Appendix C

Cost Estimating Resources

CAPTURE Guidance for Schools
Cost Estimating Resources

There is much literature that summarizes costs for various types of runoff management projects, although local social, economic, political, and other conditions will drive actual rates. As part of the One Water Initiative in the City of Los Angeles, capital cost information was compiled for many of the more commonly used SCMs. The results are shown in Table 1.

Table 1. City of Los Angeles SCM Costs Survey Results (Source: "Los Angeles Sustainable Water Project: Ballona Creek Watershed", UCLA, November 2015).

SCM	Count	Present 2014 Value ($/unit)			Unit
		Average	Minimum	Maximum	
Bioretention	5	$ 15.97	$ 3.83	$ 27.13	vol (cf)
Detention Basin	5	$ 14.29	$ 4.57	$ 34.74	vol (cf)
Infiltration Trench	14	$ 12.40	$ 3.15	$ 43.16	vol (cf)
Vegetated Swale	4	$ 18.67	$ 5.58	$ 44.26	vol (cf)
Porous Pavement	8	$ 15.48	$ 7.63	$ 19.90	area (sf)

Other literature resources are summarized below in Table 2. An annotated description of each follows.

Table 2. Resources for SCM Cost Estimating

Resource	Type of Cost		SCMs Evaluated	Cost Information Type	Associated References
	Capital	O&M			
USEPA National Stormwater Calculator[1]	X	X	• Bioretention/Rain Garden • Cistern/Rain Barrel • Downspout Disconnect • Green Roof • Infiltration Basin • Porous Pavement • Street Planter	• Regression Equations • Software Application	• Rossman and Bernagros (2014) • Clary and Piza (2017)
University of Minnesota/Weiss BMP Cost Estimation Algorithm[1]	X	X	• Bioretention/Rain Garden • Constructed Wetland • Detention Basin • Infiltration Trench • Sand Filter • Wet Basin	• Literature Review • Regression Equations	• Weiss et al. (2007) • USEPA (1999) • Clary and Piza (2017)
University of New Hampshire Maintenance Expenditure Study [1]		X	• Bioretention/Rain Garden • Porous Pavement • Sand Filter • Subsurface Wetland • Swale • Wet/Dry Pond	• Physical models at field facility	• Houle et al. (2013) • Clary and Piza (2017)
WE&RF-AWWA-UKWIR Whole-Life Costs Tool[1]	X	X	• Bioretention/Rain Garden • Detention Basin • Green Roof • Infiltration Practices Porous Pavement • Retention Pond • Vegetated Swale	• Surveys/Site Visits • Spreadsheet Tool	• Andrews and Lampe (2005) • Clary and Piza (2017)
The National Cooperative Research Program (NCHRP) Whole-Life Cost Models[1]		X	• Bioretention • Swale	• Literature Review • Surveys	• Taylor (2014)

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Resource	Type of Cost		SCMs Evaluated	Cost Information Type	Associated References
	Capital	O&M			
ASCE EWRI Survey of BMP O&M Costs[1]	X	X	• Bioretention/Rain Garden • Infiltration Basins/Trench • Permeable Pavement • Rainwater Harvesting	• National Survey • Tabular Data Tool	• USEPA (1999) • Clary and Piza (2017)
Urban Drainage and Flood Control District's BMP-REALCOST Tool[1]	X	X	• Bioretention • Constructed Wetland • Detention Basin • Permeable Concrete Paver • Retention Pond • Sand Filter Basin	• Informational Interviews • Engineering Judgment • Spreadsheet Tool	• Clary and Piza (2017) • Urban Drainage and Flood Control District (2018)
Wossink and Hunt (2003) Empirical Cost Evaluation of SCMs in North Carolina	X	X	• Bioretention • Sand Filter • Wetlands • Wet Pond	• Phone Surveys • Site Contacts • Regression Equations	• Wossink and Hunt (2003) • Clary and Piza (2017)
USEPA Water Financing Clearinghouse LID and GI Case Study Inventory	X	X	• Varies by Study	• Varies by Study	• USEPA (2013)
Green Values National (GVN) Stormwater Management Calculator	X	X	• Cisterns/Rain Barrel • Disconnect Downspout • Green Roof • Swale • Vegetated Filter Strip	• Literature Review • Regression Equations • Online Assessment Tool	• Center for Neighborhood Technology (2009)
SCM Databases for Generating Capital and O&M Cost Equations	X	X	• Biofiltration • Bioretention • Dry Pond/Detention Basin • Gravel Wetland System Infiltration Basin • Infiltration Trench • Porous Pavement • Sand Filter	• Databases • Regression Equations • Tabular Data Tool	• Urbonas (2002) • Brown and Schueler (1997) • SWRPC (1991) • Torno (1984) • Knight et al. (1994) • RS Means Company (2018)

