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COST-ESTIMATION TOOL FOR LOW-IMPACT DEVELOPMENT STORMWATER BEST MANAGEMENT PRACTICES

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COST-ESTIMATION TOOLS FOR LOW-IMPACT DEVELOPMENT STORMWATER BEST MANAGEMENT PRACTICES

1. Purpose

a. This Public Works Technical Bulletin (PWTB) describes a suite of spreadsheet-based tools to address low-impact development (LID) costs that are associated with the most common best management practices (BMPs) for controlling stormwater. The cost-estimation tools described in this PWTB will allow for informed decisions on adopting LID practices for regulatory compliance and improved water quality.

b. These tools provide information that Army stormwater managers and policymakers can use for estimating LID infrastructure costs for: (a) new construction, (b) cost reporting, and most importantly, (c) planning- and budgeting-level cost estimates.

c. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability

This PWTB applies to Department of Defense (DoD) and Army installations with a responsibility for estimating LID project costs (e.g., resource and land managers and installation planners).

3. References

a. Army Regulation (AR) 200-1, “Environmental Protection and Enhancement,” 13 December 2007.

b. Energy Independence and Security Act (EISA), Title 42, United States Code (U.S.C.), Chapter 52, Section 17094, Section 438 – “Stormwater Runoff Requirements for Federal Development Projects,” 19 December 2007.

c. Unified Facilities Criteria (UFC) – 3-210-10, “Low Impact Development,” updated 15 November 2010.

d. US Environmental Protection Agency (USEPA), “Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438, EISA 2007,” December 2009.

e. Executive Order (EO) 13514, “Federal Leadership in Environmental, Energy and Economic Performance,” 5 October 2009.

4. Discussion

a. AR 200-1 implements federal, state, and local environmental laws and DoD policies for preserving, protecting, conserving, and restoring the quality of the environment. It outlines Army environmental stewardship and defines the framework for the Army Environmental Management System.

b. The EISA contains new stormwater standards and requirements for federal development and redevelopment projects. The intent of Section 438 is to promote the responsible management of stormwater to the maximum extent technically feasible. For example, Section 438 of EISA reads (in part):

> “The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.”

c. The LID UFC provides planning, design, construction, sustainment, restoration, and cost criteria. It applies to all military departments, defense agencies, and DoD field activities. In particular, this UFC provides technical and cost criteria, technical requirements, and references for the planning and design of projects that must comply with EISA Section 438 and DoD policy.

d. The USEPA factsheet presents information on tools and design practices to meet Section 438 requirements.

e. EO 13514 requires federal agencies to lead the nation by example for improved environmental performance, including conserving and protecting water resources through efficiency, reuse, and storm management.

f. LID practices are increasingly used as a more environmentally and economically sustainable approach in urban and suburban developments to reduce stormwater nonpoint source (NPS) pollution. Recognizing that stormwater is one of the most significant contributors of NPS pollution (USEPA 2007) and with increasing interest in sustainable development, the DoD has a growing interest in LID BMPs. The USEPA (2007) reported that, with the goal of mimicking a site’s predevelopment hydrology, LID can reduce infrastructure costs and improve water quality, aesthetics, and biodiversity.

g. Significant progress has been made in areas of LID research and policy development within the DoD and the Army. The Army has established policy on LID and sustainability practices, including a requirement that LID and associated costs be documented with a form DD1391 for all projects beginning in FY 2013. There are related concerns that LID practices may require both higher capital and operation and maintenance (O&M) costs than conventional systems. While initial costs may be higher for some LID practices than their respective conventional controls, what remains uncertain is the magnitude of these differences and the key life-cycle factors that affect both conventional and LID costs.

h. Despite the fact that LID practices and technologies have been promoted and studied since the early 1990s, data regarding their costs remain limited. To fully embrace LID practices, policymakers and the installation master planning community need simple tools to quickly estimate long-term life-cycle costs that include site planning, design, construction, and maintenance.

i. Cost information was gathered by: (1) evaluating available cost data from existing DoD, federal, and other facilities; (2) performing a literature review to identify the most commonly used LID practices and the availability of data on their cost and performance; and most importantly, (3) providing discussion and instruction of the cost-estimation tools developed by USEPA and Water Environment Research Foundation (WERF). Actual estimates of capital and O&M costs are provided, to show examples of how LID practices compare to conventional stormwater management practices.

j. Benefits of the cost tools (models) discussed in this PWTB include:

i. Tool is available as a no-fee download for federal agencies after registration at the WERF website: http://www.werf.org/bmpcost.

ii. Each spreadsheet estimates capital costs, as well as operation and maintenance costs, to provide the user a whole-life cost estimate for a selected LID facility.

iii. The line item engineer's estimate allows the user to customize the project, while exposing the user to an extensive list of potential costs and opportunities to maximize value. As an example, users may also select a level of maintenance they estimate to be appropriate for their project.

iv. The "Cost Summary" page summarizes annual costs for routine maintenance, corrective or infrequent maintenance, and capital costs. From this summary, the model builds a 50-year lifetime cost estimate.

v. It is designed to produce a default planning-level cost estimate but allows the user to enter more specific cost values for every component tracked by the model. Advanced users may utilize this function to compare two separate sets of design options or system characteristics.

vi. Using the cost tool will result in consistent cost data so that users can determine the cost of each component of the LID project, both for materials and for planning and design.

vii. In addition to cost estimates, design concepts are presented in each model and this feature provides factors to consider during planning stages of an LID project.

viii. A consistent format allows data to be shared and will create a better understanding of the benefits of LID use and better decision making for LID applications.

k. To assist installations with the implementing LID practices, Appendix A summarizes their background and benefits; Appendix B explains cost-estimation tools; Appendix C discusses the factors involved in cost estimations; and Appendix D presents practical guidelines for using the suite of cost-estimation spreadsheets.

l. Appendix E lists references cited in this work along with other resources for further information. Appendix F presents a list of abbreviations and their meanings.

5. Points of Contact

a. Headquarters, US Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil.

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FOR THE COMMANDER:

For JAMES C. DALTON, P.E., SES
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APPENDIX A:
LID PRACTICES GENERAL INFORMATION

Background

To fully embrace LID practices that have been promoted and studied since the 1990s, Army policy makers and the installation master planning community need simple tools to quickly estimate the cost of implementing different LID practices. Therefore, there has been a need for developing consistent, reliable cost information that planners can use to estimate the project construction and long-term life-cycle costs (LCCs).

Although the benefits of LID have been broadly documented, and numerous municipal and suburban entities are aggressively incorporating LID practices into their stormwater management programs, LID adoption continues to be stymied by institutional issues (e.g., is rooftop or site runoff required to be directed to the street or a collection system?).

Environmental Benefits

Stormwater pollution and its treatment do not occur in a vacuum. Compared to conventional and largely single-function grey infrastructure,[1] LID practices provide a layered approach to stormwater management via more sustainable design. All DoD installations are confronted by many environmental concerns including air quality, urban heat island, energy consumption, and climate change. Traditionally, each of these issues has been dealt with separately through different programs, technologies, and policy approaches. Because LID practices rely heavily on vegetation or practices that simulate elements of the natural hydrologic cycle, the environmental benefits gained by their use will extend beyond stormwater and water quality. LID practices can be used to address environmental problems as indicated in the following subsections (Weinstein et al. 2009).

Air Quality

Air quality is negatively impacted by a number of factors. Higher temperatures that are common in urban areas can translate to lower air-quality conditions, because increased temperatures can increase ground-level ozone concentrations. Hydrocarbons and

[1] Grey infrastructure typically refers to “constructed” assets rather than “natural” assets.

nitrogen oxides react to form ground-level ozone in a process catalyzed by the ultraviolet radiation in sunlight. Higher temperatures tend to correlate with higher ozone concentrations, in part because higher temperatures increase reaction rates (Vingarzan and Taylor 2003). Air quality is also impacted by industrial emissions and mobile source pollution.

LID vegetative practices can improve air quality through several mechanisms (Bisco Werner, et al. 2001; Plumb and Seggos 2007). Vegetation’s ability to physically reduce urban temperatures decreases the reaction rates involved in the creation of ground-level ozone. Vegetation also improves air quality by physically filtering air pollutants. Leaf stomata absorb gaseous pollutants and plant surfaces can adsorb particulate matter. Adsorbed particles can remain adhered to the plant, be absorbed into the plant material, washed off to the soil, or redispersed to the atmosphere. The US Department of Agriculture (USDA) Forest Service’s Urban Forest Effects (UFORE) model has estimated that vegetation can remove significant amounts of five common urban air pollutants on an annual basis: ozone (O_3); particulate matter (PM) less than 10 microns in diameter (PM_{10}); nitrogen dioxide (NO_2); carbon monoxide (CO); and sulfur dioxide (SO_2) (Currie and Bass 2005). Bisco Werner et al. (2001) report similar air quality benefits for trees and vegetation in urban areas. Plumb and Seggos (2007) cite one study that found a single tree can remove 0.44 lb of air pollution per year.

Urban Heat Island

The “urban heat island” effect is caused by using hard surface materials throughout cities that effectively absorb and store solar energy and then reradiate it as heat. Temperatures in urban areas can average 5-10°F higher than suburban temperatures (USEPA 2010).

LID practices are able to reduce the impact from the urban heat island effect by substituting soils and vegetation for hard, heat-absorbing materials. Impacts can also be reduced by using lighter-colored, more reflective, or permeable alternatives to what may have been specified in the construction (e.g., light-colored paver blocks or permeable pavement). Vegetation creates shade and emits water vapor, both of which cool hot air. Water vapor emitted by plant material cools ambient temperatures because heat energy is used by vegetation to evaporate water, as reported in Grant et al. (2003):

> A surface’s radiation absorbing potential is measured by its albedo, the ratio of radiation reflected from a

surface to the incoming radiation onto the surface. The lower a surface’s albedo, the more radiation it absorbs. Vegetation reflects more radiation because grasses, deciduous plants and trees, and coniferous trees have albedos that are, on average, two to three times greater than those of asphalt, tar, and gravel that are typical urban construction and building materials.

Energy Consumption

Green space associated with LIDs, when incorporated on and around buildings, helps to shade and insulate buildings from wide temperature swings, thereby decreasing the energy needed for heating and cooling. For example, green roofs act as a heat sink by absorbing and holding thermal energy and releasing it when the surrounding ambient temperatures cool. Acting in this way, green roofs prevent the wide swings in surface temperatures experienced by conventional roofs and reduce the heating and cooling demand on buildings (Miller 2004). Estimates suggest that green roofs can reduce the heating and cooling costs of a building by 10%–15% (Saiz et al. 2006; City of Portland 2008).

Climate Change

If temperature increases are realized from climate change, LID practices can help to mitigate the urban impacts by counteracting the urban heat island effect (as described above). The cooling impacts of LID can also help to offset declining air quality conditions that will likely accompany higher temperatures. In addition, as temperatures increase, evapotranspiration rates are likely to also increase, potentially increasing the water retention capabilities of LID practices (Sailor 2004). Vegetated systems are dynamic systems that respond to external environmental stimuli.

Assessing the Costs of LIDs

Proponents assert that some LID techniques can achieve stormwater runoff pollutant removal goals at a lower initial cost than conventional systems, in part because they require less pipe and underground infrastructure. In cases where LID designs have had higher initial costs than traditional approaches, proponents point to lower maintenance and operating costs and other savings that result in lower LCCs than traditional approaches.

