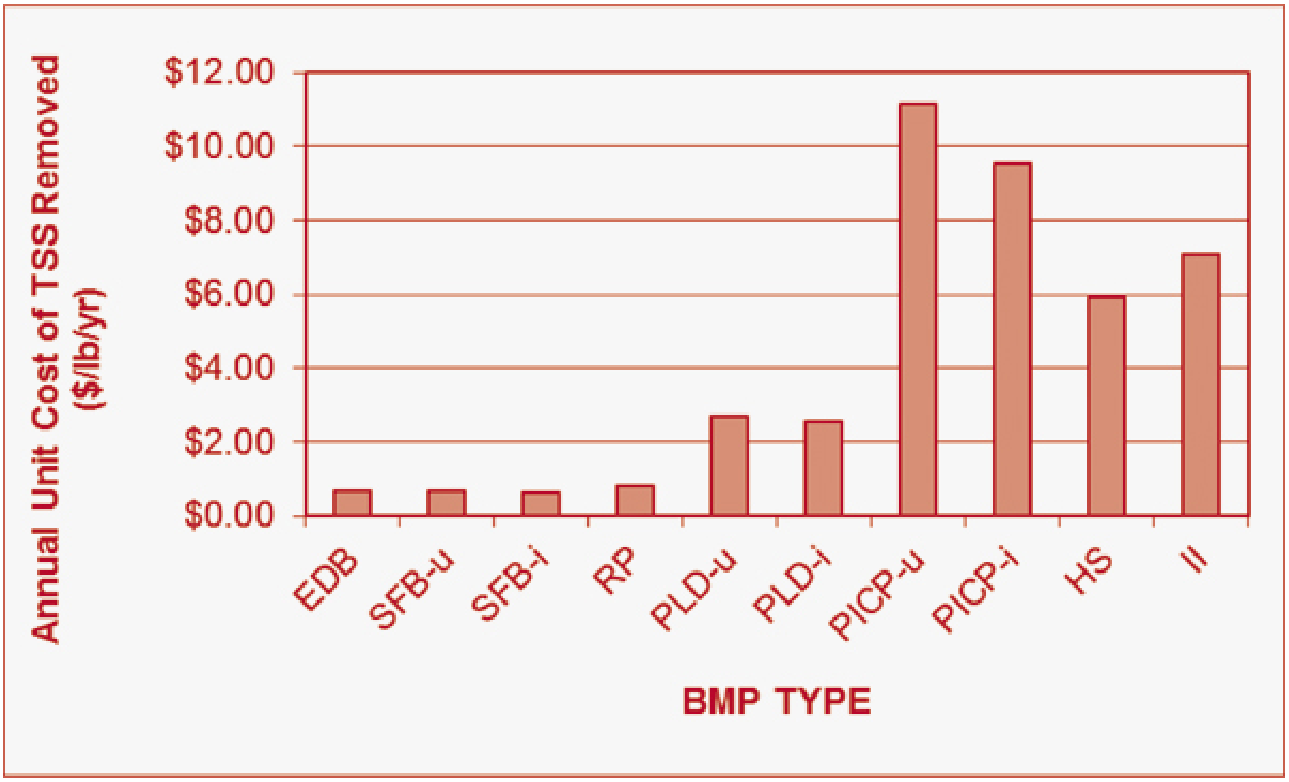

Figure 1. Unit costs of TSS load removed in $/lb/yr for each BMP in this example before subtracting cost of conventional pavement from the PICP whole-life costs