USEPA National Stormwater Calculator

The USEPA developed a user-friendly tool to calculate stormwater runoff at small sites anywhere in the United States. Computation of stormwater runoff is conducted by the USEPA's Stormwater Management Model (SWMM, v. 5.1.012; Rossman & Bernagros 2014). The model uses local soil conditions, meteorology, and land cover to assess the amount of stormwater runoff produced by historical rainfall trends at sites with varying development and stormwater control measures (SCMs).

The updated tool includes definitive estimates of construction and maintenance costs including but not limited to: impervious area disconnection, rainwater harvesting, permeable pavement, and infiltration basins. They are calculated using regression equations that are a function of fixed cost components and variable cost components linked to SCM size. Simple, typical, and complex cost curves were developed using previous cost curves and SCM costing data from a literature review. Capital and maintenance cost estimates for green infrastructure (GI) controls are accessible at Rossman and Bernagros (2014) and Clary and Piza (2017).

University of Minnesota/Weiss BMP Cost Estimation Algorithm

The best management practice (BMP; i.e., SCM) cost estimation algorithm is a product of collaborative research between the University of Minnesota (UM) and Peter Weiss at Valparaiso University. Initially, the algorithm generated expected costs of annual operation and maintenance (O&M) as a percentage of total construction costs (Weiss et al. 2007). Following the compilation of a 20-year record of SCM construction costs and annual O&M costs by UM researchers, the algorithm is now able to calculate the total present cost of SCMs in 2005 dollar terms (Clary & Piza 2017). Total present cost is defined as the current worth of a project in addition to the current worth of 20 years of annual O&M costs (Weiss et al. 2007).

The equation calculates total present cost by converting the 20-year-old annual SCM costs to present values using municipal bond yield rates and inflation values. Total present cost is a function of the SCM size (e.g., water quality volume, swale top width). According to Weiss et al. (2007), with the exception of infiltration trenches, annual SCM O&M costs (as a percentage of construction costs) decrease as construction costs increase.

Supporting information on the cost estimation algorithm can be found in Clary and Piza (2017), Weiss et al. (2007), and USEPA (1999).

University of New Hampshire Maintenance Expenditure Study

Houle et al. (2013) at the University of New Hampshire's Stormwater Center characterized and quantified the maintenance costs of low impact development (LID; i.e., SCMs) in the first two to four years of their operation. Physical models at a field facility—a 4.5-ha commuter parking lot with a series of uniformly sized, isolated, and parallel treatment systems—were used to examine the maintenance demands of seven different SCMs, including vegetated swales, dry/wet ponds, porous asphalt, and bioretention. System maintenance demands including materials, labor, and maintenance type and complexity were tracked and documented monthly using NYSDEC (2003) to help develop a framework for annual maintenance strategies and expenditures. Details on the tracking and calculation of maintenance costs are available in Houle et al. (2013).

Overall, analysis of annual maintenance demands of the SCMs compared to conventional pond systems indicates that they seldom have higher annual maintenance costs and normally have lower annual maintenance costs, and have higher water quality treatment capabilities due to elevated pollutant removal performance (Houle et al. 2013). Normalized installation and maintenance cost data can be found in Clary and Piza (2017). Key findings also provide insight into the structure of the maintenance regimes required by SCMs and their impact on maintenance costs. For example, vegetated filtration systems display lower cost and invested personnel hours than conventional pond systems. Also, maintenance approaches are frequently progressive. Initial maintenance activities are reactive (emergency- and/or complaince-driven) and, therefore, expensive. As maintenance programs evolve to include routine, periodic, and proactive inspections, they can reduce costs.

Houle et al. (2013) provides a platform to experiment with future maintenance expenditure studies that address additional factors impacting maintenance costs such as scalability and sensitivity to temporal variation and different land uses.