The costs and benefits of LID practices can be site specific and will vary depending on the LID technology used (e.g., green roof vs. bioswale) and the local biophysical conditions such as topography, soil types, and precipitation. Previous work has shown that comparing LID and conventional controls based on costs may bias the assessment against the most effective management option or against the option that yields the greatest return on investment. LID controls may cost more to build, but from an investment perspective, they may cost less in the long term because of improved stormwater control and water quality.

Construction and Infrastructure Costs

Assessing the economics of LIDs is a multi-layered process. The first step is to assess construction and infrastructure costs. This has largely been the primary area of assessment because a comparative analysis of LID and conventional stormwater construction costs is a significant area of interest for project developers. Several studies have investigated the construction costs and potential savings of LID practices (USEPA 2007; McMullan and Reich 2007; Haugland 2005).

USEPA (2007) found that capital cost savings gained from using LID practices ranged from 15%–80%, with savings realized in all but one of the 17 case studies reviewed (see Table B-1 in Appendix B). LID focuses on reducing stormwater volumes by reducing site disturbances and impervious area as well as by treating stormwater near the source. Consequently, cost savings are gained from reduced costs for site grading, paving, and landscaping. In addition, the reduced stormwater volumes gained from LID practices often reduce the size and/or need for conventional stormwater infrastructure. Additional cost savings therefore result from smaller or eliminated piping and detention facilities (USEPA 2007). These cost savings were realized in addition to improved stormwater management benefits.

In addition, full-scale evaluations of the environmental benefits of LID (as referred to earlier in this appendix) would provide a comprehensive assessment of natural resource protection and cost effectiveness. One such analysis for the Philadelphia Water Department showed significant economic benefits for an LID approach. The study compared managing 50% of the city’s stormwater runoff with LID controls versus managing all runoff with a 30-ft diameter, deep tunnel system. The analysis determined that the whole-city present value of the LID approach was $2.8 billion in benefits compared to $120 million in benefits for the deep tunnel option (Stratus Consulting 2009).

APPENDIX B:
COST-ESTIMATION TOOLS

Introduction

Powell et al. (2005) provided tools for cost-benefit comparison of LID versus conventional stormwater runoff controls. The authors considered the project costs along with the economic value of project benefits to decide whether the project was worth the cost. The USEPA (2007) report summarized 17 case studies of LID projects and concluded that LID BMPs can reduce projects costs, as shown in Table B-1. In a few cases, LID projects costs were higher than those for conventional stormwater management practices. However, in the vast majority of cases, significant savings were obtained due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Table B-1 displays EPA project details and itemized cost breakdowns for a majority of the 17 case studies. As shown, cost savings ranged from 15%–80% when LID methods were used, with a few exceptions.

Table B-1. Cost comparisons between conventional and LID approaches (USEPA 2007).

Project[a]	Conventional Develop. Cost	LID Cost	Cost Difference[b]	Percentage Difference[b]
2nd Avenue SEA (Street Edge Alternative) St., Seattle, Washington	$868,803	$651,548	$217,255	25%
Auburn Hills, Wisconsin	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall Parking Lot Retrofit, Washington	$27,600	$5,600	$22,000	80%
Bloedel Donovan Park, Bellingham, Washington	$52,800	$12,800	$40,000	76%
Gap Creek, Sherwood, Arkansas	$4,620,600	$3,942,100	$678,500	15%
Garden Valley, Pierce County, Washington	$324,400	$260,700	$63,700	20%
Kensington Estates, Pierce County, Washington	$765,700	$1,502,900	-$737,200	-96%

Project[a]	Conventional Develop. Cost	LID Cost	Cost Difference[b]	Percentage Difference[b]
Laurel Springs, Jackson, Wisconsin	$1,654,021	$1,149,552	$504,469	30%
Mill Creek, Kane County, Illinois	$12,510	$9,099	$3,411	27%
Prairie Glen, Germantown, Wisconsin	$1,004,848	$599,536	$405,312	40%
Somerset, Prince George’s County, Maryland	$2,456,843	$1,671,461	$785,382	32%

a Some of the case study results do not lend themselves to display in the format of this table (e.g., Central Park Commercial Redesigns, Crown Street, Poplar Street Apartments, Prairie Crossing, Portland Downspout Disconnection, and Toronto Green Roofs).

b Negative values denote increased cost for the LID design over conventional development costs.

Houdeshel et. al. (2011) developed tools for estimating costs of vegetative roofs, rainwater catchment systems, and bioretention facilities. These tools provide a framework to facilitate cost estimation for capital, O&M, and LCCs.

Heaney (2002) and USEPA (2007) provided a comprehensive literature review on LID cost-estimation methods. They also developed spreadsheet-based cost-estimation models and linked them to standard hydrology models (e.g., TR [Technical Release] 55 or Rational Method) and simple regression equations, by using one or two variable-developed tools on the cost of stormwater in urban areas. Information on prior cost studies of LID technologies and cost-estimating models used in these studies was collected, reviewed, and evaluated. The resulting data were evaluated to develop the results presented in this PWTB.

In 2005, WERF collaborated with the United Kingdom Water Industry Research (UKWIR), and with funding support from USEPA, released a whole-life cost (WLC) estimation spreadsheet tool as part of a report (Lampe et al. 2005). These spreadsheets include tools for costing the following traditional stormwater BMPs: retention ponds, planted swales, and extended detention basins. Permeable pavement, a source control BMP, is also included in the tool set. Capital costs for these BMPs are based on parametric equations derived from costs reported by agencies that had completed projects fitting the descriptions of each model. Capital, maintenance, and operating costs are separated into line items, to provide the user details of each cost component for individual BMP installations. See Appendix D for more details about the spreadsheet tools and recommendations for their use.

As part of an effort to encourage agencies to adopt LID approaches to stormwater management, the USEPA has expanded the WERF cost estimation tool to include selected LID facility types. This tool is available as a no-fee download for federal agencies after registration at the WERF website: http://www.werf.org/bmpcost.

Whole Life Cost in Models

The USEPA has determined that providing better cost information to landowners and agencies should encourage expansion of LID approaches to stormwater management. The WLC spreadsheet tools developed by USEPA, WERF, and UKWIR, were designed to assist in planning-level cost estimation of various stormwater BMPs, but were later expanded to include single-site decentralized LID stormwater management practices (see listing at beginning of Appendix D).

In addition to providing a general cost estimate based on drainage area, the tool synthesizes basic design concepts and parameters from multiple BMP and LID references in order to clearly describe the type of facility for which cost estimates are generated. Each spreadsheet estimates capital costs, as well as operation and maintenance costs, to provide the user a WLC estimate for a selected LID facility.

In this set of models, default capital costs as well as O&M costs are provided. Two cost estimation methods are presented for each facility type: (1) a parametric estimate based on assumed default values, and (2) an engineer’s estimate with an extensive list of project-specific line items for which the user can enter known costs. The line item “engineer’s estimate” allows the user to customize the project, while exposing the user to an extensive list of potential costs and opportunities to maximize value.

Use of this cost tool will enable consistent reporting of cost data, so that users will be able to determine the cost of each component of the LID project, both for materials and for planning and design. The model combines the selected capital cost method with whole life O&M costs to estimate the WLC of the facility.

In addition to predicting costs, this set of models is designed to be used as a cost-reporting tool. The provided format can be used to enter costs of a completed project so that LID cost information can be shared and the model may be improved in the future. Creating an understanding of the LCC benefits of LID will lead to an increase in LID and green infrastructure use in development and redevelopment.

Design and Maintenance Costs

The first spreadsheet in the WLC models requires a user to specify a series of design guidelines and system characteristics such as drainage area, project size, and/or the primary objectives of the project. Each model requires the user to answer a different series of questions relative to that specific model. For example, the design options in the cisterns model are shown in Table B-2. The user may also select a level of maintenance they estimate to be appropriate for their project in the “maintenance options” window on the first spreadsheet. Each level of maintenance assumes a different maintenance cost structure, explained on the “Maintenance Cost” page of each model.

Table B-2: Example of options from the cisterns WLC model.

Options	Unit	Default	User	Option
STORAGE REQUIREMENTS				
Drainage Area	sq ft	5,000		5,000
Max Design Rainfall Event	in	2		2
Precipitation Volume Generated per event	gal	6,233		6,233
Total Storage Needed	gal	6,300		6,300

Options	Unit	Default	User	Option
SYSTEM CHARACTERISTICS				
Type of Tank Desired (P-Plastic; M-Metal; F-Fiberglass, C-Concrete)	—	C		C
Primary Use (I- indoor, non-potable; O-outdoor)	—	O		O
Height of Building (used to calculate indoor costs)	Story	3		3
Number of Fixtures per Floor (toilets, used to calculate indoor use costs)	—	10		10
DESIGN & MAINTENANCE OPTIONS				
Choose Level of Maintenance, Irrigation (H-High; M-Medium; L-Low)	—	M		

Capital Costs

Each design option and system characteristic controls a major cost component used to calculate the simple cost estimate on the “Capital Costs” page. As in the example above, the user enters “Drainage Area” and the desired “Max Design Rainfall Event” to calculate storage size needed for the facility. This storage volume is then used to estimate the appropriate tank size and tank cost. In the “System Characteristics” box, the “Type of Tank Desired” tells the model which cost curve to use in estimating the cost of the tank, and the “Primary Use” option tells the model which equation to use to most appropriately size the distribution pump.

On the “Capital Costs” page, “Cost Option A” estimates costs based on the information entered in the “Design Options” page; it also displays default costs and allows the user to adjust the cost of each item as appropriate. Totals entered in the “User” column are read in the “Chosen Options” column, allowing the user to adjust some cost values and rely on the model defaults for others. Advanced users may utilize this function to compare two separate sets of design options or system characteristics. The “Chosen Option” cost is the cost used to calculate the WLC through the rest of the model.

On the “Capital Costs” page, “Cost Option B” is an engineer’s estimate outline for each project type. Cost Option B is designed to serve three functions: (1) provide the opportunity to incorporate a user’s project-specific costs into the WLC model, (2) provide an extensive list of anticipated cost items to assist with planning, and (3) serve as a form for recordkeeping and cost reporting so that agencies may share LID-BMP cost information in a useful and efficient way. If Cost Option B is selected as the capital costing option, the engineer’s estimate is used to calculate the WLC through the rest of the model.

Maintenance costs are calculated on the third worksheet in the model. Similar to the Capital Cost page, the model makes literature-based assumptions where available (or best professional judgment if literature values are not available), and the user may adjust these assumptions to their needs. Maintenance cost estimates include hours per service event, hourly cost of labor, hourly cost of equipment, and cost of any materials used. Maintenance costs are divided into two types in the model: (1) routine and (2) corrective or infrequent. The user may control the schedule of these activities, which affects the WLC calculations. A reference table shows the underlying costs that are used to calculate maintenance cost, based on the user-chosen level of maintenance. The user may change maintenance costs in two locations, either in the “look-up” table or in the “user” columns in the upper cost-calculating table.

Cost Summary

After capital and maintenance costs have been estimated, each WLC model compiles all costs into an estimate on the “Cost Summary” page. This page summarizes annual costs for routine maintenance, corrective or infrequent maintenance, and capital costs. From this summary, the model builds a 50-year lifetime cost estimate for the facility (shown in the “Whole Life Costs” page), including a discount rate that the user may adjust on the “Design and Maintenance Options” page, which is then graphed to show the user a year-by-year facility cost for planning. Three graphs are presented: “Present Value of Costs” over 50 years, “Cumulative Discounted Costs” over 50 years, and “Discounted Costs” per time.