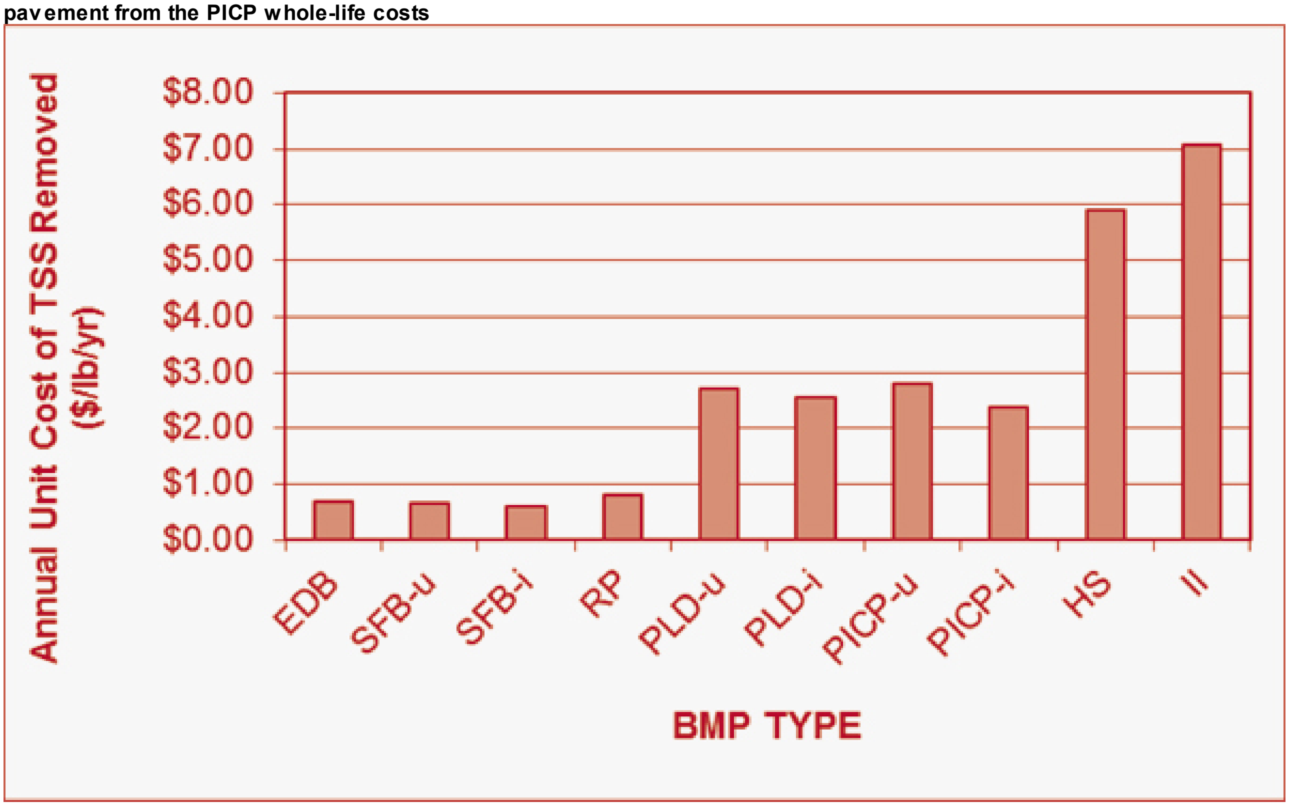

Figure 2. Unit costs of TSS load removed in $/lb/yr for each BMP in this example after subtracting cost of conventional pavement from the PICP whole-life costs

Assessment of Runoff Volume and Pollutant Load Reductions. The model also estimates the effectiveness of various BMPs in controlling pollutant loads and runoff volumes. Table 4 summarizes the relative effectiveness of the 10 BMPs in reducing annual surface runoff volumes and the annual loads for total suspended solids (TSS), total phosphorous (TP) and total copper (TCu) reaching the receiving waters. This table also lists the unit costs in dollars per pound of these three pollutants removed by each BMP. Three categories of performance emerge.

The flow-through types of BMPs, such as II and HS, have no reductions in runoff volumes. In addition, these two types of flow-through BMPs show the lowest levels of pollutant removal and, with the exception of PICPs, the highest unit costs for their removals.

All BMPs were sized to capture in total the water-quality capture volume (WQCV) as recommended in the UDFCD manual, but some have the ability to improve the water quality even when the inflow volumes somewhat exceed the WQCV. However, PICP capture ratios can vary significantly from this and were based on the ratio of impervious surface that is intercepted by the PICP as compared to the area of the PICP. The equations used to describe how surface runoff is actually captured by a PICP are described in Olson et al. 2010. The BMPs that capture a significant portion of the annual surface runoff in this study fall into two categories, those that infiltrate the water into the ground (i.e., SFB, PLD, and PICP all with infiltration) and those that discharge captured runoff volume back to the surface or underground conveyance system. The latter group contains BMPs that “filter” the captured runoff (i.e., SFB, PLD, and PICP all with underdrains) and ones that do not (i.e., EDB and RP).

All water-quality capture BMPs that do not infiltrate the water into the ground provide at least some reductions in runoff volume. The lowest reductions were by BMPs that do not provide infiltration or filtration; RPs averaged 6%, EDBs 27%, SFBs with underdrains 36%, PLDs with underdrains 51% and PICPs with underdrains 35% reductions in the annual surface runoff. Thus, even when infiltration is not being used or is possible due to site conditions, these BMPs do provide reductions in annual surface runoff volumes reaching the receiving waters.