WE&RF-AWWA-UKWIR Whole-Life Costs Tool

Andrews and Lampe (2005) developed a whole-life cost model for the Water Environment and Reuse Foundation (WE&RF), the American Water Works Association (AWWA), and the United Kingdom Water Industry Research (UKWIR) to characterize the performance and whole-life costs of the following BMPs: retention ponds, extended detention basins, vegetated swales, bioretention, porous pavements, and various infiltration practices.

The whole-life cost tool was implemented in spreadsheet format and constructed using maintenance costs collected from extensive surveys of the experiences of U.S. agencies with BMPs. Surveys were also supplemented with site visits to seven cities across the United States to determine and document differences in design elements and the factors driving variations in BMP design.

In 2009, WE&RF developed an updated 2.0 version of the whole-life cost model to calculate whole-life costs of different green infrastructure measures as a function of design and maintenance options and capital and O&M costs. Outputs from the whole-life cost model indicate that differences in geography (climate, topography), aesthetic design considerations, and economics (availability and desirability of financial resources) drive the decision-making on selecting a wide array of SCMs and the maintenance costs associated with them. The size and complexity of SCMs and adequate inspection programs determine long-term maintenance expenses (Clary & Piza 2017). Average annual SCM maintenance costs for the United States—including labor, equipment, materials, replacement and/or additional planting, and disposal—can be found in Clary and Piza (2017).

The National Cooperative Research Program (NCHRP) Whole-Life Cost Models

Taylor (2014) and the National Cooperative Highway Research Program (NCHRP) developed a comprehensive list of SCM whole-life cost models in spreadsheet format. The spreadsheet was compiled using a literature review that was supported by surveys of 50 state departments of transportation on SCM's cost, performance, and operation and maintenance information (Taylor, 2014). Green infrastructure SCMs include swales and bioretention facilities.

The California Department of Transportation (Caltrans) is progressively engaging in true, real-time collection of the costs of maintaining stormwater controls. The data collection process involves assigning maintenance codes to roadside SCMs and locating the SCMs using GPS or automatic vehicle location technology. The process creates necessary data systems that enable fine-scale calculation of long-term life-cycle costs of post-construction of stormwater controls (Taylor, 2014). Actual construction and annual maintenance costs for Caltrans BMP retrofit programs can be found in Taylor (2014).

Urban Drainage and Flood Control District's BMP-REALCOST Tool

BMP-REALCOST is an Excel-based life cycle costing model developed by the Urban Drainage and Flood Control District in Denver, Colorado (Urban Drainage and Flood Control District 2018). BMP-REALCOST determines life-cycle costs of structural stormwater SCMs in urban and suburban settings. Informal interviews with persons with SCM experience and the engineering judgement of the authors were used to inform the model's structure (i.e., the type of maintenance activities for each SCM) and assumptions (i.e., assuming a proactive and predictive maintenance regime). The model's SCM costing is a function of two factors: (1) watershed physical properties that influence runoff quality and quantity, such as contributing areas and land use; and (2) the specification of the SCMs applied to the watershed/development. The model provides the user default cost and effectiveness values, or they can input their own custom values. The entered data is then analyzed to calculate life cycle costs based on the number, size, and type of SCMs required to treat average annual runoff quality and quantity for a designated watershed.

BMP-REALCOST's maintenance cost equation includes an SCM size-independent lump-sum component (e.g., annual inspection) and size-dependent component (expressed as storage volume or design flow-rate). Average annual costs are determined by various inputs including maintenance frequency, type, and equipment and labor costs. Annual maintenance costs according to BMP-REALCOST can be found in (Clary & Piza 2017).

Wossink and Hunt Empirical Cost Evaluation of SCMs in North Carolina

Wossink and Hunt (2003) developed empirical cost equations from data collected on O&M costs of 40 SCM facilities in North Carolina. Their statistical analysis indicates that in addition to watershed size, SCM construction costs are affected by factors such as watershed composition and other engineering considerations (e.g., required excavation depth). For bioretention devices, maintenance costs were highly dependent on the composition of the used soil (clayey versus sandy soils). Overall, except for bioretention devices in non-sandy soils, the construction and maintenance costs per acre decreased as the size of the watersheds increased (Wossink & Hunt, 2003).