Cost variability of LID-BMP infrastructure across the United States is significant, as is climate variability which drives LID objectives. Thus, the WLC models are designed to produce a default planning-level cost estimate and allow the user to enter more specific cost values for every component tracked by the model. The existing WLC tools were designed to provide cost estimations for stormwater agencies in the United States and the United Kingdom. This expanded suite of WLC tools is targeted more toward single-lot smaller-scale LID stormwater controls because of the projects addressed. This basis likely will increase variability in actual costs because the agencies available to construct the LID facilities are greatly expanded. In some instances, this included opportunities for landowners to provide their own labor and sources for materials with the potential to drastically decrease whole-life cost.

Although many of the practices addressed by the tool are more applicable to smaller land areas, regional management agencies can still use these tools to examine future policy change options for shifting a large-project regional-management paradigm of conveyance to a decentralized paradigm of many smaller projects that address catching the rain where it lands.

Default Costs

Default costs used in the tool are generated from literature available in the public domain. In some instances, sufficient data were not available, or reported cost information was not sufficiently transparent to ensure appropriate cost comparisons. In such cases, design guidelines for each respective facility were summarized from multiple sources and, based on these design guidelines, cost estimates were constructed from component cost in the RS Means 100[2] and from national providers. In the parametric estimate, efforts have been made to present the model as transparently as possible, to display how costs are generated, and to allow the user to adjust many of the cost components in each model for improving the accuracy of the cost estimate generated for the user’s specific scenario. For each facility type, different methods to establish default costs are used, based on the available information in the public domain.

Evaluation of Model by LID Practice

Green Roofs

Green roofs evaluated by this model are “extensive” roofs, which are defined as having shallow soils and low plant cover, with limited roof access. Extensive roofs were evaluated because they minimize the need for structural reinforcements that may be

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[2] A national construction cost database is maintained by Reed Construction Data at http://www.reedconstructiondata.com.

required for "intensive" or deeper soil roofs, which would further complicate cost estimation. Many green roof arrangements evaluated by this model will weigh approximately 170 kg/m^2; the most basic configuration may weigh as little as 97 kg/m^2 and the more elaborate configuration can weigh over 250 kg/m^2 (Roofscapes 2008). The model can automatically generate two cost estimates based on roof area, building height, and roof : (1) cost based on a pre-manufactured modular style installation ("Option A" on "Capital Costs") and (2) a custom installation consisting of a root boundary layer, vegetative cover, and if elected, engineered soils ("Option B" on "Capital Costs"). A template is also provided for a user-entered engineer's estimate ("Option C" on "Capital Costs").

Green roof designs are not intended to be used as a substitute for a traditional roof covering. Instead, green roofs are designed to be installed on top of a conventional roof. Thus, all green roof costs are assumed to be in addition to the cost of a traditional roof covering. One suggested benefit of green roofs is the increased lifespan of a conventional roof membrane, due to the shading and insulating effects of the green roof installation. Conventional roofs have a typical life span of approximately 25 yr; installation of a green roof on top of the conventional roof has been reported to prolong the life of the conventional roof twofold (Toronto and Region Conservation Authority 2008).

A literature review suggests that the driving factor in the cost of green roof installations is the selection of landscaping options. This WLC model assumes the most basic type of installation and allows the user to create a more elaborate installation by including botanical upgrades, walkways, and irrigation. To account for the high variability in design options, the user may include or omit many green roof components and/or override all default costs on the "Capital Costs" and "Maintenance Costs" pages. While this model is designed to estimate costs for extensive roofs, it can be used to estimate costs for intensive roofs by increasing the soil depth and increasing the vegetative costs. This change will substantially increase the weight of the roof, which may require structural reinforcements as noted previously.

Residential Rain Gardens

Design guidelines and general cost information for residential rain gardens are readily available in the public forum. Many community water-quality organizations and municipalities encourage the installation of rain gardens on residential properties because of the efficiency of rain gardens in reducing runoff volume, the relatively low expense of installation and maintenance, and the limited regulations of landscaping practices on residential lots (Edgewood College 2003; Kassulke 2003; Belan and Otto 2004; City of Lincoln 2008; USEPA 2008; Maryland Department of the Environment 2000). Unlike other larger-scale stormwater management approaches, single-home owners have access to the equipment and technology required to install a rain garden in their yards. Because this access is so broad, designs and costs of rain gardens are also broad.

Based on the literature surveyed, two sets of cost information are reported for this tool. The first cost set includes estimates for landowners installing and managing residential rain gardens with labor provided at no cost (e.g., their own or volunteer labor). This cost set includes only costs of materials from local nurseries and hardware stores, averaging $47.36 per square meter of garden installed (normalized to 2008 US dollars). The second cost set includes rain gardens installed and managed by professional landscapers and averages $172.22 per square meter of garden installed (Edgewood College 2003; Kassulke 2003; City of Lincoln 2008; EPA 2008; James City County 2008). Labor, plants, and mulch costs drive the capital cost of most residential rain garden installations. The USEPA (2008) discusses the advantages of a developer installing multiple rain gardens during the initial development stage of large subdivisions, and the tool includes a cost adjustment for this installation approach. However, this WLC model is best suited to provide planning-level WLC estimates for small-parcel landowners and managers who are interested in installing small rain gardens and comparing different cost options.

Curb-Contained Bioretention

Many bioretention concepts take advantage of different design concepts; however, they are often similar in construction approaches, design, and function. This WLC model is designed to incorporate bioretention concepts that can be achieved by curbing and are designed to mitigate stormwater runoff from the surrounding pavement. Specifically, the model is designed to produce a planning-level cost estimate for a series of smaller basins that are back-filled with highly porous media and planted with vegetation that encourages infiltration and/or evapotranspiration and reduces stormwater peak runoff from expansively paved areas. These depression basins are typically surrounded by curbing to maximize storage during large events, to prevent drive-over in vehicle areas, and to include an overflow outlet or underdrain for conventional stormwater. The

RS Means cost estimate provided on the “Design and Cost Information” page includes the cost of demolition in the case of a retrofit. In the “Design and Maintenance Options,” the user may select “New” construction or “Retrofit” construction. If “Retrofit” is selected, a cost-adjustment of 16% of the estimated base facility cost is added to the total cost estimate (Clar 2004). Throughout the literature reviewed, costs for this type of installation may be higher than current practice because it is a new technology. It is expected that as familiarity with the design concepts increases, costs should decrease.

Underdrains represent a major percentage of the total project cost. The need for underdrains is dependent on soil type and overflow drain options. Thus, the WLC model includes the option for the installation of underdrains as part of the bioretention cells. If the user does not believe this model fits their design criteria, the user should refer to the Cisterns WLC model which shows WLC as a Present Value of Costs graph for large-scale LID installations such as extended detention basins, retention ponds, or swales.

In-Curb Planter Vaults

Runoff reduction for small events in smaller drainage areas may be accomplished with In-Curb Planter Vaults. These vaults are defined as subgrade storage vaults built into curbs to allow road or parking-lot drainage to enter the vault’s planter. In addition to reducing runoff volume, the planter facilitates passive precipitation storage to provide for urban vegetation in traffic islands or sidewalks. The vaults are filled with engineered structural soils to facilitate root growth, maximize porosity/water storage capacity, and support the load of the sidewalks and streets above them. These vaults can be capped by a normal sidewalk or street and include a planted opening (often planted with a shrub or small tree).

The user can choose between two installation options in this model. The first option is a precast vault, supplied by a manufacturer. In a review of available literature, the reported costs for precast vaults were all supplied by the same manufacturer (USEPA 2005; Fairfax County 2005; US DoD 2005; Calkins 2008). Cost differences were functions of local construction and transportation costs; these values were averaged to create a per-prefabricated box, installed cost estimate. Prefabricated vaults are less expensive than vaults that are formed and poured in situ, which often include installation and service contracts to maximize convenience to the developer/manager.

The second installation option is an in-curb planter box vault that is formed and poured in situ. In situ installations allow greater flexibility in all aspects of the implemented design including water treatment, storage, volume, and landscaping components. However, in situ installations include increased design, engineering, and construction management costs, in addition to a longer construction phase. In the review of literature, only the City of Portland (2005, 2008) reported costs for the in situ type of installation. Instead of reporting this cost directly in the model, the Portland-style installation costs are averaged with an RS Means-based cost estimate for a similar project. This averaging reduces the cost reported in the WLC model as compared to Portland’s reported costs, which means the model should be representative of future projects. (Portland noted that their installations, which were pilot in nature, included a number of unexpected costs that could be reduced in the future as the practices become more routine.)

Cisterns for Commercial Buildings

In this model, cisterns are defined as water catchment systems that channel rainwater from impervious surfaces into a storage tank for later use. The Cisterns Model is designed to estimate the cost of cistern systems for commercial buildings. Components included in this cost estimation model are the storage tank, tank installation, and a redistribution pump. The costs in the model were derived from a combination of literature review (CWP 2007; Hicks 2008; Ohio State Extension Service 2008), component cost analysis, and an RS Means-based estimate of standard pump, tank, and installation costs.

The model allows the choice of two reuse options to more accurately estimate component costs. These options are “Outdoor Use,” which is assumed to be an automated spray irrigation system, or “Indoor Use,” which is assumed to use the collected water for toilet flushing. Indoor use is assumed to require a larger distribution pump in order to lift water to the upper stories of a building. The parametric cost estimate model does not include any costs of irrigation systems or double-plumbing that may be necessary, depending on local regulations. Also, the model assumes that any gutters or internal conveyance systems from the roof to a storm drain are required components of a conventionally drained building. Although conventional stormwater conveyance systems and cistern conveyance systems will differ in design (e.g., the downspouts will need to be directed into the cistern instead of a gutter or storm drain and more screening may be required), the model assumes the cost difference is negligible. This model also assumes minimal screening as the only method of treatment for stored water and intends for water supplied by the cistern not to be used as a potable source. Depending on the project location, different levels of treatment may be required by the local health department before the water can be used.

Summary

The expanded set of WLC models for LID infrastructure provides planning-level estimates, describes system design approaches, and provides a standardized cost-reporting form for agencies and developers to record and share development costs. Many projects described in these models will vary greatly in design and cost, based on the specific project goal and location. Flexibility has been built into the model to allow a user to compensate for design aspects, specific to their project, that are based on climate, regulatory environment, general regional cost differences in materials and labor, or other factors.

The scale of any given project also will likely affect the final project cost. While every effort has been made to scale costs appropriately (according to the size of the project), many of the cost models are based on limited cost data and limited number of varying project sizes. Economies of scale may not be entirely captured in these cost models. The scale of the project may also affect sourcing of materials and labor. Single-lot owners and managers may have many sourcing options for materials and labor, ranging from volunteer labor to more expensive labor, depending on quality or skill levels required for the project. On larger-scale projects, a manager working for a municipality may be limited in their sourcing options for labor and materials.

To minimize the effects of the aforementioned issues, each cost model was designed independently. Cost-estimate approaches varied greatly between models because the requirements varied. For example, many sources are available on the Internet to assist a homeowner in designing, installing, and estimating the cost of a residential rain garden; based on this information, derivation of a per-garden size cost formula was direct. However, cost reporting for green roofs was not specific enough to ensure that appropriate comparisons were made between sources or even within the same source.