Whether the water-quality capture BMP infiltrates water into the ground, most exhibited reductions in the removal of annual pollutant loads that were not dramatically different. Removals for BMPs that provide a capture volume for runoff ranged TSS from 80% to 93%, for TP from 66% to 80%, and for TCu from 69% to 82%. The ones that could infiltrate the water consistently had the highest rate of pollutant removal rates and ranged for TSS from 85% to 90%, for TP from 66% to 90%, and for TCu from 85% to 90%. However, infiltration is not always possible due to geology, groundwater, structural considerations, and polluted groundwater areas.

The model based its estimates of runoff volume reductions and pollutant loads on the data collected and reported for urban surface runoff by EPA’s Nationwide Urban Runoff Program (EPA 1983) and the effluent event mean concentrations (EMCs) reported by the International Stormwater Best Management Practices Database maintained by Wright Water Engineers and Geosyntec. Those data were supplemented somewhat by data and experience gathered in the Denver region by the UDFCD. The use of various data is explained in greater detail in the Olson et al. 2010 paper. Table 4 lists the percentages of the three types of pollutants removed, which percentages were calculated by the model using mean influent, and effluent concentrations reported in these documents.

Effectiveness of Runoff Interception. According to the model and the data discussed above, EDBs (dry) and SFBs without infiltration provide somewhat similar reductions in runoff volumes. These two and RPs (wet) fall into a category of consolidated community-based BMPs. They are capable of intercepting runoff from large areas very efficiently and with little bypass, more so than inlet or lot-based BMPs such as IIs, HSs, PLDs, and possibly even PICPs. This is because most of the runoff, whether from individual properties or public streets, is directed to pass through them and there is less chance for surface runoff to bypass the consolidated community-based BMPs, extending their overall effectiveness.