A summary of the construction and maintenance cost curves per acre treated in North Carolina are available in Clary and Piza (2017) and Wossink and Hunt (2003).

ASCE EWRI Survey of BMP O&M Costs

In 2016, the American Society of Civil Engineers (ASCE) Environment and Water Resources Institute's (EWRI's) Municipal Water Infrastructure Committee (MWIC) conducted a national survey with contacts identified by the MWIC task committees to gather data on SCM O&M costs. The survey included a wide range of questions from inquiries on maintenance procedures and equipment and labor costs to stormwater program information. A comprehensive list of questions developed to guide phone interviews is found in Clary and Piza (2017).

The intended outcome of the survey was to generate a populated spreadsheet with itemized cost data on SCM installations; however, due to the lack of available data, the survey shifted its focus to collecting O&M cost data on bioretention devices for which national data was readily available. The median annual maintenance cost of bioretention devices was estimated at $0.687/sq ft with lower and higher costs of $0.13/sq ft and $2.30/sq ft, respectively. The survey also provides average annual reported maintenance costs, which range from $250 to $3880 with a median of $850. A tabular summary of bioretention O&M cost data is available in Clary and Piza (2017). According to several bioretention facilities that reported construction cost, annual maintenance costs averaged 6% of their capital costs, which falls within the estimated 5-7 percent range of maintenance cost as a percentage of capital cost (USEPA, 1999).

USEPA Water Financing Clearinghouse LID and GI Case Study Inventory

The USEPA's Water Financing Clearinghouse compiled a comprehensive list of LID and GI studies to analyze and promote the economic benefits of alternative stormwater infrastructure approaches. The list provides a compilation of study cases that track and analyze SCM capital and O&M costs (USEPA 2013). The studies include a wide array of methodological approaches that range from simple assessments of capital costs to comprehensive evaluations of infrastructure whole-life or life-cycle costs.

Many of the case studies support the cost-saving arguments of SCM-based alternatives (compared to conventional stormwater infrastructure). For example, the Capital Region Watershed District in Minnesota found considerable capital cost savings—estimated at $0.5 million—in adopting GI infiltration practices compared to traditional sewer conveyance systems. Similarly, a study in Western Union, Iowa, concluded that the O&M costs of permeable pavement would result in long-term cost saving, which begin accruing after 15 years and accumulate to an estimated $2.5 million in savings over a 57 year period.

Green Values National (GVN) Stormwater Management Calculator

The Center for Neighborhood Technnology (2009) collaborated with USEPA to develop a free online assessment tool to calculate and compare the costs of SCMs to conventional stormwater practices on single sites. The GVN calculator uses input precipitation data, runoff reduction goals, and choice of BMPs to calculate the life-cycle costs of green and grey stormwater infrastructure over 5 to 100 years. Data on lifespan data and construction and maintenance costs were gathered from available literature on green and grey stormwater infrastructure. The life cycle equation is a function of construction costs, annual maintenance costs, the number of times SCM components require replacement, annual benefits and the service age of the SCM (Center for Neighborhood Technnology 2009).

An expansive list of the definitive construction costs, maintenance costs, and component lifespan data for SCM and conventional stormwater systems are available in the Center for Neighborhood Technnology (2018).

SCM Databases for Generating Capital and O&M Cost Equations

According to Urbonas (2002), of the many databases that collect and store SCM cost information, only few are sufficiently comprehensive to provide the capital and O&M cost data required to generate cost equations. These databases include: BMP Cost Effectiveness Database (Brown & Schueler 1997), Southeastern Wisconsin Regional Planning Commission Database (SWRPC 1991), Cost Data Format for the Nationwide Urban Runoff Program (NURP) Projects (Torno 1984), USEPA's Design Manual for Wetlands (USEPA 1988), and North American Wetland Database (Knight et al. 1994). Also, the RS Means Company annually publishes a construction cost database collected by cost engineers. The 2018 construction database includes more than 85,000 unit line items of material, labor, and equipment cost at more than 970 locations (RS Means Company 2018b). Access to SCM cost data can be obtained by purchasing RS Means Company (2018a) in print or online.

The databases include study cases that provide SCM costs at different SCM facilities. Using regression analysis to quantify the relationship between SCM cost and facility characteristics (e.g., volume of the drainage area), these databases allow practitioners to formulate O&M cost equations.

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