Most sources reviewed (e.g., Toronto and Region Conservation Authority 2008; Peck and Kuhn 2008) suggest that as roof area increases, the cost per square foot of installation decreases. However, when comparing reported costs, larger green roofs tended to be more elaborate in design, and therefore, more expensive per square meter; thus, deriving a per-roof area cost proved unreliable. To overcome this unreliability, the two approaches described in the Green Roofs Section above were created (one based on a modular green roof supplier’s estimate, and one based on component cost analysis) instead of one literature-based cost equation. In all instances, if the area-based estimate is insufficient for a particular project, “Capital Cost Method B” in the model allows the user to create an engineer’s estimate for the project.

Regional LID design considerations vary greatly, and therefore, so does infrastructure cost. The WLC models described here allow a user to modify cost information sufficiently to compensate for these variations and provide adequate planning-level cost estimations. In addition to providing cost estimates, the design concepts presented in each model provide factors to consider during the planning stages of an LID project. The model’s function as a cost-reporting tool will help agencies record and share cost information. These three model components will help to fill the LID cost information void, thus improving planning and decision making for LID practices.

McMullan and Reich (2007) demonstrated significant cost benefits when using LID for stormwater control. Their assessment considered LID construction costs and cost savings gained from reductions in stormwater runoff volume provided by LID. Volume storage benefits were monetized using the national average stormwater construction cost estimate of $2 per cubic foot of storage. LID provided significant cost savings compared to conventional infrastructure for the four development scenarios assessed (medium-density residential, elementary school, high-density residential, and commercial). The combined construction and stormwater volume benefits ranged from $17,000 to $167,000. These benefits were incurred because of the volume reductions gained, even for scenarios where LID construction costs cost more than conventional options. Managing a larger volume of stormwater on site minimized downstream infrastructure expenditures (ibid.).

While several areas of economic benefits have been found with LID use, additional areas still require assessment. The avoided costs of water quality protection associated with LID have not been fully evaluated. The downstream benefits of reducing stormwater discharge volumes, peak flows, and pollutant loading can reduce flooding and stream channel impacts. The same benefits can also reduce costs for additional water-quality treatment and abatement, habitat restoration, property damage, and maintaining waterway navigability (USEPA 2007).

The hydrologic benefits of LID techniques and technologies ideally require a robust and comprehensive assessment to determine the full cost benefits of an LID approach; however, significant benefits are often realized solely by assessing construction costs and water quality.

APPENDIX C:
FACTORS USED IN COST-ESTIMATION TOOLS

The cost of installing and maintaining LID practices (and stormwater management practices in general) can vary widely due to factors such as site conditions, regional climate, and regulatory requirements. In addition, variability in the cost of LID applications can increase because of the number of practices available to achieve the stormwater management goals. Therefore, it is often necessary to identify the cost factors that influence the overall project costs.

Typical Cost Factors for LID Practices

- *Drainage area:* The size and land-cover type of the area contributing stormwater runoff to the LID practice.

- *Stormwater management requirements:* The level of control required for the volume, rate, or quality of stormwater discharges will impact the volume of treatment needed.

- *Material availability and transport:* The ease of obtaining construction materials and the time and distance for delivery.

- *Site conditions:* Accessibility by construction equipment, slope, and existing buildings and their uses.

- *Subgrade:* Subgrade soils such as clay may result in the need for additional base materials, added stormwater storage volume, or underdrains.

- *Project size:* Larger areas may tend to have lower per-square-foot costs due to construction efficiencies (economies of size).

Costs can also vary according to site activities and access, drainage, curbing and underdrains (if used), labor rates, contractor expertise, and competition.

Cost Information for Common LID Practices

More detailed cost information is provided here for the five most commonly used LID practices, as listed below.

1. bioretention

2. vegetated swales

3. green roofs

4. permeable pavement

5. cisterns

Bioretention

Bioretention cells and swales are vegetated systems that rapidly filter stormwater through bioretention soil media, which is typically a mixture of sand, topsoil, and mulch. The stormwater is treated to improve runoff water quality by: (a) biological and chemical reactions in the mulch, soil matrix, and root zone; (b) physical straining; and (c) infiltration into the underlying subsoil. The volume of stormwater is reduced by retaining water in the cell, vegetative uptake and evapotranspiration, and infiltration into the subsoil. Bioretention can be introduced as rain gardens, enhanced tree boxes, planter boxes, curb extensions, or bioswales. Table C-1 provides the estimated costs of the bioretention components.

Table C-1: Estimated costs of typical bioretention components (WERF 2009).

Item	Unit Cost	Unit	Natl. Avg. from Lit. Search
Bioretention soil media	$30 - $60	CY	$30
Mulch	$30 - $35	CY	$30
Plants (examples):			
Ornamental grasses	$15.65	EA	$15.65
Shrubs	$25	EA	$25
Perennials / annuals	$5 - $20	EA	$5
Small trees	$200	EA	$200
Filter fabric	$1 - $5	SY	$2.50
Underdrain to conventional storm drain	$10 - $20	LF	$15.68
Pea gravel	$30 - $35	CY	$30
Gravel	$30 - $35	CY	$30
Observation and cleanout pipe	$10 - $20	LF	$15.68
Liner	$1	SY	$1
Energy dissipation: apron / inflow structure, riprap	$650	EA	$650

In addition to assessing the cost of the individual bioretention components, several studies have estimated the cost of bioretention per square foot of treatment area. Table C-2 provides a summary of these costs.

Table C-2: Estimated cost of typical bioretention (WERF 2009).

Literature Source	Project Name	Bioretention Area Cost (per sq ft)
Edgewood College (2003)	10 Steps to Building a Rain Garden	$12.70 - $15.00
Kassulke (2003)	A Run on Rain Gardens	$11.50 - $13.90
EPA (2008)	Bioretention Costs	$10.00 - $40.00
James City County (2008)	Rain Garden Guide	$10.00
Lincoln (2008)	Alternate Stormwater BMPs	$8.00 - $14.00
RS Means 100 Estimate of Elaborate Garden (2008)		$16.63
Average		**$16.05**

Vegetated Swales

Vegetated swales are broad, shallow channels designed to convey stormwater runoff and treat it by filtering and infiltration. The swales are vegetated along the bottom and sides of the channel, with side vegetation at a height greater than the maximum design flow depth. The design of swales seeks to (a) reduce stormwater volume through infiltration and interception, uptake, and evapotranspiration by the plants; (b) improve water quality through infiltration and vegetative filtering; and (c) reduce runoff velocity by increasing flow path lengths and channel roughness. Removal of pollutants has been positively linked to the length of time the stormwater remains in contact with the herbaceous materials and soils. Swales are well suited for use within the right-of-ways of linear transportation corridors. Table C-3 provides the estimated costs of vegetated swale components.

Table C-3: Estimated costs of typical vegetated swale components (WERF 2009).

Item	Unit Cost	Unit
Permeable soil	$20 - $30	CY
Vegetation examples:		
Sod	$2 - $4	SF
Grass seed	$1 - $2	SF
Ornamental grasses	$15.65	EA
Shrubs	$25	EA
Perennials / annuals	$5 - $20	EA
Filter fabric	$1 - $5	SY
Underdrain to conventional storm drain	$10 - $20	LF
Pea gravel	$30 - $35	CY
Observation and cleanout pipe	$10 - $20	LF
Liner	$1	SY
Energy dissipation: apron / inflow structure, riprap	$650	EA

Green Roofs

Green roofs are structural roof components that filter, absorb, and retain/detain the rain that falls on them through a layer of soil media and vegetation. These roofs consist of an impermeable membrane, an engineered soil medium, and plants. Rainfall that infiltrates into the green roof soil media is lost to evaporation or transpiration by plants, or, once the soil has become saturated, rainfall percolates through to the drainage layer and is discharged through the roof downspouts. Between storm events, stored water is returned to the atmosphere through evapotranspiration by plants and the medium’s surface. Green roofs can provide high rates of rainfall retention and decrease peak flow rates, creating hydrologic function approaching that of undeveloped areas.

Table C-4 provides the estimated costs of green roof components. Aggregated green roof component costs result in an estimated total cost for green roofs of $16 per square foot.

Table C-4: Estimated costs of typical green roof components with estimated total per square foot (WERF 2009).

Item	Unit Cost	Unit
Plants:		
Sedum mat	$13.25	SF
Ornamental grasses	$15.00	EA
Annuals	$2.00	EA
Growing medium	$4.00	CY
Drainage layer	$2.00	SF
Insulation layer	$2.00	SF
Root barrier	$2.25	SF
Waterproof membrane	$1.00	SY
Estimated Total Cost	**$16.00**	**SF**

Permeable Pavements

Permeable pavements are used to reduce the volume of stormwater runoff by converting an impervious area to a treatment unit. Permeable pavements contain small voids that allow stormwater to drain through the pavement to an aggregate reservoir and then infiltrate into the soil. Permeable pavements may be a modular paving system (concrete, grass, or gravel pavers) or poured-in-place solutions (porous concrete, permeable asphalt). Permeable concrete and asphalt are similar to their impervious counterparts, but are open graded or have reduced fines and typically have a special binder added. Methods for pouring, setting, and curing these permeable pavements also differ from the impervious versions. The concrete and grid pavers are modular systems. Concrete pavers are installed with gaps between them that allow water to pass through to the base. Grid pavers are typically a durable plastic matrix that can be filled with gravel or vegetation. All permeable pavement systems have an aggregate base that provides structural support, runoff storage, and pollutant removal through filtering and adsorption.

Permeable pavements have been used in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways.

Table C-5 provides the estimated costs of permeable pavement components.

Table C-5: Estimated costs of permeable pavement components (WERF 2009).

Item	Unit Cost	Unit
Permeable pavement:		
Permeable asphalt	\$0.50 - \$1.00	SF
Permeable concrete	\$2.00 - \$6.50	SF
Interlocking concrete paver blocks	\$5.00 - \$10.00	SF
Grass / gravel pavers	\$1.50 - \$5.75	SF
Gravel	\$30 - \$35	CY
Filter fabric	\$1 - \$5	SY
Underdrain to conventional storm drain	\$10 - \$20	LF
Pea gravel	\$30 - \$35	CY
Observation and cleanout pipe	\$10 - \$20	LF
Liner	\$1	SY

Cisterns

Cisterns are rainwater harvesting and storage systems which capture and store runoff from downspouts to reduce stormwater runoff and provide a non-potable water source. Cisterns typically hold several hundred to several thousand gallons of rainwater. They can be used in a variety of settings and provide an ideal source of non-potable water for outdoor irrigation, toilet and urinal flushing, cooling system make-up, and equipment and vehicle washing. The rainwater collection area for cisterns is usually limited to rooftops because it contains lesser concentrations of pollutants than runoff from other surface areas.

Table C-6 provides the estimated costs of cistern components. The largest cost of a cistern system is typically for the storage tank. Other costs include those for pre- and post-tank treatment units, pumps, and additional piping.

Table C-6: Estimated costs of typical cistern system components (Texas Water Development Board 2005; WERF 2009).

Item	Unit Cost	Unit	Natl. Avg. from Lit. Search
Cistern Type:			
Metal (150–15,000 gal)	$0.50 - $3.00	Gal	$2.51
Concrete (2,000–35,000 gal)	$0.30 - $2.00	Gal	$1.66
Polyethylene (50–5,000 gal)	$0.75 - $2.00	Gal	$1.43
Fiberglass (10,000–35,000 gal)	$0.35 - $1.00	Gal	$1.33
Polypropylene (300–10,000 gal)	$0.50 - $4.00	Gal	—
Roof Washer	$400 - $800	EA	—
Filter			—
Sand	$150 - $500	EA	—
Cartridge	$20 - $60	EA	—
Disinfection			
UV	$350 -$1,000	EA	—
Ozone	$700 - $2,600	EA	—
Chlorine (manual dose)	$1/month	EA	—
Chlorine (auto system)	$600 - $3,000	EA	—
Pump (0.75 – 5 hp)	$1,000 - $4,000	EA	—

Additional research has associated cistern installation costs to tank size, and then presented the findings as a percentage of tank costs. Table C-7 provides a summary of the data.