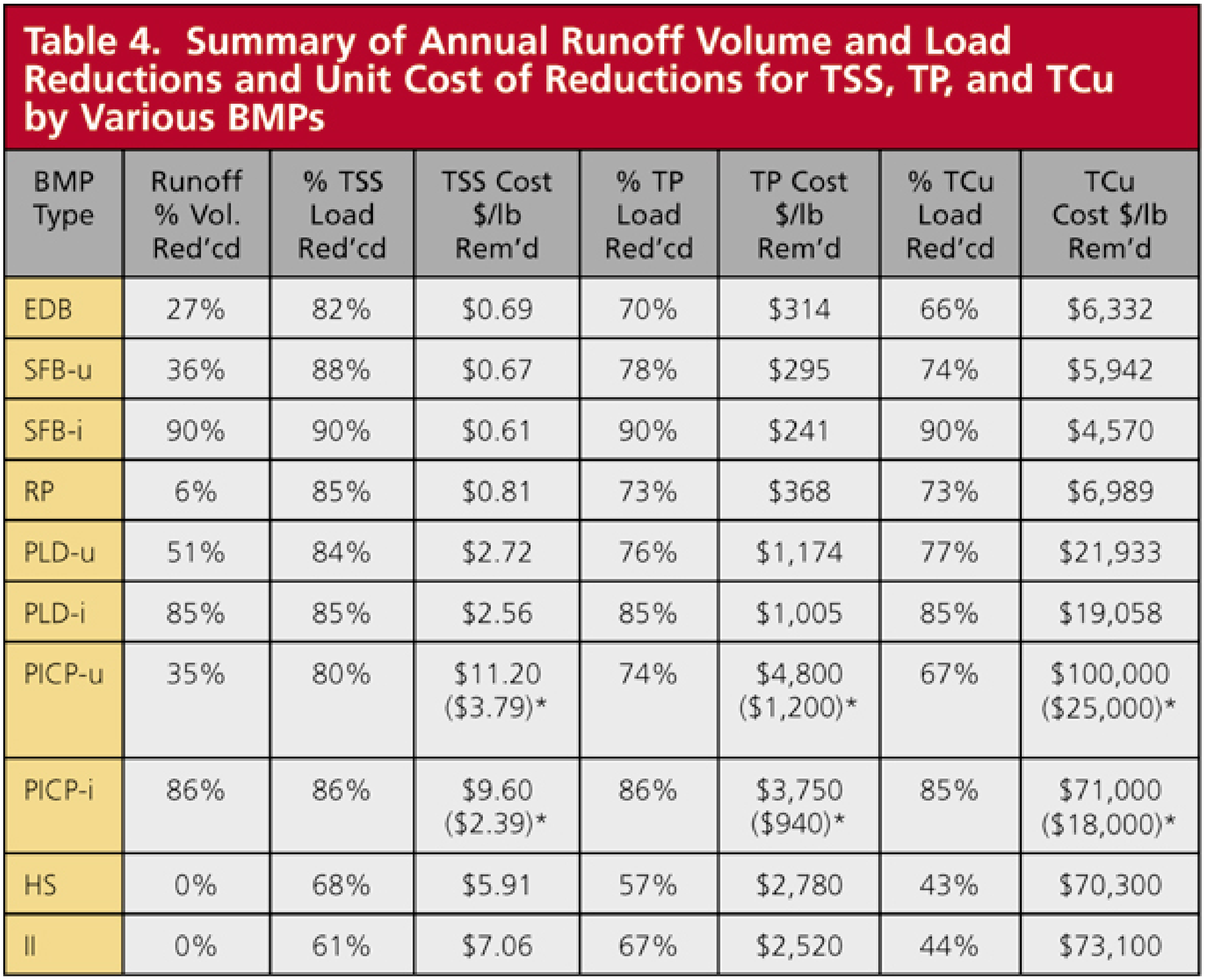

Table 4. Summary of Annual Runoff Volume and Load Reductions and Unit Cost of Reductions for TSS, TP, and TCu by Various BMPs

BMP Type	Runoff % Vol. Red'cd	% TSS Load Red'cd	TSS Cost $/lb Rem'd	% TP Load Red'cd	TP Cost $/lb Rem'd	% TCu Load Red'cd	TCu Cost $/lb Rem'd
EDB	27%	82%	$0.69	70%	$314	66%	$6,332
SFB-u	36%	88%	$0.67	78%	$295	74%	$5,942
SFB-i	90%	90%	$0.61	90%	$241	90%	$4,570
RP	6%	85%	$0.81	73%	$368	73%	$6,989
PLD-u	51%	84%	$2.72	76%	$1,174	77%	$21,933
PLD-i	85%	85%	$2.56	85%	$1,005	85%	$19,058
PICP-u	35%	80%	$11.20 ($3.79)*	74%	$4,800 ($1,200)*	67%	$100,000 ($25,000)*
PICP-i	86%	86%	$9.60 ($2.39)*	86%	$3,750 ($940)*	85%	$71,000 ($18,000)*
HS	0%	68%	$5.91	57%	$2,780	43%	$70,300
II	0%	61%	$7.06	67%	$2,520	44%	$73,100

*** ( ) Cost after 75% reduction for life-cycle cost of conventional pavement**

Conclusions and Observations

BMP-REALCOST is a relatively simple desktop model that provides estimates and assessments of the reductions in average annual surface runoff volumes and pollutant loads and whole-life cycle economics. The whole-life cycle cost model includes costs for planning, design, construction, maintenance, rehabilitation, and administration of the MS4 program to support each BMP in the ground, all adjusted for inflation and geographic location in United States using the ENR CCI.

One trend that emerged is that the NPC of different BMPs is proportional to the density of their use; the higher the density, the higher the cost. The site-level or lot-based BMPs such as PLDs, PICP, HSs, and IIs had the higher NPCs, and the community-based BMPs such as EDBs, SFBs, and RPs had the lowest. In terms of their ability to reduce runoff, some of the community-based BMPs, namely SFBs, were as robust as PLDs, while the EDBs were almost as robust as PICPs and SFBs with underdrains.

While the PICPs had the highest unadjusted NPCs, this may not to be the case after the NPC cost of conventional pavement is subtracted for an equivalent area. As a result, their use in urban areas may be well justified on the basis of whole-life cycle costs and effectiveness once the appropriate cost adjustments are made. In addition, the extremely high cost of land in ultra-urban areas may offer savings when compared to other BMPs that require land to be set aside for their installation. Regardless of the higher initial cost, PICPs and other types of permeable pavements have a significant role in ultra-urban high-density applications, especially when the cost of the land is high.

When considering which BMPs to select, it would be very beneficial to consider not only capital costs, but also the long-term maintenance costs. In doing so, consider that the ones doing the development will favor BMPs that have the lowest capital costs. The cost of long-term maintenance and rehabilitation is then passed on to the owner of the BMPs and/or the MS4.