Table C-7: Estimated cistern installation costs (WERF 2009).

Source	Tank Cost	Installation Cost	Tank-to-Installation Cost Ratio
Hicks (2008)	$17,300	$9,300	0.54
Miller (2008)	$3,050	$1,850	0.61
Miller (2008)	$10,200	$7,000	0.69
Average:			**0.59**

APPENDIX D:
USING THE SUITE OF COST ESTIMATION TOOLS

This appendix provides guidance on the use of a suite of WLC tools for LID. This suite of tools includes a spreadsheet-based cost model for each of the nine LID practices listed below.

1. extended detention
2. retention pond
3. vegetated swale
4. permeable pavement
5. green roof
6. large commercial cistern
7. residential rain garden
8. curb-contained bioretention
9. in-curb planter vault

These spreadsheets were developed under two efforts. Under the first effort, spreadsheets were developed for extended detention basin, retention pond, vegetated swale, and permeable pavement LID practices via a joint project between WERF and UKWIR. (Refer to Appendix B for details of this model's development.)

The second effort included collaboration between WERF and the USEPA for expansion of the original suite of tools to include bioretention, green roofs, and cisterns. These spreadsheet models have been adapted within this PWTB with permission from WERF.

Model Structure - Zip File

Each model consists of a series of spreadsheet tabs that cover the cost components to be addressed in a WLC assessment. Table D-1 provides a description of each spreadsheet and related data-entry requirements and outputs.

Table D-1. Spreadsheet descriptions (WERF 2009).

Sheet No.	Sheet Title	Spreadsheet Description	Reference Section
1	Design & Maintenance Options	Requires inputs needed for the parametric cost estimations and WLC calculations. For example, the Retention Pond Model required input on the following: ♦ Watershed Characteristics ♦ Facility Storage Volume ♦ Design & Maintenance Options ♦ Whole Life Cost Options (discount rate) A few of these inputs are essential user-entries. Model default values are available for all cells, but should be overridden with site-specific data wherever possible.	4
2	Capital Costs	Calculates the facility base costs and associated capital costs (e.g., engineering, land). Two methods are presented: ♦ Parametric estimate(s) ♦ User-entered engineering estimate. For cost items in both methods, the user can enter specific unit costs and quantities.	5
3	Maintenance Costs	Calculates the ongoing costs associated with the operation of the system. The following costs are included: ♦ routine, scheduled maintenance; ♦ corrective maintenance (e.g., periodic repair); and ♦ infrequent maintenance (e.g., sediment removal). Users can adjust existing and create new categories.	6
4	Cost Summary	Summarizes the costs entered into the model. The user can choose to include and exclude costs from the WLC calculation for sensitivity analyses or scenario testing.	7

Sheet No.	Sheet Title	Spreadsheet Description	Reference Section
5	Whole Life Costs	Presents a time series of the costs for the system and computes the present value of these costs.	8
6	Present Value Graph	The present value of cost over time is graphed, along with cumulative discounted cost and discounted cost over time.	9

Model Philosophy

The models provide a framework for the calculation of capital and long-term maintenance costs associated with individual BMPs. Many of the model inputs should be entered by the user (e.g., facility drainage area, water-quality volume (where applicable), and system type, most notably). Model default values are available for all inputs, but are generic and should be over-ridden with site-specific data wherever possible. Assumptions have been made in developing these simple, generic models and these assumptions are set out in this document and detailed in the model’s Tab 7 (Design and Cost Information) for the Bioretention, Green Roof, and Cistern tools. All assumptions should be reviewed for appropriateness. The model is sufficiently flexible that assumptions can be changed wherever improved knowledge is available.

Limitations of the Model Tools

The accuracy of the cost data in these tools is limited to those sources identified in the reference section of the spreadsheet (for Bioretention, Curb-Contained Bioretention, Rain Gardens, Green Roofs, and Cisterns). For the other BMPs, the accuracy of cost data is limited by the references and data found in Lampe et al. (2005).

To determine if the cost estimates generated by the tool are appropriate for an LID application, the user should refer to the references and review the original source information. The amount of data available, the specificity of the elements included in a cited cost, the geographic region of the country where a cited project is located, and the scale of the cited project may make the estimates in the cost tool inappropriate for some user's specific needs. Users are encouraged to modify the tool by entering local cost data to meet their project needs.

In generating cost estimates for LID BMPs, the results of this cost tool should be viewed in light of the cost of conventional development and not interpreted as a separate, additional cost in a development. For example, the cost of Curb-Contained Bioretention includes high costs for curb construction. However, if the developer is required to construct landscape islands, the costs of curb-contained bioretention in lieu of conventional landscape islands may be significantly less (if piping and ponds can be eliminated). Furthermore, these tools do not attempt to quantify the different benefits provided by various BMP or LID techniques as described in PWTB 200-1-121 (Sharif 2012). All such benefits should be considered by decision makers in evaluating various stormwater control alternatives.

Each model offers the user two operational modes:

Generic Application (Default)

The user can generate costs with minimal inputs to make planning-level cost estimates. The user need only enter basic information, such as system size, drainage area, and system type. When available, costs are calculated using parametric cost equations derived from literature review; where these data were not available, costs are calculated using default system design assumptions and unit costs that reflect average values of costs from manufacturers, RS Means 100, or as reported by stormwater agencies from around the country.

In the WERF spreadsheet tool, under Tab 7 (Design and Cost Information) is information about how costs were calculated in the Bioretention, Green Roof, and Cistern spreadsheet models. The WERF report by Lampe et al. (2005) provides details of how costs were calculated for the Extended Detention Basin, Retention Pond, Swale, and Permeable Pavement Models.

This generic default option is a “first cut” for cost analysis; it should be used cautiously and only as a starting point. However, basic cost dynamics are made apparent by this application, such as the relative importance of capital cost versus maintenance cost for different BMPs.

Site-Specific Application or User-Entered Engineer’s Estimate

The user can enter custom values for virtually every component tracked by the model such as system design and sizing, capital costs, maintenance costs, WLCs, etc. This customized option best reflects costs for a given geographical area and site conditions.

The user can employ a combination of default and user-entered values as desired. However, the user will likely want to start with a basic, default scenario and then enter site-specific information as available. Again, given the significant differences in system design requirements and regional cost variables (e.g., labor costs, frequency of maintenance due to variation in climate), it is difficult to generalize by using default values. When parametric equations are used to drive capital cost estimates, the regions of the original cost data are listed in each tool’s respective “design and cost information” sheets. Note that regional cost data were not normalized to national cost data. When cost data were available for multiple locations, they were averaged.

Site-specific costs and characteristics should be entered in the model wherever possible. As an example, all references to RS Means 100 assume a representation of cost that is based on the historical national average of construction costs and can be adjusted to a specific location and time by multiplying the RS Means 100 cost by location and time factors. A first step in improving the accuracy of a user-created cost estimate would be for the user to multiply these unit costs by the appropriate location factor, adjust to the current year using a similar factor, then enter the resulting product in the “user entered” column. As a minimum, the assumptions and costs components should be reviewed for appropriateness prior to application of the model in a generic mode. The cells that are required data in order to achieve a model result are highlighted in Table D-2 – Table D-10 and described in text.

The Green Roof, Commercial Cistern, and Residential Rain Garden tools contain an information page and references to describe the basic design guidelines the model assumes. Many of the references provide design criteria and LID approaches used to define cost assumptions. In these spreadsheets, cells with a small red flag in the upper right hand corner have scroll-over notes with short explanations of how the item is calculated.

Design and Maintenance Options (Sheet 1)

This sheet establishes the design and maintenance criteria that influence both capital and maintenance costs. The sheets are self-explanatory for most part; therefore this section presents selected examples for general discussion. (See Appendix B for detailed overview of each spreadsheet in the suite.)

Watershed Characteristics

Table D-2 presents the watershed characteristic data required for the Retention Pond model, as an example.

Table D-2. Data-entry cells for the watershed characteristics of the Retention Pond Model (WERF 2009).

Watershed Characteristics	Unit	Model Default	User	Chosen option
Drainage Area (DA)	ac	50.00		50.00
Drainage Area Impervious Cover (IC)*	pct	40%		40%
Watershed Land Use Type *("R"-Residential; "C"-Commercial; "Ro"-Roads; "I"-Industrial)*		R		R

* Included since frequently used to calculate storage volume.

The terms used in the Retention Pond Model (Table D-2) are those generally adopted in stormwater management practices, but the terms are defined below for clarity.

- ***Drainage Area*** influences the water quality volume and (where applicable) flood control and other storage volumes required or provided. This is an essential user entry cell.
- ***Drainage Area Impervious Cover*** is included as it frequently is used to calculate water quality volume.
- ***Watershed Land Use Type*** is used by the model to set a default maintenance level. Commercial and residential land uses are assumed to have a "medium" level of maintenance. Roadway and industrial land uses are given default maintenance levels of "low."

Specific Design and Maintenance Approaches

Each model has specific design and maintenance approaches, which are discussed below.

Swale simply requires the user to "Choose a Level of Maintenance" in the model, which includes the option for "high", "medium" and "low" maintenance efforts.

Retention Pond and Extended Detention: Table D-3 displays the data related to facility storage volume that is included in the Retention Pond and Extended Detention models.

Table D-3. Data-entry cells for facility storage volume of the Retention Pond Model (WERF 2009).

Facility Storage Volume – Retention Pond Model	Unit	Model Default	User	Chosen Option
Water Quality Volume (WQV)*	ft^3	90,750		90,750
Permanent Pool Volume as Ratio of Water Quality Volume**	ratio	1.00		1.00
Permanent Pool Volume	ft^3	90,750	90,750	90,750
Flood Detention/Attenuation Volume	ft^3			0
Channel Protection/Erosion Control Volume***	ft^3			0
Other Volume (e.g., recharge volume)	ft^3			0
Total Facility Storage Volume	**ft^3**		**90,750**	**90,750**

* Model default is ½ in. of capture over drainage area; actual volume will depend on regional regulatory requirements and site-specific characteristics, etc. ** Model default ratio = 1.0 (i.e., permanent pool volume EQUALS the water quality volume). *** For example, 24-hr extended detention storage.

The definitions of terms that are used in Table D-3 are given below.

- ***Water Quality Volume*** is the main measure of system size for pond and basin systems. The user should enter in a value here if possible. The default value is calculated as ½ in. of capture depth over the watershed area, though this is simply a placeholder given the considerable variation in requirements across US jurisdictions. This volume is used to later calculate sediment volumes anticipated for removal by periodic maintenance. The user would also use this value in calculations for an engineering estimate of capital costs.

- ***Permanent Pool Volume as Ratio of Water Quality Volume*** is a ratio to facilitate configuring systems where the permanent pool is required to be larger than the water quality volume. The default value is 1.0 (no difference in water quality volume and permanent pool volume).

- ***Permanent Pool Volume*** is the product of the water quality volume and the permanent pool volume ratio.

- ***Flood Detention/Attenuation Volume*** serves to facilitate user entry of a flood control volume, where applicable. The default setting is to provide no additional storage.

- ***Channel Protection/Erosion Control Volume*** serves to facilitate user entry of an erosion control volume, where applicable (e.g., in Maryland). The default setting is to provide no additional storage.

- ***Other Volume (e.g., recharge volume)*** enables additional storage to be entered. The default setting is to provide no additional storage.

- ***Total Facility Storage Volume*** adds the above storage volumes together. The model does not use this information for default settings. However, the user can utilize this volume to help calculate key design parameters (e.g., excavation) that are used for capital cost in the Engineers Estimate.

Table D-4 provides the data-entry cells for additional design and maintenance options for the Retention Pond and Extended Detention Basin Models.

Table D-4. Data-entry cells for the Retention Pond and Extended Detention Models for design and maintenance options (WERF 2009).

Design & Maintenance Options: Retention Pond and Extended Detention Models	Unit	Model Default	User	Chosen Option
Choose Level of Maintenance (H = high; M = medium; L = low)	–	M		M
Forebay Size (Pct. of Total Pool) [Enter 0% if no forebay or if not maintained separately from main pool]*	%	0%		0%
Forebay Volume	yd^3	0		0
Main Pool Volume	yd^3	3,361		3,361
Pct. Full when sediment removed from Forebay/Main Pool**	%	25%		25%
Quantity of Sediment Removed from Forebay	yd^3	0		0
Quantity of Sediment Removed from Main Pool	yd^3	840		840

* Model default is no separate maintenance of the forebay.
** Can adjust to be higher if expect heavy soils/sediment deposition to basin.

Descriptions of the cells in Table D-4 are given below.

- ***Choose Level of Maintenance*** asks for an entry of high, medium, or low/minimum levels. The default level of maintenance is assumed to be “medium” for commercial and residential land uses and “low” for roadway and industrial land uses.

- ***Forebay Size*** queries the percentage of the total pool area occupied by the forebay[3]. This allows a later calculation of a sediment volume to be captured and removed from the forebay. Where systems have no forebay or no separate maintenance of the forebay is anticipated (both the forebay and main pool will be maintained as one), the user can enter “0%.”

- ***Forebay Volume*** is used to calculate sediment accumulated in the forebay. It might also be used by the user in the Engineering Estimate for capital costs.

- ***Main Pool Volume*** is similar to the Forebay Volume for the purpose of sediment calculation, except it is for the main pool.

- ***Pct. Full When Sediment Removed from Forebay/Main Pool*** reflects that various jurisdictions have different requirements for when this occurs. The user should study the expected frequency of sediment removal and the contributing watershed characteristics (e.g., soil erosivity, active construction continuing over time, on-line vs. off-line system) when choosing both the percentage full of basin and the frequency of sediment removal. The default value is 25%.

- ***Quantity of Sediment Removed from Forebay*** (Retention Ponds only) is the product of the size of the forebay and the percentage full at the time of sediment removal. The user can skip to this cell and avoid entries in the other two if desired.

- ***Quantity of Sediment Removed from (Main) Pool*** is similar to the preceding forebay option.

[3] Forebay is a small pool located near the inlet of a storm basin or other stormwater management facility.

Permeable Pavement Model: Table D-5 provides the design and maintenance data cells for the Permeable Pavement Model.

Table D-5. Data-entry cells for design and maintenance options of the Permeable Pavement Model (WERF 2009).

Design and Maintenance Options for Permeable Pavement Model	Unit	Model Default	User	Chosen Option
Choose among the following (affects default cost calculations):	-	1		1
1. Asphalt	User-Selected Pavement Type = Asphalt			
2. Porous Concrete				
3. Grass / Gravel Pavers				
4. Interlocking Concrete Paving Blocks				
5. Other				
Choose Capital Cost Level (H = high; L = low)	-	H		H
Choose Level of Maintenance (H = high; M = medium; L = low)	-	M		M

Four pavement types are supported by the model shown in Table D-5 with a fifth, user-specified option possible. In “Choose Capital Cost Level,” the choice of pavement type and cost level of “high” or “low” determines the default capital cost functions (see Capital Cost Section below). The user should choose a pavement option rather than rely on the default value.

Residential Rain Garden: Table D-6 provides the design and maintenance data cells for the Residential Rain Garden Model.

Table D-6. Data-entry cells for design and maintenance options of the Residential Rain Garden Model (WERF 2009).

Design and Maintenance Options for Residential Rain Garden Model	Unit	Model Default	User	Chosen Option
Installation (S = self or volunteer; P = professional)		P		P
Single house (S) or entire neighborhood (>100 homes, N)		S		S
Choose Level of Maintenance (H = high, ornate garden; M = medium, standard garden; L = low, wild area)	-	M		M

Residents may choose to install and perform maintenance themselves, at no monetary cost. If “S” (self or volunteer) is selected for installation, all labor costs associated with installation and labor are assumed to be zero. In this spreadsheet, if “low” level of maintenance is chosen, all maintenance costs are zero. This is to allow for a scenario where the property owner wishes to perform their own maintenance or allow the rain garden to go natural.

In-Curb Planter Vault: Table D-7 provides design and maintenance data cells for the In-Curb Planter Vault Model.

Table D-7. Data-entry cells for design and maintenance options of the In-Curb Planter Vault Model (WERF 2009).

Design & Maintenance Options for In-Curb Planter Vault Model	Unit	Model Default	User Entered	Chosen Option
Select Construction Type: P = Prefabricated Vault, I = in-situ vault fabrication	-	P		P
Choose Level of Maintenance *(H = high; M = medium; L = low)*	-	M		M

Options for in-curb planter vault installation include a pre-fabricated vault or a vault that is cast in place. These construction methods have different capital costs and reference different cost curves. Tab 7 (Design and Cost Info.) of the model provides more information.

Table D-8 provides the data-entry cells for the Cistern Model.

Table D-8. Data-entry cells for storage requirements and system characteristics for the Cistern Model (WERF 2009).

Storage Requirements	Unit	Default	User	Option
Impervious Drainage Area (often roof area)	sq ft	5,000		5,000
Max Design Rainfall Event	in.	2		2
Precipitation Volume Generated per Event	gal	6,233		6,233
Total Storage Needed	gal	6,300		6,300
System Characteristics	**Unit**	**Default**	**User**	**Option**
Type of Tank Desired (P = Plastic, M = Metal, F = Fiberglass, C = Concrete.)	-	C		C
Primary Use (I = Indoor*, Non-potable; O = Outdoor Irrigation.)	-	O		O
Height of Building (Used to calculate Indoor Use costs)	story	3		3
Number of Fixtures per Floor (toilets, used to calculate Indoor Use costs)	ea	10		10
Choose Level of Maintenance, Irrigation *(H = high; M = medium; L = low)*	-	M		M

* Local health codes strictly control indoor water use. Before installing any indoor rainwater use system, check with local regulations to insure it is permitted. Regulations may require rainwater be treated before indoor use; this model does not estimate costs associated with treatment as systems may vary significantly. If the cost of the treatment system is know, the user may enter this cost in the "other" row in either Capital Cost Method A or B.

Primary cost factors for cisterns are the selection of tank materials and the plans for water use, to be decided by the user. The cistern storage volume is calculated based on roof size and a (default) 2 in. storm event. Tank material is required for cost calculations. The “Tank Type Cost Chart” provides a typical tank material based on the storage size needed. Sources for the costs in this table are noted in Tab 7 of the spreadsheet model. Desired use (outdoor or indoor) for the water stored in the cistern must be specified. Costs for fixtures or plumbing beyond the pump are not included in the model; however, the model estimates pump cost, and the size of the pump depends on the use. In most cases, non-potable indoor use requires a larger pump.

Green roof: Table D-9 provides the data-entry cells for the Green Roof Model.

Table D-9. Data-entry cells for design and maintenance options for the Green Roof Model (WERF 2009).

Green Roof Characteristics	Unit	Model Default	User	Chosen Option
Roof Area (RA)	sq ft	10,000	1,000	1,000
Building Height	Stories	4	2	2
Design & Maintenance Options	**Unit**	**Model Default**	**User**	**Chosen Option**
Primary Roof Function (O = Operational, only basic costs are added to achieve basic Green Roof benefits; P = Promotional or Aesthetics and social environment enhancement; P assumes a more elaborate installation. See below for details.)	-	O		O
Irrigation Need (N = no, Y=yes; if P is elected above, Y is assumed)	-	N		N
Choose Level of Maintenance (H = high; M = medium; L = low)	-	M		M

The available literature suggests that costs of green roofs are driven mostly by landscaping options and roof accessibility. To account for this in the model, the desired “Primary Roof Function” must be specified as either “O” for operational, or “P” for promotional or aesthetic. If “O” is selected, a basic green roof is assumed which includes a basic Sedum variety vegetation mat, plus 4 in. of soil media, and no supplementary irrigation or walking spaces. If “P” is selected, a $10 per square foot botanical upgrade, 8 in. growth media with irrigation to support the upgraded plants, and 10% roof area coverage of walkways to view the upgraded plants is assumed. An 8 in. soil depth represents a moderately ornate green roof because it allows more vegetal variety, but still limits plant selection. If an estimate for a more elaborate design is desired, the depth of the growth media should be increased, and higher costs should be entered in the Capital Cost worksheet as appropriate.

Within the Green Roof Model, the Design and Maintenance sheet also includes capital cost considerations. For example, a 10% increase in cost is assumed for buildings over four stories tall, assuming that a crane would be needed to transport materials to the roof. A scaling factor is included in the model to adjust for this need. If another method of lifting materials to the roof is available, such as a cargo elevator with roof access, this default factor can be eliminated in the “Capital Cost” worksheet (see next section).

Capital Costs (Sheet 2)

This sheet displays Base Facility Costs and associated Capital Costs (e.g., engineering, land). The BMP types have different formats for capital cost estimation, based on the variety of factors associated with each type. Two methods are included in the models: *Method A*, which is a simple, automated (default costs provided) method that is based on correlating drainage area size or *Method B*, a user-entered Engineering Estimate with no default costs provided (i.e., based on user entries only).

Method A: Simple Cost, Based on Drainage Area

Method A is simple and can be used to obtain planning-level estimates for large numbers of facilities (using an average facility size). It should be compared to site-specific information, if possible, to ensure that the basic assumptions (especially base facility costs) are reasonable.

Retention Pond, Swale, and Extended Detention: Capital costs for BMPs in the United States range dramatically from region to region because of significant differences in labor rates, system requirements, weather-related factors, and other considerations. Therefore, in order to provide at least a minimum level of Capital Cost information for a model default setting, a simple method is provided to correlate drainage area (which also roughly measures facility size) with capital cost. Data of this type were available for some US agencies interviewed during the 2005 phase of the project (WERF 2009), and the results were checked against more site-specific examples. The method also allows the user to modify many of the inputs.

With this method, the user chooses a “Base Facility Cost per acre of DA [Drainage Area].” Typical costs range (widely) from $1,000–$15,000 per acre as indicated in the notes below the table. Associated costs are then added for engineering, planning, land cost, and user-entered values. A simple set of cost curves was also added to account for higher per-unit costs for facilities on the smaller end of the facility size spectrum for Retention Ponds, Extended Detention Basins, and Swales

(Table D-10). Note that larger facilities generally provide economies of scale for capital costs.)

Table D-10. Data-entry cells for the Retention Pond, Swale, and Extended Detention Models for simple cost, based on drainage area (Method A) (WERF 2009).