Of very great significance to the MS4 permit holders, when assessing the whole-life economics of BMPs they approve or accept, is what fiscal commitments are being made for long-term maintenance and rehabilitation of the approved BMPs. Whether the maintenance is provided by the property owner, the homeowners association, or the MS4 permit holder, the permit holder is responsible to the state or federal government to ensure that the approved BMPs will be maintained and rehabilitated as needed to keep them in operation in perpetuity. This model can assist the responsible parties in planning for the economic liabilities that they will face in the future.

Figure 3 illustrates the cost escalations in maintenance due to inflation over the 50-year life-cycle period used in this analysis, and Figure 4 does the same for construction and rehabilitation costs. The escalation in annual, and cumulative cost is quite evident and is something the decision makers need to consider. The BMP-REALCOST model provides information on the long-term cost and effectiveness implications for them to consider before selecting which BMP types will be approved for use in their community or state. One question that the decision makers should not ignore is whether their revenue increases keep up with the fiscal demands for maintenance and rehabilitation of their stormwater management system in the future. However, other factors may affect the selection of BMPs the MS4 needs to use, such as regulatory mandates, community preferences, local politics, specific environmental concerns, and other factors that preempt the decisions based solely on effectiveness and/or economics.

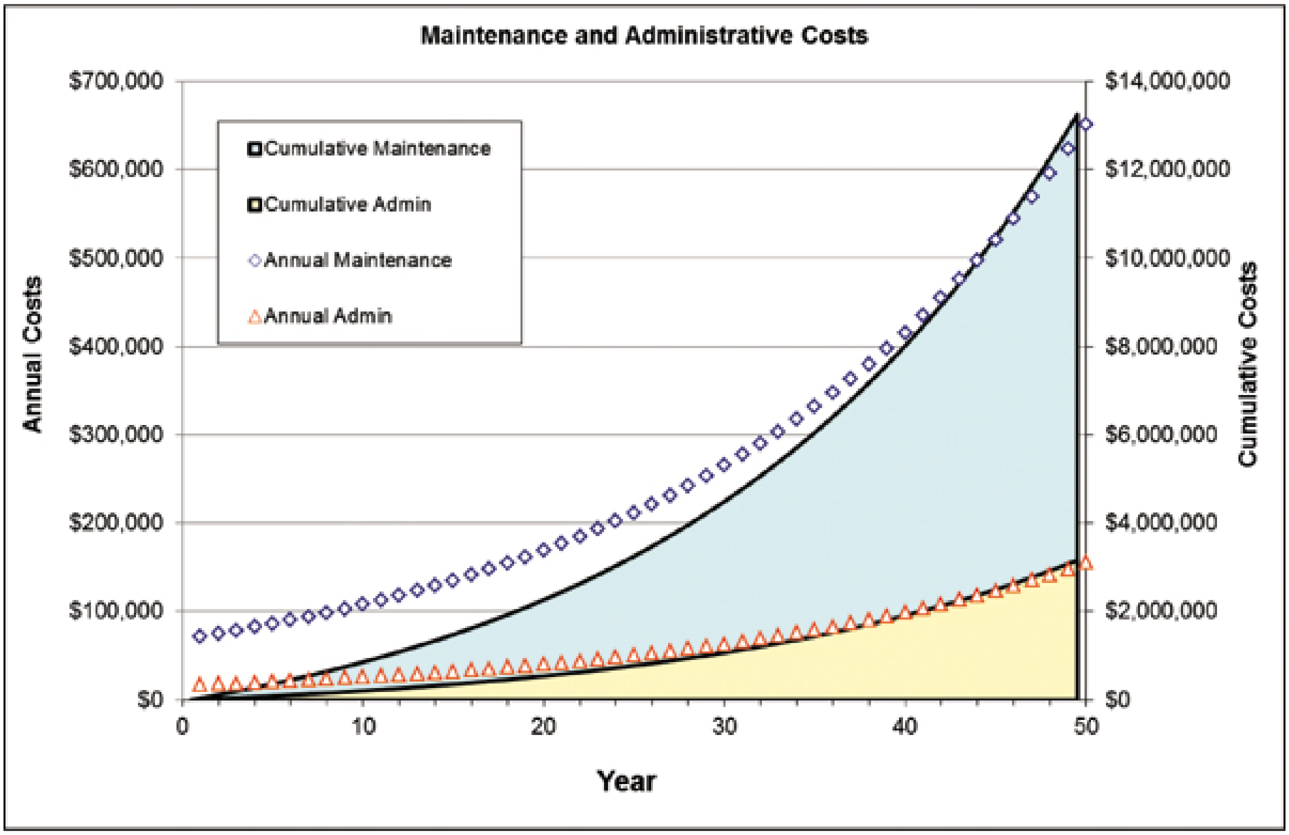

Figure 3. Maintenance and administrative costs over 50-year life for a PLD (rain garden) with underdrains