Cost based on Drainage Area	Cost per Acre of DA Treated Model Default	User	(Chosen Option)
Drainage Area (DA) (acres)	50.00		50.00
Base Facility Cost per acre DA*	$3,000		$3,000
Default Cost Adjustment for Smaller Projects**	1.42		1.42
Resulting Base Cost per acre DA	$4,260		$4,260
Base Facility Cost (rounded up to nearest $100)	$213,000		**$213,000**
Engineering & Planning (default = 25% of Base Cost)	$53,250		$53,250
Land Cost	$0		$0
Other Costs	$0		$0
Total Associated Capital Costs (e.g., engineering, land)			**$53,250**
Total Facility Cost	**$266,250**		**$266,250**

Permeable Pavement costs are largely dependent on the type of pavement selected. The user selects the pavement type and a “high” or “low” cost (entered in Worksheet 1, Design & Maintenance Options). These unit cost estimates are shown in Table D-11. The estimates should be substituted with local data for the pavement type selected.

Table D-11. Default unit costs for permeable pavement systems (WERF 2009).

Paver System	Cost Per Square Foot (Installed)	
	Low	High
Asphalt	$0.50	$1.00
Porous Concrete	$2.00	$6.50
Grass / Gravel Pavers	$1.50	$5.75
Interlocking Concrete Paving Blocks*	$5.00	$10.00
Other	$5.00	$10.00

* Upper-end cost dependent on depth of base and site accessibility.

Green Roof Model generates two separate, simple, cost models that are based on user-entered roof characteristics — a pre-assembled modular green roof installation and a custom multilayered installation based on component cost. Please see Tab 7 of the model for more information.

Other models (In-Curb Planter Vault, Residential Rain Garden, Curb Contained Bioretention, Cistern) have similar data-entry tables, to facilitate simple cost estimation.

Method B: User-Entered Engineer's Estimate

The best method of capital cost estimation for individual facilities comes from site-specific Engineer Estimates. The model for each BMP type provides a table with potential cost items. No quantities or unit costs are given as model defaults, so the exercise will be entirely user-entered. Many of the cost items may not be applicable to a given project and can be ignored and additional costs may also need to be added as appropriate.

Method B is not as readily used for regional or multi-facility cost estimation (unlike Method A), due to the site-specific nature of individual LID BMPs. For example, a retention pond site in a natural low point with favorable entire facility volume and an impermeable liner will have a lower construction cost than a different site, even though the two sites might be located in close proximity.

Table D-12 is the blank Engineer’s Estimate Worksheet, here shown as an example for Retention Ponds.

Table D-12. Blank user-entered Engineer’s Estimate Worksheet (Method B) for Retention Ponds (WERF 2009).

Total Facility Base Costs*	Unit	Unit Cost	Quantity	Cost
Mobilization	LS			$ –
Clearing & Grubbing	AC			$ –
Excavation/Embankment	CY			$ –
Dewatering	LS			$ –
Haul/Dispose of Excavated Material	CY			$ –
Sediment Pretreatment Structure (e.g., inlet sump)	LF			$ –
Trash Rack	LF			$ –
Inflow Structure(s)	LS			$ –
Energy Dissipation Apron	LS			$ –
Outflow Structure	LS			$ –
Overflow Structure (concrete or rock riprap)	CY			$ –
Dam/Embankment	CY			$ –
Impermeable Liner	SY			$ –
Water’s Edge Vegetation	SF			$ –
Wetlands Vegetation	SF			$ –
Site Landscaping (e.g., trees)	LS			$ –
Maintenance Access Ramp/Pad	LS			$ –
Revegetation/Erosion Controls	SY			$ –
Traffic Control	LS			$ –
Amenity Items (e.g. recreational facilities, seating)	LS			$ –

Total Facility Base Costs*	Unit	Unit Cost	Quantity	Cost
Signage, Public Education Materials, etc.	LS			$ –
Other				$ –
Other				$ –
Other				$ –
Total Facility Base Cost				$ –

*Select from the list, as applicable to the project or facility type; add items where necessary.

Maintenance Costs (Sheet 3)

Maintenance costs were developed from interviews with stormwater management agencies, literature review, RS Means 100, and when no other information was available, best professional judgment. The references used for estimating maintenance costs for the bioretention, green roof, and cistern tools are cited in Tab 8 of the models. The extensive data collection exercise undertaken for the 2005 project (Lampe et al. 2005) has provided the following information and insights:

- Maintenance activities required will differ according to each site, to ensure performance.
- Variation in these activities is required to meet different aesthetic and amenity needs for a particular site.
- Cost for maintenance activities varies at each site, based on labor, machinery, and materials requirements.

Model default hours and rates were taken from data collected from agencies across the United States, when available. From the original report, it was not generally possible to see the influence of the system's size on cost. Indeed, the data showed that there is likely to be a range of other, often more significant factors that may influence the level of maintenance inputs required at a particular site, such as the proximity of the nearest litter source. This assumption was not carried through the latest expansion of the WLC tools, and so the approach used for each tool is described below.

When data were not available, an engineering estimate was used. Both the rates and default frequencies reflect the differing requirements of high-medium-low maintenance categorization. The user can enter site-specific rates, hours, and frequencies for all activities.

Swale and Permeable Pavement

These models do not account for relationships between size and maintenance costs. Data for corrective maintenance for permeable pavement is extremely limited and thus, very general assumptions were made to assume the need to replace the system after a period of decades (replacement date varies with high, medium, and low maintenance levels) at the same cost as the Base Facility Cost (and no Associated Costs). These assumptions need further study and site-specific data would be especially useful.

Extended Detention Basin and Retention Pond

In these models, sediment removal (which is a dominant maintenance cost category for these systems) scales with the size of the installation.

Green Roof, Curb-Contained Bioretention, and Residential Rain Garden

For these models, maintenance costs are scaled by adjusting the hours per maintenance event required, relative to the surface area of the installation. Also in these models, “Materials and Incidental Costs/Events” are copied (and in some cases reduced by an assumed multiplier) from the “Capital Costs” page to estimate replacement costs of growing media, mulch, and other materials.

In-Curb Planter V*ault*

Maintenance costs in this model are scaled based on the number of vaults installed.

Cistern

This model scales labor costs by increasing hours required for roof maintenance relative to the user-entered roof size. The cost of pump replacement is dependent on pump size and references the water pump cost from the “Capital Costs” page. Pump replacement is assumed to occur every 5 yr.

Using Model Default Settings

The model user must use professional judgment in either accepting or changing the model default settings. The original model spreadsheets (Extended Detention Basin, Retention Pond, Swale and Permeable Pavement) were set up for “average sized” facilities in an “average setting.” For example, in most jurisdictions, the average maintenance crew was able to mow grass and pick up trash (“Vegetation Management with Trash & Minor Debris Removal”) for about two sites per day (hence 4 hr labor assumed per site). This labor includes going to a maintenance yard, determining which sites to visit, driving equipment to the site, and actually performing the task. Some locations will have much larger facilities or longer drive times (or the opposite), all of which will influence the actual time spent. Labor rates and equipment costs, as well as crew sizes, will be site-specific as well. Therefore, care should be taken in reading through and selecting the options desired for all of the maintenance categories.

The Maintenance Cost worksheet is organized as a two tables, as shown in Table D-13 and Table D-14. Table D-13 calculates cost per event by assuming a high, medium, or low/minimum level of maintenance and/or using costs entered by the user. The user can enter values for individual items or as a lump sum at the end. Most users will only use this first table and not the second maintenance table. (Only this table is defined in the worksheet’s Print Area; if a printout of the second table is desired, the Print Area has to be reset.)

The first maintenance table combines the following six factors together in developing a final cost per visit for each maintenance category.

- hours per event
- facility size
- average labor crew size
- average (pro-rated) labor rate per hour
- machinery cost per hour
- cost of materials & incidentals per event

Later in the model (Cost Summary Worksheet), the frequency of the event (months between maintenance events) is used to calculate annualized costs, though frequency is presented and entered in the Maintenance Cost worksheet.

Additional items can also be added in as user-entry tasks (denoted as “add additional activities if necessary”). In addition, the user has the option to enter a lump sum cost for each activity (per maintenance event).

The second maintenance table, shown in Table D-14, presents high-medium-low categories. This section is not explicitly set up for user-entry changes, but some users may want to modify this section. Changes made here will be reflected in the default values of the first maintenance table. Some items have little disaggregation (e.g., “Intermittent Facility Maintenance).” Generally, these types of categories are very difficult to predict (due to widely ranging activities and costs), and thus a straightforward lump sum annual cost is preferable. However, some jurisdictions may have sufficient data to fill in the specific categories of labor rates, frequencies, etc. Detailed values for sediment removal have been entered for hours per event, average labor crew size, labor rate, and machinery cost per hour, yet only the cost per cubic yard of disposal is used in the cost calculations. It was considered that some users might want to add in more detail for this category, and thus the additional, unused detail was retained for informational purposes.

Table D-13. Example maintenance cost worksheet for Retention Pond (cost per event calculation) (WERF 2009).

Retention Pond

M	User entered MEDIUM maintenance level in Sheet 1.

** Change on Sheet 1 if desired/applicable
**

Site Name:
Site Location:

User may enter lump sum here*

Maintenance Costs

ROUTINE MAINTENANCE ACTIVITIES (Frequent, scheduled events)																					
Cost Item	Frequency (mo. between maint. events)			Hours per Event			Average Labor Crew Size			Avg. (Pro-Rated) Labor Rate/Hr. ($)			Machinery Cost/Hour ($)			Materials & Incidentals Cost/Event ($)			Total cost per visit ($)		
	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input
Inspection, Reporting & Information Management	36		**36**	2		**2**	1.0		**1.0**	40		**40**	30		**30**	0		**0**	**140**		**140**
Vegetation Management with Trash & Minor Debris Removal	12		**12**	4		**4**	2.0		**2.0**	30		**30**	60		**60**	0		**0**	**480**		**480**
Vector Control	36		**36**	0		**0**	1.0		**1.0**	40		**40**	200		**200**	200		**200**	**200**		**200**
Add additional activities if necessary.	0		**0**	0		**0**	0.0		**0.0**	0		**0**	0		**0**	0		**0**	**0**		**0**

(Table D-13 continues on the next page.)

(Table D-13, continued from the previous page.)

CORRECTIVE AND INFREQUENT MAINTENANCE ACTIVITIES (Unplanned and/or > 3 yrs. between events)

Cost Item	Frequency (mo. between maint. events)			Hours per Event			Average Labor Crew Size			Avg. (Pro-Rated) Labor Rate/Hr. ($)			Machinery Cost/Hour ($)			Materials & Incidentals Cost/Event ($)			Total cost per visit ($)		
	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input	Model	User	Input
Intermittent Facility Maintenance (Excluding Sediment Removal)	12		**12**			**0**			**0.0**			**0**			**0**			**0**	**1,000**		**1,000**
Add additional activities if necessary.			**0**			**0**			**0.0**			**0**			**0**			**0**	**0**		**0**

Cost Item	Frequency (mo. between maint. events)			Sediment Quantity (yds^3) [from Sheet 1]			Cost per yd^3 to Remove, Dispose of Sediment												Total cost per visit ($)		
	Model	User	Input	Model	User	Input	Model	User	Input										Model	User	Input
Sediment Dewatering & Removal: Forebay	96		**96**	0		**0**	50.0		**50.0**										**0**		**0**
Sediment Dewatering & Removal: Main Pool	240		**240**	840		**840**	50.0		**50.0**										**42,014**		**42,014**
Add additional activities if necessary			**0**			**0**			**0.0**										**0**		**0**
Add additional activities if necessary			**0**			**0**			**0.0**										**0**		**0**

* Note: For facilities judged to require larger or smaller amounts of maintenance (due to land area, etc.), consider multiplying the Model output in Column U by a multiplier (e.g., 120%) in Column V. Another quick means of adjustment would be to multiply the number of Hours per Event by a multiplier in the User Input field.

Table D-14. Example maintenance cost worksheet (lookup table value).

Lookup Table Value

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
Lookup ID	**HIGH, MEDIUM, AND LOW (MINIMUM) MAINTENANCE COST TABLES**																					
		Frequency (mo. between maint. events)			**Hours per Event**			**Average Labor Crew Size**			**Avg. (Pro-Rated) Labor Rate/Hr. ($)**			**Machinery Cost/Hour ($)**			**Materials & Incidentals Cost/Event ($)**			**Total cost per visit ($)**		
	Cost Item	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High	Low	Med	High
1.0	**Routine Maintenance Activities (frequent, scheduled)**																					
1.1	Inspection, Reporting & Information Management	36	36	12	2	2	2	1	1	2	15	40	50	30	30	30	0	0	0	90	140	260
1.2	Vegetation Management with Trash & Minor Debris Removal	36	12	1	4	4	8	2	2	5	15	30	30	60	60	60	0	0	0	360	480	1,680
1.3	Vector Control	72	36	1	0	0	4	1	1	5	40	40	40	200	200	375	200	200	375	200	200	2,675
1.4	*Add additional activities if necessary*																					
1.5	*Add additional activities if necessary*																					

(Table D-14 continues on the next page.)

(Table D-14, continued from the previous page.)

2.0	**Corrective and Infrequent Maintenance Activities (Unplanned and/or > 3 yr between events)**																					
2.1	Intermittent Facility Maintenance (excluding sediment removal)	12	12	12																500	1,000	3,400
2.2	*Add additional activities if necessary.*																					
2.3	*Add additional activities if necessary.*																					
2.4	**Corrective and Infrequent Maint. Activities (Unplanned and/or > 3 yr between events)**																**Cost per Cubic Yard Disposal**					
2.4	Sediment Dewatering & Removal: Forebay	240	96	24	4	4	4	2.5	2.5	2.5	30	30	30	150	150	150	20			50	65	Function of quantity removed
2.5	Sediment Dewatering & Removal: Main Pool	480	240	120	16	16	16	2.5	2.5	4.5	30	30	30	150	150	150	20			50	65	
2.6	*Add additional activities if necessary.*																					
2.7	*Add additional activities if necessary.*																					

Maintenance Activities

Maintenance costs are split into the tasks given below.

♦ Routine maintenance

♦ Intermittent (corrective) maintenance (e.g. repair of component damage or deterioration)

♦ Infrequent maintenance (e.g., sediment removal)

♦ Construction stage sediment removal

See Section 7 of the report by Lampe et al. (2005) for a detailed discussion of each of the above categories. Most are self-explanatory in the model, however.

Cost Summary (Sheet 4)

This sheet summarizes all the cost items that have been calculated within the model. The user can choose whether a given item should be included in the whole life costing analysis, facilitating scenario testing and/or sensitivity testing that may be required as part of the planning and design process.

Table D-15 is the Cost Summary sheet for In-Curb Planter Vaults.

Table D-15. Cost summary spreadsheet for In-Curb Planter Vaults.

In-Curb Planter Vault	**M**	**User-entered 'MEDIUM' maintenance level in Sheet 1.**
Site Name:	**P**	**User-entered 'Pre-Fabricated' Installation Option on Sheet 1.**
Site Location:	**A**	**User-entered 'Option A' Capital Cost Option in Sheet 2.**
Date:		

Cost Summary

CAPITAL COSTS	Total Cost	Included in WLC Calculation		
		Model	User	Chosen Option
Total Facility Base Cost	$10,000	$10,000		$10,000
Total Associated Capital Costs (e.g., Engineering, Land, etc.)	$0	$ –		$ –
Capital Costs		$10,000		$10,000

Regular Maintenance Activities (per vault)	Months between Events	Cost per Event	Total Cost per Year	Included in WLC Calculation		
				Model	User	Chosen Option
Inspection, Reporting & Information Mgmt	12	$30	$30	$30		$30
Litter & Minor Debris Removal, and Vegetation Management	6	$60	$120	$120		$120
In-Curb Planter Vault Sweeping	6	$80	$160	$160		$160
Additional Activities	0	$0	$0	$ –		$ –
Number of Vaults:				1		1
Annual Totals, Regular Maintenance Activities				$310		$310

NOTE: Table D-15 is continued on next page.

CORRECTIVE AND INFREQUENT MAINTENANCE ACTIVITIES (Unplanned and/or >3yrs. between events)	Months between Events	Cost per Event	Total Cost per Year	Included in WLC		
				Model	User	Chosen Option
Unclog Drain	24	$160	$80	$80		$80
Up-Fill Growth Medium	24	$130	$65	$65		$65
Additional activities	0	$0	$0	$ –		$ –
Number of vaults:				1		1
Annual Totals, Corrective & Infrequent Maint. Activities				$145		$145

Whole Life Costs (Sheet 5)

This sheet combines the selected cost components and discounts future costs to the present, in order to calculate a Present Value. Table D-16 presents an example of a Whole Life Costs sheet for Permeable Pavement.

Table D-16. Whole-life cost tabulation spreadsheet example.

Permeable Pavement

Site Name:
Site Location:

Year	Discount Factor	Capital & Assoc. Costs	Regular Maint. Costs	Correc. Maint.	Total Costs	Present Value of Costs	Cumulative Costs	
							Cash	Present Value
Cash Sum ($)					**$62,667**	**$36,286**		
0	1.000	**$28,780**			$28,780	$28,780	$28,780	$28,780
1	0.948	$ –	**$247**	$ –	$247	$234	$29,027	$29,014
2	0.898	$ –	$247	$ –	$247	$222	$29,273	$29,235
3	0.852	$ –	$247	$ –	$247	$210	$29,520	$29,445
4	0.807	$ –	$247	$ –	$247	$199	$29,767	$29,645
5	0.765	$ –	$247	$ –	$247	$189	$30,013	$29,833
6	0.725	$ –	$247	$ –	$247	$179	$30,260	$30,012
7	0.687	$ –	$247	$ –	$247	$170	$30,507	$30,182
8	0.652	$ –	$247	$ –	$247	$161	$30,753	$30,343
9	0.618	$ –	$247	$ –	$247	$152	$31,000	$30,495
10	0.585	$ –	$247	$ –	$247	$144	$31,247	$30,639
11	0.555	$ –	$247	$ –	$247	$137	$31,493	$30,776

Year	Discount Factor	Capital & Assoc. Costs	Regular Maint. Costs	Correc. Maint.	Total Costs	Present Value of Costs	Cumulative Costs	
							Cash	Present Value
12	0.526	$ –	$247	$ –	$247	$130	$31,740	$30,906
13	0.499	$ –	$247	$ –	$247	$123	$31,987	$31,029
14	0.473	$ –	$247	$ –	$247	$117	$32,233	$31,145
15	0.448	$ –	$247	$ –	$247	$110	$32,480	$31,256
16	0.425	$ –	$247	$ –	$247	$105	$32,727	$31,361
17	0.402	$ –	$247	$ –	$247	$99	$32,973	$31,460
18	0.381	$ –	$247	$ –	$247	$94	$33,220	$31,554
19	0.362	$ –	$247	$ –	$247	$89	$33,467	$31,643
20	0.343	$ –	$247	$ –	$247	$85	$33,713	$31,728
21	0.325	$ –	$247	$ –	$247	$80	$33,960	$31,808
22	0.308	$ –	$247	$ –	$247	$76	$34,207	$31,884
23	0.292	$ –	$247	$ –	$247	$72	$34,453	$31,956
24	0.277	$ –	$247	$ –	$247	$68	$34,700	$32,024
25	0.262	$ –	$247	$ –	$247	$65	$34,947	$32,089
26	0.249	$ –	$247	$ –	$247	$61	$35,193	$32,150
27	0.236	$ –	$247	$ –	$247	$58	$35,440	$32,208
28	0.223	$ –	$247	$ –	$247	$55	$35,687	$32,263
29	0.212	$ –	$247	$ –	$247	$52	$35,933	$32,315
30	0.201	$ –	$247	$ –	$247	$49	$36,180	$32,365
31	0.190	$ –	$247	$ –	$247	$47	$36,427	$32,412
32	0.180	$ –	$247	$ –	$247	$44	$36,673	$32,456
33	0.171	$ –	$247	$ –	$247	$42	$36,920	$32,499
34	0.162	$ –	$247	$ –	$247	$40	$37,167	$32,538
35	0.154	$ –	$247	$21,800	$22,047	$3,385	$59,213	$35,923
36	0.146	$ –	$247	$ –	$247	$36	$59,460	$35,959
37	0.138	$ –	$247	$ –	$ 247	$34	$59,707	$35,993
38	0.131	$ –	$247	$ –	$247	$32	$59,953	$36,025
39	0.124	$ –	$247	$ –	$247	$31	$60,200	$36,056
40	0.117	$ –	$247	$ –	$247	$29	$60,447	$36,085
41	0.111	$ –	$247	$ –	$247	$27	$60,693	$36,112
42	0.106	$ –	$247	$ –	$247	$26	$60,940	$36,138
43	0.100	$ –	$247	$ –	$247	$25	$61,187	$36,163
44	0.095	$ –	$247	$ –	$247	$23	$61,433	$36,186
45	0.090	$ –	$247	$ –	$247	$22	$61,680	$36,209
46	0.085	$ –	$247	$ –	$247	$21	$61,927	$36,230
47	0.081	$ –	$247	$ –	$247	$20	$62,173	$36,249
48	0.077	$ –	$247	$ –	$247	$19	$62,420	$36,268
49	0.073	$ –	$247	$ –	$247	$18	$62,667	$36,286
50	0.069	$ –	$247	$ –	$248	$17	$62,914	$36,303

APPENDIX E:
REFERENCES AND RESOURCES

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APPENDIX F: ABBREVIATIONS IN TEXT

Term	**Spell out**
AR	Army Regulation
BMPs	best management practices
CECW	Directorate of Civil Works, U. S. Army Corps of Engineers
CEMP-CE	Directorate of Military Programs, U. S. Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
CO	carbon monoxide
CWP	Center for Watershed Protection
DoD	Department of Defense
EISA	Energy Independence and Security Act
EO	Executive Order
ERDC	Engineer Research and Development Center
FY	fiscal year
HQUSACE	Headquarters, US Army Corps of Engineers
LCC	life-cycle costs
LID	low-impact development
NO_2	nitrogen dioxide
NPS	non-point source
O_3	ozone
O&M	operation and maintenance
PM	particulate matter

Term	**Spell out**
POC	point of contact
PWTB	Public Works Technical Bulletin
SO_2	sulfur dioxide
TR	Technical Release
UFC	Unified Facilities Criteria
UFORE	Urban Forest Effects
UKWIR	United Kingdom Water Industry Research
USACE	US Army Corps of Engineers
U.S.C.	United States Code
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency
WERF	Water Environment Research Foundation
WLC	whole-life cost
WQV	water quality volume