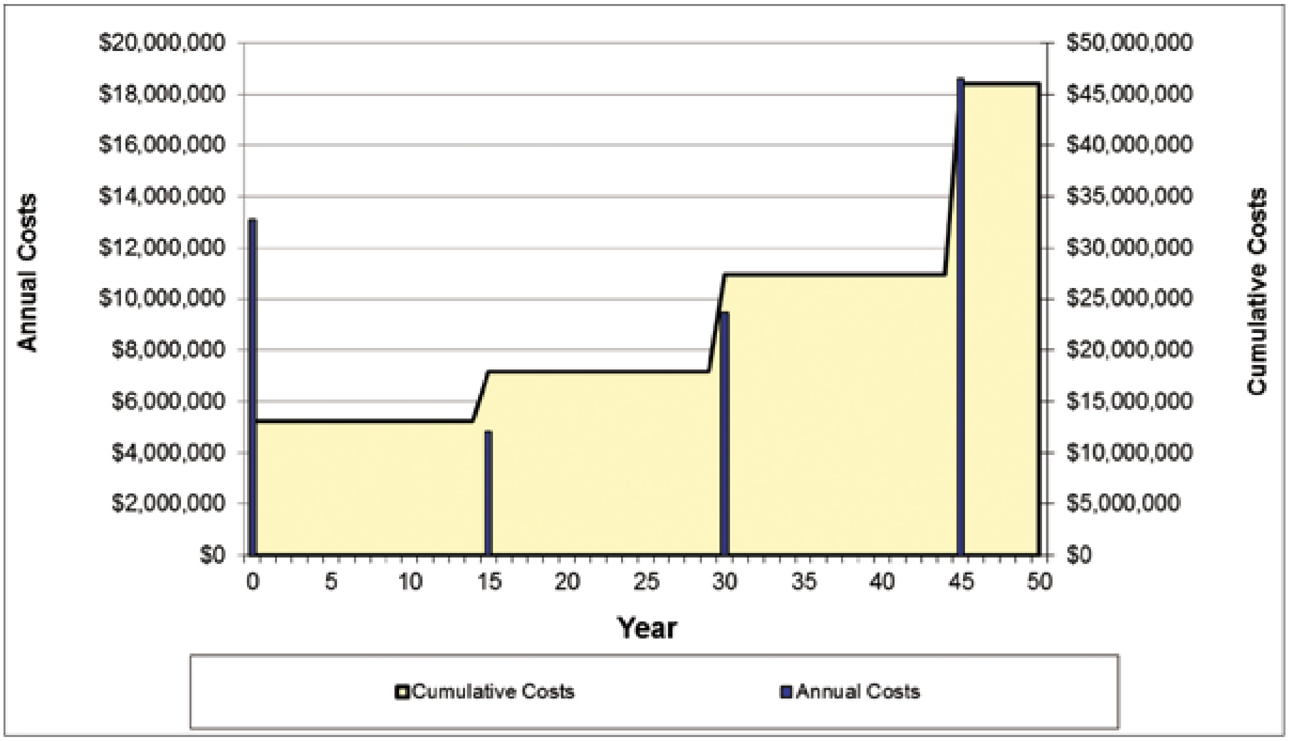

Figure 4. Construction and rehabilitative costs over 50-year life for a PLD (rain garden) with underdrains

Clearly, the results from this model are strongly influenced by the assumptions made for the maintenance needs and rehabilitation cycles and costs. It is incumbent on the user of any model to carefully examine these costs and assumptions used in the model and to bring them in line with local experience and expectations. At the same time, costs such as administration of the MS4 program to oversee the BMPs and manpower overhead costs including costs of supervision, support facilities, and general upkeep of personnel and equipment, should not be overlooked. Reasonable estimates of many of these costs are built into this model as default values that can be overridden by the user.

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